NE 204: Introduction to Computational Models of Brain and Behavior

http://cns.bu.edu/~barnes/ne204

Spring 2012

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Prerequisites
Textbook None
Classes MA123 and MA124 or consent of instructor

Schedule
Lecture MWF 10:00–11:00 AM SAR 101
Lab A2 F 9:00–10:00 AM CAS 327
Lab A3 F 11:00–12:00 PM CAS 327
Lab A4 F 12:00–1:00 PM CAS 327
Lab A5 W 11:00–12:00 PM CAS 327

Course Overview
NE 204 introduces students to important concepts in cognitive neuroscience and computational modeling of biological neural systems. The course combines a systems-level overview of brain function with an introduction to the modeling of brains using neural networks. Key concepts regarding brain function are illustrated through visual and auditory illusions, neurological disorders with striking behavioral consequences, and neural modeling accounts of these phenomena.
Lab
Weekly lab sessions cover applications of that week’s lecture topic and provide an opportunity to begin the computational portion of homework assignments with help from the teaching fellow. A major emphasis of some of these labs will be the use of graphical tools to develop qualitative solutions to differential equations. Other labs will implement simple neural network models of brain functions related to perception, learning, or memory.

Homework
In the weekly homework assignments, you will explore in greater detail the mathematical material presented in lecture. At times these assignments will require computational software, such as MATLAB, that is accessible online to the BU community. Collaborating with other students is encouraged, but you must submit your own version of the assignment, written in your own words. Homework will be posted on the course website by Wednesday morning before the lab period and will be due at the beginning of Wednesday’s lecture the following week. Late homework will not be accepted without prior permission of the teaching fellow.

Exams
Midterm Exam  10:00–11:00  Friday, March 9
Final Exam  TBD
Missed exams must be rescheduled in advance with the instructor’s permission.

Grading
Homework (Lab) Exercises  50% of grade
Midterm Exam (1 hr, in class)  25% of grade
Final Exam (1 hr, in class)  25% of grade

Academic Honesty
Students are required to abide by the CAS Academic Conduct Code, which can be found at http://www.bu.edu/academics/resources/academic-conduct-code/. Cases of academic misconduct, including cheating on exams, will be reported to the Dean of CAS and the Director of the Neuroscience Program.

University Drop Dates  etc. can be found at http://www.bu.edu/reg/dates/ides-spring12.html.
1 Overview of Computational Modeling in Neuroscience

Jan. 18–20. The field of computational neuroscience is introduced, including treatment of several example neural models. These models are defined at different “grains” of analysis, ranging from models of single neuron activity to simple networks to hierarchical systems. The idea of modeling learning as changes in synaptic strength within a neural network is also introduced.

Lab 1 (Due Jan. 25). Introduction to MATLAB. Details for how to install and run MATLAB on a personal computer or via computers in the 111 Cummington basement lab will be provided. An introduction to the MATLAB interface along with basic concepts and methods for programming neural network simulations will also be presented.

2 Foundations

Jan. 23–27. Tools for investigating brain function, ranging from physiological measurement techniques to psychophysics and illusions to computational methods, are introduced. Mathematical principles used in the course, such as differential equations and linear algebra, are shown with simple examples. Bottom-up and top-down approaches to studying the brain are introduced, and the philosophical notion of computational neuroscience is defined within this framework.

Lab 2 (Due Feb. 1). Leaky Integrator. Leaky Integrator: Students will learn to build a MATLAB script for the leaky integrator differential equation using Euler’s method.

3 Introduction to Mathematical Modeling of Physical Systems

Jan 30–Feb 3. An introduction to the mathematical modeling of physical systems is undertaken. A “barrel and water” system is used to illustrate the construction of additive equations. A second physical system, involving temperature control of water in a barrel, is used to introduce the shunting equation. The use of these equations is then generalized to the modeling of neural activity in a neural network.

Lab 3 (Due Feb. 8). Shunting neural network, CELEST Brightness Lab. This lab introduces students to an ordinary differential equation (ODE) shunting network, changing of parameters, and plot visualization in MATLAB. A perceptual experiment in which students match the brightness of different regions on the screen is then performed and the results analyzed. Students are then guided through the construction of Grossberg’s shunting neural network model while being introduced to terminology, graphing symbols, and typical neural interactions of excitatory and inhibitory connections.

4 Introduction to Modeling Individual Neurons and Action Potentials

Lecturer: Dr. John Burke

Feb. 6–10. We introduce the concept of differential equations and why dynamical models of the nervous system are useful. We describe the physiological and electrochemical properties of neurons responsible for the generation of action potentials, and consider a new mathematical model of neural activity: the integrate and fire model. We discuss both the strengths and weaknesses of this model in comparison to the behavior of actual neurons.

Lab 4 (Due Feb. 15). RC Circuit. The goal of this week’s lab is to show how the axon acts like a resistor and capacitor in parallel. The RC circuit will be built in MATLAB.
5  **Hodgkin-Huxley Equation**

Lecturer: Dr. John Burke

**Feb. 13–17.** We introduce the Hodgkin-Huxley equations as a fundamental model for the generation of an action potential in a neuron. We describe the important currents included in this model, and how the dynamic interaction of these currents results in action potentials.

**Lab 5 (Due Feb. 22). Hodgkin-Huxley Simulator.** Students will gain an intuition about how the Hodgkin-Huxley model of an action potential functions computationally. The class will learn how to use HHsim, a graphical simulation of a section of excitable neuronal membrane using the Hodgkin-Huxley equations.

6  **The FitzHugh-Nagumo Model**

Lecturer: Dr. John Burke. No lecture on 2/20 for President’s Day. Lecture 1 will be on Tuesday, 2/21.

**Feb. 21–24.** We introduce the (two dimensional) FitzHugh-Nagumo model as a practical compromise between the intuitive behavior of low dimensional systems (such as the integrate and fire model) and the detailed description associated with higher dimensional systems (such as the Hodgkin-Huxley equation).

**Lab 6 (Due Feb. 29). FitzHugh-Nagumo phase plane analysis.** For this lab, dynamics of the FitzHugh-Nagumo model equations can be viewed with PPLANE (http://math.rice.edu/~dfield/). This week’s lab builds upon the one-dimensional notion of an action potential by discussing two-dimensional phase plane analysis of an action potential via the FitzHugh-Nagumo model.

7  **The FitzHugh-Nagumo (cont’d) and Theta Models**

Lecturer: Dr. John Burke

**Feb. 27–Mar. 2.** We present the graphical method of phase portrait analysis as a useful tool for describing the behavior of two dimensional systems. We apply this technique to the FitzHugh-Nagumo model to develop an intuitive understanding of the mechanism involved in the generation of an action potential. We also present the theta model as an abstract but useful one dimensional model of neural activity. We use this simple model to introduce the concept of a bifurcation, and show how this is relevant to the distinction between neurons that are excitable and those that fire continuously.

**Lab 7 (Due Mar. 7). Theta neuron in MATLAB.** In this lab students will explore the concept of a bifurcation in a dynamical system. Students will use MATLAB to simulate the Theta neuron, and they will characterize regions where the neuron is either excitable or continuously firing.

8  **Midterm Exam**

**Mar. 5.** We finish by taking a quick look at how coupling models of single neurons can allow their firing to synchronize.

**Mar. 7.** Midterm review

**Mar. 9.** Midterm

**No Lab**
9 Biological Bases of Long Term Memory Changes

Mar. 19–23. Synaptic dynamics are considered in an attempt to understand the biophysical basis of long term memory changes. The cellular changes underlying habituation, sensitization, and classical conditioning in aplysia are investigated. Simple neural network learning laws based on neurophysiological findings are described.

Lab 8 (Due Mar. 28). MATLAB Simulation of BCM Theory. The Bienenstock, Cooper, and Munro (BCM) theory, also known as the BCM rule, is simulated in MATLAB in order to demonstrate a physiologically realistic model of synaptic plasticity. Also discussed is the BCM theory’s difference from standard Hebbian learning.

10 Building a Simple Network Model of Classical Conditioning

Mar. 26–30. The classical conditioning paradigm is revisited, and key findings from classical conditioning studies are presented. A simple neural network is constructed to explain key data, including the use of synaptic weight equations to account for learned associations between stimuli and responses. Differences in the network-level properties of presynaptically and postsynaptically gated learning laws are discussed.

Lab 9 (Due Apr. 4). Modeling Section of CELEST Associative Learning Lab. The ability to learn temporal conditioning is a critical survival competence because it enables the learning of which earlier events predict later consequences, as well as which event combinations are not causative. In this way, the individual can make the optimal choices for successful, adaptive behavior. Students begin with an experimental, interactive conditioning task; performance data is presented in multiple formats for analysis. The computer simulates the student interaction based on key learning parameters. The module uses a neural network model for eye-blink conditioning to develop a deeper understanding of types of memory learning.

11 Diffuse Neuromodulatory Systems and Psychoactive Drugs

Guest Lecturer: Dr. Anatoli Gorchetchnikov

Apr. 2–6. Neuromodulatory systems with diffuse innervation of the CNS play an important role in behavioral function. The cellular properties of acetylcholine may set the dynamics for encoding of new information within cortical structures. Models of the role of acetylcholine in encoding are described, along with models of the transition from encoding to retrieval or consolidation during low levels of acetylcholine. The role of dopamine as an error signal for reinforcement learning is also addressed. Effects of psychoactive drugs on the brain are considered with reference to various neuromodulatory systems.

Lab 10 (Due Apr. 11). Neuromodulators and Learning Students will investigate a MATLAB script illustrating how cholinergic presynaptic inhibition of glutamatergic synaptic transmission enhances the encoding of associations.

12 Neural Networks and Graphs

Apr. 9–13. Graph-theoretic concepts are introduced and related to typical neural network connectivities. Connectomics and functional connectivity research are related to studies of network robustness.

Lab 11 (Due Apr. 18). TBA.
13 Neural Map Reorganization in the Brain: Data and Modeling (Part 1)

No lecture on 04/16 — Patriot’s Day

Apr. 18–20. Neurophysiological studies of plasticity in sensory maps in the auditory, somatosensory, and visual cortices are reviewed. Evidence for modification of motor maps in primary motor cortex is also discussed. Unusual sensory syndromes in amputees and stroke patients are discussed within the context of these plasticity studies.

Lab 12 (Due Apr. 25). Consolidating MATLAB Skills In this lab students will review the MATLAB skills they have learned over the semester and receive further instruction on how to use MATLAB in typical laboratory settings.

14 Neural Map Reorganization in the Brain: Data and Modeling (Part 2)

Apr. 23–27. Early neural network models of neural map formation are introduced. One more modeling account for cortical reorganization studies is provided, and decoding of neural activity using the population vector is introduced.

Lab 13 (Due May 2). A Simple Self-Organizing Map (SOM) How do nodes (or neurons) self-organize in the brain? A MATLAB implementation of a simple SOM will be implemented based on Kohonen’s (1982) weight update equation, which demonstrates how lateral interaction between neurons plays a key role in cortical mapping. Students will also run the SOM Toolbox located at http://www.cis.hut.fi/projects/somtoolbox/ in order to learn the effects of different parameters in the model and visualize SOM variations.

15 Neural Prosthesis and Final Exam Study Session

Apr. 30. The field of neural prosthesis, involving brain-machine interfaces (BMIs) that restore communication and motor abilities to paralyzed patients, is investigated. Particular attention is paid to BCIs involving electrodes implanted into the cerebral cortex of profoundly paralyzed humans.

May 2. Final exam study session.

No Lab