Prerequisites

Students should be comfortable with a numerical programming language (e.g. Python, Matlab, R) and will ideally 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. Generally speaking, the goal is to make this course maximally accessible to students from diverse backgrounds, so please contact the instructor if you are uncertain.

Office hours

Sam Gershman (instructor): by appointment (gershman@fas.harvard.edu)

Yang Xiang (TF): by appointment (yyx@g.harvard.edu)

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. Each presentation will be allotted 20 minutes, plus 5 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 may complete the project independently or in groups. The project can focus on any topic covered in the course. Each group 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 must get approval of their project plan (a one paragraph description is sufficient) from either the instructor or the TF by April 12. Students will present a progress report on their projects during the last 2 days of class. The final report is due on the first day of the examination period (May 2).

(3) Class participation (10%): every week, students will be given reading assignments. Students are expected to be able to answer questions about these readings during lectures.

Lottery

In the event that the course is over-enrolled, there will be a lottery. Petitions will be accepted according to the following preference ordering: (i) Psychology and Neurobiology concentrators; (ii) applied math concentrators with a Psychology application area; (iii) students on the MBB track in any concentration; (iv) graduate students in Psychology or Neuroscience; (v) everyone else.

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+â€¨ 63-66 Dâ€¨ 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 Headâ€™s inability to respond in a timely manner. All discussions will remain confidential, although AEO may be consulted to discuss appropriate implementation.

Mini-projects

Group 1: Project 1, Project 2, Project 3, Project 4

Group 2: Project 1, Project 2, Project 3, Project 4

Group 3: Project 1, Project 2, Project 3, Project 4

Group 4: Project 1, Project 2, Project 3, Project 4

Group 5: Project 1, Project 2, Project 3, Project 4

Group 6: Project 1, Project 2, Project 3, Project 4

Class 1: Reverse engineering the brain

Monday, 1/22/24

Lecture slides

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.

Class 2: Principles of perceptual representation

Wednesday, 1/24/24

Lecture slides

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, 79â€“87.

Class 3: Object recognition

Monday, 1/29/24

Lecture slides

Readings:

DiCarlo, J.J., Zoccolan, D., & Rust, N.C. (2012). How does the brain solve visual object recognition? Neuron, 73, 415-434.

Class 4: Perceptual decision making

Wednesday, 1/31/24

Lecture slides

Readings:

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

Class 5: Neuroeconomics

Monday, 2/5/24

Lecture slides

Readings:

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

Class 6: Mini-project presentations

Wednesday, 2/7/24

No readings

Groups 1-3, Project 1

Class 7: Reinforcement learning

Monday, 2/12/24

Lecture slides

Readings:

Niv, Y. (2009). Reinforcement learning in the brain. Journal of Mathematical Psychology, 53, 139-154.

Class 8: Mini-project presentations

Wednesday, 2/14/24

No readings

Groups 4-6, Project 1

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

Wednesday, 2/21/24

Lecture slides

Readings:

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

Monday, 2/26/24

No readings

Groups 1-3, Project 2

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

Wednesday, 2/28/24

Lecture slides

Readings:

Yu, A.J. & Dayan, P. Uncertainty, neuromodulation, and attention. Neuron, 46, 681â€“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

Monday, 3/4/24

No readings

Groups 4-6, Project 2

Class 13: Synaptic plasticity

Wednesday, 3/6/24

Lecture slides

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, 169â€“200.

Class 14: Mini-project presentations

Monday, 3/18/24

No readings

Groups 1-3, Project 3

Class 15: Complementary learning systems

Wednesday, 3/20/24

Lecture slides

Readings:

McClelland, J.L., McNaughton, B.L., & Oâ€™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, 419â€“457.â€¨

Class 16: Mini-project presentations

Monday, 3/25/24

No readings

Groups 4-6, Project 3

Class 17: Working memory

Wednesday, 3/27/24

Lecture slides

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

Monday, 4/1/24

No readings

Groups 1-3, Project 4

Class 19: Time and space

Wednesday, 4/3/24

Lecture slides

Readings:

McNaughton, B.L. et al. (2006). Path integration and the neural basis of the 'cognitive map'. Nature Reviews Neuroscience, 7, 663-678.
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

Monday, 4/8/24

No readings

Groups 4-6, Project 4

Class 21: Probabilistic inference in neural circuits

Wednesday, 4/10/24

Lecture slides

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

Monday, 4/15/24

Lecture slides

Readings:

Huys, Q.J.M., Maia, T.V., & Frank, M.J. (2016). Computational psychiatry as a bridge from neuroscience to clinical applications. Nature Neuroscience, 19, 404-413.

Class 23: From biological to artificial intelligence

Wednesday, 4/17/24

Lectures slides

Readings:

Lake, B.M., Ullman, T.D., Tenenbaum, J.B., & Gershman, S.J. (2017). Building machines that learn and think like people. Behavioral and Brain Sciences, 40, e253.

Class 24: Final project presentations

Monday, 4/22/24

No readings

Groups 1-3

Class 25: Final project presentations

Wednesday, 4/24/24

No readings

Groups 4-6