ECE-498-NCS: *Neural signals, circuits and systems*; Spring 2021

Instructor & Course Coordinator: Jont Allen
Prerequisites: One of: MATH 384, 385, 386: Differential Equations
Target Audience: Fourth year undergraduates
Text: *Neuroscience, a mathematical primer*; Author: Alwyn Scott
Alternate instructors: Viktor Gruev, Mark Hasegawa-Johnson; Zhi-Pei Liang

Outline: This course presents an introduction for an engineering audience of research and models of brain function. This is an important topic usually taught to students of neuroscience, reformulated for the Electrical and Computer Engineering undergraduate student. Neuroscience courses presently taught in the neuroscience department do not present the topic in a mathematical framework. This version of the course will take a more qualitative modeling approach to brain signal processing. Neural circuits and system delve into Boolean signal processing, based in nonlinear diffusion equations and delay-and-add synaptic signal processing.

The more than 200 year history is highly relevant so that students learn from the past discoveries rather than trying to "reinvent the wheel." To work in machine learning, mastery of what we know today about brain signal processing is essential. Homework sets cover key topics; There are three exams: two midterm Exams, and a final.

The material is presented in the order as suggested by the Textbook author (A. Scott), in the preface (p. ix), in four parts:

I. Introduction and History: Historically relevant material, plus a broad overview.

II. Structure of a Neuron: Function, physiology and models.

III. Neuronal Assemblies: Various brain circuits.

IV. Chapter 10: Brain theories.

Syllabus:[1]

			Part I. Introduction and History
Lec	W/D	Ch	Description
1	4/25	20	Instruction Begins Jan 25, 2020
			Introduction to Neruoscience for engineers; Some history
2	27		Structure of a nerve cell
3	29		Organization of the brain; Density and numbers of neurons
4	5/1	12	Hierarchical nature of brain dynamics; Integration of the five sensory inputs
5	3		Feedback: negative vs. positive; causality
6	5		Biological reductionism; Objections to reductionism;
7	6/8		Possibile numbers of amino acids vs actual number; Biodiversity

			Part II. Structure of a Neuron
L	W/D	Ch	
8	10	12	The generic neuron
9	12	2	Synapses
10	7/15		McCulloch-Pitts model
-	17		University Holiday; No Class
11	19		Real neurons (Fig. 2.1); $\Sigma\Delta$ codec
12	8/22		Lipid bilayers; Active membrane Impedances
13	24	3	Channels and pumps
14	26		Neural information transmission
15	9/1		Exam I (Optional in class review)
			Neural Modeling
16	3	4	Ionic currents (conduction vs diffusion currents)
17	5		Nernst, Planck and Einstein relations; Membrane models; Resting potentials and pumps
18	10/8	7	Squid voltage patch methods; op-amp technology and methods
19	10	9	Modeling the membrane;
20	12		Active fiber branching
21	11/15		Role of calcium and short-term memory
22	17		Dendritic logic

[1] Based on suggestions in Scott Preface.

			Part III: Neuronal Assemblies
L	W/D	Ch	Description
23	19		$\Delta\Sigma$ modulation codec (Large dynamic range; noise dynamics)
			`https://en.wikipedia.org/wiki/Delta-sigma_modulation`
24	12/22	11	Cell assemblies; Associative networks
-	24		University Holiday; No Class
25	26		Real assemblies and their roles
26	13/29	4	Hodgkin-Huxley; Spike generation concepts
27	31		Space and voltage clamping (HW using HH matlab model)
			`https://virtualrat.org/hodgkin-huxley-model-action-potential-squid-giant-axon`
28	2		Leading edge models
			Signal velocity (spikes, sound, light) (p. 148); Frog, cat, rabbit, squid motor nerves
29	14/5		FritzHugh-Nagumo model
30	7		Review of HH and modeling
31	9		Exam II: (Optional in class review)

			Part IV: Brain Theories
L	W/D	Ch	Description
32	15/12	10-a	Nets without circles (No feedback)
33	14	10-a	Nets with circles (Feedback)
34	16	10-b	Learning networks
35	16/19	10-b	Learning with feedback (back-tracing)
36	20	8	Ephaptic Evidence (Robustness models). (p. 165)
37	21	10-c	Field theories of Neocortex
38	17/24	10-c	Field theories of Neocortex
39		26-d	Control theory
40		28-e	Model of brain signal processing
41	18/19	31-f	Boolean logic decision processing
42	21		Last day of class; Review for Final (May 5)

Final Grade: The final grade will be based on a weighted average of the two midterm exams and the final exam (95%), and a 5% weight for the home works and class participation. An extra hour of 497 credit is given for a student project (with approval of the instructor).

Course outline by lecture, week and chapter.

References

Agmon-Snir, H., Carr, C. E., and Rinzel, J. (1998). The role of dendrites in auditory coincidence detection. *Nature*, 393(6682):268.

Dayan, P. and Abbott, L. F. (2001). *Theoretical neuroscience: computational and mathematical modeling of neural systems*. Computational Neuroscience Series.

Eliasmith, C. and Anderson, C. (2004). Neural engineering: Computation. *Representation, and Dynamics in Neurobiological Systems*.

Koch, C. (2004). *Biophysics of computation: information processing in single neurons*. Oxford university press.

Scott, A. (2002). *Neuroscience: A mathematical primer*. Springer Science & Business Media.

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