NPTEL Syllabus Template

Course Title	Matrix Theory and Applications
Discipline	Electrical Engineering, Computer Science
Duration of course 4/8/12 weeks (10/20/30 hours @2.5 hrs/week)	12 weeks
Number of times you have taught this course totally and in the last 5 years (2-3 times is preferable, if not more)	4
Is this course syllabus approved by AICTE or by Senate in your/any institute? If yes, please give the course name and institute under which this is approved.	Related courses: EE5609 Matrix Theory and EE2100 Matrix Theory, approved by IIT Hyderabad Senate; some overlap with EE5606 Convex Optimization (also approved by IITH Senate)
The time frame of when you would want to offer the course: (Jan 2024/July 2024)	July 2024
Will it map to any course in the AICTE model curriculum? LINK to AICTE Curriculum LINK 1 LINK 2 LINK 3 LINK 4 Will it map onto any of the NPTEL domain? LINK to Domain page: https://nptel.ac.in/noc/Domain/	This course is similar to Applied Linear Algebra https://nptel.ac.in/courses/108106171. Pls see details below.

Differentiating Factors from Current NPTEL Offerings

The proposed course, "Matrix Theory and Applications" envisions a layered learning experience where theoretical insights are accompanied by examples and applications. The course hopes to explore the links between matrix theory and its many applications, primarily to probability, machine learning and optimization. The aim is to equip students with theoretical know-how on working with matrices, which is needed to excel in the evolving landscape of data science and machine learning. The course is split into two parts - the first half (6 weeks) covers the basics along with relevant examples, and the second half covers the applications of the ideas learnt in the first half to probability, optimization and learning. The proposed course draws significant inspiration from the following texts

a. "Introduction to Applied Linear Algebra – Vectors, Matrices, and Least Squares" by Stephen Boyd and Lieven Vandenberghe. While it doesn't exhaustively cover all topics, the text's elegant simplicity and emphasis on examples and applications align well with the course's philosophy.
b. “Linear Algebra and Learning from Data.” by Gilbert Strang. The text covers a wide variety of topics, providing a valuable complement to the text by Boyd and Vandenberghe above.

The course assumes a prior background in elementary probability and multivariable calculus.

The following points summarize the salient features of this course proposal that differentiate it from existing offerings

1. ***Broader scope:*** In addition to introducing the basic concepts up to SVD, the course aims to briefly cover some of the many applications of these ideas; primarily to machine learning via least squares and optimization techniques. The course plan includes covering least squares and variants, including recursive least squares; Gradient descent in the context of least squares, Newton's method; low-rank approximations and PCA; in addition to the topics mentioned below.
2. ***Pacing:*** In order to cover the planned content, the course plans for an economy of ideas by sacrificing some generality. For instance, topics on Gaussian elimination (and LU/LDU decomposition), determinants, and infinite dimensional spaces are skipped. The focus on finite-dimensional inner product spaces from the outset allows us to adopt a matrix-theoretic perspective of basic linear algebraic constructs. Mathematical rigour is not sacrificed, though some of the later topics in the course will include only partial proofs that convey the key ideas.
3. ***Least squares:*** The course places consistent emphasis on connections to machine learning and plans to delve deeper into additional variants and algorithms related to least squares and its applications. We cover multiobjective least squares (optimal tradeoff curves), constrained least squares (which also provides an introduction to Lagrange multipliers), rank one updates leading to recursive least squares. In other parts of the course, we also discuss gradient descent for least squares and the key ideas behind fast implementations for large matrices (randomized least squares).
4. ***Algorithmic considerations:*** The course covers computational complexity issues associated with matrix operations. Motivated by (Boyd & Vandenberghe 2016) the course starts with QR decomposition as the sole computational tool for solving systems of linear equations and least squares. Later on in the course, randomized algorithms for basic matrix operations (randomized linear algebra) are introduced, followed by random projections (linear embeddings); we then discuss how to apply these ideas to least squares.
5. ***Closer integration with probability:*** The course explores the connections between matrix theory and probability for e.g. by introducing Schur complements via conditional probability, Perron Frobenius theorem via the study of Markov Chains, etc. The later part of the course also includes concepts from randomized linear algebra and the universality of the spectra of random matrices.

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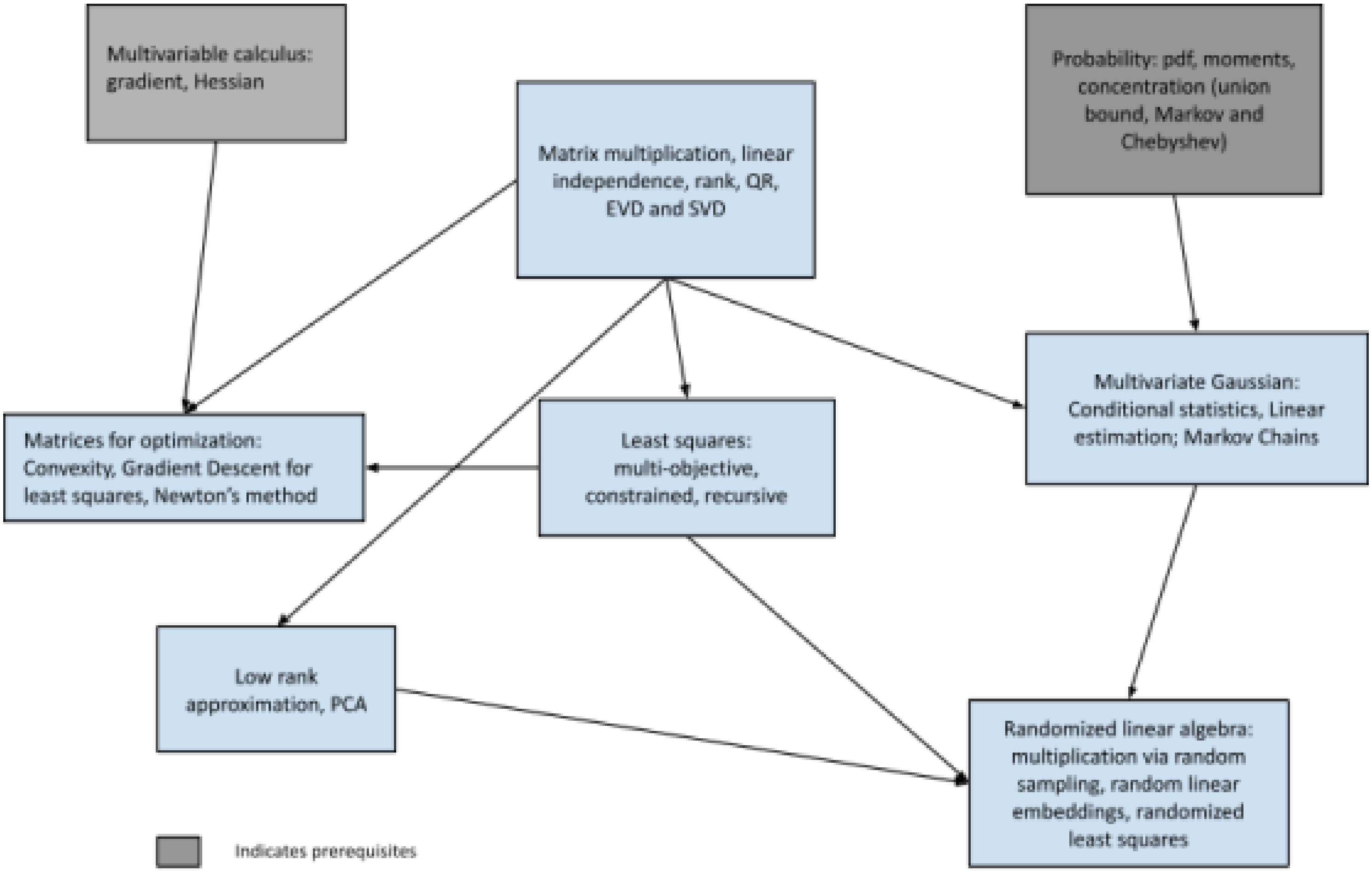

Proposed learning roadmap

Intended audience	Undergraduate, first-year postgraduate students in EE, CSE, AI/Data Science
Is it a core/elective course?	Elective
Is it a UG/PG/PhD level course?	Undergraduate, first-year postgraduate
Is this course relevant for GATE exam preparation?	Yes
Which degrees would it apply to? (BE/ME/MS/BSc/MSc/PhD etc)	BTech, Mtech (1st yr)

Advanced Linear algebra and convex optimization are immediate

What are the next set of courses that can be taken by students who complete this?

follow-up courses. The course also provides a better understanding of concepts used in other core engineering courses in EE, CSE and AI/Data Science.

Pre-requisites in terms of educational qualification of participants, or if any other courses should be done before this course can be taken	Familiarity with basic mathematical notation and arguments, basic probability and basic multivariate calculus are the main prerequisites. Many of the examples will draw from data science, but prior exposure to these topics is not required.
Industry recognition of this course – List of companies/industry that will recognize/value this online course	This is a foundational course that improves the general understanding of other core engineering techniques involving linear algebra. In addition, this course will draw a lot of examples from Machine Learning, which may be useful for students interested in pursuing further courses in AI.
Will the final certification exam be– paper/pen type or computer based - both are proctored	**Computer-based**
Will the course require use of any software such as MATLAB or any programming language, etc. or any other tool? If yes, does it have a Linux based compiler available or if licensed, can we get the educational license for the same?	The course assignments will use open-source software (numpy/julia)
Names of 2 reviewers for the course (can be from other institutes – will be used if we need any additional inputs on the course) – Name, Dept, email id, Institute	Kindly pick any reviewers as required. Below, I am giving names of instructors who I know have taught similar courses before Name : Prof. Sumohana Channappayya Dept. EE Institute : IIT Hyderabad Email : sumohana@ee.iith.ac.in Name : Prof. Andrew Thangaraj Dept. : EE Institute : IIT Madras Email : andrew@iitm.ac.in
List of reference materials/books	Strang, Gilbert. *Linear algebra and learning from data*. Wellesley-Cambridge Press, 2019. Boyd, Stephen, and Lieven Vandenberghe. *Introduction to applied linear algebra: vectors, matrices, and least squares*. Cambridge university press, 2018 Horn, Roger A., and Charles R. Johnson. *Matrix analysis*. Cambridge university press, 2012 Strang, Gilbert, et al. *Introduction to linear algebra*. Vol. 3. Wellesley, MA: Wellesley-Cambridge Press, 1993. Axler, Sheldon Jay. *Linear algebra done right*. Vol. 2. New York: Springer, 1997.

FOR GETTING THE INTRODUCTORY COURSE PAGE READY – TO OPEN FOR ENROLLMENTS

1. Introduce the course in about 4-5 lines

This course introduces basic linear algebra, matrix decompositions, least squares, associated algorithms, and applications to optimisation, machine learning and probability; specially tailored for engineering students. No prior exposure to optimization or machine learning is required. Alongside theoretical instruction, the course also covers algorithmic implementations and includes programming assignments.

2. Photograph of instructor(s)

3. About the instructor(s)

Aditya Siripuram completed his B.Tech and M.Tech degrees in Electrical Engineering from the Indian Institute of Technology Bombay, followed by a Ph.D. in Electrical Engineering from Stanford University. He has been a faculty member in the Department of Electrical Engineering at IIT Hyderabad since 2017. His primary research interest lies in the design and analysis of algorithms for signal-processing applications. Aditya Siripuram has served as the primary instructor for multiple summer courses at Stanford University, and numerous foundational courses at IITH- especially relating to Optimisation, Probability and application of Matrices. His commitment to education has been recognized with the Excellence in Teaching Award from IIT Hyderabad in both 2019 and 2022.

4. An introductory video about the course (2-5 minutes' duration)

Weekly Course Plan		
Weeks	Lecture Names	Assignments
Week 1	***Basics:*** Vectors and vector spaces, inner products, distances, matrix product, linear transformations, common matrices (diagonal, triangular, symmetric), systems of linear equations, solving diagonal and triangular systems	Online
Week 2	***Matrix Spaces:*** linear dependence and independence, column and null spaces, rank and dimension	Online
Week 3	***Computing with Matrices:*** Orthogonal matrices, Projection, Gram-Schmidt orthogonalization, QR Decomposition, Trace, complexity of standard matrix operations	Online
Week 4	***Least Squares:*** Inverse, Pseudoinverse, Least squares; Data fitting with least squares, Least squares variants (multi-objective, constrained), rank one update and Recursive least squares	Online
Week 5	***EVD:*** Eigenvalues and eigenvectors, Spectral decomposition, Positive definite matrices, Rayleigh quotients.	Online
Week 6	***SVD:*** Singular value decomposition, selected applications of matrix decompositions (orthogonal Procustes, spectral graph clustering), matrix norms and circle theorems	Online

Week 7 Week 8, Week 9	***Matrices for Dimensionality Reduction:*** Low-rank approximations, Eckart Young Misrky theorem, Principal component analysis, applications ***Matrices for Statistics I:*** Review of basic probability (mean, variance, correlation), covariance matrices, multivariate Gaussian, least squares for multivariate Gaussian, conditioning and Schur complements ***Matrices for Statistics II:*** Markov chains, Perron Frobenius theorem, steady state	Online Online
Week 9, Week 10	***Matrices for Convex Optimization I:*** Convexity, min norm problems, Gradient descent and Newton's method ***Matrices for Convex Optimization II:*** Nonlinear least squares, Lagrange multipliers for Linear and quadratic programs	Online
Week 11, Week 12	***Computing with Large Matrices:*** Approximate matrix multiplication with random sampling, random linear embeddings and JL Lemma, randomized least squares	Online
Week 12	***Random Matrices:*** Motivation, Wigner matrix ensembles (GOE, Symmetric bernoulli), Wigner semicircle law	Online

TA Details			
	:	Teaching Assistant 1	Teaching Assistant 2
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