Indian Institute of Technology Jodhpur

PG Course Booklet

Indian Institute of Technology Jodhpur

July 2021

॥ त्वं ज्ञानमयो विज्ञानमयोऽसि ॥

M.Tech. & M.Tech-Ph.D. Dual Degree

in

Data and Computational Science

(1) Introduction

Data Science is the art of generating insight, knowledge and predictions by processing of data gathered about a system or a process. Computational Science is the art of developing validated (simulation) models in order to gain a better understanding of a phenomenon (system's or processes). Computational sciences focus on development of causal models using latent patterns in the observed data, rather than only extracting patterns or knowledge from data by statistical methods.

(2) Objective of the Programme

To produce professionals with deep knowledge and innovative analytical and computational research skills to handle problems in a variety of domains including governance, finance, security, transportation, healthcare, energy management, agriculture, population studies, weather prediction, economics, social sciences, predictive maintenance, structural health monitoring, smart manufacturing and computational structural biology.

(3) Expected Graduate Attributes (M.Tech.)

1. Skill set to clean, process, analyze, manage and handle security and privacy aspects of structured and unstructured data.
2. Ability to identify, design and apply appropriate pattern recognition and data mining methods for generating relevant insight from data.
3. Knowledge and capability to develop and apply machine learning techniques for data driven modelling.
4. Ability to develop models and simulation schemes based upon domain knowledge in chosen domains and possible combination with data driven models.
5. Capability to follow uniquely interdisciplinary approach for solving problems, using knowledge of mathematics, statistics, computing and one or more selected domains among physics, chemistry, biology and engineering sciences.
6. Skill to use and design appropriate visualization techniques for representation and presentation of insights and solutions.
7. Ability to innovate and contribute towards next generation data driven technology development.
8. High quality technical communication skills.
9. Appreciation and adherence to norms of professional ethics.
10. Ability to plan and manage technical projects.

(4) Learning outcome:

1. Strong Understanding of fundamentals of Data Mining, Machine Learning, Modelling & Simulation, Optimization and Numerical Techniques.
2. Basic understanding of Cryptographic and Blockchain Techniques.
3. Knowledge about basics and use of visual analytics.
4. Skill set to develop applications using Big Data.
5. Advanced analytical and data driven modelling and simulation skills to address technological challenges in one or more specialized knowledge domains like physics, chemistry, biology and engineering sciences.
6. Demonstrate skills to communicate scientific ideas and/or application systems.
7. Acquire project management skills.

(5) Program Structure:

[Bridge Course]: Data Structures and Algorithms									
Semester I					**Semester II**				
Cat.	**Course No.**	**Course Title**	**L-T-P-D**	**Credits**	**Cat.**	**Course No.**	**Course Title**	**L-T-P-D**	**Credits**
C	MAL7XX0	Introduction to Data Science	1-0-0-0	1	C	MAL7XX0	Mathematical Modeling and Simulation	1-0-2-0	2
C	CSL7XX0	Machine Learning	3-0-0-0	3	C	CSL7XX0	Deep Learning	3-0-0-0	3
C	MAL7XX0	Linear Algebra for Data Science	2-0-0-0	2	C	CSL7XX0	Algorithms for Big Data	3-0-0-0	3
C	MAL7XX0	Statistics for Data Science	2-0-0-0	2	E	XXXXXXX	PE2	3-0-0-0	3
C	MAL7XX0	Optimization for Data Science	2-0-0-0	2	E	XXXXXXX	PE3	3-0-0-0	3
C	MAL7XX0	Introduction to Modelling	1-0-0-0	1	NG		Professional Ethics	1-0-0-0	1
C	MAP7XX0	Data Analytics Lab	0-0-2-0	1					
E	XXXXXXX	PE1	3-0-0-0	3					
NG		Technical Communication	1-0-0-0	1					
			Total:	**16**				Total:	**15**
Semester III					**Semester IV**				
Cat.	**Course No.**	**Course Title**	**L-T-P-D**	**Credits**	**Cat.**	**Course No.**	**Course Title**	**L-T-P-D**	**Credits**
E	XXXXXXX	PE4	3-0-0-0	3	E	XXXXXXX	OE2	3-0-0-0	3
E	XXXXXXX	PE5	3-0-0-0	3					
E	XXXXXXX	OE1	3-0-0-0	3					
P	MAP7XXX	Project	0-0-0-5	5	P		Project	0-0-0-11	11
NG		System Engineering and Project Management	1-0-0-0	1	NG		IP Management and Exploitation	1-0-0-0	1
			Total:	**15**				Total:	**15**

Core : 20 (incl. 2 labs)	**PE: 15**	**OE: 6**	**Project: 16**	**NG: 4**

(6) Content of compulsory courses:

Title	**Introduction of Data Science**	Number	MAL7XX0
Department	Mathematics	L-T-P-D [C]	1–0–0-0 [1]
Offered for	M.Tech.(DCS)	Type	Compulsory
Prerequisite			

Objectives

The Instructor will:

1. Introduce the basics of data science and its underlying concepts.
2. Introduce data processing, manipulation and cleaning techniques.

Learning Outcomes

The students are expected to have the ability to:

1. Acquire familiarity with the basic concepts of data science.
2. Distinguish between different kinds of data and data governance.
3. Understand the preparation and processing of the data.

Contents

[14 Lectures] Data preparation, Data pre-processing, Data Cleaning, Data Integration, Data Transformation, Data Reduction, Redundancy Removal, Data storage, Data Handling, Querying Data, Data Representation and Exploration, Big Data.

Text Books

1. Kotu, V. and Deshpande, B. (2018) Data Science: Concepts and Practice, Morgan Kaufmann.
2. Saltz, J.S. and Stanton, J.M. (2017) An Introduction to Data Science, SAGE Publications.
3. Kelleher, J.D., and Tierney, B. (2018) Data Science, MIT Press.

Reference Books

1. Moreira, J., Carvalho, A. and Horvath, T. (2018) A General Introduction to Data Analytics, John Wiley & Sons.
2. Mayer-Schonberger, V. and Cukier, K., (2013) Big data: The essential guide to work, life and learning in the age of insight, John Murray Publications.

Online course Material

Not Available

Title	**Machine Learning**	Number	CSL7XX0
Department	Computer Science and Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech. (CSE, AI, DCS), PhD	Type	Compulsory
Prerequisite	Introduction to Computer Sc., Probability, Statistics and	Antirequisite	IML, PRML

Objectives

1. To understand various key paradigms for machine learning approaches
2. To familiarize with the mathematical and statistical techniques used in machine learning.
3. To understand and diferentiate among various machine learning techniques.

Learning Outcomes

The students are expected to have the ability to:

1. To formulate a machine learning problem
2. Select an appropriate pattern analysis tool for analyzing data in a given feature space.
3. Apply pattern recognition and machine learning techniques such as classifcation and feature selection to practical applications and detect patterns in the data.

Contents

Fractal I: Supervised Learning

Introduction: Defnitions, Datasets for Machine Learning, Diferent Paradigms of Machine Learning, Data Normalization, Hypothesis Evaluation, VC-Dimensions and Distribution, Bias-Variance Tradeof, Regression (Linear) (7 Lectures)

Bayes Decision Theory: Bayes decision rule, Minimum error rate classifcation, Normal density and discriminant functions (5 Lectures)

Parameter Estimation: Maximum Likelihood and Bayesian Parameter Estimation (2 Lectures)

Fractal II: Unsupervised Learning

Discriminative Methods: Distance-based methods, Linear Discriminant Functions, Decision Tree, Random Decision Forest and Boosting (6 Lectures)

Feature Selection and Dimensionality Reduction: PCA, LDA, ICA, SFFS, SBFS (4 Lectures)

Clustering: k-means clustering, Gaussian Mixture Modeling, EM-algorithm (4 Lectures)

Fractal III: Kernels and Neural Networks

Kernel Machines: Kernel Tricks, SVMs (primal and dual forms), K-SVR, K-PCA (6 Lectures) Artifcial Neural Networks: MLP, Backprop, and RBF-Net (4 Lectures) Foundations of Deep Learning: DNN, CNN, Autoencoders (4 lectures)

Title	**Linear algebra for data science**	Number	MAL7XXX
Department	Mathematics	L-T-P-D [C]	2-0-0-0 [2]
Offered for	M.Tech.(DCS)	Type	Core
Prerequisite			

Objectives:

1. Present the framework of linear algebra for matrix theory
2. Introduce numerical aspects of linear algebra and its applications

Learning Outcomes

The students are expected to

1. Learn the theoretical framework of linear algebra for matrices to carry out various matrix operations, matrix decompositions and to solve the matrix eigenvalue problems
2. Understand the numerical linear algebraic methods and their usage for data analysis.

Contents

Matrix theory [1-0-0-0]
*Matrix Algebra [8 Lectures]***:** Matrix operations and type of matrices, Rank of Matrix, Eigenvalues, Eigenvectors, and Diagonalizable matrices, Vector spaces R^{n}, linear independence, basis, linear mappings, affine spaces, Vector Norms, Matrix Norms, lengths, and distances, angles and orthogonality, orthogonal basis, orthogonal complement, inner product, orthogonal projections, matrix derivatives
*Matrix Decompositions [6 Lectures]***:** Spectral decomposition, Schur Decomposition, QR Factorization, Singular value decomposition (SVD), Polar Decomposition, Pseudo Inverse.

Numerical linear algebra [1-0-0-0]
Introduction[2 lectures]: Condition of a linear system, condition of the eigenvalue problem, sparse matrices, numerical linear algebra software
Linear solvers [6 lectures]: Direct methods and iterative methods (Gaussian elimination method, LU factorization method, Cholesky factorization method, QR factorization method, Householder’s method, Gradient descent, conjugate gradients, generalized minimal residual method preconditioning)
Computing eigenvalues [6 lectures]: Direct methods and iterative methods(power iteration, inverse iteration, shifting, deflation, QR iteration, SVD decomposition, Krylov subspace methods, the Arnoldi and Lanczos methods)

Textbooks

1. Strang, G., (2019), Linear Algebra and learning from data, Wellesley-Cambridge Press
2. Elden, L. (2007) Matrix Methods in Data Mining and Pattern Recognition, SIAM.
3. Deisenroth, M. P., Faisal, A. A. and Ong, C. S. (2019), Mathematics for machine learning, Cambridge University Press.

Reference books

1. Mayer, C.D. (2000) Matrix Analysis and Applied Linear Algebra, SIAM.
2. M Goloub, G.H., and Charles, F.V.L. (2013) Matrix Computations, JHU Press.
3. Charu Agarwal (2020), Linear Algebra and Optimization for Machine Learning, Springer.
4. Dan A Simovici (2012), Linear Algebra Tools for Data Mining, World Scientific Publishing Company.

Online Course Material

Agrawal, P.N., Numerical Linear Algebra, NPTEL course material, Department of Mathematics, Indian Institute of Technology Roorkee, https://nptel.ac.in/courses/111107106/

Title	**Statistics for Data Science**	Number	MA7XXX
Department	Mathematics	L-T-P-D [C]	2–0–0-0 [2]
Offered for	M.Tech. (DCS)	Type	Core
Prerequisite	Basic Probability & Statistics		

Objectives
The Instructor will provide an understanding of some of the statistical concepts and their real-life applications.

Learning Outcomes
The students are expected to have the ability to:
1. Perform hypotheses testing and estimation of the parameters for a given parametric family of distributions;
2. Gain the basic knowledge of association, correlation, mixture models, latent models and stochastic processes;
3. Gain the knowledge of Markov chains and sequence models.

Contents:

Statistical Inference [14 Lectures]:

Probability Models and Sampling Techniques [3 Lectures]: Normal, Chi-Square and t distributions, Basic concepts of random sampling, sampling from normal distribution, properties of sample mean and sample variance.

Estimation [5 Lectures]: Point estimation-Maximum likelihood estimator, Bayes estimator; Methods of evaluating estimators: Unbiasedness, MSE; Interval estimation: Finding confidence intervals for the mean and the variance of a normal population using pivot technique.

Testing of Hypotheses [6 Lectures]: Basic concepts of statistical hypotheses testing, simple and composite hypotheses, critical regions, Type-I and Type-II errors, size and power of a test, UMP test, Neyman Pearson lemma, tests for one-sample and two-sample problems from normal populations.

Statistical Techniques [14 Lectures]:

Association and Correlation Analysis [6 lectures]: Categorical data, consistency of data, independence and association of attributes; Measures of association – Pearson's and Yule's measures, Goodman-Kruskal's γ, Odds Ratio; Properties of product moment correlation coefficient, Spearman's rank correlation coefficient.

Mixture Models and Latent Models [3 Lectures]: Basic ideas, finite mixtures, continuous mixtures, conditional mixing distributions; Latent models.

Stochastic Processes [5 Lectures]: Definition and classification of general stochastic processes; Poisson processes: Interarrival and waiting time distributions, NHPP, compound Poisson process; renewal theory: Distribution of N(t), Wald's equation, renewal reward processes; Random walks

Text Books

1. Ross, S.M. (2014). Introduction to Probability and Statistics for Engineers and Scientists, Academic Press.
2. Ross, S.M. (2014). Introduction to Probability Models, Academic Press
3. Agresti, A. (2019). An Introduction to Categorical Data Analysis, Wiley & Sons.

Reference Books

1. Rohatgi, V.K. and Saleh, A.K.M.E. (2018), An Introduction to Probability and Statistics, Wiley.
2. Castaneda, L.V., Arunachalam, V. and Dharmaraja, S. (2016), Introduction to Probability and Stochastic Processes with Applications, Wiley.
3. Bishop, C.M. (2006). Pattern Recognition and Machine Learning, Springer.

Online Course Material:

1. Kumar, S. Statistical Inference, IIT KGP, NPTEL course material: https://nptel.ac.in/courses/111/105/111105124/
2. Dharmaraja, S. Stochastic Processes, IIT Delhi, NPTEL course material: https://nptel.ac.in/courses/111/102/111102098/

Title	**Optimization for Data Science**	Number	MAL7XXX
Department	Mathematics	L-T-P-D [C]	2–0–0–0 [2]
Offered for	M.Tech. (DCS)	Type	Core
Prerequisite	None		

Objectives

1. To provide the students with Optimization Techniques used in Data Sciences and related fields.
2. To equip the students with sufficient tools in numerical optimization which can be used in their areas of interest.

Learning Outcomes

1. Understanding of line search and iterative methods.
2. Algorithms for optimization using techniques like Penalty method and interior point methods.

3. Working and understanding of optimality conditions and KKT method.

Contents

Unconstrained Optimization [14 Lectures]: Convex sets and functions, Optimality conditions: First order, second order, line search methods, least squares, steepest descent, newton method, Quasi-Newton Method, conjugate gradient methods.

Constrained Optimization [14 Lectures]: barrier method, penalty method, interior point methods, KKT method and Lagrangian Duality, simplex, Frank and Wolfe method, applications to dynamic programming and optimal control.

Textbook

1. Amir Beck, Introduction to Nonlinear Programming (2014), Theory, Algorithms and Applications with Matlab, MOS-SIAM Series on Optimization.
2. M.S.Bazaraa, H.D. Sherali, and C.M.Shetty (2006), Nonlinear Programming: Theory and Algorithms, Third Edition, Wiley.

Reference Books:

1. Luenberger, D.G.; Ye Y. (2008), Linear and nonlinear programming, International Series in Operations Research & Management Science, Springer.
2. Mykel J. Kochenderfer, Tim A. Wheeler (2019), Algorithms for Optimization, The MIT Press.

Online Course Material:

Shevade, Shirish K., Numerical Optimization , NPTEL Course Material, Department of Computer Science and Automation, IISc Bangalore, https://nptel.ac.in/courses/106/108/106108056/

Title	**Introduction to Modeling**	Number	MAL7XX0
Department	Mathematics	L-T-P-D [C]	3–0–0-0 [1]
Offered for	M.Tech.(DCS)	Type	Compulsory
Prerequisite			

Objectives

The Instructor will:
1. Introduce various modeling techniques
2. Explain how to analyses mathematical models

Learning Outcomes

The students are expected to have the ability to:
1. Model a given scenario using appropriate mathematical techniques
2. Analyze and draw conclusions about the process/system under consideration

Contents

Principles of mathematical modeling [4 lectures]: Assumptions, approximations, abstraction, scale, conservation and balance principles, dimensional homogeneity and consistency, model validation

Modeling Methods [10 lectures]: Continuous models, discrete models, models of hybrid systems, use of differential equations, variational principles, Data driven models.

Textbooks

1. Gershenfeld, N. (1999) The Nature of mathematical modelling, Cambridge University Press.
2. Haberman, R. (1998) Mathematical models, SIAM.

Reference Books

1. Dym, C.L. (2004) Principles of mathematical modeling, Academic Press.
2. Boccara, N. (2010) Modeling complex systems, Springer.

Online Course Material

Not available

Title	**Data Analytics Lab**	Number	MAP7XX0
Department	Mathematical	L-T-P-D [C]	0–0–2-D [1]
Offered for	M.Tech.(DCS)	Type	Compulsory
Prerequisite			

Objectives

The Instructor will

1. Introduce the basics of R software and then train to write scripts, create a work environment, and data handling and data visualization.
2. Enable students to be able to analyse the data using R.

Learning Outcomes

The students are expected to have the ability to:

1. Understand R language fundamentals and basic syntax.
2. Comprehend What R is and how it's used to perform data analysis.
3. Create their own R code for visualizations of data.

Contents

Basic calculations with R, Descriptive statistics [3 Labs]: Introduction to R Software, Basics and calculations with Data Vectors, Built-in-commands and Missing Data Handling, Operations with Matrices, Variables and Types of Data, Absolute, relative frequency and frequency distribution, Graphs and plots.

*Central tendency of data and Variation in data [4 Labs]:*Arithmetic Mean, Median, Quantiles, Mode, Geometric Mean and Harmonic Mean, Range, Interquartile Range and Quartile Deviation, Absolute Deviation and Absolute Mean Deviation, Mean Squared Error, Variance and Standard Deviation, Coefficient of Variation and Boxplots.

*Moments, Association of Variables, Fitting of Linear Models [7 Labs]:*Central Moments, Absolute Moments and Computation of Moments, Skewness and Kurtosis, Univariate and Bivariate Scatter Plots, Quantile in 3D plots, Correlation Coefficient, Rank Correlation Coefficient, Measure of Association for Discrete and Counting Variables, Least Squares Method.

Text Books

1. Wickham, H. and Grolemund, G. (2016) R for Data Science: Import, Tidy, Transform, Visualize, and Model Data, 'O'Reilly Media, Inc.
2. Toomey, D. (2014) R for Data Science, Packt Publishing Ltd.
3. Healy, K. (2018) Data Visualization: A Practical Introduction, Princeton University

Press.

Reference Books

1. Knell, R.J. (2014) Introductory R: A Beginner's Guide to Data Visualisation,
2. Stinerock, R. (2018) Statistics with R: A Beginner's Guide, SAGE publication.

Online Course Material

1. Shalab, Descriptive Statistics with R Software, NPTEL Course Material, Department of Mathematics and Statistics, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/111104120/

Title	**Technical Communication**	Number	HSNXX
Department	Humanities and Social Sciences	L-T-P [C]	1–0–0 [1]
Offered for	M.Tech and PhD	Type	Compulsory
Prerequisite	None		

Objectives

The Instructor will:

1. Enable a student to face the challenges in communication, primarily in a technical milieu.

2. Enhance a student's English Language skills namely listening, speaking, reading and writing (LSRW) and the role played by them in the process of communication.

3. Make students conversant in addressing communication challenges that impact organizations through sharing of best practices and group learning.

Learning Outcomes

The students are expected to have the ability to:

1. Comprehend, recognize and articulate the formal elements of specific genres of technical communication.

2. To gain a familiarity with practical and theoretical aspects of various trends and debates in technical communication

3. To develop a sensibility and appreciation for some of the ideas, issues, and problems involved in writing about technology and in workplace writing.

Contents Part I (HSS Faculty) Total – 07 hours (07 Lectures)

Introduction to Communication – Introduction to Communication and the Importance of Communicating in English, Role of Emotions in Communication, Basics of Communication, Purpose and Audience, Cross-Cultural Communication, Language as a tool of communication, LSRW. (1 hour)

Listening -Introduction to Listening, Types of Listening, Active Listening, Barriers to Listening, Listening to pre-recorded audio visual material/film. (1 hour)

Speaking –Introduction to Speaking, Mock Personal Interviews, Body Language, Organizing and learning to make a presentation, Phonetics and Basic Pronunciation, Common Errors in English, Telephone Etiquette, Group Discussions.(2 hour)

Reading - Purpose of Reading, Topic Sentence and its role, Reading for different purposes, Reading Comprehension, Reading Techniques. (1 hour)

Writing– Introduction, Importance, Characteristics, Impersonal and Formal language, Elements of Style, Techniques for Good Technical Writing, Paragraph Writing, Writing a Formal Letter, Writing an Email, Plagiarism. (2 hours)

Part II (Faculty of Engineering and Sciences) – 07 hours (07 Lectures)
Introduction to Technical Communication

Writing – Mechanics of Technical Writing, Organization and Structure in Technical Writing, Writing an abstract, Writing a Research Paper, Writing a Review, Report Writing, Writing Technical descriptions, Copyediting and formatting, Referencing, Citations, Plagiarism.(4 hours)

Reading – Identifying Language Errors, Reading Comprehension with specific reference to passages/articles in Science and Technology. (1 hour)

Lectures with Hands on Training – Grammarly, End note, Language software, Document processing using software.(2 hours)

Reference Books

1. Raman, Meenakshi and Sangeeta Sharma. Technical Communication: Principles and Practice. Oxford University Press: New Delhi, 2011.

2. A Text Book of English for Engineers and Technologists. Division of Humanities and Social Sciences, Anna University, Orient Black Swan: Chennai, 2002.

Online Course Material

1.Technical English for Engineers-https://nptel.ac.in/courses/109106094/

Title	**Mathematical Modeling and Simulations**	Number	MAL7XXX

Department	**Mathematics**	L-T-P-D [C]	1–0–2 [2]
Offered for	**M.Tech. (DCS)**	Type	Core
Prerequisite	**Introduction to Modelling**		

Objectives

The Instructor will:

1. Introduce various modeling techniques
2. Introduce various simulation techniques
3. Explain how to analyze mathematical models and simulation results

Learning Outcomes

The students are expected to have the ability to:

1. Model a given scenario using appropriate mathematical techniques
2. Simulate the model to gain insight into the process/system under consideration
3. Analyze and draw conclusions about the process/system under consideration

Contents

Analysis tools [4 lectures]: Linearization, stability analysis, perturbational analysis

Modern models [10 lectures]: Data-based models, graph-based models, Monte Carlo methods

Simulation tools *[12 lab sessions]*:

1. Graphical tools [1 session]: Plotting, linear and nonlinear curve fitting
2. Numerical differentiation and integration [2 sessions]
3. Numerical linear algebra [3 sessions]: Matrix factorizations, linear solvers, eigenvalue problem solvers
4. Numerical solution of ordinary and partial differential equations [3 sessions]
5. Fourier transformation tools [1 session]
6. Data analysis tools [2 sessions]: Principal components, power-law distributions, etc.

Indicative Assignments: Linear and nonlinear mass-spring system, single pendulum: Linear and nonlinear models, population models: one species models, Predator and Prey models/Competing models, Stochastic birth processes, traffic flow models, small-world networks, social network and friendship model, heat conduction model, wave propagation model, random number generation, Monte Carlo method to compute the value of Pi, signal analysis using fast Fourier transformation, Clustering models, Wave Signal analysis:

Textbooks

1. Gershenfeld, N. (1999), *The Nature of mathematical modeling*, Cambridge University Press.
2. Haberman, R. (1998), *Mathematical models*, SIAM Publication.
3. Kutz, J. N. (2013), Data-Driven Modeling & Scientific Computation: Methods for Complex Systems & Big Data, Oxford University Press.

Reference Books

1. Boccara, N. (2010), *Modeling complex systems*, 2nd Ed., Springer.
2. Graham, C. and Talay, D. (2013), *Stochastic Simulation and Monte Carlo Methods: Mathematical Foundations of Stochastic Simulation*, Springer.
3. Dym, C. L. (2004), *Principles of mathematical modeling*, 2nd Ed., Academic Press.

Online Course Material

Nayak, Ameeya Kumar (IIT Roorkee), NPTEL course on '*Introduction to mathematical modeling'*, https://nptel.ac.in/courses/111/107/111107113/

Title	**Deep Learning**	Number	CSL8XX0
Department	Computer Science and Engineering	L-T-P [C]	3–0–0 [3]
Ofered for	M.Tech. 1st Year, Ph.D. 1st Year	Type	Compulsory
Prerequisite	Machine Learning	Antireq	4xx DL Course

Objectives

1. Provide technical details about various recent algorithms and software platforms related to Machine Learning with specifc focus on Deep Learning.

Learning Outcomes

The students are expected to have the ability to:

1. Design and program efcient algorithms related to recent machine learning techniques, train models, conduct experiments, and develop real-world DL-based applications and products

Contents

Fractal 1: Foundations of Deep Learning

Deep Networks: CNN, RNN, LSTM, Attention layers, Applications (8 lectures)

Techniques to improve deep networks: DNN Optimization, Regularization, AutoML (6 lectures)

Fractal 2: Representation Learning

Representation Learning: Unsupervised pre-training, transfer learning, and domain adaptation, distributed representation, discovering underlying causes (8 lectures)

Auto-DL: Neural architecture search, network compression, graph neural networks (6 lectures)

Fractal 3: Generative Models

Probabilistic Generative Models: DBN, RBM (3 lectures)

Deep Generative Models: Encoder-Decoder, Variational Autoencoder, Generative Adversarial Network (GAN), Deep Convolutional GAN, Variants and Applications of GANs (11 lectures)

Text Book

1. Goodfellow,I., Bengio.,Y., and Courville,A., (2016), Deep Learning, The MIT Press .

Reference Book

1. Charniak, E. (2019), Introduction to deep learning, The MIT Press.
2. Research literature.

Self Learning Material

1. https://www.deeplearningbook.org/

Title	**Algorithms for Big Data**	Number	CSL7XX0
Department	**Computer Science and Engineering**	L-T-P [C]	3–0–0 [3]
Offered for	**B. Tech., M.Tech., PhD**	Type	Compulsory
Prerequisite	**None**		

Objectives

The Instructor will:

1. Introduce some algorithmic techniques developed for handling large amounts of data.
2. Emphasize both theoretical as well as practical aspects of such algorithms.

Learning Outcomes

The students are expected to have the ability to:

1. Design and Analyzing existing algorithms as well as design novel algorithms pertaining to big data.

Contents:

Introduction: Randomized algorithms, Universal hash family, Probabilistic algorithm analysis, Approximation algorithms,ε-Approximation schemes, Sublinear time complexity, Sublinear Algorithms. (7 lectures)

Property Testing: Testing list’s sortedness or monotonicity, Distribution testing (5 lectures)

Testing properties of bounded degree graphs, Dense graphs and General graphs. (6 lectures)

Sketching and Streaming: Extremely Small-Space Data Structures, CountMin Sketch, Count Sketch (5 lectures)

Linear Sketching, AMS Sketch, Turnstile Streaming, Graph Sketching, Graph Connectivity (5 lectures)

MapReduce: MapReduce Algorithms in Constrains Settings such as small memory, few machines, few rounds, and small total work, Efcient Parallel Algorithms (7 lectures)

External memory and cache-obliviousness: Minimizing I/O for large datasets, Algorithms and data structures such as B-trees, Bufer trees, Multiway merge sort (7 lectures)

Self Learning Material

1. Department of Computer Science, Harvard University, Algorithms for Big Data
2. https://www.sketchingbigdata.org/
3. “Introduction to Property Testing” (link) by Oded Goldreich
4. http://grigory.us/big-data.html

Title	**Professional Ethics I**	Number	
Department	Humanities and Social Sciences	L-T-P [C]	0-1-0[1]
Offered for	UG	Type	Compulsory
Prerequisite	Nil		

Objectives

The course will:

1. Foster awareness of ethical responsibilities associated with professions
2. Assist students in identifying, assessing and resolving ethical dilemmas in professional contexts
3. Help students becoming responsible professionals

Learning Outcomes

The students are expected to have the ability to:

1. Understand the responsibilities linked to professions
2. Identify normative commitments of technological knowledge and artifacts
3. Think analytically and critically

Contents

Professional Ethics: Basic Notions: Thinking Like an Engineer; Moral Conflicts and Dilemmas; What Morality Is and What Morality Is Not; Structure of Moral Reasoning; Ordinary Morality and Professional Ethics; Tools and Techniques in Ethics; Professionalization and Normative Commitments (7 classes)

Major Moral Problems in Professional Contexts (case study based):Rights, Duties, and Violations; Conflicts of Interests; Corruption; Contracts; Obligations in Special Relations; Deception and Puffery; Paternalism; Consent and Dissent; Whistleblowing (7 classes)

Textbook

1. Callahan, J.C. (1988), *Ethical Issues in Professional Life*, New York: Oxford University Press.

Reference Books

1. Meijers, A. (2009). *Philosophy of Technology and Engineering Sciences*, Amsterdam: Elsevier.
2. Fleddermann, C.B. (2012). *Engineering Ethics* (4th edition). Boston: Prentice Hall.

Online Resources

1. Sanders, J., *Professional Ethics*, Rochester Institute of Technology, www.openculture.com/philosophy_free_courses

Illinois Institute of Technology, Center for the Study of Ethics in the Professions, ethics.iit.edu/library/ethics-resources-online

Title	**Systems Engineering and Project Management**	Number	**OAL7XX0**
Department		L-T-P [C]	1-0-0 [1]
Offered for	M.Tech Program	Type	Compulsory NGU
Prerequisite			

Objectives

Systems Engineering is an interdisciplinary approach and means to enable realization of successful systems. It focuses on defining requirements and then proceeding with design synthesis and system validation while considering the complete problem including operations, performance, test, manufacturing, cost, and schedule.

This course intends to help students to develop the capability of systems thinking by introducing basics of systems engineering theory, methods, and tools through lecture and practice.

Learning Outcomes

After taking this class, you should be able to:

- Develop a systems engineering plan for a realistic project.
- Judge the applicability of any proposed process, strategy, or methodology for systems engineering
- Apply systems engineering tools (e.g., requirements development and management, robust design, Design Structure Matrix) to realistic problems.
- Know how to proactively design for and manage system lifecycle targets.
- Understanding TRL and MRL concepts
- Use project management tools

Contents

- Introduction - Terminology, Systems Thinking, Today's Challenges (1 L)
- Requirements Elicitation, Documenting System Requirements - Proper Specification Language, Depth of Definition (1 L)
- Requirements Analysis - Context Diagrams, Functional Analysis, State Diagrams (2 L)
- Requirements Validation - User Feedback Techniques, Requirements Reviews (1 L)
- System Architecture - Subsystem Definition, Hierarchical Analysis, Design for Reuse, Interface Management (2 L)
- Specialty Engineering - Producibility/Manufacturability, Reliability/Availability, Maintainability/Serviceability, Usability/User Interface, Design-to-Cost (2 L)

Managing Systems Engineering - Estimating, Planning, Tracking, System Engineering Management Plan, Work Breakdown Structure, Technical Reviews (2 L)

- Introduction to the concepts of TRL (Technology Readiness Levels) and MRL(Manufacturability Readiness level) (1 L)
- Course Project (8 hrs of self-work corresponding to 2 scheduled contact hours)
    - Application of Systems Engineering Methodology to the Major Project (M.Tech)
    - Use of Microsoft Project as the software tool for managing their M.Tech project

Evaluation

Presentation of Systems Engineering Process of the Major Project

Textbook

1. Introduction to Systems Engineering by Ian Faulconbridge, Michael Ryan (Kindle Edition)
   Argos Press, 2015.
2. Systems Engineering Fundamentals
   https://ocw.mit.edu/courses/aeronautics...systems-engineering.../sefguide_01_01.pdf
3. https://www.sebokwiki.org/wiki/Introduction_to_Systems_Engineering

Web Resources

1. https://www.coursera.org/learn/systems-engineering
2. https://ocw.mit.edu/courses/aeronautics-and-astronautics/16-842-fundamentals-of-systems-engineering-fall-2015/

(7) Content of Program Electives:

Department of Mathematics

Title	**Financial Engineering**	Number	MAL7XX0
Department	Mathematics	L-T-P-D [C]	3–0–0-0 [3]
Offered for	M.Sc.(MA)/M.Tech.(DCS)/PhD (MA)	Type	Elective
Prerequisite			

Objectives
The Instructor will:

1. Securities Pricing Securities, Risk Management Assessment, prediction and decision making, under uncertainty, regarding future events and their consequences
2. Portfolio Optimization Balancing risk and return
3. Modeling Pricing of derivatives and Itos calculus

Learning Outcomes
The students are expected to have the ability to:
1. Valuation of financial portfolio
2. Pricing of financial derivatives (options and contracts)
3. Understanding risk and return

Contents

*[18 lectures]*Introduction to financial markets and financial instruments, financial derivatives, risk and return, risky and risk free assets, interest rates, bonds, bonds pricing, spot and forward rates, investment portfolio, mean-variance analysis, capital asset pricing model, arbitrage pricing theory.

*[22 lectures]*Discrete time models, stock and money market models, principle of no arbitrage, pricing of contracts (forward and future), options, put-call parity, option pricing, martingales, Binomial model, CRR model, Black-Scholes formula, Greeks, random walk, Brownian motion, stochastic process, Itos integral and Ito-Deoblins formula.

Textbook
1. M. Capinski and T. Zastawniak (2010). Mathematics for finance: an introduction to financial engineering, Springer.
2. S.N. Neftci (2009). Principles of financial engineering. Academic Press/Elsevier.

Reference Books
1. J.C. Hull (2011). Options, futures and other derivatives. Pearson India.
2. S.E. Shreve (2000). Stochastic calculus for finance I: The binomial asset pricing model, Springer

Online Course Material
Not Available

Title	**Computational Game Theory**	Number	MAL8XX0
Department	Mathematics	L-T-P [C]	3–0–0-0 [3]
Offered for	M.Tech.(DCS)/PhD (MA)	Type	Elective
Prerequisite	Basics of Optimization Theory		

Objectives

1. Provide background in the area of computational game theory.
2. Provide sufficient knowledge of the subject which can be used by students for further applications in their respective domains of interest.

Learning Outcomes
1. Understanding of fundamentals like Nash equilibrium, dominant strategies and their applications.
2. Basic understanding of the Co-operative games, iterated games and mixed strategies.
3. Knowledge of non-co-operative games, Zermelo's algorithm and their applications.

Contents
[12 lectures]: Von Neumann and Morgenstern utility functions, expected utility and expected utility maximization, Paradoxes of expected utility maximization, Compact representations for preference relations, Dichotomous preferences and goals. Representations for specifying goals, Strategic Form Non-Cooperative Games, Basic model and solution concepts, pure strategy Nash equilibrium, dominant strategies, notable games, coordination games and focal points, complexity of pure strategy Nash equilibrium.

[14 Lectures]: Mixed strategies: Nash's theorem and Nash equilibrium, Computing mixed strategy Nash equilibria, Lemke-Howson algorithm, Zero sum games, Minimax Theorem, Compact representations for strategic form games, Boolean games, congestion games, Iterated Games: Finitely repeated games and backward induction, Infinitely repeated games, measuring utility over infinite plays modelling strategies as finite state machines with output (Moore machines); The Folk theorems, Iterated Boolean games, Axelrod's tournament, the Hawk-Dove game, evolutionary game theory, evolutionarily stable strategies.

[16 lectures]: Extensive Form Non-Cooperative Games: Zermelo's algorithm and backward induction, subgame perfect equilibrium, Zermelo's theorem, Compact representations for extensive form games, PEEK games and EXPTIME-completeness results, the Game Description Language (GDL), Imperfect information games, PEEK games with incomplete information, Cooperative Games: Transferable utility (TU) characteristic function games, basic model, stability & fairness solution concepts, cost of stability, Shapley value, Banzhaf index, induced subgraph representation, marginal contribution nets, Simple TU games, swap and trade robustness, weighted voting games, vector weighted voting games, network flow games, NTU games and their representations

Textbooks
1. G. Chalkiadakis, E. Elkind, and M Wooldridge, Computational Aspects of Cooperative Game Theory, Morgan-Claypool, 2011.
2. Machler, E. Solan, S. Zamir, Game Theory, Cambridge U.P., 2013.
3. M. J. Osborne, An Introduction to Game Theory, Oxford U.P., 2004.

Reference Books
1. R. D. Luce and H. Raiffa, Games and Decisions, Wiley, 1958
2. M. J. Osborne and A. Rubinstein, A Course in Game Theory, 1994.

Online course Material
Not Available

Title	**Advanced topics in Computational PDE**	Number	MAL8XX0
Department	Mathematics	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech.(DCS)/PhD (MA)	Type	Elective
Prerequisite	ODEs, PDEs and numerical methods		

Objectives

The Instructor will:

1. Introduce multi-grid methods,
2. Introduce parallel computing methods,
3. Explain use multi-grid methods and parallel computing methods.

Learning Outcomes

The students are expected to have the ability

1. to solve partial differential equation using multi-grid methods,
2. to speed up computations using parallel numerical methods.

Contents

Multi-grid methods [20 lectures]: Review of classical finite difference schemes for numerical solution of partial differential equations, Fourier analysis for error propogation, influence of grid parameters, grid hierarchies, multi-grid cycles, convergence monitors, smoother, W-cycle and nested iteration, coarse-grid solver, multigrid as a preconditioner, Numerical implementations with Diffpack programming

Parallel Computing [20 lectures]: Need for parallel computation, different hardware architectures, message-passing programming model, multicomputer model, OPEN MP, MPI, CUDA, parallel linear algebra operations, parallel algorithms for linear systems with special structures, parallel implementation of direct and iterative methods for solution of linear systems, parallelizing finite difference schemes (wave Equation, heat condunction equation)

Textbooks

1. Langtangen H. P. and Tveito, A. (Editors) (2003) Advanced topics in computational partial differential equations: Numerical methods and Diffpack programming, Springer
2. Briggs, W. L., Henson, V. E., and McCormick, S. F. (2000) A multigrid tutorial, 2nd Ed., SIAM
3. Grama, A., Gupta, A., Karypis, G., and Kumar, V. (2003) Introduction to parallel computing, 2nd Ed, Pearson

Reference Books

1. Quarteroni, A. and Valli, A. (1997), Numerical approximations of partial differential equations, 2nd Edition, Springer
2. Bertsekas, D. P. and Tsitsiklis, J. N. (1997) Parallel and distributed computation: Numerical methods, Prentice-Hall

Online Course Material

1. M. Ramakrishna, Introduction to computational fluid dynamics, NPTEL course material, Department of Aerospace Engineering Indian Institute of Technology Madras, https://nptel.ac.in/syllabus/101106045/

Subodh Kumar, Parallel Computing, NPTEL course material, Department of Computer Science and Engineering Indian Institute of Technology Delhi, https://nptel.ac.in/courses/106102114/

Course Title	**Dynamical Systems**	Course No.	MAL7XX0
Department	Mathematics	L-T-P-D [C]	3–0–0-0[3]
Offered for	M.Sc.(MA)/M.Tech.(DCS)/PhD (MA)	Type	Elective
Pre-requisite			

Objectives

1. To introduce the concept of linear and nonlinear dynamical systems.
2. To learn the basic concepts in dynamical systems, like, evolution of system, fixed points, periodic points, attractors, bifurcation process and stability of the systems.

3. To understand the nonlinearity in nature and study of the nonlinear models in engineering and its dynamics.
4. Use Matlab and simulink for solving dissipative dynamical systems, which are relevant for engineering models.

Learning Outcomes

1. Construction of phase portraits of nonlinear system and understanding of fundamental difference between linear and nonlinear systems.
2. Identification of attractors, like, fixed points, periodic attractors, Cantor sets, Chaotic attractor and in the continuous case, limits cycles.
3. Understanding the different bifurcations, like, saddle node, period doubling etc.

Contents

Linear and Nonlinear Dynamical Systems [Lectures 12]: History of Dynamics, The importance of being Nonlinear, A Dynamical view of the world, Examples of dynamical systems, Uncoupled Linear systems, Diagonalization, Exponential of operators, Linear systems in R^2 and Stability theory, Nonhomogeneous Linear systems, Nonlinear differential equations, Vector field of nonlinear systems, Phase portrait, Limit cycles and their stability.

One-dimensional Discrete maps [Lectures 12]: Logistic maps, period doubling bifurcations, Flip and tangent bifurcations, Periodic windows, Intermittency transcritical, Lyapunov exponent, Universality and Experiments.

Dynamics of Continuous and Discrete Systems: [Lectures 18]: Lorenz equations, Rossler Equation, Chua's circuit, Forced pendulum, Stable and Unstable manifolds, Basin boundary, Horseshoe maps, Boundary crisis, Interior crisis, Statistics of Chaotic attractor, Frequency spectra of orbits, Matrix times circle.

Textbook

1. Steaven, S., *Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering*, 1st Ed., Levant Books, 2007
2. Alligood, K., Sauer, T., and Yorke, J., *Chaos: An Introduction to Dynamical Systems*, Second Edition, Springer, 2008.

Reference Books

1. Devaney, R.L., *An Introduction to Chaotic Dynamical Systems*, Addison Wesley, 2005.
2. Holmgren, A.R., A First course in discrete dynamical systems, Springer.

Online course Material

1. Banerjee S., NPTEL Course on Chaos, Fractals and Dynamic Systems, Department of Electrical Engineering, IIT Kharagpurhttps://nptel.ac.in/courses/108105054/

Title	**Time Series Analysis**	Number	MA7XXX
Department	Mathematics	L-T-P [C]	3–0–0-0 [3]
Offered for	M.Tech. (DCS)	Type	Elective
Prerequisite	Probability, Statistics and Random Processes		

Objectives

1. To provide working knowledge of time series techniques and forecasting methods
2. To provide with techniques and receipts for estimation and assessment of quality of econometric models with time series data

Learning Outcomes

1. To develop the skills needed to do empirical research in fields operating with time series data sets

Contents

Models for Time Series [8 Lectures] Time series data, trend, seasonality, cycles and residuals, strong and weak stationarity, autocorrelation function, linear processes, estimation of mean and covariance functions, Wold decomposition Theorem.

Models of stationary process [8 Lectures] ARMA (p, q) processes, ACF and PACF, Modeling using ARMA processes, estimation of parameters, testing model adequacy, Order estimation.

Univariate Forecasting Models [8 Lectures] Prediction in stationery processes, special reference to ARMA processes, Frequency domain analysis – spectral density and its estimation, transfer functions.

Multivariate Forecasting Models [8 Lectures] Single equation models, Vector AR and ARMA models, econometric models

Non-stationary Models [10 Lectures] Stationarity through differencing, ARIMA model, ARMAX, ARIMAX models and introduction to ARCH models.

Indicative Assignments: Analysis of real data (namely, NEON data, IMD data, etc.) using different time series models

Textbook

1. Blockwell, P. J. and Davis, R. A. (2017). Introduction to Time Series and Forecasting, 2nd Edition, Springer.

2. Chatfield, C. (2004) The Analysis of Time Series – An Introduction, Chapman and Hall / CRC, 4th ed.

Reference Book:

1. Box, G.E.P., Jenkins, G. and Reinsel, G. (1994) Time Series Analysis-Forecasting and Control, 3rd ed., Pearson Education

Online material:

Mikusheva, Anna, Time Series Analysis, Department of Economics, Massachusetts Institute of

Technology, MIT OpenCourseware Course Material, https://ocw.mit.edu/courses/economics/14-384-time-series-analysis-fall-2013/recitations/

Title	**Reliability Theory**	Number	MAL8XX0
Department	Mathematics	L-T-P-D [C]	3–0–0-0 [3]
Offered for	M.Tech.(DCS)/PhD (MA)	Type	Elective
Prerequisite	Probability and Statistics		

Objectives

1. To understand the basic concepts of statistical reliability theory and their various real-life applications.

Learning Outcomes

1. Understand the basic notion of systems, different reliability measures, different notions of ageings, different semiparametric models, shock models and dependence structures;
2. Gain the ability to handle different issues in system reliability.

Contents

Basic Notion of Systems [6 lectures]: Structure function, coherent systems, *k*-out-of-*n* systems, dual structures, cut and path sets, modular decomposition.

Reliability Measures [5 lectures]: Survival/Reliability functions, hazard rate function, reversed hazard rate function, residual lifetime, inactivity time, mean residual lifetime function, mean inactivity time, reliability bounds.

*Semiparametric Models [6 lectures]:*Common life distributions, scale model, proportional hazard rate model, proportional reversed hazard rate model, proportional odds model, proportional mean residual lifetime model.

Stochastic Ageings [8 lectures]: Notions of stochastic ageing, different ageing classes, ageing properties of common life distributions, closure properties of different ageing classes under formation of coherent structures, convolutions and mixtures.

Shock Models and Dependence Structures [7 lectures]: Univariate and bivariate shock models, notions of bivariate and multivariate dependence structures.

Issues in System Reliability [10 lectures]: Maintenance and replacement policies, availability of repairable systems, optimization of system reliability with redundancy.

Text Books

1. Barlow, R.E. and Proschan, F. (1975). *Statistical Theory of Reliability and Life Testing*. Holt, Rinehart and Winston, New York.
2. Lai, C.D. and Xie, M. (2006). Stochastic Ageing and Dependence for Reliability. Springer, New York.
3. Marshall, A.W. and Olkin, I. (2007). Life Distributions. Springer, New York.

Reference Books

1. Barlow, R.E. and Proschan, F. (1965). *Mathematical Theory of Reliability.* Wiley, New York.

2. Samaniego, F.J. (2007). System Signatures and their Applications in Engineering Reliability. Springer, New York.

Online Course Material
Not Available

Title	**Stochastic Processes**	Number	MAL8XX0
Department	Mathematics	L-T-P-D [C]	3–0–0-0 [3]
Offered for	M.Tech.(DCS)/PhD (MA)	Type	Elective
Prerequisite	Probability and Linear Algebra		

Objectives
The Instructor will:

1. Provide background in the area of Random Processes.
2. Provide sufficient knowledge of the subject which can be used by students for further applications in their respective domains of interest.

Learning Outcomes
The students are expected to have the ability to:
1. Develop basic understanding of the Stochastic Process, Random Walk and Martingales.
2. Impart knowledge in Markov Chain, Birth and Death Process, Brownian Motion, Stochastic Calculus

Contents
[4 Lectures] Conditional probability and conditional expectation, properties of conditional expectation.

[8 Lectures]Stochastic processes, stationarity, finite-dimensional distributions, stopping times, stopped sigma-fields and processes, right-continuous and canonical filtrations, adapted and previsible processes.

[8 Lectures]Random walk; Gaussian distribution: for variables, vectors and processes, non-degeneracy, stationarity, closeness under 2-mean convergence.

[12 Lectures]Brownian motion, Gaussian construction, independence of increments, scaling and time inversion, Levy's martingale characterization, reflection principle, law of its maximum in an interval and first hitting time of positive levels, modulus of continuity, quadratic and total variation. Related processes: Geometric Brownian motion, Brownian bridge, Ornstein-Uhlenbeck process and martingales.

[10 Lectures]Poisson distribution, approximation, rate, construction, independence of increments, memoryless property of the Exponential law, the dual process of independent Exponential inter- arrivals, the order statistics of independent uniform samples.

Textbook
1. Ross, S. M. (2018), Stochastic Processes, Wiley

Reference Books
1. Ross, S. M. (2005), Introduction to Probability Models, Elsevier
2. Shreve, S. E. (2008), Stochastic Calculus for Finance II, Springer

Online course Material

1. Wu, H., Introduction to Stochastic Processes, Massachusetts Institute of Technology: MIT Open Courseware, https://ocw.mit.edu/courses/mathematics/18-445-introduction-to-stochastic-processes-spring-2015/.

Title	**Linear algebra with data**	Number	MAL7XXX
Department	Mathematics	L-T-P-D [C]	1-0-0-0 [1]
Offered for	M.Tech DCS	Type	Elective
Prerequisite	Linear Algebra for Data Science		

Objectives:

1. To introduce computational aspects of linear algebra for Data Science Applications.

Learning Outcomes

1. Understand the numerical linear algebraic methods and their usage for data analysis.

Contents

[6 lectures] Least square approximations, Dimensionality reduction, Low-Rank Approximation, Principal Component Analysis.
[8 lectures] Kernels and their properties, Designing Kernels, Kernel feature extraction (Kernel PCA), Kernel methods on manifolds.

Textbooks

1. Deisenroth, M. P., Faisal, A. A. and Ong, C. S. (2019), Mathematics for machine learning, Cambridge University Press.
2. Schölkopf, B.; and Smola, A.J., (2018), Learning with Kernels, MIT Press.

Reference books

1. Goloub M. , G.H., and Charles, F.V.L. (2013) Matrix Computations, JHU Press.
2. Charu Agarwal (2020), Linear Algebra and Optimization for Machine Learning

Online Course Material

Diesenroth, M.P.; Mathematics for Machine Learning, Online Course Offered by Imperial College London, https://www.coursera.org/learn/pca-machine-learning

Title	**Markov Models**	Number	MA7XXX
Department	Mathematics	L-T-P-D [C]	1–0–0-0 [1]
Offered for	M.Tech.(DCS)	Type	Elective
Prerequisite	Statistics for Data Science		

Objectives
The Instructor will provide an understanding of Markov and sequence models.

Learning Outcomes

1. Knowledge of Markov chains, Hidden Markov Models their applications.

Contents:

Markov Chains [8 Lectures]: DTMC: Definition, transition probability matrices, Chapman-Kolmogorov equation, classification of states, stationary and limiting distributions, time reversible Markov chain, reducible Markov chain, Google page rank; CTMC: Birth and Death processes.

Sequence Models [6 Lectures]: Markov Models, Markov Random Field, Hidden Markov Models, Viterbi Algorithm, Baum-Welch Algorithm.

Text Books

1. Ross, S.M. (2014). Introduction to Probability Models, Academic Press

Reference Books

1. Castaneda, L.V., Arunachalam, V. and Dharmaraja, S. (2016). Introduction to Probability and Stochastic Processes with Applications, Wiley.
2. Jurafsky, D. and Martin, J. (2009). Speech and Language Processing, Pearson.

Online Course Material

1. Dharmaraja, S. Stochastic Processes, IIT Delhi, NPTEL course material: https://nptel.ac.in/courses/111/102/111102098/

Title	**Evolutionary Optimization**	Number	MAL7XXX
Department	Mathematics	L-T-P-D [C]	1–0–0–0 [1]
Offered for	M.Tech (DCS)	Type	Elective
Prerequisite	Optimization for Data Science		

Objectives

1. To provide the students with basic understanding of Evolutionary Optimization.

Learning Outcomes

1. Understanding and working of Genetic Algorithms.
2. Understanding and implementation techniques like Ant Colony Optimization and Particle Swarm Optimization.

Contents

[6 lectures] Introduction to Evolutionary Optimization, Genetic Algorithms, Mathematical Models for Genetic Algorithms,
[8 lectures] Evolutionary Programming and Evolution Strategies, Ant Colony Optimization, Particle Swarm Optimization.

Textbook

1. Dan Simon, Evolutionary Optimization Algorithms, Wiley, 2013.

Reference Books:

1. Deb K., Optimization for Engineering Design – Algorithms and Examples, Prentice Hall of India Pvt. Ltd., New Delhi, 1995.
2. R. Fletcher, Practical Methods of Optimization, 2nd edition, Wiley, 2000.

Online Course Material:

Sharma, D. EVOLUTIONARY COMPUTATION FOR SINGLE AND MULTI-OBJECTIVE OPTIMIZATION, Department of Mechanical Engineering, IIT Guwahati, NPTEL course material: https://nptel.ac.in/courses/112/103/112103301/

Title	**Data Engineering**	Number	MAL7XXX
Department	Mathematics	L-T-P-D [C]	3-0-0-0 [3]
Offered for	M.Tech. (DCS)	Type	Elective
Prerequisite		Antirequisite	Software and Data Engineering

Objectives

The Instructor will:

1. Introduce fundamental concepts in representing data, accessing it and analyzing it
2. Explore applications in data science and big data projects

Learning Outcomes

The students will have the ability to:

1. Develop suitable data science ecosystem for the given application
2. Understand various data storage and retrieval techniques
3. Understand SQL and NoSQL databases and their usage
4. Analyze data using Python and Python-based tools

Contents

Representing data [4 lectures]: Data science ecosystem, data sources, data storage model, data model and design, Structured data, unstructured data, semi-structured data.

Accessing data [24 lecture]: Introduction to database management systems - Basic concepts, SQL: RDBMS, NoSQL database: column database, graph database, XML, JSON, and HBase, Query languages (SQL, hive, pig, etc), data format interchange, indexing, Hierarchical Indexing, Integer Indexing, parallel data reads/writes for high throughput, distributed database

Analysing data [14 lecture]: Data analysis tools (e.g. Python NumPy, IPython, matplotlib, and pandas, etc), arrays and vectorized computation, slicing, data processing (with arrays, pandas data structures, DataFrame, etc), indexing objects, data wrangling, data aggregation, joins and group operations, distributed data processing (introduction)

Indicative Assignments: Indexing implementation for the structured data, Indexing implementation for the unstructured data, SQL basics (schema design),SQL queries (select, count, where, etc),Data format interchange using XML, JSON,NoSQL system (HBase, hive), Data wrangling, data operations (e.g. NumPy), Data plotting, Data slicing and aggregation (joins), Group operations using query languages

Textbooks

1. Kleppmann, M. (2017), Designing Data-Intensive Applications The Big Ideas Behind Reliable, Scalable, and Maintainable Systems, O'Reilly.
2. Weise, L. (2015), Advanced Data Management: For SQL, NoSQL, Cloud and Distributed Databases, Walter de Gruyter GmbH.
3. Silberschatz, A., Korth, H. F., and Sudarshan, S. (2011), Database System Concepts, 6th Ed., McGraw Hill Publications.
4. McKinney, W. (2013), Python for Data Analysis, O'Reilly.

Reference books

1. Molina, H. G., Ullman, J. D., and Widom, J. (2001), Database Systems The Complete Book, Pearson Education.
2. Raj, P., Raman, A., Nagaraj, D., and Duggirala, S. (2015), High-Performance Big-Data Analytics: Computing Systems and Approaches, Springer.

Self-Learning Material

1. NPTEL course on 'Indexing and Searching Techniques in Databases' by Dr Arnab Bhattacharya, IIT Kanpur, https://nptel.ac.in/courses/106/104/106104021/

NPTEL course on ‘NOC: Fundamentals of Database Systems’ by Dr Arnab Bhattacharya, IIT Kanpur, https://nptel.ac.in/courses/106/104/106104135/

Title	**Representations of finite groups**	Number	MAL7XX0
Department	**Mathematics**	L-T-P-D [C]	3–0–0-0 [3]
Offered for	**M.Sc.(MA)/M.Tech.(DCS)/PhD (MA)**	Type	Elective
Prerequisite			

Objectives

1. The goal of this course is to give an introduction to representation theory and to understand representations of symmetric groups.

Learning Outcomes

1. Representation theory and characters of finite groups.
2. Representation theory of Symmetric groups.

Contents

Group Action and Modules[6 Lectures]: Groups and Examples (Recall), Group action, Conjugacy Classes, Modules: Definition and Examples.

Basic concepts of Representation Theory[10 Lectures]: Representations and basic

examples, FG-modules, Group algebra, Irreducible representations, complete reducibility and Maschke’s theorem, Schur’s lemma.

Characters and Burnside’s pq Theorem[10 Lectures]: Character theory of representations, orthogonality relations, decomposition of the regular representation. Character Tables of some groups, Characters and Algebraic Integers, Burnside’s pq-theorem.

Representation theory of symmetric groups[16 Lectures]: Tensor products, Restriction of a representation, induced representations, Frobenius reciprocity, Mackey’s irreducibility criterion, Representation theory of symmetric groups, Few applications of Representation Theory (if time permits).

Text Books

1. Benjamin Steinberg, Representation Theory of Finite Groups, Springer (Universitext), 2012.
2. Gordon James and Martin Liebeck, Representations and Characters of Groups, Cambridge University Press, 2001.

Reference Books

1. William Fulton and Joe Harris, Representation Theory: A First Course, Springer (Graduate Texts in Mathematics 129), 1991.
2. Amritanshu Prasad, Representation Theory: A Combinatorial Viewpoint, Cambridge University Press, 2015.

Online Course Material

Not Available

Department of Electrical Engineering

Title	**Digital image processing and applications**	Number	EEL7XX0
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. IV Year, M. Tech., Ph.D.	Type	Elective
Prerequisite	Fourier analysis		

Objectives

The Instructor will:

1. introduce basic concepts in image signal capture and display
2. provide an in-depth coverage of few recent applications of digital image processing

Learning Outcomes

The students are expected to have the ability to:

1. implement end-to-end systems that can capture, process and render a digital image in a desired fashion

Contents

*Introduction:*basic concepts of image signal capture, relation of pixels to physical luminance (3 lectures)

Display modeling: concept of dynamic range, color correction, modeling of a conventional display, modeling of modern Led-backlit displays, applications (6 lectures)

*Image processing and Machine Learning:*similarities and differences between traditional and ML based models, augmenting traditional image processing with ML (6 lectures)

Sparse models for image processing: dictionary learning, modeling of natural image patches, applications of sparse modeling (denoising, inpainting, super resolution) (7 lectures)

Image inpainting: use-case scenarios, analytical methods (PDE, SVD, dictionary learning etc.) for inpainting, exemplar-based inpainting, content-aware filling in Adobe Photoshop CS5, semantic inpainting using machine learning (10 lectures)

Image saliency: bottom-up and top-down mechanisms, saliency due to color and texture, automatic saliency prediction using traditional and ML based approaches, applications of saliency (6 lectures)

Perceptual image processing: masking, contrast sensitivity, angular frequency and viewing

Distance (4 lectures)

Textbook

1. Gonzalez, R.C. and Woods, R.E., (2018), *Digital Image Processing,* 4th Edition, Prentice Hall

Self Learning Material

1. Katsaggelos, A.K., *Fundamentals of Image and Video Processing*, Coursera, Northwestern University, https://www.coursera.org/learn/digital

Preparatory Course Material

1. Rao, R. V., *Advanced Matrix Theory and Linear Algebra For Engineers*, NPTEL Course Material, Centre for Electronics Design and Technology, Indian Institute of Science, Bangalore, https://nptel.ac.in/courses/111108066/

Title	**Digital video processing**	Number	EEL7XX0
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. IV Year, M. Tech., Ph.D.	Type	Elective

Prerequisite	Fourier analysis		

Objectives

The Instructor will:

1. introduce foundations of image and video signal processing and highlight similarities and differences between the two

2. Expose student to importance of motion in videos and its estimation, and use it for applications such as video compression, object tracking/recognition

Learning Outcomes

The students are expected to have the ability to:

1. meaningfully exploit the concept of spatio-temporal information in visual signals to develop applications in the broad area of multimedia signal processing

Contents

*Motion analysis in video signals:*Concepts of 2D motion, optical flow, block-based and pel-recursive methods for motion estimation, regularization techniques (8 lectures)

Recent trends in video technologies:

Stereo and multiview videos:introduction to depth perception and disparity estimation, view

Synthesis, stereo and multiview display (14 lectures)

HDR and Wide Color Gamut (WCG) videos: capture via exposure fusion, single HDR cameras,

HDR display modeling, Standard-gamut versus wide color gamut, ITU-T BT.709 and BT.2020

(10 lectures)

HDR-HFR-UHD-WCG: dependencies from human visual system perspective, issue of viewing

distance (6 lectures)

360-degree videos: introduction to 360-degree (omni directional) video capture and display,

challenges in applying traditional 2D video processing techniques (4 lectures)

Textbook

1. Tekalp,M., (2015), *Digital Video Processing*, 2nd Edition, Prentice Hall

Self Learning Material

1. Katsaggelos, A.K., *Fundamentals of Image and Video Processing*, Coursera, Northwestern University, https://www.coursera.org/learn/digital

Preparatory Course Material

1. Jagannatham, A. K., *Principles of Signals and Systems*, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/108104100/

Title	**Coding Theory**	Number	EEL7XX0
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. IV Year, M. Tech., Ph.D.	Type	Elective
Prerequisite	Knowledge of Probability Theory and Fundamentals of Communications		

Objectives

The Instructor will:

1. Provide an introduction to different types of channel codes.
2. Familiarize students with the fundamentals of error detection and correction.

Learning Outcomes

The students are expected to have the ability to:

1. Design channel codes for error detection and correction.
2. Analyze and compare the performance of uncoded and coded communication systems.

Contents

Introduction: Review of information theory, motivation for channel coding(3 Lectures)

Introduction to Linear Algebra: Introduction to finite fields, field arithmetic, vector spaces(4 Lectures)

Linear Block Codes: Properties of LBCs, some specific LBCs (Repetition codes, Hamming codes, LDPC codes), soft decision decoding of LBCs, Hard decision decoding of LBCs, Bounds on minimum distance of LBCs(7 Lectures)

Cyclic Codes: Definition and properties, polynomial representation, encoding and decoding of cyclic codes, burst error correction (7 Lectures)

BCH and RS codes: Introduction to BCH Codes: Generator Polynomials, Multiple Error Correcting BCH Codes, Decoding of BCH Codes, Introduction to RS codes, Decoding RS codes(7 Lectures)

Convolutional Codes: Structure of convolutional codes, decoding of convolutional codes, distance bounds for convolutional codes, punctured convolutional codes(7 Lectures)

Trellis coded modulation: Introduction to TCM, Ungerboeck"s TCM design rules, TCM decoder, performance evaluation of TCM schemes(7 Lectures)

Textbook

1. Lin, S. and Costello, D. J., (2004), *Error Control Coding*, 2nd Edition, Prentice Hall
2. Proakis, J. G. and Salehi, M., (2007), *Digital Communications*, 5th Edition, McGraw-Hill

Bose, R., (2017), *Information Theory, Coding and Cryptography*, 3rd Edition, McGraw-Hill

Self-Learning Material

1. Thangraj, A., *Coding Theory*, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Madras, https://nptel.ac.in/courses/117106031/

Preparatory Course Material

1. Jagannatham, A. K., *Principles of Communication II*, Department of Electrical Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/108104098/

Title	**Compressive Sensing**	Number	EEL7XX0
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech., M. Tech. and Ph. D.	Type	Elective
Prerequisite	Signals and Systems, Random Signal Analysis		

Objectives

The Instructor will:

1. Introduce development of compressed sensing and matrix completion, focusing on the design and analysis of algorithms to recover data from its compressed and/or incomplete measurements.

Learning Outcomes

The students are expected to have the ability to:

1. Use signal processing techniques to solve undetermined linear systems.

Contents

Sparse representation: Sparse representation in over-complete basis, Uniqueness and uncertainty principles, l_0 minimization and l_1 minimization (7 Lectures)

Model selection in linear regression: Prediction risk, l_0-penalized regression and Lasso, Risk inflation, Minimax risk for sparse vectors (7 Lectures)

Lasso algorithms and extensions: Proximal gradient methods, Nesterov accelerated methods, Group lasso and elastic net (7 Lectures)

Compressed sensing and sparse recovery: Restricted isometry property (RIP), A RIPless theory, Golfing scheme, Phase transition and convex geometry (7 Lectures)

Low-rank matrix recovery: Spectral method, Nuclear norm minimization (4 Lectures)

Super-resolution and spectral estimation: Model mismatch issue in compressed sensing, Matrix pencil approach, Atomic norm minimization, Connection to low-rank matrix completion (10 Lectures)

Textbook

1. Hastie T., Tibshirani R. and Wainwright M., (2015), Statistical learning with sparsity: the Lasso and generalizations, CRC.

2. Foucart S. and Rauhut H., (2013), A mathematical introduction to compressive sensing, Springer.

Self-Learning Material

1. Compressive Sensing resources, Rice University, http://dsp.rice.edu/cs/

Title	**Data Compression**	Number	EEL7XX0
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B. Tech., M.Tech., and Ph.D	Type	Elective
Prerequisite	Elementary knowledge of Information Theory		

Objectives

The Instructor will:

1. Introduce basic principles of data compression methods

2. Familiarize students with the advances in data compression methods

Learning Outcomes

The students are expected to have the ability to:

1. Implement some of the existing compression methods

2. Contribute in developing application-specific such methods

Contents

*Basic Techniques:*Run length coding, sampling and quantization, some statistical methods such Huffman, Arithmetic, Golomb, and QM Coder(4 lectures)

*Dictionary Methods:*String compression, Lemple and ziv methods and some of their variants. Zip and Gzip (4 Lectures)
*Image and Video Coding:*Concept of spatial and temporal redundancies, Predictive and transform based methods for Lossless and Lossy Image compression, Lossless Medical Image compression standards, Some still image compression standards such JPEG Baseline, JPEG-LS, JPEG 2000, Video Coding, Block matching and computational issues, MPEGs, Compression standards for 3D TV (18 Lectures)
Audio Compression: Human Auditory system, A-Law and mu-Law companding, Adaptive DPCM and computational issues, Delta modulation, Audio and Speech compression, MPEG-1 audio coding (14 Lectures)
Case studies: Current needs in Image, video, and text compression (2 Lectures)
Textbook

1. Khalid, S., (2006), *Introduction to Data Compression*, Elsevier
2. Solomon, D., (2007), *Data Compression*, The complete Reference, Springer

Self-Learning Material

1. Sengupta, S., *Digital Voice and Picture Communication*, NPTEL Course Material, Department of Electrical and Electronics Communication Engineering, Indian Institute of Technology Kharagpur, https://nptel.ac.in/courses/117105081/

Preparatory Material

1. Lathi, B. P., Ding, Z., Gupta, H. M., *Modern Digital And Analog Communication Systems*, Chapter 12 Introduction to Information Theory: Fourth Edition, Oxford University Press

Department of Bioscience and Bioengineering

Title	**Introduction to Omics Technologies**	Number	BBL7XX0
Department	Bioscience & Bioengineering	L-T-P [C]	2–0–0 [2]
Offered for	M.Tech.	Type	Elective

Prerequisite	Nil		

Objectives

The Instructor will:

1. Introduce various technologies and relevant instrumentation applicable in genomics and transcriptomics research
2. Introduce the instrumentation and various technologies applicable in proteome analyses and provide context for generation and analyses of proteome data

Learning Outcomes

The students are expected to have the ability to:

1. Identify the right technology and method to be used in biological experiment design involving genomics and transcriptomics
2. Choose the correct proteomics technology and supporting instrumentation to answer a specific biological question

Contents

Genomics & Transcriptomics Technologies: Cell lysis & nucleic acid extraction; quality control; conventional nucleic acid sequencing; next-generation sequencing technologies & instrumentation, fragmentation, size selection & purification strategies; single molecule real-time sequencing technology; multiplexing strategies; strategies for aiding in analyses of data; microarray fabrication, hybridization & scanning equipment (14 Lectures)

Proteomics technologies: Protein extraction, fractionation, separation & purification, protein sequencing, isoelectric focusing, 1D & 2D gel electrophoresis based approaches, gel imaging equipment & analysis software, mass spectrometry for gel based proteomics, gel-independent separation & mass spectrometry methods, tandem mass spectrometry, quantitative proteomics (14 Lectures)

Textbook

1. Lesk A., (2017), *Introduction to Genomics*, 3rd Edition, Oxford University Press
2. Lovric, J., (2011), *Introducing Proteomics: From Concepts to Sample Separation, Mass Spectrometry and Data Analysis*. 11th Edition, Wiley-Blackwell.

Reference Books

1. Pevsner J., (2015), *Bioinformatics and Functional* Genomics, 3rd Edition, Wiley Blackwell.
2. Thangadurai D., Sangeetha J., (2015), *Genomics and Proteomics: Principles, Technoogies & applications*, 1st Edition, CRC Press

Twyman R., (2013), *Principles of Proteomics*, 2nd Edition, CRC Press

4. Conn P.M., [Ed.] (2003), *Handbook of Proteomic Methods*, Springer

Self-Learning Material

1. Vikash Kumar Dubey, *Proteomics & Genomics*, NPTEL Course Material, Department of Biosciences & Bioengineering, Indian Institute of Technology Guwahati, https://nptel.ac.in/courses/102103017/
2. S. Ganesh, *Functional Genomics*, NPTEL Course Material, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/102104056/
3. Sanjeeva Srivastava, *Proteomics: Principles and Techniques*, NPTEL Course Material, Department of Biosciences & Bioengineering, Indian Institute of Technology Bombay, https://nptel.ac.in/courses/102101007/6

Title	**Algorithms in Biology**	Number	BBL7XX0
Department	Bioscience & Bioengineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech	Type	Elective
Prerequisite	Nil		

Objectives:

1. To develop an understanding of the main algorithmic approaches used in solving computational problems that arise in the analysis of biomolecular data (such as DNA/RNA/amino acid sequences, mass spectra of proteins, whole genomes, or gene expression levels).

Learning outcomes:

The students are expected to:

1. Understand various algorithms related to biological data analysis.
2. Develop new efficient algorithm to solve biological data.

Contents

Algorithms and Complexity: What is an algorithm?, Biological Algorithm versus Computer Algorithms, The change problem, Correct versus Incorrect Algorithms, Recursive Algorithms, Iterative versus Recursive Algorithms, Fast vs Slow Algorithms, Big-O Notation, Algorithm Design Techniques, Tractable versus Intractable Problems *(10 lectures)*

Greedy Algorithms: Genome Rearrangements, Sorting by Reversals, Approximation Algorithms, Breakpoint: A different face of greed, A greedy approach to motif finding *(10 lectures)*

Dynamic programming algorithms: The power of DNA sequence comparison, the change problem revisited, the manhattan tourist problem, edit distance and alignments, longest common subsequences, global sequence alignment, local sequence alignment, alignment and gap penalties, multiple alignment, gene prediction. *(10 lectures)*

Clustering and Trees: Gene expression analysis, Hierarchical Clustering, *k*-means clustering, clustering and corrupted cliques, evolutionary trees, distance based tree reconstruction, Evolutionary trees and hierarchical clustering, small parsimony problem, large parsimony problem *(7 lectures)*

Gene selection algorithms: SAM, eBayes, Limma, CFS, mRMR, MRMS *[5 lectures]*

Textbook

1. Jones N. C. ,Pevzner P. A. (2014), An Introduction to Bioinformatics Algorithms, MIT Press

Reference Books

1. Mitra S. and Acharya T. (2003), Data Mining: Multimedia, Soft Computing, and Bioinformatics, New York: John Wiley

2. Mitra S., Datta S., Perkins T. and Michailidis G. (2008), Introduction to Machine Learning and Bioinformatics, New York: Chapman & Hall/CRC Press.

Online Course Material : None

Department of Computer Science and Engineering

Title	**Artificial Intelligence I**	Number	CSL7XX0
Department	Computer Science and Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech. 1st Year, Ph.D. 1st Year	Type	Compulsory
Prerequisite	None		

Objectives

The Instructor will:

1. Cover various paradigms that come under the broad umbrella of AI.

Learning Outcomes

The students are expected to have the ability to:

1. Develop an understanding of where and how AI can be used.

Contents

Introduction (1 lecture)

Propositional logic (8 lectures)

Search: Uninformed strategies (BFS, DFS, Dijkstra), Informed strategies (A* search, heuristic functions, hill-climbing), Adversarial search (Minimax algorithm, Alpha-beta pruning) (10 lectures)

Predicate logic: Knowledge representation, Resolution (6 lectures)

Rule-based systems: Natural language parsing, Context free grammar (3 lectures)

Constraint satisfaction problems (4 lectures)

Planning: State space search, Planning Graphs, Partial order planning (4 lectures)

Uncertain Reasoning: Probabilistic reasoning, Bayesian Networks, Dempster-Shafer theory, Fuzzy logic (6 lectures)

Textbook

1. Russel,S., and Norvig,P., (2015), *Artificial Intelligence: A Modern Approach*, 3rd Edition, Prentice Hall

Reference Books

1. Research literature

Self Learning Material

1. Department of Computer Science, University of California, Berkeley, http://www.youtube.com/playlist?list=PLD52D2B739E4D1C5F
2. NPTEL: Artificial Intelligence, https://nptel.ac.in/courses/106105077/

Title	**Software and Data Engineering**	Number	CSL7XX0
Department	Computer Science and Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech.	Type	Compulsory
Prerequisite			
Objectives			

The Instructor will:
1. Discuss techniques to manage a large amount of data
2. Provide mechanisms to design and develop data-intensive computing systems

Learning Outcomes

The students are expected to have the ability to:
1. Design complex end-to-end data pipeline for data processing
2. Critically identify and use the tools for data handling and management
3. Use modern software technologies to design and develop data analytical systems

Contents

CSL7XX0 Cloud Computing and Virtualization 1-0-0 [1]

Basics of complex software design: Concept of modular software, microservices, communication, 4+1 architectural views and patterns (5 lectures)
Cloud Computing: Architecture of cluster computing, design of data centers, open data center platforms, fault-tolerant system design (5 lectures)
Virtualization: Type-1 and Type-2 virtualization, virtual machine, containers, dockers (4 lectures)

CSL7XX0 Data Management 1-0-0 [1]

Data Management: Structured data, relational database management, unstructured data, semi-structured data, Nosql database management (mongodb), column database, graph database, XML, JSON, HDFS, Handling drift in data, sensor data reliability at software and algorithmic level, sensor data analysis techniques (14 lectures)

CSL7XX0 Data Intensive Processing Systems 1-0-0 [1]

Data Intensive Processing Systems: Architecture of large scale data processing systems, Hadoop, Apache Spark, Storm, parallel data processing concepts such as map-reduce, directed acyclic graph, resilient distributed datasets, dynamic resource allocation, partial & shared computation, storage architecture (14 lectures)

Textbook

1. Bass L., Clements P., Kazman R., (2012), *Software Architecture in Practice*, 3rd edition, Addison-Wesley Professional
2. Martin K., (2017), *Designing Data-Intensive Applications: The Big Ideas Behind Reliable, Scalable, and Maintainable Systems*, 1st Edition, O'Reilly Media

Self Learning Material

1. Tylor,R.N., Medvidovic,N. and Dashofy,E.M., (2014), *Software Architecture Foundation: Theory and Practice*, Wiley

Preparatory Course Material

1. IEEE Transactions on Knowledge and Data Engineering
International Conference on Data Engineering

Title	**Security and Its Application**	Number	CSL7XX0
Department	Computer Science and Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech.	Type	Elective
Prerequisite	Networks		

Objectives

The Instructor will:
1. Provide the fundamental principles of access control models and techniques, authentication and secure system design
2. Introduce a strong understanding of different cryptographic protocols and

techniques and be able to use them

3. Provide methods for authentication, access control, intrusion detection and prevention

Learning Outcomes

The students are expected to have the ability to:

1. Understand cryptography and network security concepts and application
2. Identify and investigate network security threat
3. Analyze and design network security protocols

Contents

CSL7xx1 Introduction to Cryptography 1-0-0 [1]

Shannon's Approach to Cryptography: Measures of security, Perfect secrecy, Definition of entropy, One-time pad (3 lectures)

Symmetric Key Cryptography: The notion of a symmetric key cryptography, The Data Encryption Standard (DES) and differential cryptanalysis, The Advanced Encryption Standard (AES) (4 lectures)

Cryptographic Hash Functions: Definition of hash functions and properties, Unkeyed hash functions, Keyed hash functions, Message Authentication Codes (MAC), The Random Oracle Model (ROM) (4 lectures)

Authentication: Definition of authentication, A simple authentication protocol and possible attacks, Strong password protocols, BM Encrypted Key Exchange (EKE), Key Distribution Centers (KDC), Certification authorities and certificate revocation, KDC based authentication protocols (3 lectures)

CSL7xx2 Network Security 1-0-0 [1]

Public Key Cryptosystems: Fundamentals of Public-key Cryptography, Background on number theory, The RSA public key cryptosystem, The ElGamal public key cryptosystem and discrete logs *Digital Signatures:* An RSA based signature scheme, The ElGamal based signature scheme,The Schnorr signature scheme, The Digital Signature Algorithm (DSA) (6 lectures)

Key Distribution and Key Agreement Protocols: Key Predistribution: Diffie-Hellman key Exchange, The MTI key Exchange (4 lectures)

Network Security: TCP/IP threats, The IPSEC protocol, The SSL and TLS protocols, Firewalls and Virtual Private Networks (VPNs), Electronic mail security, Worms, DDoS attacks, BGB and security considerations (4 lectures)

CSL7xx3 Cyber-physical security and Blockchain 1-0-0 [1]

(fractal 3) *Cyber-physical security*: IoT security, sensor actuator network security (4 lectures) *Block Chain:* Introduction to Blockchain, Blockchain Architecture and Design, Consensus (Byzantine Fault, Proof of Work, Poof of Stake,), Permissioned Blockchains, Components of blockchain (10 lectures)

Laboratory Experiments

Programming exercises using Exata and AVISPA Tools

Textbook

1. Stallings, W. (2017). *Cryptography and network security, 7/E*. Pearson Education India
2. Douglas R. Stinson, Maura B. Paterson (2018). *Cryptography: theory and practice*. 4/E Chapman and Hall/CRC

Reference Books

1. Mao, W. (2004). *Modern cryptography: theory and practice*. Pearson Education India
2. Pfleeger, C. P., & Pfleeger, S. L. (2018). *Security in computing*. 5/E, Prentice Hall Professional Technical Reference
3. Goldreich, O. (2009). *Foundations of cryptography: volume 2, basic applications*. Cambridge university press
4. Forouzan, B. A. (2015). *Cryptography & network security*. 3/E, McGraw-Hill, Inc.

Self Learning Material

1. Network and Computer Security - MIT OpenCourseWare

https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-857-network-and-computer-security-spring-2014/ 2. Cryptography I, Coursera, Stanford University, https://www.coursera.org/learn/crypto

Department of Metallurgical and Materials Engineering

Title	**Computational Materials Engineering**	**Number**	MT7LXX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–2 [4]
Offered for	M.Tech. and Ph.D.	Type	Compulsory
Pre-requisite			

Objective

1. To understand different modeling and simulations techniques for studying various materials.

Learning Outcomes

1. Student will be able to understand and use the first-principles calculations
2. Student will be able to understand and run the Molecular dynamics simulations

Course Content

First-principles calculations (28 lectures)

Introduction, Density functional theory (5 lectures), Kohn-Sham method (4 lectures), Exchange-correlation energy (2 lectures), Crystal structure (1 lecture), Pseudopotential approach (2 lectures), Bloch's theorem (2 lectures), Structure relaxation (1 lecture), Electronic band structure and density of states (3 lectures), Fermi-Dirac distribution (1 lecture), Smearing methods (1 lectures), Lattice dynamics (1 lectures), Phonon dispersion relations (1 lecture), Force constants (3 lectures), Vibrational thermodynamics (1 lecture)

Molecular dynamics simulations (14 lectures)

Introduction (1 lecture), Potentials (2 lectures), Newtons Equation of motion (2 lectures), Algorithms (2 lectures), Simulation parameters (2 lectures), Types of ensembles (2 lectures), Temperature control and data analysis (3 lectures)

Laboratory Experiments

Preparation of input files, Technical parameters optimization, Structure optimization, Electronic band structure calculation, density of states calculation, metallic system simulation, phonon band structure calculation

Text Books

1. Lee, J., *Computational Materials Science: An Introduction*, 2nd Edition, CRC Press 2016.
2. Sholl, D. S., and Steckel, J. A., *Density Functional Theory: A Practical Introduction*, 1st Edition, Wiley, 2009.
3. Dove, M.T., *Introduction to Lattice Dynamics*, 1st Edition, Cambridge University Press, 1993.

Self-Learning Material

1. Parr, R.G., and Yang, W., *Density-Functional Theory of Atoms and Molecules*, 1st Edition, Oxford Science Publications, 1994.
2. Raabe, D., *Computational Materials Science: The Simulation of Materials, Microstructures and Properties*, Wiley VCH, 1998.

Online Course Materials

MIT open courseware: Gerbrand Ceder, and Nicola Marzari. 3.320 Atomistic Computer Modeling of Materials (SMA 5107). Spring 2005. Massachusetts Institute of Technology: MIT OpenCourseWare, https://ocw.mit.edu. License: Creative Commons BY-NC-SA

Department of Mechanical Engineering

Title	**Robotics**	Number	MEL7XX0
Department	Mechanical Engineering	L-T-P-Th [C]	3-0-2-0 [4]
Offered for	B. Tech (ME), M. Tech(AMD) and PhD	Type	Program Core
Prerequisite			

Objectives

1. To introduce fundamental aspects of modeling and control of robot manipulators.
2. To provide a brief of results from geometry, kinematics, dynamics, motion planning and control

Learning Outcomes

1. The course will equip students with theoretical and practical knowledge of robot modeling, programming and control.

Contents:

Fractal 1: Robot Modeling [MEL7XX1] [1-0-0]

1. Rotational Transformations, Composition of Rotations, Parameterizations of Rotations, Rigid Motions, Homogeneous Transformations (2 lectures)
2. Forward and Inverse Kinematics – Kinematic Chains, Forward Kinematics: The Denavit- Hartenberg Convention, Inverse Kinematics, Kinematic Decoupling (4 lectures)
3. Velocity Kinematics – The Jacobian: Angular and Linear Velocity: The General Case, Derivation of the Jacobian, Analytical Jacobian, Singularities, Inverse Velocity and Acceleration (4 lectures)
4. Robot Dynamics: Equations of Motion, Kinetic and Potential Energy, Euler-Lagrange Equations, Properties of Robot Dynamic Equations, Recursive Newton-Euler Formulation (4 lectures)

Fractal 2: Motion Planning and Programming [MEL7XX2] [1-0-0]

1. Path and Trajectory Planning: Path vs. Trajectory, The Configuration Space, Path Planning Using Configuration Space, Potential Fields, Trajectory Planning, Point To Point Motion, Paths Specified by Via Points, Probabilistic Roadmap Planner (5 lectures)
2. Vision-Based Control: The Geometry of Image Formation, Camera Calibration, Camera Motion and Interaction Matrix, Image-Based Control Laws, Relation between End Effector and Camera Motions, Partitioned Approaches (4 lectures)
3. Robot Operating System (ROS): Basic ROS concepts, Writing RoS Programs, Log Messages, Graph Resource Name, Launch Files, Parameters, Services, Recording and Replaying Services (5 lectures)

Fractal 3: **Robot Control[MEL7XX3] [1-0-0]**

1. Sensors and Actuators: Joint Actuating Systems, Drives, Proprioceptive Sensors, Exteroceptive Sensors (3 lectures)
2. Linear Control: Feedback and closed-loop control, second-order linear systems, control of second-order systems, Control-law partitioning, trajectory-following control, disturbance rejection, continuous vs. Discrete time control, modeling and control of a single joint, architecture of an industrial-robot controller (3 lectures)
3. Nonlinear control: Nonlinear and time-varying systems, multi-input, multi-output control systems, control of manipulators, practical considerations, current industrial-robot control systems, lyapunov stability analysis, cartesian-based control systems, adaptive control (4 lectures)
4. Force Control: Interaction with Environment, Compliance Control, Impedance Control, Force Control, Hybrid Force/Motion control (4 lectures)

Laboratory Classes (12 exercises)

DH Parameters, Forward and Inverse Kinematics of Robot, Robot Trajectory

Planning, Robot Operating System (ROS), Control of Robot through ROS, Path Planning, Vision Based control, Force Control

Reference Books

1. Saha S. K., Introduction to robotics. Tata McGraw-Hill Education
2. Spong M. W., Hutchinson, S., and Vidyasagar, M., Robot modeling and control. New York: Wiley.
3. O'Kane J. M., A Gentle Introduction to ROS, ISBN 978-1492143239
4. Craig J. J, Introduction to robotics: mechanics and control. Pearson/Prentice Hall.

Self Learning Material

1. https://see.stanford.edu/Course/CS223A

Title	**Probabilistic Methods in Engineering Design**	Number	MEL7XX0
Department	Mechanical Engineering	L-T-P-Th [C]	3-0-0-0 [3]
Offered for		Type	Open Elective
Prerequisite			

Objectives

1. To provide a unified probabilistic approach to design aspects in transport phenomena, hydrology, climatic events, properties of materials and dealing with environmental and ecological variables.

Learning Outcomes

The students are expected to have the ability to:

1. Ability to model and predict phenomena such as development of strength in composite materials, size effect in failure theories, precipitation events, earth quake occurrences, and system behaviors etc.
2. To assess the reliability of engineering structures, to assess hazard rates of extreme climatic events, to assess the multi-parameter influences on flow, electro-kinetic parameters.

Contents

Data: Hydrologic Data, Big data, Overview of how data can be helpful in designing and planning urban spaces, social data, experimental data and specific nature of the data related to heat measurement, electricity, dielectric strength, porosity, particle size distribution, and other materials properties, stochastic data and its behavior, line diagram representation of linear and nonlinear data (8 lectures)

Prior and Post event categorization: Collective and exhaustive events, Total probability theorem, Bayes Theorem, Calculations of Probability Density Function, Cumulative Density Function when experimental data is provided (6 lectures)

Data Reduction: Descriptive statistics, Skewness, Moments, Kurtosis, Parameter Estimation, Chebyshev Inequality, Law of Large Numbers, Descriptive statistics introduction and training exercises in design of experiments and data compilation (6 lectures)

Presentation: Hydrographs, Distribution graph, flood frequency studies, normal annual precipitation events, lognormal models in fracture of materials and strength characterization, Gumbel Distribution, Log Pearson Type III Distribution, Extreme events type 1 distrbution, Raleigh Distribution (assessing errors in projectile motion), exponential distribution, Erlangs distribution and its variation the gamma distribution, Markov Processes. MINITAB 15/16 introduction and training exercises on transforming data as required by the software (8 lectures)

Analysis: Auto-correlation, hydrologic time series, spectral density functions, Regression, removing correlations between predictor variables, linear multi-parameter regression, Principal components, factor analysis, multi-variate regression analysis, Boot strapping and Jack Knife Procedures. Exercises to find correlation matrices from available experimental data, finding principal components using multi-variate analysis etc. Introduction to GEPHI and social network data analysis with intra-levels (10 lectures)

Testing: Sensitivity Analysis, Kolmogorov Smirnov Tests, Chi square Tests, Analysis of variance. Exercises to perform normality tests and variance analysis. (4 lectures)

Laboratory Experiments

MINITAB 15/16 introduction and MATLAB training exercises on transforming data as required by the software.

Reference Books

1. Benjamin J. R. and Cornell A. C., Probability, Statistics and Decision for Civil Engineers, McGraw Hill
2. Ang A. H. S. and Tang W. H., Probability Concepts in Engineering, Planning and Design Vol- 1- Engineering and Design, John Wiley
3. Ang A. H. S. and Tang W. H., Probability Concepts in Engineering, Planning and Design Vol- 2- Decision, Risk and Reliability, John Wiley

Online Course Material

1. https://nptel.ac.in/courses/105105045/

Department of Physics

Title	**Computational Physics**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

1. To incorporate modern computational skills into the scientific problem solving paradigm.

Learning Outcomes

1. The successful students will become familiar with commonly used numerical techniques to solve problems in physics.

Contents

(Fractal 1) **PHL7XX1** ***Numerical Methods-I*** **[1-0-0]** Solution of algebraic and transcendental equations: Iterative, bisection and Newton Raphson methods, Solution of simultaneous linear equations: Matrix inversion method (14 lectures)

(Fractal 2) **PHL7XX2** ***Numerical Methods-II*** **[1-0-0]** *Interpolation*: Newton and Lagrange formulas, Numerical differentiation, Numerical Integration, Trapezoidal, Simpson and Gaussian quadrature methods, Least-square curve fitting, straight line and polynomial fits. (8 lectures)

Numerical solution of ordinary differential equations: Euler and Runge-Kutta methods. (6 lectures)

(Fractal 3) **PHL7XX3 S*imulations*: *Numerical Methods* [1-0-0]**Generation of uniformly distributed random integers, Statistical tests of randomness, Monte-Carlo evaluation of integrals and error analysis, Non-uniform probability distributions, Importance sampling, Rejection method, Metropolis algorithm, Molecular diffusion and Brownian motion as random walk problems and their Monte Carlo simulation. (8 lectures)

Quantum Simulations: Time-independent Schrodinger equation in one dimension (radial or linear equations), Scattering from a spherical potential, Born Approximation, Bound State solutions. (6 lectures)

The students will be assigned computer laboratory work based on the above syllabus.

Textbook

1. Koonin, S. E. and Meredith, D. C., Computational Physics, Addison-Wesley, 1990.
2. Tao Pang, An Introduction to Computational Physics, Cambridge Univ. Press, 1997.

Self-Learning Material

1. https://nptel.ac.in/courses/115104095/
2. https://nptel.ac.in/syllabus/115106060/

Reference Course Material

1. Landau, R. H. and Mejia, M. J. P., Computational Physics, John Wiley, 1997.
2. Thijssen, J. M., Computational Physics, Cambridge Univ. Press, 1999.

Title	**Computational Materials Science**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Help in understanding the physical properties of materials.
2. Help in implementing the theoretical concepts to compute materials properties.

Learning Outcomes

The students are expected to have the ability to:

1. Learn theoretical concepts of different computational techniques in materials science.
2. Simulate and compute material properties using density functional theory, molecular dynamics and Monte Carlo methods.

Contents

(Fractal 1) **PHL7XX1** ***Basic concepts in Density Functional Theory (DFT) (1-0-0)***

Uniform electron gas, Thomas-Fermi model, The Hohenberg-Kohn theorems, formulation of DFT, Kohn-Sham variational principle, Local/spin density approximation (LDA/LSDA), Generalized-gradient approximations (GGAs), Orbital dependent functional, Hybrid functionals, Introduction to Quantum Espresso. (14 lectures)

(Fractal 2) **PHL7XX2** ***Molecular dynamics Simulations (1-0-0)***

Equations of motion, integrators, Interaction potential models, Force calculations, Long- range corrections, Molecular dynamics in various ensembles, Advanced MD techniques, Linear response theory and Introduction to LAMMPS & GROMACS. (14 lectures)

(Fractal 3) **PHL7XX3** ***Monte Carlo Simulations (1-0-0)***

Monte Carlo integration, Importance sampling, Metropolis algorithm, Detailed balance, Free energy calculations, Widom insertion and Grand canonical Monte Carlo. (14 lectures)

Textbook

1. Sholl, D, and Steckel, J. A., *Density Functional Theory: A Practical Introduction*, Wiley- Interscience 2009.
2. Frenkel, D, and Smit, B., *Understanding Molecular Simulation: From algorithms to applications*, Academic Press 2001.
3. Landau, D. P. and Binder, K., *A Guide to Monte Carlo Simulations in Statistical Physics*, 3rd Edition, Cambridge University Press 2009.

Reference Books

1. Martin, R. M., *Electronic Structure Basic Theory and Practical Methods*, Cambridge University Press 2004.

Allen, M. P., and Tildesley, D. J., *Computer Simulation of Liquids*, Oxford University Press, 2nd ed. 2017.

Online Course Material

1. MIT Open Course Ware, 3.320 “Atomistic Computer Modeling of Materials (SMA 5107)”, by Ceder, G. and Marzari, N.; Spring 2005, https://ocw.mit.edu/courses/materials-science- and-engineering/3-320-atomistic-computer-modeling-of-materials-sma-5107-spring-2005/
2. NPTEL course by Prof. Tembe, B. L., Department of Chemistry, IIT Bombay; “Computational Chemistry and Class Molecular Dynamics”; https://nptel.ac.in/courses/104101095/.
3. LAMMPS MD simulation package https://lammps.sandia.gov/index.html.

IDRP: Quantum Computing

Title	**Quantum Computing**	Number	QCL7XX0
Department	IDRP (QC)	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Impart mathematical framework of Quantum Computation to students familiar with basic concepts of quantum mechanics and quantum information

2. Discuss advanced topics and State-of-the-Art research in quantum information and computation (QIC)

Learning Outcomes

The students are expected to:

1. Use the concepts taught in class to various aspects of quantum information, communication and cryptography
2. Understand and appreciate the technological evolution at theoretical and experimental front in QIC

Contents

Mathematical Preliminaries: Quantum Mechanics, Matrix representations of quantum states and operators, Cauchy-Schwartz and Triangle Inequalities, Classical and Quantum Correlations (6 Lectures)

Notions of Quantum Information: Classical and Quantum state Registers, Pure and Mixed states, Reduction and Purification of states, Quantum Channels, Completely Positive and trace Preserving Maps (6 Lectures)

Entropy: Quantitative bounds on Shannon and relative Entropy, Von-Neumann and quantum relative entropy, Klein's inequality, Concavity and subadditivity of von Neumann entropy, Strong subadditivity of von Neumann entropy, Accessible Information, Holevo information (8 Lectures)

Entanglement and Nonlocality: Separability Criteria, Classical, Separable and Entangled states, Local Operations and Classical Communications, Distillable entanglement and entanglement cost, Bound entanglement, Bell's Inequality and Nonlocality, Nonlocality in multiqubit Systems, Entanglement Measures (12 Lectures)

Quantum Error Correction: Bit flip and phase flip codes, Quantum Hamming Bound, Calderbank-Shor-Steane codes, Gottesman-Knil theorem, Fault-tolerant quantum computation, quantum algorithms and cryptography (10 Lectures)

Textbooks

1. Nielsen, M. A. and Chuang, I. L., *Quantum Computation and Quantum Information*, Cambridge University Press, 2000
2. Vedral, V., *Introduction to Quantum Information Science,* Oxford University Press, 2006

Reference Books

1. Griffiths, D. J., *Introduction to Quantum Mechanics*, Pearson Prentice Hall, 2006
2. Bouwmeester, D., Ekert, A. and Zeilinger, A., *The Physics of Quantum Information*, Springer, 2000
3.

Self Learning Material

1.Goswami, D., *Quantum Computing*, *Mathematics for Chemistry,* NPTEL Course Material, Department of Chemistry, Indian Institute of Technology Kanpur
https://onlinecourses.nptel.ac.in/noc18_cy07/preview

Title	**Facets of Quantum Information**	Number	QCL7XX0
Department	IDRP (QC)	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide an appreciation for the classical and quantum aspects of information theory.
2. Help in developing an understanding of the exciting world of quantum

computation and information

Learning Outcomes

The students are expected to have the ability to:

1. Understand the fundamental principles of quantum information.
2. Appreciate some modern applications of quantum mechanics.

Contents

Review of basics of quantum information and computation (4 Lectures)

Entanglement and Separability criterion, Entanglement measures, Purification and distillation, multi qubit entanglement, nonlocal correlations, multi qubit Bell-type inequalities (12 Lectures)

Quantum Computation: Quantum logic gates; quantum Fourier transform; quantum algorithm; physical realization of quantum computers (8 Lectures)

Classical Information and Communication: What is information and how can it be used? Concepts of communication channels; Shannon entropy; coding theory and communication complexity. (8 Lectures)

Quantum Information: What is information theory from the perspective of quantum mechanics? Quantum entropy; quantum mutual information; fidelity. (6 Lectures)

Some Unconventional Models of Computing: Brief introduction to cellular computation and communication; chaos based computing; DNA computing. (4 Lectures)

Textbook:

1. Nielsen Michael, A. and Chuang Isaac , I., *Quantum Computation and Quantum Information*, Cambridge University Press, 2010.

Self-Learning Material:

1. Ghosh, D., Quantum Information and Computing, Indian Institute of Technology Bombay, https://nptel.ac.in/syllabus/115101092/.

Title	**Quantum Cryptography and Coding**	Number	QCL6XX0
Department	IDRP (QC)	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Introduce the students to the fascinating field of cryptography and coding, with specific emphasis on the quantum aspects of it.
2. Highlight a number of facets of these theories having some parallel with the more familiar classical world.

Learning Outcomes

The students are expected to have the ability to:

1. Understand the fundamental principles of quantum cryptography and coding.
2. Become familiar with the modern aspects of the theory, including its experimental

implementation.

Contents

What is cryptography? Various aspects of modern cryptography; number theoretic concepts.

Classical Coding Theory: Concepts of entropy, mutual information and related aspects; Shannon's coding theorem. (10 Lectures)

Basic concepts of Quantum Mechanics: From the perspective of information and cryptography: Hilbert space, states, operators: Hermitian and Unitary, simple measurements. (5 Lectures)

Some basic no-go theorems: With implications to cryptography. (2 Lectures)

Some basic applications pertinent to quantum cryptography: Entanglement, teleportation, dense coding. (6 Lectures)

Various Quantum Cryptography protocols: Quantum Key Distribution protocols: BB84, B92, Ekert protocol, Goldenberg-Vaidman, counterfactual quantum cryptography; protocols of quantum dialogue; Quantum secret sharing protocol; Quantum cheating and cryptography; Protecting information and QKA (quantum key agreement); Shor's factoring algorithm and modern cryptography; Experimental progress in quantum cryptography. (15 Lectures)

Quantum Coding: Quantum aspects of Shannon coding theorem. (4 Lectures)

Textbook:

1. Nielsen Michael, A. and Chuang Isaac , I., *Quantum Computation and Quantum Information*, Cambridge University Press, 2010.

Self-Learning Material:

1. MIT Open Course, *18.435J* “Quantum Computation”, by Shor. P.; Fall 2003, https://ocw.mit.edu/courses/mathematics/18-435j-quantum-computation-fall-2003/

(9) List of Program Electives:

<table>
<tr><td>Department of Mathematics</td><td>Department of Computer Science and Engineering</td></tr>
<tr><td rowspan="3">Financial Engineering
Computational Game Theory
Advanced topics in computational PDE
Dynamical Systems
Time Series Analysis
Reliability Theory
Stochastic Processes
Linear Algebra with Data (1-0-0-0)
Markov Models (1-0-0-0)
Evolutionary Optimization (1-0-0-0)
Data Engineering
Group Theory for Machine Learning
Representation Theory of Finite Groups
Shared Computational Economics
Mathematical Biology
Statistical Models and Regression
Topological Data Analysis
Chaos Theory and its Applications</td><td>Natural Language Understanding
Artificial Intelligence
Advanced Artificial Intelligence
Advanced HMI
Software and Data Engineering
Security and its Applications
Graph Theory and its Applications
Bio-image Computing
Computer Vision
Information Retrieval
Graph Theoretic Algorithms
Introduction to AR and VR</td></tr>
<tr><td>Department of Metallurgical and Materials Engineering</td></tr>
<tr><td>Computational Materials Engineering</td></tr>
<tr><td>Department of Electrical Engineering</td><td>Department of Mechanical Engineering</td></tr>
<tr><td rowspan="3">Digital Image Processing and Applications
Digital Video Processing
Coding Theory
Compressive Sensing
Machine Learning for Communication
Data Compression</td><td>Robotics
Probabilistic Methods in Engineering Design</td></tr>
<tr><td>Department of Physics</td></tr>
<tr><td>Computational Physics
Computational material science</td></tr>
<tr><td>Department of Bioscience and Bioengineering</td><td>IDRP: Quantum Computing</td></tr>
<tr><td>Introduction to Omics Technologies
Algorithms in Biology</td><td>Quantum Computing
Facets of Quantum Information
Quantum Cryptography and Coding</td></tr>
</table>