MA4550: A MATHEMATICAL INTRODUCTION TO MACHINE LEARNING FOR DATA SCIENCES

Effective Term
Semester A 2024/25

Part I Course Overview

Course Title
A Mathematical Introduction to Machine Learning for Data Sciences

Subject Code
MA - Mathematics
Course Number
4550

Academic Unit
Mathematics (MA)

College/School
College of Science (SI)

Course Duration
One Semester

Credit Units
3

Level
B1, B2, B3, B4 - Bachelor's Degree

Medium of Instruction
English

Medium of Assessment
English

Prerequisites
MA2503 Linear Algebra and MA3518 Applied Statistics;
OR
MA1503 Linear Algebra with Applications and MA2510/MA2506 Probability and Statistics and SDSC2102 Statistical Methods and Data Analysis

Precursors
Nil

Equivalent Courses
Nil

Exclusive Courses
Nil

Part II Course Details

Abstract

This elective course is to provide the elementary mathematical and numerical theories relevant to the machine learning for data sciences. The basic knowledge of linear algebra, probability theory and statistical models is required and the familiarity of basic numerical methods and one programming language (Python or R or MATLAB or C or SAS, etc) is also preferred or required. The course will discuss fundamental rules, major classes of models, and principles of standard numerical methods. There will be a careful balance between heuristic vs rigorous, simple vs general. The perspective is from the applied and computational mathematics rather than an attitude of "alchemy". This course is a highly integrated undergraduate course for computational math major and it has a wide spectrum in various math knowledge and computational techniques. It can be also a companion theoretic course to a hands-on-experience-oriented machine learning course, for engineering major students with an exceptional math background.

This course will introduce the basic concepts of machine learning (supervision and unsupervised learning) and review the popular models used in machine learning and explain the underlying mathematical theories behind these models: linear regression, logistic regression, support vector machine, Besides, this course also focuses on the neural network models. The machine learning algorithms such as unsupervised learning, stochastic gradient descent and deep learning techniques will be also an important part of this course. The examples of specific application will be given as exercises to enhance understanding. During this course, the students are encouraged to apply the techniques to solve some realistic appreciations in the framework of Discovery&Innovation Curriculum. The students who complete this course are expected to be prepared for the modern development of more advanced machine learning theories and practical techniques.

Course Intended Learning Outcomes (CILOs)

	CILOs	Weighting (if app.)	DEC-A1	DEC-A2	DEC-A3
1	Explain the basic math models and concepts in learning theory and understand the functionalities of mathematics.	20	x	x	
2	Demonstrate the mathematical foundations underlying learning algorithms including probability, statistics, linear algebra, and optimization.	10		x	
3	Apply various regression techniques, including linear and non-linear regression models. Analyze and interpret the results of regression models and understand their limitations.	30		x	
4	Implement Classification Algorithms: Implement and assess the performance of classification algorithms such as logistic regression, support vector machines.	20	x	x	
5	Explore Neural Network Architectures: Describe the structure and function of neural networks, including feedforward, convolutional networks, transformers.	20	x	x	x

A1: Attitude
Develop an attitude of discovery/innovation/creativity, as demonstrated by students possessing a strong sense of curiosity, asking questions actively, challenging assumptions or engaging in inquiry together with teachers.

A2: Ability
Develop the ability/skill needed to discover/innovate/create, as demonstrated by students possessing critical thinking skills to assess ideas, acquiring research skills, synthesizing knowledge across disciplines or applying academic knowledge to real-life problems.

A3: Accomplishments

Demonstrate accomplishment of discovery/innovation/creativity through producing /constructing creative works/new artefacts, effective solutions to real-life problems or new processes.

Learning and Teaching Activities (LTAs)

	LTAs	Brief Description	CILO No.	Hours/week (if applicable)
1	Lectures	Learning through teaching is primarily based on lectures	1, 2, 3, 4	39 hours in total
2	Assignment	Learning through take-home assignments helps students understand basic concepts and theory, and develop the ability of thinking both heuristically and rigorously.	1, 2, 3, 4	After-class

Assessment Tasks / Activities (ATs)

	ATs	CILO No.	Weighting (%)	Remarks (e.g. Parameter for GenAI use)
1	Assignments (3 or above)	1, 2, 3, 4, 5	20	
2	Quizzes/Test/Midterm	1, 2, 3, 4, 5	20	

Continuous Assessment (%)

40

Examination (%)

60

Examination Duration (Hours)

2

Additional Information for ATs

40% Coursework
60% Examination (Duration: 2 hours)

For a student to pass the course, at least 30% of the maximum mark for the examination must be obtained.

Assessment Rubrics (AR)

Assessment Task

1. Assignments

Criterion

Ability to demonstrate a strong understanding of mathematical concepts relevant to machine learning, such as linear algebra, calculus, probability theory, and statistics. Capacity to interpret mathematical notations and formulas commonly used in machine learning algorithms

Excellent (A+, A, A-)

Demonstrates a thorough understanding of the concepts, theories, techniques and algorithms in machine learning and can always apply this understanding to solve a range of machine learning problems.

Good (B+, B, B-)

Demonstrates a substantial understanding of the concepts, theories, techniques and algorithms in machine learning and can usually apply this understanding to solve a range of machine learning problems.

Fair (C+, C, C-)

Demonstrates a general understanding of the concepts, theories, techniques and algorithms in machine learning and can sometimes apply this understanding to solve a range of machine learning problems.

Marginal (D)

Demonstrates a partial understanding of the concepts, theories, techniques and algorithms in machine learning and can rarely apply this understanding to solve a range of machine learning problems.

Failure (F)

Demonstrates a little understanding of the concepts, theories, techniques and algorithms in machine learning and can rarely apply this understanding to solve a range of machine learning problems.

Assessment Task

2. Quizzes/Test/Midterm

Criterion

Capability to formulate machine learning problems mathematically and develop appropriate solutions. Ability to analyze the performance of machine learning models using mathematical metrics and techniques.

Excellent (A+, A, A-)

Demonstrates a thorough understanding of the concepts, theories, techniques and algorithms in machine learning and can always apply this understanding to solve a range of machine learning problems.

Good (B+, B, B-)

Demonstrates a substantial understanding of the concepts, theories, techniques and algorithms in machine learning and can usually apply this understanding to solve a range of machine learning problems.

Fair (C+, C, C-)

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Assessment Task

3. Examination

Criterion

Capability to formulate machine learning problems mathematically and develop appropriate solutions. Ability to analyze the performance of machine learning models using mathematical metrics and techniques.

Excellent (A+, A, A-)

Demonstrates a thorough understanding of the concepts, theories, techniques and algorithms in machine learning and can always apply this understanding to solve a range of machine learning problems.

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Part III Other Information

Keyword Syllabus

classification, linear regression, logistic/softmax regression, support vector machine, deep neural network; bias-variance trade-off, regularization, model complexity, Rademacher complexity, VC-dimension, generalization error; estimation of approximation error, reproducing Kernel Hilbert spaces, probability inequalities; empirical risk minimization, convex optimization, K-means, stochastic gradient descent

Reading List

Compulsory Readings

	Title
1	Lecture notes distributed in class

Additional Readings

	Title
1	The “Machine Learning” course of Andrew Ng at the website: https://www.coursera.org/learn/machine-learning
2	Cucker, F., & Zhou, D. (2007). Learning theory: An approximation theory viewpoint (Cambridge Monographs on Applied and Computational Mathematics). Cambridge: Cambridge University Press.
3	Simon J.D. Prince. Understanding Deep Learning. MIT Press.
4	Pattern Recognition and Machine Learning, by Christopher M. Bishop. Springer, 2006
5	Francis Bach. Learning Theory from First Principles.