CS 4756 / 5756: Robot Learning

Syllabus for Spring 2023

Instructor: Sanjiban Choudhury (sc2582@cornell.edu)

Class Meeting Time

Tue / Thurs, 9.40 - 10.55 a.m.

Credits

4.0 Credits, Letter Grade. 3 credits are for lecture/homework component, and 1 additional credit for independent work on the final project.

Course Description and Objectives

Advances in machine learning have proved critical for robots that continually interact with humans and their environments. Robots must solve the problem of both perception and decision making, i.e., sense the world using different modalities and act in the world by reasoning over decisions and their consequences. Learning plays a key role in how we model both sensing and acting. This course covers various modern robot learning concepts and how to apply them to solve real-world problems. We look at:

- Learning perception models using probabilistic inference and 2D/3D deep learning.
- Imitation and interactive no-regret learning that handle distribution shifts, exploration/exploitation.
- Practical reinforcement learning leveraging both model predictive control and model-free methods.
- Open challenges in visuomotor skill learning, forecasting and offline reinforcement learning.

Prerequisites

MATH 1920/ MATH 2220, MATH 294, CS 1110, CS 4780 or permission of instructor. This course is targeted towards senior-level undergraduate students and junior graduate

students. Graduate students should enroll in the graduate version of the course. Students should have a solid background in linear algebra and probability. This course involves implementing state of the art algorithms on real world datasets and simulators. Hence, strong familiarity with Python and neural network libraries (Pytorch / TensorFlow/ JAX) is required.

Learning Outcomes

At the end of the course, the student will be able to:

1. Formulate various robot perception problems, e.g. state estimation, object detection, mapping as probabilistic inference.
2. Formulate various robot decision making problems, e.g. self-driving, manipulation, assistive robots, as Markov Decision Problems (MDP).
3. Implement and compare various deep learning approaches to train robot perception models for 2D / 3D vision.
4. Implement and compare various learning algorithms to train robot policies for imitation learning, reinforcement learning and model predictive control.
5. Identify sources of distribution shift in robot learning and apply appropriate techniques from online learning to counter it.
6. Design and benchmark robot learning algorithms that integrate with open-source robot datasets and simulation platforms.

Topics Covered

1. **Fundamentals:** Probability review, Bayes filters, Markov Decision Processes
2. **Maximum likelihood inference:** Filtering, Smoothing, Least squares SLAM as graph optimization, learning with factor graphs.
3. **Visual Learning and Recognition:** CNNs, 2D object detection, Geometry, camera calibration, Visual SLAM, 3D deep learning.
4. **Imitation Learning**: Feedback and regimes of covariate shift, behavior cloning, interactive experts (Dagger), maximum entropy inverse optimal control.
5. **Model Based Reinforcement Learning**: System identification, model predictive control.
6. **Reinforcement Learning**: Temporal difference learning, approximate dynamic programming, fitted value iteration, actor critic methods
7. **Joint Perception and Decision Making:** Visuomotor skill learning, Forecasting

Course Materials / Course Readings

Relevant Textbooks

Modern Adaptive Control and Reinforcement Learning, James A. Bagnell, Byron Boots and Sanjiban Choudhury
Reinforcement Learning: An Introduction, Richard S. Sutton and Andrew G. Barto
Online Learning and Online Convex Optimization, Shai Shalev-Shwartz
Probability Theory: The Logic of Science, E.T. Jaynes
Dynamic Programming and Optimal Control, Vols I and II, Dimitri P. Bertsekas

Grading Rubric

Component	Details	%Grade
Assignments	Assignment 1 (15%): Object detection. Implement a 3D object detector using deep learning techniques.	60%
	Assignment 2 (15%): Tracking. Train a filter to track a pedestrian moving through occlusion.	
	Assignment 3 (15%): Imitation Learning. Implement behavior cloning and Dagger to control a Lunar Lander to land safely.	
	Assignment 4 (15%): Reinforcement Learning. Learn to maneuver a helicopter using limited number of interactions with the simulator	
Final Project	The final project is a chance for students to team up in groups of up to 2 to apply the techniques they learned on a problem of their choice. You are	30%

	welcome to select any topic that may be relevant to your research, an open problem of interest or from a list of potential projects. Extended Abstract: 5% Final Report: 20% Final Presentation: 15%	
Participation	In-class participation and Ed discussions	10%
Total		100%

Grading Scale

A+	>97
A	90-97
A-	80-90
B+	55-80
B	45-55
B	35-45
C+	<35

Late Policy

Assignments must be submitted by the posted due date. You are allowed up to 3 total LATE DAYs for any deliverable throughout the entire semester. Any assignment turned in late will incur a reduction in score by 33% for each late day. The final presentation must be presented on time, no late policy applies. Regrade requests, if the case is strong and a significant number of points are at stake, should be submitted online via a private post on Ed within one week of when a deliverable is returned to the student. You must provide a justification for the regrade request.

In case of a legitimate situation or medical emergency that arises during the semester that is going to hinder your ability to complete the work on time, contact Prof. Choudhury as soon as possible. Extensions (beyond the already assigned slip days) will be granted only in exceptional circumstances, such as documented illness, not for situations such as job interviews or large workloads in other courses.

Academic Integrity

This course adheres to all aspects of Cornell's Code of Academic Integrity. Any work presented as your own must be your own, with no exceptions tolerated. All violations of this policy will result in a penalty depending on the severity. The penalty may be a failing grade on the relevant assignment or exam, or a failing grade in the class. The code can be found at: http://cuinfo.cornell.edu/aic.cfm

Diversity, Equity and Inclusion

Students in this course come from a variety of backgrounds, abilities, and identities. In order to ensure an environment conducive to learning, all members of the course must treat one another and the course staff with respect. If you feel your needs are not being adequately accommodated by the other students or instruction staff, please contact Prof. Choudhury.

COVID-19 related issues

For students becoming ill or needing to quarantine during the semester, we will address your needs on a case-by-case basis. Please contact Dr. Choudhury if you have any concerns.

Accomodations

If you have a disability-related need for reasonable academic adjustments in this course, please reach out to Student Disability Services to guide us through next steps. If you are experiencing undue personal or academic stress during the semester, we encourage you to reach out to the instructor for support.
We encourage you to check out the comprehensive set of resources compiled by EARS, Reflect, Cornell Minds Matter, and Body Positive Cornell: Cornell Mental Health Resources Guide 2022-23