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

Lecture times: MWF 2:00 – 3:00 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 neuronal systems to advanced undergraduate and beginning graduate students. It involves a balanced content of neurophysiology, mathematical modeling 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 contributed to 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 the neuron not only to generate action potentials but also to use them to encode and transmit information.
The course contains a well-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:
- To develop an understanding of the fundamentals of the physiology and the physical basis of the functioning of neurons.
- To 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.

- To introduce the basics of modeling applied to neurological processes and to work in hands-on lab experiments directly related to the material discussed in the lectures
- To 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.
- To explore the biophysics of signaling and movement at the cellular level, using mathematical modeling of nerve cells function.
- To provide an understanding of biophysical measurements used in neurobiology, and data acquisition and analysis.

At the conclusion of the 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 modeled. Furthermore students should be able to use basic computer simulations to work on problems in neurodynamical systems.

Format:
This is a 3 credit-hours course with 3 lectures (50 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:
If you need special accommodation to fully participate in this class, please contact Student Access and Accommodation Service at 438-5853 (voice), ableisu@ilstu.edu (email).

Tentative Topics Distribution:

Week 01 –

Monday: Lecture	Introduction to neuroscience (Stein) and introduction to numerical simulation of biological systems (Rosa)
Wednesday: Lecture (Rosa)	Mathematics background review I: Difference equations, discrete maps, logistic equation
Friday: Lecture (Rosa)	Mathematics background review II: Differential equations, mathematical representation of RC circuits, leaky integrate-and-fire neuron model

Week 02 –

Monday: Lab (Rosa)	Numerical simulations: Logistic equation, bifurcation diagram
Wednesday: Lecture (Stein)	Introduction to neurophysiology I: Nernst potential, membrane potential, equilibrium potential
Friday: Lecture (Stein)	Introduction to neurophysiology II: Electric currents, ion channels

Week 03 –

Monday:	Labor Day – No Class
Wednesday: Lecture (Stein)	Hodgkin-Huxley equations, leak, sodium and potassium channels
Friday: Lecture (Stein)	Activation and inactivation functions, refractory period

Week 04 –

Monday: Lab (Rosa)	The Hodgkin-Huxley model I
Wednesday: Lab (Rosa)	The Hodgkin-Huxley model II
Friday: Lecture (Stein)	Action potential propagation I

Week 05 –

Monday: Lecture (Stein)	Action potential propagation II
Wednesday: Lecture (Stein)	Refractory period
Friday: Lecture (Rosa)	The axon model

Week 06 –

Monday: Lab (Rosa)	Computer simulation of axonal propagation
Wednesday: Lecture (Rosa)	Temperature effects on physical systems
Friday: Lecture (Stein)	Temperature effects on biological systems

Week 07 –

Monday: Lab (Rosa)	Computer simulation of temperature effects on the single compartment model
Wednesday: Lab (Rosa)	Computer simulation of temperature effects on axonal propagation
Friday: Lab (Stein)	Biological action potential propagation

Week 08 –

Monday: Lab (Stein)	Temperature effects on biological action potential propagation
Wednesday: Lecture (Rosa)	Waves propagation in physical systems
Friday: Lab (Rosa)	Computer simulation of action potential collision

Week 09 –

Monday: Lecture (Stein)	Electrical coupling between neurons I
Wednesday: Lecture (Stein)	Electrical coupling between neurons II
Friday: Lab (Rosa)	Computer simulations of electrically coupled neurons

Week 10 –

Monday: Lecture (Stein)	Chemical synapses: Ionotropic coupling
Wednesday: Lecture (Rosa)	Modeling of ionotropic coupling
Friday: Lab (Rosa)	Computer simulations of chemically (ionotropic) coupled neurons

Week 11 –

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

Week 12 –

Monday: Lab (Stein)	Synaptic potentials in biological systems
Wednesday: Lecture (Stein)	Building blocks of neuronal rhythmic systems
Friday: Project I	You will be given a few options for the project. Also, you may suggest your own project which will be subject to approval by the instructors.

Week 13 –

Monday: Project I	You will continue with project I.
Wednesday: Project I	Continue and finish project I.
Friday: Lecture (Stein)	Ionic pumps

Week 14 –

Fall break – No classes this week

Week 15 –

Monday: Lab (Rosa)	Bifurcation diagrams I
Wednesday: Lecture (Rosa)	Bifurcation diagrams II
Friday: Lab (Rosa)	Computer simulations of ionic pump effects on neuronal activity

Week 16 –

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