Computational Brain Modeling and Analysis Lab
Computational Biomedicine Imaging and Modeling Center
Department of Computer Science
Rutgers University

01:198:443:01

Seminar Course

Integration of Computer and Brain Sciences

Instructor: Konstantinos Michmizos
Class meetings: Tuesday and Friday 08:40 – 10:00 am
Place: ARC – 204
Reading: Class hand–outs and research papers
Prerequisite Course: 01:198:111 or equivalent

Course Overview

As computer applications are starting to overcome the physical barrier between the hardware and the human body, Computer and Brain Sciences are re-establishing their synergy. This seminar course will offer to students the opportunity to discover, and understand, how the human brain computes to achieve intelligent behavior and how this knowledge guides the development of new computational algorithms that mimic the neural activity. The course will introduce the use of computational methods for modeling the brain activity from the micro (neural) to the macro (behavioral) level. We will combine theoretical lectures and hands-on tutorials on brain simulation environments such as NEURON, NEST, Brian, and the Virtual Brain. At the end of the course the students are expected to have expanded their knowledge of how the brain solves simple problems on the visual and motor domain, and how one can develop neuro-inspired algorithms to tackle emergent problems in computer science.

Course Structure

We will first work on acquiring some basic familiarity with the building blocks of the brain, across the various hierarchical functional levels. As we will be building this background, we will gradually start covering the computational aspects of analyzing and modeling brain behavior. The main reading material will be the class hand–outs, typically a 3–4 page summary of the lecture. During the semester, there will be a transition from lectures to tutorials, group discussions about research papers and finally to presentations of the term-projects, that will be chosen by the students.

Expected work

There are four expected components to participating in the seminar course:

1. **Reading and class participation**: Everyone will be expected to read the class hand-outs and the assigned review papers (no more than 1 paper per week).

2. **Tests**: There will be an in-class test every approximately 2 weeks. The test will take no more than 10 minutes, it will have 1 or 2 comprehensive questions and it will take place either at the beginning or at the end of the lecture, addressing issues taught at the previous or current lecture, respectively. The lowest graded test of each student will be dropped.

3. **Paper discussion**: Students will discuss approximately 5 papers that will be either assigned to or selected by them.

4. **Course project**: All students will complete a research project involving reading additional papers, identifying a research question, and developing attempts at solving it. This will be done with instructor's guidance, and with check-in meetings a few times during the semester (schedule to be determined). The projects will conclude with a 5-page write–up of the chosen area and project results, as well as a presentation to the seminar.

Weekly schedule	
Weeks 1–2	**Fundamentals of Computational Neuroscience:** Historical landmarks, spatial and temporal scales of brain computation, the language of the brain, methods for recording brain data.
Weeks 3–4	**Computational Modeling of Brain Activity:** Hodgkin-Huxley / Integrate and fire neurons; conductance- based / current-based synapses; Synaptic plasticity - spike timing, firing rate; Networks of spiking neurons - coupled differential equations through network connectivity matrix; neural mass model; learning in a single neuron: the perceptron; attractor neural networks.
Weeks 5–6	**Computational mechanisms of the brain in solving fundamental problems:** We will examine how the brain solves several problems that are inherent to its function: delays, redundancy, uncertainty, nonlinearity, non-stationarity, and noise. After reviewing these problems, we will present the computational mechanisms that the brain is currently believed to use to limit their deleterious effects: optimal feedback control, impedance control, predictive control, Bayesian decision theory, and learning. **Due date for finalizing the term–project's theme: Friday, October 9**
Weeks 7–8	**Brain-Computer Interfaces and current trends in Robotic Neuro–Rehabilitation:** We will discuss about current algorithmic approaches in invasive / non-invasive Brain Stimulation.
Weeks 9–10	**Computational approach of brain pathophysiology:** We will also examine how brain models are used to test hypotheses on brain dysfunction and guide therapy (for example, how one could change the parameters from a model that emulates how the brain controls a limb, to simulate the Parkinsonian tremor?) **Due date for submitting the term–project draft: Friday, November 13**
Weeks 11–12	**Brain-inspired algorithms and Neuro-morphic Computing:** We will examine the differences between brain-inspired neuromorphic processors and current von Neumann processors architectures is the way in which memory and processing is organized. We will see how brain-inspired processor architectures can support models of cortical networks and deep neural networks. We will also see how these architectures, ranging from serial clocked implementations of multi-neuron systems to massively parallel asynchronous ones and from purely digital systems to mixed analog/digital systems, may exhibit adaptation and learning mechanisms analogous to the ones found in biological nervous systems. **Due date for submitting the term–project: Tuesday, December 8**
Weeks 13–15	**Students' presentations**

Suggested Readings

- **Books**

  Lytton "From Computer to Brain" Springer, 2002.

  Ermentrout and Terman "Mathematical Foundations of Neuroscience" Springer, 2010.

  Dayan and Abbott "Theoretical Neuroscience: Computational and Mathematical Modeling of Neural Systems" MIT Press, 2001.

  Kandel et al (eds.) "Principles of Neural Science" McGraw-Hill, 2012.

  Von Neumann, John, and Ray Kurzweil. The computer and the brain. Yale University Press, 2012.

- **Book Chapters**

  Krebs HI, Michmizos KP, Susko T, Lee H, Hogan N "Beyond Human or Robot Administered Treadmill Training" 2015

- **Review papers**

  Franklin DW, and Wolpert DM "Computational mechanisms of sensorimotor control" Neuron 72.3 (2011): 425-442.

  Scott SH "The computational and neural basis of voluntary motor control and planning" Trends in cognitive sciences 16.11 (2012): 541-549.

  Indiveri G, and Liu S-C "Memory and information processing in neuromorphic systems" Proceedings of the IEEE 103.8 (2015): 1379-1397.

  Floreano D, Ijspeert AJ and Schaal S "Robotics and Neuroscience" Current Biology 24.18 (2014): R910-R920.

  Rucci M, Bullock D, and Santini F "Integrating robotics and neuroscience: brains for robots, bodies for brains" Advanced Robotics 21.10 (2007): 1115-1129.