# Lahore University of Management Sciences

## PHY 316 / PHY 5116 / BIO 438 - Introduction to Computational Neuroscience
Spring 2021-22

| | |
|---|---|
| Instructor | Dr. Farzada Farkhooi |
| Room No. | TBA |
| Office Hours | TBA |
| Email | farzada@bccn-berlin.de |
| Telephone | N/A |
| Secretary/TA | TBA |
| TA Office Hours | TBA |
| Course URL (if any) | N/A |

| Course Teaching Methodology (Please mention following details in plain text) |
|---|
| ● Teaching Methodology: The class is designed to be taught as face-to-face, synchronous lessons.<br>● 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 | 2 | Duration | 75 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 |
| Close for Student Category | N/A |

### COURSE DESCRIPTION

This course introduces basic computational methods for understanding what nervous systems do and determining how they function. Specific topics that will be covered are:

- Single-neuron biophysics.
- Representation of information by spiking neurons.
- Example of information processing in neural networks.

We will explore the computational principles governing various aspects of the early mammalian visual system. We will use some basic scientific programming exercises to better understand the concepts and methods introduced in the course. The theoretical lectures are combined with student presentations of biological and experimental papers with the help of the instructor. The course primarily aims to build a basic theoretical foundation for understanding how the brain processes information.

### COURSE PREREQUISITE(S)

- Basic biology, chemistry, and physics.
- Differential equations and Linear algebra
- Knowledge of scientific programming with Matlab/Python/Julia etc.

### COURSE OBJECTIVES

| | |
|---|---|
| | *This course is designed to give students an understanding of:*<br>● Basic biophysics of neurons<br>● Archetypes of neuronal networks in nervous systems<br>● Fundamental analysis and modeling of neuronal dynamics and their interactions<br>● the computation in mammalian early visual system |

| Learning Outcomes | |
|---|---|
| | *After the course, students will be able to:*<br>● To follow the state-of-art literature on the subject on their own.<br>● analyze neuronal spiking data<br>● Simulate a simplified neural network and study its relevant functional properties |

| Grading break up: Component Details and weightages |
|---|
| Homework assignment: 30%<br>Presentations or written reports on the assigned peer-reviewed papers : 30%<br>Final Examination: 40%<br><br>Attendance will not be mandatory. |

| Examination Detail | |
|---|---|
| Midterm Exam | Yes/No: No<br>Duration: N/A<br>Preferred Date: N/A<br>Exam Specifications: N/A |
| Final Exam | Yes/No: Yes<br>Duration: 3 hours<br>Exam Specifications: TBA |

| COURSE OVERVIEW | | | |
|---|---|---|---|
| **Week** | **Topics** | **Recommended Readings** | **Objectives/ Application** |
| | | **Introduction** | |
| **1** | ● Biology and evolution<br>● Brain Complexity<br>● Bridging scales in neuroscience<br>● Scaling and dynamical systems | ● Bassett, D. S. & Sporns, O. Network neuroscience. Nat Neurosci 20, 353–364 (2017).<br>● van Hemmen, J. L. Neuroscience from a mathematical perspective: key concepts, scales and scaling hypothesis, universality. Biol Cybern 108, 701–712 (2014).<br>● Nature, R. D. at S. Bridging scales in neuroscience. Research Data at Springer Nature (2019). | ● Understanding the complexity of biological processes in nervous system<br>● Describing fundamental problem that neuroscience face to bridge from sub-cellular systems to cognitive processes |
| | | **Part I: Model Neurons** | |
| **2-6** | ● Electrical properties of neurons<br>● Hodgkin-Huxley model<br>● Spatially extended neurons | Book chapters:<br>● Chapters 5, and 6 in Dayan and Abbot | ● Understanding of basic neuronal dynamics |

| | | | |
|---|---|---|---|
| | • Active dendritic cable<br>• Synaptic Conductances<br><br>*Assignment 1: Simulations of Hodgkin-Huxley model*<br><br>*Paper presentations by students on neuronal voltage dependent conductances* | • Chapter 1, 2 and 5 in Izhikevich<br><br>Some additional reading lists of peer-reviewed articles will be provided. | • Learning about neuronal voltage dependent conductances.<br>• Understanding of spike generation dynamics and its physiological relevance.<br>• Learning about synaptic integration |
| **Part II: Neural Encoding** | | | |
| **7-10** | • Neuronal Firing rate and spiking statistics<br>• Neuronal variability<br>• Firing rate model of early visual system<br>• Example: Organization of receptive fields in V1 and model of early vision<br><br>*Assignment 2: Spike train data analysis (various data sets will be available).*<br><br>*Paper presentations by students on spike train statistics and data analysis* | Book chapters:<br>• Chapters 1 and 2 in Dayan and Abbot<br><br>Lecture note on point process theory<br><br>Some additional reading lists of peer-reviewed articles will be provided. | • Learning about neuronal input output relation<br>• Understanding different strategy of temporal coding<br>• Basic understanding of spike train data analysis<br>• Learning about mammalian visual systems.<br>• Learning the analysis of the model for an early visual processing |
| **Part III: Noise in neuronal models** | | | |
| **11-12** | • Noise in nervous system<br>• Simplified model neuron: Integrate and fire model<br>• Analysis of First Passage Time for the simple neuronal model<br><br>*Assignment 3: Simulation of noisy Leak-integrate and fire model and its spike train statistics* | Book chapters:<br>• Chapter 5 in Dayan and Abbot<br>• Chapter 9 in Tuckwell<br><br>Lecture note on Fokker-Planck equation<br><br>Some additional reading lists of peer-reviewed articles will be provided. | • Understanding of importance of noisy dynamics in neuronal system<br>• Learning about simplications that complex systems require to be treated analytically.<br>• Understanding the connection between spike train statistics and neuronal dynamics |
| **Part IV: Network Models** | | | |
| **13-14** | • Firing rate models<br>• Feedforward networks<br>• Recurrent networks<br>• Spiking cortical networks<br>• Example of the orientation in the spiking V1 model<br><br>*Paper presentations by students on cortical network functions and statistics* | Book Chapters:<br>• Chapter 7 in Dayan and Abbot<br><br>Some additional reading lists of peer-reviewed articles will be provided. | • Learning neuronal interactions<br>• Feedforward and recurrent network archetypes will be presented<br>• Understanding network level fluctuations and cortical non-equlinum dynamics<br>• A functional example of emergence of orientation selectivity in the early visual cortex will be learned. |
| **15** | **Final exam** | | |

| Textbook(s)/Supplementary Readings |
|---|
| The material is based on the following textbooks:<br><br>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, 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 experience 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 is encouraged.***

**Academic Honesty:** All academic work will be done by the student to whom it is assigned without unauthorized aid of any kind. Plagiarism, cheating, and other forms of academic dishonesty are prohibited. For further information, students should make themselves familiar 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. A 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.