Oxford University, Hilary term 2020, Syllabus for: Advanced Econometrics

Foundations of machine learning

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Overview and Objectives

This class will cover some of the theoretical foundations of machine learning. We first consider regularization and data-driven choice of tuning parameters. We will discuss the canonical normal means model. In this model, we will motivate shrinkage estimators in different ways, and will prove the famous result that shrinkage estimators can uniformly dominate conventional estimators. As an example of a supervised learning method that builds on these ideas, we will discuss (deep) neural nets, including some numerical methods used for training them, such as stochastic gradient descent.

After that, we will discuss methods for active learning in the context of multi-armed bandit settings. We will review some theoretical results providing performance guarantees (regret bounds) for algorithms used for learning in bandit settings. We will then turn to a generalization of bandit problems, Markov decision problems, and will discuss reinforcement learning approaches for solving these.

Practice problems I will post example exam question on my course homepage. Additionally, the slides contain a lot of practice problems, which you will have to solve in class. The idea is to have you complete most of the proofs, after I pointed you in the right direction. After a few minutes, we will discuss the solutions to these problems. These problems provide good guidance for what you might expect from the midterm exam.

I encourage you to come to office hours with any questions. If you need any special accommodations for physical or medical reasons, please see me after class or send me an email.

Outline of the course

Decision theory

- Basic definitions
- Optimality criteria
- Relationships between optimality criteria
- Analogies to microeconomics
- Two justifications of the Bayesian approach

Shrinkage in the normal means model

- Setup: the normal means model $\boldsymbol{X} \sim N(\boldsymbol{\theta}, I_k)$ and the canonical estimation problem with loss $\|\widehat{\boldsymbol{\theta}} - \boldsymbol{\theta}\|^2$.
- The James-Stein (JS) shrinkage estimator.
- Three ways to arrive at the JS estimator (almost):
    1. Reverse regression of θ_i on X_i.
    2. Empirical Bayes: random effects model for θ_i.
    3. Shrinkage factor minimizing Stein's Unbiased Risk Estimate.
- Proof that JS uniformly dominates $\boldsymbol{X}$ as estimator of $\boldsymbol{\theta}$.
- The normal means model as asymptotic approximation.

Deep neural nets

- What are neural nets?
- Network design:
  Activation functions, network architecture, output layers.
- Calculating gradients for optimization:
  Backpropagation, stochastic gradient descent.
- Regularization using early stopping.

Bandit problems

- Setup: The multi-armed bandit problem.
  Adaptive experiment with exploration / exploitation trade-off.
- Two popular approximate algorithms:
  1. Thompson sampling
  2. Upper Confidence Bound algorithm
- Characterizing regret.
- Characterizing an exact solution: Gittins Index.
- Extension to settings with covariates (contextual bandits).

Reinforcement learning

- Markov decision problems.
- Expected updates – dynamic programming.
- Sample updates:
  - On policy: Sarsa.
  - Off policy: Q-learning.
- Approximation:
  - On policy: Semi-gradient Sarsa.
  - Off policy: Semi-gradient Q-learning.
  - Deep reinforcement learning.

References

Review of decision theory

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Shrinkage in the normal means model

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