Neuroscience Educational Simulation Platform Development

2D/3D Neuron Visualization & User Interface Design

Christine Zeng, Rachel Weldy, Danny Siu, Izabela Jedrasiak-Cape, Omar J. Ahmed

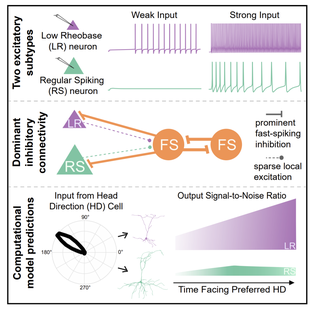
Abstract

While there is much research on how neurons and neural networks communicate, an effective neuroscience tool to simulate this communication does not yet exist. Neuropia, the educational software Omar Lab is developing using JavaScript, Python, HTML, CSS, and Neuron, strives to solve this issue, creating accessible neuron interaction simulations for University of Michigan's Neuroscience and Psychology students and those interested in learning Neuroscience. Implementation and improvements for Neuropia include:

1. 3D visualizations and integration of low-rheobase(LR) & regular spiking(RS) neurons in the retrosplenial cortex, a brain region critical for memory, learning, and navigation, and fast spiking(FS) neurons
2. new LR and RS simulation using experimental data gathered from the Omar Lab allow the user to modify the neuron inputs and view graphs of resulting neuron interaction in real time
3. greater accessibility and streamlined interface to the educational program's design

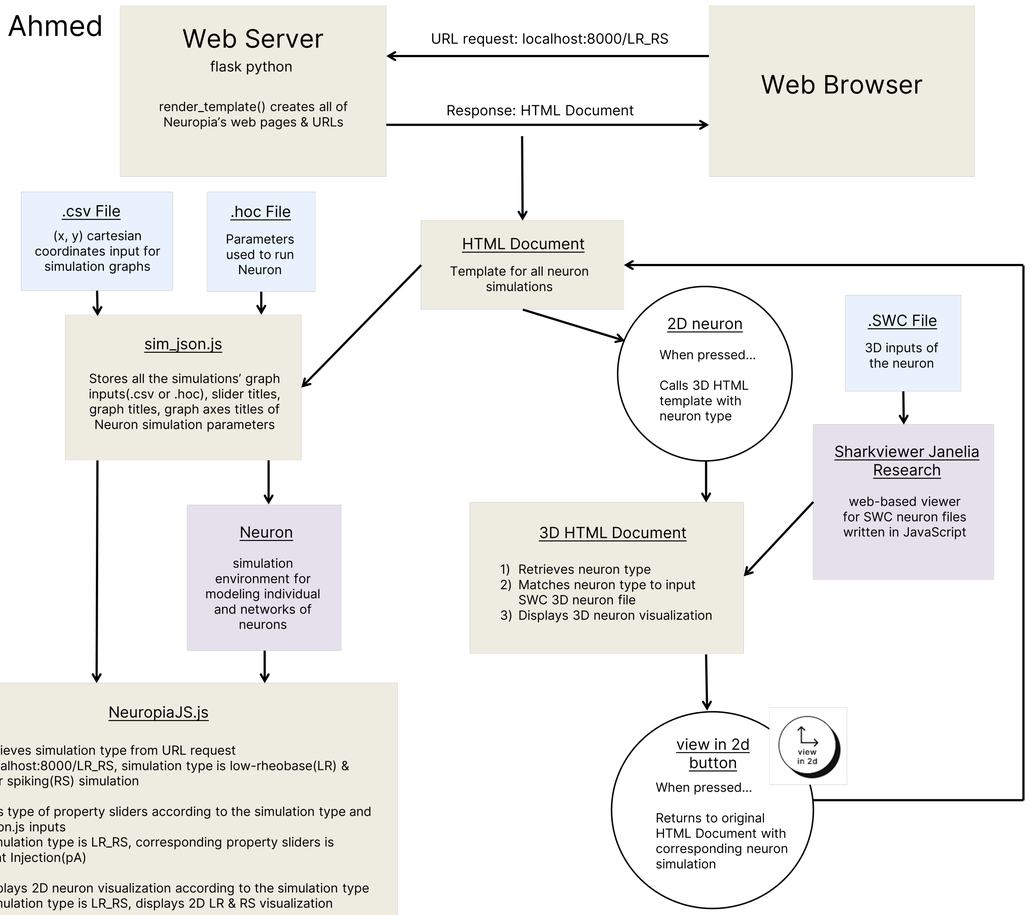
Background

The retrosplenial cortex is an understudied brain region that is important for navigation and memory. There are two distinct subtypes of excitatory neurons that are found in the retrosplenial cortex; the low-rheobase (LR) neuron and the regular spiking (RS) neuron (Brennan et al., 2020, 2021). The unique properties of LR neurons, in particular, are ideally suited to support the spatial orientation and memory functions of the retrosplenial cortex. In separate projects, our lab is studying how these neurons are altered in neurological diseases including Alzheimer's and Parkinson's. Here, we create web-based, interactive simulations to facilitate concept learning about the importance of distinct neuronal subtypes and their functions in health and disease.

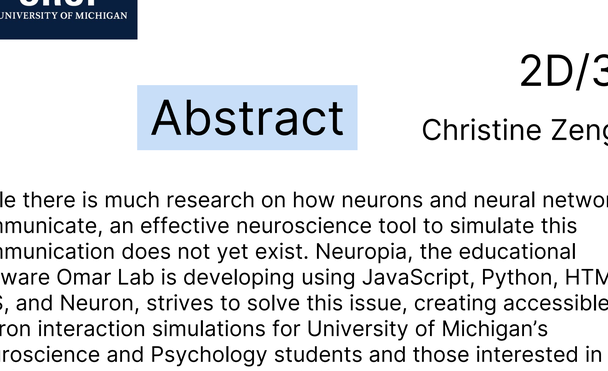


A diagram modeling the functions of LR/RS cells

Methods

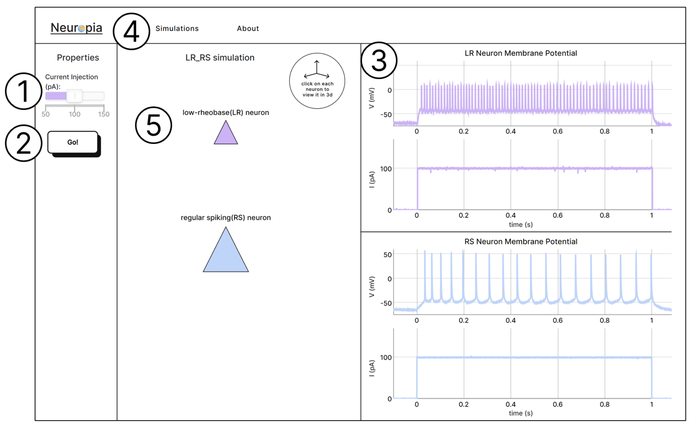


Results

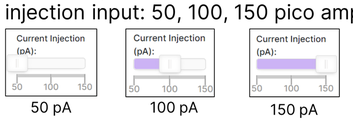


Neuropia's original home screen, running the excit simulation

Low-rheobase(LR) & regular spiking(RS) simulation



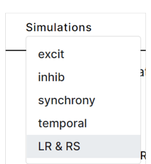
① Current Injection property is interactive, user chooses current injection input: 50, 100, 150 pico amps(pA)



② Pressing Go! will run simulation, generates LR and RS neuron's voltage and current graphs based on property values

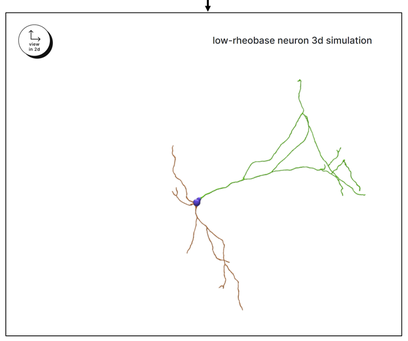
③ Voltage and current reaction graphs; colors correspond to 2D neuron colors: LR purple, RS blue

④ Navigation bar allows quick navigation between different neuron interaction simulations

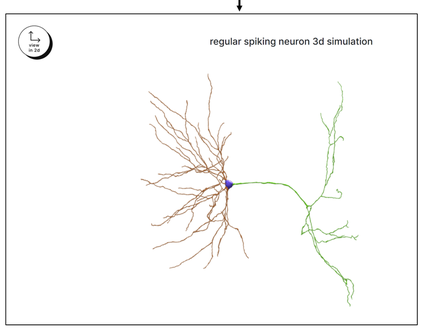


⑤ Clicking each 2D neuron will display it's 3D visualization

low-rheobase neuron



regular spiking neuron

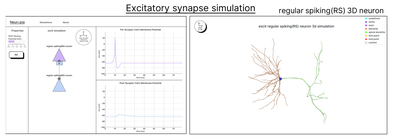


Overall interface display & usability improvements

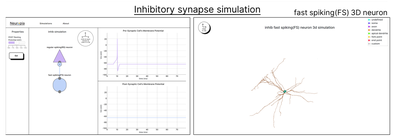
- Added 3D simulations to 2D neuron simulations
- Organized content(Properties bar, 2D simulation, graphs) to follow visual hierarchy
- Improved design
- Added labels for each neuron and neuron simulation to guide student learning

Other developed simulations

Excitatory synapse simulation — regular spiking(RS) 3D neuron



Inhibitory synapse simulation — fast spiking(FS) 3D neuron



Conclusion

- Programmed 3D visualization tool for each neuron, aiding in further analysis of the structure of LR, RS, FS neurons
- New 2D simulation of LR and RS neurons, neurons critical for both spatial and non-spatial behaviors
- Neuropia interface improvements, conducive for better learning and discovery
- Brought awareness to neuron interactions associated with Alzheimer's Disease while encouraging Neuroscience exploration and advocacy.

Future Work

- Create a more universal curriculum – introductory summaries and photos of neuron structures to expand audience
- Design a neuronal connectivity toolkit, allowing users to construct their own neuron interactions

Acknowledgments & References

Acknowledgments:
OmarLab, Max Berkowitz, Rex Hu, Shyam Kumar Sudhakar, Ruben Wu, Sharkviewer, Neuron

References:

Brennan EW, Sudhakar SK, Jedrasiak-Cape I, John T, Ahmed OJ (2020). Hyperexcitable neurons enable precise and persistent encoding in the superficial retrosplenial cortex. Cell Reports 30:1598-1612

Brennan EW, Jedrasiak-Cape I, Kailasa S, Rice SP, Sudhakar SK, Ahmed OJ (2021). Thalamus and claustrum control parallel layer 1 circuits in retrosplenial cortex. eLife 10:e62207

Charlotte Weaver et al., "Janeliascicomp/Sharkviewer," Shark Viewer (Howard Hughes Medical Institute, Janelia Research Campus, 2014), https://github.com/JaneliaSciComp/SharkViewer.