

Statistical Models of the Brain: Topics

1. **Overview of course: Statistical models of neural coding and human behavior**
2. ***Background:* Basic probability and statistics, including likelihood functions and maximum likelihood estimation**

Required reading, with comment, for non-computational students: Kass, Brown, Eden (KBE), Sections 3.1.4, 7.3.8–7.3.9, 5.2, 5.4.2–5.4.6, 5.5, 6, 8.1–8.3.
- 3a. ***Background:* More on maximum likelihood; statistical tests; ROC curves; likelihood ratio tests**

Required, with comment, for non-computational students: KBE 8.4, 10.4, 11.1.
- 3b. **ROC curves in human discrimination tasks**

Required, with comment: Swets, J.A. (1986) Form of empirical ROCs in discrimination and diagnostic tasks: Implications for theory and measurement of performance, *Psychol. Bull.*, 99: 181–198.
- 4a. **Power laws for stimulus intensity and learning time**

Required, with comment: Stevens, S.S. (1970) Neural events and the psychophysical law, *Science*, 170: 1043–1050.

Recommended additional reading: Newell, A. and Rosenbloom, P.A. (1981) Mechanisms of skill acquisition and the law of practice, in J.R. Anderson, ed., *Cognitive Skills and Their Acquisition*, pp. 1–56. *Read pages 1-19 and page 35*

Stevens, S.S. (1961) To honor Fechner and repeal his law, *Science*, 133: 80–86.
- 4b. **Neurons and the Hodgkin-Huxley model**

Required: Nicholls, Martin, Wallace, Fuchs, *From Neuron to Brain*, Chs 5-6.

Required for computational students: Gerstner on-line book (icwww.epfl.ch/~gerstner//SPNM/node12.html) sections 2.1-2.2.

5. Firing rate and neural coding

Required, with comment: Shadlen, M.N. and Newsome, W.T. (1998) The variable discharge of cortical neurons: implications for connectivity, computation, and information coding. *J. Neurosci.*, 18: 3870–3896. *Required up to Section 2, p. 3877; rest recommended.*

Recommended: Barlow, H.B. (1972). Single units and sensation: A neuron doctrine for perceptual psychology. *Perception*, 1: 371-394.

Parker, A.J. and Newsome, W.T. (1998) Sense and the single neuron: Probing the physiology of perception. *Ann. Rev. Neurosci.*, 21: 227–277.

Softky, W.R. and Koch, C. (1993) The highly irregular firing of cortical cells is inconsistent with temporal integration of random EPSPs. *J. Neurosci.*, 13: 334-350.

6. *Background:* Multiple regression and generalized regression

Required, with comment, for non-computational students: KBE 12.5, 14.1–14.4; 16.1-16.2.

7. Spike trains as point processes, part I: Poisson neurons

Required, with comment: KBE 19, through Section 19.2.2 *non-computational students may skip mathematical details.*

8. Spike trains as point processes, part II: Neurons with refractory periods, bursting, and other spike history effects

Required, with comment: Remainder of KBE 19, *non-computational students may skip mathematical details.*

9a. Matlab code for point process models

9b. Firing rate: Spike-triggered average and point process models

Required: Dayan and Abbott, *Theoretical Neuroscience*, pp. 19-21.

10. Integrate-and-fire neurons (Satish Iyengar)

Required: Koch, C. (1999) *Biophysics of Computation*, Chapters 14-15.

Recommended for computational students: Gerstner on-line book (node26).

11. **Neural variability, part I (Brent Doiron)**

Required: Stein, R.B., Gossen, E.R., and Jones, K.E. (2005) Neuronal variability: Noise or part of the signal? *Nature Rev. Neurosci.*, 6: 389–397.

Recommended: Doiron, B. (2010) The role of variability in populations of spiking neurons, in C. Laing and G.J. Lord, eds., *Stochastic Methods in Neuroscience*, Oxford U. Press, pp. 153–180.

12. **Neural variability, part II (Brent Doiron)**

Required and recommended, same as part I

13a. **Follow-up on multiplicative firing rate models**

Recommended: Kass, R.E. and Ventura, V. (2006) Spike count correlation increases with length of time interval in the presence of trial-to-trial variability, *Neural Comput.*, 18: 2583–2691.

Salinas, E., and Sejnowski, T.J. (2001) Gain modulation in the central nervous system: where behavior, neurophysiology, and computation meet, *Neuroscientist*, 7: 430–440.

13b. ***Background:* Bayes' Theorem and optimal classification**

Required: KBE, insert notes.

13c. **Rate coding versus temporal coding in the retina**

Required, with comment: Jacobs, A.L., Fridman, G., Douglas, R.M., Alam, N.M., Latham, P.E., Prusky, G.T., and Nirenberg, S. (2009) Ruling out and ruling in neural codes, *Proc. Nat. Acad. Sci.*, 106: 5936–5941.

14. **Information theory in neural coding, part I**

Required, with comment: KBE, insert notes.

Rieke, F., Warland, D., de Ruyter van Steveninck, R., Bialek, W. (1997) *Spikes: Exploring the Neural Code*, MIT Press. *Read pages 101–113, 148–156.*

Recommended: Optican, L.M. and Richmond, B.J. (1987) Temporal encoding of two-dimensional patterns by single units in primate inferior temporal cortex. III. Information theoretic analysis. *J. Neurophysiol.*, 57: 162–178.

15a. **Information theory in human behavior**

Required, with comment: Miller, G.A. (1956) The magical number seven, plus or minus two, *Psychol. Rev.*, 63: 343-355.

Recommended: Garner, W.R. and Hake, H.W. (1951) The amount of information in absolute judgments, *Psychol. Rev.*, 58: 446–59.

15b. **Information theory in neural coding, part II**

Required, with comment: Nirenberg, S., Carciari, S.M., Jacobs, A.L. and Latham, P.E. (2001) Retinal ganglion cells act largely as independent encoders, *Nature*, 411: 698–701.

Required for computational students: Vu, V.Q., Yu, B., and Kass, R.E. (2007) Coverage adjusted entropy estimation, *Statist. Med.*, 26: 4039–4060. *Read through section 3.2.*

16. **Background: Time series methods—autoregressive models and spectral analysis**

Required, with comment: KBE, 18, through section 18.3.

17. **Oscillations and functional connectivity**

Required, with comment: remainder of KBE, 18.

Brovelli A, Ding M, Ledberg A, Chen Y, Nakamura R, Bressler SL. (2004) Beta oscillations in a large-scale sensorimotor cortical network: Directional influences revealed by Granger causality. *Proc. Nat. Acad. Sci.*, 101:9849–9854.

18. (*note:* occurred before 16) **Background: Bayesian inference**

Required for non-computational students: KBE 15, through section 15.2.

19. **Population coding, part I: population vector and state-space models**

Required, with comment: Black, M.J. and Donoghue, J.P. (2007) Probabilistically modeling and decoding neural population activity in motor cortex, in G. Dornhege, J. del R. Millan, T. Hinterberger, D. McFarland, K.-R. Muller (eds.), *Toward Brain-Computer Interfacing*, MIT Press, pp. 147–159.

Recommended: Brockwell, A.E., Kass, R.E., and Schwartz, A.B. (2007) Statistical signal processing and the motor cortex, *Proc. IEEE*, 95: 881–898.

Georgopoulos, A.P., Lurito, J.T., Petrides, M., Schwartz, A.B., and Massey, J.T. (1989) Mental rotations of the neuronal population vector, *Science*, 243: 234–236.

Lewis, J.E. and Kristan, W.B. (1998) A neuronal network for computing population vectors in the leech, *Nature*, 391: 76–79.

20. **Population coding, part II: Dynamics of persistent neural activity (Byron Yu)**

Required: Brody, C.D., Romo, R., and Kepecs, A. (2003) Basic mechanisms for graded persistent activity: discrete attractors, continuous attractors, and dynamic representations, *Curr. Opinion Neurobiol.*, 13: 204–211.

Churchland, M.M., Yu, B.M., Sahani, M. and Shenoy, K.V. (2007) Techniques for extracting single-trial activity patterns from large-scale neural recordings. *Curr. Opinion Neurobiol.*, 17: 609–618.

Recommended: Yu, B.M., Afshar, A., Santhanam, G., Ryu, S.I., Shenoy, K.V., and Sahani, M. (2006) Extracting dynamical structure from embedded activity, *Advances in Neural Information Processing Systems*, 18: 1545–1552.

21. **Optimal observers in perception and action**

Required, with comment: Ernst, M.O. and Banks, M.S. (2002) Humans integrate visual and haptic information in a statistically optimal fashion, *Nature*, 415: 429–433.

Körding, K.P. and Wolpert, D.M. (2004) Bayesian integration in sensorimotor learning, *Nature*, 427: 244–247.

22. **Bayesian neural computation and its implementation**

Required, with comment: Knill, D. and Pouget, A. (2004) The Bayesian brain: the role of uncertainty in neural coding and computation, *Trends in Neurosci.*, 27: 712–719.

Ma, W.J., Beck, J.M., Latham, P.E., and Pouget, A. (2006) Bayesian inference of probabilistic population codes, *Nature Neurosci.*, 9: 1432–1438.

Recommended: Körding, K.P. and Wolpert, D.M. (2006) Bayesian decision theory in sensorimotor control, *Trends in the Cognitive Sciences*, 10: 320–326.

Salinas, E. (2006) Noisy neurons can certainly compute, *Nature Neurosci.*, 9: 1349–1350.

23. Semantic learning (Tom Mitchell)

Required: Haynes, J.D. and Rees, G. (2006) Decoding mental states from brain activity in humans, *Nat. Neurosci. Rev.*, 7: 523–534.

Mitchell, T.M., Shinkareva, S.V., Carlson, A., Chang, K.-M., Malave, V., Mason, R.A., and Just, M.A. (2008) Predicting human brain activity associated with the meanings of nouns, *Science*, 320: 1191–1195.

24. Sensory representation (Tai-Sing Lee)

Required: Barlow, H.B. (1961) Possible principles underlying the transformation of sensory messages, in W.A. Rosenblith, ed., *Sensory Communication*, MIT Press, pp. 217-234.

Simoncelli, E.P. and Olshausen, B.A. (2001) Natural image statistics and neural representation, *Ann. Rev. Neurosci.*, 24: 1193–1216.

25. Category learning, part I (Charles Kemp)

Required: Rosch, E. (1978). Principles of categorization. In E. Rosch and B. B. Lloyd (Eds.), *Cognition and categorization*. Hillsdale, NJ: Erlbaum.

Required for computational students: Griffiths, T. L., Sanborn, A. N., Canini, K. R., and Navarro, D. J. (2008). Categorization as nonparametric Bayesian density estimation. In M. Oaksford and N. Chater (Eds.). *The probabilistic mind: Prospects for rational models of cognition*.

26. Category learning, part II (Charles Kemp)

Required: as above, part I

27. (note: occurred before 24) **The role of synchrony**

Required, with comment: Engel AK, Fries P, Singer W (2001) Dynamic predictions: oscillations and synchrony in top-down processing. *Nature Reviews Neurosci.* 2: 704-716.

Uhlhaas, P.J., Pipa, G., Lima, B., Melloni, L., Neuenschwander, S., Nikoić, D., and Singer, W. (2009) Neural synchrony in cortical networks: history, concept, and current status, *Frontiers Integrative Neurosci.*, 3: DOI 10.3389/neuro.07.017.2009.

28. **Statistical detection of synchrony**

Required, with comment: Harrison, M., Amarasingham, A., and Kass, R.E. (2012) Statistical aspects of synchrony detection, in P.M. Di Lorenzo and J.D. Victor (eds.), *Spike Timing: Mechanism and Function*, CRC Press.

Required for computational students: Kass, R.E., Kelly, R.C., and Loh, W.-L. (2011) Assessment of synchrony in multiple neural spike trains using loglinear point process models, *Ann. Appl. Statist.*, 5, to appear.

28. **Neural correlation and synchrony (Matt Smith)**

Required: Averbeck, B., Latham, P.E., and Pouget, A. (2006) Neural correlations, population coding, and computation, *Nature Rev. Neurosci.*, 7: 358-366.

Smith, M.A. and Kohn, A. (2008) Spatial and temporal scales of neuronal correlation in primary visual cortex, *J. Neurosci.*, 28: 12591-12603.

Recommended: Kohn A, Zandvakili A, Smith MA (2009) Correlations and brain states: from electrophysiology to functional imaging. *Curr Opin Neurobiol*, 19: 434-438.

Cohen, M.R., Maunsell, J.H.R. (2009) Attention improves performance primarily by reducing interneuronal correlations. *Nature Neuroscience* 12:1594-1601.

29. **Graph theory for neural networks (Cosma Shalizi)**

Required: Bullmore, E. and Sporns, O. (2009) Complex brain networks: graph theoretical analysis of structural and functional systems, *Nature Rev. Neurosci.*, 10: 186-198.

Newman, M.E.J. (2003) The structure and function of complex networks, *SIAM Review*, 45: 167–256. *Read sections I, II, III, IVA, VI, VIIA, VIIB, VIIE, VIIIA, VIIIE; computational students also read sections IVB and V.*