AMERICAN UNIVERSITY OF BEIRUT
FACULTY OF ENGINEERING AND ARCHITECTURE

Computational Neuroscience
BMEN 609

1. Course Administration

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2. Course Description [3 credits]

The human brain, perhaps the most complex, sophisticated, and complicated learning system, controls virtually every aspect of our behavior. Neuroscience is the study of the brain, and computational neuroscience divides this study into three subspecialties: neural coding, biophysics of neurons, and neural networks. This course will introduce engineers, physicists, computational scientists, mathematicians and other audiences to the neurosciences from the cellular level and the network level by giving a mathematical introduction to neural coding and dynamics. Basic techniques of modeling biophysics, excitable membranes, small network and large scale network systems will be introduced. The course begins with a consideration of mathematical models of excitable membranes, including the Hodgkin-Huxley model and simplifications such as the Morris-Lecar and FitzHugh-Nagumo models. It will provide hands-on laboratory experience in modeling membranes, neurons, and neural networks. The course explores the use of differential equations, numerical simulation, and graphical techniques for modeling compartmental and connectionist neural systems. The range of topics include simulations of electrical properties of membrane channels, single cells, neuronal networks, learning and memory models, stochastic models of ion channels, and models of synaptic transmission.

3. Time and Place

MW: 12:30 – 1:45
Place: MAMC 207

4. Prerequisites

BIOL 201, MATH 202, Knowledge of Matlab

5. Textbook and Software

- Material will be selected form book chapters, review articles and research journals.
- Recommended (but not required) books:
  - Peter Dayan & Larry Abbott. *Theoretical Neuroscience: Computational and Mathematical Modeling of Neural Systems*. MIT Press, 2001
  - Irwin B. Levitan & Leonard K. Kaczmarek. *The Neuron: Cell and Molecular Biology*. Oxford University Press, 4th edition, 2015.
- Required software: Matlab

6. Course Objectives

- Define the basic cellular and network-level organization of neurons in selected systems.
- Understand the properties of cells that make up the nervous system including the propagation of electrical signals used for cellular communication, and relate the properties of individual cells to their function in organized neural circuits and systems.
- Construct biophysical models of neural systems that emulate electrical behavior of neurons and construct mathematical models that provide a probabilistic account of neural spiking activity.
- Perform mathematical analyses of data recorded during neurophysiology experiments to describe the principles of neural information coding in sensory and motor systems.
- Understand how neurons, and networks of neurons can be modeled mathematically by constructing mathematical models to describe neural activity/behavioral responses in terms of experimentally manipulated variables.
- Apply statistical techniques to examine the structure and distribution of experimental datasets; use unsupervised learning techniques for linear/nonlinear dimensionality reduction and clustering; visualize and interpret the latent structure in neuroscientific data.
- Formulate hypotheses captured by mathematical models, as possible explanations of observed relationships between experimental outcomes and manipulations.
- Be knowledgeable about carrying intracellular recordings in the lab efficiently with all its components, from handing the animal to preparing solutions, slicing the brain and patching onto cells.

7. Lab component

This course consists of a laboratory part designed to give students experience with basic techniques for conducting basic and systems neuroscience research. It includes sessions on anatomical, neurophysiological, and data acquisition and analysis techniques, and the ways these techniques are used to study nervous system function. *However, this part is contingent this semester upon easing the lockdown to campus and allowing lab accesses in small groups.*

8. Student Assessment

Assignments	**20%**
Lab reports & performance	**10%**
Quizzes	**40%**
Final exam	**30%**

9. Moodle

Students are expected to check for updates on Moodle on a daily basis. Announcements, course handouts, and assignments will be available in "pdf" format from Moodle.

10. Course Topics

WEEK #	TOPICS
1	**Cellular Neuroanatomy** The prototypical neuron. Classifying neurons. Glia. Ionic basic of resting membrane potential. The action potential.
2	**Neurophysiology** Patch clamp. Voltage clamp. Extracellular single-unit and multi-unit recordings. Local field potentials. Nerve conduction studies.
3	**Electrophysiology of the Neuron** Mechanisms of action potential generation. Properties of ionic currents (I_{Na}, I_K, I_{Ca}, I_{AHP}, I_M…). Synaptic potentials. Electronics and physics backbones of intracellular recording.
4-5	**Theory and Modeling in Neuroscience** Computational neuroscience VS machine learning. Primer on linear algebra and probability. Phase plane analysis. Dynamical systems in neuroscience.
6	**Hodgkin-Huxley model: from Ion Channels to Mathematics** Ionic-based single and multiple compartment mathematical modeling of neurons, and networks of neurons.
7-8	**Biophysical Models of Neurons** Fitzhugh-Nagumo model. Phase plane analysis. Integrate and fire neurons. Resonate and fire neurons. Izhikevich models.
9	**Neural Coding: Temporal and Spatial** Receptive fields. Tuning Curves. Spike triggered averages. Firing rates. Oscillations, synchrony and cell assemblies. Time and place cells.
10-11	**Learning and Memory** Neurobiology of learning and memory. Models of human memory. Associative and working memory. Linear oscillators. Hopfield networks. Supervised, unsupervised, Hebbian and reinforcement learning.

WEEK #	TOPICS
12-13	**Plasticity and Neural Networks** Spiking neural networks. LTP, STDP and LTD. Structural connectivity. Functional connectivity. Causal inference. Nonlinear dynamical systems.
14	**Systems: Vision** Visual processing: Eye and Retina. Bioengineering approaches to vision science (visual neuroprosthetics, optic nerve implants, neural modeling …).
15	**Systems: Audition** Auditory System: Structure and Function. Bioengineering approaches to audition (cochlear implant design, speech procession, neural modeling of auditor system …).
16	**Systems: Somatosensation and Optogenetics** The Somatic Sensory System. Neurophysiological and Engineering basis of Optogenetics (channelrhodopsin, two-photon imaging …).
17	**Systems: Motor** Motor Systems (spinal reflexes, descending motor pathways, motor cortex, basal ganglia, cerebellum, ocular motor system…). Bioengineering and computational approaches.
18	**Neuroprosthetics: Artificial arms, BCI and EEG** Neural Prostheses: Linking brain signals to prosthetic devices. Overview and milestones of BCI and EEG. Physiological signals and components of BCI and EEG (signals acquisition, features extraction and translation …).

11. Educational Diversity

AUB strives to make learning experiences as accessible as possible. If you anticipate or experience. AUB strives to make learning experiences as accessible as possible. If you anticipate or experience academic barriers due to a disability (such as ADHD, learning difficulties, mental health conditions, chronic or temporary medical conditions), please inform the Accessible Education Office (AEO). In order to ensure that you receive the support you need and to facilitate a smooth accommodations process, you must register with the AEO as soon as possible. AEO's email address is accessibility@aub.edu.lb. The Office is located in West Hall room 318, and its AUB phone extension is 3246.

12. Non-Discrimination and Anti-Discriminatory Harassment at AUB

In line with its commitment to the principle of equal opportunity in education and employment, AUB policies protect you from discrimination on the basis of protected characteristics, including discriminatory harassment and sexual harassment. Protected characteristics include: race, color, religion, age, national or ethnic identity, sex, gender or

gender identity, sexual orientation, pregnancy, marital status, disability, genetic predisposition or carrier status, alienage or citizenship status, and political affiliation.

The policies are applicable to all the AUB Community including: officers, faculty, staff, academic appointees, students (including medical interns and residents), visiting students, alumni, trainees, visitors, contractors, subcontractors, suppliers, located on campus and at AUB Medical Center, Advancing Research Enabling Communities Center (AREC), or any other facility or program affiliated with the University. The "AUB community" also includes the dependents and domestic employees of faculty and staff dwelling on campus and at AREC.

If you think you have experienced discrimination, discriminatory harassment, or sexual harassment, we encourage you to inform the Equity/Title IX Coordinator, Mitra Tauk at 01-350000 ext. 2514, titleix@aub.edu.lb, report to a Title IX deputy at your faculty or at any other faculty (www.aub.edu.lb/titleix), or report online (www.aub.ethicspoint.com). Reports may be submitted anonymously or not. Please know that the University will maintain the confidentiality of the complaint and privacy of the persons involved to the greatest extent possible, consistent with its goal of conducting a thorough and complete investigation and to the extent permitted by law.

You need also to know that the University has designated academic and administrative department/unit heads, managerial level staff, academic advisors, protection officers, and residence hall staff/monitors, as responsible employees or "mandatory reporters", and may designate others at its discretion. These individuals are obligated to report actual or suspected discrimination or discriminatory harassing conduct to the Equity/Title IX Coordinator, unless they are a "confidential" resource. The following have been designated as confidential resources: on campus counselors in the Counseling Center of the Office of Student Affairs and AUB Medical Center counselors, and healthcare providers at the University Health Services (UHS) and at the AUB Medical Center. Confidential resources are not required to report actual or suspected discrimination or harassment to appropriate university officials, except in cases of suspected abuse of a minor, in the event of an external investigation or prosecution, or in the event of imminent danger to the reporting party or others.