Lahore University of Management Sciences

EE 212, ENGG302, SCI304 – Mathematical Foundations for Machine Learning and Data Science

Fall 2022

Instructors	Dr. Zubair Khalid
Room No.	9-251
Office Hours	Tuesday, Thursday 1:30 pm to 2:45 pm
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Course URL (if any)	Current: https://www.zubairkhalid.org/ee212_2022.html Past: https://www.zubairkhalid.org/ee212_2021.html

Course Teaching Methodology (Please mention following details in plain text)
• Teaching Methodology: In-Person • Attendance is not mandatory but maintaining a good record will help students in many ways. Students not frequently attending the lecture will find difficult to cope with the course. We may take attendance during the session and monitor your presence in the class.

Course Basics				
Credit Hours	3			
Lecture(s)	Nbr of Lec(s) Per Week	2	Duration	1 hour and 15 minutes
Tutorial (per week)	Nbr of Lec(s) Per Week	1	Duration	1 hour (tentative)

Course Distribution	
Core	
Elective	Elective Course for Electrical Engineering
Open for Student Category	BS students
Close for Student Category	

COURSE DESCRIPTION

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Machine Learning and Data Science are being used these days in a variety of applications including, but not limited to, forecasting in economics and finance, predicting anomalies or signal analysis in engineering, identification of speaker in acoustics, detection of cosmic bubbles in astrophysics and diagnosis in medical imaging.

While machine learning and data science have enabled many success stories, and tools are readily available to analyse data or design machine learning systems, the strong mathematical foundations in these areas are of significant importance to understand, review, analyse and evaluate the technical details of the machine learning systems and data science algorithms that are usually abstracted away from the user. This course focuses on the mathematical foundations that are essential to build an intuitive understanding of the concepts related to Machine Learning and Data Science.

Topics covered are
- Linear Algebra: vectors and matrices, vector spaces, system of linear equations, eigen-value decomposition, singular value decomposition, regression, least-squares, regularization
- Calculus: Multivariate calculus and differentials for optimization, gradient descent
- Probability: probability axioms, Bayes rule, random variable, probability distributions
- Statistics: descriptive stats, inferential stats, statistical tests
- Introduction to supervised learning: regression and classification
- Introduction to Neural Networks: single and multi-layer perceptron(s), feedforward and feedback networks
- Application to machine learning and data science: principal component analysis (PCA), time series forecasting, clustering etc
- Hands-on exercises: Implementation of the exercises will be carried out in Python

COURSE PREREQUISITE(S)	
•	Pre-requisites: None
•	Co-requisites: None

COURSE OBJECTIVES	
	The goal of this course is to provide mathematical foundations of Machine Learning and Data Science. In broad brush, this course aims to: • Provide a thorough introduction to both fundamental and advanced topics of linear algebra necessary for machine learning and data science • Build mathematical foundations of calculus, probability and statistics • Provide an appreciation for applications of ML and Data Science • Equip the students with the basics of Python to enable them to implement and evaluate Machine Learning and Data Science algorithms

Learning Outcomes	
CLO1:	The students should be able to: Understand the core theoretical concepts serve as foundations of Machine Learning and Data Science

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CLO2:	Understand the core theoretical concepts of calculus, probability theory and statistics that serve as foundations of Machine Learning and Data Science
CLO3:	Formulate problems in machine learning and data science
CLO4:	Implement the machine learning and data analysis problems using Python

Grading break up: Component Details and weightages

Assignments, 20 %
Programming Assignments, 15 %
Quizzes, 15 %
Mid-Exam and Mid-Viva, 25 %
Final Exam and Final Viva 25 %

Project Details:
The objective of the project is to apply the different concepts covered in the course to formulate the machine learning or data analytics problem, devise a solution and implement the resulting algorithm in Python from scratch. The project is expected to consume roughly two weeks of moderately concentrated effort. We encourage you to work in a group of two students (every student in the group will receive same score). We require you to submit project report, project code and 3 minute video presentation summarizing your work.

Plagiarism policy details:
Usual LUMS plagiarism policy will apply; Following the honor code is expected from students while being assessed in online mode. They are expected to work on their own without consultation from their fellow students for any assessment component except where group work is explicitly indicated; The discussion partners, website, and other sources used in assignments that have contributed to the solution must be acknowledged. Instructions regarding close book task have to be strictly observed; You are advised to work regularly and target consistency in performance. Any abnormal inconsistency in performance in an individual assessment task with the ongoing general performance can be further scrutinized for plagiarism.

Disciplinary Action policy:
Clear cases of noncompliance with regard to violation of honor code, above instructions and plagiarism may also be sent for disciplinary actions. Similarly any other non-serious behavior disrupting the smooth execution of online course may also be referred to DC.

Examination Detail	
Midterm Exam	Yes/No: Yes Combine Separate: Combined Duration: 120 minutes

	Preferred Date: TBA Exam Specifications: TBA
Final Exam	Yes/No: Yes Combine Separate: Combined Duration: 180 minutes Exam Specifications: TBA

Textbook(s)/Supplementary Readings

Books:

- S.Boyd and L. Vandenberghe. **Introduction to Applied Linear Algebra – Vectors, Matrices, and Least Squares.** Cambridge University Press, 2019
- M. P. Deisenroth, A. A. Faisal and Cheng Soon Ong. **Mathematics for Machine Learning**. Cambridge University Press, 2019
- Roger A. Horn, Charles R. Johnson. **Matrix Analysis (2nd ed.)**. Cambridge University Press, 2013.
- G. Strang. **Introduction to Linear Algebra.** 2016
- Wilfred Kaplan. **Advanced Calculus (5th ed.).** Pearson, 2002.
- Trevor Hastie, Robert Tibshirani, Jerome Friedman. **The Elements of Statistical Learning: Data Mining, Inference and Prediction (2nd ed.)**. Springer, 2008.
- J. A. Gubner, **Probability and Random Processes for Electrical and Computer Engineers**, Cambridge University Press, 2006.
- S. L. Miller and D. Childers, **Probability and Random Processes: With Applications to Signal Processing and Communications.**
- A. Papoulis and S.U. Pillai, **Probability, Random Variables, and Stochastic Processes.**
- Class notes will be provided to supplement these readings

Course Topics

Module	Topic	Additional Remarks
Basic Linear Algebra (2 weeks)	Course Overview, notation, vectors and matrices, basic Operation on vectors	**Tutorial 1:** Basic matrix and vector operations **Programming Assignment 0:** Intro to Python **Programming Assignment 1:** Linear independence, basis, matrix rank
	Advanced operations on vectors, norm, angle, inner product	
	Operations on matrices	
	Linear independence, basis, matrix rank	
	Matrix vector product interpretation	

	Vector spaces, Gram-Schmidt orthogonalization	
Advanced Linear Algebra (2-3 weeks)	Systems of Linear Equations, Formulation, Inverses, Left-inverse, Right-inverse, Inverse, Pseudo-inverse, Connection with the linear equations	**Tutorial 2:** Advanced matrix and vector operations **Tutorial 3:** Solving a system of linear equations, least-squares regularization **Programming Assignment 2:** Least-squares application: data-fitting **Programming Assignment 3:** Eigen value decomposition
	Least-squares, constrained least squares regularization	
	Least-squares application: Regression, data-fitting, clustering	
	Eigenvalue decomposition plus geometric interpretation	
	Singular-value decomposition (SVD) plus geometric interpretation	
	Curse of Dimensionality and Principal Component Analysis (Application of EVD)	
Calculus (1-2 weeks)	Intro to Calculus, functions, convex functions, derivatives, gradient, Hessian, Jacobian, anti-derivatives	**Tutorial 4:** Interpretation: derivative, integration, weighted average, moving average
	Interpretation of derivative and first-order difference of the data	
	Interpretation of integration, weighted average, moving average of time-series	
Probability & Statistics (1-2 weeks)	Probability Theory overview, Probability models, Axioms of probability, Conditional probability Bayes theorem, Law of total probability	**Tutorial 5:** Axioms of probability **Programming Assignment 4:** Probability distributions and Statistical Inference, Statistical tests interpretation of output
	Independence, Combinatorics	
	Random variables and probability distributions	
	Introduction to statistical inference, Statistical tests	
	Bayesian analysis overview	
Machine Learning Overview and Introduction to Neural Networks (3-4 weeks)	Overview of supervised learning, ML nomenclature, problem setup and train-test split	**Programming Assignment 5:** Applications: PCA and Classification **Tutorial 6:** Hands-on working: single layer perceptron example
	kNN algorithm for classification : Overview and Analysis	
	Analysis and Evaluation of Classifier's Performance	
	Overview of Perceptron Classifier, Logistic Regression	
	Introduction to neural network. Single layer perceptron	
	Multi-layer perceptron, feedforward and feedback networks, back propagation	
Applications (2 weeks)	Linear Regression, Time-series forecasting	
	Classification: Perceptron classifier, Logistic Regression	
	Clustering: k-means clustering	