**2016 Syllabus - BIO 338 - "From Synapse to Circuit: Self-organization of the Brain"**

Exploration of basic neural and synaptic mechanisms and the operation of representative brain circuits, using both theoretical approaches and experimental evidence.Particular attention will be given to Hebb's Rule ("cells that fire together, wire together"), its cellular basis, its consequences for circuit self-organization, and its limits*.

The course is aimed at anyone with curiosity about the brain, who is willing to tackle a range of reading, including original research papers. A solid background in a mathematical, physical or biological science is desirable, though the course will be largely self-contained. The course is NOT a general introduction to neuroscience, unlike BIO 334. Although we will consider some specific parts of the brain, the focus will be on general concepts, particularly on how "high level" properties of the brain (such as "mind") emerge from the interaction of vast numbers of "low level" units such as neurons, synapses and molecules.
Please note that we will use some basic mathematics (statistics, exponential function, a bit of calculus, simple linear algebra). All concepts will be illustrated graphically, but if you are mathphobic please consider carefully before taking the course.

*Note on the Hebb Synapse. An important unifying concept of the course is the "Hebb Synapse". This is a special sort of neural connection which responds to the coincident electrical activity of the 2 nerve cells making the connection (as well as other signals) by becoming stronger (or, possibly, weaker). There are 2 important issues here: (1) how is it that a subcellular structure can behave in this special way, as a result of the interaction of the molecules of which it is composed. (2) why is it that this special synaptic property can lead to "self-organization" of extremely complex structures, such as the human brain? – structures which seem to have minds, even though the constituent molecules, synapses and neurons do not? So the course both looks "down" from synapses to molecules and "up" from synapses to minds.
The course starts out by considering 2 other examples of "looking both up and down":

(1) Phase transitions: atomic/molecular interaction leads tounexpected properties such as the melting of ice and themagnetization of iron.
(
2) Life: Molecular selfreplication leads to even more unexpected properties: life.

Course Objectives
General Learning Objectives: by the end of this course the students should have
1. Understood the principles of self-organization, evinced by the mean field ferromagnetism model , Eigen's molecular evolution model, action potential generation, recurrent neural networks and unsupervised and supervised learning models.
2. Understood of the quantitative framework of key biophysics/molecular neuroscience concepts (membrane potential, ion channel permeation passive membrane, Hodgkin-Huxley and reduced spike models, transmitter release and ion channels statistics)
3. Understood of some specific neural circuits (cerebellum; olfaction; hippocampus; retina; thalamus andneocortex)
4 Acquired notions of linear algebra, calculus and learning rules applied to neural network models.
5. Be able to relate the 2 main functions of synapses: transmitting current information and adjusting strengths to reflect past information.
6 Learned about the neural machinery of learning: neuroscience is different in principle from the rest of biology because information is stored in (Hebbian) synapses not DNA.
7. Appreciate that neuroscience is not yet a mature discipline, and major differences in viewpoint and ongoing controversies are endemic at scientific frontiers.
8. Gained experience in writing detailed scientific papers on specific topics, and revising in response to criticism.
9. Grasped neuroscience modeling approaches and relevant circuitry for higher level cognitive and behavioral functions.
10. Related bottom-up (molecular/cellular viewpoint) and top-down (circuit/systems) approaches to brain function.

Specific Goals: by the end of this course students will be able to 1. Use the Boltzmann distribution and thermal agitation concepts to analyze ferromagnetism, polynucleotide copying, and membrane potential.
2. Apply Eigen's theory to the origin of life, protocells, and other major evolutionary transitions.
3. Understand how ions cross membranes and how different types of channel interact electrically, e.g. in the HodgkinHuxley model
4. Write and using equations to represent biophysical properties of neurons.
5. learn about ion channel (especially potassium channels and nicotinic receptors) and synapse structure/function.
6. Comprehend ion channel block, transmitter release statistics and mini generation.
7. Understand the basis of Inhibition and Neuro-modulation
8 Understand how statistical ideas such as random variables, probability distributions, independence/dependence, regression/information maximization and Principal and Independent Component analysis are used in unsupervised learning neural models.
9 Acquired rudiments of structure/function relations in the brain (e.g. motor learning; memory; data compression; representation) in cerebellum, olfactory centers, hippocampus, retina, thalamus and neocortex.
10 Understand the idea of receptive fields and its relation to PCA and ICA
11. Acquired basic concepts in Supervised Learning: delta rule; back-propagation learning rule; reinforcement learning; spike-based learning

Instructor : Professor Paul Adams, Room 518, Life Sciences Building. Email: paul.adams@stonybrook.edu. Phone 26938. You are encouraged to submit questions about any aspect of the course by email. You MUST include a subject line which mentions "BIO 338", otherwise your emails may not be read. My office hours (held at variable announced times, in Room 518 unless otherwise announced) will be posted on BlackBoard. If possible notify me if you plan to visit my office, and when.
Co-instructor : Professor Giancarlo La Camera Room 513 email: Lacamerag@gmail.com

BlackBoard : You MUST regularly consult the BlackBoard listing for this course: http://blackboard.stonybrook.edu Emails: Please send me an email (at paul.adams@stonybrook.edu ) to confirm that you are taking this class. I will then be able to send you emails with important course announcements and reminders, in addition to announcements on BlackBoard.

Grading . Your grade will be based on 2 term papers, which should be submitted both electronically and as a hardcopy. Detailed instructions will be provided. Each paper will carry equal weight. If you do not submit your papers on time, you risk lowering your grade. If you are unavoidably delayed in submitting either term paper, you must send Paul Adams an email stating the reason and a firm date for submission. For the first paper, your topic should be chosen from the list to be provided (and posted on BlackBoard). You will have the opportunity to revise your paper, and improve your grade by as much as one letter grade (eg B to A), based on our feedback (provided via the annotated hardcopy and personal feedback). I strongly suggest you meet me in person about revising your paper. For the second paper, you must submit your own proposed topic (based on course material) for approval, with a paragraph summarizing your plan, by email to Paul Adams by Nov 18. You are welcome to come to my office to discuss your proposed paper. Please note that you may be personally interviewed to check that you understand your own term paper! Also, your grade will partly reflect the extent to which your paper evinces thorough understanding of the material covered in the lectures. A term paper that does not relate to the lecture material but is otherwise excellent will not receive a top grade. The final term paper MUST be submitted in definitive form: drafts and revisions not allowed. All papers must be submitted both electronically and as hardcopies. The date of your complete electronic submission will be definitive.

**Lectures** (Mon, Wed, 4- 5.20 Room 054 Life Sciences). Please note that the following listing is subject to revision as the course advances, and the timing is slightly flexible.)

Aug 28 Introduction to the Course. Mind and Brain. Neurons and Synapses; "selforganization"
Aug 30 Self-organization in simple physical systems: ferromagnetism
Sept 6 Self-Organization of Matter. Polynucleotide replication
Sept 11 Eigen's molecular evolution theory
Sep 13 Membrane and membrane potential, receptors, channels
Sept 18 Passive Properties of Neurons. Cable Theory
Sept 20 The Action Potential
Sept 25 The Hodgkin Huxley Theory of the action potential
Sept 27 Spike Threshold, propagation and frequency
Oct 2 A well understood synapse: The neuromuscular junction; first term paper topics announced
Oct 4 Transmitter release and other statistics
Oct 9; Ion channel statistics; Channel block; minis ; First term paper topic choice must be made by now
Oct 11 The nicotinic acetylcholine receptor
Oct 16 Central excitatory synapses 1; Cerebellum;
Oct 18 Central excitatory synapses 2;
Oct 23 Central excitatory synapses 3; First Paper Due
Oct 25 Smell: a simple circuit in action
Oct 30 Simple Neural Networks and Linear Algebra
Nov 1 The Linear Associator as a neural network model of memory
Nov 6 Hippocampus and Memory
Nov 8 ; Hebb Synapses
Nov 13 Long Term Potentiation
Nov 15 Hopfield Networks and the Hippocampus
Nov 20 Unsupervised Learning : PCA, ICA; Retina and Thalamus
Nov 27 Cortical Networks of Spiking Neurons (La Camera) Topics for Second Paper Due; Revised First Paper Deadline
Nov 29 Supervised and Reinforcement Learning (LaCamera)
Dec 4 Neocortex 1.
Dec 6 Neocortex 2; Origin of Language
Final Term Paper due ; final grade will be delayed and/or an Incomplete will appear if you are late.

Text and Readings
There is no prescribed textbook for the course. However, it is suggested that students purchase /borrow/have accessto, and use, one or more of the following standard textbooks of neuroscience. It's not necessary to consult the latestedition – I suggest buying a cheap early edition and making it bedside reading!
"Neuroscience: Exploring the Brain", by Bear, Connors and Paradiso; (HSC, Melville) (Probably the best, and cheapest choice; relaxed style; however the other books present much the same material with different emphases and illustrations).
"Principles of Neuroscience" by Kandel, Schartz and Jessell; Comprehensive.
"From Neuron to Brain". Nicholls, Martin, Wallace, Fuchs, Brown et al . Sinauer (excellent for illustrations of important experiments and detailed references to original papers).
"Fundamental Neuroscience" Squire, Bloom etc. Academic Press. A doorstopper but the discussion of some topics is very complete.
"Neuroscience" Purves, Augustine etc. Sinauer. Very good, and comes with a neuroanatomy CD.
When researching a topic, use several of these texts if possible as background: different texts have different emphases.
In addition, the following texts will be found useful; they have been placed on reserve in the HSC or Melville Libraries.
"Theoretical Neuroscience: Computational and Mathematical Modeling of Neural Systems", by Dayan and Abbott; HSC; Melville (Tough going for nonmathematicians)
"An Introduction to Neural Networks", by Anderson. HSC; Melville. Included a primer on linear algebra)
Johnston and Wu, Foundations of Neurophysiology (Bradford) HSC, Melville. Engineering influenced accounts of basic neuron electrical properties.
Shepherd, Synaptic Organisation of the Brain (Oxford) HSC (Good descriptions of individual systems(hippocampus, olfaction, thalamus,neocortex)
Levitan and Kaczmarek, The Neuron : Cell and Molecular Biology. Oxford. A basic guide to neurons, with a more biochemical flavor.
Mountcastle: Perceptual Neuroscience: The Cerebral Cortex. Harvard

More Advanced Texts with material relevant to this course.
Modeling Brain Function: The world of attractor neural networks. Amit. Cambridge.
Spikes: Exploring the Neural Code. Rieke et al. Bradford.
Introduction to the theory of Neural Computation. Hertz, Krogh, Palmer. AddisonWesley
Ionic Channels of Excitable Membranes. Hille. Sinauer
Biophysics of Computation: Information processing in single neurons. Koch. Oxford.
Steps toward Life. Eigen. OUP

Lighter Reading:
Here are several books written for the "intelligent layman" which are stimulating and interesting:

The Astonishing Hypothesis. Frances Crick. The discoverer of the double helix, one of the most penetrating minds in modern biology, argues that the mind is just the interaction of neurons.
Synaptic Self : Joseph Ledoux. An expert on neural basis of emotion looks at learning and the brain
On Intelligence: Jeff Hawkins. The inventor of the Palm Pilot on the neural basis of intelligence. Starts well.
The Quest for Consciousness: Christoph Koch. A theoretical neuroscientist writes breezily about experimental work on awareness.
What is thought? Eric Baum. Interesting on AI, neural networks and evolution (but wrong conclusions)