Quantitative Neuroscience for Bioengineering
Spring 2022

Department of Biomedical Engineering
Boston University

Catalog Description

BE471. Quantitative Neuroscience (4)
Introductory cellular and systems-level neuroscience for biomedical engineering students with emphasis on control mechanisms and engineering principles. This course will introduce the mechanisms that underlie signal and information propagation in biological cellular neural networks, and the computational potential of such networks in the brain, as well as neuroengineering applications such as neural prosthesis and technologies for interfacing with the nervous system. This course will serve as a foundational elective for BE571 Introduction to Neuroengineering and BE572 Neurotechnology Devices.

Course Goals

The main goal of this course is to equip students with foundational neuroscience knowledge for a career in neuroengineering including neural probe technology and devices, optical, magnetic and electrical neurotechnologies.

Course Outcome

1) Discover the power of quantitative reasoning to unravel fundamental organizing principles of brain function
2) Study key neuroscience concepts and the relevant parameter space at the cellular and systems level
3) Gain fundamental understanding of the biophysical basis of neuronal computation
4) Acquire knowledge about advanced experimental neurotechniques
5) Learn how engineering principles are applied to interface with the nervous system in health and disease
6) Build awareness of the growing field of neuroethics and unprecedented ethical concerns that arise from rapidly developing neurotechnologies

Text

The textbooks listed below are helpful references, not required texts. I'll make handouts available for the most relevant material.

- "Principles of Computational Modelling in Neuroscience" *by Sterratt, Graham, Gilles, Willshaw*
- "From Neuron to Brain" *by Nicholls, Martin, Wallace, Fuchs*
- "Principles of Neural Science" *by Kandel and Schwartz*
- "Vander's Human Physiology: The Mechanisms of Body Function" *by Widmaier, Raff, Strang*
- "Neuroscience, Exploring the Brain" *by Bear*
- "Foundations of Cellular Neurophysiology" *by Johnston and Wu*
- "Mathematical Foundations of Neuroscience" *by Ermentrout and Terman*

Useful online resources:
https://nba.uth.tmc.edu/neuroscience/m/index.htm
https://www.coursera.org/learn/medical-neuroscience
https://www.brainfacts.org/

Instructor

Anna Devor, Ph.D.
Associate Professor
Department of Biomedical Engineering
https://sites.bu.edu/nil/
Associate Director
Boston University Neurophotonics Center
https://www.bu.edu/neurophotonics/
Editor-in-Chief
SPIE Neurophotonics

Recitation

Martin Thunemann, Ph.D.
Research Assistant Professor
Department of Biomedical Engineering
https://sites.bu.edu/nil/

Contacting Dr. Devor

Email: adevor@bu.edu
Please use "Quant Neuro" in the subject line.

Grading

20% Mid-term exam
20% Final exam
60% Homework

Exam Policies

ALL parts of exams must be answered unless otherwise stated. The exams must be legible, show good use of English, and be organized. Points will be given or deducted for these qualities accordingly. The Department of Biomedical Engineering adheres to the BU Policy on Integrity in Scholarship. Cheating of any kind whatsoever WILL NOT BE TOLERATED in any form in this course and will be punishable as per university rules and policies. The full policy is available at https://www.bu.edu/academics/policies/academic-conduct-code/. In cases of suspected academic dishonesty, the case will be referred to the appropriate Dean. Generally, the penalty for academic dishonesty is a failing grade at minimum, with other more severe academic penalties possible.

Course Schedule and Topics

	Topics
Week 1 **1/24, 1/26**	**Introduction:** Elements and principles; the neuroengineering approach; reasoning with models; neuroethics.
Week 2 **1/31, 2/2**	**Single-cell biophysics:** Basic principles of electricity; ion transport; diffusion; ion current in an electric field; modeling passive membranes as RC circuits.
Week 3 **2/7, 2/9**	**Single-cell biophysics:** Resting membrane potential; Nernst potential; the Goldman-Hodgkin-Katz equation; electrical neutrality; equivalent electrical circuit.
Week 4 **2/14, 2/16**	**Single-cell biophysics:** The action potential; single channel properties, Hodgkin-Huxley model.
Week 5 **2/22, 2/23**	**Single-cell biophysics:** Signal propagation in axon and dendrites; Rall's cable theory; multi-compartment models. **Introduction to Exercise #1: H&H model.**
Week 6 **2/28, 3/2**	**Single-cell biophysics:** Chemical synapses in the equivalent circuit; the Integrate-and-fire model. **Discussion of Exercise #1: H&H model.**
**********SPRING BREAK**********	
Week 7 **3/24, 3/16**	**RECAP and Midterm Exam**
**********Exercise #1 is due 3/20**********	
Week 8 **3/21, 3/23**	**Microscopic sensing and manipulation:** 1-photon and 2-photon fluorescence microscopy; voltage and Ca^{2+} imaging; deconvolution; opto- and chemogenetics. **Introduction to Exercise #2: Estimation of spikes for 2-photon Ca^{2+} imaging data.**

Week 9 **3/28, 3/30**	**Microscopic sensing and manipulation:** Intra- and extracellular electrophysiological recordings; auto- and cross-correlation; spectral decomposition. **Discussion of Exercise #2: Estimation of spikes for 2-photon Ca^{2+} imaging data.**
Week 10 **4/4, 4/6**	**Measurements and modeling of neuronal circuit activity:** Sensory systems; receptive fields; space-time separability; Artificial Neural Networks, Perceptrons.
**********Exercise #2 is due 4/10**********	
Week 11 **4/11, 4/13**	**Measurements and modeling of neuronal circuit activity:** Optical imaging technologies for large-scale measurements of neuronal activity. **Introduction to Exercise #3: Mesoscopic Ca^{2+} imaging data.**
Week 12 **4/20**	**Measurements and modeling of neuronal circuit activity:** imaging of blood flow and metabolism; the hemodynamic response; HRF. **Discussion of Exercise #3: Mesoscopic Ca^{2+} imaging data.**
Week 13 **4/25, 4/27**	**Noninvasive imaging:** contrast mechanism and principles of EEG, MEG, fMRI, fNIRS, PET.
**********Exercise #3 is due 5/1**********	
Week 14 **5/2, 5/4**	**Neuroengineering in brain disease:** Replacement therapy, brain-machine interface**.** **RECAP**
5/**10**	**Final Exam**