PHY 380A80 – Topics in Contemporary Physics: Biophysics of Neurological Systems

Fall 2018 – Syllabus

Lecture times: Mon Wed 5:00 – 6:15 PM

Classroom: MLT 309

Instructors:

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Text (recommended, not required): Neuronal Dynamics by W. Gerstner, W. M. Kistler, R. Naud and L. Paninski, Cambridge (2014). Online: http://neuronaldynamics.epfl.ch/

Introduction:
This course is the result of a joint Physics-Biology effort, designed to provide an active learning environment in the area of biophysics of neurological systems primarily to advanced undergraduate and beginning graduate students. It involves a well-structured content of neurophysiology, mathematical modeling, computer simulations and hands-on experiments for a solid introduction to physics applied to neuroscience.
Biophysics in general is an interdisciplinary field that applies the principles, theories and techniques of the physical sciences to the study of biological organisms and processes. As a fast growing research area, Biophysics is important to many fields including medicine, bioengineering, genetics, ecology and neuroscience. Neuroscience in particular is a fascinating topic where the merge of Physics and Biology has greatly advanced our understanding of living organisms.

Content:
The neuron, as the building block of neurological systems, is at the core of the studies in this class. Neurological systems are governed by physical principles underlying neuronal behaviors and interactions at the cellular level, and as such, the focus of the course is on the understanding of the mechanisms allowing neurons not only generate action potentials but also to use them to encode and transmit information.
The course contains a balanced distribution of lectures on the biological structure and function of neurons, and on the corresponding biophysical principles, including mathematical modeling, computer simulations and hands-on lab activities.

Objectives:

- Develop an understanding of the fundamentals of the physiology and the physical basis of the functioning of neurons.

- Show how the basic principles of diffusion and electricity apply to neural cells, giving rise to membrane properties, including resting and action potentials as well as synaptic transmission.
- Introduce the basics of modeling applied to neurological processes and work in hands-on lab experiments directly related to the material discussed in the lectures.
- Apply the basics of computer programing and numerical simulations for solving neural model equations, as well as to use effective graphical representation of scientific data.
- Explore the biophysics of signaling and movement at the cellular level, using mathematical modeling of nerve cells function.
- Provide an understanding of biophysical measurements used in neurobiology, and data acquisition and analysis.

At the conclusion of this course, students should have acquired the theoretical foundation to understand the biophysical properties of nerve cell functions, and understand the principles by which their actions are simulated. Furthermore students should be able to use basic numerical simulations to work on problems in neurodynamical systems.

Format:
This is a 3 credit-hours course with 2 lectures (75 minutes each) per week, including lab activities, both hands-on and computer simulations. We will augment lecture material with papers from the primary literature. In addition, neurons, synapses and circuits and their plasticity will be studied using computer simulations and experiments. In the first few weeks, we will review the biophysical principles of cell membrane function and communication. We will then discuss and study the cellular processes that allow nerve cells to function using computer and electrical modeling.

Attendance & Participation:
Attendance is obligatory for this course, including the lab sections.

Grading:
Grading will be based on assigned projects connected to the topics of the course. Graduate students will have to complete also one special topic assignment, consisting of preparing a 5-page research paper selected by the instructors from a variety of topics. Final grades will be determined based upon the following scale: A = 100 - 90, B = 89 - 80, C = 79 - 70, D = 69 – 60, F = below 60

Academic Misconduct and Dishonesty:
Academic misconduct will not be tolerated. See the following website for a complete listing of what constitutes academic misconduct at Illinois State University:
http://deanofstudents.illinoisstate.edu/conflict/conduct/code/academic.php

Disabilities:
Any student needing to arrange a reasonable accommodation for a documented disability and/or medical/mental health condition should contact Student Access and Accommodation Services at 350 Fell Hall, (309) 438-5853, or visit the StudentAccess.IllinoisState.edu.

Note:
This syllabus is tentative and subject to changes.

PHY 380A80 Biophysics of Neurological Systems – Fall 2018 – Tentative Topics Distribution

Week 01 – Aug 20, 22	
Monday: Lecture (Rosa)	Introduction to neuroscience, mathematical modeling and numerical simulations of neurological systems
Wednesday: Lecture (Rosa)	Mathematics background review I: Difference equations, discrete maps, logistic equation Mathematics background review II: Differential equations, mathematical representation of RC circuits, leaky integrate-and-fire neuron model
Week 02 – Aug 27, 29	
Monday: Lab (Rosa)	Numerical simulations: Logistic equation, bifurcation diagram
Wednesday: Lecture (Stein)	Introduction to neurophysiology I: Nernst potential, membrane potential, equilibrium potential Introduction to neurophysiology II: Electric currents, ion channels
Week 03 – Sep 3, 5	
Monday	Labor Day – No Class
Wednesday: Lecture (Stein)	Physiology of ion channels
Week 04 – Sep 10, 12	
Monday: Lab (Rosa)	Hodgkin-Huxley equations, leak, sodium and potassium channels Activation and inactivation functions, refractory period
Wednesday: Lecture (Rosa)	The Hodgkin-Huxley model
Week 05 – Sep 17, 19	
Monday: Lab (Rosa)	Conductance effects on firing rates
Wednesday: Lecture (Stein)	Temperature effects on biological systems
Week 06 – Sep 24, 26	
Monday: Lab (Rosa)	Computer simulations of temperature effects on the single neuron
Wednesday: Lecture (Stein)	Action potential propagation I – Passive propagation (length constant), loss of energy (insulation, material), myelin sheath, nodes of Ranvier (why propagation speeds up, no opening/closing of ion channels), electric circuit equivalent of coupled compartments.
Week 07 – Oct 1, 3	
Monday: Lecture (Stein)	Action potential propagation II – Review more relevant points of last lecture. To make it faster, make it wider, isolate. Refractory period.
Wednesday: Lab (Rosa)	Computer simulations of action potential propagation
Week 08 – Oct 9, 11	
Monday: Lab (Stein)	Biological action potential propagation
Wednesday: Lecture (Stein)	Temperature effects on biological action potential propagation

Week 09 – Oct 15, 17

Monday: Lecture (Stein)	Electrical coupling between neurons
Wednesday: Lab (Stein)	Chemical synapses

Week 10 – Oct 22, 24

Monday: Lecture (Stein)	Chemical synapses: Ionotropic coupling
Wednesday: Lab (Rosa)	Modeling of ionotropic coupling

Week 11 – Oct 29, Oct 31

Monday: Lecture (Stein)	Chemical synapses: Metabotropic coupling
Wednesday: Lab (Rosa)	Computer simulations of chemically (metabotropic) coupled neurons

Week 12 – Nov 5, 7

Mon/Wed: Project I – You will be given a few options for the project. Alternatively, you may suggest your own project which will be subject to approval by the instructors.

Week 13 – Nov 12, 14

Monday: Lab (Stein)	Synaptic potentials in biological systems
Wednesday: Lecture (Stein)	Building blocks of neuronal rhythmic systems

Week 14 – Nov 20, 22

Fall break – No classes this week

Week 15 – Nov 26, 28

Monday: Lecture (Rosa)	Bifurcation diagrams I
Wednesday: Lab (Rosa)	Bifurcation diagrams II

Week 16 – Dec 3, 5

Mon/Wed - Project II:	You will be given a few options for the project. Alternately, you may suggest your own project which will be subject to approval by the instructors.