Course Syllabus

EE599 Signal Processing and Control in Neural Systems
Ming Hsieh Department of Electrical Engineering
University of Southern California
Spring 2016

Instructor	**Teaching Assistant**
Maryam M. Shanechi	TBA
Email: shanechi@usc.edu	Email: TBA
Office: EEB408	Office: TBA
Office Hours: Tuesday 11am-12pm	Office Hours: TBA

Lectures: Tuesday and Thursday, 9:30am-10:50am, VHE-217

Course Description:

This course teaches the machine learning, signal processing, and control methods used to study systems, with particular emphasis on neural systems and neural data. Topics include state-space modeling, 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 neural prosthetic control, and closed-loop control of brain states. This is a graduate-level course that is of interest to electrical engineering, computer science, biomedical engineering, 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 will be posted on the Blackboard website for many parts of the course. There will be various papers used as reference reading material (listed at the end of this document) and can be accessed through the libraries. The books will be put on reserve at the libraries but will not be required for purchase.

Course Grade:

This is an advanced graduate class. There will be no problem sets or exams. The course grade will be on the basis of participation, a class project, a 20min final presentation, and a final report. The final project and presentation could be on a related theoretical algorithm or on the application of the learned algorithms to neural or biological datasets. The topic should be submitted for approval by the end of the 6th week of class. The final report will be due on the last lecture.

Participation: 10%
Final Presentation: 35%
Final Report: 55%

Course Topics:

The course will cover the following tentative topics.

	Topics/Daily Activities	**Readings**
Week 1 1/11-1/15	Course overview and review of probability concepts	[1-4]
Week 2 1/18-1/22	State-space models	[1-4]
Week 3 1/25-1/29	Estimation of Gauss-Markov models, Kalman filtering, Kalman Smoothing	[1-6]
Week 4 2/1-2/5	Introduction to point process theory	[7-12]
Week 5 2/8-2/12	Estimation of static point process models	[11,12]
Week 6 2/15-2/19	Point process filtering and smoothing	[13,14]
Week 7 2/22-2/26	Granger causality	[15-17]

Week 8 2/29-3/4	Expectation-Maximization algorithm and application to learning neural encoding models	[13,18,19]
Week 9 3/7-3/11	Application to hippocampal dynamics, application to open-loop neural decoding	[13, 14, 20]
Week 10 3/21-3/25	Dynamic programming, Linear quadratic regulator, Linear Gaussian regulator	[21,22]
Week 11 3/28-4/1	Application to closed-loop neural prosthetic algorithms	[23-28]
Week 12 4/4-4/8	Application to closed-loop control of burst-suppression	[29]
Week 13 4/11-4/15	Student presentations	
Week 14 4/18-4/22	Student presentations	
Week 15 4/25-4/29	Student presentation	

REFERENCES

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

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

[3] J. M. Mendel, Lessons in Estimation theory for signal processing, communica- tions, and control. Prentice Hall NJ:, 1995.

[4] S. S. Haykin, Adaptive Filter Theory, Pearson Education India, 2005.

[5] R. E. Kalman, "A new approach to linear filtering and prediction problems," Journal of basic Engineering, vol. 82, no. 1, pp. 35–45, 1960.

[6] 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.

[7] E. N. Brown, “Theory of point processes for neural systems,” Les Houches, vol. 80, pp. 691–727, 2005.

[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.

[9] E. Brown, R. Barbieri, V. Ventura, R. Kass, and L. Frank, “The time-rescaling theorem and its application to neural spike train data analysis,” Neural compu- tation, vol. 14, no. 2, pp. 325–346, 2002.

[10] R. E. Kass and V. Ventura, “A spike-train probability model,” Neural computa- tion, vol. 13, no. 8, pp. 1713–1720, 2001.

[11] L. Paninski, J. Pillow, and J. Lewi, “Statistical models for neural encoding, decoding, and optimal stimulus design,” Progress in brain research, vol. 165, pp. 493–507, 2007.

[12] 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.

[13] A. Smith and E. Brown, “Estimating a state-space model from point process observations,” Neural Computation, vol. 15, no. 5, pp. 965–991, 2003.

[14] 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.

[15] M. Kamin´ski, M. Ding, W. Truccolo, and S. Bressler, “Evaluating causal relations in neural systems: Granger causality, directed transfer function and statistical assessment of significance,” Biological cybernetics, vol. 85, no. 2, pp. 145–157, 2001.

[16] 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.

[17] M. Okatan, M. Wilson, and E. Brown, “Analyzing functional connectivity using a network likelihood model of ensemble neural spiking activity,” Neural compu- tation, vol. 17, no. 9, pp. 1927–1961, 2005.

[18] 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.

[19] J. A. Bilmes et al., “A gentle tutorial of the em algorithm and its application to parameter estimation for gaussian mixture and hidden markov models,” Inter- national Computer Science Institute, vol. 4, no. 510, p. 126, 1998.

[20] R. Barbieri, L. Frank, D. Nguyen, M. Quirk, V. Solo, M. Wilson, and E. Brown, “Dynamic analyses of information encoding in neural ensembles,” Neural Com- putation, vol. 16, no. 2, pp. 277–307, 2004.

[21] D. Bertsekas, Dynamic Programming and Optimal Control. Athena Scientific, 2005.

[22] R. F. Stengel, Optimal control and estimation. Dover publications, 1994.

[23] V. Gilja, P. Nuyujukian, C. A. Chestek, J. P. Cunningham, B. M. Yu, J. M. Fan, M. M. Churchland, M. T. Kaufman, J. C. Kao, S. I. Ryu, and K. V. Shenoy, “A high-performance neural prosthesis enabled by control algorithm design,” Nat. Neurosci., vol. 15, pp. 1752–1757, Dec. 2012.

[24] A. L. Orsborn, S. Dangi, H. G. Moorman, and J. M. Carmena, “Closed-loop decoder adaptation on intermediate time-scales facilitates rapid bmi performance improvements independent of decoder initialization conditions,” IEEE Trans. Neural Syst. Rehabil. Eng., vol. 20, no. 4, pp. 468–477, Jul. 2012.

[25] M. M. Shanechi, R. C. Hu, M. Powers, G. W. Wornell, E. N. Brown, and Z. M. Williams, “Neural population partitioning and a concurrent brain-machine in- terface for sequential motor function,” Nat. Neurosci., vol. 15, no. 12, pp. 1715–1722, Dec. 2012.

[26] M. M. Shanechi, Z. M. Williams, G. W. Wornell, R. Hu, M. Powers, and E. N. Brown, "A real-time brain-machine interface combining motor target and trajec- tory intent using an optimal feedback control design," PLOS ONE, vol. 8, no. 4, p. e59049, Apr. 2013.

[27] M. M. Shanechi, R. C. Hu, and Z. M. Williams, "A cortical-spinal prosthesis for targeted limb movement in paralysed primate avatars," Nat. Commun., vol. 5, no. 3237, Feb. 2014.

[28] M. M. Shanechi and J. M. Carmena, "Optimal feedback-controlled point process decoder for adaptation and assisted training in brain-machine interfaces," in Proc. IEEE EMBS Conference on Neural Engineering (NER), San Diego, CA, Nov. 2013.

[29] M. M. Shanechi, J. J. Chemali, M. Liberman, K. Solt, and E. N. Brown, "A brain-machine interface for control of medically-induced coma," PLoS Comput. Biol., vol. 9, no. 10, p. e1003284, Oct. 2013.

Statement on Academic Conduct and Support Systems

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

A number of USC's schools provide support for students who need help with scholarly writing. Check with your advisor or program staff to find out more. Students whose primary language is not English should check with the *American Language Institute* http://dornsife.usc.edu/ali, which sponsors courses and workshops specifically for international graduate students. *The Office of Disability Services and Programs* http://sait.usc.edu/academicsupport/centerprograms/dsp/home_index.html provides certification for students with disabilities and helps arrange the relevant accommodations. If an officially declared emergency makes travel to campus infeasible, *USC Emergency Information* *http://emergency.usc.edu* will provide safety and other updates, including ways in which instruction will be continued by means of blackboard, teleconferencing, and other technology.