UCSD Spring 2017 April 4, 2017
TTh 9:30-10:50 AM Center Hall 212 Terrence Sejnowski

BIPN 146: Computational Neurobiology

Course Text: *The Computational Brain*, P. S. Churchland and T. J. Sejnowski, 2nd edition, MIT Press (2017)

April 4	Introduction	Chapter 2
April 6	Neural Coding and Decoding	Chapter 3
April 11	Olfactory coding	Chapter 3
April 13	Retina	Chapter 4
April 15	Visual cortex	Chapter 4
April 17	Development of visual cortex	Chapter 5
April 18	Color vision	Chapter 4
April 20	Stereo and motion vision	Chapter 4
April 25	Attention	Chapter 4
April 27*	Space and Gaze (Dave Peterson)	Chapter 4
May 2*	*Midterm Exam*	
May 4	Working memory	Chapter 5
May 9	Motor cortex	Chapter 6
May 11	Central pattern generators	Chapter 6
May 16	Reinforcement learning	Chapter 5
May 18	Deep Learning	Chapter 5
May 23*	Neuromodulation (Samat Moldakarimov)	Chapter 5
May 25	Long-term memory	Chapter 5
May 30	Sleep rhythms	Chapter 5
June 1	Memory consolidation	Chapter 5
June 6	Resting states and default mode	Appendix
June 8	Course Holiday	

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Textbook (available at the campus bookstore):

P. S. Churchland and T. J. Sejnowski, *The Computational Brain*, 2nd ed. MIT Press (2017)

Background Texts:

Kandel, Schwartz and Jessell, *Principles of Neural Science*, 5th Ed., McGraw-Hill (2012)
Squire, Bloom, McConnell, Roberts, Spitzer and Zigmund, *Fundamental Neuroscience*, 4th Ed., Academic Press (2012)
Nicholls, Martin, Wallace and Fuchs, *From Neuron to Brain*, 4th Ed., Sinauer (2001).
Dayan and Abbott, *Theoretical Neuroscience*, MIT Press (2001)
Johnston and Miao-Sin Wu, Foundations of Cellular Neurophysiology (1994)

Course Goals:

This course will provide an introduction to a variety of computer modeling techniques being used to study brains at the systems level.

Course Requirements:

Students are expected to have a basic background in both neurobiology and mathematics; Calculus is an essential mathematical background and experience with differential equations in a physics or chemistry class is desirable.

Course Project: cnl.salk.edu/~terry/BIPN

This course project will count toward 20% of the final grade for the course.

The purpose of the project is to explore a question in neurobiology that can be approached from combined experimental and modeling approaches. You should read several papers in the area to get the background needed to prepare a critique of the computational models that have been developed in that area.

Choose one of the topic areas in the course readings. Read all the papers. Look up references to previous papers, particularly the experimental papers. Pick one of the articles identified with an asterisk (*) as the target article for your paper.

The paper should be no longer than 5 pages double spaced.

Imagine that you have been sent the paper by the journal and are asked to review the paper for publication. The format of the paper is a scientific review:

Required Sections:

1. Citation: Authors of the paper, Title of the paper, Journal, Volume, pages and year.

2. Summary – A brief, one paragraph overview stating the question being asked and the main results.

3. General Comments – Here are some examples of issues that could be addressed:
   a. Did the model provide an explanation for something that previously was unclear?
   b. What were the strengths and weaknesses of the model?
   c. How successful was the paper in answering the question being asked?
   d. What are the testable predictions?
   e How well organized is the presentation?
   f. What was the most successful and least successful parts of the paper?

4. Minor Comments – Details that could help with the presentation
   a. Can the figures be improved?
   b. Is the writing clear? If not, give examples of bad sentences.
   c. Were there technical terms that were not defined?
   d. Typos?

5. Grade: A = Publish after minor problems are corrected
   B = Requires re-review after revisions in response to the reviews
   C = Major revisions before the paper can be reconsidered
   D = Reject
   F = Submit to another journal

Papers are due on Tuesday, June 3, 2014

Exams and Grading:

There will be a midterm exam, a final exam, problems that will be covered in the sections, and a critique:

Midterm	30%
Final	30%
Sections	20%
Project	20%

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* Target articles for Class Project.
Non target papers are for background reading.

Neural networks

Bell, A. J.; Sejnowski, T. J.; An Information-Maximization Approach to Blind Separation and Blind Deconvolution, *Neural Computation*, 7, 1129-1159 (1995).

* Bell, A., J., and Sejnowski, T. J., The 'Independent components' of natural scenes are edge filters, *Vision Research*, 37(23) 3327-3338 (1997).

LeCun Y, Bengio Y, Hinton G., Deep learning. Nature. May 28: 436-44 (2015)

* Yamins DL, DiCarlo JJ. Using goal-driven deep learning models to understand sensory cortex. Nat Neurosci. 19(3): 356-65 (2016).

Neural coding and decoding

Haider, B., Krause, M.R., Duque, A., Yu, Y., Touryan, J., Mazer, J.A., and McCormick, D.A. Synaptic and network mechanisms of sparse and reliable visual cortical activity during nonclassical receptive field stimulation. Neuron 65, 107-121. (2010).

*Wang, H.P.; Spencer, D.; Fellous, J. M.; Sejnowski, T. J.; Synchrony of Thalamocortical Inputs Maximizes Cortical Reliability, *Science*, 328: 106-109, (2010)

Mainen, Z. F.; Sejnowski, T. J.; Reliability of Spike Timing in Neocortical Neurons, *Science*, 268, 1503-1506 (1995).

* Bialek W, Rieke F, de Ruyter van Steveninck RR, Warland D. Reading a neural code. *Science*. 252:1854-7 (1991).

Olfactory Coding

Broome, B. M., Jayaraman, V. and Laurent, G. Encoding and decoding of overlapping odor sequences. *Neuron* 51: 467-482 (2006).

* Murthy M, Fiete I, Laurent G. Testing odor response stereotypy in the Drosophila mushroom body. Neuron. 59(6):1009-23 (2008).

Stopfer M, Bhagavan S, Smith BH, Laurent G. Impaired odour discrimination on desynchronization of odour-encoding neural assemblies. *Nature*. 390:70-4 (1997).

* Bazhenov, M.; Stopfer, M.; Sejnowski, T. J.; Laurent, G. J.; Fast Odor Learning Improves Reliability of Odor Responses in the Locust Antennal Lobe, *Neuron*, 49, 483-492 (2005).

Retina

Takemura SY, Bharioke A, Lu Z, Nern A, Vitaladevuni S, Rivlin PK, Katz WT, Olbris DJ, Plaza SM, Winston P, Zhao T, Horne JA, Fetter RD, Takemura S, Blazek K, Chang LA, Ogundeyi O, Saunders MA, Shapiro V, Sigmund C, Rubin GM, Scheffer LK, Meinertzhagen IA, Chklovskii DB. A visual motion detection circuit suggested by Drosophila connectomics. Nature. 500:175-81, 2013

* Maisak MS, Haag J, Ammer G, Serbe E, Meier M, Leonhardt A, Schilling T, Bahl A, Rubin GM, Nern A, Dickson BJ, Reiff DF, Hopp E, Borst A. A directional tuning map of Drosophila elementary motion detectors. Nature. 500:212-6 2013

Field GD, Gauthier JL, Sher A, Greschner M, Machado TA, Jepson LH, Shlens J, Gunning DE, Mathieson K, Dabrowski W, Paninski L, Litke AM, Chichilnisky EJ. Functional connectivity in the retina at the resolution of photoreceptors. *Nature*. 467:673-677 (2010).

* Pillow JW, Paninski L, Uzzell VJ, Simoncelli EP, Chichilnisky EJ. Prediction and decoding of retinal ganglion cell responses with a probabilistic spiking model. *J. Neurosci.* 25:11003–13 (2005).

Visual cortex

Kandel, E. An introduction to the work of David Hubel and Torsten Wiesel, J Physiol. 592(Pt 1):1-11 (2014)

* Tsodyks, M. V. and Sejnowski, T. J., Rapid state switching in balanced cortical network models, *Network* 6, 111-124 (1995).

Mechler F. and Ringach, D. L., On the classification of simple and complex cells *Vision Research* 42, 1017-1033 (2002)

* Churchland, P. S.; Ramachandran, V. S.; Sejnowski, T. J.; A Critique of Pure Vision Koch, C.; Davis, J.; (Eds.), In: *Large-Scale Neuronal Theories of the Brain*, Cambridge, MA: MIT Press, 23-60, 1994

Development of Visual Cortex

Frank, M. G., Issa, N. P. & Stryker, M. P. Sleep enhances plasticity in the developing visual cortex. *Neuron* 30, 1-20 (2001).

Miller KD, Erwin E. Effects of monocular deprivation and reverse suture on orientation maps can be explained by activity-instructed development of geniculocortical connections. Vis Neurosci. 18(5):821-34. 2001

Stereo vision

Freeman, R. D. & Ohzawa, I. (1990). On the neurophysiological organization of binocular vision. *Vision Research, 30,* 1661-1676.

* Qian, N. and Zhu, Y. Physiological computation of binocular disparity. *Vision Research*, 37: 1811-1827 (1997).

Westheimer G. Optical superresolution and visual hyperacuity. Prog Retin Eye Res. 31(5):467-80. 2012

* Lehky, S. R. and Sejnowski, T. J., Neural model of stereoacuity and depth interpolation based on a distributed representation of stereo disparity, *Journal of Neuroscience* 10: 2281-2299 (1990).

Color vision

Wachtler, T.; Sejnowski, T. J.; Albright, T. D.; Representation of Color Stimuli in Awake Macaque Primary Visual Cortex, Neuron, 37, 681-691, 2003

* Wachtler T, Doi E, Lee T, Sejnowski TJ., Cone selectivity derived from the responses of the retinal cone mosaic to natural scenes. *Journal of Vision* 7(8):6. (2007)

Wachtler, T., Sejnowski, T. J., and Albright, T. D., Representation of Color Stimuli in Awake Macaque Primary Visual Cortex, *Neuron* 37, 681-691 (2003).

*Brainard, D. H., Longère, P., Delahunt, P. B., Freeman, W. T., Kraft, J. M., & Xiao, B. Bayesian model of human color constancy. *Journal of Vision*, *6*(11):10, 1267-1281 (2006).

Visual Motion

Britten KH, Shadlen MN, Newsome WT, Movshon JA. The analysis of visual motion: a comparison of neuronal and psychophysical performance. *Journal of Neuroscience*. 12: 4745-65. (1992)

* Nowlan, S. and Sejnowski, T. J., A selection model for motion processing in area MT of primates, *Journal of Neuroscience* 15, 1195-1214 (1995).

Rust, N. C Mante, V Simoncelli, E. P Movshon, J A, How MT cells analyze the motion of visual patterns, *Nature Neuroscience* 9, 1421 - 1431 (2006)

* M. Jazayeri and J. A. Movshon Optimal representation of sensory information by neural populations. *Nature Neuroscience* **9**, 690-696 (2006).

Space

Dobbins AC, Jeo RM, Fiser J, Allman JM. Distance modulation of neural activity in the visual cortex. *Science*. 281: 552-5. (1998)

* Pouget, A.; Sejnowski, T. J.; A Neural Model of the Cortical Representation of Egocentric Distance, *Cerebral Cortex*, 4, 314-329, (1994)

Andersen RA, Buneo CA., Intentional maps in posterior parietal cortex. *Annu Rev Neurosci.* 2002;25:189-220.

* Pouget, A., and Sejnowski, T. J., Simulating a lesion in a basis function model of spatial representations: Comparison with hemineglect, *Psychological Review*, 108: 653-673 (2001).

Gaze

Gittis AH, du Lac S., Intrinsic and synaptic plasticity in the vestibular system. Curr Opin Neurobiol. 16(4): 385-90 (2006)

* Porrill J, Dean P., Cerebellar motor learning: when is cortical plasticity not enough? PLoS Comput Biol. 3(10):1935-50 (2007).

Lisberger SG, Morris EJ, Tychsen L. Visual motion processing and sensory-motor integration for smooth pursuit eye movements. *Annu Rev. Neurosci*.10: 97-129 (1987)

* Lisberger SG, Internal models of eye movement in the floccular complex of the monkey cerebellum. Neuroscience. 162(3), 763-76 (2009)

Attention

Reynolds, J. H. and Chelazzi, L. Attentional Modulation of Visual Processing, *Annual Review of Neuroscience* 27: 611-647 (2004).

* Reynolds JH, Heeger DJ. The normalization model of attention. *Neuron* 61(2):168-85 (2009).

Fries P, Reynolds JH, Rorie AE, Desimone R. Modulation of oscillatory neuronal synchronization by selective visual attention. *Science*. 291(5508):1560-3 (2001).

* Jadi, M. P.; Sejnowski, T. J.; Cortical Oscillations Arise from Contextual Interactions that Regulate Sparse Coding, Proceedings of the National Academy of Sciences, USA, 111: 6780-6785 (2014)

Motor cortex

Aflalo, TN, Graziano MSA Possible origins of the complex topographic organization of motor cortex: reduction of a multidimensional space onto a two-dimensional array. *J. Neurosci*. 26: 6288-6297 (2006).

*Zhang, K.; and Sejnowski, T. J.; A Theory of Geometric Constraints on Neural Activity for Natural Three-Dimensional Movement, *Journal of Neuroscience*, 19(8), 3122-3145, (1999).

Brecht M, Schneider M, Sakmann B, Margrie TW. Whisker movements evoked by stimulation of single pyramidal cells in rat motor cortex. *Nature.* 427, 704-10 (2004).

* Velliste, M., Perel, S., Spalding, M. C., Whitford, A. S., and Schwartz, A. B. Cortical control of a prosthetic arm for self-feeding, *Nature,* 453: 1098 (2008).

Central pattern generators

Marder E and Calabrese RL Principles of rhythmic motor pattern production. *Physiological Reviews* 76: 687–717 (1996).

*Rowat PF; Selverston AI. Modeling the gastric mill central pattern generator of the lobster with a relaxation-oscillator network. *Journal of Neurophysiology* 70:1030-53 (1993).

Grillner A, Wallén P, Brodin L and Lansner A Neuronal network generating locomotor behavior in lamprey: circuitry, transmitters, membrane properties, and simulation. *Annual Review of Neuroscience* 14: 169–199. (1991).

*Ermentrout, G.B. and Kopell, N., Inhibition-produced patterning in chains of coupled nonlinear oscillators, *SIAM J. Appl. Math.* 54: 478-507 (1994).

Reinforcement learning

Sutton, R.S. and Barto A.G., Toward a modern theory of adaptive networks: expectation and prediction. *Psychol Rev*. 88:135-70 (1981).

*Montague PR, Dayan P, Person C, Sejnowski TJ. Bee foraging in uncertain environments using predictive hebbian learning. *Nature* 26;377(6551):725-8 (1995).

O'Doherty, J, Dayan, P, Friston, K, Critchley, H & Dolan, R Temporal difference models and reward-related learning in the human brain *Neuron* 38: 329-337. (2003).

*Montague, P. R.; Dayan, P.; Sejnowski, T. J.; A Framework for Mesencephalic Dopamine Systems Based on Predictive Hebbian Learning, *Journal of Neuroscience*, 16(5), 1936-1947 (1996).

Neuromodulation

Marder E. Neuromodulation of neuronal circuits: back to the future. Neuron. 4;76(1):1-11. 2012

* Hasselmo, ME Neuromodulation and cortical function: modeling the physiological basis of behavior Behavioural Brain Research 67: l-27 (1995)

Working memory

Durstewitz, D.; Seamans, J. K.; Sejnowski, T. J.; Neurocomputational Models of Working Memory, *Nature Neuroscience Supplement*, 3: 1184-1191, (2000)

*Murphy, B.K. and K.D. Miller Balanced amplification: A new mechanism of selective amplification of neural activity patterns. *Neuron* 61:635-648 (2009).

Pesaran B, Pezaris JS, Sahani M, Mitra PP, Andersen RA., Temporal structure in neuronal activity during working memory in macaque parietal cortex. Nat Neurosci. 5(8):805-11 (2002).

*Machens, C.K., R. Romo, and C.D. Brody. Flexible control of mutual inhibition: a neural model of two-interval discrimination. *Science* 307:1121–1124 (2005).

Long-term memory

McClelland, J. L., McNaughton, B. L., O'Reilly, R. C. Why there are complementary learning systems in the hippocampus and neocortex: Insights from the successes and failures of connectionist models of learning and memory. *Psychological Review*. 102(3): 419-457 (1995).

* Fusi, S., Drew, P. and Abbott, L.F. Cascade Models of Synaptically Stored Memories. *Neuron* 45:599-611 (2005).

Redondo, R.L., and Morris, R.G.M. Making memories last: the synaptic tagging and capture hypothesis. Nat Rev Neurosci *12*, 17–30 (2011).

* O'Donnell , C. and Sejnowski, T. J. Selective Memory Generalization by Spatial Patterning of Protein Synthesis, Neuron, 82, 398-412 (2014)

Sleep

Steriade, M., McCormick, D. A., Sejnowski, T. J., Thalamocortical oscillations in the sleeping and aroused brain, *Science* 262, 679-685 (1993).

* Bonjean, M.; Baker, T.; Bazhenov, M., Cash, S., Halgren, E.; Sejnowski , T.; Interactions between core and matrix thalamocortical projections in human sleep spindle synchronization, *Journal of Neuroscience*, 32: 5250-5263 (2012)

Tononi, G. and C. Cirelli. Sleep function and synaptic homeostasis. *Sleep Med. Rev.* 10: 49-62 (2006).

*Muller, L. Piantoni, S. Koller, D. Cash, S. S. Halgren, E. Sejnowski, T. J. Rotating waves during human sleep spindles organize global patterns of activity during the night, eLife, e17267.

Resting State

* Beckmann, C. F., DeLuca, M., Devlin, J. T., & Smith, S. M. (2005). Investigations into resting-state connectivity using independent component analysis. Philosophical Transactions of the Royal Society B-Biological Sciences, 360(1457), 1001-1013

Smitha KA, Akhil Raja K, Arun KM, Rajesh PG, Thomas [1], Kapilamoorthy TR, Kesavadas C. Resting state fMRI: A review on methods in resting state connectivity analysis and resting state networks. Neuroradiol J. 2017 Jan 1:1971400917697342

* Target articles for Class Project
Non * papers are for background reading