STATS220/320: Machine Learning Methods for Neural Data Analysis
Cross-listed as NBIO220 (and CS339N)
Instructor: Prof. Scott Linderman
Stanford University

Course Description:
With modern high-density electrodes and optical imaging techniques, neuroscientists routinely measure the activity of hundreds, if not thousands, of cells simultaneously. Coupled with high-resolution behavioral measurements, genetic sequencing, and connectomics, these datasets offer unprecedented opportunities to learn how neural circuits function. This course will study statistical machine learning methods for analysing such datasets, including: spike sorting, calcium deconvolution, and voltage smoothing techniques for extracting relevant signals from raw data; markerless tracking methods for estimating animal pose in behavioral videos; network models for connectomics and fMRI data; state space models for analysis of high-dimensional neural and behavioral time-series; point process models of neural spike trains; and deep learning methods for neural encoding and decoding. We will develop the theory behind these models and algorithms and then apply them to real datasets in the homeworks and final project.

Prerequisites:
Students should be comfortable with basic probability (STATS 116) and statistics (at the level of STATS 200) as well as multivariate calculus and linear algebra. This course will emphasize implementing models and algorithms, so coding proficiency is required.

Relation to other courses:
This course is similar to STATS215: Statistical Models in Biology and STATS366: Modern Statistics for Modern Biology, but it is specifically focused on statistical machine learning methods for neuroscience data.

Logistics:
Frequency: Meet three times a week (50 minutes each)
Level: advanced undergrad and up in statistics, computer science, neuroscience
Grading basis: credit or letter grade
Component: Lecture Mon/Wed; in-class labs on Fri. *We intend to host another lab session at a time that is more favorable for students in other timezones.*
Office hours: Han (9am Tu), Scott (1pm Wed), Jaime (5pm Th)
Enrollment cap: None
Final exam: No (project based)

Tentative Schedule:

Unit I: Extracting biological signals from raw data		
Mon, Jan 11	Lecture 1	Course Overview
Wed, Jan 13	Lecture 2	Basic spike sorting
Fri, Jan 15	Lab 1	A simple spike sorting algorithm
Mon, Jan 18	*MLK Day*	
Wed, Jan 20	Lecture 3	A more modern spike sorting algorithm
Fri, Jan 22	Lab 2	Spike sorting via conv. matrix factorization
Mon, Jan 25	Lecture 4	Demixing and deconvolving calcium imaging
Wed, Jan 27	Lecture 5	L0 deconvolution via changepoint models
Fri, Jan 29	Lab 3	Calcium deconvolution via constrained NMF
Unit II: Encoding and decoding models for neural data		
Mon, Feb 1	Lecture 6	Pose tracking in behavioral videos
Wed, Feb 3	Lecture 7	Encoding neural spikes with Poisson GLMs
Fri, Feb 5	Lab 4	Markerless animal pose tracking with CNNs
Mon, Feb 8	Lecture 8	Deep convolutional encoding models
Wed, Feb 10	Lecture 9	Decoding movement with Bayesian decoders
Fri, Feb 12	Lab 5	Deep encoding models of retinal spike trains
Mon, Feb 15	*President's Day*	
Wed, Feb 17	Lecture 10	Decoding as structured prediction
Fri, Feb 19	Lab 6	Decoding movement from neural data
Unit III: Unsupervised models of neural and behavioral data		
Mon, Feb 22	Lecture 11	Bayesian sequence detection in spike trains

Wed, Feb 24	Lecture 12	Hidden Markov models of behavior
Fri, Feb 26	Lab 7	Autoregressive HMMs for animal movements
Mon, Mar 1	Lecture 13	Latent factor models / VAEs
Wed, Mar 3	Lecture 14	Linear dynamical systems / Sequential VAEs
Fri, Mar 5	Lab 8	Switching LDS model of neural data
Mon, Mar 8	Lecture 15	Sparse ICA for fMRI data
Wed, Mar 10	Lecture 16	Network and graph models for connectomics
Fri, Mar 12	Lab 9	*Work on final projects*
	Project Presentations	
Mon, Mar 15	Presentations	In class project presentations
Wed, Mar 17	Presentations	In class project presentations
Fri, Mar 19	Presentations	In class project presentations

Assignments:

- Weekly in-class labs, which will require some out-of-class work to complete
- 1 final project proposal
- 1 final project report (with code)

Policies:

This is an extraordinary year and we're all struggling to do our best despite the challenges of COVID19. Though we're studying remotely, I do expect students to engage in lecture with their camera on, if possible. Please be respectful of other students, especially since we're coming from so many different backgrounds. Different people know different things, but everyone has something to contribute. Please take the group activities seriously, as this is an opportunity to interact with your peers and learn from one another. In return, I'll be understanding of the extenuating circumstances and allow each student 8 late days total to be used over the quarter, and I'll drop the lowest assignment.

Honor Code:

See https://communitystandards.stanford.edu/policies-and-guidance/honor-code