Computational Neuroscience

Academic year 2015-16

1. Teaching activity identification
Computational Neuroscience is a 4 ECTS optional course from the Biomedical Engineering degree that will be taught during the third trimester of the 4th course. Theoretical analysis and computational modeling will be at the basis of this course, which will provide the student with tools for studying the nervous system. The machine learning concepts and tools that will be taught are transversal and transferable to many other disciplines, such as modern data analysis, visual processing and pattern recognition. The subject is divided in two parts, which will have special emphasis on the study of: 1) biophysics of neurons and neuronal populations, and 2) computations that neuronal networks can perform, such as memory storage and pattern recognition.

2. Coordination and teaching staff
The professors of the course will be Rubén Moreno Bote (DTIC, coordinator) and Jordi Garcia Ojalvo (DCEXS). The subject will be taught in English, but optionally Catalan and/or Spanish can be used as well.

3. Competences
- Implement conductance-based models and reduced variants (in terms of both dimensionality and nonlinearities) to describe the dynamics of isolated neurons
- Understand and represent mathematically the influence of synaptic inputs on the behavior of single neurons
- Develop a mean-field approximation that allows for a description of neuronal dynamics in terms of average firing rates
- Understand the attractor picture as a framework to study the behavior of networks of spiking neurons
- Use the brain as an inspiration for advanced pattern recognition
- Model cognitive functions in neuronal networks
- Emulate memory and retrieval functions using simulations of neuronal networks
- Simulate learning in neuronal networks
- Apply neuronal networks for classification and pattern recognition

4. General objectives
The overall goal of the subject is to gain fundamental insights into brain function and the neural mechanisms underlying such function. To this end, theoretical and computational tools will be presented, which largely rely on the theory of dynamical systems and machine learning. The behavior of the nervous system will be considered at different levels of complexity ranging from the neuronal level to the system level in which biophysically plausible networks of neurons will be studied. The students are expected to gain a fundamental understanding into the concepts and methods presented during the course rather than just memorizing details. This is why hands-on practical work will be central to this course. Such type of activities will provide the student with opportunities to manipulate real data, simulate neuronal networks and apply the learned methods.

5. Teaching methodology
All the teaching activities have been developed to promote both a critical thinking by the students and their active participation in the classroom.

The proposed teaching activities are as follows:

5.1 Lectures
The lecturer will present the main theoretical contents and will promote subsequent discussions by the group. Graphic support will be used in the lectures in the form of slides, videos and computer simulations, which will be published on Aula Global.

5.2 Seminars and Practical work
Seminars and hands-on practical work will complement some of the topics learned in the theoretical classes. In these sessions, the students will gain further insight into the main concepts and methods studied in the lectures by addressing practical problems in neuroscience. To this end, the students will make use and/or write their own scripts in Matlab and Python to perform the computational analysis of real neuronal data.

6. Course Program (4 ECTS)

1 Neurons
   Conductance-based models: Hodgkin-Huxley
   Two-dimensional models: FitzHugh-Nagumo and Morris-Lecar
   Noise in spiking neuron models

2 Synapses
   Modelling synaptic input and synaptic transmission
   Excitatory and inhibitory synapses
   Postsynaptic potential

3 Neuronal populations
   The population density approach
   Mean-field models
   Attractor networks

4 Memory and retrieval in neuronal networks
   Modeling memory and retrieval with neuronal networks
   Hebbian learning
   Hopfield networks
   Storage limit capacity

5 Recognition by neuronal networks
   Perceptrons, linear classifiers and patterns recognition
   Boltzmann machines
   Error back-propagation
   Deep-learning in multi-layered networks
   Classification and pattern recognition revisited
   Belief propagation
   Convolutional networks
References


C.M. Bishop, Pattern Recognition and Machine Learning, Springer, 2006