



## 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 —



Matthew Clapp



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 understand the unknown.

## Grading

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

## Homework

Homework will be tied to each in-class lab and designed to evaluate retention of the core skills and concepts shown in the lab. Homework will be submitted as links to Jupyter notebooks posted on each student's Github account.

## Discussion Questions

Each non-lab class is centered on a question that we will address via an open-ended discussion. In order to stimulate discussion, prior to each class, students are expected to prepare no fewer than 2 discussion questions structured so as to get a deeper understanding of the assigned materials for that class. Each question should be accompanied by a set of initial thoughts on possible answers by the student (approximately 1 paragraph). This should be submitted no later than 2 hours prior to 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 will submit 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 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. 19th, 2021.

## 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 questions not submitted within 48hrs 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 and Inclusion Committee, Jessica Cantlon [jcantlon@andrew.cmu.edu](mailto:jcantlon@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. <i>Science</i> , 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. <i>Neuron</i> , 93(3), 480-490.
		van Rooij, I., & Baggio, G. (2021). Theory before the test: How to build high-verisimilitude explanatory theories in psychological science. <i>Perspectives on Psychological Science</i> .
Week 2	How does the brain evolve?	Cisek, P. (2019). Resynthesizing behavior through phylogenetic refinement. <i>Attention, Perception, &amp; Psychophysics</i> , 81(7), 2265-2287.
	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. <i>Proceedings of the National Academy of Sciences</i> , 109(43), 17490-17494.
		Huo, H., He, R., Zhang, R., & Yuan, J. (2021). Swimming Escherichia coli Cells Explore the Environment by Lévy Walk. <i>Applied and Environmental Microbiology</i> , 87(6), e02429-20.
Week 3	<i>Lab A: Random exploration</i>	
	How do you use evidence to make a decision?	Gold, J. I., & Shadlen, M. N. (2007). The neural basis of decision making. <i>Annu. Rev. Neurosci.</i> , 30, 535-574.
Week 4	Does the cortex make a decision?	Churchland, A. K., Kiani, R., & Shadlen, M. N. (2008). Decision-making with multiple alternatives. <i>Nature neuroscience</i> , 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. <i>Science</i> , 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. <i>Neural computation</i> , 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. <i>Elife</i> , 4, e08723.
Week 5	What's so special about navigation?	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. <i>Cell</i> , 183(5), 1249-1263.
	<i>Lab B: Accumulation of evidence</i>	
Week 6	How can you optimally forage?	Pirolli, P., & Card, S. (1999). Information foraging. <i>Psychological review</i> , 106(4), 643.

	Can you explore without the past?	Ashraf M. (2021). Reinforcement Learning Demystified: Markov Decision Processes (Part 1). Become Sentient.
Week 7	<i>Lab C: Foraging</i>	
	No class	Fall break
Week 8	<i>Project Concepts Roundup</i>	
	How can you learn what is the best decision?	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.
Week 9	How does the brain learn the best decision?	Dunovan, K., & Verstynen, T. (2016). Believer-skeptic meets actor-critic: rethinking the role of basal ganglia pathways during decision-making and reinforcement learning. <i>Frontiers in neuroscience</i> , 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. <i>PLoS computational biology</i> , 15(5), e1006998.
	<i>Lab D: Reinforcement learning</i>	
Week 10	What is the value of information?	Sheridan, T. B. (1995). Reflections on information and information value. <i>IEEE transactions on systems, man, and cybernetics</i> , 25(1), 194-196.
		Kobayashi, K., & Hsu, M. (2019). Common neural code for reward and information value. <i>Proceedings of the National Academy of Sciences</i> , 116(26), 13061-13066.
	When do you explore and when do you exploit?	Wilson, R. C., Bonawitz, E., Costa, V. D., & Ebitz, R. B. (2021). Balancing exploration and exploitation with information and randomization. <i>Current Opinion in Behavioral Sciences</i> , 38, 49-56.
Week 11	What is curiosity?	Peterson E., Verstynen T. Curiosity eliminates the exploration-exploitation dilemma, <i>bioRxiv</i> 671362; doi: <a href="https://doi.org/10.1101/671362">https://doi.org/10.1101/671362</a>
	<i>Lab E: Curiosity</i>	
Week 12	Is there a purpose to imagination and play?	Chu, J., & Schulz, L. E. (2020). Play, curiosity, and cognition. <i>Annual Review of Developmental Psychology</i> , 2, 317-343.
	What is the future of exploration?	TBD
Week 13	<i>Final Project Presentations</i>	
	No Class	Thanksgiving break
Week 14	<i>Final Project Presentations</i>	
	<i>Final Project Presentations</i>	

