Spring 2019

Stanford
AA 203: Optimal and Learning-based Control

Instructor:
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Location and time: Herrin T175, Mondays and Wednesdays, 1:30pm–2:50pm

Office Hours:
Prof. Pavone: Mondays, 3:00-5:00pm (Durand 261), after class, and by appointment
C.A.: Tuesdays and Thursdays, 3pm-4:30pm (Durand 271/Durand 272)

Units: 3.

Course website: `http://asl.stanford.edu/aa203/`

Course Notes: A set of course notes will be provided covering all the content presented in the class. In addition to these notes, the textbooks below may be valuable for context or further reference.

Textbooks (Optional):

- D. P. Bertsekas. Dynamic Programming and Optimal Control, Vol. I and II, Athena Scientific, 2012, ISBN-10: 188652908. Price: $134.50.
- D. P. Bertsekas. Nonlinear Programming, Athena Scientific, 2016, ISBN-10: 1886529051. Price: $89.00.

- D. P. Bertsekas. Reinforcement Learning and Optimal Control, Athena Scientific, 2019. Draft version available online at:
`http://web.mit.edu/dimitrib/www/RLbook.html`

- F. Borrelli, A. Bemporad, M. Morari. Predictive Control for Linear and Hybrid Systems, 2017, ISBN-10: 1107652871. Price: $64.99.

- D. K. Kirk. Optimal Control Theory: An introduction. Dover Publications, 2004, ISBN-10: 0486434842. Price: $18.23.

- R. S. Sutton and A. G. Barto. Reinforcement Learning: An Introduction. MIT Press, 2018, ISBN-10: 0262039249. Available online at:
`http://www.incompleteideas.net/book/RLbook2018.pdf`

Course Content: Optimal control solution techniques for systems with known and unknown dynamics. Dynamic programming, Hamilton-Jacobi reachability, and direct and indirect methods for trajectory optimization. Introduction to model predictive control. Model-based reinforcement learning, and connections between modern reinforcement learning in continuous spaces and fundamental optimal control ideas.

Course Goals: To learn the *theoretical* and *implementation* aspects of main techniques in optimal control and model-based reinforcement learning. In particular, dynamic programming, Hamilton-Jacobi reachability, direct and indirect methods for optimal control, model predictive control (MPC), regression models used in model-based RL, practical aspects of model-based RL, and the basics of model-free RL. To learn how to use such techniques in applications and research work with tools such as MATLAB, Python, CPLEX, CVX, and Tensorflow. At the end of the class the student will be able to:

- Apply optimal control techniques to optimize the operations of physical, social, and economic processes (e.g., aerospace vehicles, autonomous cars, robotic systems, financial systems, etc.).
- Design learning-based control schemes and apply them to the aforementioned applications.

Target audience: *Undergraduate* and *graduate* students interested in achieving an advanced knowledge of optimal control and dynamic optimization techniques. Specifically, this course should benefit anyone who performs research or plans to become a professional in the following fields of engineering: Electrical Engineering (control of electro-mechanical systems); Aero & Astro (guidance, navigation, and control of aerospace systems), Mechanical & Civil Engineering (especially robotics, automotive), Computer Science (especially machine learning, robotics), Chemical Engineering (control of complex chemical plants). The course may be useful to students and researchers in several other fields including Neuroscience, Mathematics, Political Science, Finance, Economics.

Prerequisites: Familiarity with linear algebra (e.g., EE 263 or CME 200).

Course Grade Calculation:

- (30%) homework; homework are assigned on Wednesday and due the following Wednesday in class.
- (30%) midterm test (on May 2nd).
- (35%) final project. Projects can be done in teams of up to three students. Guidelines for final projects will be posted on course website.
- (5%) grading quality.

Homework Policy

- There will be a total of eight problem sets (some of them requiring the use of MATLAB and other software packages), assigned on Wednesday and due the following Wednesday in class. Together with the graded homework, we will provide you with a grading rubric that highlights the most common mistakes.
- Because of the multiple topics that will be pursued in the course, it is important to keep up with the assignments. Late homework will be accepted only in **extraordinary** circumstances.
- Cooperation is allowed in doing the homework. You are encouraged to discuss approaches to solving homework problems with your classmates, however **you must always write up the solutions on your own**. You **must** write on your problem set the names of the classmates you worked with. Copying solutions, in whole or in part, from other students or any other source will be considered a case of **academic dishonesty**.

Students with Documented Disabilities: Students who may need an academic accommodation based on the impact of a disability must initiate the request with the Office of Accessible Education (OAE). Professional staff will evaluate the request with required documentation, recommend reasonable accommodations, and prepare an Accommodation Letter for faculty dated in the current quarter in which the request is made. Students should contact the OAE as soon as possible since timely notice is needed to coordinate accommodations. The OAE is located at 563 Salvatierra Walk (phone: 723-1066, URL: `http://studentaffairs.stanford.edu/oae`).

Schedule subject to some slippage:

Lectures:

Date	Topic	Assignment
04/01	Introduction, nonlinear optimization	
04/03	Constrained nonlinear optimization	HW1 out
04/08	Dynamic programming, discrete LQR	
04/10	Iterative LQR, DDP, and LQG	HW2 out, HW1 due
04/15	HJB and HJI equations	
04/17	Reachability analysis	HW3 out, HW2 due
04/22	Calculus of variations	
04/24	Indirect methods for optimal control	HW4 out, HW3 due
04/29	Pontryagin's maximum principle	
05/01	Numerical aspects of indirect optimal control	HW5 out, HW4 due
05/02	Midterm (In the evening, location TBD)	
05/06	Direct methods for optimal control	
05/08	Direct collocation and sequential quadratic programming	HW6 out, HW5 due
05/13	Introduction to MPC	
05/15	Feasibility and stability of MPC	HW7 out, HW6 due
05/20	Adaptive optimal control, dual control, and adaptive LQR	
05/22	Model-based RL: linear methods	HW8 out, HW7 due
05/27	Memorial Day (holiday, no classes)	
05/29	Model-based RL: nonlinear methods	
06/03	Introduction to model-free RL, connections to model-based RL	HW8 due
06/05	Exploration and safety in RL	

Recitations:

Date	Topic
04/05	Linear dynamical systems
04/12	Nonlinear dynamical systems and stability
05/07	Linear, quadratic, convex, and mixed-integer linear programming
05/14	Linear regression, Gaussian processes, and neural networks