SI231 – Matrix Computations
Fall 2020-21, ShanghaiTech

Basic Information:

Instructor: Prof. Ziping Zhao (https://zipingzhao.github.io)
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SI231 – Matrix Computations [4 credits: 3+1]
Website: http://si231.sist.shanghaitech.edu.cn/
Lecture Time: Tue/Thu 10:15am – 11:55am
Lecture Venue: Rm. 101, Teaching Center ~~Rm. 202, Teaching Center, Rm. 1D-108, SIST Building~~

Description:

Matrix analysis and computations are widely used in engineering fields — such as statistics, optimization, machine learning, computer vision, systems and control, signal and image processing, communications and networks, smart grid, and many more — and are considered key fundamental tools.

SI231: Matrix Computations covers topics at an advanced or research level especially for people working in the general areas of Data Analysis, Signal Processing, and Machine Learning.

This course consists of several parts.

- The first part focuses on various matrix factorizations, such as eigendecomposition, singular value decomposition, Schur decomposition, QZ decomposition and nonnegative factorization.
- The second part considers important matrix operations and solutions such as matrix inversion lemmas, linear system of equations, least squares, subspace projections, Kronecker product, Hadamard product and the vectorization operator. Sensitivity and computational aspects are also studied.
- The third part explores presently frontier or further advanced topics, such as matrix calculus and its various applications, deep learning, tensor decomposition, and compressive sensing (or managing undetermined systems of equations via sparsity). Especially, matrix concepts are key for understanding and creating machine learning algorithms, and hence, a special focus will be given on how matrix computations are applied to neural networks.

In each part, the relevance to engineering fields is emphasized and applications are showcased.

Textbooks:

- Gene H. Golub and Charles F. Van Loan, Matrix Computations (Fourth edition), The John Hopkins University Press, 2013.
- Roger. A. Horn and Charles. R. Johnson, Matrix Analysis (Second Edition), Cambridge University Press, 2012.
- Jan R. Magnus and Heinz Neudecker, Matrix Differential Calculus with Applications in Statistics and Econometrics (Third Edition), John Wiley and Sons, New York, 2007.
- Gilbert Strang, Linear Algebra and Learning from Data, Wellesley-Cambridge Press, 2019.
- Carl D. Meyer, Matrix Analysis and Applied Linear Algebra, SIAM (Society for Industrial and Applied Mathematics), 2000.
- Alan J. Laub, Matrix Analysis for Scientists & Engineers, SIAM (Society for Industrial and Applied Mathematics), 2004.

Prerequisite:

Students are expected to have a solid background in linear algebra and know basic machine learning and signal processing. They are also expected to have research experience in their particular area and be capable of reading and dissecting scientific papers.

Grading:
Assignments: 30% (auditors too)
Mid-term exam: 40% (auditors too)
Final Project: 30% (homeworks and midterm are required to be passed)

Course Schedule:

Date	Lec.	Topic	HW out	HW in
Sept-8	1	Lecture 0: Overview		
Sept-10	2	Lecture 1: Basic Concepts I		
Sept-15	3	Lecture 1: Basic Concepts II		
Sept-17	4	Lecture 2: Linear Systems I	HW1	
Sept-22	5	Lecture 2: Linear Systems II		
Sept-24	6	Lecture 2: Linear Systems III		HW1
Sept-29	7	Lecture 3: Least Squares I		
~~Oct-1~~ (National Day holiday)	~~8~~		HW2	
~~Oct-6~~ (National Day holiday)	~~9~~			
~~Oct-8~~ Oct-10	10	Lecture 3: Least Squares II		HW2
Oct-13	11	Lecture 4: Orthogonalization and QR Decomposition I		
Oct-15	12	Lecture 4: Orthogonalization and QR Decomposition II	HW3	
Oct-20	13	Lecture 5: Eigenvalues, Eigenvectors, and Eigendecomposition I		
Oct-22	14	Lecture 5: Eigenvalues, Eigenvectors, and Eigendecomposition II		HW3
Oct-27	15	Lecture 5: Eigenvalues, Eigenvectors, and Eigendecomposition III		
Oct-29	16	Lecture 5: Eigenvalues, Eigenvectors, and Eigendecomposition IV	HW4	
Nov-3	17	Lecture 5: Eigenvalues, Eigenvectors, and Eigendecomposition V		
Nov-5	18	Lecture 6: Positive Semidefinite Matrices		HW4
Nov-10	19	Lecture 7: Singular Value Decomposition I		
Nov-12	20	Lecture 7: Singular Value Decomposition II	HW5	
Nov-17	21	Lecture 8: Least Squares Revisited I		
Nov-19	22	Lecture 8: Least Squares Revisited II		HW5
Nov-24	23	Tensor Decompositions (guest lecture)		
Nov-26	24	Lecture 9: Kronecker Product and Hadamard Product Lecture 10: Review		
	Recitation			
Dec-24	**Final Project Presentation**			

	extra	Neural Networks		
		Matrix Calculus		
		Reduced-Rank Regression		