# Psychology / Neuroscience 506A
# Computation in Neural Systems
F 9:00AM - 11:45AM
Room 317B, Psychology Building

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Office hours: after class or by appointments, LSN 384.

## COURSE OVERVIEW

This course is intended to provide a basis for understanding how brains acquire, assimilate, store and retrieve information and how they compute adaptive responses to external inputs. Understanding these processes requires a basic working knowledge of both the theoretical principles and biological mechanisms underlying neural signaling, knowledge representation and data storage. The course begins with a review of the fundamentals of membrane physiology & neuronal excitability, synaptic transmission & synaptic plasticity, and the integrative properties of dendrites. This is followed by a discussion of associative ('Hebbian') learning in networks of neurons, focusing on how activity patterns and pattern sequences may be stored and retrieved, and on the mechanisms by which networks can be trained to produce an adaptive response to arbitrary inputs. We then consider how information is 'coded' in the activities of single neurons and in the collective activity patterns of large networks of neurons. Finally, we explore how some specific models have been used to make sense of computation in the brain. Additional topics include the spatial representation in the hippocampus, the transformation of neuronal representations from sensory to motor 'coordinates' and several other examples of 'higher' cognitive functions.

The course is intended for graduate students with an interest in the basic principles of brain computation. Although prior coursework in basic neurobiology, biopsychology and cognitive processes is useful, the course is intended to be accessible to students from a broad range of disciplines, with varying background knowledge in the field. The theoretical principles are presented using simple biological examples and a minimum of mathematics.

Lectures will be supplemented with suggestions for optional further reading.

The course constitutes the first part of a two part Core Curriculum for students in the Cognition and Neural Systems Program in Psychology, and it fulfills the Systems Neuroscience Core requirement in the Graduate Interdisciplinary Program in Neuroscience.

**Introductory texts recommended as background reading in basic neuroscience and neural computation:**

1) Delcomyn, F. (ed). Foundations of Neurobiology. New York: W.H. Freeman and Company, 1998. (Chapters 2,4 & 5)
2) Kandel et al., (Eds) Principles of Neural Science 4th Edition, McGraw-Hill, 2000
3) Squire L.R. et al., (Eds) Fundamental Neuroscience 2nd Edition, Academic Press, 2003
4) Churchland, P.S. and Sejnowski T.J. The Computational Brain. Bradford MIT Press, 1989. (an excellent introduction to neural computation and coding – no math)
5) Shepherd G.M. (Ed.) The Synaptic Organization of the Brain, Oxford University Press 1990.
6) Purves D., Augustine GJ, Fitzpatrick D., Katz L. LaMantia A.S., McNamara J.O. and Wiliams S.M. Neuroscience 2nd edition. Sinauer Associates 2001.
Note: these texts cover some but not all of the topics covered in class.

**More advanced texts and articles on specific topics:**
1) Nicholls, D.G. Proteins, Transmitters and Synapses. Blackwell Science, 1994
2) Dyan, P., Abbott, L.F. Theoretical Neuroscience.
3) Bliss, T.V.P., Collingridge, G.L. and Morris R.G.M. (eds.) Long-term potentiation: enhancing neuroscience for 30 years. Phil. Trans. Roy. Soc. (Biological Sciences) 358: 603-842, 2003. A series of excellent review articles on the theme of long-term synaptic modification, prepared by major contributors to the field over the past 3 decades.
4) Cooper, J., Bloom, F., Roth R., The Biochemical Basis of Neuropharmacology. Elsevier, 1997 Focuses on the neurotransmitters, the chemicals that carry nerve impulse between nerve cells. This seventh edition includes a new chapter on the genetics of psychiatric and neurological diseases and a discussion on the new gaseous modulators, nitric oxide and carbon monoxide.
5) Arbib, M.A., Erdi, P., Szentagothai, J. Neural Organization: Structure, Function and Dynamics. MIT Press, 1998. An excellent introduction to understanding neural circuits in the brain and their relationship to behavior and cognition.

## GRADES

Evaluation will be based on two exams (30% midterm, 40% final), a few quizzes (15%) and class participation (15%). Evaluations of exams are based both on the informativeness of the answer, relevance to the course theme, and on the writing style. Students who are unsure of their writing effectiveness are encouraged to consult a text on scientific writing style (e.g., "The Craft of Scientific Writing" by Michael Alley – Springer, NY, 3rd ed, 1996 – ISBN0-387-94766-3). In addition, the University offers an excellent Writing Skills Improvement Program (http://wisp.web.arizona.edu) and a Graduate Writing Workshop (Dr. Victoria Stefani; Modern Languages Bldg. Room 410).

As part of the "class participation" grade, at the beginning of each lecture, one or two students will present a short review of the *main concepts* from the preceding lecture. Each presenter should have his/her own PowerPoint presentation (use a CDR, USB drive or email instructor no later than 8pm the day before class). Please arrive 10 minutes early on the day you are to present, if possible. The presentation should last less than 20 mins (i.e. about 15 slides).

The two written exams will be based on the cumulative material covered in class up to that point. The exams will include a set of questions that must be answered in the form of brief essays. Material in suggested references will not be *explicitly* tested unless covered in class, but students may include this and other material in their answers. The exams will be done in class and will be close book. Students are responsible for providing a lap-top computer on which to write the exam, preferably as MSWord or text files. Exams will be collected in electronic form at the end of the exam period. The document names should contain the course number, your name and the exam number (e.g., Psych 506-Lynn Smith-Exam1.doc ). Please save your work at regular intervals throughout the exam as a "lost file" will be counted as a failure. Do not delete your exam until after a grade has been assigned. The midterm may have a take-home component. The final will be all in-class.

"Borrowing" (cutting and pasting) text from other sources: Term papers and exams may contain short excerpts from published material if they clearly enhance the presentation; however, all "borrowed" text must be contained within quotation marks and clearly attributed. Likewise, ideas that are paraphrased from the works of others (including lecture handouts) must be clearly attributed. If you have any uncertainty about what constitutes plagiarism consult the following:
http://www.baruch.cuny.edu/facultyhandbook/documents/PlagiarismLiteratureReview.pdf
http://slate.msn.com/?id=2061056

## CLASS SCHEDULE

| Date | Topic |
|---|---|
| Aug 26 | Introduction – **Making Sense of Neural Computation through Modeling**: overview of basic phenomenological computational models of single neurons, learning rules, perceptron and classifiers. |
| Sept 2 | **Channels and Excitability (neuronal computations):** Review of fundamental neural signaling mechanisms; membranes, channels, ionic equilibria and neuronal excitation. |
| Sept 9 | **Synaptic Transmission (synaptic computations: Part I)**: basic synaptic physiology. Transmitter release, excitation/inhibition in post-synaptic cell. Electrical signaling. |
| Sept 16 | **Dendrites and axons (dendritic computations)**: morphology, physiology and integrative properties. |
| Sep 23 | **Synaptic Bases of Memory (synaptic computations: Part II)**: Modification of synaptic communication through experience; short and long-term changes; associative vs. non-associative synaptic plasticity. |
| Sep 30 | **Neural Circuits (network computations)**: A survey of some typical and some atypical synaptic networks in the brain. |

Oct 7 **Computing with noise: Neurophysiology of Sleep**, noise, background activity, reliability and precision of spiking.

Oct 14 **Midterm** (all material including Oct 7)

Oct 21 **Computing in the context of memory: Associative Memory in Neural Networks** - Basic principles of associative memory; pattern completion; constraints on storage capacity; sequence storage and retrieval.

Oct 28 **Consolidation, Reconsolidation, the Hippocampus, and the Cortex**: Memory consolidation in cortical hierarchies and the hippocampus. (L. Nadel)

Nov 4 **Computing in the context of spatial navigation: Spatial Representation in the Hippocampus** - Place fields, grid fields and spatial navigation, including recent advances in understanding the origins of spatial information (L. Schimanski).

Nov 11 NO CLASS (Veteran's day)

Nov 18 **Computing at the systems level: Higher brain Functions** - Introduction to the fMRI technique, a discussion of some 'higher' brain functions; planning, decision making, memory, emotion, social interactions and diseases such as Alzheimer's. (G. Alexander)

Nov 25 NO CLASS (Thanksgiving)

Dec 2 **Representation in the Brain:** Philosophical look at representation. Early AI and the computer metaphor, connectionism, ecological approach to perception, dynamical systems, and embodied cognition. (L. Nadel)

Dec 15 **Final Exam.** 9:00 am – 11:00am, Psych 317B

(possible extra lectures)
**Neural Coding**: Basic concepts of scalar and vector coding. Spike timing and spike interval codes. Population coding examples.