Biologically Intelligent eXploration (BIX)

CMU 85-435 & 85-735

Instructor Info

Tim Verstynen PhD

Thursdays 2:45-3:30pm

335G Baker Hall

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Course Info

Prereq: 85-213/221 & 21-111/120/115

Tues & Thurs

1:25-2:45pm EST

336B Baker Hall & Zoom

TA Info

Jack Burgess

TBD

tbd

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Overview

The drive to explore is fundamental in all intelligent life. Bees wander into new meadows. Mice engage in social play. Cephalopods explore novel objects. Children find bugs on playgrounds and adults send robots to explore other planets. The tangible benefits of these actions are usually unknown at first and, in some cases, the outcome can even be harmful (e.g., coming across a predator, injury, loss of money). Yet they are taken anyway, simply to understand. This "impulse towards better cognition", as William James called it, has stymied researchers since the advent of psychology, despite it capturing the attention of some of the most consequential scientists in the field.

Classes will be a mixture of lectures, open discussions, and interactive lab tutorials, focused on understanding the neural, behavioral, and computational processes that drive intelligent exploration.

Topics include (but are not limited to):

- Levels of analysis
- Models of optimal decision making
- Foraging
- Curiosity
- Reinforcement learning
- Markov decision processes
- Cortical & subcortical circuits of decision making

Learning Objectives

This course is primarily designed to get at the fundamental cognitive and neural processes of decision-making and learning that drive exploration.

Successfully meeting the objectives of this course will allow you to learn:

1. To evaluate and communicate research from cognitive science and neuroscience.
2. To guide content discussions.
3. To critically analyze computational models at multiple levels of analysis.
4. To think critically about both theoretical and empirical material.

Materials

Class Github Repository

`https://github.com/CoAxLab/BiologicallyIntelligentExploration`

Other Readings

Any required journal articles and book chapters will be provided on Canvas.

Tutorial notebooks

All tutorials will be provided as Jupyter notebooks on the class Github repository.

Lectures

Any in class lectures/slides will be posted on Canvas ahead of class discussions.

Necessary Tools

- A computer
- A Github account
- Jupyter notebooks

FAQs

Do I need to know how to program?

Some experience with python is helpful, but otherwise you'll learn the coding you need along the way.

Can I use my own data for the final project?

The final project is meant to be something that interests you. So please feel free to use your own data (so long as you have the appropriate permissions to use the data).

What is the best way learn?

Be curious. That's the optimal way to explore when coming into a new topic with little background. Let your curiosity run wild.

What does it mean to explore?

Exploration means to seek to understand the unknown.

Grading

30%	Homework
30%	Discussion Answers
10%	Participation
30%	Final Project

Homework

Homework will be designed to evaluate retention of the core skills and concepts shown in the lectures, labs, and dicussions. Homework will be submitted as links to Jupyter notebooks posted on each student's Github account.

Discussion Answers

Each non-lab class is centered on a question that we will address via an open-ended discussion. At the end of these discussions I would like to hear your answers *constrained on the reading(s) and in class discussion.* Answers should be in the form of 1-2 short paragraphs outlining your "take home message". This should be submitted no later than 24 hours after class time.

Participation

Since this lab is a collective endeavor that relies on discussing the core material, your attendance participation will be a critical part of your evaluation. Missing more than 3 classes or regularly not engaging in classroom discussions (including brief answers to directed questions), will result in a 0% for the Participation grade.

Final Project

At the end of the semester, you present a final project consisting of a computationally oriented project connected to one or more of the topics discussed in class. In some cases this may be related to a research project outside of class (e.g., a masters theses). The final project will be presented, in class, as Jupyter notebooks accessible on GitHub. Final projects must be presented in class at the end of the semester and submitted as a link to a Jupyter notebook on the your Github account by 12 pm EST on the last day of classes.

Your final project topic must be approved by the instructor no later than Oct. 13th, 2022.

Late Work Policy

There is a 10% penalty per week for late homework assignments (e.g., 2 weeks late means 20% penalty). Homework submitted 3 weeks after original deadline or after the last day of the semester (whichever comes first) will not be accepted. Discussion answers submitted more than 24hrs of the in-person class time will not receive credit. Final projects submitted after the deadline will receive a 10% penalty and any project not submitted within 24hrs of the deadline will not receive any credit.

Academic Integrity

Cheating and plagiarism are defined in the CMU Student Handbook, and include (1) submitting work that is not your own for papers, assignments, or exams; (2) copying ideas, words, or graphics from a published or unpublished source without appropriate citation; (3) submitting or using falsified data; and (4) submitting the same work for credit in two courses without prior consent of both instructors. Any student who is found cheating or plagiarizing on any work for this course will receive a failing grade for that work. Further action may be taken, including a report to the dean.

Equal Opportunity Accommodations

All efforts will be made to minimize conflict with students' religious schedules (e.g., holidays, prayer services, etc.) and/or any disabilities. Students should consult with the Equal Opportunity Services (EOS) office at the beginning of the semester in order to setup any necessary accommodations for the class.

Respect in the Classroom

It is my intent to present materials and activities that are respectful to the diverse backgrounds and perspectives of students in the classroom. You may feel free to let me know ways to improve the effectiveness of the course for you personally or for other students or student groups. If you feel uncomfortable discussing this with me or your TA, you may voice your concerns to the Chair of the Department of Psychology Diversity, Equity, and Inclusion Committee, Kody Manke *kmanke@andrew.cmu.edu*.

Self Care

Do your best to maintain a healthy lifestyle this semester by eating well, exercising, avoiding drugs and alcohol, getting enough sleep and taking some time to relax. This will help you achieve your goals and cope with stress.

- All of us benefit from support during times of struggle. You are not alone. There are many helpful resources available on campus and an important part of the college experience is learning how to ask for help. Asking for support sooner rather than later is often helpful.
- If you or anyone you know experiences any academic stress, difficult life events, or feelings like anxiety or depression, we strongly encourage you to seek support. Counseling and Psychological Services (CaPS) is here to help: call 412-268-2922 and visit their website at `http://www.cmu.edu/counseling/`. Consider reaching out to a friend, faculty or family member you trust for help getting connected to the support that can help.

Class Schedule

Week 1	What is the brain if not exploration perservering?	Turner, C. H. (1909). The behavior of a snake. Science, 30(773), 563-564.
	How do we understand an intelligent system?	Krakauer, J. W., Ghazanfar, A. A., Gomez-Marin, A., MacIver, M. A., & Poeppel, D. (2017). Neuroscience needs behavior: correcting a reductionist bias. Neuron, 93(3), 480-490. van Rooij, I., & Baggio, G. (2021). Theory before the test: How to build high-verisimilitude explanatory theories in psychological science. Perspectives on Psychological Science.
Week 2	What is the goal of life?	Vlastelica M. (2019). Learning Theory: Empirical Risk Minimization. Towards Data Science. PAC learning. Wikipedia. Valiant, L. G. (2009). Evolvability. Journal of the ACM (JACM), 56(1), 1-21.
	How and why does the brain evolve?	Cisek, P. (2019). Resynthesizing behavior through phylogenetic refinement. Attention, Perception, & Psychophysics, 81(7), 2265-2287.
Week 3	How do you explore without a brain?	Reid, C. R., Latty, T., Dussutour, A., & Beekman, M. (2012). Slime mold uses an externalized spatial "memory" to navigate in complex environments. Proceedings of the National Academy of Sciences, 109(43), 17490-17494. Huo, H., He, R., Zhang, R., & Yuan, J. (2021). Swimming Escherichia coli Cells Explore the Environment by Lévy Walk. Applied and Environmental Microbiology, 87(6), e02429-20.
	How do we get meaning from information?	Dretske, F. I. (1983). Précis of Knowledge and the Flow of Information. Behavioral and Brain Sciences, 6(1), 55-63..
Week 4	How do we extract signal from noise?	Stanislaw, H., & Todorov, N. (1999). Calculation of signal detection theory measures. Behavior research methods, instruments, & computers, 31(1), 137-149.
	How do you use evidence to make a decision?	Gold, J. I., & Shadlen, M. N. (2007). The neural basis of decision making. Annu. Rev. Neurosci., 30, 535-574.
Week 5	Does the cortex make a decision?	Churchland, A. K., Kiani, R., & Shadlen, M. N. (2008). Decision-making with multiple alternatives. Nature neuroscience, 11(6), 693-702. Latimer, K. W., Yates, J. L., Meister, M. L., Huk, A. C., & Pillow, J. W. (2015). Single-trial spike trains in parietal cortex reveal discrete steps during decision-making. Science, 349(6244), 184-187.
	Does the subcortex make a decision?	Bogacz, R., & Larsen, T. (2011). Integration of reinforcement learning and optimal decision-making theories of the basal ganglia. Neural computation, 23(4), 817-851.

		Dunovan, K., Lynch, B., Molesworth, T., & Verstynen, T. (2015). Competing basal ganglia pathways determine the difference between stopping and deciding not to go. Elife, 4, e08723.
Week 6	What good is the world in your head?	Ha, D., & Schmidhuber, J. (2018). World models. arXiv preprint arXiv:1803.10122.
	How do concepts relate to each other?	Sims, C. R. (2018). Efficient coding explains the universal law of generalization in human perception. Science, 360(6389), 652-656.
		Sorscher, B., Ganguli, S., & Sompolinsky, H. (2021). The geometry of concept learning. bioRxiv.
Week 7	Are concepts anchored in space?	Whittington, J. C., Muller, T. H., Mark, S., Chen, G., Barry, C., Burgess, N., & Behrens, T. E. (2020). The Tolman-Eichenbaum machine: Unifying space and relational memory through generalization in the hippocampal formation. Cell, 183(5), 1249-1263.
	Project proposals	
Week 8	(Fall Break, no classes)	
Week 9	What is the best way to forage?	Charnov, E. L. (1976). Optimal foraging, the marginal value theorem. Theoretical population biology, 9(2), 129-136.
		Pirolli, P., & Card, S. (1999). Information foraging. Psychological review, 106(4), 643.
	What is the best way to wander?	Ashraf M. (2021). Reinforcement Learning Demystified: Markov Decision Processes (Part 1). Become Sentient.
Week 10	How do we learn to value future actions?	Sutton, R. S., & Barto, A. G. (2020). Chapter 1: Introduction. In Reinforcement learning: An introduction (2nd edition). MIT press.
		Sutton, R. S., & Barto, A. G. (2020). Chapter 2: Multi-armed bandits. In Reinforcement learning: An introduction (2nd edition). MIT press.
	How does the brain learn from feedback?	Dunovan, K., & Verstynen, T. (2016). Believer-skeptic meets actor-critic: rethinking the role of basal ganglia pathways during decision-making and reinforcement learning. Frontiers in neuroscience, 10, 106.
		Dunovan, K., Vich, C., Clapp, M., Verstynen, T., & Rubin, J. (2019). Reward-driven changes in striatal pathway competition shape evidence evaluation in decision-making. PLoS computational biology, 15(5), e1006998.
Week 11	(Election Day, no classes)	
	How do you change your mind?	Shine, J. M. (2021). The thalamus integrates the macrosystems of the brain to facilitate complex, adaptive brain network dynamics. Progress in Neurobiology, 199, 101951.

Week 12	What is the value of information?	Sheridan, T. B. (1995). Reflections on information and information value. IEEE transactions on systems, man, and cybernetics, 25(1), 194-196.
		Kobayashi, K., & Hsu, M. (2019). Common neural code for reward and information value. Proceedings of the National Academy of Sciences, 116(26), 13061-13066.
	When to explore rather than exploit?	Peterson E., Verstynen T. (2021) Embracing curiosity eliminates the exploration-exploitation dilemma, bioRxiv 671362; doi: https://doi.org/10.1101/671362
Week 13	How do you learn for the future?	Vogelstein, J. T., et al. (2022). Prospective Learning: Back to the Future. arXiv preprint arXiv:2201.07372.
	No Class	Thanksgiving break
Week 14	*Final Project Presentations*	
	Final Project Presentations	
Week 15	*Final Project Presentations*	
	Final Project Presentations	