ORF 544

Stochastic Optimization and Learning

Spring, 2019

Course description: Stochastic optimization and learning is the science of making decisions over time under uncertainty, a universal activity that we all face in our day to day life. In fact, the range of problems that fall under this broad umbrella is so diverse that a number of research communities have evolved to address these problems with a range of modeling styles and algorithmic approaches. We call this the "jungle of stochastic optimization." While each of these communities offer powerful tools, they can be viewed as a hammer looking for a nail, and if you problem is not the right type of nail, you may have invested a lot of time in a hammer that does not work in practice.

ORF 544 is designed around a new universal framework that covers all the modeling and algorithmic styles in the "jungle." We will show how to properly model any sequential decision problem, and provide a toolbox that pulls together the contributions of all of these communities (including one that has been largely overlooked by the research communities, but is very popular in practice).

Audience: The course is aimed at students who are interested in modeling and solving real problems. For this reason, my goal is to make the course as accessible as possible to a broad audience. You will need at a course in probability and statistics (for example, an understanding of Bayes theorem).

Instructor: Warren B. Powell (powell@princeton.edu) – I can usually be found in my lab in Sherrerd 110, diagonally opposite the main entrance.
Office hours: By appointment (please send request via email).

Teaching assistant: Not yet assigned.

Web site: http://www.castlelab.princeton.edu/orf-544/

Readings: The course will be centered on a new book, *Stochastic Optimization and Learning*, which is downloadable from the website (this will be updated periodically).

Requirements:

Problem sets and class participation:	40 %
Take-home midterm:	25 %
Take-home final:	35 %

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Course outline
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All readings are from *Stochastic Optimization and Learning* on the course website: http://www.castlelab.princeton.edu/orf-544/.

I will refine the readings as the course progresses.

Part I: Introduction and learning

Week 1 – Feb 9: Introduction

An overview of application domains
The universal modeling framework
Decisions and uncertainty
Some major problem classes
Read: Chapter 1, skim Chapter 2

Week 2 – Feb 16: Recursive learning

The five classes of learning problems
Lookup tables, parametric and nonparametric models
Recursive learning algorithms
Read: Chapter 3

Part II: Pure learning problems ("state-independent problems")

Week 3 – Feb 23: Stochastic optimization and derivative-based stochastic search

Fundamental approaches to stochastic optimization (Chapter 4)
Derivative-based stochastic search (Chapter 5)
Stepsize policies (Chapter 6 – skim)

Week 4 – March 1: Derivative-free stochastic search I

Examples of learning problems with discrete choices
The four classes of policies
The first two classes (PFAs and CFAs)

Read Chapter 7, sections 7.1-7.10 (to be modified)

Week 5 – March 8: Derivative-free stochastic search II

VFA-based policies (Gittins indices – very brief)
DLA – direct lookaheads, including knowledge gradient
Read Chapter 7, sections 7.11 – 7.14 (to be modified)

Part III: General sequential decision problems

Week 6 – March 15: Modeling sequential decision problems

Examples of state-dependent decision problems
The modeling framework
Skim Chapter 8; read chapter 9, sections 9.1-9.8.

Spring break!

Week 7 – March 29: Uncertainty quantification and policies

Modeling uncertainty and uncertainty quantification
The four classes of policies
From old reinforcement learning to new reinforcement learning
Read: Chapter 10 (uncertainty) and Chapter 11 (policies)

Part IV: The four classes of policies

Week 8 – April 5: Policy function approximations (PFAs)

Policy search I: derivative-based, policy gradient method
Policy search II: derivative-free stochastic search
Read Chapter 12

Week 9 – April 12: Cost function approximations (CFAs)

CFA for learning problems (upper confidence bounding, interval estimation)
Parameterized optimization problems
Read Chapter 13

Week 10 – April 19: Backward dynamic programming I (VFAs)

Discrete Markov decision processes (Chapter 14)
Backward approximate dynamic programming (Chapter 16)

Week 11 – April 26: Forward dynamic programming II (VFAs)

Q-learning (reinforcement learning)
Forward approximate dynamic programming
Learning the value of a policy
Learning policies
Read Chapter 17-18

Week 12 – May 3: Direct lookahead approximations (DLAs)

Monte Carlo tree search
Model-predictive control/rolling horizon procedures
Read Chapter 20