NIRMA UNIVERSITY

Institute:	Institute of Technology
Name of Programme:	BTech CSE (Artificial Intelligence & Machine Learning)
Course Code:	XXXX
Course Title:	Computational Mathematics for AI&ML
Course Type:	Core
Year of Introduction:	2025-26

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Course Learning Outcomes (CLO):

At the end of the course, the students will be able to:

1. explain optimization problems (BL1)
2. apply unconstrained and constrained optimization techniques (BL2,3)
3. implement gradient-based and heuristic optimization algorithms (BL3,6)
4. analyse convergence and performance of optimization algorithms in ML model training. (BL4,5)

Unit	Contents	Teaching Hours (Total 45)
Unit-I	**Introduction to Optimization:** Definitions: Objective function, constraints, feasible region, Types of optimizations: Linear, Non-linear, Convex, Combinatorial, Formulating ML problems as optimization tasks	06
Unit-II	Loss functions and optimization goals, Optimization in Linear Regression, Logistic Regression, Optimization Challenges in DL like Saddle points, plateaus, Overfitting vs. underfitting, Generalization and flat minima	08
Unit-III	**Unconstrained Optimization:** Single-variable and multivariable optimization, First and second-order optimality conditions, Gradient descent and its variants: Stochastic, Mini-batch, Momentum, Momentum-based methods, Nesterov Accelerated Gradient (NAG), Gradient clipping and exploding/vanishing gradients, Second-order methods (Newton, Quasi-Newton), Optimization landscapes and visualization, Implicit bias in optimizers	10
Unit-IV	**Constrained Optimization:** Equality and inequality constraints, Lagrange multipliers and KKT conditions, Penalty and barrier methods	06
Unit-V	**Convex Optimization:** Convex sets and convex functions, convex optimization problem formulation, Duality and Slater's condition, Applications in Support Vector Machines (SVM)	06
Unit-VI	**Metaheuristic and Evolutionary Optimization**: Genetic Algorithms, Simulated Annealing, Particle Swarm Optimization (PSO), Use cases in hyperparameter tuning	09

Self-Study:

The self-study contents will be declared at the commencement of the semester. Around 10% of the questions will be asked from self-study content

Suggested Readings/ References:

1. Edwin K. P. Chong and Stanislaw H. Zak, An Introduction to Optimization, Wiley
2. Stephen Boyd and Lieven Vandenberghe, Convex Optimization, Cambridge University Press
3. Jorge Nocedal and Stephen Wright, Numerical Optimization, Springer
4. Deisenroth et al., Mathematics for Machine Learning, Cambridge University Press

Laboratory Work:

Laboratory work will be based on the above syllabus with a minimum of 10 experiments to be incorporated. The students in a suitable group size will design and perform one experiment as a part of Laboratory work.

Sr. No.	List of Experiments/Exercises	Hours
1	Implement linear regression with gradient descent on convex and non-convex functions.	02
2	Implement logistic regression with cost minimization.	02
3	Solve a constrained optimization problem using Lagrangian formulation.	04
4	Solve quadratic programming problem.	04
5	Implement hard/soft-margin SVM using convex optimization tools.	04
6	Tune model parameters using optimization-based search	02
7	Use SGD, Adam, and RMSProp on a simple neural network (TensorFlow/PyTorch).	04
8	Use early stopping and Model checkpointing to prevent overfitting in long training runs.	02
9	Apply GA for optimizing feature subset selection.	04
10	Use Particle Swarm Optimization to find minima of a non-convex function.	04