PSY 1401

Computational Cognitive Neuroscience: Building Models of the Brain

Fall 2016

T/Th 10-11:30am

Location: William James B6

Instructor: Sam Gershman, gershman@fas.harvard.edu

Office hours: M 4-5:30pm, W 9:30-11am (Northwest 295.05)

"What I cannot create, I do not understand." – *Richard Feynman*

Course description

This course applies Richard Feynman's dictum to the brain, by teaching students how to simulate brain function with computer programs. Special emphasis will be placed on how neurobiological mechanisms give rise to cognitive processes like learning, memory, decision-making, and object perception. Students will learn how to understand experimental data through the lens of computational models, and ultimately how to build their own models.

Prerequisites

Students should be comfortable with a numerical programming language (e.g. Python, Matlab, R) and have taken Science of Living Systems 20 (or equivalent) or MCB 80 before enrolling in this course, or obtain permission from the instructor. Familiarity with probability theory, linear algebra and calculus is useful but not required.

Course Requirements

Grading will be based on the following elements:

(1) Mini-projects (50%): in the second week of the course, students will be divided into groups of 3-4. Each group will be assigned a new mini-project typically every 2 weeks. Each mini-project involves implementing a computational model, simulating empirical phenomena, and making a presentation to the class that covers the simulations and empirical/theoretical background. Three groups will present each week. Each presentation will be allotted 20 minutes, plus 10 minutes for discussion; the presenters should pose several discussion questions at the end of their presentation.

(2) Final project (40%): students will carry out a computational modeling project in which they develop a new model of their choosing. Students must complete the project independently. The project can focus on any topic covered in the course. Each student will write a report (approximately 10 pages, single-spaced, 12pt font) covering the relevant background, the scientific question addressed by the project, simulations showing how the model captures a set of empirical phenomena, and novel experimental predictions made by the model. Students should meet with the instructor at least once before the last day of class to discuss their choice of final project. The final report is due on the first day of the examination period (December 10th).

(3) Reading responses and class participation (10%): every week, students will be given reading assignments. By 9pm on the night prior to the lecture, students should submit by e-mail a set of questions or comments about the reading (at least one question or comment per paper). These will be used as the basis for discussion in the lecture.

Grading Rubric

94-100 A	90-93 A-	87-89 B+	83-86 B
80-82 B-	77-79 C+	73-76 C	70-72 C-
67-69 D+	63-66 D	60-62 D-	Below 60 E (fail)

Academic Honor

You are expected to submit your own, original work for the exam and the final paper. Any misconduct will be reported, as is required by the college. Discussing your ideas with others and getting feedback on your work is encouraged, but you are required to cite any and all ideas that are not your own, and ensure that any assignments you turn in are your own writing and the result of your own research.

Accessibility

Any student needing academic adjustments or accommodations is requested to present their letter from the Accessible Education Office (AEO) and speak with the professor by the end of the second week of the term, (specific date). Failure to do so may result in the Course Head's inability to respond in a timely manner. All discussions will remain confidential, although AEO may be consulted to discuss appropriate implementation.

Class 1: Reverse engineering the brain

Thursday, 9/1/16

Readings:

- Marr, D. (1982). *Vision*. MIT Press. [Chapter 1]
- Daugman, J. (2001). Brain metaphor and brain theory. Chapter 2 in *Philosophy and the Neurosciences*, Bechtel et al. (Eds). Blackwell.
- Lazebnik, Y. (2002). Can a biologist fix a radio? *Cancer Cell, 2*, 179-182.
- [BONUS]: Brown, J. (2014). The tale of the neuroscientists and the computer: why mechanistic theory matters. Frontiers in Neuroscience.

Class 2: Principles of perceptual representation

Tuesday, 9/6/16

Readings:

- Olshausen, B.A. & Field, D.J. (1996). Emergence of simple-cell receptive field properties by learning a sparse code for natural images. *Nature, 381*, 607-609.
- Rao, R.P. & Ballard, D.H. (1999). Predictive coding in the visual cortex: a functional interpretation of some extra-classical receptive field effects. *Nature Neuroscience, 2*, 79–87.
- Lee, T.S. & Mumford, D. (2003). Hierarchical Bayesian inference in the visual cortex. *Journal of the Optical Society of America, A., 20*, 1434–1448.

Class 3: Object recognition

Thursday, 9/8/16

Readings:

- DiCarlo, J.J., Zoccolan, D., & Rust, N.C. (2012). How does the brain solve visual object recognition? *Neuron, 73*, 415-434.
- Edelman, S. (1997). Computational theories of object recognition. *Trends in Cognitive Sciences, 1*, 296-304.

Class 4: Perceptual decision making

Tuesday, 9/13/16

Readings:

- Gold, J.I. & Shadlen, M.N. (2007). The neural basis of decision making. *Annual Review of Neuroscience*, *30*, 535–574.

Class 5: Neuroeconomics

Thursday, 9/15/16

Readings:

- Fehr, E. & Rangel, A. (2011). Neuroeconomic foundations of economic choice—recent advances. *The Journal of Economic Perspectives*, *25*, 3-30.

Class 6: Mini-project presentations

Tuesday, 9/20/16

No readings

Class 7: Reinforcement learning

Thursday, 9/22/16

Readings:

- Schultz, W., Dayan, P., & Montague, P. R. (1997). A neural substrate of prediction and reward. *Science*, *275*, 1593–1599.
- Niv (2009). Reinforcement learning in the brain. *Journal of Mathematical Psychology*, *53*, 139-154.

Class 8: Mini-project presentations

Tuesday, 9/27/16

No readings

Class 9: Computational neuromodulation, part one: serotonin and dopamine

Thursday, 9/29/16

Readings:

- Dayan, P. (2012). Twenty-five lessons from computational neuromodulation. *Neuron*, *76*, 240-256.
- Cools, R., Nakamura, K., & Daw, N.D. (2011). Serotonin and dopamine: unifying affective, activational, and decision functions.*Neuropsychopharmacology*, *36*, 98-113.

Class 10: Mini-project presentations

Tuesday, 10/4/16

No readings

Class 11: Computational neuromodulation, part two: acetylcholine and norepinephrine

Thursday, 10/616

Readings:

- Yu, A.J. & Dayan, P. Uncertainty, neuromodulation, and attention. *Neuron*, *46*, 681–692.
- Newman, E.L., Gupta, K., Climer, J.R., Monaghan, C.K., & Hasselmo, M.E. (2012). Cholinergic modulation of cognitive processing: Insights drawn from computational models. *Frontiers in Behavioral Neuroscience*, *6*, 24.

Class 12: Mini-project presentations

Tuesday, 10/11/16

No readings

Class 13: Synaptic plasticity

Thursday, 10/13/16

Readings:

- Abbott, L.F., & Nelson, S.B. (2000). Synaptic plasticity: taming the beast. *Nature Neuroscience, 3*, 1178-1183.
- Gallistel C. R., Matzel L. D. (2012). The neuroscience of learning: beyond the Hebbian synapse. *Annual Review of Psychology,64*, 169–200.

Class 14: Mini-project presentations

Tuesday, 10/18/16

No readings

Class 15: Complementary learning systems

Thursday, 10/20/16

Readings:

- McClelland, J.L., McNaughton, B.L., & O'Reilly, R.C. (1995). 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*, 419–457.

Class 16: Mini-project presentations

Tuesday, 10/25/16

No readings

Class 17: Working memory

Thursday, 10/27/16

Readings:

- Ma, W.J., Husain, M., & Bays, P.M. (2014). Changing concepts of working memory. *Nature Neuroscience*, *17*, 347-56.

Class 18: Mini-project presentations

Tuesday, 11/1/16

No readings

Class 19: Time and space

Thursday, 11/3/16

Readings:

- Derdikman, D., & Moser, E.I. (2010). A manifold of spatial maps in the brain. *Trends in Cognitive Sciences*, *14*, 561-569.
- Buhusi, C.V., & Meck, W.H. (2005). What makes us tick? Functional and neural mechanisms of interval timing. *Nature Reviews Neuroscience*, *6*, 755-765.

Class 20: Mini-project presentations

Tuesday, 11/8/16

No readings

Class 21: Probabilistic inference in neural circuits

Thursday, 11/10/16

Readings:

- Buesing, L., Bill, J., Nessler, B., & Maass, W. (2011) Neural dynamics as sampling: A model for stochastic computation in recurrent networks of spiking neurons. *PLOS Computational Biology*, *7*, e1002211.
- Pouget, A., Beck, J.M., Ma, W.J., & Latham, P.E. (2013). Probabilistic brains: knowns and unknowns. *Nature Neuroscience*, *16*,1170-1178.

Class 22: Computational psychiatry

Tuesday, 11/15/16

Readings:

- Adams, R.A., Huys, Q.J.M., & Roiser, J.P. (2015). Computational Psychiatry: towards a mathematically informed understanding of mental illness. *Journal of Neurology, Neurosurgery & Psychiatry*.
- Pellicano, E. & Burr, D. (2012). When the world becomes 'too real': a Bayesian explanation of autistic perception, 504–510.
- Maia, T.V. & Frank, M.J. (2011). From reinforcement learning models to psychiatric and neurological disorders. *Nature Neuroscience*, *14*, 154–62.

Class 22: Cognitive control and metareasoning

Thursday, 11/17/16

Readings:

- Botvinick, M.M., & Cohen, J.D. (2014). The computational and neural basis of cognitive control: charted territory and new frontiers.*Cognitive Science*, *38*, 1249–1285.
- Gershman, S.J., Horvitz, E.J., & Tenenbaum, J.B. (2015). Computational rationality: A converging paradigm for intelligence in brains, minds and machines. *Science*, *349*, 273-278.

Class 23: From biological to artificial intelligence

Tuesday, 11/22/16

Readings:

- Lake, B.M., Ullman, T.D., Tenenbaum, J.B., & Gershman, S.J. (2016). Building machines that learn and think like people. *CBMM Memo 046*.

Class 24: Final project presentations

Tuesday, 11/29/16

No readings

Class 25: Final project presentations

Thursday, 12/1/16

No readings