Department of Computer Science
Ramakrishna Mission Vivekananda Educational and Research Institute

CS 211 : Optimization for Machine Learning

(August-December 2023)

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Course Overview: This course focuses on select topics from convex optimization theory, algorithms of unconstrained and constrained optimization, batch gradient methods etc. that are needed to build a solid understanding of, as well as implement several machine learning algorithns. The purpose of this course is to summarize and analyze classical and modern optimization methods from a machine learning perspective.

Prerequisite(s): Linear Algebra, Multivariate calculus

Credit Hours: 4

Course Objectives: Optimization techniques are used in various fields like machine learning, graph theory, VLSI design and complex networks. The intersection and interaction between two vital and growing fields, machine learning and optimization, has led to many interesting developments in the field of computational data science. On one hand optimization formulations are vital in designing machine learning algorithms, and on the other hand, machine learning feeds to the development of new optimization ideas.

Knowledge Gained: Students will gain knowledge about

- Theory of convex functions, sets and convex optimization
- Geometric interpretation of feasibility and optimality conditions
- Conditions for existence and uniqueness of optimal solution
- Different unconstrained and constrained algorithms used in Machine Learning models

Skill: Students will have the following skills

- How to formulate optimization problems
- How to write a computer program to solve a mathematical optimization problem
- How to perform sensitivity analysis on the optimal solution of a problem

Competency: Students will earn the following competencies

- Ability to understand the interplay between optimization and machine learning.
- Ability to understand the workings of various standard optimization libraries/solvers and use them to solve optimization problems

Text Book: The course material will be drawn from multiple book chapters, journal articles, reviewed tutorials etc. However, the following books are recommended texts for this course.

- *Optimization for Machine Learning*, Suvrit Sra, Sebastian Nowozin and Stephen Wright (Editors), The MIT Press, Dec. 2011.
- *Nonlinear Programming: Theory and Algorithms*, Wiley-Blackwell; 3rd Edition (2006) M. S. Bazaraa, Hanif D. Sherali, C. M. Shetty, **ISBN-13:** 978-0471486008
- *Convex Optimization*, Cambridge University Press; 1st Edition (2004) Stephen Boyd and Lieven Vandenberghe, **ISBN-13:** 9780521833783

Course Policies:

- **Modality**

  This course will be conducted through LMS. Lecture notes, assignments etc will be posted in LMS Students should visit course page on LMS regularly.

Table 1: **Topics**

Mathematical Preliminaries

- Norms of vectors, Sets and Functions in euclidean space
- Derivatives of multivariate functions, directional derivative, Gradient, Jacobian and Hessian

Theory of Convex Optimization

- Convex sets, convex functions and their characterizations
- Convexity preserving operations
- Composition of convex functions
- Generalized convexity
- Unconstrained Optimization: Necessary and Sufficient conditions
- Constrained Optimization: Necessary and Sufficient conditions for problems with equality and inequality constraints, KKT optimality conditions, Constraint Qualification, Lagrangian Duality and Saddle Point Optimality Criteria

Optimization in ML : – Analysis of ML model(s) from the point of Convex Optimization Theory

Optimization Algorithms used in Machine Learning

- First-order Algorithms: Steepest/Gradient Descent, Properties of GD
- (if time permits) Conjugate Gradient, Stochastic Gradient Descent

- **Academic Integrity**

  1. Students are expected to work independently in the Assignments. Discussion amongst students is encouraged but offering solution to others as well as accepting solutions from others both are act of academic dishonesty. In such cases students will be penalized according to the *Academic Honesty Policy* of University.

- **Assignments/Quizes**

  1. Except under medical reasons late assignments will **not be accepted**. Late assignments will be marked down by 10%
  2. Surprise quizes may be conducted to check attentiveness, attention and attendance in the online class mode.

- **Attendance and Absence**

  Students are not supposed to miss class without strong reasons such as medical needs or emergency situations. Students must be aware that, except these cases, if a student falls short of attendance requirement specified by the Controller of Examination/Head of the Department then he may not be allowed to appear in the final examination. **A minimum of 80% attendance is required in order to appear for the finals.** Students are responsible for all missed work, regardless of the reason for absence. It is also the absentee's responsibility to get all missing notes or materials.

Grade Distribution:

Assignments	30%
Midterm Exam	30%
Final Exam	40%

Grading Policy: $> 95 : A+, 75 - 95 : A, 60 - 75 : B, 45 - 60 : C, 30 - 45 : D, < 30 : F$