Lahore University of Management Sciences

PHY 316 / PHY 5116 / BIO 438 Summer - Introduction to Computational Neuroscience
Summer 2024

Instructor	Dr. Farzada Farkhooi
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Course URL (if any)	N/A

Course Teaching Methodology (Please mention the following details in plain text)
● Teaching Methodology: The class will be face-to-face, synchronous lessons. ● Presentation by students under the instructor's supervision is an essential part of the teaching and evaluation. ● Lecture details: The lectures will be 100% live interaction, and a pre-recorded feature is not included.

Course Basics				
Credit Hours	3			
Lecture(s)	Nbr of Lec(s) Per Week	4	Duration	90 minutes each
Recitation/Lab (per week)	Nbr of Lec(s) Per Week	0	Duration	N/A
Tutorial (per week)	Nbr of Lec(s) Per Week	0	Duration	N/A

Course Distribution	
Core	No
Elective	Yes
Open for Student Category	SBASSE (Chemistry) – 2nd and 3rd-year students
Close for Student Category	Non-SBASSE

COURSE DESCRIPTION

This course introduces students to computational methods and theories developed over the last 50 years to understand nervous systems and their function. Specific topics that will be covered are

- Theory of evolution and nervous systems
- Single-neuron biophysics,
- Neuronal networks,
- Representation of information by spiking neurons,
- Examples of information processing in neural networks.

We will use basic scientific programming exercises to understand better the concepts and methods introduced in the lectures. The theoretical lectures are combined with student presentations of biological and experimental papers with the help of the instructor. The course aims to build a basic theoretical foundation for understanding the biological principles of nervous system function across species.

COURSE PREREQUISITE(S)	
	● Basic biology, chemistry, and physics. ● Differential equations and Linear algebra, numerical methods

	● A scientific programming knowledge (Fortran/C/Matlab/Python/Julia, etc.) is necessary.

COURSE OBJECTIVES	
	This course is designed to give students an understanding of: ● *Basic biophysics of neurons and nervous systems* ● *Archetypes of biological neuronal networks* ● *Fundamental analysis and modeling of neuronal dynamics and their interactions*

Learning Outcomes	
	After the course, students can ● follow the state-of-art literature on the subject independently, ● Analyze neuronal spiking data, ● Simulate simplified neural networks, and study their relevant functional properties.

Project assignments: 50% Presentations or written reports on the assigned peer-reviewed papers: 40% Class engagement: 10% Attendance will be mandatory.

Examination Detail	
Midterm Exam	Yes/No: NO Duration: NA Preferred Date: NA Exam Specifications: NA
Final Exam	Yes/No: NO Duration: NA Exam Specifications: NA

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COURSE OVERVIEW

Week	Topics	Recommended Readings	Objectives/ Application
Introduction			
1	• Biology and evolution • Brain Complexity • Bridging scales in neuroscience • Scaling and dynamical systems	• Bassett, D. S. & Sporns, O. Network neuroscience. Nat Neurosci 20, 353–364 (2017). • van Hemmen, J. L. Neuroscience from a mathematical perspective: key concepts, scales and scaling hypothesis, universality. Biol Cybern 108, 701–712 (2014). • Nature, R. D. at S. Bridging scales in neuroscience. Research Data at Springer Nature (2019).	• Understanding the complexity of biological processes in the nervous system • Describing fundamental problem that neuroscience faces to bridge from sub-cellular systems to cognitive processes
Part I: Model Neurons			
1	• Electrical properties of neurons • Hodgkin-Huxley model • Spatially extended neurons • Active dendritic cable • Synaptic Conductances *Assignment 1: Simulations of Hodgkin-Huxley model* *Paper presentations by students on neuronal voltage dependent conductances*	Book chapters: • Chapters 5, and 6 in Dayan and Abbot • Chapter 1, 2 and 5 in Izhikevich Some additional reading lists of peer-reviewed articles will be provided.	• Understanding of basic neuronal dynamics • Learning about neuronal voltage-dependent conductances. • Understanding of spike generation dynamics and its physiological relevance. • Learning about synaptic integration
Part II: Neural Encoding			
2-3	• Neuronal Firing rate and spiking statistics • Neuronal variability • Firing rate model of early visual system • Example: Organization of receptive fields in V1 and model of early vision *Paper presentations by students on spike train statistics and data analysis*	Book chapters: • Chapters 1 and 2 in Dayan and Abbot Lecture note on point process theory Some additional reading lists of peer-reviewed articles will be provided.	• Learning about neuronal input-output relation • Understanding different strategies of temporal coding • Basic understanding of spike train data analysis • Learning about mammalian visual systems. • Learning the analysis of the model for early visual processing
Part III: Noise in neuronal models			

3-4	• Noise in nervous system • Simplified model neuron: Integrate and fire model • Analysis of First Passage Time for the simple neuronal model *Assignment 3: Simulation of noisy Leak-integrate and fire model and its spike train statistics*	Book chapters: • Chapter 5 in Dayan and Abbot • Chapter 9 in Tuckwell Lecture note on Fokker-Planck equation Some additional reading lists of peer-reviewed articles will be provided.	• Understanding of importance of noisy dynamics in neuronproblemseproblemsrning about simplications that complex systems require to be treated analytically. • Understanding the connection between spike train statistics and neuronal dynamics
Part IV: Network Models			
5-6	• Firing rate models • Feedforward networks • Recurrent networks • Spiking cortical networks • Example of the orientation in the spiking V1 model *Paper presentations by students on cortical network functions and statistics*	Book Chapters: • Chapter 7 in Dayan and Abbot Some additional reading lists of peer-reviewed articles will be provided.	• Learning neuronal interactions • Feedforward and recurrent network archetypes will be presented • Understanding network level fluctuations and cortical non-equlibium dynamics • A functional example of the emergence of orientation selectivity in the early visual cortex will be learned.

Textbook(s)/Supplementary Readings
The material is based on the following textbooks: • Izhikevich, E. M. Dynamical Systems in Neuroscience: The Geometry of Excitability and Bursting. (The MIT Press, 2010). • Dayan, P. & Abbott, L. F. Theoretical Neuroscience: Computational and Mathematical Modeling of Neural Systems. (The Mit Press, 2005). • Tuckwell, H. C. Introduction to Theoretical Neurobiology: Volume 2, Nonlinear and Stochastic Theories. (Cambridge University Press, 2005). Additional reading list based on peer-reviewed articles on each part will be provided.

Policies
All students are expected to read assigned material, seek and share additional resources, and participate in class discussions based on readings and other resources. Students are encouraged to consult any relevant resources, especially those that provide critiques or contrasting views, and to share their personal experiences and expertise with the class. Assignments may be individual or group. ***Discussions will be open and respectful of all viewpoints. Constructive and polite criticism and debate are encouraged.*** **Academic Honesty:** All academic work will be done by the student to whom it is assigned without unauthorized aid. Plagiarism, cheating, and other forms of academic dishonesty are prohibited. For further information, students should familiarize themselves with the relevant section of the LUMS student handbook. **Harassment policy:** There will be zero tolerance for any behavior that is intended or has the result of making anyone uncomfortable and negatively impacts the class environment or an individual's ability to work to the best of their potential. Strict

action will be taken against those who breach the privacy of the students or the faculty member.
To file a complaint, please write to harassment@lums.edu.pk

SSE Council on Equity and Belonging: To seek counsel related to any issues, please feel free to approach either a member of the council or email at cbe.sse@lums.edu.pk

Rights and Code of Conduct for Online Teaching: The lectures will be recorded but not shared on any public forum unless consent is taken from those appearing. Only designated people will be allowed to record.