Computational Methods in Optimization

Code: CS31123CS	Course Type: Elective	Semester: I
Evolution Scheme (TA-MSE-ESE): 20-30-100	Total Marks: 150	L-T-P (Credits): 3-0-0 (3)

Pre-Requisites: Linear Algebra, Probability Theory, Numerical Methods, Programming (Python/MATLAB), Basic Knowledge of Algorithms.

Course Objective: To develop a rigorous understanding of optimization theory and advanced computational methods, enabling students to design, analyze, and implement scalable optimization algorithms for complex engineering and data-driven applications.

Course Outcomes: At the end of the course, the student will be able to

CO-1	Formulate and analyze optimization problems using rigorous mathematical frameworks.
CO-2	Apply advanced deterministic optimization algorithms with theoretical guarantees.
CO-3	Design and implement large-scale and stochastic optimization methods.
CO-4	Critically evaluate and deploy optimization techniques in real-world and research settings.

Course Articulation Matrix:

PO	PEO-1	PEO-2	PEO-3	PEO-4	PEO-5
CO-1	3	2	2	-	-
CO-2	3	3	2	-	1
CO-3	3	3	3	1	2
CO-4	3	3	2	2	3

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Unit-1: Mathematical Foundations of Optimization
Convex sets and functions, separation theorems, duality theory, Lagrangian and saddle-point theory, Karush-Kuhn-Tucker (KKT) conditions, sensitivity and perturbation analysis, strong vs weak duality, geometric interpretation of optimization problems.

Unit-2: Advanced Deterministic Optimization Algorithms
Linear Programming: Revised simplex method, primal-dual methods, interior-point methods (theory and complexity), Nonlinear Optimization: Gradient methods, accelerated gradient methods, Newton and quasi-Newton methods (BFGS, L-BFGS), constrained optimization (SQP), convergence rate analysis.

Unit-3: Large-Scale and Stochastic Optimization
Stochastic Gradient Descent (SGD) and variants (Adam, RMSProp), variance reduction methods, distributed and parallel optimization, coordinate descent methods, proximal algorithms, convex-concave saddle point problems, optimization in machine learning contexts.

Unit-4: Metaheuristics and Emerging Optimization Paradigms

Evolutionary algorithms (GA, ES), swarm intelligence (PSO, ACO), simulated annealing, hybrid optimization frameworks, multi-objective optimization (Pareto optimality), robust optimization, applications in deep learning, smart systems, and industrial optimization problems..

Learning Resources:

Text Books:

1.Jorge Nocedal and Stephen J. Wright, Numerical Optimization, Springer.
2.Dimitri P. Bertsekas, Nonlinear Programming, Athena Scientific.

Reference Books:

1. Stephen Boyd and Lieven Vandenberghe, Convex Optimization, Cambridge University Press.
2. Amir Beck, First-Order Methods in Optimization, SIAM.
3. Kalyanmoy Deb, Multi-Objective Optimization using Evolutionary Algorithms, Wiley.
4. Bubeck, Convex Optimization: Algorithms and Complexity, Foundations and Trends in ML.