ECE-498-NCS: *Neural signals, circuits and systems*; Fall 2019

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 a summary of up to date (2002) research into brain function. An important topic that is highly relevant for students of neuroscience, that is presently not taught in the Electrical Engineering curriculum. The neuroscience courses that are presently taught do not present the topic in a mathematical framework. Brain function is a topic, that today, is based on neural signal processing, steeped in nonlinear diffusion equations and delay and add synaptic signal processing. The more than 200 year history is highly relevant so that students do not try to reinvent the wheel. If one wishes to work in the area of machine learning, then mastery of this course is essential. Ten homework sets covering key issues; There are three exams: Exam I, II, final;

The material is presented in the order as suggested by the author in the preface (p. ix), in three 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.

Syllabus:[1]

			Part I. Introduction and History
L	W	Ch	Description
1	1	1	Dynamics of a Nerve Impulse (p. 1)
2			The Structure of a Nerve Cell (p. 8)
3			Organization of the brain (p. 11)
4	2	12	The Hierarchical Nature of Brain Dynamics (p. 293)
5			Causality and impedance; Feedback: Negative vs. positive (p. 13)
6			Biological Reductionism; Objections to Reductionism (p. 294)
7	3		Number of amino acids is immensely greater than the number that exist (p. 296)
8			Protein structures odds (p. 297)

			Part II. Structure of a Neuron
L	W	Ch	Description
9		2	The generic neuron (p. 25)
10	4		Synapses (p. 35)
11			Neural models: McCulloch–Pitts (MP) (p. 41)
12			Real neurons (p. 44)
13	5		Exam I
15		3	**Nerve membranes**
16			Lipid bilayers and electrical properties (capacitance and conductance) (p. 50)
11	6		Ionic currents (conduction, diffusion currents) (p. 56)
17			Nernst, Plank and Einstein relations (p. 59) (p. 58)
18			Membrane model (Sect. 3.4, p. 60)
19	7		Resting potentials and pumps (p. 63)
20			**Neural Modeling:**
21		9	Dendritic trees (p. 188)
22	8		Branching (p. 195, 204); Tapered Fibers (p. 199)
23			Dendritic information processing and logic (State machines) (p. 206-217, Fig. 9.5)
24			Information processing (p. 217-220)
25	9		A comparison of the neuron with the Σ-Δ codec. `https://en.wikipedia.org/wiki/Delta-sigma_modulation`
27			Exam II:

[1] Subject to modifications.

			Part III: Neuronal Assemblies
28	10	11	Early Evidence for Cell Assemblies (p. 261)
29			Dynamics (p. 266)
30			Associative Network (p. 277)
31	11		Recent Evidence for Cell assemblies (p. 282)
32		4	Hodgkins-Huxley (HH) Axon (p. 67)
33			Space, voltage and current clamps (Op Amp circuits) (p. 67)
34	12		Patch of Squid Membrane (p.70)
35			RC Cable equations (p. 77)
36			Traveling-wave solutions of HH (p. 79-84);Stable vs. unstable solutions (p. 84-87)
37	13		Refractory and Enhancement zones (Lessons learned) (p. 87)
38		6	FitzHugh-Nagumo (FN) neuristor simplified model (p. 122)
39			Structure of an FN impulse (p. 124)
40	14	7	Myelinated nerves: Nodes of Ranvier (Domino effect) (p. 140, 146); Signal velocity (spikes, sound, light) (p. 148); Frog, cat, rabbit, squid motor nerves (p.)
41		8	Ephaptic Evidence (Robustness models). (p. 165)
42			Final exam

Yet to be integrated into the course:

Ch 10 **Brain theories:**

(a) Nets with and without circles (p. 234)

(b) Learning networks (p. 237)

(c) Fields theories of Neocortex (p. 248)

Final Grade: The final grade will be based on a weighted average of the three midterm exams and the final exam (95%), and a 5% weight for the home works and class participation. An extra hour of 397 credit is given for a student project (with approval of the instructor).

Course outline by lecture, week and chapter.[2]

References

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

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.

Version 1.3 February 7, 2019

[2]L: Lecture; Ch: Chapter