

# Machine Learning Methods for Social Science Research

(Spring 2019)

This course aims to introduce PhD students in Management to Machine Learning methods. The first half discusses underlying principles and applications of many predictive models. The second half discusses graphical models to develop and estimate probabilistic models. The students will learn from discussion of the underlying theories of the methods, discussion of research articles in social sciences that apply similar methods, and doing programming/estimation assignments modeled after current research in this area.

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Grade breakdown:

1. Assignments: 50
2. Final project: 30
3. Participation: 20

Pre-requisite:

We expect students to have taken introductory statistics or econometrics courses (e.g., Statistics for Economists (EC 507) and Econometrics (EC 508) or their equivalent) before taking this course. Familiarity with Python programming language is recommended. A pre-assignment is provided at the end of syllabus to help you learn Python enough to get ready for the class.<sup>1</sup>

Textbooks:

1. Bishop: Pattern Recognition and Machine Learning—Christopher M. Bishop
2. Murphy: Machine Learning: A Probabilistic Perspective—Kevin Murphy  
(Feel free to skip the \*'ed sections while reading for class, unless explicitly included.)

Weekly Schedule:

1. Introduction to Machine Learning
  - a. Supervised vs unsupervised learning
  - b. Parametric vs non-parametric methods, k-nearest neighbor
  - c. Inference vs prediction

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<sup>1</sup> You may use a different language such as R or MATLAB to do the class assignments. However, I'll provide most of the solutions in Python.

- d. Review of probability theory: properties, expectation, Bayes rule, conditional independence
- e. Discrete and continuous probability distributions
- f. Information theory (entropy, KL divergence, mutual information)

Background:

- Murphy 1, 2.2, 2.8;
- (Optional) Murphy 2.3-2.6; Bishop 1.1–1.4, 1.6, 2

Conceptual papers:

- Shmueli, G. (2010). To explain or to predict?. *Statistical science*, 25(3), 289-310.
- Kleinberg, J., Ludwig, J., Mullainathan, S., & Obermeyer, Z. (2015). Prediction policy problems. *American Economic Review*, 105(5), 491-95.

## 2. Introduction to model estimation and comparison

*Objective: Learn common model estimation techniques.*

- a. MLE, MAP, and predictive distribution
- b. Common distribution estimation; Naïve Bayes classifier
- c. Model comparison: AIC/BIC, Bayes Factor, cross validation, ROC curve.
- d. Decision theory
- e. Optimization techniques for parameter estimation: Quasi Newton methods, automated differentiation, accommodating constraints, and large-scale optimization techniques such as Stochastic Gradient Descent.

Background:

- Murphy 3, 5
- (Optional) Bishop 1.5, 3.4, 3.5

## 3. Some common linear classifiers

*Objective: Learn some of the linear models for classification; evaluate how well they work for a dataset.*

- a. Gaussian discriminant analysis
- b. Logistic regression and choice models
- c. Bayesian treatment of logistic regression

Background:

- Bishop 4
- Murphy 4.2–4.4
- (Optional) Murphy 8.1–8.4
- Conditional Logit Analysis of Qualitative Choice Behavior, by: Daniel Mcfadden, edited by: P. Zarembka, In *Frontiers in econometrics* (1974), pp. 105-142

Application paper:

- McFadden, D. (1986). The choice theory approach to market research. *Marketing science*, 5(4), 275-297.

#### 4. Model Tuning

*Objective: Learn how to identify a small subset of features that contains most of the information for predicting the output.*

- a. Feature selection
- b. Regularization
- c. Active learning

Background:

- Murphy 13

Application Papers:

- Active Feature-Value Acquisition—Maytal Saar-Tsechansky, Prem Melville, Foster Provost (2009) *Management Science*

#### 5. Support Vector Machines

*Objective: learn how kernel representation helps classify datasets with highly non-linear separating boundaries in the original feature space.*

- a. Kernels functions
- b. Maximum margin classifiers
- c. SVM for regression and classification

Background:

- Murphy 14.1–14.6
- (Optional) Bishop 6.1–6.3, 7

Application Papers:

- Cui, D., & Curry, D. (2005). Prediction in marketing using the support vector machine. *Marketing Science*, 24(4), 595-615.
- Cecchini, M., Aytug, H., Koehler, G. J., & Pathak, P. (2010). Detecting management fraud in public companies. *Management Science*, 56(7), 1146-1160.

#### 6. Tree-based Methods and ensembles

*Objective: non-linear classification techniques with implicit feature selection.*

- a. Decision trees

- b. Bagging, Boosting, and Random Forest
- c. Causal trees

Background:

- Bishop 14.1–14.4
- Murphy 16.1–16.4
- Athey, S., & Imbens, G. (2016). Recursive partitioning for heterogeneous causal effects. *Proceedings of the National Academy of Sciences*, 113(27), 7353-7360.

## 7. Introduction to Graphical Models

*Objective: learn how to graphically specify conditional independences in probabilistic models and exploit them to simplify estimation/inference.*

- a. Semantics: conditional independence, d-separation
- b. Exact inference, variable elimination
- c. Structure learning

Background:

- Bishop 8
- Paper: Michael I. Jordan. Graphical Models. *Statistical Science* 19(1):140-155, 2004.
- (Optional) Murphy 10, 20, 26

Application Papers:

- Machine learning for direct marketing response models: Bayesian networks with evolutionary programming—G Cui, ML Wong, HK Lui (2006) *Management Science*

## 8. Latent Variable Models

*Objective: understand how/why latent variables are used in many common probabilistic models and estimation challenges they pose.*

- a. Mixture models
- b. Factor analysis, PCA
- c. Expectation Maximization framework for estimation

Background:

- Bishop 9
- Murphy 11, 12
- (Optional) Bishop 12, 14.5
- (Optional) Dempster, A. P., Laird, N. M., & Rubin, D. B. (1977). Maximum likelihood from incomplete data via the EM algorithm. *Journal of the royal statistical society. Series B (methodological)*, 1-38.

Application Papers:

- A Dynamic Analysis of Market Structure Based on Panel Data—Erdem, Tülin (1996) *Marketing Science*
- The generalized multinomial logit model: accounting for scale and coefficient heterogeneity—DG Fiebig, MP Keane, J Louviere, Nada Wasi (2010), *Marketing Science*

## 9. Approximate Inference (Functional)

*Objective: learn how to successively approximate a desired model, which is hard to optimize numerically, via simpler functions.*

- Expectation Maximization
- Variational approximation
- Variational Bayes

Background:

- Bishop 10
- (Optional) Murphy 21, 22
- (Optional) Jordan, M. I., Ghahramani, Z., Jaakkola, T. S., & Saul, L. K. (1999). An introduction to variational methods for graphical models. *Machine learning*, 37(2), 183-233.
- (Reference) Martin J. Wainwright and Michael I. Jordan. Graphical Models, Exponential Families and Variational Inference. *Foundations and Trends in Machine Learning* 1(1-2):1-305, 2008.

Application Papers:

- Variational Inference for Large-scale Models of Discrete Choice—Michael Braun and Jon McAuliffe (2010), *Journal of the American Statistical Association*
- Active Machine Learning for Consideration Heuristics—Daria Dzyabura, John R. Hauser (2011), *Marketing Science*

## 10. Approximate Inference (Stochastic)

*Objective: understand why this is one of the most used inference techniques, when to use and when there might be better alternatives with a little bit of work.*

- Importance sampling, MCMC, Metropolis Hasting, Gibbs
- Convergence diagnostics
- Tools that facilitate MCMC based estimation

Background:

- Bishop 11
- Murphy 23.1–23.4, 24

Application Papers:

- Path to purchase: A mutually exciting point process model for online advertising and conversion—L Xu, JA Duan, A Whinston (2014), *Management Science*

## 11. Dynamic Bayesian Networks

*Objective: understand tradeoffs, independence assumptions and computational challenges, between different models of sequential data.*

- a. HMM, State space models, and their variants
- b. Dynamic programming for inference on chains
- c. Particle filtering

Background:

- Murphy 17, 18, 23.5–23.6
- Bishop 13
- (Optional) Murphy 27

Application Papers:

- A Hidden Markov Model of Collaborative Filtering—Nachiketa Sahoo, Param Vir Singh, Tridas Mukhopadhyay (2012) *Management Information Systems Quarterly*
- A Hidden Markov Model of Customer Relationship Dynamics—Oded Netzer, James M. Lattin, V. Srinivasan (2008), *Marketing Science*
- (Optional) Modeling Online Browsing and Path Analysis Using Clickstream Data Alan L. Montgomery, Shibo Li, Kannan Srinivasan, John C. Liechty (2004), *Marketing Science*

## 12. Text Mining

*Objective: transform unstructured text documents to a structured form, apply some of the already discussed machine learning techniques, and learn a few specialized techniques.*

- a. Pre-processing, representation
- b. Text classification
- c. Document clustering, topic models (Latent Dirichlet Allocation)

Background:

- Ch 2.1–2.2, 6.2–6.4 of “Introduction to Information Retrieval” by Manning, Raghavan, Schütze ([Free book copy by the authors: https://nlp.stanford.edu/IR-book/information-retrieval-book.html](https://nlp.stanford.edu/IR-book/information-retrieval-book.html)).
- Hofmann, T. (1999, July). Probabilistic latent semantic analysis. In *Proceedings of the Fifteenth conference on Uncertainty in artificial intelligence* (pp. 289-296)
- Blei, D. M., Ng, A. Y., & Jordan, M. I. (2003). Latent dirichlet allocation. *Journal of machine Learning research*, 3(Jan), 993-1022.
- (Optional) Blei, D. M., & Lafferty, J. D. (2009). Topic models. In *Text Mining* (pp. 101-124). Chapman and Hall/CRC.

#### Application Papers:

- Netzer, O., Feldman, R., Goldenberg, J., & Fresko, M. (2012). Mine your own business: Market-structure surveillance through text mining. *Marketing Science*, 31(3), 521-543.
- Yang, M., Adomavicius, G., Burtch, G., & Ren, Y. (2018). Mind the gap: Accounting for measurement error and misclassification in variables generated via data mining. *Information Systems Research*, 29(1), 4-24.

#### 13. Text Mining – II

*Objective: learn analyses that preserve the order of the words in a sentence.*

- a. Information extraction
- b. Embeddings, word2vec

#### Background:

- Ch 7, 8.1–8.5 “Natural Language Processing with Python” by Steven Bird, Ewan Klein, and Edward Loper (free online version at <http://www.nltk.org/book/cho7.html> & [cho8.html](http://www.nltk.org/book/cho8.html)).
- Mikolov, T., Sutskever, I., Chen, K., Corrado, G. S., & Dean, J. (2013). Distributed representations of words and phrases and their compositionality. In *Advances in neural information processing systems* (pp. 3111-3119).
- Mikolov, T., Yih, W. T., & Zweig, G. (2013). Linguistic regularities in continuous space word representations. In *Proceedings of the 2013 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies* (pp. 746-751).

#### Application Papers:

- Deriving the pricing power of product features by mining consumer reviews—N Archak, A Ghose, PG Ipeirotis (2011) *Management Science*

# Python Pre-assignments

## Install the software

I recommend using conda package manager for installing python and python packages because it simplifies the process. Please install [Miniconda](#) for Python 3 for your operating system. Then, using conda, install the packages numpy, scipy, matplotlib, ipython, pandas, statsmodel, seaborn, sympy, and scikit-learn. You might find the [conda cheat sheet](#) helpful. I recommend the Integrated Development Environment (IDE) [PyCharm](#) for writing Python code (professional version is [free for students](#)).

## Become familiar with Python

Please read and do the examples/exercises in the following sections of [Scipy Lecture Notes](#) :

- Chapter 1.1. Python scientific computing ecosystem
- Chapter 1.2.1–1.2.7. The Python language
- Chapter 1.3.1–1.3.5 NumPy: creating and manipulating numerical data
- Chapter 1.5.1–1.5.7, 1.5.11 (up to p 231) Scipy: high-level scientific computing
- Chapter 3.1.1–3.1.5 Statistics in Python

You should write the code yourself and experiment with variations as you work through these chapters. Let me know if you get stuck or have questions.