

Theoretical and Computational Neuroscience

[PHYS 585: Syllabus: December 28, 2010]

Vijay Balasubramanian (DRL 2N3A)

TA: Isaac Carruthers (3E5, isaac.carruthers@gmail.com)

Course Lecture: TR 9-10:30 in the Barchi Library (140 John Morgan)

(Lecture will be moved DRL A4 on Jan 20 and Feb 10 to accommodate NGG recruiting)

Office Hours: R 10:30-1:30 (Vijay Balasubramanian); T 3-5 (Isaac Carruthers)

DRL = David Rittenhouse Laboratory

Course description: This course will develop theoretical and computational approaches to structural and functional organization in the brain. The course will cover: (i) the basic biophysics of neural responses, (ii) neural coding and decoding with an emphasis on sensory systems, (iii) approaches to the study of networks of neurons, (iv) models of adaptation, learning and memory, (v) models of decision making, and (vi) ideas that address *why* the brain is organized the way that it is. The course will be appropriate for advanced undergraduates and beginning graduate students. A knowledge of multi-variable calculus, linear algebra and differential equations is required (except by permission of the instructor). Prior exposure to neuroscience and/or Matlab programming will be helpful.

Pre-requisites: *Mathematics:* Knowledge of multi-variable calculus, some linear algebra and some differential equations is necessary for this course. The methods will be developed in class for the benefit of students without much exposure to this material. Students without some prior background must have the permission of the instructor to take this class. *Computation:* Prior knowledge of Matlab will be useful, but students will go through programming exercises to develop their skills. *Neuroscience:* Basic knowledge of the architecture of the brain, and of the mechanisms of neural signaling will be very useful. However, for the benefit of students from physics and bioengineering without background in neuroscience, the necessary material will also be developed in class and in tutorial sessions.

Books: Required book is available for purchase at the Penn Book Center (corner of Sansom and 34th Street). All these books are also on reserve in Math-Physics library in the David Rittenhouse Laboratory.

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

Optional:

1. F. Rieke, D. Warland, R. de Ruyter van Steveninck, and W. Bialek, "Spikes: Exploring the Neural Code", MIT Press, 1997. *Useful reference on the neural code and information theoretic methods.*
2. E. Kandel, "Principles of Neural Science", McGraw-Hill, 2000. *The standard neuroscience textbook, useful if you don't have prior exposure.*
3. P. Wallisch et al., "Matlab for neuroscientists: An introduction to scientific computing in Matlab", Academic Press, 2008. *An introduction to algorithms and computational methods that are useful in neuroscience. Useful if you don't have much programming experience.*

4. M. Diamond and A. Scheibel, "The human brain coloring book", Collins Reference, 1985. *Coloring this book (get out your crayons) will teach you the basics of neuroanatomy.*

Handouts: The textbook will be supplemented with readings from the literature that will be posted on Blackboard.

Matlab: Penn has a site license for MATLAB. You can buy a student copy for your own computer, or use it at: (1) SAS Computing Multi-Media Services (basement DRL), (2) Undergrad Data Analysis Lab (104/108 McNeil), (3) Weigle Information Commons (Van Pelt), (4) SEAS virtual PCs: <http://www.seas.upenn.edu/cets/answers/virtualLab.html>, (3) More info at: <http://www.sas.upenn.edu/computing/instructional/labs.html> and <http://www.upenn.edu/computing/view/labs/lablist.html> A free, and mostly compatible alternative to MATLAB is Octave: <http://www.gnu.org/software/octave/>

Final project: There will be a final project that students will carry out in small teams. Suggestions for possible final projects will be made early in the semester, and a 1-2 page proposal for the final project will be due at midterm. Projects will consist of two parts: (i) reading and summarizing the literature on a particular theoretical/computational problem in neuroscience and (ii) building and analyzing a theoretical or computational model in this domain. An interim report on the project of 1-2 pages will be due a few weeks before the end of term, and a 7-10 page final report will be due at the end of term.

Problem Sets: There will be regular problem sets that will be due in class on the Thursday after they are issued.

Grades: Problem sets: 65% (2 lowest homework grades dropped)
Final project proposal: 5%
Final project interim report: 5%
Final project report: 25%

Other Policies: We do not discuss grades over email. Late work not be accepted unless there is a legitimate excuse (illness or a family crisis).

Topics Covered

1. Single Neurons
 - a. Biophysics of spike generation and action potential propagation (Ch. 5 & 6; Weeks 1 & 2)
 - b. Neural coding and decoding – models of neural response, spike-triggered characterizations of response (Ch. 1 – 3; handouts; Weeks 3-5)
 - c. Measuring neural information (Ch. 4; Week 6)
 - d. Adaptation of neural responses (handouts)
 - e. Normative models of function (handouts)
2. Neural Populations

- a. Receptive field maps (handouts)
 - b. Parallel Channels (handouts)
 - c. Correlations and interactions (handouts)
 - d. Network structure and computation (Ch. 7)
3. Higher level functions
- a. Memory – the Hopfield model (handouts)
 - b. Decision making and Bayesian analysis (handouts)
 - c. Synaptic plasticity and learning (Ch. 8)
 - d. Reinforcement Learning (Ch. 9)
 - e. Representational learning (Ch. 10)