Biologically Intelligent eXploration (BIX)

CMU 85-435 & 85-735

Instructor Info

Tim Verstynen PhD

Thursdays 1-2pm

335F Baker Hall

timothyv@andrew.cmu.edu

Course Info

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

Tues & Thurs

2:00-3:20pm EST

336B Baker Hall or Zoom

TA Info

Aden Eagle

Tuesdays 3:20-4:30pm

336B Baker Hall

aeagle@andrew.cmu.edu

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):

- Random Walks
- Chemotaxis
- 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.

Labs

`https://coaxlab.github.io/BIX-book/intro.html`

Lectures

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

Necessary Tools

- A computer
- A Github account
- A Google Colab account

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%	Labs
40%	Synthetic Designs
30%	Final Project

Labs

We will have 10 labs throughout the semester. These will be done together in class with guidance from the TA or instructor. Each lab has questions or tasks for you to answer or complete independently. These should be submitted as links to Jupyter notebooks posted on each student's Github account. These submissions are due no later than 1 week after the class in which we do the lab together.

Synthetic Designs

Throughout the semester we will be going over the algorithms of discovery and exploration. With each algorithmic agent that we cover, you will be asked to sketch out a design for a mechanical system that can implement the algorithm. This will consist both of drawings and short summaries (<400 words) describing how the mechanical device would work. Submissions will evaluated based on creativity, rational logic, and alignment to the algorithm being implemented.

Within one week (7 days) of receiving your feedback and grade for a synthetic designs assignment, you will be allowed to submit a revision for *no more than* 50% of the points lost on the original submission. Late make up assignments will not be allowed.

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. 11th, 2024.

Late Work Policy

There is a 10% penalty per week for late homework assignments (i.e., labs or synthesis papers). For example, a lab submitted 2 weeks late will incur a 20% late penalty taken off the top. Homework submitted 3 weeks after original deadline or after the last day of the semester (whichever comes first) will not be accepted. 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 of Dietrich College.

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 (D = Discussion, L = Lab)

Week 1	What is exploration? (D)	Braitenberg, V. (1986). Vehicles: Experiments in synthetic psychology. MIT press.
	How do we understand an intelligent system? (D)	Braitenberg, V. (1986). Vehicles: Experiments in synthetic psychology. MIT press.
Week 2	Is randomness a good strategy? (L)	Berg, H. C. (Ed.). (2004). E. coli in Motion. New York, NY: Springer New York.
	What is life like at a low Reynold's number? (D)	Berg, H. C. (Ed.). (2004). E. coli in Motion. New York, NY: Springer New York.
Week 3	When to tumble and when to run?(L)	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 you follow a scent? (D)	Baker, K. L., Dickinson, M., Findley, T. M., Gire, D. H., Louis, M., Suver, M. P., ... & Smear, M. C. (2018). Algorithms for olfactory search across species. Journal of Neuroscience, 38(44), 9383-9389. Porter, J., Craven, B., Khan, R. M., Chang, S. J., Kang, I., Judkewitz, B., ... & Sobel, N. (2007). Mechanisms of scent-tracking in humans. Nature neuroscience, 10(1), 27-29.
Week 4	How do we extract signal from noise? (L)	Abdi, H. (2007). Signal detection theory (SDT). Encyclopedia of measurement and statistics, 886-889.
	How do you use evidence to make a decision? (L)	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? (D)	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? (L)	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.
Week 6	What is the nature of information? (L)	Timme, N. M., & Lapish, C. (2018). A tutorial for information theory in neuroscience. eneuro, 5(3).
	What is the value of information? (D)	Sheridan, T. B. (1995). Reflections on information and information value. IEEE transactions on systems, man, and cybernetics, 25(1), 194-196.
Week 7	Can information be its own signal? (L)	Vergassola, M., Villermaux, E., & Shraiman, B. I. (2007). 'Infotaxis' as a strategy for searching without gradients. Nature, 445(7126), 406-409.
	Project proposals	
Week 8	(Fall Break, no classes)	

Week 9	What makes patch foraging difficult? (D)	Barack, D. L. (2024). What is foraging?. Biology & Philosophy, 39(1), 3.
	What is the best way to forage in patches? (L)	Charnov, E. L. (1976). Optimal foraging, the marginal value theorem. Theoretical population biology, 9(2), 129-136.
Week 10	What is the value of future actions? (D)	Van Otterlo, M. (2009). Markov decision processes: Concepts and algorithms. Course on 'Learning and Reasoning.
	How do we maximize the value future actions? (L)	Sutton, R. S., & Barto, A. G. (1998). Chapter 1: Introduction. In Reinforcement learning: An introduction (2nd edition). MIT press. Sutton, R. S., & Barto, A. G. (1998). Chapter 2: Multi-armed bandits. In Reinforcement learning: An introduction (2nd edition). MIT press.
Week 11	No Class	Democracy Day
	How does the brain learn from feedback? (D)	Lee, D., Seo, H., & Jung, M. W. (2012). Neural basis of reinforcement learning and decision making. Annual review of neuroscience, 35, 287-308..
Week 12	When to explore rather than exploit? (D)	Mehlhorn, K., Newell, B. R., Todd, P. M., Lee, M. D., Morgan, K., Braithwaite, V. A., & Gonzalez, C. (2015). Unpacking the exploration–exploitation tradeoff: A synthesis of human and animal literatures. Decision, 2(3), 191
	Can curiosity solve the e-e dilemma? (L)	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 discover what you don't know? (D)	TBD
	Do we look forward or backward when acting? (D)	Seligman, M. E., Railton, P., Baumeister, R. F., & Sripada, C. (2013). Navigating into the future or driven by the past. Perspectives on psychological science, 8(2), 119-141.
Week 14	*Final Project Prep Time*	
	No Class	Thanksgiving break
Week 15	*Final Project Presentations*	
	Final Project Presentations	