GS14 1153 **Theoretical Neuroscience: From Cells to Learning Systems**

Instructor Contact Information

Instructors: Fabrizio Gabbiani (BCM) and Harel Shouval (UT)
Office: FG at Baylor College of Medicine, Rm S557C; HS at UTHSC, Room 7.264
Email: gabbiani@bcm.edu, harel.shouval@uth.tmc.edu
Office Hours: FG and HS each TTh 1-2pm

Course Objectives and Learning Outcomes

Goal of the course is to introduce the most salient features of neural systems at the biophysical, cellular and systems level, as well as to develop the ability to construct and test mathematical models from basic principles of biophysics. Upon completion of the course, students should be able to:

1. Formulate and solve algebraic equations for the resting state of cells,
2. Formulate and solve differential equations for the dynamic state of cells and their interactions,
3. Use Fourier transforms to describe the response properties of visual neurons,
4. Apply probabilistic models to describe synaptic transmission and behavior,
5. Analyze the responses of networks of neurons and study learning in such networks.

Assigned readings for the first 14 lectures are specified in the schedule. There will be an online quiz over each reading prior to the class period where it is needed. Exercises will be pursued in groups of 2 to 4 during class. During the second part of the course, there will be no required readings and quizzes.

Required Texts and Materials

Mathematics for Neuroscientists and **MATLAB** for $99 or **Octave** free**.**

Homework and Exams

27 online quizzes/assignments, two exams and a final project.

Additionally a final project is required.

Grade Policies

Your quiz/assignment average is 50% of your grade. Over the first 14 lectures, weekly assignments will be given that will contribute 50% of each quiz/assignment total. Over the second part of the course, there will be only assignments and no quizzes.

2 exams, each covering 14 lectures. The exams will be pledged 3-hour and take-home.
Each exam is worth 20% of your grade. The final project is worth 10% of the final grade.

Syllabus Change Policy

This syllabus is only a guide for the course and is subject to change with advanced notice.

COURSE SCHEDULE

Week/Lecture	Topics	Instructor
Week 1	**The Passive Isopotential Cell – Numerical Solution of Differential Equations**	
8/23/16	Nernst Potential, Membrane Conductance, Capacitance, Synaptic Conductance. [MN Chapter 2].	Gabbiani
8/25/16	Differential Equations, Exact and Numerical Solutions. [MN Chapter 3, sections 1, 4, 5].	Gabbiani
Week 2	**The Active Isopotential Cell**	
8/30/16	Delayed Rectifier Potassium Channel, Sodium Channel. [MN Chapter 4, sections 1 & 2].	Gabbiani
9/1/16	Hodgkin-Huxley Equations. [MN Chapter 4, section 3].	Gabbiani
Week 3	**The Passive Cable**	
9/6/16	The Discrete Passive Cable Equation, Numerical Solution. [MN Chapter 6, sections 1 & 3, Chapter 5, section 2].	Gabbiani
9/8/16	The Passive Cable Equation, Numerical Solution with Synaptic Inputs. [MN Chapter 6, section 4 and 5].	Gabbiani
Week 4	**The Passive and Active Tree**	
9/13/16	The Passive Dendritic Tree, Differential Equation and Numerical Methods. [MN Chapter 8, section 1, 3 & 4].	Gabbiani
9/15/16	The Active Cable and Dendritic Tree. [MN Chapter 9, section 1, 3, & 5].	Gabbiani
Week 5	**Fourier Transforms – Early Vision**	
9/20/16	Fourier Transforms, Discrete and Continuous. [MN Chapter 7].	Gabbiani
9/22/16	Receptive Fields of Retinal Ganglion Cells and Simple Cells in Visual Cortex. [MN Chapter 20, section 2-5, Chapter 21, section 1].	Gabbiani
Week 6	**Visual Cortex – Probabilities**	
9/27/16	Non-Separable Receptive Fields, Motion Energy Model. [MN Chapter 21, sections 2-5].	Gabbiani
9/29/16	Basic Probability, Binomial, Poisson and Gaussian Random Variables. [MN Chapter 11, sections 1-6].	Gabbiani
Week 7	**Introduction to Signal Detection Theory and Psychophysics**	
10/4/16	Hypothesis Testing, Ideal Decision Rules, Poisson and Gaussian Models. [MN Chapter 24, sections 1-3, Chapter 25, section 1].	Gabbiani

10/6/16	Single Photon Detection, Psychophysics, Motion Detection. [Chapter 25, sections 2 and 3].	Gabbiani
Week 8	**Recess – Synaptic Transmission**	
10/11/16	Midterm Recess: No Class	
10/13/16	Quantal Release Model. [MN Chapter 12, sections 1-6].	Shouval
Week 9	**Synaptic Transmission – Synaptic Plasticity and Learning**	
10/18/16	Short Term Synaptic Plasticity, Receptor Dynamics (Markov models). [MN Chapter 12, sections 6, 7].	Shouval
10/20/16	Long Term Synaptic Plasticity, the Basis of Learning and Memory – Introduction.	Shouval
Week 10	**Synaptic Plasticity – Unsupervised Learning**	
10/25/16	Hebb's and Oja's Rules, Principal Component Analysis, Links to Receptive Field Development. [MN Chapter 14, sections 1-3].	Shouval
10/27/16	The Bienenstock-Cooper-Munroe (BCM) Rule, Application to Receptive Field Development.	Shouval
Week 11	**Unsupervised Learning – Supervised Learning**	
11/1/16	Objective Function Formulation and Independent Component Analysis.	Shouval
11/3/16	Perceptron Rule for Linear Neurons.	Shouval
Week 12	**Supervised Learning – Biophysics of Synaptic Plasticity**	
11/8/16	Multilayered Networks, Backpropagation Learning Rule.	Shouval
11/10/16	Biophysical Mechanisms of Synaptic Plasticity.	Shouval
Week 13	**Biophysics of Synaptic Plasticity – Molecular Mechanisms of Synaptic Plasticity**	
11/15/16	Linear Pair-Based Superposition Models.	Shouval
11/17/16	Modeling Molecular Interactions Underlying Plasticity Models.	Shouval
Week 14	**Molecular Mechanisms of Synaptic Plasticity**	
11/22/16	Calcium Dependent Plasticity Models.	Shouval
11/24/16	Thanksgiving Recess: No Class	Shouval
Week 15	**Receptive Fields and Reinforcement Learning**	
11/29/16	Receptive fields with Calcium Based Models.	Shouval
12/1/16	Reinforcement Learning.	Shouval