ECE/CS 8580 Machine Learning in Neuroscience

Brief description: Basics of neuronal and network dynamics including spikes and communication between regions, including via competing hypotheses. Machine learning fundamentals including linear, logistic and artificial neural network mappings. Integration of data-driven and theory-driven models, with emphasis on insights into neuroscience via XAI approaches. Software automation in neuroscience including python notebooks and cyberinfrastructure tools for interacting with repositories and HPC resources.

Prerequisites: ECE/CS 4590 or consent of instructor

Instructor: Satish S. Nair, 229 EBW (882-2964; nairs@missouri.edu)

Credits/ Class hours: 3 credits; Tue, Thurs 4-5:15 pm, 103 Naka Hall

Text + notes: *An Introduction to Modeling Neuronal Dynamics,* Springer International Publishing, 2017+ Supplemental material related to 'Machine Learning' and other relevant topics hosted at the Canvas site, and with codes developed using open source software packages for both neuronal dynamics (using NEURON) and machine learning (using Keras).

Grading:	Homeworks & Projects	30%
	Quizzes	10%
	One Mid-Term Exam	25%
	Final Exam	35%

Letter grades: A-F, Curve grading

Academic dishonesty: Academic honesty is fundamental to the activities and principles of a University. Any effort to gain an advantage not given to all students is dishonest whether or not the effort is successful. The academic community regards academic dishonesty as an extremely serious matter, with consequences that range from probation to expulsion. When in doubt about plagiarism, paraphrasing, quoting, or collaboration, consult the course instructor. If you are caught cheating on an exam or assignment, you will either receive a grade of zero for the exam/assignment, or an F for the course. Weekly assignments are individual assignments, so do not copy someone else's assignment.

If you are caught committing academic dishonesty, your actions will be reported to the Provost's office, according to university policy.

Special needs: If you need accommodations because of a disability, if you have emergency medical information to share with me, or if you need special arrangements in case the building must be evacuated, please inform an instructor immediately. Please see an instructor privately after class, or during office hours. To request academic accommodations (e.g. a note-taker) students must register with Disability Services, AO38 Brady Commons, 882-4696. It is the campus office responsibility to review documentation provided by students requesting academic accommodations, and for accommodations planning in cooperation with students and instructors, as needed and consistent with course requirements. For other MU resources for students with disabilities, click on "Disability Resources" on the MU homepage.

DETAILED LISTING OF TOPICS

A. Neuronal and network dynamics:

Notes hosted at website, including extensive software codes that students will extend/manipulate.

- Dynamics of single neurons and networks of neurons via software packages
- Temporal and Phasic coding principles, and communication strategies in brains
- Analysis techniques for neuronal time series data
- Agent-based modeling framework with neurons communicating to implement useful functions.

Open source software such as NEURON (https://www.neuron.yale.edu/neuron/) and python notebooks are used for all modeling tasks. Canned codes for several of these models will be further tweaked by students, and they will also supplement it with tools to analyze the neural output.

B. Basics of machine learning using neuroscience datasets:
Basics of linear and nonlinear regression, including gradient descent, etc. using python notebooks. We also stress derivation of arithmetic mean, gradient descent, etc. by hand using optimization theory. We also use material from the coursera course only for the theoretical part: https://www.coursera.org/learn/machine-learning. Also have extensive notes with videos as alternative. The codes use Keras are entirely different, i.e., nothing to do with the course. They are developed by students, starting with templates provided to them. The datasets are a mixture of those created by our own detailed physiological models of neurons and networks, and some publicly available ones. The models used for these will include linear, logistic, deep learning and convolutional neural networks, as well as Bayesian techniques. One of the goals will be to introduce students to integrating theory-driven with data-driven models, and to emphasize "explainable artificial intelligence" (XAI).

C. Stochastic noise models, and software projects:
Nose models including normal, binomial, Poisson, and log-normal distributions with extensive MATLAB and python-based codes. Then the focus will be on noise types occurring in brain signals, including Poisson and colored noise, including the determination of SNRs.
After the students have exposure to NEURON codes for single cell and network models as well as to the analysis of the outputs of the neuronal codes, they will be working on projects related to data analysis using machine learning schemes. Such projects will be focused on neuroscience topics. Representative projects will be at two levels: Level 1 will be related to analysis of data from neuronal recordings of brains (primarily rodents) and will include topics such as analysis and detection of brain waves (alpha, beta, gamma, etc.) and modeling of the local field potential. Level 2 will include machine learning schemes to model datasets from patients related to neuropsychiatric disorders such as anxiety. Such datasets are publicly available and we have some from our collaborators also. The models used for these will include linear, logistic, deep learning and convolutional neural networks, as well as Bayesian techniques, with an emphasis on "explainable artificial intelligence" (XAI). NIMH has recently started a new initiative titled 'Computational Psychiatry' which will require a workforce with background in all these areas: https://www.nimh.nih.gov/about/organization/dtr/adult-psychopathology-and-psychosocial-interventions-research-branch/computational-psychiatry-program.shtml
As another option at Level 2, students could instead work on software automation tools, including cyberinfrastructure tools in neuroscience such as using HPC computers around the nation. An example project would be to automate developing networks of cells using an Allen Institute open-source python code, including usage of programming interface (APIs) to access the Neuroscience Gateway (of our collaborator on an NSF award with P Calyam) to run HPC jobs. Finally, they will also have opportunities to create their own interface tools, to address emerging needs of big data in neuroscience.

Learning outcomes

Upon completion of the course, the students should be able to:
1. Learn how neurons encodes information in the form of binary signals (action potentials), which are triggered in a variety of patterns such as tonic spiking, adaptation, etc.
2. Appreciate the complexity of the nervous system and understand the modalities of communication of information between different regions, including via oscillations such as delta, alpha, beta and gamma waves that are hypothesized to facilitate communications differentially in different brain states.
3. Appreciate the role of computation in neuroscience, and how models and software can be used to illustrate the functioning of neurons and networks.
4. Understand the basics of machine learning and explore their niche in modeling functioning of biological neuronal networks.
5. Appreciate how software automation may be critical to enable discovery in neuroscience by freeing up the researchers to focus on science as opposed to learning about software and associated platforms to run them.