Fall 2018
Biophysical and network models of neurons

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Prerequisites:
Prerequisite: Behavioral Integrative Neuroscience
Co- or pre-requisite: Cellular and Molecular Neurobiology
or by permission of the instructor.
Experience with Matlab is not required. Students will be taught basic programming skills and provided with 'skeleton' programs when necessary.

Schedule:
All lectures will be held in Meyer 760, Wednesday 2-4pm

Required Materials:
Molecular and Cellular Physiology of Neurons; chapters available for free at http://www.degruyter.com/viewbooktoc/product/430001
MatLab (License available for free through NYU)

Grading:
20% will be based on weekly homework assignments; 20% on project proposal (oral presentation); 50% on project (written & oral); and 10% on class participation. Students will develop a computer program that simulates a neural phenomenon of their choosing. Students are expected to formulate a hypothesis, perform the appropriate simulations, analyze/interpret the results, and present their results to the class.

Description: A fundamental goal in neuroscience is to understand how information about the external world is encoded, transformed, and stored in neural networks of the brain. Computer simulations are often used to elucidate the processing capabilities of networks and provide a foundation for interpreting the massive data that are being collected with experiments. However, a caveat is that simplifications and assumptions are necessary in order to make the problems more tractable computationally. In this course, students will construct biophysically accurate models of neurons and synapses and compare their properties to highly simplified neurons. Students will then construct large networks and examine their ability to represent and store signals.

Course Organization: Class meets once a week for 2 hours. The first hour will be a discussion of the assigned material. The second hour will be devoted to writing codes for simulations.

Learning Goals: Upon completion of the course, students will be able to write computer programs for simulating neurons and networks of neurons. Importantly, by running simulations, students will develop a strong intuition about the dynamics of neural networks that underlie information processing and storage.

Course Syllabus

1. (September 5): Introduction

Review of differential equations;
Euler method for solving differential equations
Matlab exercises:
Basic Matlab programming techniques: program structure, loops, vectors/matrices

2. (September 12): Passive properties of neurons; Nernst Equilibrium Potential

Review of Passive properties of neurons and resting/equilibrium potentials
Reading:
Fain, Chapt.2 (p. 31-45); handout for Nernst equation
Matlab exercises:
Using Euler method for modeling passive properties with resistors and capacitors in parallel; Na, K equilibrium potentials and resting potential
Homework: effects of membrane properties/ion concentration on voltage response

3. (September 19): Biophysics of Action Potentials: Hodgkin and Huxley I

Using H&H experimentally-derived variables to model channel behavior
Reading:
Fain, Chapt.5 (p. 145-188);
Matlab exercises:
Modeling Sodium and Potassium conductances
Homework: Effects of H&H kinetics on macroscopic currents

4. (September 26): Biophysics of Action Potentials: Hodgkin and Huxley II

Relationship between H&H equations and action potential shape
Reading:
Fain, Chapt.5 (p. 145-188);
Matlab exercises:
Incorporate H&H channels into passive model of neuron
Homework: Input/output properties of H&H neurons

5. (October 3): Features of H&H that are essential for coding

Replicating salient features of H&H neurons with simple models;
When/when not to use these simple models
Reading:
Handout (Naud et al., 2008, Biol Cybern. 99:335);
Matlab exercises:
Leaky-integrate-and-fire neurons and variants
Homework: Comparing LIF with HH neuron models

6. (October 10): Biophysics of Synapses: Postsynaptic mechanisms

Factors that affect time course of synapses: dendritic filtering, receptor kinetics
Excitatory vs inhibitory synapses;

Reading:
Handout (Johnston & Wu chapter);
optional: Fain, Chapt. 9, 10;
Matlab exercises:
Conductance based synapses; Using convolution to generate synaptic trains
Homework: Examine temporal and spatial summation of excitatory/inhibitory synapses

7. (October 17): Biophysics of Synapses: presynaptic mechanisms
Mathematics of quantal hypothesis
Presynaptic depression/facilitation
Reading:
Reyes et al. (1998) Nat. Neurosci 1: 279
Handout (Johnston & Wu chapter); optional: Fain, Chapt. 9, 10;
Matlab exercises:
Incorporating depression/facilitation in models
Homework: Effects of release probability, quantal content on synaptic potential and firing

8. (October 24): Features of synapses essential for coding
Simple models of synaptic potentials and assumptions
Conductance based vs current based models: shunting inhibition
Properties of synaptic barrages evoked *in vivo*.
Reading:
Handout (Softky WR, Koch C; (1993); J Neurosci 13:334-50)
Matlab exercises:
Generating synaptic barrages
Homework: Comparing conductance and current based models effect on firing

9. (October 31): Network Architecture I: Connection profiles
Connection probability spatial profiles between Excitatory/inhibitory neurons
Reading:
Handout (Levy & Reyes, J. Neurosci. 2012);
Matlab exercises:
Constructing networks of connected neurons
Homework: Generate inputs to networks

9. (November 7): Network Architecture II: generating inputs to network
External inputs to networks
Reading:
Handout (Levy & Reyes, PLoS Comp Bio (2011));
Matlab exercises:
Incorporate external input to networks
Homework: Effects of input characteristics on network activity

****arrange meeting with professor to discuss potential projects***

10. (November 14): Biophysics of Synaptic Plasticity

Postsynaptic mechanisms for long-term potentiation: NMDA-receptors

Hebbian rules for plasticity

Reading: Fain Chapt.14 (p509-523);

Handout (TBD)

Matlab exercises:

Incorporating Hebbian rules into 3 neuron network

Homework: none, work on presentation

11. (November 21): Presentation of Project Proposals

12. (November 28): Techniques for data analyses

Reading:

TBD

Matlab exercises:

Algorithms for cross- and auto-correlation, poststimulus time histograms

Homework: none, work on projects

13. (December 5): Work on projects in class

14. (December 12): Student Presentation I

15. (exam week): Student presentations II (if needed)