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Introduction to Modeling and Computational Neuroscience using Python

Neuroscience offers a rich domain of crosscutting sciences (e.g. biology, chemistry, physics) and therefore has the potential to be of interest to a wide variety of students. The subject of the [human] brain adds even more appeal due to its wondrous complexity and remarkable abilities, e.g. learning, memory, vision, consciousness – concepts that everyone can appreciate. Computational neuroscience brings in more core subject areas, primarily mathematics and computer science. It offers students an important hands-on experience, letting them apply concepts learned in their classrooms and, for some, challenging them to step outside their comfort zone into higher math and new programming languages.

As part of a NSF grant related to the analysis of causal connectivity of neurons, our university team has formed a collaboration with a high school physics teacher to share the excitement of neuroscience with high school students and, hopefully, establish a long term academic relationship that will help encourage students to major in science or mathematics in college. The first phase of this collaboration involved a presentation to four different physics classes (Honors or AP-level), consisting of about 100 students total, who ranged from freshmen to seniors. The presentation discussed computational science, in general: experiments, modeling, simulation, and analysis; but the focus was on computational neuroscience and the Python programming language. Many of the students were completing a unit on electronic circuits, so we demonstrated, using visually engaging simulations, how a neuron could be modeled as a simple (leaky integrate and fire (LIF)) R-C circuit and how this led to the important concept of a neuron spike. We then introduced the differential equation associated with the LIF model and the few lines of Python code that could numerically solve it. Following this simple, single neuron model, we discussed the historically significant Hodgkin-Huxley model (with its more complicated differential equation and electronic circuit). Lastly, we demonstrated the Izhikevich model, a pair of coupled differential equations, and how it was used to simulate a network of spiking neurons.

The presentation included many visuals related to the structure and function of neurons – axons, synapses, spiking behavior, and neuron networks. We also asked thought-provoking questions about memory, self-awareness, etc., as well as ethical questions related to animal testing. Somewhat related to this last topic, we also pointed out the availability of inexpensive do-it-yourself (DIY) neuroscience experiments that involve a cockroach leg.

This initial phase of our high school-university collaboration certainly had its challenges. Probably the most challenging was the mathematics (differential equations) since only about half of the students had taken calculus. But overall, we believe it was a very positive experience – for all of us. We asked the students to anonymously answer just two follow-up questions related to the presentation – what did they like best and what did they like least? We will present some simple statistics about these answers.

There are a number of directions our collaboration could take from this point: simple email exchanges or social networking groups, tours of university labs, or the formation of afterschool or weekend clubs, e.g. Python programming/simulations or DIY experiments using hardware. We are discussing the possibilities and we hope to learn lessons from other science educators.