Integrating programming into neuroscience courses

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UC San Diego Neurobiology

To get us started...

Please take the pre-workshop survey
https://forms.gle/2HosnNnvGrtH3QWTA

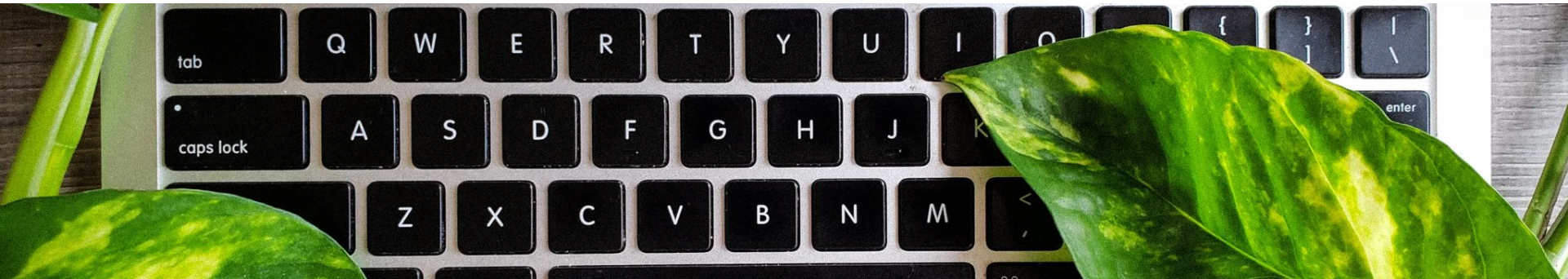
(Optional) Make a GitHub account:
http://www.github.com

(Optional) Request a Dandihub account:
https://dandiarchive.org/

All of the materials for today's workshop
live here: http://www.github.com/ajuavinett/FUN_2023

By the end of this workshop, you'll be able to:

- Identify multiple ways of integrating programming into your course
- Access and use internet-based computing platforms (e.g. Google Colab)
- Write & edit code in Jupyter (or similar) notebooks
- Access Neurodata Without Borders datasets for both teaching and research



Workshop plan

Time	Description
2:45 - 3:00 pm	**Part I:** Motivation & Framework
3:00 - 3:30 pm	**Part II:** The Tools (choosing a programming language, working with Jupyter/Colab notebooks)
3:30 - 3:40 pm	Break
3:40 - 4:20 pm	**Part III:** Cell Types Lesson
4:20 - 4:40 pm	**Part IV:** Neurodata Without Borders
4:40 - 4:50 pm	**Part V:** Wrap-up & promising practices for teaching coding

PART I

The Motivation

Neuroscience data is getting bigger

One ~500 mm^3 mouse brain…

assuming ~1,000 connections for each neuron, the resulting connection matrix contains ~10^{11} entries

≃ **a few hundred gigabytes**

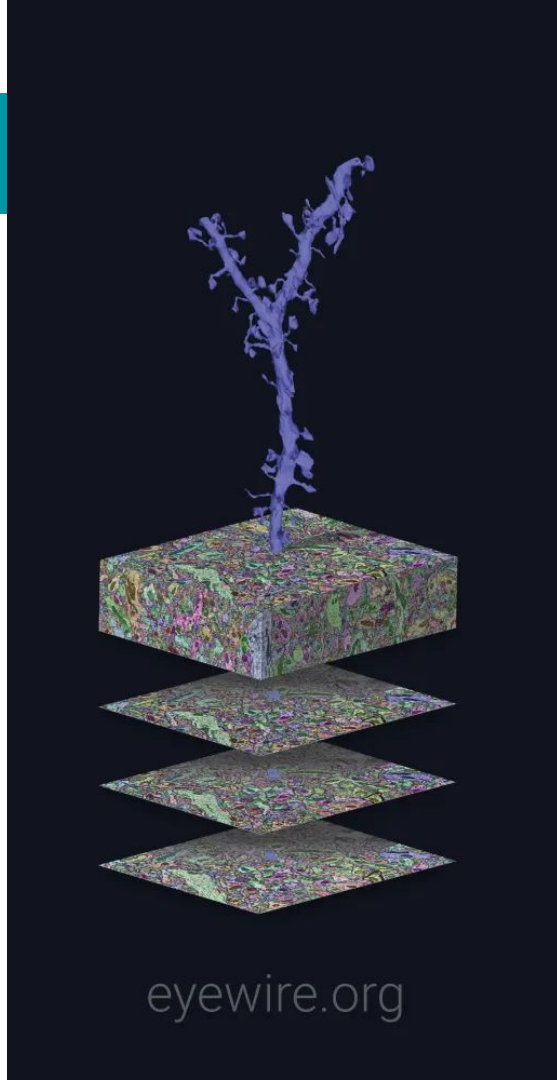
imaging at 5 nm × 5 nm × 40 nm resolution

≃ **500 petabytes**

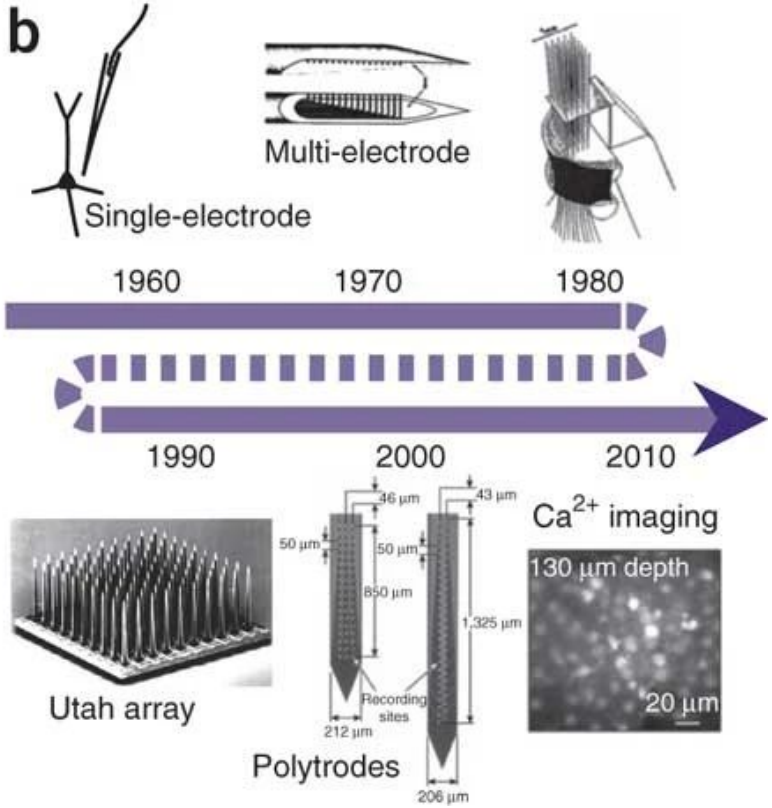
recording from each pixel for 20 min at 1000 Hz

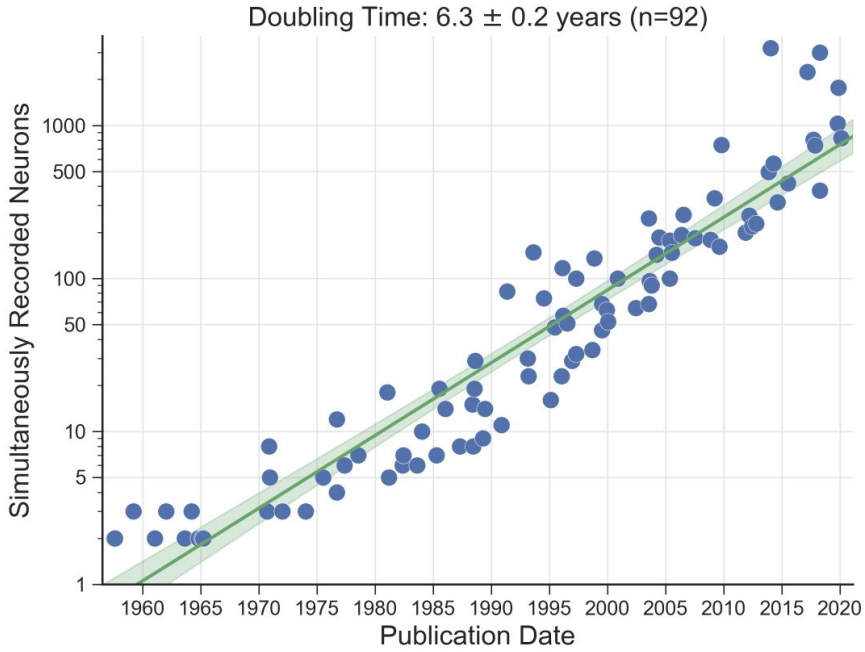
≃ **500 petabytes**

Estimates: Engert, 2014; Image: EyeWire



The number of neurons we can record from is growing exponentially





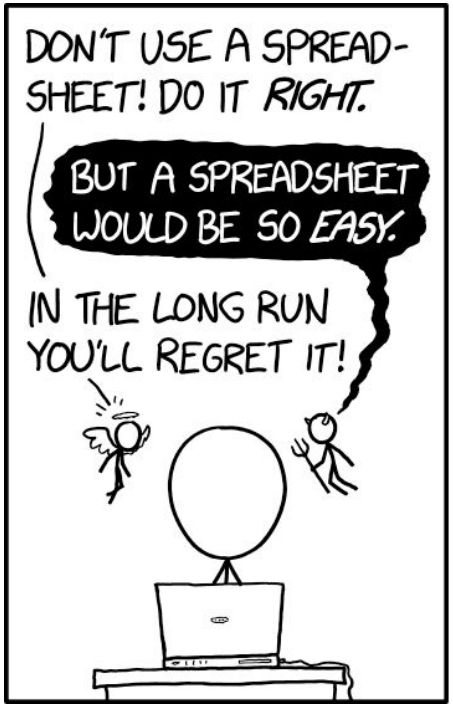
Stevenson & Kording, 2011;
https://stevenson.lab.uconn.edu/scaling/

Excel can only handle datasets with **~1 million rows, and ~16,000 columns** — many datasets in biology are much larger than this!

You can automate analyses in Excel, but this is quite limited.

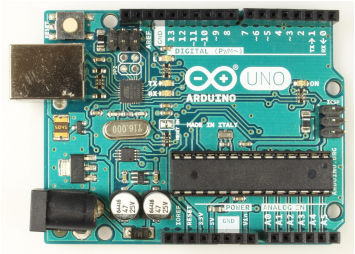
There are also specialized biological data analysis software programs, but often these are limited in how much they can be customized.

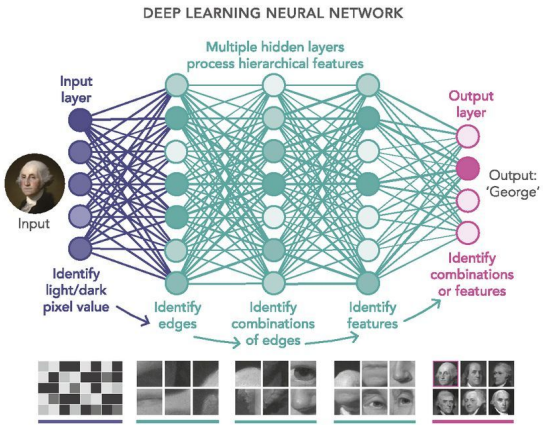
Code is *infinitely* customizable.



https://xkcd.com/2180/

Why do neurobiology students need to learn how to code?





wrangling large datasets

custom data acquisition

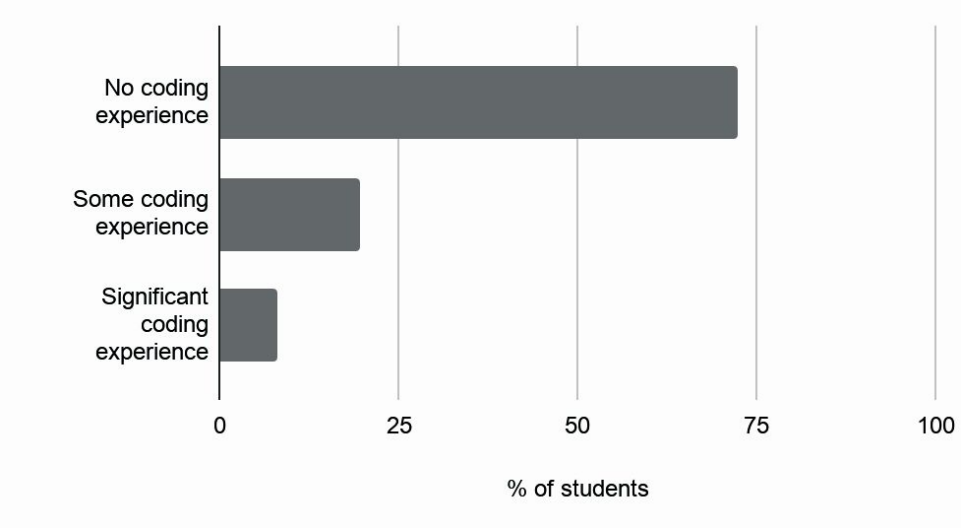
statistics, data analysis & visualization

computational modeling

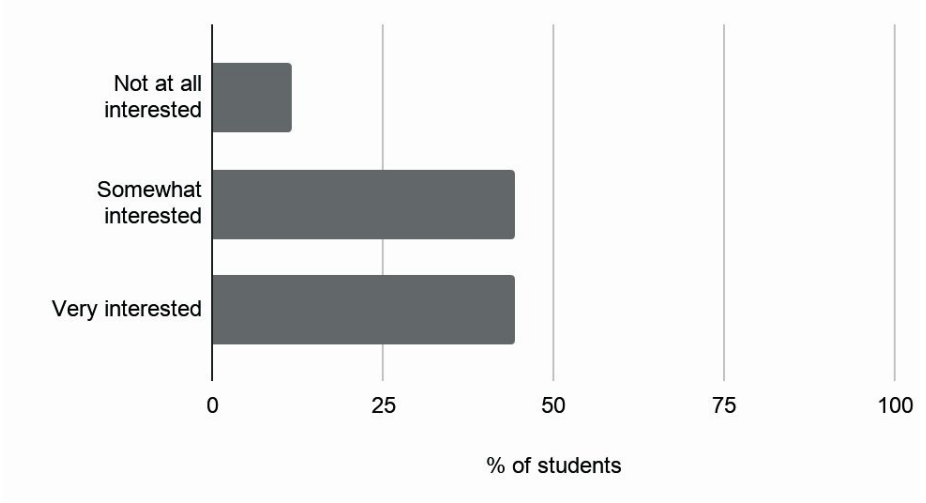

The next generation of neuroscientists needs new skills to adapt to this changing landscape of data.

Mismatch between experience and interest

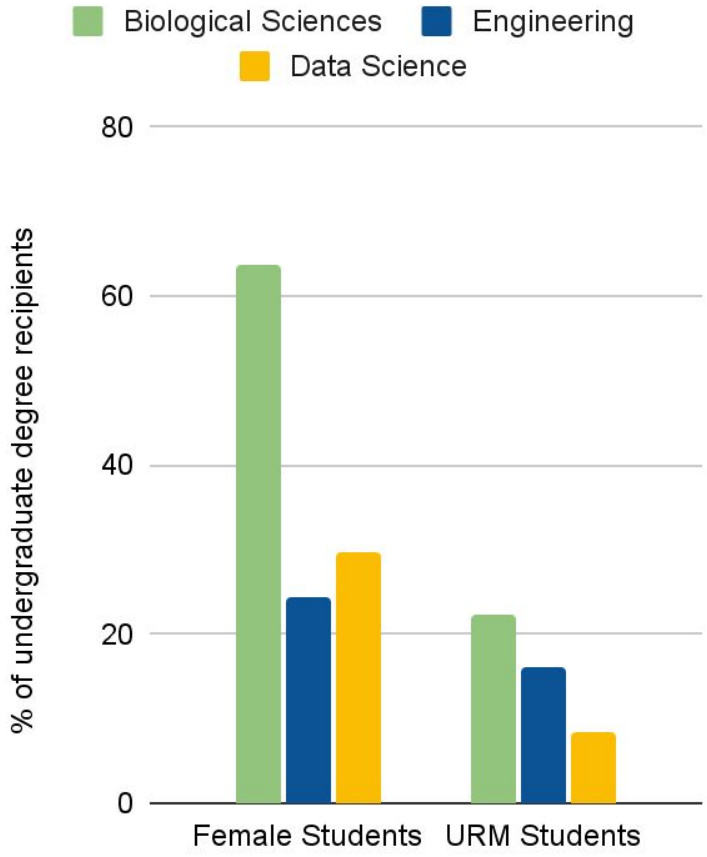
How much coding experience do you have?



How interested are you in learning how to code?



4 sections of neurobiology lab; 138 students total

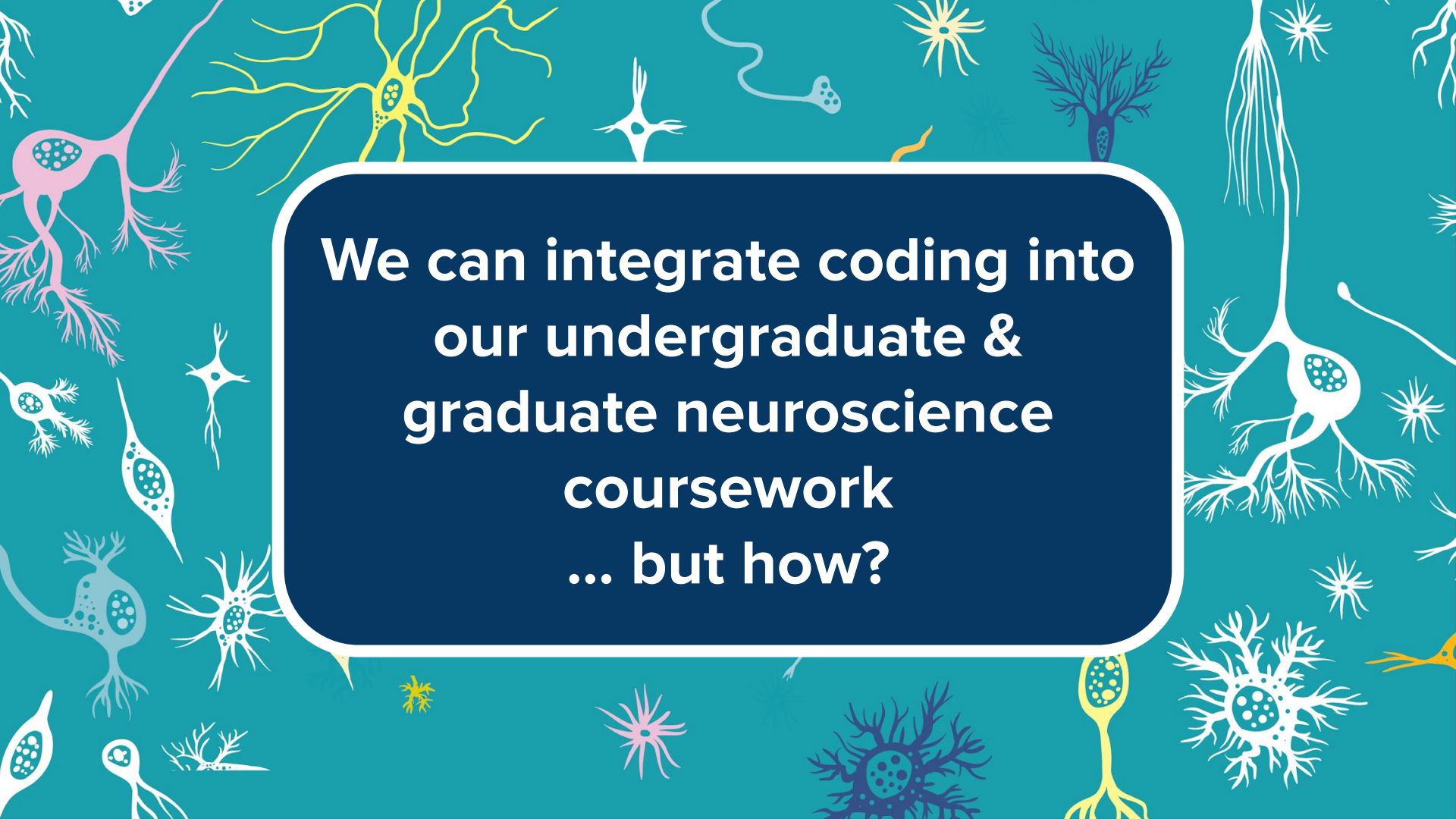


https://ir.ucsd.edu/undergrad/stats-data/ug-degree.html

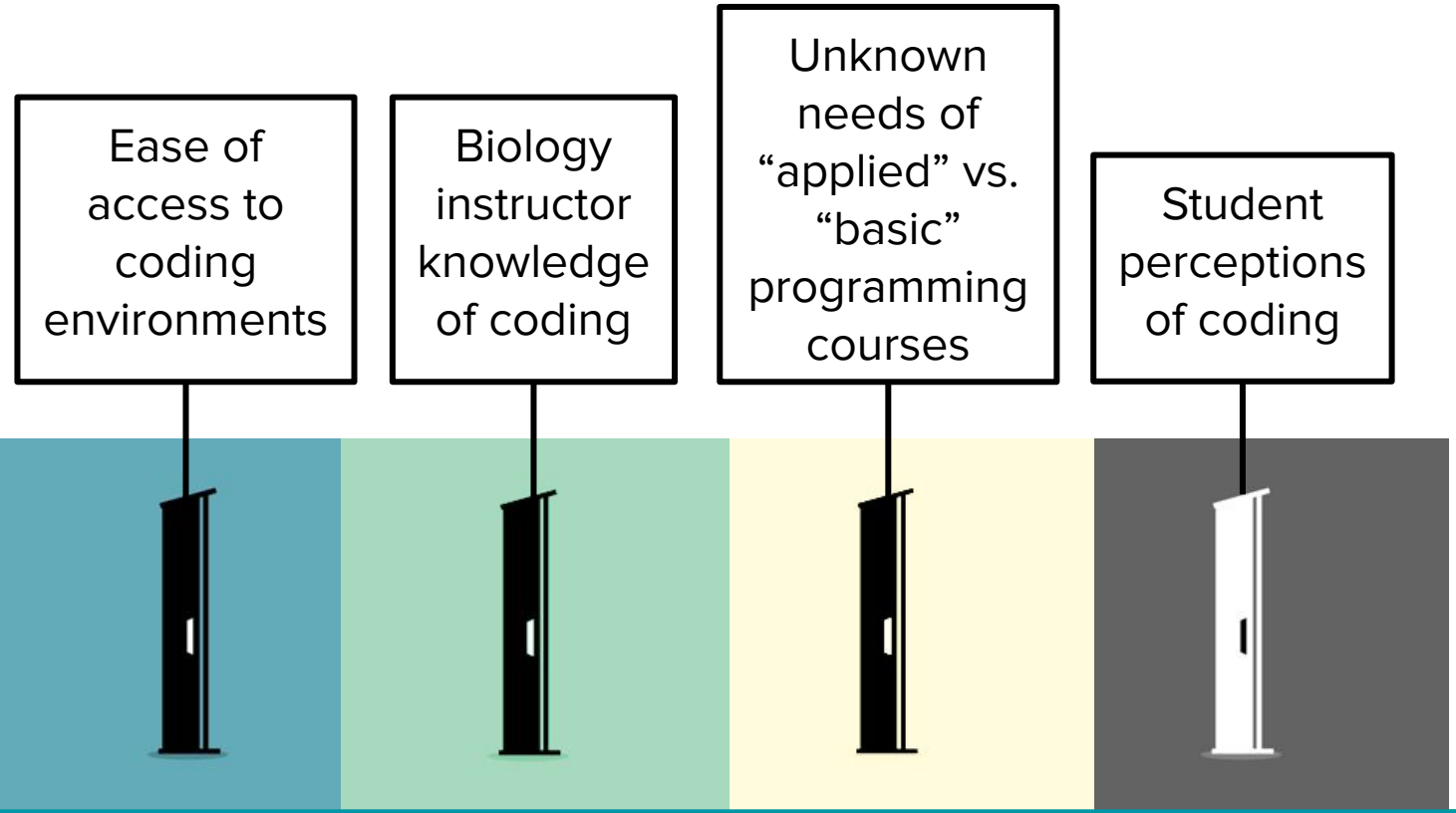
This is also a matter of equity.

More and more jobs require programming experience, and the jobs that do pay more.

(see report by Burning Glass: https://www.burning-glass.com/research-project/coding-skills/)


We can integrate coding into our undergraduate & graduate neuroscience coursework
... but how?

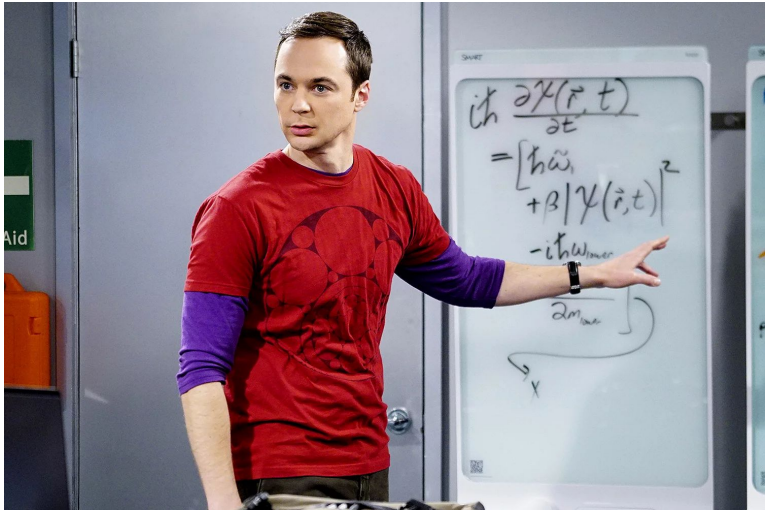
Barriers to bringing coding into neuroscience courses



Juavinett, *Neuron,* “The next generation of neuroscientists needs to learn how to code, and we need new ways to teach them” 2022

Student perceptions of coding & computer science (CS)

- **singularly focused** - CS requires an obsession with CS, necessarily at the exclusion of having other interests or meeting personal needs.
- **asocial** - computer scientists do not have social skills and CS requires working in isolation.
- **competitive** - CS courses (and thus potentially the field as a whole) are competitive and CS work is done individually as opposed to in collaboration with others.
- **male** - success in CS requires one to identify as male, or men are innately more talented in CS than women.



Lewis et al., “I Don’t Code All Day”: Fitting in Computer Science When the Stereotypes Don’t Fit (2016)

See also Cheryan et al., 2009, 2011, & 2013; Cvencek et al., 2015; Ensmenger, 2012; Goodenow, 1993; Lee 1998; Margolis & Fisher, 2003; Margolis et al., 2010; Steele, 1997

Neurobiology students start with preconceived notions about coding

I am intimidated because I have some buddies who are computer science majors and share their stresses to me sometimes

I've heard very awful things about computer science courses but it seems interesting especially if the connection to neurobiology is there!

Not very comfortable since I'm not very much a computer person, also **numbers stress me out**

I'm curious about it. I don't know if I'll be a good coder or not.

Responses to the question *"How do you feel about learning how to code?"*

Barriers to bringing coding into neuroscience courses

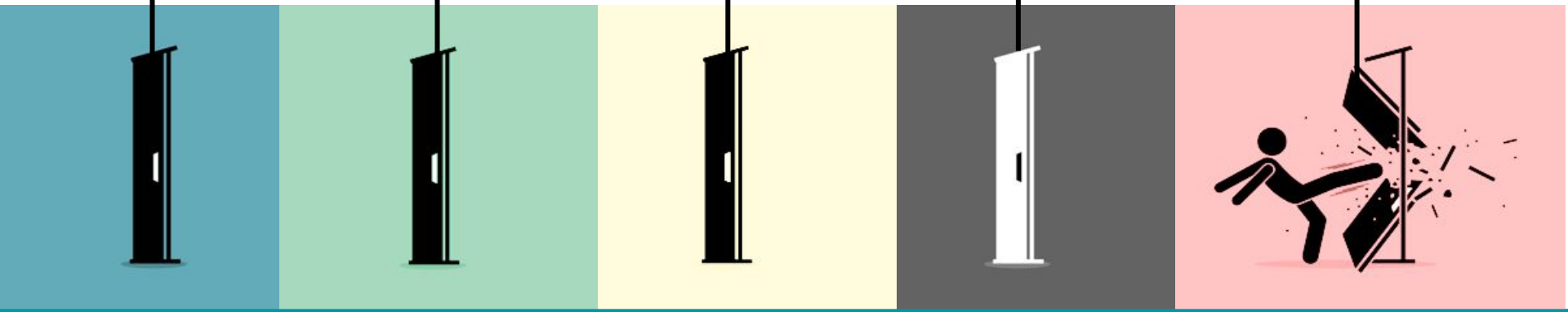
Ease of access to coding environments

Biology instructor knowledge of coding

Unknown needs of “applied” vs. “basic” programming courses

Student perceptions of coding

Accessible, discipline-specific coding resources for all educators



Three possible ways to include coding into the curriculum

Exposure to coding in coursework

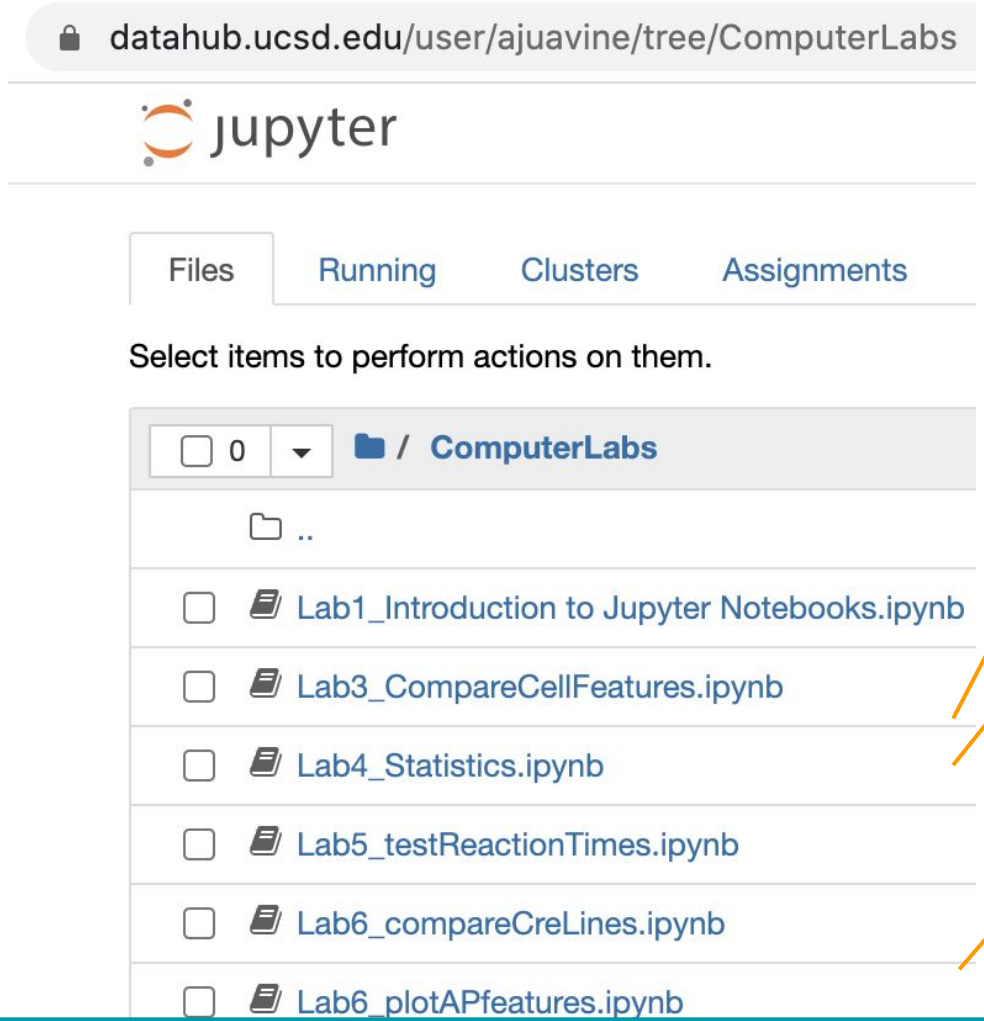
- Limited time to devote to coding
- Students *see* utility and *edit* code but do not *write* their own code
- Using code may even be optional

Less independent coding
Lower instructor proficiency

Integration of coding in coursework

- 1-2 hours dedicated to contextualized, introductory programming lessons
- Students edit code and *begin* to write their own
- Lessons exist in standalone modules
- Students can ask their own questions of data

More independent coding
Higher instructor proficiency



Notebooks for a neurobiology lab class

Choose cell features to compare — *data from the Allen Institute*

Demonstrate statistical concepts and implement two-sample statistics

Compare electrophysiological properties between cell types — *data from the Allen Institute*

Course JupyterBook:
bipn145.github.io

Notebooks are designed to expose students to coding, with straightforward tasks to complete

> **Task**: Choose two different Cre lines to compare, and assign them to the variables below by replacing the `...`. The value of your variable needs to be a **string** -- in other words, it should have quotes around it. The cell will print how many cells are in your datasets. If you have less than 10 cells, consider choosing a different Cre-line.

> You can find information on the different cre-lines that are available in this glossary or on the Allen Institute's website.

> **Note**: Be sure that you are using the *entire* name of the Cre line -- that means *everything* within the single quotes above.

In [ ]:
```
cre_line_1 = ...
cre_line_2 = ...

cre_line_1_df = mouse_ephys_df[mouse_ephys_df['transgenic_line']==cre_line_1]
cre_line_2_df = mouse_ephys_df[mouse_ephys_df['transgenic_line']==cre_line_2]

print(cre_line_1 + ' has ' + str(len(cre_line_1_df)) + ' cells')
print(cre_line_2 + ' has ' + str(len(cre_line_2_df)) + ' cells')
```

Three possible ways to include coding into the curriculum

Exposure to coding in coursework

- Limited time to devote to coding
- Students *see* utility and *edit* code but do not *write* their own code
- Using code may even be optional

Contextualized (discipline-based) coding classes

- An entire class dedicated to teaching coding in the context of neuroscience
- Students design & write their own code
- May include novel research projects

Less independent coding
Lower instructor proficiency

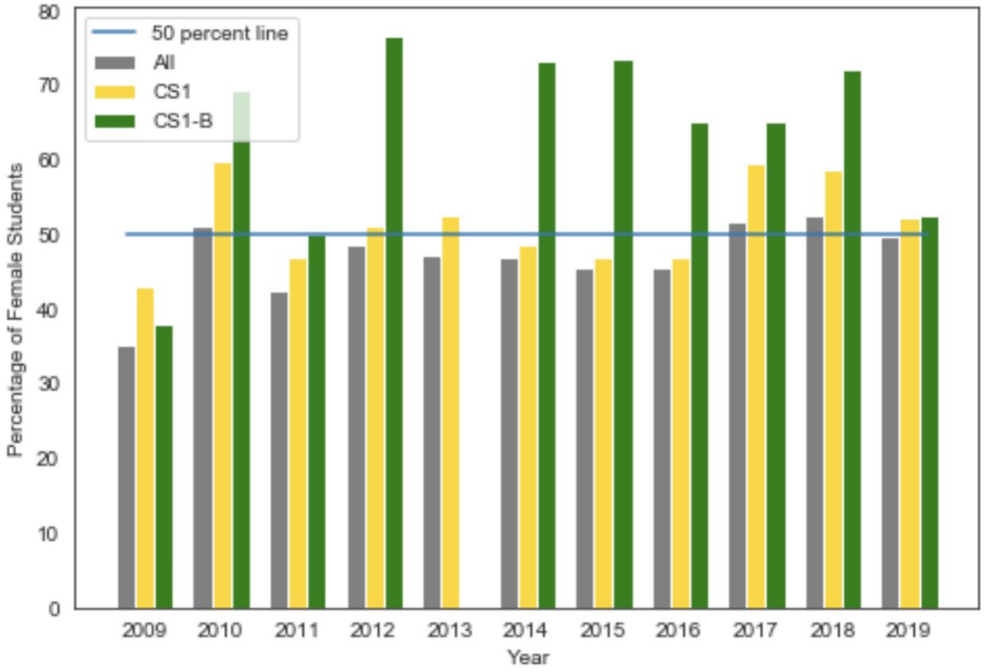
Integration of coding in coursework

- 1-2 hours dedicated to contextualized, introductory programming lessons
- Students edit code and *begin* to write their own
- Lessons exist in standalone modules
- Students can ask their own questions of data

More independent coding
Higher instructor proficiency

Contextualized coding invites in more female students

Figure 2: Female Students: % in CS1 and CS1-B, per year



learn how to code while looking at

> genes
> cells
> brains

Introduction to Python for Biologists (BILD 62)
Spring 2022, T/Th@2pm

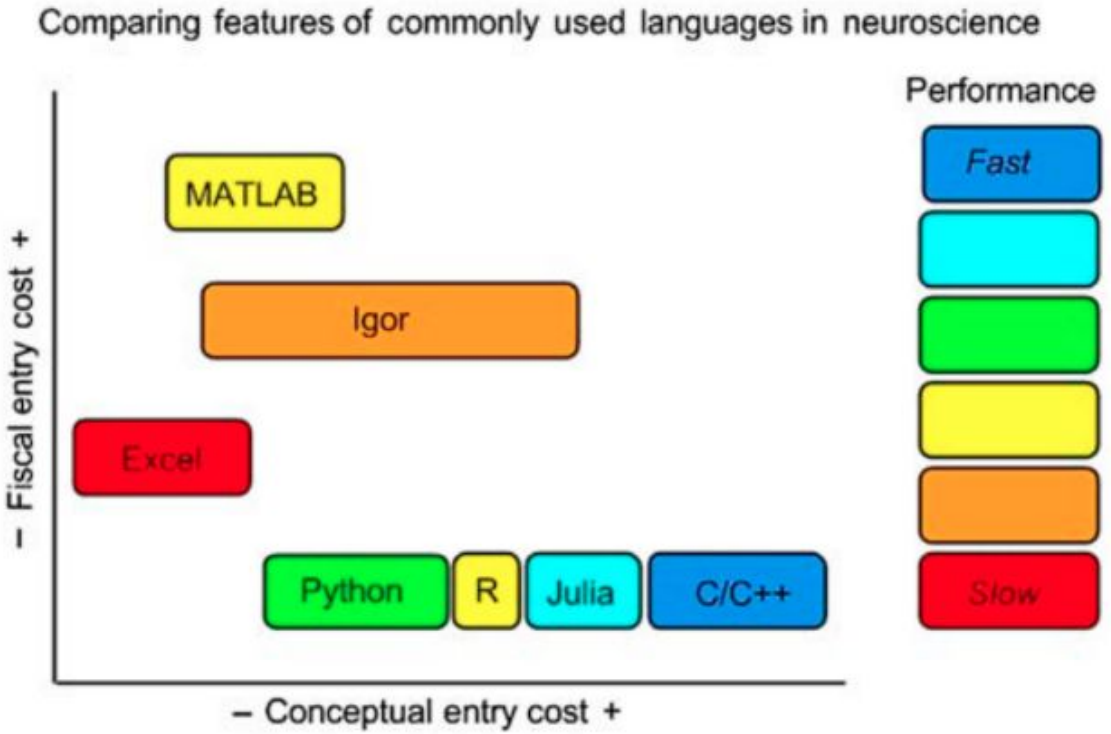
Dodds et al., *SIGCSE* 2021
"A Biology-based CS1: Results and Reflections, Ten Years in"
(results from this study less clear for first-generation or URM students)

PART II

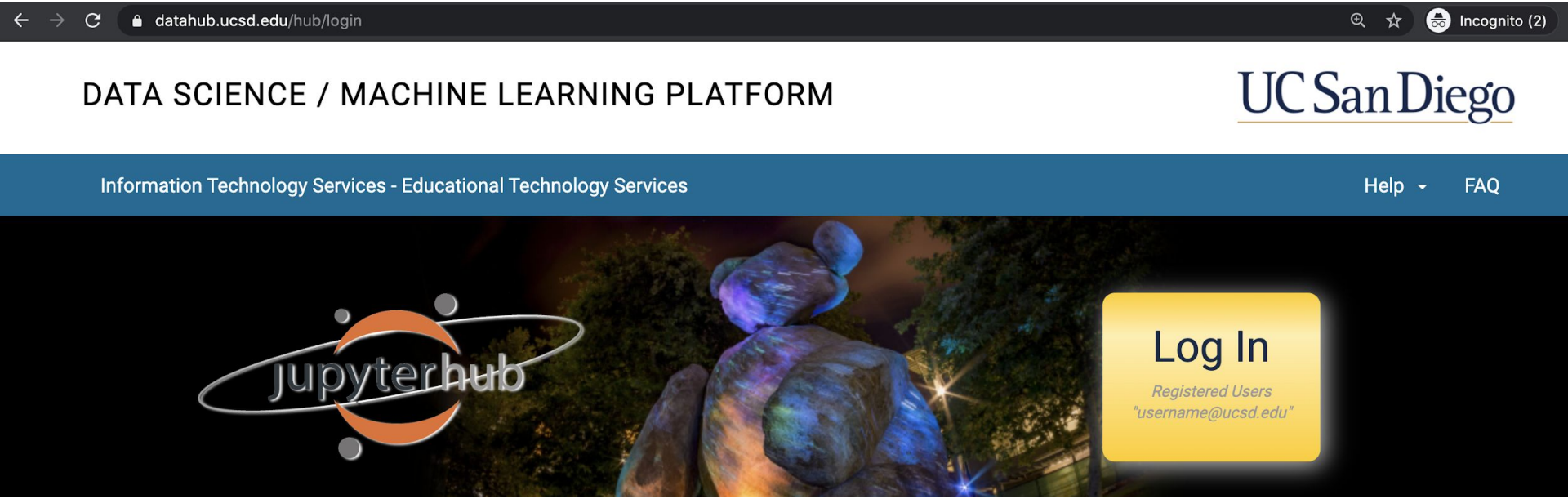
The Tools

Considerations for choosing a programming language

- Fiscal & conceptual entry (see right)
- Usage in neuroscience
- Ease of use
- *My recommendation:* Python or R



From Wallisch (2017)



UCSD has a data science online platform designed for exactly this, and Google Colab works well for educators at institutions without a Jupyter Hub

Considerations when choosing tools & a teaching approach

- How much do you want students to write code *de novo* versus editing provided code?
  - Carpentries Model: live coding on a blank page
- Do you want students to be dependent on (sometimes expensive) school or course-provided software?
- Do students have their own laptops (or do they have iPads)?
- Do students have access to a computer with a decent internet connection?

THE CARPENTRIES

https://carpentries.org/

Tools for today

- **Parts II & III:** Google Colab, a cloud-based computing *notebook*
  - Very similar to Jupyter notebooks, with small differences.
  - Conveniently saves & launches from Google Drive
- **Parts IV**: Dandihub (optional), cloud-based computational environment that includes Jupyter Notebooks & pre-configured docker container

BRAIN Initiative archive for publishing and sharing neurophysiology data including electrophysiology, optophysiology, and behavioral time-series, and images from immunostaining experiments.


Let’s open up our first notebook from
http://www.github.com/ajuavinett/FUN_2023

PART III

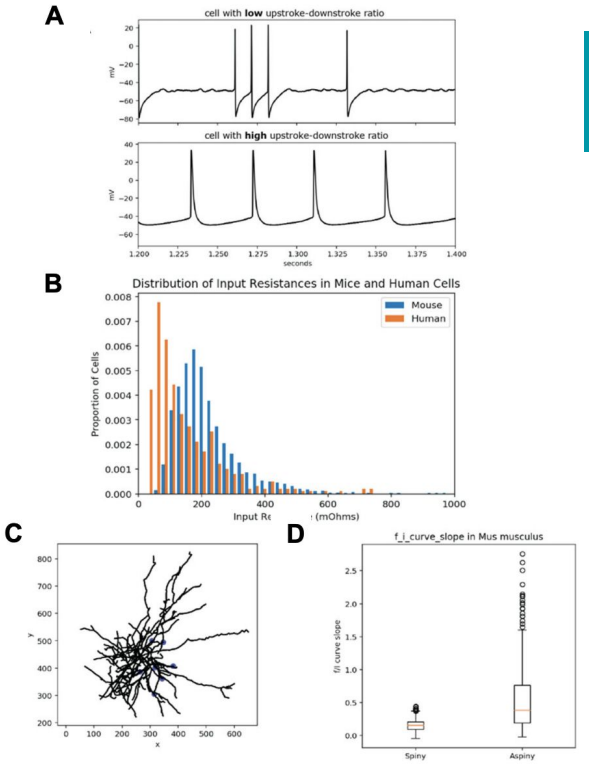
Cell Types Lesson

Cell Types Lesson Learning Objectives

- Relate the diverse intrinsic electrophysiological features of neurons to their structure and function
- Compare electrophysiological characteristics of neurons in humans and mice
- Practice using Jupyter Notebooks to run and edit Python code
- Develop a sense of belonging and self-efficacy in coding and neuroscience research

More information & resources:

https://sites.google.com/ucsd.edu/neuroedu/cell-types



Juavinett, “Learning to code while analyzing an open access dataset,” *JUNE*, 2020

PART IV

Teaching with Open Datasets

(e.g. Neurodata Without Borders)

Neuroscience datasets are increasingly being shared online

neuropixels

SEPT 2003 Allen Institute for Brain Science launched

DEC 2004 Allen Mouse Brain Atlas

JULY 2008 Allen Mouse Spinal Cord Atlas

NOV 2008 Allen Developing Mouse Brain Atlas

OCT 2009 NIH Blueprint Non-Human Primate Atlas

MAY 2010 Allen Human Brain Atlas

OCT 2010 BrainSpan Atlas of the Developing Human Brain

OCT 2011 Allen Mouse Brain Connectivity Atlas

MAY 2015 Allen Cell Types Database

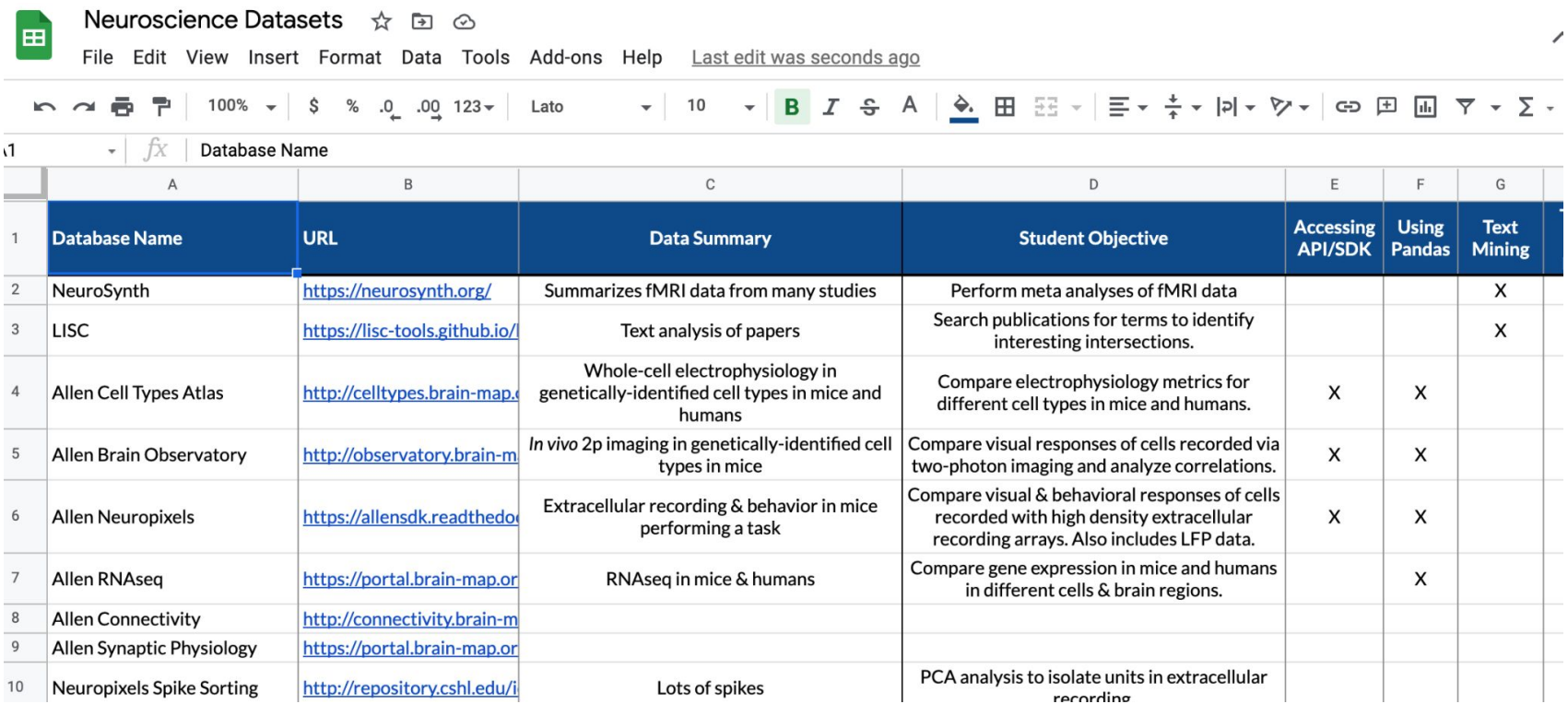
MAY 2015 Ivy GAP

MAR 2016 Aging, Dementia and TBI

JUNE 2016 Allen Brain Observatory

NEURODATA WITHOUT BORDERS

DANDI
dandiarchive.org



	Database Name	URL	Data Summary	Student Objective	Accessing API/SDK	Using Pandas	Text Mining
2	NeuroSynth	https://neurosynth.org/	Summarizes fMRI data from many studies	Perform meta analyses of fMRI data			X
3	LISC	https://lisc-tools.github.io/l	Text analysis of papers	Search publications for terms to identify interesting intersections.			X
4	Allen Cell Types Atlas	http://celltypes.brain-map.(	Whole-cell electrophysiology in genetically-identified cell types in mice and humans	Compare electrophysiology metrics for different cell types in mice and humans.	X	X	
5	Allen Brain Observatory	http://observatory.brain-m	*In vivo* 2p imaging in genetically-identified cell types in mice	Compare visual responses of cells recorded via two-photon imaging and analyze correlations.	X	X	
6	Allen Neuropixels	https://allensdk.readthedo(	Extracellular recording & behavior in mice performing a task	Compare visual & behavioral responses of cells recorded with high density extracellular recording arrays. Also includes LFP data.	X	X	
7	Allen RNAseq	https://portal.brain-map.or	RNAseq in mice & humans	Compare gene expression in mice and humans in different cells & brain regions.		X	
8	Allen Connectivity	http://connectivity.brain-m					
9	Allen Synaptic Physiology	https://portal.brain-map.or					
10	Neuropixels Spike Sorting	http://repository.cshl.edu/i	Lots of spikes	PCA analysis to isolate units in extracellular recording			

Open Neuroscience Datasets https://bit.ly/openneurodatasets

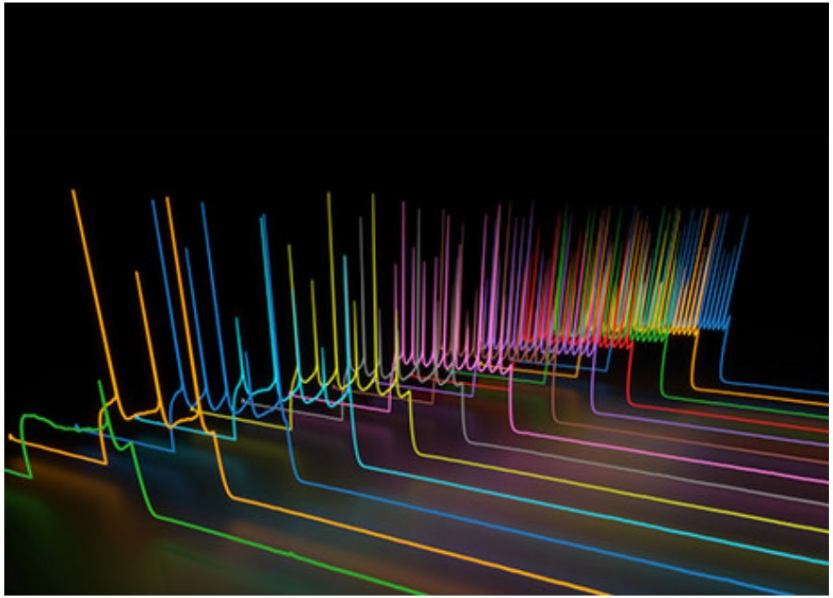
NEURODATA WITHOUT BORDERS

ABOUT COMMUNITY

Neurodata Without Borders

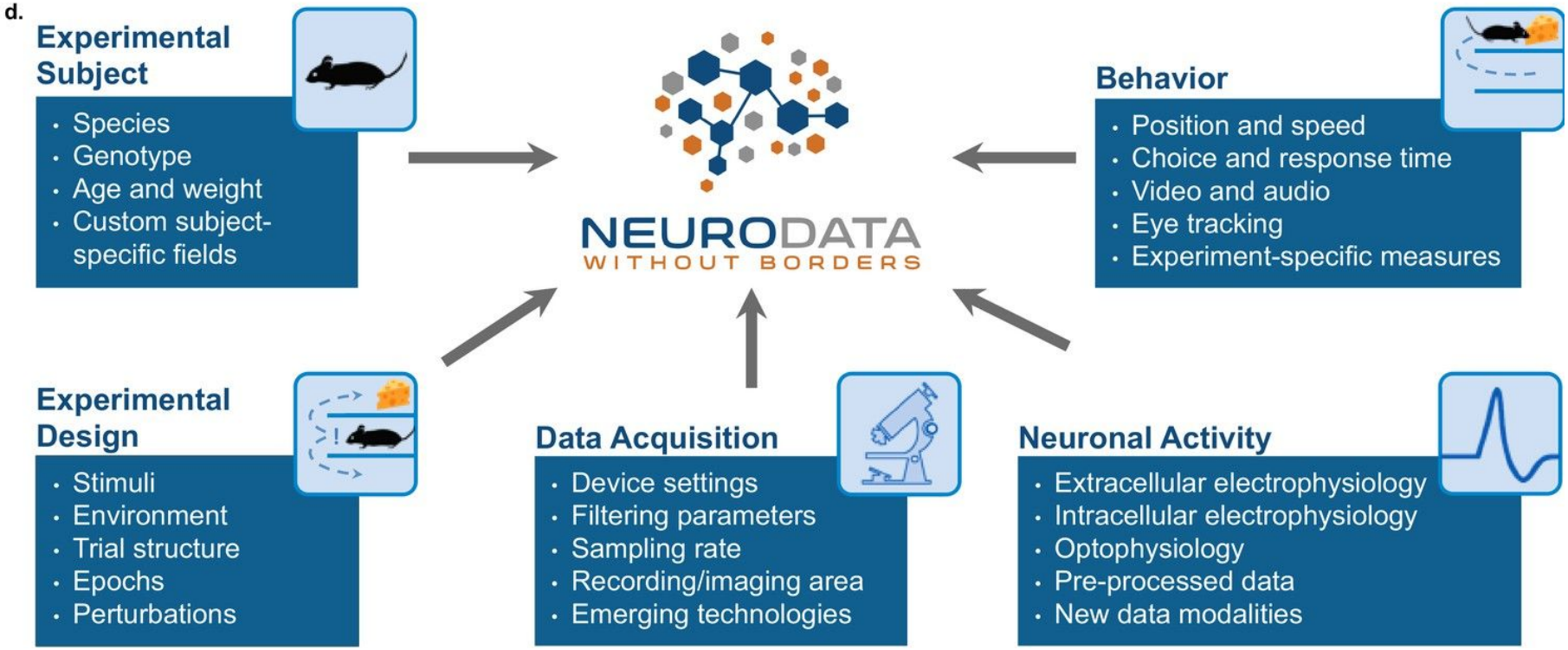
Neurodata Without Borders (NWB) is a data standard for neurophysiology, providing neuroscientists with a common standard to share, archive, use, and build analysis tools for neurophysiology data. NWB is designed to store a variety of neurophysiology data, including data from intracellular and extracellular electrophysiology experiments, data from optical physiology experiments, and tracking and stimulus data.

The **NWB team** consists of neuroscientists and software developers who recognize that adoption of a unified data format is an important step toward breaking down the barriers to data sharing in neuroscience.

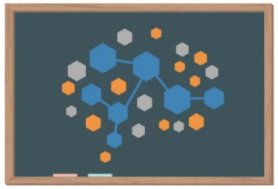


(Courtesy of the Allen Institute for Brain Science)

See also Rübel et al. (2022):
https://elifesciences.org/articles/78362



Rübel et al. (2022): https://elifesciences.org/articles/78362



Teaching and Learning with NWB Datasets

For many, many years in neuroscience, the landscape of file formats has been the wild west. Everyone either uses a format either dictated by their lab or by the equipment they're using. This poses a huge challenge to data sharing: if you want to collaborate with the lab next door and share data with them, one of the first questions is, "what format is your data in?" While static images taken from a microscope and standard biology lab procedures like western blots are fairly straightforward to share, physiology and behavior data types are much more diverse.

That's where Neurodata Without Borders (NWB) comes in. NWB is a consortium of researchers who are aiming to *standardize neuroscience data on an international scale.* The use of this standard dataset format will make sharing and contributing to open source projects easier, ultimately accelerating discovery.

NWB has pioneered a data format called Neurodata Without Borders: Neurophysiology (NWB:N). NWB:N is a standard to share, store, and build analysis tools for neuroscience data. It is built on HDF5 (hierarchical data format), which was designed for large data storage and multi-language accessibility. In other words, it's good at doing exactly what we need it to do.

Standardized data for education

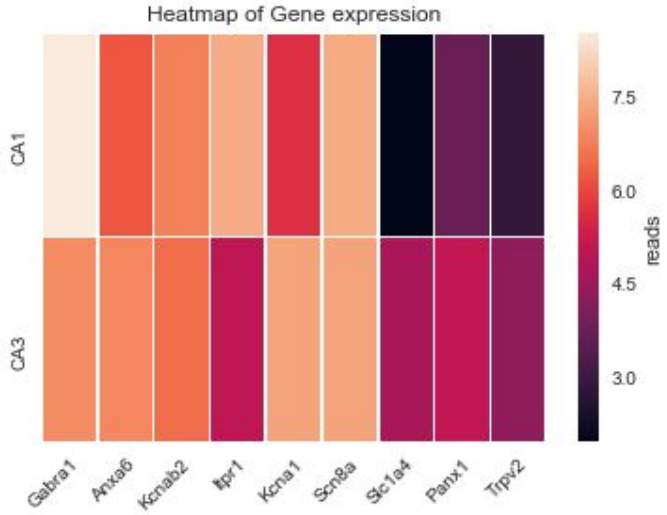
A standardized and accessible data format like NWB also opens possibilities for more easily integrating these cutting-edge datasets into the classroom. **This online textbook aims to provide interactive and self-**

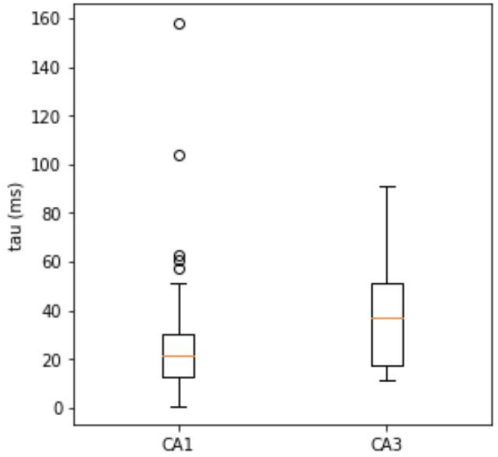
Looking for paid test users!

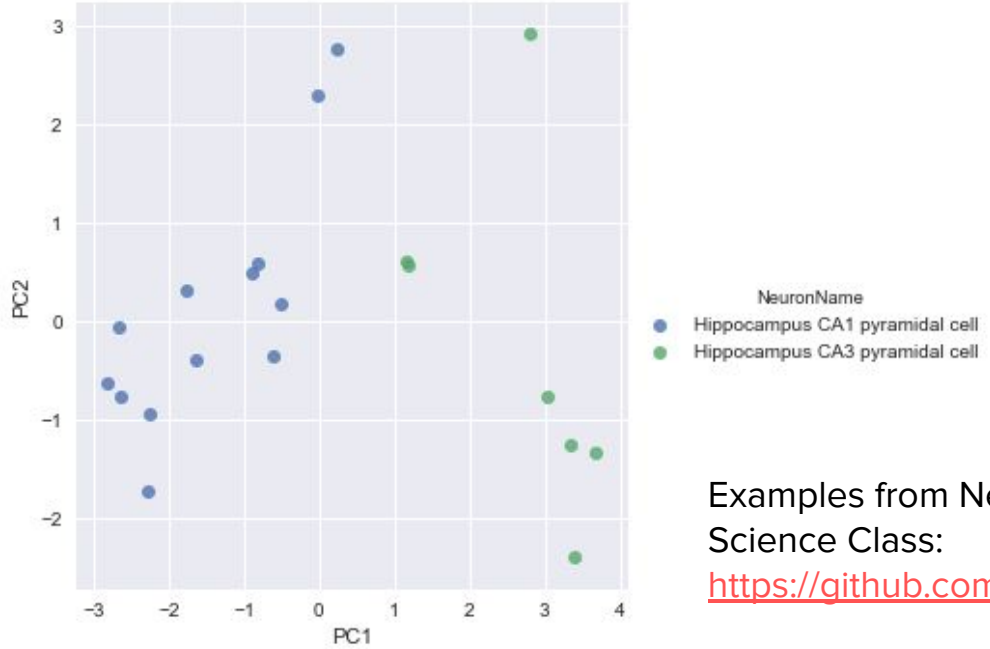
THE KAVLI FOUNDATION

In progress: online lessons using NWB datasets at nwb4edu.github.io

Students perform *real*, novel research







Examples from Neural Data Science Class: https://github.com/BIPN162

For the final demo, we'll work out of the Dandihub: hub.dandiarchive.org

```
git clone https://github.com/ajuavinett/FUN_2023
```

PART V

Wrap-Up & Promising Practices

A general framework for teaching coding to neuroscience students

- Live code in front of students
- Encourage **pair programming**
- Normalize errors and **searching for answers**

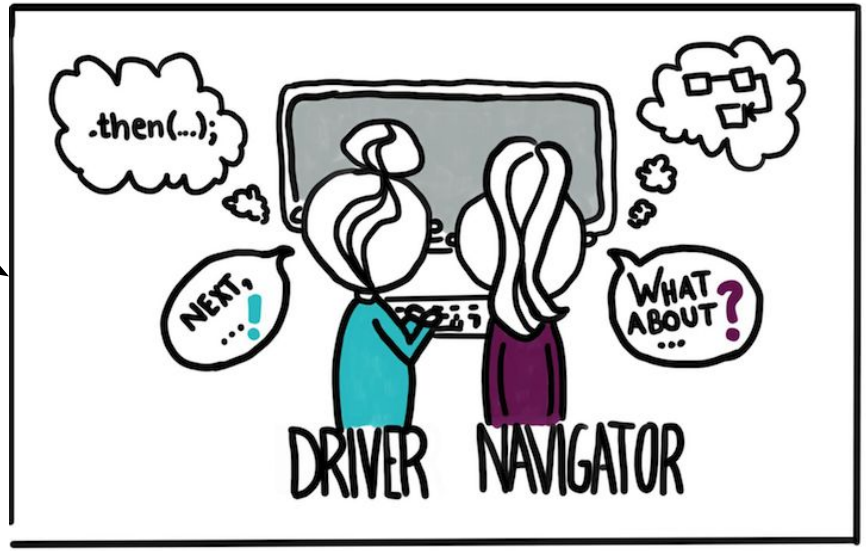


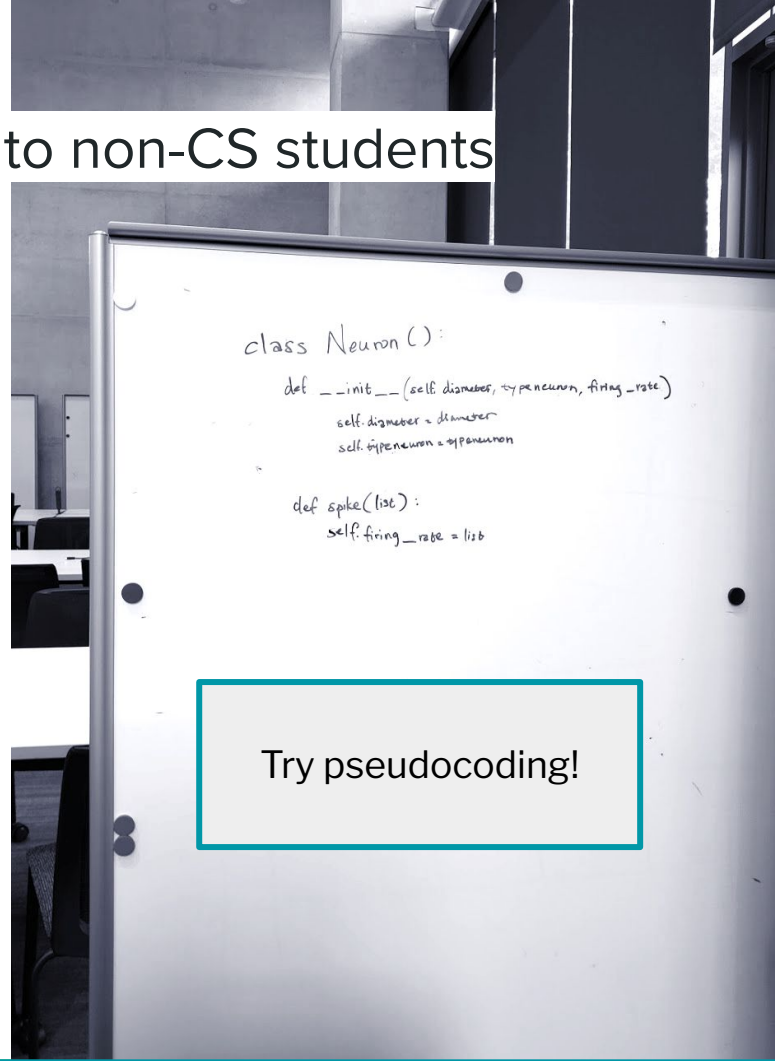
Image Source

More thoughts on this: Ten quick tips for teaching programming

A general framework for teaching coding to non-CS students

- Frame coding as a **skill** — *it's like learning a language*
- Encourage **growth mindsets** around coding
  - Students with growth mindsets perform better over time
  - Beliefs about whether computational abilities are fixed or malleable impact: sense of belonging, how we respond to difficulties, and ultimately, achievement

More thoughts on this: Medium | There is No Such Thing as a Computational Person



Oh yeah, what about chatGPT (or other LLMs)?

You (and your students) can and *should* use it to learn!

How you integrate it into your class depends on your learning objectives!

Extensions of what you've seen here

- Addition of transcriptomic data (ongoing work)
- Recent publication by Ho et al. (2021)
- Your work?

The Journal of Undergraduate Neuroscience Education (JUNE), Fall 2021, 20(1):A100-A110

ARTICLE

Pandemic Teaching: Using the Allen Cell Types Database for Final Semester Projects in an Undergraduate Neurophysiology Lab Course

Yi-Yun Ho[1], Andrea Roeser[1], Gwenda Law[2], and Bruce R. Johnson[1]

[1]Department of Neurobiology and Behavior, Cornell University, Ithaca, NY 14853; [2]Department of Biomedical Engineering, Cornell University, Ithaca, NY 14853.

We designed a final semester research project that allowed students to apply the electrophysiological concepts they learned in a lab course to propose and answer experimental questions without access to laboratory equipment. We created the activity based on lesson plans from Ashley Juavinett and the Allen Institute for Brain Science (AIBS) Allen SDK online examples. An interactive graphic interface final semester project allowed students to ask real-world medical and scientific questions from "start to end". Through this project, students developed skills to navigate an extensive online database and gained experience with coding-based data analysis. They chose neuronal populations from human and mouse brains to compare passive properties and neuronal excitability

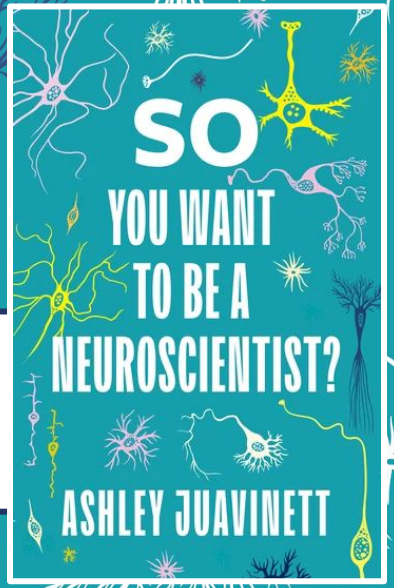
Thank you.

THE KAVLI FOUNDATION

Support for online neural data science textbook

Victor Magdaleno-Garcia, mentee & research intern

@analog_ashley



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Support for using & sharing datasets
Kaitlyn Casimo, Saskia De Vries, Tom Chartrand

Austin Zuckerman
Current research on computing attitudes in biology students