IIT Mandi

Proposal for a New Course

Course number	**:** EE 541
Course Name	**:** Tensors: Techniques, Algorithms, Applications for Signal Processing, and Machine Learning.
Credit Distribution	**:** 3-0-2-4
Intended for	**:** B.Tech. (3rd/4th year)/ MTech/ MS/ PhD of the SCEE.
Prerequisite	**:** Linear algebra, basic probability, and statistics.
Mutual Exclusion	**:** None (at present)

1. Preamble:

Many modern applications in signal processing for communications and neuroscience, text mining, computer vision, time series, and pattern recognition generate massive amounts of multimodal data. Multimodal data are generally referred to the datasets that are characterized by more than two modes, for example, images, time series data, video, etc. Tensors provide a natural way to represent such datasets. Intuitively, a tensor can be considered a multidimensional array and a generalization of matrices and vectors. Thus, making tensor ubiquitous in signal and data analytics at the confluence of signal processing, statistics, data mining, and machine learning.

The course aims to provide a good starting point for researchers and practitioners interested in learning about and working with tensors. It focuses on the fundamentals required to learn the tensor based techniques. The course aims to strike an appropriate balance of breadth, depth and applications enabling the students to apply, do research, and/ or develop algorithm, and software. The course consists of multilinear algebraic operators and their interpretations; several types of tensor decomposition techniques and their applications in signal processing and machine learning, such as source separation, collaborative filtering, topic modelling, learning HMMs, and algorithmic techniques to compress tensors that retain the inherent properties of the uncompressed one.

2. Course Modules with quantitative lecture hours:

I. *Linear algebra recap:* *(5 hours)*
Vector spaces, subspaces, linear in/dependence, bases, dimensions, principle of orthogonality and projections, linear models least-squares problems, Rank-decomposition for matrix, SVD and low-rank matrix approximation.

II. *Working with Tensors:* *(10 hours)*
Useful products and their properties (Inner, Outer, Hadamard, Kronecker, and Khatri-Rao, and mode-n). Tensor, its different views, and reshaping. Operators on tensors, tensor contraction, their algebraic properties, tensor rank, low rank tensor approximation, Tensor calculus and it's fundamental operations.

III. *Tensor factorization and its computation:* *(9 hours)*
Rank decomposition for tensor, CP decomposition (CANDECOMP/ PARAFAC), properties of CP decomposition, Hardness of CP decomposition, algorithms for computing decompositions (ALS, Jennrich's algorithm, etc.); Other notions of tensor decomposition: Tucker decomposition, HOSVD (higher order SVD), Tensor train decomposition (TT-SVD).

IV. *Techniques for compressing tensors:* *(8 hours)*
Dimensionality reduction (random projection) for vectors, Tensorized random projection, Compressing Tensors using Count Sketch, Higher Order Count Sketch.

V. *Applications:* *(10 hours)*
Blind Multiuser CDMA, Blind Source Separation, Harmonics, Gaussian Mixture parameter estimation, learning latent variables, Topic modelling, Learning Hidden Markov Models, Community detection, Collaborative filtering-based recommender systems, including recent ML/ SP based approaches.

Laboratory/ practical/ tutorial Modules:
The two-hours of lab session will enhance the understanding of the concepts taught in the class. The lab will cover the concepts including, principle of orthogonality, least Squares, SVD, low-rank matrix decomposition, Inner, Outer, Hadamard, Kronecker, and Khatri-Rao products, mode-n Tensor, PARAFAC, HOSVD, TT-SVD, ALS, low-rank tensor decomposition, etc.

3. Text books:

[1]. J. Landsberg, Tensors: Geometry and Applications, vol. 128. Providence, RI, USA: Amer. Math. Soc., 2011.
[2]. Haiping Lu, Konstantinos N. Plataniotis, Anastasios Venetsanopoulos, Multilinear Subspace Learning - Dimensionality Reduction of Multidimensional Data, CRC press, 1st Edition, 2015.

4. References:

[3]. Ankur Moitra, Algorithmic aspects of machine learning. Cambridge University Press, 2018.
[4]. T. G. Kolda, B. W. Bader, Tensor Decomposition and Applications. SIAM Review, 2009.
[5]. N. D. Sidiropoulos, L. De Lathauwer, X. Fu, K. Huang, E. E. Papalexakis, and C. Faloutsos, Tensor decomposition for signal processing and machine learning, IEEE Trans. Signal Process., vol. 65, no. 13, pp. 3551–3582, Jul. 2017.

5. Similarity with the existing courses:
(Similarity content is declared as per the number of lecture hours on similar topics)

S. No.	Course Code	Similarity Content	Approx. % of Content
1.	EE522, CS512, MA512	Linear algebra recap	10%