Systems and Cognitive Neuroscience
(NEU 502A / PSY 502A / MOL 502A)

Spring 2025

Professor: Jonathan Cohen (jdc@princeton.edu)

AI: Alex Ku (alexku@princeton.edu)

Course Description

A survey of experimental & theoretical approaches to understanding how cognition arises in the brain. This complements NEU 501A, focusing on the mechanisms responsible for perception, attention, decision making, memory, cognitive & motor control, and planning, with emphasis on the representations involved & their transformations in the service of cognitive function. Source material will span neuroscience, cognitive science, & work on artificial systems. Relevance to neurodegenerative and neuropsychiatric disorders will also be discussed. This is the 2nd term of a double-credit core lecture course required of all Neuroscience Ph.D. students.

Course Structure

Lectures: M/Th 2-4:30

Format: the two classes each week will be divided into three parts: "orienting" lectures, a "deep dive" by a visiting lecturer, and a student paper presentation. There will be two orienting lectures by the course instructor (one each class); on Mondays, that will be followed by a deep dive lecture by another faculty member in PNI, and on Thursdays it will be followed by a student paper presentation.

Grading

Class participation: 50%
Paper presentation: 50%

Lectures and Readings

Note: The readings listed under each lecture are meant to be a resource, for additional background and/or deeper coverage of the material presented in the lectures. Asterisked readings are required.

Schedule

Week 1 ———————————

SECTION 1: SENSATION and PERCEPTION - INFERENCE and CONSTRAINT SATISFACTION

Class 1 (Monday Jan 27) — Overview / History and Methods in Cognitive Neuroscience / Constraint satisfaction, perceptual phenomena and attractor networks (Cohen)

*__Symbolic vs. Connectionist Models:__ Minsky, M. & Papert, S. (1988), *Perceptrons*. Cambridge, MA: MIT Press:

*Prologue, pp. vii-xv
Epilogue, pp. 247-281

***Parallel Distributed Processing (PDP)**. McClelland, J. and Rumelhart, D. (1986). *Parallel distributed processing: Explorations in the microstructure of cognition. Vol. 1: Foundations*. Cambridge, MA: MIT Press:

* Chapter 1. The appeal of parallel distributed processing, pp. 3-44
* Chapter 4. The PDP Framework for Information Processing, pp. 110-137
Chapter 2. A General Framework for Parallel Distributed Processing, pp. 45-76
Chapter 9. An introduction to linear algebra in parallel distributed processing, pp. 365-421

Spreading Activation Models. Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review*, 82, 407-428.

100 Step Challenge. Feldman, J. A., & Ballard, D. H. (1982). Connectionist models and their properties. *Cognitive Science*, *6*(3), 205-254.

Modularity and Generativity. Fodor, J. A. & Pylyshyn, Z. W. (1988) Connectionism and cognitive architecture: A critical analysis. *Cognition*, 28, 3-71

Modeling. McClelland, J. L. (2009). The place of modeling in cognitive science. *Topics in Cognitive Science*, *1*(1), 11-38.

* **Attractor networks**. Hopfield, J. J. (1982). Neural networks and physical systems with emergent collective computational abilities. *Proceedings of the national academy of sciences*, *79*(8), 2554-2558.

Perceptual Bistability. Gigante G, Mattia M, Braun J, Del Giudice P (2009) Bistable Perception Modeled as Competing Stochastic Integrations at Two Levels. *PLoS Computation Biology 5*(7): e1000430 [https://doi.org/10.1371/journal.pcbi.1000430]

Class 2 (Thursday Jan 30) — Visual processing and inference **(Pillow)** [IAC Model / Necker Cube]

* **The physiology of the retina.** Barlow, HB (1982). The senses, pp 102--113. Cambridge University Press.

* **Receptive fields of single neurones in the cat's striate cortex.** Hubel, DH & Wiesel, TN (1959). The Journal of Physiology, pp. 148, 574-591.

Possible principles underlying the transformation of sensory messages. Barlow, H (1961). Sensory Communication, Cambridge, MA: MIT Press. pp. 217-234.

Emergence of simple-cell receptive field properties by learning a sparse code for natural images. Olshausen BA & Field DJ (1996). *Nature*, 1996, 381, 607-609.

Week 2 ——————————————

Class 3 (Monday Feb 3) — Associative learning, feature maps and cortical organization **(Graziano)**
[Hebbian learning]

* **Semantic feature organization**. Kohonen, T. (1982). Self-organized formation of topologically correct feature maps. *Biological cybernetics*, *43*(1), 59-69.

* **Cortical Organization of representations**. Graziano, M. S., & Aflalo, T. N. (2007). Mapping behavioral repertoire onto the cortex. *Neuron, 56*(2), 239-251.

Occular Dominance Columns. Miller, K. D., Keller, J. B., & Stryker, M. P. (1989). Ocular dominance column development: Analysis and simulation. *Science, 245*, 605-615.

* **Hebbian Learning**. Hebb, D. O. (1949). *The Organization of Behavior.* Introduction, xi–xix; and Chapter 4: The first stage of perception: growth of an assembly, 60–78.

Biological Plausibility. Song, S., Miller, K. D., & Abbott, L. F. (2000). Competitive Hebbian learning through spike-timing-dependent synaptic plasticity. *Nature neuroscience*, *3*(9), 919.

Class 4 (Thursday Feb 6) — High level vision, object recognition and faces **(Gomez - 3:15)**

Week 3 ——————————————

SECTION 2: DECISION MAKING - INTEGRATION

Class 5 (Monday Feb 10) — Dynamics of integration and decision making **(Cohen)**
[TAFC tasks / DDM]

Class 6 (Thursday Feb 13) — Optimization of decision making (Cohen)

Week 4 ——————————————

SECTION 3: REINFORCEMENT LEARNING - REWARD and NEUROMODULATION

Class 7 (Monday Feb 17) — Reward systems, reinforcement learning, dopamine and basal ganglia **(Daw)**; drives, modularity and psychodynamics (Cohen)
[Predictive learning task / RL/TD]

Class 8 (Thursday Feb 20) — Explore/exploit and noradrenergic neuromodulation

Week 5 ——————————————

SECTION 4: SEMANTIC MEMORY - STATISTICAL LEARNING and DISTRIBUTED REPRESENTATION

Class 9 (Monday Feb 24) — Statistical learning, backprop, semantics and neocortex
[Rumelhart Network / BP]

Class 10 (Thursday Feb 27) — Bayesian approaches and bounded rationality (**Griffiths**)

Week 6 ———————————

Class 11 (Monday March 3) — Statistical learning and language processing **(Goldberg)**
[Size/Category judgment task / ISC Model]

Class 12 (Thursday March 6) — LLMs
[Semantic judgment tasks / ISC-CI Model] / [LLM Probing exercise]

Spring Break

Week 7 ———————————

SECTION 5: EPISODIC MEMORY - BINDING

Class 13 (Monday March 17) — Complementary learning systems and hippocampal function / oscillatory inhibition, sleep and PTSD **(Norman)**

Class 14 (Thursday March 20) — Binding and abstraction
[ART tasks / ESBN]

Week 8 ———————————

SECTION 6: ATTENTION, WORKING MEMORY AND COGNITIVE CONTROL - MODULATION

Class 15 (Monday March 24) — Selective attention, automaticity and control
[Stroop Model]

Class 16 (Thursday March 27) — Working memory, oscillatory dynamics and prefrontal function **(Buschman)**

Week 9 ———————————

Class 17 (Monday March 31) — Multitasking, shared vs. separated representations, compositional vs. conjunctive coding, capacity constraints, and Miller's Law [Multitasking network / EGO Model]

Class 18 (Thursday April 3) — Optimization and control - EVC [Sequential adjustment effects / EVC model]

Week 10 ———————————

SECTION 7: MOTOR FUNCTION

Class 19 (Monday April 7) — Motor representations, compositionality, and dynamics **(Graziano / Buschman)**

Class 20 (Thursday April 10) — Motor control, learning and cerebellar function **(Taylor)**

Week 11 ———————————

SECTION 8: DEVELOPMENT and SOCIAL COGNITION

Class 21 (Monday April 14) — Development

Class 22 (Thursday April 17) — Social cognition **(Hasson)**

Week 12 ———————————

SECTION 9: DISORDERS

Class 23 (Monday April 21) — Cognitive Neuropsychology **(Kastner)**

Class 24 (Thursday April 24) — Origins of Computational Psychiatry (Cohen) / Modern Computational Psychiatry **(Niv)**