MIDS 207: Introduction to Machine Learning

Course Summary
Machine learning is a rapidly growing field at the intersection of computer science and statistics and concerned with finding patterns in data. It is responsible for tremendous advances in technology, from personalized product recommendations to speech recognition in cell phones. The goal of this course is to provide a broad introduction to the key ideas in machine learning. The emphasis will be on intuition and practical examples rather than theoretical results, though some experience with probability, statistics, and linear algebra will be important. Through a variety of lecture examples and programming projects, students will learn how to apply powerful machine-learning techniques to new problems, how to run evaluations and interpret results, and how to think about scaling up from thousands of data points to billions.

Prerequisites
1. Students must have completed the following core data science courses prior to enrollment:
      a. Research Design
      b. Storing and Retrieving Data
      c. Exploring and Analyzing Data
2. Undergraduate-level probability and statistics. Linear algebra is recommended.
3. Programming experience in Python. Homework will often require students to consult the scikit-learn library documentation.

Assignments and Grading
Course grades will be based mostly on three guided programming projects designed to synthesize concepts introduced in the lectures and one more open-ended final project. Please see this document for more details.

Course Resources
Most textbooks on machine learning are written with considerable technical detail. As a result, there is no one textbook that aligns with this course. We will list readings that correspond to each week, including some general philosophy and landmark research papers, as well as few chapters from Hal Daume's unfinished textbook.

Week 1: Introduction
- Overview of machine-learning applications
- Brief history
- Fundamentals of machine learning

Read Halevy, Norvig, Pereira, The unreasonable effectiveness of data

Week 2: Problem Setup and Nearest Neighbors
- Why prediction?

- Training and test data; cross-validation
- Evaluation and baselines
- Generalization and overfitting: linear models vs. nearest neighbors
- K-nearest neighbors, distance metrics
- Case study: real estate value, digit classification

Read [Feynman, R. (1974, June). Cargo cult science. *Engineering and Science 37*(7).](#)
Read [Domingos, A few useful things to know about machine learning](#)
Optional [Hawkins, The problem of overfitting](#)

Week 3: Supervised Learning I: Naive Bayes
- Probability review: Random variables, Independence, Bayes rule
- Generative models and Naive Bayes
- Maximum likelihood estimation and smoothing
- Case study: spam classification

Read [Paul Graham on Naive Bayes (2002](#))
Optional [Michael Collins tutorial on Naive Bayes (with math), see pages 1–4](#)
Optional [Norvig, How to write a spelling corrector](#)

Week 4: Supervised Learning II: Decision Trees
- Decision Trees
- Information Gain
- Overfitting and pruning
- Ensemble methods
- Case study: customer churn, fuel efficiency

Read [blog post from yhat about predicting churn](#)
Optional [Carter, An introduction to information theory and entropy](#)
Optional [Freund and Schapire, A Short introduction to Adaboost](#)
Optional [Delgado, et al, Do we need hundreds of classifiers to solve real-world problems?](#)

Week 5: Supervised Learning III: Regression
- Review of linear regression
- Inference and prediction
- Logistic regression and classification
- Extensions and advanced topics

Optional: [Breiman, Statistical Modeling: The Two Cultures](#)
Optional: [Deriving Least Squares](#)
Optional: [Freedman, Statistical Models and Shoe Leather](#)

Week 6: Supervised Learning IV: More Linear Models

- Gradient descent for regression
- Regularization

Read [Hal Daume, Gradient Descent (chapter 6)](#)
Optional [Bottou, Stochastic Gradient Descent Tricks](#)

Week 7: Supervised Learning V: Neural Networks
- The perceptron
- State of the art: neural networks for speech recognition

Read [Hal Daume, Neural Networks (chapter 8)](#)
Optional [LeCun, et al, Deep Learning](#)

Week 8: Supervised Learning VI: SVMs, Choosing Classifiers, Speech Recognition
- Support Vector Machines
- Comparing classifiers: performance, training speed, model size, interpretability
- Feature engineering tips
- Speech recognition overview

Read [An empirical comparison of supervised learning algorithms](#).
Optional [Cosma Shalizi SVM lecture notes](#).
Optional [On comparing classifiers: Pitfalls to avoid and a recommended approach](#).
Optional [SKLearn classifier comparisons for toy problems](#).

Week 9: Unsupervised Learning I: Cluster Analysis
- What if our data don't have labels?
- Distance metrics (Hamming, Euclidean, Cosine, Mahalanobis)
- K-means clustering
- Hierarchical clustering

Optional [Zhao and Karypis, Hierarchical clustering algorithms for document datasets](#)
Optional [Eisen et al., Cluster analysis and display of genome-wide expression patterns](#)

Week 10: Unsupervised Learning II: Expectation Maximization
- Expectation-Maximization and the idea of hidden variables
- Basics of Gaussian Mixture Models
- Case study: speaker identification

Read [Tibshirani lecture notes on EM](#)
Optional [Doug Reynolds original paper on GMMs for speaker identification](#)

Week 11: Unsupervised Learning III: Dimensionality Reduction
- Motivation

- Dimensionality reduction
- Principal Component Analysis
- Case study: Eigenfaces
- Other methods for dimensionality reduction: SVD, NNMF, LDA

Optional [Hal Daume, Unsupervised Learning (chapter 13)](#)
Optional [Turk and Pentland, Eigenfaces for Recognition](#)

Week 12: Network Analysis
- Graph algorithms (pagerank).
- Network link predictions.
- Scaling and other challenges.

Read [Page and Brin, The Anatomy of a Large-Scale Hypertextual Web Search Engine](#)
Optional [Barabasi, The Scale-Free Property](#)

Week 13: Recommender systems
- Motivation
- The Netflix challenge
- Content-based methods
- Learning features and parameters
- Nearest-neighbor CF

Optional [Gomez and Hunt, The Netflix Recommender System: Algorithms, Business Value, and Innovation](#)
Optional [Koren, Collaborative Filtering with Temporal Dynamics](#)

Week 14: Wrap-Up
- Topics beyond the scope of this course
- What your instructors do