NX-465

Computational neurosciences: neuronal dynamics

Gerstner Wulfram

Cursus	Sem.	Type
Auditeurs en ligne	E	Opt.
Biocomputing minor	E	Opt.
Biomedical technologies minor	E	Opt.
Computational Neurosciences minor	E	Opt.
Computational biology minor	E	Opt.
Computational science and Engineering	MA2, MA4	Opt.
Computer science	MA2, MA4	Opt.
Cybersecurity	MA2, MA4	Opt.
Data Science	MA2, MA4	Opt.
Electrical Engineering		Opt.
Electrical and Electronical Engineering	MA2, MA4	Opt.
Life Sciences Engineering	MA2, MA4	Opt.
Neuro-X minor	E	Opt.
Neuro-X	MA2, MA4	Opt.
Neuroprosthetics minor	E	Opt.
Neuroscience		Opt.
SC master EPFL	MA2, MA4	Opt.

Language of teaching	English
Credits	5
Session	Summer
Semester	Spring
Exam	Written
Workload	150h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

In this course we study mathematical models of neurons and neuronal networks in the context of biology and establish links to models of cognition. The focus is on brain dynamics approximated by deterministic or stochastic differential equations.

Content

I. Models of single neurons
1. Introduction: brain, computers, and a first simple neuron model
2. Models on the level of ion current (Hodgkin-Huxley model)
3./4. Two-dimensional models and phase space analysis

II. Neuronal Dynamics of Cognition
5. Associative Memory and Attractor Dynamics (Hopfield Model)
6. Neuronal Populations and mean-field methods
7. Continuum models and perception
8. Competition and models of Decision making

III. Noise and the neural code
9. Noise and variability of spike trains (point processes, renewal process, interval distribution)
10: Variance of membrane potentials and Spike Response Models
11. Population dynamics: Fokker-Planck equation

IV. Plasticity and Learning
12. Synaptic Plasticity and Long-term potentiation and Learning (Hebb rule, mathematical formulation)
13. Summary: Fitting Neural Models to Data

Keywords

neural networks, neuronal dynamics, computational neuroscience, mathematical modeling in biology, applied mathematics, brain, cognition, neurons, memory, learning, plasticity

Learning Prerequisites

Required courses

undergraduate math at the level of electrical engineering or physics majors
undergraduate physics.

Recommended courses

Analysis I-III, linear algebra, probability and statistics
For SSV students: Dynamical Systems Theory for Engineers or "Mathematical and Computational Models in Biology"

Important concepts to start the course

Differential equations, Linear equations,

Learning Outcomes

By the end of the course, the student must be able to:

- Analyze two-dimensional models in the phase plane
- Solve linear one-dimensional differential equations
- Develop a simplified model by separation of time scales
- Analyze connected networks in the mean-field limit
- Predict outcome of dynamics
- Prove stability and convergence
- Describe neuronal phenomena
- Test model concepts in simulations

Transversal skills

- Plan and carry out activities in a way which makes optimal use of available time and other resources.
- Collect data.
- Continue to work through difficulties or initial failure to find optimal solutions.
- Write a scientific or technical report.

Teaching methods

- Classroom teaching, exercises and miniproject. One of the two exercise hours is integrated into the lectures.
- Short mooc-style videos are available as support
- Textbook available as support

Expected student activities

-participate in ALL in-class exercises.
- do all homework exercises (paper-and-pencil)
- study video lectures if you miss a class
- study suggested textbook sections for in-depth understanding of material
- submit miniprojects

Assessment methods

Written exam (70%) & miniproject (30%)
The miniproject is done in teams of 2 students.

Supervision

Office hours	No
Assistants	Yes
Forum	Yes
Others	The teacher is available during the breaks of the class. Some exercises are integrated in class in the presence of the teacher and the teaching assistants.

Resources

Bibliography

Gerstner, Kistler, Naud, Pansinski : Neuronal Dynamics, Cambridge Univ. Press 2014

Ressources en bibliothèque

- Neuronal dynamics: from single neurons to networks and models of cognition / Wulfram Gerstner, Werner M. Kistler, Richard Naud, Liam Paninski

Websites

- https://neuronaldynamics.epfl.ch/
- https://lcnwww.epfl.ch/gerstner/NeuronalDynamics-MOOCall.html

Moodle Link

- https://go.epfl.ch/NX-465

Videos

- https://lcnwww.epfl.ch/gerstner/NeuronalDynamics-MOOCall.html