Fall 2018
Biophysical and network models of neurons

Faculty: Alex Reyes, Rm 1057 Meyer
Phone: 212 998-3994
reyes@cns.nyu.edu
Office hours: by appointment

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

   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 \textit{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)