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NEUR 391.01: Neural Systems of Behavior & Cognition

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NEUR 391 (future: 381) -- Neural Systems of Behavior & Cognition

Spring 2022 (3 credits)

Lectures: Tuesday/Thursday 1-2:20 pm, Chemistry 102
https://umontana.zoom.us/j/95205302577?pwd=YUZHa0dXVXRmaG5ZdlpnNWlyWUVLQT09
(Meeting ID: 952 0530 2577, Passcode: 944371)

Contact Information

Instructor: Nathan Insel (nathan.insel@umontana.edu)

Office Hours:

In person: by appointment only (see "COVID-19 accommodations" below)
Zoom: Mondays 10 to 11:30, https://umontana.zoom.us/j/99275418068 and by appointment

Course Description

How does a collection of cells signaling to one-another give rise to movement, perception, emotion, thought… even consciousness? We can think of each neuron, and each group of neuron, as a machine that converts inputs into outputs. In other words, we can think of these parts of the nervous system, and the brain itself, as "computing". The field of **systems neuroscience** addresses how neurons work together as a computing system. This means learning not only about the structure of the system, but also its physiology, and considering these with reference to functions for behavior and cognition.

The present course will provide a survey of knowledge and concepts in systems neuroscience. The class is roughly divided into 3 sections. The first section focuses on basic principles of how neuron circuits work (e.g., diverse functions of inhibitory neurons, neuromodulation, and oscillations). The second section on mechanisms of cognition (perception, decisions, space, time, memory, emotion), and the final section will elaborate more on how neural systems are studied, how systems-level approaches might be used to treat pathologies, and assorted other topics (e.g., student presentations, social cognition). Please note that the course covers only a *minimum* of early sensory and motor systems, but these are addressed in more depth in PSYX 250 and NEUR 281. In general, this class is intended to build on the foundations offered by PSYX 250 or NEUR 280/281 (*Spring 2022: since both NEUR 281 and 381 are new courses, it is understood that that students will have taken NEUR 280 or PSYX 250, but not NEUR 281*).

Reading Material

- This course has no textbook! Systems neuroscience has evolved rapidly over the past 50 years, with changes every few years in what is considered "foundational". There are currently no textbooks which properly cover the "bare essentials". Lecture slides will be provided on Moodle, and I will be recommending readings and handouts that relate to the lecture material as we go. Most importantly: take good notes, read the notes, understand them, and ask many questions!

Course Evaluation

Evaluation in this course will involve 3 graded items, as follows:

- A final exam (worth 40% of your final grade)
- A midterm test (worth 30% of your final grade)

- An oral presentation on a topic relevant to the course, along with participation in oral presentation Q&A (worth 30% of your final grade)

The **oral presentation** will be a short (~10 minutes) slide presentation on a topic of your choosing related to systems/behavioral/cognitive neuroscience. You will be required to choose a topic by March 10^{th} and email the instructor. The instructor will find an accessible journal article related to that topic to base your presentation on. OR, if you already have a journal article (or more than one) please email the instructor for approval. The presentations will be given toward the end of the term (see course outline, below).

For inspiration, here is a short list of possible example topics for presentation:

- How the brain perceives music
- Neurophysiology of dreaming
- Circuit/network changes in Alzheimer's Disease
- Estrogen effects on neural circuits/systems
- *Any course-relevant topic of interest to you*

Course Policies

General

Success in this class will depend on your attendance. We understand there will be circumstances beyond your control that require you to occasionally leave class early or be absent. Please plan accordingly by notifying the instructor before class. You should always feel free to ask any questions in class. Also, please feel comfortable approaching the instructor during office hours or over email about any classroom issue.

Drop Date

Policies on dropping can be found online (http://www.umt.edu/registrar/students/dropadd.php). Beginning the 46^{th} instructional day of the semester through the last day of instruction before scheduled examinations, students must petition to drop.

Academic Misconduct

All students must practice academic honesty. Academic misconduct is subject to an academic penalty by the course instructor and/or a disciplinary sanction by the University. All students need to be familiar with the Student Conduct Code (http://www.umt.edu/vpsa/policies/student_conduct.php).

Accommodation and Accessibility

UM assures equal access to instruction through collaboration between students with disabilities, instructors, and the Office for Disability Equity (ODE). If you anticipate or experience barriers based on disability, please contact ODE at: 243-2243, ode@umontana.edu, or visit www.umt.edu/disability for more information. Retroactive accommodation requests will not be honored, so please don't delay. As your instructor, I will work with you and ODE to implement an effective accommodation, and you are welcome to contact me privately if you wish.

Course Outline

Date	Lecture topic	Core concepts (subject to change)	Optional readings
Jan 18th	1. Explain the mem-brain	Levels of abstraction; computation, mechanism, function; top down vs bottom up explanations; structure vs. dynamics; consequences vs. evolution	**Recent, in-depth examination of "levels of analysis":** Love BC, Levels of biological plausibility *Phil Trans Biol* 2021 (On Moodle, abstract and intro in particular)
Jan 20th	2. Computation by single neuron: The XOR conundrum.	neural encoding/representation, McCulloch & Pitts neurons, Boolean logic, non-linear summation	**Recent news article on non-linear computing in neurons:** https://www.quantamagazine.org/neural-dendrites-reveal-their-computational-power-20200114/ **More in-depth description on McCulloch & Pitts neurons:** https://towardsdatascience.com/mcculloch-pitts-model-5fdf65ac5dd1
Jan 25	3. Plasticity: neurons change their tune	Short-term plasticity, long term potentiation (LTP), neurogenesis, growth cones and pruning, critical periods	**Short overview of short and long-term synaptic plasticity:** https://nba.uth.tmc.edu/neuroscience/s1/chapter07.html **In depth look at plasticity in brain development:** https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3222570/
Jan 27th	3. What are neural circuits?	Excitatory vs. inhibitory neurons, projection neurons vs. interneurons, feedback vs. feedforward signals, circuit motifs, measuring circuits with wires or cameras	**Short, instructor-authored handout:** Neural circuits handout (on Moodle)
Feb 1st	4. Inhibition and inhibition	subtraction and division, global inhibition, lateral inhibition, gain control, disinhibition,	See above handout
Feb 3rd	5. Stable and unstable states	attractors, head direction, working memory	See above handout
Feb 8th	7. Neuromodulation	modulation, acetylcholine, norepinephrine, signal-to-noise, changing circuits, "neuroendocrine"	**Detailed review n neurobiology of neuromodulation:** Marder, Neuron, 2012 **Detailed review of neuromodulation in attention:** ThieleBellgrove, Neuron, 2018
Feb 10th	8. Rhythms: What's in a wave?	From ripples to circadian cycles: how do waves form, and how might they organize thought? Lokta Voltera, central pattern generators, intrinsic vs inherited oscillations, cell vs. circuit oscillations, circadian rhythms, gamma, theta	**Review of rhythms in the brain (pages 345-351 valuable, subsequent pages more for details):** Buzsaki and Watson, Brain rhythms and neural syntax: implications for efficient coding of cognitive content and neuropsychiatric disease. 2012

Feb 15th	review/catch-up/activities	TBA	
Feb 17th	9. Where in the brain represents Carmen Sandiego?	Parsing the brain: brainstem, thalamus, hypothalamus, cortex , direction terminology, concept of encoding/representation, convergence and divergence of information, tuning curves	**Brief overview of brain anatomy:** https://www.hopkinsmedicine.org/health/conditions-and-diseases/anatomy-of-the-brain **Detailed review of "neural coding":** Stanley, Reading and Writing the Neural Code. *Nature Neuroscience,* 2013
Feb 22nd	10. Perception/cognition: the temporal lobe and "what"	"ventral" pathway (focus on vision), thalamus, temporal lobe, bottom-up and top-down signaling, view invariance, fusiform face area, semantic net	**Review of "sparse coding" in human temporal lobe:** Quiroga et al., TICS 2008
Feb 24th	11. Perception/cognition: the parietal lobe and "where"	"dorsal" pathway (focus on vision), parietal lobe, proprioception, optic flow, "coordinate transformations" (eye, head, body, hand), hemineglect, spatial attention	**Detailed review on space in the parietal lobe:** Kravitz & Mishkin, Nature Reviews of Neuroscience 2011
Mar 1st	12. Which came first, the action or the "where"?	Motor cortex, pre-motor cortex, corollary discharge, saccades, superior colliculus	**Brief overview of the cortical motor system (with animations):** https://nba.uth.tmc.edu/neuroscience/m/s3/chapter03.html
Mar 3rd	13. Where am I?	Place cells, grid cells, head direction cells, distance cells, path integration ("dead reckoning"), the cognitive map, space versus time, hippocampus, medial entorhinal cortex, retrosplenial cortex	**Detailed review on "allocentric" space in the brain:** Grieves & Jeffery, The representation of space in the brain. Behavioral Processes. 2017
Mar 8th	**Term Test**		
Mar 10th	14. Decisions and motivation	Decisions as binary choices, exploration versus exploitation, the basal ganglia direct and indirect pathways, dopamine	**2-min introductory videos on direct & indirect Basal Ganglia pathways:** https://www.youtube.com/watch?v=c-mhDChCD4Y https://www.youtube.com/watch?v=RzcXkvxXKEQ
Mar 15th	15. Associative memory and the hippocampus	Hebb-Marr network (McNaughton parlor game), brain hierarchy, pattern completion vs. pattern separation, memory consolidation	
Mar 17th	16. Taming time and guessing the future with	Hippocampal sharpwave-ripples (navigation, consolidation), prefrontal working memory correlates (robustness against	**Detailed review of sharpwave-ripples:** Joo & Frank, Nature Reviews Neuroscience, 2018

	hippocampus and prefrontal cortex	interruption), ramping activity, mental time travel (e.g., regret/fictive reward), temporal context correlates in lateral entorhinal cortex	**Detailed review of working memory in the brain:** Miller et al., Working Memory 2.0 Neuron 2018
Mar 22th / Mar 24th	**SPRING BREAK, Woohoo!**		
Mar 29th	17. Sleep & cognition	sleep stages & learning, memory consolidation/reprocessing, sleep inertia, REM and forgetting, insight	**Detailed review of sleep and creativity:** Lewis et al., TICS 2018
Mar 31st	18. Reinforcement learning	Supervised versus unsupervised learning, type of supervisors, examples in the brain (cerebellum, striatum), computer neural networks (perceptrons and deep networks)	**Detailed review on learning systems in the brain:** Califiore et al., The super-learning hypothesis: integrating learning processes in the cortex, cerebellum, and basal ganglia Neur & biobehav reviews 2019
Apr 5th	19. The science of feelings	Viscerosensory, visceral control, hierarchy (reflexes, hypothalamus, amygdala (including basolateral and central nuclei), ventral medial prefrontal cortex, hippocampus	**Review of history of theories on emotion in the brain:** Dalgleish, The emotional brain Nature Reviews Neuroscience, 2004
Apr 7th	review/catch-up/activities	TBA	
Apr 12th	20. What's social about social neuroscience?	"middle" sensory pathway, theory of mind & the STS, empathy, roles of insular cortex, amygdala, anterior cingulate cortex, oxytocin & vasopressin, serotonin and social reward, testosterone, estrogens & cortisol modulation of prosocial behavior	Handout?
Apr 14th	21. Measuring, manipulating, and modeling nervous systems	Human neuroimaging—including fMRI, brain-wide networks, and brain variance. Optogenetics & chemogenetics. Engram tagging and stimulation	
Apr 19th	22. Drugs at the systems level	opioids, cannabinoids, psychedelics, dopamine	**Detailed review of current knowledge on neurobiology of psychedelics:** Vollenweider and Preller, Psychedelic drugs: neurobiology and

			potential treatment of psychiatric disorders. *Nature*, 2020
Apr 21st	23. Treating disease at the circuit/systems level	Electrical neurostimulation versus pharmacological neuromodulation, gene therapy & chemogenetics	
Apr 26th	**Student presentations**		
Apr 28th	**Student presentations**		
May 3rd	24. Externalized thought: from markings to the AI revolution	TBA	
May 5th	**Final exam (to lecture 23)**		

Course Learning Outcomes

1) Understand the meaning of "mechanism", "function", and computation in the context of neuroscience.
2) Understand the link between how neurons are connected and what they compute.
3) Know different forms of synaptic plasticity, and how plasticity changes in development.
4) Understand basic principles of neural circuits, including the meaning of "circuit motif" and be able to identify several examples of motifs and their function.
5) Know several different classes of inhibitory interneuron types, and link these to circuit-level function.
6) Understand what is meant by "stable activity patterns" (or "attractor states") in networks with recurrent excitatory connections.
7) Understand what is meant by "neuromodulation", and be able to link specific neurotransmitter neuromodulators with circuit and behavioral functions.
8) Understand the mechanisms and functions of different types of oscillations found in the brain.
9) Be able to describe features of "ventral stream" processing of perceptual information, including subregions of the temporal lobe and how "top-down" signals are combined with "bottom-up".
10) Be able to describe features of dorsal-stream processing of perceptual information, including the meaning of "coordinate transformations".
11) Understand the importance of movement and action for brain organization, perception, and cognition.
12) Know the regions and processes associated with "allocentric space", including how directions and spatial maps are represented in the brain.
13) Understand how decisions are built from both learned behaviors and through processing of prospective/retrospective information.
14) Understand the basic properties of associative memory networks, including pattern completion and pattern separation and how these may be supported by the hippocampus.
15) Understand the different ways in which prefrontal cortex and hippocampus may help the brain process the past and future.
16) Understand how memories are processed during different stages of sleep (e.g., through reactivation).
17) Understand what is meant by "reinforcement learning", and how the brain implements reinforcement learning.
18) Understand how regions like the ventral striatum, ventral prefrontal cortex, and ventral hippocampus, and amygdala interact with the hypothalamus and brainstem to support emotions.
19) Be able to identify where and what processes in the brain are associated with social perception, social reward, social memory, and social actions (such as vocalizations).
20) Know some of the primary methods used to study systems neuroscience, including their applications to monitoring, manipulating, and modeling the nervous system.
21) Understand how different chemicals or stimulation methods can help treat or alter brain states at the systems level.
22) Have a basic understanding of how animals and humans alter their bodies and their environments to offload cognition.