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.

Content

**I. Models of single neurons**
1. Introduction: brain vs computer 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./6. Associative Memory and Attractor Dynamics (Hopfield Model)
7. Neuronal Populations and networks
8. Continuum models and perception
9. Competition and models of Decision making

**III. Noise and the neural code**
10. Noise and variability of spike trains (point processes, renewal process, interval distribution)
11: Variance of membrane potentials and Spike Response Models

**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
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
- Formulate stochastic models of biological phenomena
- Formalize biological facts into mathematical models
- Prove stability and convergence
- Apply model concepts in simulations
- Predict outcome of dynamics
- Describe neuronal phenomena

Transversal skills

- Plan and carry out activities in a way which makes optimal use of available time and other resources.
- Collect data.
- Write a scientific or technical report.

Teaching methods

Classroom teaching, exercises and miniproject. One of the two exercise hours is integrated into the lectures.

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%)

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
Notes/Handbook
The textbook is online at: http://neuronaldynamics.epfl.ch/

Videos
http://lcn.epfl.ch/~gerstner/NeuronalDynamics-MOOC1.html
http://lcn.epfl.ch/~gerstner/NeuronalDynamics-MOOC2.html