RUTGERS
Rutgers Business School
Newark and New Brunswick

22:544:631 Algorithmic Machine Learning
26:711:685 Algorithmic Machine Learning
Fall 2024
Classroom: 302 at 1WP
Wednesdays 2:00 PM - 5:00 PM

Farid Alizadeh
Web site: https://canvas.rutgers.edu
Office # Rm 1062 and on WebEx
Office Hours: W 11:00 am - 12:00 pm
held in office or on WebEx at
https://rutgers.webex.com/meet/alizadeh

COURSE DESCRIPTION

In this course, we cover the broad topic of machine learning both from computer science and the theory of algorithms and from statistics points of view, with emphasis on the Bayesian approach. Applications in business will be emphasized.

On the statistical side, we cover the so-called parametric and non-parametric methods for both classification and regression. We also describe and distinguish the frequentist vs. Bayesian approach. We cover variance reduction methods such as bootstrapping and bagging, boosting, and over-fitting remedies such as regularization (e.g. ridge and lasso), cross-validation, the Akaike Information Criterion (AIC), and the Schwarz's Bayesian Information Criterion (BIC).

For classification, we will go over many well-known techniques. We describe the Bayes decision rule and cover the main techniques, namely CART, kNN, logistic regression SVM, and neural nets. Among the general methods we look at are the Maximum likelihood (ML) and the semi-Bayesian Maximum a posteriori (MAP) approaches. In this context, the expectation-maximization algorithm will be covered. We will also cover the Bayesian approach to model selection.

For unsupervised learning topics such as the k-means algorithm, hierarchical clustering, and Google Page rank algorithm is covered. We also describe the Principal Component Analysis (PCA) and related feature extraction methods, as well as their applications to anomaly detection and recommender systems.

On the algorithmic side, we will cover the computational complexity and resource usage of various algorithms. We cover issues in optimization algorithms that arise from large-scale data and involve tens of thousands to millions of data points and up to thousands of features. Many real-world applications and projects will be used as case studies.

COURSE MATERIALS

1. Aurélien Géron, *Hands-on Machine Learning with Scikit-Learn, Keras & TensorFlow*, 3rd edition 2022, O'Reilly publishers(**required**)
2. C.M. Bishop. *Pattern Recognition and Machine Learning* Springer 2006 (**recommended** reference)
3. K.P. Murphy. *Probabilistic Machine Learning, An Introduction*, MIT Press, 2022 (**recommended**) A pdf version can be accessed through the MIT Press site:

https://mitpress.mit.edu/9780262046824/probabilistic-machine-learning/ (**recommended** reference)

4. T. Hastie, R. Tibshirani and J. Friedman. *The Elements of Statistical Learning*, Springer, 2009 (available online in pdf format from authors web site) (**recommended** reference)

And additional lecture notes at the discretion of the instructor

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LEARNING GOALS AND OBJECTIVES

- To become proficient in basic techniques of machine learning,
- to understand the statistical foundations of the methods and learn efficient algorithms for implementing learning ideas,
- to understand the Bayesian point of view and its contrast with the frequentist approach,
- to learn to extract essential features from the data,
- to learn aspects of unsupervised learning, ranking, and clustering,
- to become familiar with the most effective approaches, including the so-called kernel trick, and estimating latent variables through the expectation-maximization algorithm,
- to develop programming and software skills for implementing machine learning methods
- to learn about most common machine learning software libraries and how to find one when available and write their own when not available.

ACADEMIC INTEGRITY

I do NOT *tolerate cheating*. Students are responsible for understanding the RU Academic Integrity Policy (http://academicintegrity.rutgers.edu/files/documents/AI_Policy_2013.pdf). I will strongly enforce this Policy and pursue *all* violations. On all examinations and assignments, students must sign the RU Honor Pledge, which states, "On my honor, I have neither received nor given any unauthorized assistance on this examination or assignment." Don't let cheating destroy your hard-earned opportunity to learn. See business.rutgers.edu/ai for more details.

ATTENDANCE AND PREPARATION POLICY

- Attendance is required, and students are responsible for what is said in class.

CLASSROOM CONDUCT

Please respect your fellow classmates by not disrupting the lectures or talking while they are trying to ask questions.

PREREQUISITES

- Good knowledge of the Python programming language
- Good understanding of probability theory (reviewed in the first lecture provided in lecture notes)
- Good understanding of linear algebra and basic matrix and matrix-vector algebra (reviewed in supplementary lecture notes.)

EXAM DATES AND POLICIES

- No exams are given.
- Five or six homework assignments, including problem-solving and programming projects.
- A team project to be prepared by students and presented in class at the end of the semester. The project must involve real data (for instance, from the Kaggle site) and be tested with multiple models. The teams should upload their code and presentation to a GitHub page.

GRADING POLICY

- Fifty percent of homework and programming assignments
- Fifty percent end of term group project

COURSE SCHEDULE

Week 1. Quick Review of probability, statistics, Bayes rule, Bayesian vs. frequentist approach, entropy, Kulback-Liebler deviance, loss, risk, empirical risk, Bayes decision rule, feature extension technique, and manufacturing new features from current ones

Week 2. Simple models such as the k-Nearest Neighbor (kNN), the Naive Bayes method, Classification and Regression Trees (CART), random forests, adaptive and gradient boosting, cross-entropy, importance of normalization and standardization

Week 3. Continuation of Week 2

Week 4. The general concept of Maximum Likelihood (ML), the Bayesian version, Maximum A Posteriori (MAP) approaches

Week 5. Continuation of Week 6

Week 6. A quick review of optimization techniques used for ML: gradient descent, stochastic gradient descent, quadratic programming, Lagrange multiplier theory

Week 7. The linear regression model and the logistic regression approach to classification and interpretation as a maximum likelihood approach, the MAP approach to regression

Week 8. The notion of basis Expansion, regularization (Bayesian interpretation) and lasso, cross-validation, and AIC and BIC methods, kernelization and the kernel trick for linear and logistic regression

Week 9. Introduction to Support Vector Machines (SVM), the hinge loss function, kernelization and the kernel trick for SVM, the notion of VC dimension and connection to SVM

Week 10. Introduction to neural networks and deep learning

Week 11. Introduction to Unsupervised (unlabeled) learning: Cluster analysis, k-means and related methods, the Expectation-Maximization algorithm, and application to mixed models, anomaly detection

Week 12. Principal Component Analysis and other feature extraction and compression methods, Page rank and related ranking methods, kernel PCA, application to recommender systems and anomaly detection
Week 13. Continuation of Week 12

SUPPORT SERVICES

If you need accommodation for a *disability*, obtain a Letter of Accommodation from the Office of Disability Services. The Office of Disability Services at Rutgers, The State University of New Jersey, provides student-centered and student-inclusive programming in compliance with the Americans with Disabilities Act of 1990, the Americans with Disabilities Act Amendments of 2008, Section 504 of the Rehabilitation Act of 1973, Section 508 of the Rehabilitation Act of 1998, and the New Jersey Law Against Discrimination. https://ods.rutgers.edu

If you are a military *veteran* or are on active military duty, you can obtain support through the Office of Veteran and Military Programs and Services. http://veterans.rutgers.edu/

If you are in need of *mental health* services, please use our readily available services.
[Rutgers University-Newark Counseling Center: http://counseling.newark.rutgers.edu/]
[Rutgers Counseling and Psychological Services – New Brunswick: http://rhscaps.rutgers.edu/]

If you are in need of *physical health* services, please use our readily available services.
[Rutgers Health Services – Newark: http://health.newark.rutgers.edu/]
[Rutgers Health Services – New Brunswick: http://health.rutgers.edu/]

If you are in need of *legal* services, please use our readily available services: http://rusls.rutgers.edu/

If you are in need of additional *academic assistance*, please use our readily available services.
[Rutgers University-Newark Learning Center: http://www.ncas.rutgers.edu/rlc
Rutgers University-Newark Writing Center: http://www.ncas.rutgers.edu/writingcenter]