Course Syllabus

EE675 - **Data analysis and control techniques for neurotechnology design**

Ming Hsieh Department of Electrical and Computer Engineering

University of Southern California

Instructor
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Office Hours: TBA

Lectures: Tuesday and Thursday, 9:00am-10:50am, ZHS352

Units: 4

Course Description:

This course teaches the data analysis, machine learning and control-theoretic tools used to study large-scale datasets and systems, with emphasis on neural datasets and brain-machine interface systems. Topics include state-space modeling, dynamical systems, theory of point processes, Bayesian inference, expectation-maximization (EM), and optimal control. Applications include construction of neural encoding models, system-identification in neural systems, decoding neural data, analyzing neural receptive field plasticity, algorithms for brain-machine interfaces, and closed-loop neurostimulation. This is a graduate-level course that is of interest to electrical and computer engineering, biomedical engineering, computer science, and neuroscience students.

Prerequisites:

EE503, or equivalent, or permission of the instructor. Students should be familiar with basic probability concepts. EE503 will be **waived** for any such students. Please contact the instructor if you are unsure of the prerequisite.

Course Website:

The course material and problem sets will be posted on Blackboard:

https://blackboard.usc.edu

Readings:

There are no required textbooks. Lecture slides/notes will be posted on the Blackboard website for many parts of the course. There will be various papers used as helpful reference reading material (examples listed below) and can be accessed through the libraries.

Course Grade:

This is an advanced graduate class. The course grade will be on the basis of a class project, a project proposal combined with a project pitch presentation in the 6th week of the course, a 15min final project presentation, a final project report, and homework assignments. The project and presentation should involve developing and implementing a data analysis technique and testing it on real and/or simulated data. The topic should be submitted for approval by the end of the 6th week of class in the form of a project proposal and project pitch presentation. In lieu of a final exam, the final report will be due at the time normally reserved for this class's final exam.

Tentative Course Schedule: A Weekly Breakdown

	Topics/Daily Activities	**Readings**
Week 1	Course overview and review of probability concepts	[1-5]
Week 2	Linear dynamical systems State-space models	[1-5]
Week 3	Recursive Bayesian estimation Kalman filtering and smoothing	[1-5]
Week 4	Point process theory Generalized linear models Spike train analysis	[6-11]
Week 5	Machine learning methods for spiking models: maximum-likelihood, time-rescaling theorem, goodness of fit, simulating a point process	[6-11]
Week 6	Recursive Bayesian estimation for spike trains: point process filtering, point process smoothing	[5,6,12,13] Project proposal due Project pitch presentations will be held in the 6th week
Week 7	Measures of functional connectivity, Granger causality, directed information	[14-19]
Week 8	Unsupervised learning and application to neural data analysis: expectation-maximization (EM) subspace identification	[12,20-24]
Week 9	Application to hippocampal neural activity	[12, 13, 25]

	Application to open-loop neural decoding	
Week 10	Dynamic programming and optimal control Linear quadratic regulator (LQR), linear Gaussian regulator (LQG)	[26,27]
Week 11	Closed-loop neurotechnologies for control of movement	[28-42]
Week 12	Closed-loop neurotechnologies for control of anesthesia	[43-46]
Week 13	Closed-loop neurotechnologies for electrical brain stimulation	[47-53]
Week 14	Multiscale and multimodal data fusion, modeling, and decoding	[54-57]
Week 15	Student final presentations	
FINAL Date	Final report is due at the time the University would otherwise designate for a final exam for this class	

REFERENCES

The following list contains the list of example books and papers that will be used as helpful reference reading material and can be accessed through the libraries. Each semester, the list of papers will be updated with new papers added to the list. The books will not be required for purchase.

[1] T. Kailath, A. Sayed, and B. Hassibi, Linear estimation. Prentice Hall NJ: 2000, vol. 1.

[2] J. M. Mendel, Lessons in estimation theory for signal processing, communications, and control. Prentice Hall NJ: 1995.

[3] S. M. Kay, Fundamentals of statistical signal processing: estimation theory. Prentice Hall NJ: 1993.

[4] H. E. Rauch, C. Striebel, and F. Tung, "Maximum likelihood estimates of linear dynamic systems," AIAA journal, vol. 3, no. 8, pp. 1445–1450, 1965.

[5] M. M. Shanechi, "Brain-machine interface control algorithms", IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 25, no. 10, pp. 1725–1734, 2017.

[6] W. Truccolo, U. Eden, M. Fellows, J. Donoghue, and E. Brown, "A point process framework for relating neural spiking activity to spiking history, neural ensemble, and extrinsic covariate effects," Journal of Neurophysiology, vol. 93, no. 2, pp. 1074–1089, 2005.

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[8] D. Daley and D. Vere-Jones, An introduction to the theory of point processes: volume II: general theory and structure. Springer, 2007, vol. 2.

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[12] A. Smith and E. Brown, "Estimating a state-space model from point process observations," Neural Computation, vol. 15, no. 5, pp. 965–991, 2003.
[13] U. Eden, L. Frank, R. Barbieri, V. Solo, and E. Brown, "Dynamic analysis of neural encoding by point process adaptive filtering," Neural Computation, vol. 16, no. 5, pp. 971–998, 2004.
[14] C. J. Quinn, T. P. Coleman, N. Kiyavash, N. G. Hatsopoulos, "Estimating the directed information to infer causal relationships in ensemble neural spike train recordings," Journal of Computational Neuroscience, vol. 30, no. 1, pp. 17–44, 2011.
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[17] S. Kim, D. Putrino, S. Ghosh, and E. Brown, "A Granger causality measure for point process models of ensemble neural spiking activity," PLoS Computational Biology, vol. 7, no. 3, p. e1001110, 2011.
[18] M. Okatan, M. Wilson, and E. Brown, "Analyzing functional connectivity using a network likelihood model of ensemble neural spiking activity," Neural Computation, vol. 17, no. 9, pp. 1927–1961, 2005.
[19] C. Wang, M. M. Shanechi M. M., "Estimating multiscale direct causality graphs in neural spike-field networks", IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 27, no. 5, pp. 857–866, 2019.
[20] A. P. Dempster, N. M. Laird, and D. B. Rubin, "Maximum likelihood from incomplete data via the EM algorithm," Journal of the Royal Statistical Society. Series B (Methodological), pp. 1–38, 1977.
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Academic Conduct

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in *SCampus* in Section 11, *Behavior Violating University Standards* https://scampus.usc.edu/1100-behavior-violating-university-standards-and-appropriate-sanctions. Other forms of academic dishonesty are equally unacceptable. See additional information in *SCampus* and university policies on scientific misconduct, http://policy.usc.edu/scientific-misconduct.

Discrimination, sexual assault, and harassment are not tolerated by the university. You are encouraged to report any incidents to the *Office of Equity and Diversity* http://equity.usc.edu or to the *Department of Public Safety* http://adminopsnet.usc.edu/department/department-public-safety. This is important for the safety of the whole USC community. Another member of the university community – such as a friend, classmate, advisor, or faculty member – can help initiate the report, or can initiate the report on behalf of another person. *The Center for Women and Men* http://www.usc.edu/student-affairs/cwm/ provides 24/7 confidential support, and the sexual assault resource center webpage http://sarc.usc.edu describes reporting options and other resources.

Support Systems

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