Indian Institute of Technology Jodhpur

PG Course Booklet

Indian Institute of Technology Jodhpur

July 2019

॥ 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:

Cat.	Course Number	Course Title	L-T-P	Credits	Cat.	Course Number	Course Title	L-T-P	Credits
Semester 1					**Semester 2**				
C	MAL7XX0	Introduction to Data Science	1-0-0-0	1	C	MAL7XX0	Numerical Methods for PDE	1-0-0-0	1
C	CSL7XX0	Machine Learning 1	3-0-0-0	3	C	CSL8XX0	Machine Learning 2	3-0-0-0	3
C	MAL7XX0	Mathematics for Data Science	3-0-0-0	3	C	CSL7XX2	Software and Data Architecture*	1-0-0-0	1
C	MAL7XX0	Statistics 2	2-0-0-0	2	C	CSL7XX0	Security and its Application	3-0-0-0	3
C	MAL7XX0	Introduction to Modeling	1-0-0-0	1	C	MAP7XX0	Data Analytics Lab	0-0-2-0	1
E	xxxxx	PE1	3-0-0-0	3	E	Xxxxx	PE2	3-0-0-0	3
C	CSP7XX0	Data structures and practices	0-0-2-0	1	E	Xxxxx	PE3	3-0-0-0	3
NG	xxxxx	Technical Communication	1-0-0-0	1	NG	xxxxx	Innovation andIP Management	1-0-0-0	1
			Total	**15**				**Total**	**16**
Semester 3					**Semester 4**				
E	xxxxx	PE4	3-0-0-0	3	E	Xxxxx	OE2	3-0-0-0	3
E	xxxxx	PE5	3-0-0-0	3					
E	xxxxx	OE1	3-0-0-0	3					
P	MA6xx	Project	0-0-0-5	5	P	MA6xx	Project	0-0-0-11	11
NG	xxxxx	System Engineering and Project Management	1-0-0-0	1	NG	xxxxx	Professional Ethics	1-0-0-0	1
			Total	**15**				**Total**	**15**
								Grand Total	**61**

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Credit Distribution				
S.No.	***Category***	***Course Category Title***	***Total Courses***	***Total Credits***
1	C	*Compulsory*	9	18
2	C	*Labs*	2	02
3	PE	*Program Electives*	5	15
4	OE	*Open Electives*	2	6
5	P	Project	1	16
			Total (without non-graded courses)	**57**

(6) Topic Cloud

Compulsory Topics:

(a) Data pre-processing (including redundancy removal), Data storage, data representation, data handling, data query, data cleaning.
(b) Relational data bases, graph databases, NoSQL (columnar DB), unstructured data, Map reduced techniques and Indexing.
(c) Distributions, test of hypothesis, stochastic process, queuing process, sampling techniques, Probabilistic models, Mixture models, Latent Models, prediction models, Association Analysis, Correlation analysis, Evaluation and Validation, performance analysis/metrics
(d) Vector and matrix algebra, Decompositions, SVD, pseudo inverse, rank approximation
(e) Linear and Non-linear Programming.
(f) Classification, regression, prediction, clustering, anomaly detection, feature engineering, supervised/ unsupervised Learning, Fundamental of SVM, Kernel techniques, States space machine, Markov decision process, ANN, Deep learning and its implementation, Deep learning application lab (GPU environment, Python environment) , Higher level Machine learning, Transfer learning, online and incremental learning, reinforcement learning, explain-ability in Machine Learning, Bias variance trade-off, ensemble learning, Auto ML
(g) Discrete models, continuous models, Hybrid models (both analytical and data driven models), assumptions, approximations, models validation, MCS
(h) Numerical methods for PDEs
(i) Cryptosystems (types)

Elective Topics:

Financial engineering, Computational finance, Computational Game Theory, Graph Theory, Dynamical Systems, Reliability Theory, Stochastic Processes, Representation of Finite Groups, Computational linguistics, Computational economics, Digital Humanities, Cultural informatics, Blockchain, security and privacy, AR/VR, Natural Language Processing and Text analytics, Visualization, Machine learning for big data, Human-machine interface, Computational modelling in materials design, Bioinformatics, Computational biology, Digital Image Analysis, Coding Theory, Robotics, Computational electro magnetism, Computational optics, Quantum Information System, Quantum Cryptography, Quantum Computing, Computational Physics, Computational material science, Computational chemistry, adaptive numerical methods, multi-grid methods, parallel methods, GPU computation.

(7) List of Program Electives

(a) Electives from sister Departments:

S.No.	Course Title	S.No.	Course Title
Department of Mathematics		**Department of Electrical Engineering**	
1	Financial Engineering	19	Digital Image Processing and Applications
2	Computational Game Theory	20	Digital Video Processing
3	Advanced topics in computational PDE	21	Coding Theory
		22	Compressive Sensing
4	Dynamical Systems	23	Machine Learning for Communication
5	Reliability Theory	24	Compressive Sensing
6	Stochastic Processes	25	Data Compression
7	Representation of Finite Groups	**Department of Mechanical Engineering**	
8	Shared Computational Economics	26	Robotics
Department of Humanities and Social Sciences		27	Probabilistic Methods in Engineering
		Department of Physics	
9	Cultural informatics	28	Computational Physics
Department of Computer Science and Engineering		29	Computational material science
		Department of Chemistry	
10	Computational linguistics	30	Computational Chemistry
11	Introduction to Virtual and Augmented Reality	**Department of Metallurgical and Materials Engineering**	
12	Natural Language Processing	31	Computational Materials Engineering
13	Visualization/Data Visualization	**Department of Biosciences and bioengineering**	
14	Artificial Intelligence 1		
15	Artificial Intelligence 2	32	Omics Technologies
16	Human Machine Interface	33	Algorithm development
17	Graph Theory and its Applications	34	Computational modeling in material design
17	Bio-image Computing		
18	Computer Vision	35	Applications in Multi Omics data, Imaging, Sensors

(b) Electives from IDRPs:

Digital Humanities	
1	Introduction to Digital Humanities
Quantum Computing	
2	Introduction to Quantum Information
3	Quantum Computing
4	Facets of Quantum Information
5	Quantum Cryptography and Coding

(c) Specialized electives:

1	Selected Topics in Data and Computational Science - I (1-0-0-0)
2	Selected Topics in Data and Computational Science - II (2-0-0-0)
3	Selected Topics in Data and Computational Science - III (3-0-0-0)

(8) 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	**Mathematics for 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. Provide an understanding statistical concepts for data scientist.
2. Train the student to do Matrix Computations for implementing various numerical linear algebra algorithms.
3. Train student in the domain of linear and non-linear programming.

Learning Outcomes

The students are expected to have the ability to:

1. Derive distributional results needed for the statistical hypothesis testing and perform the hypothesis testing for the parameters of the normal population.
2. Understand the numerical linear algebraic methods and their usage for data analysis.
3. Apply programming concepts for further applications in different areas of interest.

Contents:

MAL7XX1: Statistical Techniques [1-0-0-0]

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.

Tests of Hypotheses[5 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, Neyman Pearson lemma, tests for one-sample and two-sample problems from normal populations.

Stochastic Processes[6 Lectures]: Definition and classification of general stochastic processes; Markov Chains: definition, transition probability matrices, classification of states, limiting properties; Poisson process, Birth and death processes, exponential queuing model.

MAL7XX2: Matrix Computations [1-0-0-0]

*Matrix Algebra [3 Lectures]:*Matrix operations and type of matrices, Rank of Matrix, Eigenvalues, Eigenvectors and Diagonalizable matrices, Vector Norms, Matrix Norms.

*Decompositions [9 Lectures]:*Spectral decomposition, Schur Decomposition, QR Factorization, Singular value decomposition (SVD), Polar Decomposition, Pseudo Inverse.

Approximations [2 Lectures]: Least square approximations, Low-Rank Approximation.

MAL7XX3: Optimization [1-0-0-0]

Linear Programming Problem[4 Lectures]: Linear combination of vectors, Convex set, Convex hull, Linear programming problem, feasible solution, basic feasible solution, graphical solution, Simplex method, Charne's M method.

Duality and IPP[6 Lectures]: Dual of an LPP, Integer Programming, Gomory's cut-constraint method.

Nonlinear Programming[4 Lectures]: First and second order conditions, Constrained optimization - Lagrange Multipliers, Karush-Kuhn-Tucker conditions.

Text Books

(Fractal 1)

1. Casella, G. and Berger, R. (2002), Statistical Inference, Cengage Learning.
2. Ross, S.M. (1996), Stochastic Processes, Wiley.

(Fractal 2)

3. Mayer, C.D. (2000) Matrix Analysis and Applied Linear Algebra, SIAM.
4. Strang, G., (2006), Linear Algebra and its Applications.
5. Elden, L. (2007) Matrix Methods in Data Mining and Pattern Recognition, SIAM.

(Fractal 3)

6. Luenberger, D. G., *Linear and Nonlinear Programming*, Yinyu Ye, Third Edition, Springer, 2008
7. Kambo, N. S., *Mathematical Programming Techniques*, Second Edition, Affiliated East West Press, 2005

Reference Books

(Fractal 1)

1. Rohatgi, V.K. and Saleh, A.K.M.E. (2018). An Introduction to Probability and Statistics, Wiley.
2. Ross, S.M. (2010). An Introduction to Probability Models, Elsevier.
3. Hoel, P.G., Port, S.C. and Stone, C.J. (1972). Introduction to Stochastic Processes, Houghton Mifflin Company.

(Fractal 2)

4. M Goloub, G.H. and Charles, F.V.L. (2013) Matrix Computations, JHU Press.
5. Lancaster, P. and Tismenetsky, M. (1985) The Theory of Matrices: With Applications, Academic Press.

(Fractal 3)

6. Bazaraa, M. S., Sherali, H.D., and Shetty, C. M., Nonlinear *Programming: Theory and Algorithms*, Third Edition, Wiley publications, 2006
7. Darst, R, *Introduction to Linear Programming: Applications and Extensions*, Dekker Publications, 1991

Online course Material

(Fractal 2)

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

(Fractal 3)

2. Goswami A., Chakraborty D., *Optimization,* NPTEL Course Material, Department of Mathematics, Indian Institute of Technology Kharaggpur, https://nptel.ac.in/courses/111105039/

Title	**Advanced Statistical Techniques**	Number	MAL7XX0

Department	Mathematics	L-T-P-D [C]	2–0–0-0 [2]
Offered for	M.Tech.(DCS)	Type	Compulsory
Prerequisite			

Objectives

The Instructor will:

1. Provide an understanding of the statistical concepts and their real-life applications.

Learning Outcomes

The students are expected to have the ability to:

1. Estimate the parameters of the underlying population;
2. Gain the basic knowledge of mixture models, latent models, association, correlation and regression analysis.

<u>Contents:</u>

Estimation [4 Lectures]: Point estimation-maximum likelihood estimator, methods of evaluating estimators; Interval estimation- Methods of finding confidence intervals.

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

Association and Correlation Analysis [7 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; Fitting of logit model through least squares, Properties of product moment correlation coefficient, Spearman's rank correlation coefficient.

*Regression Analysis [14 lectures]:*Model building, data collection, uses of regression; Simple linear regression model - Least-Squares estimation of the parameters, hypothesis testing on the slop and the intercept, interval estimation, prediction of new observations, coefficient of determination; Multiple linear regression model - estimation of the model parameters, hypothesis testing, confidence intervals, prediction of new observations; Model adequacy checking-residual analysis; Validation techniques.

Text Books

1. Casella, G. and Berger, R. (2002). Statistical Inference, Cengage Learning.
2. Marshall, A.W. and Olkin, I. (2007). Life Distributions: Structure of Nonparametric, Semiparametric and Parametric families, Springer.
3. Gun, A.M., Gupta, M.K. and Dasgupta, B. (1998): Fundamentals of Statistics (V-1), World Press.
4. Montgomery, D.C., Peck, E.A. and Vining, G.G. (2012). Introduction to Linear Regression Analysis, Wiley.

Reference Books

1. Rohatgi, V.K. and Saleh, A.K.M.E. (2018). An Introduction to Probability and Statistics, Wiley.
2. Draper, N.R. and Smith, H. (1998). Applied Regression Analysis, Wiley.
3. Ross, S. (2012). Simulation, Academic Press

Online course Material

1. Panchenko, D., Statistics for Applications, Massachusetts Institute of Technology: MIT Open Courseware, https://ocw.mit.edu/courses/mathematics/18-443-statistics-for-applications-fall-2006/#.

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	**Numerical Methods for PDE**	Number	MAL8XX1
Department	Mathematics	L-T-P-D [C]	1–0–0-0 [1]
Offered for	M.Tech.(DCS)/Ph.D.(MA)	Type	Elective
Prerequisite			

Objectives
The Instructor will
1. Introduce finite difference schemes for numerical solutions of partial differential equations.
2. Carry out numerical analysis of various finite difference schemes.

Learning Outcomes
The students are expected to have the ability to:
1. Apply finite difference schemes for numerical solution of partial differential equations.
2. Undertake out error analysis and stability analysis of finite difference schemes

Contents
[8 Lectures] Characterization of PDEs, Finite difference methods for elliptic, parabolic and hyperbolic problems.

*[6 Lectures]*Stability, consistency and convergence theory, dissipation and dispersion, error estimates.

Text books
1. Quarteroni, A. and Valli, A. , *Numerical Approximation of Partial Differential Equations*, Springer, 1997
2. Morton, K. W. and Mayers, D. F. , *Numerical solution of partial differential equations*, CUP, 2005

Reference Books
1. Thomas, J. W. , *Numerical partial differential equations: Finite difference methods*, Springer, 1995
2. Trefethen, L. N. and David Bau III, *Numerical Linear Algebra*, SIAM, 1997

Online Course Material
1. Nayak, A. K. , Numerical methods: Finite Difference Approach, NPTEL Course Material, Department of Mathematics, Indian Institute of Technology Roorkee, https://nptel.ac.in/courses/111107107/

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/

(9) Content of Elective courses:

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

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	**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	**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

Title	**Computational Linguistics**	Number	CSL8XX0
Department	Computer Science and Engineering	L-T-P-D [C]	3–0–0-0 [3]
Offered for	M.Tech./PhD	Type	Elective
Prerequisite	Basic Probability Theory		

Objectives
The Instructor will:

1. Enable students to develop computational models for languages.
2. Introduced linguistic structure of an unfamiliar language in terms of morphology, syntax, and orthography.
3. Impart knowledge of linguistic descriptions of a language combined with some textual resource in the language.

Learning Outcomes
The students are expected to have the ability to:
1. Do an exhaustive search of resources in and about a language without many resources.
2. Resolve technical, logistical, and ethical issues involved in constructing a keyboard layout for a language's morphology and orthography.
3. Design and implement general approaches in rule-based machine translation.

Contents

Introduction[2 Lectures]: Definition of computational linguistics, Ambiguity and uncertainty in language, The Turing test.
Regular Expressions[6 Lectures]: Chomsky hierarchy, regular languages, and their limitations, Finite-state automata, Practical regular expressions for finding and counting language phenomena, morphology, syntax and orthography.
String Edit Distance[6 Lectures]: Key algorithmic tool: dynamic programming, optimal alignment of sequences, String edit operations, edit distance, spelling correction, and machine translation.
Context Free Grammar[4 Lectures]: Constituency, CFG definition, use and limitations. Chomsky Normal Form, Top-down parsing, bottom-up parsing, Efficient CFG parsing with CYK, Earley parser.
Language modelling[10 Lectures]: Definition of information and its measurement, noisy channel model, the language Shannon game, Entropy, cross-entropy and information gain for language phenomena, Probabilistic language modelling and its applications, estimating the probability of a word, and smoothing, Generative models of language and their application to building an automatically-trained email spam filter, and automatically determining the language.
Part of Speech Tagging[4 Lectures]: The concept of parts-of-speech, examples and usage, the Penn Treebank and Brown Corpus, Collocations and Noun Phrase Parsing.
Word Sense Disambiguation and Clustering[10 Lectures]: Homonomy, polysemy, different meanings, the power of context, Language neighbourhood as a vector, Agglomerative clustering, Clustering by expectation maximization, Using clustering to discover different word senses, Semi-supervised document classification.

Textbook
1. Grishman, R. (1986) Computational Linguistics: An Introduction, Cambridge University Press.
2. Rosner, M. and Johnson, R. (1992) Computational Linguistics and Formal Semantics, Cambridge University Press.
3. Jurafsky, D. (2000) Speech & Language Processing, Pearson Education India.

Reference Books
1. Mitkov, R. (2004) The Oxford Handbook of Computational Linguistics, Oxford University Press.
2. Manning, C.D. and Schütze, H. (1999) Foundations of Statistical Natural Language Processing, MIT Press.

Online Course Material

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

Objectives
The Instructor will:

1. Enable students to understand computational economic models.
2. Impart knowledge to design expressive marketplaces.

Learning Outcomes
The students are expected to have the ability to:
1. Do an exhaustive search of computational economic models.
2. Analyse expressive marketplaces.
3. Design and implement optimal market mechanisms.

Contents
[6 Lectures] Definition of computational economics, basic techniques from mathematics, Linear programming, (Mixed) integer linear programming, Computational problems, Algorithms, Runtime of algorithms, Easy and hard problems.

[12 Lectures] Single-item auctions, Combinatorial auctions, Bidding languages, Winner determination problem, Reverse auctions and exchanges, Expressive financial securities, Barter exchanges/matching markets.

[12 Lectures] Kidney exchange, Expressive negotiation over donations, Voting and social choice, Iterative mechanisms/preference elicitation.

[12 Lectures] Risk neutrality and risk aversion, Expected utility theory, Incentive compatibility, Individual rationality, Revelation principle, Clarke mechanism, Groves mechanisms, Automated mechanism design and Proper scoring rules.

Textbook

1. Miranda, M.J. and Fackler, P.L. (2004) Applied Computational Economics and Finance, MIT Press.
2. Afonso, O. and Vasconcelos, P.B. (2015) Computational Economics: A concise introduction, Routledge.

Reference Books

1. Stokey, N.L. (1989) Recursive Methods in Economic Dynamics, Harvard University Press.
2. Chen, S.-H., Kaboudan, M. and Du, Y.-R. (2018) The Oxford Handbook of Computational Economics and Finance, Oxford University Press.

Online Course Material

Title	**Computational Chemistry**	Number	CYL7XX0
Department	Chemistry	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech.(DCS)	Type	Elective
Pre-requisite			

Objectives

The Instructor will:

1. Describe knowledge of modern techniques in computational methods applied in chemistry.

Learning Outcomes

The students are expected to:

1. Use modern computational chemistry techniques to solve fundamental problems related to chemistry.

Contents

Basics: Fundamentals of quantum, classical, and statistical mechanics, mathematical techniques (10 lectures)

Electronic structure: Variation theory, perturbation theory, electron spin, He atom, Pauli exclusion principle, Slater determinant (6 lectures)

Electronic structure of diatomic molecules: Born Oppenheimer approximation, Atomic units, H2+ ion, H2 molecule, VB theory, MO theory (8 lectures)

Wave function based theory: Hartree-Fock theory, Electron correlation, Self-consistent field wave function, Moller-Plesset theory, Coupled cluster formulation (10 lectures)

Basics of Molecular Dynamics: Theoretical foundation, Boltzmann's relation, harmonic oscillator and harmonic baths, Algorithms for equations of motions (7 lectures)

Textbook

1. Levine, I. N., (2000) Quantum Chemistry, Pearson education.
2. Lowe, J. P., (1995) Elementary Quantum Chemistry, Academic Press.

Reference Books

1. Szabo, A. and Ostlund, N. S., (1996) Modern Quantum Chemistry, Dover.
2. D. Frenkel and B. Smith, (2002), Understanding Molecular Dynamics Simulations,1st Edition, Academic Press

Self learning Material

1. K. Mangala Sunder, Introduction to Chemistry & Quantum Chemical Methods, NPTEL course material, Department of Chemistry, IIT Madras, http://nptel.iitm.ac.in