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(शिक्षा मंत्रालय, भारत सरकार के अधीन एक राष्ट्रीय महत्व का संस्थान / An Institute of National Importance under Ministry of Education, Gov. of India)
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## CSXX0238: Theory of Learning and Kernel methods

**L - T - P – Cr: 2 - 0 - 2 – 3**

**Pre-requisites:** Probability and Statistics, Machine Learning, Programming Knowledge.

**Course Objectives:**

- Understand the theoretical foundations of machine learning.
- Study formal models of learning, generalization, and hypothesis classes.
- Learn kernel methods and their application in machine learning.
- Understand the interplay between theory and practice in model selection and regularization.

**Course Outcomes:**

By the end of this course, students will be able to:

1. **Understand and evaluate theoretical learning frameworks.**
2. **Apply empirical risk minimization and structural risk minimization principles.**
3. **Develop and analyze linear models with various loss functions and regularization techniques.**
4. **Implement and utilize kernel methods.**
5. **Explore advanced kernel-based techniques.**

**CO-PO Mapping**

| Course Outcomes (COs) | PO1 | PO2 | PO3 | PO4 | PO5 | PO6 | PO7 | PO8 | PO9 | PO10 | PO11 | PO12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CO1** | 3 | 3 | 2 | 2 | 1 | – | – | – | – | – | – | 2 |
| **CO2** | 3 | 3 | 2 | 2 | 1 | – | – | – | – | – | – | 2 |
| **CO3** | 3 | 3 | 3 | 2 | 2 | – | – | – | – | – | – | 2 |
| **CO4** | 3 | 3 | 3 | 2 | 3 | – | – | – | – | – | – | 2 |
| **CO5** | 2 | 3 | 3 | 3 | 3 | – | – | – | 1 | 1 | 1 | 3 |

## Detailed Syllabus

**UNIT 1: Foundations of Statistical Learning** **Lectures: 0*5 hrs***

Introduction to supervised learning, Hypothesis spaces and inductive bias, Empirical Risk Minimization (ERM), Consistency and generalization, Bias-variance decomposition.

**UNIT 2: Theoretical Learning Models** **Lectures: 0*6 hrs***

PAC (Probably Approximately Correct) learning, Sample complexity, VC-Dimension and VC-theory

Structural Risk Minimization (SRM), Rademacher complexity, No Free Lunch theorem.

**UNIT 3: Linear Models and Regularization** **Lectures: 0*5* *hrs***

Linear classifiers and regressors, Loss functions: hinge, logistic, squared, Regularization (L1, L2)

Ridge regression and Lasso, Duality and Representer Theorem.

**UNIT 4: Kernel Methods and SVM** **Lectures: 0*7* *hrs***

Kernel trick and feature spaces, Common kernels: linear, polynomial, RBF, sigmoid, Mercer's theorem, SVMs: hard and soft margin, Dual formulation and kernelized SVM, Sequential Minimal Optimization (SMO)

**UNIT 5: Advanced Topics and Applications** **Lectures: 0*5* *hrs***

Kernel PCA, Multiple Kernel Learning (MKL), Graph and string kernels, Applications in NLP, vision, and bioinformatics, Generalization in deep learning (overview), Double descent phenomenon.

**Textbooks & References**

1. ***Understanding Machine Learning: From Theory to Algorithms* by Shai Shalev-Shwartz and Shai Ben-David**
2. **Machine Learning with SVM and other kernel methods, K.P. Soman, R Loganathan, and V. Ajay, PHI publisher.**
3. ***Learning with Kernels* by Bernhard Schölkopf and Alexander J. Smola**
4. ***Pattern Recognition and Machine Learning* by Christopher M. Bishop**

**Research papers on PAC learning, kernel methods, and VC-dimension**