NUIN 443 – COMPUTATIONAL NEUROSCIENCE

Spring 2024

Course Directors

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Course Description

This course is primarily targeted at first- and second-year graduate students in labs that use advanced computational tools for modeling and data analysis, and by other graduate students who are interested in computational neuroscience. We will cover core topics in systems, computational and theoretical neuroscience, including but not limited to: analysis of time series (e.g., generalized linear models, dimensionality reduction, systems identification), latent variable models, manifold inference, dynamical systems modeling, learning rules, and artificial neural networks. Students enrolling in the class are expected to be familiar with python programming and basic mathematical concepts, especially linear algebra.

Learning Objectives

- Understand the theoretical and mathematical foundations of modern computational methods to analyze and model neuroscience data.
- Understand the use cases and limitations of those methods.
- Gain familiarity with common python packages to analyze and model data.
- Write code to model real neuroscience datasets.
- Understand how neural circuits implement neural computation

Course Requirements

- Familiarity with coding in python
- Linear algebra

Readings

- Hastie, Tibshirani and Friedman. *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*. Book website (free).
- Kevin Murphy. *Probabilistic Machine Learning: An Introduction.* Book (free)
- Kevin Murphy. *Probabilistic Machine Learning: Advanced Topics.* Book (free)
- Additional readings for individual lectures will be posted on Canvas

Schedule and Format

- Classes are Mondays and Wednesdays 2-4 PM in Weiboldt 712.
- All lectures will be in person.
- Lecture slides will be posted on Canvas and https://github.com/lucas-pinto/NUIN443, at the latest on the day after class.
- Most classes will involve live coding exercises, please bring a laptop.

	Day	Class	Instructor
1	Tues, March 26	Linear regression, Generalized linear models	Pinto
2	Wed, March 27	Principal components analysis, Canonical correlation analysis, Systems identification	Pinto
3	Mon, April 1	Journal club 1	Pinto
4	Wed, April 3	Classification, Decoding, Clustering	Pinto
5	Mon, April 8	Model of decision making: Signal detection theory, Drift diffusion, Mutual inhibition, Reinforcement learning	Pinto
6	Wed, April 10	Journal club 2	Pinto
7	Mon, April 15	Latent variable modeling intro, Factor Analysis, Gaussian processes	Glaser
8	Wed, April 17	Hidden markov models, Linear dynamical systems	Glaser
9	Mon, April 22	Journal club 3	Glaser

10	Wed, April 24	Statistical inference for model fitting: Expectation-maximization, Markov chain monte carlo (MCMC) and variational inference.	Glaser
11	Mon, April 29	Switching dynamical systems, Poisson linear dynamical systems, Variational autoencoders	Glaser
12	Wed, May 1	Journal club 4	Glaser
13	Mon, May 6	Dynamical systems overview (linear vs nonlinear, autonomous vs input-driven), Euler and exponential Euler methods, fixed points and bifurcation diagrams, Poincare diagram	Kennedy
14	Wed, May 8	In-class coding exercises: Morris-Lecar simulations and stability analysis	Kennedy
15	Mon, May 13	Journal club 5	Kennedy
16	Wed, May 15	Modeling neural populations: spiking models, firing rate models, population size effects, oscillations and chaos	Kennedy
17	Mon, May 20	In-class coding exercises: reservoir computing, training RNNs.	Kennedy
18	Wed, May 22	Journal club 6	Kennedy
19	Wed, May 29	Journal club 7	Glaser / Kennedy

Grading

- Problem sets (50% total): 1 problem set per lecture
- Journal club presentations (25% total)
- Participation (25%): participation points will be awarded for both 1) participation in journal club presentations (every student is expected to speak at least once during discussions), and 2) as a fraction of classes attended. Half-points will be given for a particular day if you are more than 10 min late. If you cannot attend a particular class or must be late, please email the module directors for an excuse to avoid deductions in your participation grade; this includes classes missed for religious observance (see below).

Office hours and communication

- Communication with instructors will happen exclusively via canvas announcements and emails. We will reply to emails within 24 h of receiving them.
- Office hours will be held on Mondays prior to class, from 1-2pm in Weiboldt 712.

Problem sets

Links to individual problem sets will be posted on Canvas, but they can also be found here: https://github.com/lucas-pinto/NUIN443. Please do not edit the version on github. First, save a copy by clicking on "File > Save a copy in drive". Then rename by adding your last name and first initial as a prefix, e.g. PintoL_NUIN443_ps1_Regression. When you are done, please submit the assignment on Canvas simply as a link to your copy.

Journal Clubs

Each student will lead one paper discussion in journal club. Papers will be assigned by the instructors based on ranked preferences submitted on the first day of class. Each presentation should consist of a 30-minute slide presentation followed by a 20-min discussion led by the student. The discussion will be based on a list of topics / questions submitted by the discussion leader one day before the journal club.

Journal Club 1, April 1:

1) "Encoding and decoding in parietal cortex during sensorimotor decision-making" (Park et al 2014): https://www.nature.com/articles/nn.3800
2) "Spatial structure of complex receptive fields measured with natural images " (Touryan et al 2005): https://www.cell.com/neuron/fulltext/S0896-6273(05)00061-9

Journal Club 2, April 10:

1) "Rats and humans can optimally accumulate evidence for decision making" (Brunton et al 2013): https://www.science.org/doi/10.1126/science.1233912
2) "A map of object space in primate inferotemporal cortex" (Bao et al 2020): https://www.nature.com/articles/s41586-020-2350-5

Journal Club 3, April 22:

1) "Gaussian-process factor analysis for low-dimensional single-trial analysis of neural population activity" (Yu et al 2008): https://proceedings.neurips.cc/paper_files/paper/2008/file/ad972f10e0800b49d76fed33a21f6698-Paper.pdf
2) "Unsupervised identification of the internal states that shape natural behavior" (Calhoun et al 2019): https://www.nature.com/articles/s41593-019-0533-X

Journal Club 4, May 1:

1) "Inferring single-trial neural population dynamics using sequential auto-encoders" (Pandarinath et al 2018): https://www.nature.com/articles/s41592-018-0109-9
2) "An approximate line attractor in the hypothalamus encodes an aggressive state" (Nair et al 2023): https://www.sciencedirect.com/science/article/pii/S0092867422014714

Journal Club 5, May 13:

1) "Differential signaling via the same axon of neocortical pyramidal neurons" (Markram, Wang, and Tsodyks 1998): https://www.pnas.org/doi/full/10.1073/pnas.95.9.5323
2) "Balanced amplification: a new mechanism of selective amplification of neural activity patterns" (Murphy and Miller 2009): https://www.cell.com/neuron/pdf/S0896-6273(09)00128-7.pdf

Journal Club 6, May 22:

1) "Similar network activity from disparate circuit parameters" (Prinz, Bucher, and Marder 2004): https://www.cell.com/neuron/pdf/S0896-6273(09)00547-9.pdf
2) "Generating coherent patterns of activity from chaotic neural networks" (Sussillo and Abbott 2009): https://www.cell.com/neuron/pdf/S0896-6273(09)00547-9.pdf

Journal Club 7, May 29:

1) "The importance of mixed selectivity in complex cognitive tasks" (Rigotti et al., 2013): https://www.nature.com/articles/nature12160
2) "Arithmetic and local circuitry underlying dopamine prediction errors" (Eshel et al., 2015): https://www.nature.com/articles/nature14855

Academic Integrity

Students in this course are required to comply with the policies found in the booklet, "Academic Integrity at Northwestern University: A Basic Guide". All papers submitted for credit in this course must be submitted electronically unless otherwise instructed by the professor. Your written work may be tested for plagiarized content. We expect students to implement their own code. The use of ChatGPT or similar AI tools should be strictly restricted for coding hints or troubleshooting. For details regarding academic integrity at Northwestern refer to the url linked above.

Accessibility Statement

Northwestern University is committed to providing the most accessible learning environment as possible for students with disabilities. Should you anticipate or experience disability-related barriers in the academic setting, please contact AccessibleNU to move forward with the university's established accommodation process (e-mail: accessiblenu@northwestern.edu; phone number: 847-467-5530). If you already have established accommodations with AccessibleNU, please let us know as soon as possible, preferably within the first two weeks of the term, so we can work together to implement your disability accommodations. Disability information, including academic accommodations, is confidential under the Family Educational Rights and Privacy Act.

Statement of Inclusivity

This course strives to be an inclusive learning community, respecting those of differing backgrounds and beliefs. As a community, we aim to be respectful to all students in this class, regardless of race, ethnicity, socio-economic status, religion, gender identity or sexual orientation. If you have any concerns regarding inclusivity in the classroom, contact the course directors. We are always open to suggestions for improvement.

Religious Observance Statement

Northwestern is committed to fostering an academic community respectful and welcoming of persons from all backgrounds. To that end, the policy on academic accommodations for religious holidays stipulates that students will not be penalized for class absences to observe religious holidays. If you will observe a religious holiday during a class meeting, scheduled exam, or assignment deadline, please let me know as soon as possible, preferably within the first two week of class. If exams or assignment deadlines on the syllabus fall on religious holidays you observe, please reach out so that we can discuss that coursework.

Prohibition of Recording of Class Sessions by Students

Unauthorized student recording of classroom or other academic activities (including advising sessions or office hours) is prohibited. Unauthorized recording is unethical and may also be a violation of University policy and state law. Students requesting the use of assistive technology as an accommodation should contact AccessibleNU. Unauthorized use of classroom recordings – including distributing or posting them – is also prohibited. Under the University's Copyright Policy, faculty own the copyright to instructional materials – including those resources created specifically for the purposes of instruction, such as syllabi, lectures and lecture notes, and presentations. Students cannot copy, reproduce, display, or distribute these materials. Students who engage in unauthorized recording, unauthorized use of a recording, or unauthorized distribution of instructional materials will be referred to the appropriate University office for follow-up.

Support for Wellness and Mental Health

Northwestern University is committed to supporting the wellness of our students. Student Affairs has multiple resources to support student wellness and mental health. If you are feeling distressed or overwhelmed, please reach out for help. Students can access confidential resources through the Counseling and Psychological Services (CAPS), Religious and Spiritual Life (RSL) and the Center for Awareness, Response and Education (CARE). Additional information on all of the resources mentioned above can be found here:

- https://www.northwestern.edu/counseling/
- https://www.northwestern.edu/religious-life/
- https://www.northwestern.edu/care/