M.Sc. Mathematics

Course booklet
July 2026

Department of Mathematics
Indian Institute of Technology Jodhpur

(1) Introduction:

Classical mathematics provides a strong foundation for analyzing the key principles behind modern and emerging technologies. Furthermore, advanced analytical tools, integrated with contemporary mathematical approaches, open new avenues for exploration and innovation.

The M.Sc. (Mathematics) program at IIT Jodhpur aims to leverage these opportunities by developing a highly skilled workforce with expertise in mathematical methods essential for ensuring advancement of key technologies. The proposed four-semester program is designed to maintain a balance between theoretical analysis and practical applications of mathematics which can help students undertake the path of interest for a secure future.

The core courses establish a solid foundation in fundamental mathematical concepts while enhancing the analytical capabilities of students. In addition, students can explore their specific interests through program electives and open elective courses.

The thesis component, spread over the final two semesters, provides significant research opportunities and enables students to apply their mathematical skillset to real-world problems. Students are also required to undertake research-oriented summer internships at reputed institutes, industries, and R&D organizations.

(2) Objectives of the Program:

The M.Sc. program in Mathematics at IIT Jodhpur is designed to nurture motivated students in frontier areas of mathematics and to develop a well-trained workforce for industry and academia. The program also aims to create a vibrant academic environment that fosters independent thinking, innovation, and a strong spirit of teamwork.

(3) Graduate Attributes:

Graduates of the program will be able to:

- Analyze and interpret abstract mathematical structures.
- Demonstrate a strong understanding of contemporary areas in pure and applied mathematics, including algebra, analysis, statistics, and differential equations.
- Formulate mathematical problems inspired by real-world scenarios.
- Develop and apply mathematical models relevant to applied sciences and engineering.
- Comprehend and work effectively with abstract mathematical structures and concepts.
- Apply analytical and scientific reasoning to pursue higher studies and research in diverse areas of mathematics and allied areas.
- Communicate mathematical ideas effectively in both written and oral forms.

(4) Learning Outcomes:

Upon completion of the program, students will be able to:

- Demonstrate strong understanding of the fundamental concepts of real, complex, and functional analysis.
- Apply the principles of linear and abstract algebra.
- Utilize concepts from probability theory, statistics, and differential equations in theoretical and applied contexts.
- Employ analytical techniques and programming skills to solve mathematical problems.
- Use symbolic computation tools such as MATLAB or Mathematica effectively.
- Communicate scientific ideas and mathematical results clearly in both academic and applied settings.
- Demonstrate quality project management skills in academic and research-oriented tasks.

(5) Structure of the program:

	Min. credits
Program Core	42
Program Elective	12
Open Elective	6
(Non-Graded) Industry-Academia Summer Internship (Academic internship allowed in IIT Jodhpur)	2
Thesis*	12
Total Credit	**72**

**The thesis work must be aligned with the objectives of the enrolled program as stated in the concept note.*

(6) Semester-wise courses:

Cat.	Course Number	Course Title	L-T-P	Credits	Cat.	Course Number	Course Title	L-T-P	Credits
Semester 1					**Semester 2**				
C	MAL6XXX	Linear algebra	3-1-0	4	C	MAL6XXX	Measure and Integration	3-1-0	4
C	MAL6XXX	Real analysis	3-1-0	4	C	MAL6XXX	Complex Analysis	3-1-0	4
C	MAL6XXX	Ordinary Differential Equations	3-1-0	4	C	MAL6XXX	Functional analysis	3-1-0	4
C	MAL6XXX	Probability and Statistics	3-1-0	4	C	MAL6XXX	Multivariable Calculus and Differential Geometry	3-1-0	4
C	MAL6XXX	Abstract Algebra	3-1-0	4	C	MAL6XXX	Programming Lab	0-0-4	2
					C	MAL6XXX	Topology	3-1-0	4
			Total	**20**				**Total**	**22**
Summer Semester: (Industry-Academia Summer Internship, 2 Credits)									
Semester 3					**Semester 4**				
PE	XXXXX	PE1	3-0-0	3	PE	XXXXX	PE4	3-0-0	3
PE	XXXXX	PE2	3-0-0	3	OE	XXXXX	OE2	3-0-0	3
PE	XXXXX	PE3	3-0-0	3	T	MAT7XXX	Thesis	0-0-9	9
OE	XXXXX	OE1	3-0-0	3					
T	MAT7XXX	Thesis	0-0-3	3					
			Total	**15**				**Total**	**15**
								Grand total	**72**

(7) Program electives:

MAL6XXX: Partial Differential Equations	MAL7XXX: Statistical Inference
MAL6XXX: Galois Theory	MAL7XXX: Statistical Models and Regression
MAL6XXX: Analytic Number Theory	MAL7XXX: Optimization
MAL7XXX: Module Theory	MAL7XXX: Machine Learning and Pattern Recognition
MAL7XXX: Numerical Analysis	MAL7XXX: Time Series Analysis
MAL6XXX: Dynamical Systems	CSL7XXX: Graph Theory and its Applications

Detailed Course Content of Compulsory Courses

Course Title	**Linear Algebra**	Course Number	MAL6XXX
Department	Mathematics	L-T-P (C)	3-1-0 (4)
Offered for	M.Sc.	Type	Core
Pre-requisite			

Objectives

1. To give sufficient knowledge of the subject which can be used by students for further applications in their respective domains of interest.

Learning Outcomes

1. Concept of linear spaces, mapping between spaces, norm and their action on spaces.
2. Eigenvalues, eigenvectors and diagonalization, and Primary decomposition theorem.
3. Normal operators and Spectral theory of real symmetric normal operators.

Contents

Vector Spaces, Matrices and System of Linear Equations [10 Lectures]: System of linear equations, Matrices and rank, Vector Spaces over fields, Subspaces, Bases and dimension, Direct sum of the sub spaces.

Linear Transformation and Inner Product Spaces [10 Lectures]: Linear Transformations, Rank and Nullity theorem, Representation of linear transformations by matrices, duality and transpose. Inner product spaces, Gram-Schmidt orthonormalization, orthogonal projections.

Operators and Spectral Theorem [19 Lectures]: Linear functionals and adjoints, Hermitian, self-adjoint, Unitary and normal operators, Spectral theorem for real operators, Eigenvalues, Eigenvectors, Characteristic polynomials, minimal polynomials, Cayley Hamilton Theorem, triangulation, diagonalization, Jordan canonical forms (without proof).

Textbook

1. Hoffman, K., and Kunze R., Linear Algebra, Pearson Education (India) 2003.
2. Axler, S., Linear Algebra Done Right, 1997.

Reference Books

1. Lang, S., Linear Algebra, 3rd Edition, Springer, 2004.
2. Ramachandra Rao, A., Bhimasankaram, B., Linear Algebra, 2nd Edition, Hindustan Book Agency, 2000.

Online course Material

1. Rana, I.K., Basic Linear Algebra, NPTEL Course material, Department of Mathematics, IIT Bombay, https://nptel.ac.in/courses/111101115/

Course Title	**Real Analysis**	Course Number	MAL6XXX
Department	Mathematics	L-T-P (C)	3-1-0 (4)
Offered for	M.Sc.	Type	Core
Prerequisite			

Objectives

1. Develop a rigorous understanding of metric and function spaces.
2. Study convergence and approximation of sequences and series of functions.
3. Develop integration theory, including the Riemann–Stieltjes integral.

Learning Outcomes

1. Demonstrate a deep understanding of metric and function spaces
2. Analyze and rigorously justify different modes of convergence of functions.
3. Evaluate and apply integration techniques, including the Riemann–Stieltjes integral.

Content

Metric Spaces [15 Lectures]: Review of Real Number System, Countable & uncountable sets, Definition and Examples, Open and Closed Sets, separable metric spaces, Continuity, Connectedness, Completeness, Compactness, Baire's Theorem and its Applications, Heine-Borel Theorem.

Sequences and Series of Functions [15 Lectures]: Pointwise and Uniform Convergence, Interchanging Limits, Dini’s theorem, Space of bounded as well as continuous functions, Weierstrass M-test, The Weierstrass Approximation, Equicontinuity, The Baire-Osgood theorem, The Arzelà-Ascoli Theorem, and The Stone-Weierstrass Theorem.

The Riemann-Stieltjes integral [9 Lectures]: The Riemann-Stieltjes Integral, Properties, Function of Bounded Variation, Integration by Parts, Riemann Integral, Fundamental Theorem of Calculus.

Textbooks

1. N. L. Carothers, Real Analysis, Cambridge University Press, 2000.
2. T. M. Apostol, Mathematical Analysis, Narosa Publishing House, 2nd Ed., Addison-Wesley, 1974.

Reference Books

1. W. Rudin, Principles of Mathematical Analysis, 3rd Ed., McGraw-Hill, 1976.
2. T. M. Apostol, “Calculus,” 2nd Edition, John Wiley & Sons, Singapore, Vol. 2, 1969.

Online Course Material

1. S. H. Kulkarni, Real Analysis, NPTEL Course Material, Department of Mathematics, IIT Madras, https://nptel.ac.in/courses/111106053/
2. I. K. Rana, Basic Real Analysis, NPTEL Course Material, Department of Mathematics, IIT Bombay, https://nptel.ac.in/courses/111101134

Course Title	**Ordinary Differential Equations**	Course Number	MAL6XXX
Department	Mathematics	L-T-P (C)	3-1-0 (4)
Offered for	M.Sc.	Type	Core
Prerequisite			

Objectives

1. Introduce the concepts of existence and uniqueness of solution of ordinary differential equations.
2. Develop analytical techniques to solve ordinary differential equations.
3. Understand the properties of the solution of ordinary differential equations.

Learning Outcomes

1. Understanding existence, uniqueness, and other properties of a solution of ordinary differential equations.
2. Solving ordinary differential equations with the series method, Green's function method.
3. Solving systems of ODEs, and characterization of their solutions.

Contents

Motivations and origins, Existence-Uniqueness [6 Lectures]: Existence of solutions by Picard's method, uniqueness and continuous dependence w.r.t. initial conditions and parameters, continuation of solutions, existence and uniqueness of solutions to system of differential equations.

Second Order Linear Equations [20 Lectures]: General solution of differential equations using method of undetermined coefficients, method of variation of parameters, variable coefficients equations, Power series solution method, Legendre's equation, Frobenius method, Bessel's equation, Green's function method, Sturm-
Liouville problems, orthogonal eigen-function expansions, Sturm comparison theorem, Sturm separation theorem.

Systems of Differential Equations [13 Lectures]: Phase plane method, critical points of the system and their stability analysis, algebraic properties of solutions, the eigenvalue-eigenvector method of finding solutions, fundamental matrix solutions, matrix exponential, nonhomogeneous equations.

Text Books

1. Ross, S. L., Introduction to ordinary differential equations, 4th Ed., John Wiley Publications, 1982.
2. Chicone, C., Ordinary Differential Equations with Applications, 2nd Ed., Springer, 2006.

Reference Books

1. Coddington, E. A., An Introduction to Ordinary Differential Equations, PHI Learning 1999.
2. Birkhoff, G. and Rota G., Ordinary Differential Equations, 4th Ed., Wiley Publications, 1989.
3. Simmons, G., Differential Equations with Applications and Historical Notes, 2nd Ed., McGraw Hill Education, 2017.

Online Course Material

1. Agrawal, P. N. and Pandey, D. N., Ordinary and partial differential equations and applications, NPTEL Course Material, Department of Mathematics, IITRoorkee, https://nptel.ac.in/courses/111107111/
2. Raghavendra V., Ordinary differential equations, NPTEL Course Material, Department of Mathematics, IIT Kanpur, https://nptel.ac.in/courses/111104031/

Course Title	**Probability and Statistics**	Course Number	MAL6XXX
Department	Mathematics	L-T-P (C)	3-1-0 (4)
Offered for	M.Sc.	Type	Core
Prerequisite			

Objectives

1. Demonstrate an understanding of the basic principles of probability theory.
2. Use of the properties of discrete and continuous random variables with their joint, marginal, and conditional distributions.
3. Use of the various families of probability distributions to model various types of data.

Learning Outcomes

1. Understanding of probability theory and statistics to solve industrial problems.
2. Understanding of random sampling, theory of estimation and testing of hypotheses.

Contents

Probability spaces and Random Variables [12 lectures]: Probability space, conditional probability, Bayes' theorem, Random variable, cumulative distribution function and its properties, probability density function, functions of a random variable, standard discrete and continuous distributions and their applications, Transformation, moments, Chebyshev's inequality.

Joint Distributions [8 lectures]: Random vectors, joint, marginal and conditional distributions, conditional expectation, independence, correlation and regression, Bi-variate normal distribution, functions of random vectors, transformation.

Limit Theorems [3 lectures]: Convergence of sequences of random variables, weak and strong laws of large numbers, central limit theorems.

Estimation and Tests of Hypotheses [16 lectures]: Sampling distributions, point estimation of parameters, maximum likelihood method and method of moments, interval estimation, testing of hypotheses.

Text Books

1. Rohatgi, V. K., and Saleh, A. K. M. E., An Introduction to Probability and Statistics, Second Edition, Wiley India, 2000.
2. Casella, G. and Berger, R, Statistical Inference, Cengage Learning, 2002.

Reference Books

1. Hogg, R. V., McKean J. W., and Craig A., Introduction to Mathematical Statistics, Sixth Edition, Pearson Education India, 2006.
2. Prakasa Rao, B. L., S., A First Course in Probability and Statistics, World Scientific/Cambridge University Press India, 2009.
3. Castaneda, L. B., Arunachalam, V., and Dharmaraja, S., Introduction to probability and stochastic processes with Applications. Wiley, 2012.

Online Course Material

1. Kumar, S., Probability and Statistics, NPTEL Course Material, Department of Mathematics, IIT Kharagpur, https://nptel.ac.in/courses/111105090/

Course Title	**Abstract Algebra**	Course Number	MAL6XXX
Department	Mathematics	L-T-P (C)	3-1-0 (4)
Offered for	M.Sc.	Type	Core
Prerequisite			

Objectives
1. To train the student in the domain of Abstract Algebra.
2. To give sufficient knowledge of the subject which can be used by students for further applications in their respective domains of interest.

Learning Outcomes
The student will be able to:
1. precisely define terms like group, normal subgroup, quotient group, ring, ideal, and fields.
2. identify and provide examples of various algebraic structures, such as Dihedral Groups, Symmetric and Alternating Groups, and Polynomial rings.
3. apply the theory to solve a variety of problems, including determining the structure of finite abelian groups, checking whether a given group is simple, and factorizing a polynomial.

Contents
Review of Groups [8 lectures]: Definition of Group and Examples, Subgroups, Normal subgroups, Quotient groups, Isomorphism Theorems, Lagrange's Theorem, Direct product of groups. Fundamental Theorem of finite abelian groups (without proof).

Group action and Sylow Theorems [9 lectures]: Group action, Conjugacy classes and Class equation, Cayley's Theorem, Cauchy Theorem, Sylow Theorems and their applications, overview of finite simple groups, nilpotent and solvable groups.

Ring Theory [6 lectures]: Definition of Ring and Examples, Subrings and Characteristics of a ring, polynomial rings, Ideals, Quotient Rings, Ring Homomorphism and Isomorphism Theorems, Prime and maximal ideals. Applications in Number Theory.

Factorization of Polynomials [8 lectures]: Integral domain, Principal Ideal Domain, Unique Factorization Domain, Euclidean domain, factorization of polynomials, Eisenstein's criterion.

Field extensions [8 lectures]: Basic theory of field extensions, Algebraic extensions, Classical Straightedge and Compass Constructions.

Textbooks
1. Gallian, J.A, Contemporary Abstract Algebra, 7th Edition, Brooks-Cole/Cengage Learning, 2010.
2. Dummit, D.S. and Foote, R.M., Abstract Algebra, 3rd Edition, John Wiley and Sons, 2003.
3. Bhattacharya, P.B., Jain, S.K., and Nagpaul, S.R., Basic Abstract Algebra, 2nd Edition, Cambridge University Press, 1994.

Reference Books
1. Artin, M., Algebra, Prentice Hall, 1991.
2. Herstein, I.N., Topics in Algebra, 2nd Edition, John Wiley and Sons, 1975.
3. Hungerford, T.A., Algebra, Graduate Texts in Mathematics, Vol. 73, Springer-Verlag, 1980.

Online Course Material
1. NPTEL, Introduction to Abstract Group Theory, Prof. Krishna Hanumanthu, Chennai Mathematical Institute. https://nptel.ac.in/courses/111106113
2. NPTEL, Introduction to Rings and Fields, Prof. Krishna Hanumanthu, Chennai Mathematical Institute. https://onlinecourses.nptel.ac.in/noc21_ma06/preview

Course Title	**Measure and Integration**	Course Number	MAL6XXX
Department	Mathematics	L-T-P (C)	3-1-0 (4)
Offered for	M.Sc.	Type	Core
Prerequisite	Basics of Set theory and Real Analysis		

Objectives

1. Introduce and explain the fundamental concepts of measure theory, which include measurable sets, measure spaces, and Lebesgue measure.
2. Develop and apply the theory of Lebesgue integration and its advantages over Riemann integration.
3. Analyse and extend concepts of convergence, integrability, and advanced theorems in measure theory for mathematical applications.

Learning Outcomes

1. Demonstrate understanding of measurable sets, measures, and the construction of Lebesgue measure and integration.
2. Apply and analyse key results such as convergence theorems (Monotone, Dominated, Fatou's lemma) and inequalities in Lp spaces.
3. Evaluate and interpret advanced concepts like modes of convergence, product measures, and decomposition theorems in theoretical and applied contexts.

Contents

Introduction to Measure [13 Lectures]: Motivation towards generalisation of length, Lebesgue Outer measure, Extension Theorems, Lebesgue measure, Measurable Sets, Measurable space, Measures on Algebra of Sets, Lebesgue-Stieltjes measure, Measure spaces, Properties of measure and measure space, Completeness of measure space.

Integration [14 Lectures]: Measurable functions, functions between measurable spaces, Simple functions and their integrals, integral of a nonnegative measurable function, integral of extended real-valued non-negative function, Monotone Convergence Theorem, Fatou's lemma, Radon-Nikodym Theorem (without proof), Real and complex integrable functions, Lebesgue Dominated Convergence Theorem.

Lebesgue spaces and Modes of convergence [6 Lectures]: Lebesgue Spaces L_p, Holder's Inequality, Minkowski's Inequality, completeness theorem, Relations between convergence almost everywhere, convergence in measure and convergence in L_p spaces, Egoroff's Theorem.

Special Topics and Theorems [6 Lectures]: Product measure, Fubini's theorem (without proof), Signed measure, Hahn Decomposition Theorem, Jordan Decomposition Theorem, Lebesgue Decomposition Theorem.

Text Books

1. Royden, H. L., & Fitzpatrick, P. M., Real Analysis, (4th ed.). Pearson, 2010.
2. Axler, Sheldon, Measure, Integration & Real Analysis, Springer International Publishing. Graduate Texts in Mathematics 282, 2020.
3. Nair, M. T., Measure and Integration: A First Course, CRC Press, 2019.

Reference Books

1. Cohn, D. L., Measure Theory, (2nd ed.). Birkhäuser, 2013.
2. Folland, G. B., Real Analysis: Modern Techniques and Their Applications, (2nd ed.). Wiley, 2019.
3. Tao, T., An Introduction to Measure Theory, American Mathematical Society, 2011.
4. Rudin, W., Real and Complex Analysis, (3rd ed.). McGraw-Hill, 1987.

Course Title	**Complex Analysis**	Course Number	MAL6XXX
Department	Mathematics	L-T-P (C)	3-1-0 (4)
Offered for	M.Sc.	Type	Core
Prerequisite			

Objectives

1. To train the student in the area of complex analysis.
2. To give sufficient knowledge of the subject which can be used by students for further applications in their respective domains of interest.

Learning Outcomes

1. Demonstrate a deep understanding of Cauchy-Riemann Equations, Homotopy of paths.
2. Apply and analyze Cauchy-Goursat theorem and Cauchy's Integral Formula.
3. Develop and apply the theory to evaluate improper integrals.

Contents

Functions of complex variables [13 Lectures]: Elementary functions, continuity, differentiability, Analytic Functions, Cauchy Riemann Equations.

Complex Integration [13 Lectures]: Line and Contour Integrals, anti-derivatives of a complex function, Cauchy-Goursat Theorem, Simply and multiply connected domains, Cauchy's Integral formula, Taylor and Laurent Series expansion, Liouville's Theorem, Fundamental Theorem of Algebra, Maximum modulus principle.

Residue Theory [9 Lectures]: Residues and poles, Cauchy's residue theorem, Jordan's Theorem, evaluation of Improper integrals

Conformal mappings[4 Lectures]: Conformal mapping, Special transformation, Mobius transformation.

Text Books

1. Lang, S., Complex Analysis, Fourth Edition, Springer-Verlag, 1999.
2. Brown, J. W. and Churchill, R. V., Complex variables and applications, 9 Ed., McGraw Hill Publications, 2013.

Reference Books

1. Ahlfors, L.V., Complex Analysis, 3rd edition, McGraw Hill, 2000.
2. Ablowitz, M. J., and Fokas, A. S., Complex variables: Introduction and applications, 2 Ed., Cambridge University Press, 2003.
3. Shastri, A.R., An Introduction to Complex Analysis, Macmillan India, New Delhi, 1999.

Online Resources

1. Sree Krishna, P.A.S., Complex Analysis, NPTEL Course Material, Department of Mathematics, IIT Guwahati, https://nptel.ac.in/courses/111103070/
2. Swaminathan, A. and Katiyar, V.K. Complex Analysis, NPTEL Course Material, Department of Mathematics, IIT Roorkee, https://nptel.ac.in/courses/111107056/

Course Title	**Functional Analysis**	Course Number	MAL6XXX
Department	Mathematics	L-T-P (C)	3-1-0 (4)
Offered for	M.Sc., B.S. M&C	Type	Core
Prerequisite			

Objectives

1. To introduce the structure and properties of normed, Banach, and Hilbert spaces.
2. To study bounded linear operators and their properties on function spaces.
3. To develop understanding of fundamental theorems of Functional Analysis.
4. To introduce basic concepts and results of spectral theory of bounded operators.

Learning Outcomes

1. Define and analyze normed linear spaces, Banach spaces, quotient spaces, and Hilbert spaces.
2. Examine bounded linear operators and determine their continuity and norms.
3. Apply major Functional Analysis theorems to solve theoretical problems.
4. Analyze dual spaces, weak convergence, weak* convergence, separability, and reflexivity.
5. Use Hilbert space techniques including orthogonality, projections, and compact operators.

Contents

Normed Linear Spaces and Banach spaces [10 Lectures]: Normed linear space, Equivalent norms, Banach spaces, Linear operator, norm of a linear operator, boundedness and continuity, Quotient spaces.

Bounded linear operators on function spaces [15 Lectures]: l_p spaces, L_p spaces, uniformly bounded operator, principle of uniform boundedness, Open mapping theorem, Closed graph theorem, Hahn-Banach Theorem, dual of a normed linear space, separability and reflexivity of normed linear space, weak convergence, weak* convergence

Hilbert Spaces and their Applications [9 Lectures]: Inner product spaces, polarisation identity, Bessel's inequality, Hilbert space, Riesz representation theorem, Operators on Hilbert spaces, compact operators, projections and idempotents.

Introduction to spectral theory [5 Lectures]: Eigenvalues of linear operators, spectrum of bounded linear operators, spectral properties of bounded linear operators

Text Books

1. Limaye, B. V., Functional Analysis, Second Edition, New Age International, 1996.
2. Kesavan, S. Functional Analysis, Second Edition, Springer, 2023.

Reference Books

1. Conway, J. B., A course in Functional Analysis, Second Edition, Springer-Verlag, 1994.
2. Kreyzig, E., Introduction to Functional Analysis with Applications, John Wiley & Sons, 1978.
3. Vaidyanathan, P., Functional Analysis, Cambridge University Press, 2023.

Online Course Material

1. Srivastava, P. D., Functional Analysis, NPTEL Course Material, Department of Mathematics, IIT Kharagpur, https://nptel.ac.in/syllabus/111105037/

Course Title	**Multivariable Calculus and Differential Geometry**	Course Number	MAL6XXX
Department	Mathematics	L-T-P (C)	3-1-0 (4)
Offered for	M.Sc.	Type	Core
Prerequisite			

Objectives

1. Develop a working knowledge of the fundamental concepts, principles, and techniques of multivariable calculus and differential geometry.
2. Explain and analyze the concepts of continuity, differentiability, integrability, curves, and surfaces through their analytical and geometrical properties.
3. Develop a foundational understanding for advanced studies in Riemannian and other geometrical theories.

Learning Outcomes

1. Describe the fundamental concepts of continuity, differentiability, integrability, and their applications in multivariable calculus and differential geometry.
2. Demonstrate understanding of curves by computing and analyzing arc length, reparametrization, and curvature.
3. Analyze surfaces using fundamental concepts and apply key theorems to solve geometrical problems.

Contents

[19 Lectures] Functions of Several Variables: Continuity, Partial Derivatives, Directional Derivatives, Gradient, Hessian, Divergence, Differentiability, Jacobian, Chain Rule, Taylor's, Inverse Mapping, and Implicit Mapping Theorems, Double and Triple Integrations, Change of Variables, Fubini's Theorem, Multiple Integrations and Their Applications to Calculate Area, Volume, and Surface Area, Line and Surface Integrals, Green's, Gauss and Stokes' Theorems.

[05 Lectures] Curves in R^2 and R^3: Basic Definitions and Examples, Arc Length, Reparametrization, Curvature, Torsion, Frenet-Serret Apparatus, Fundamental Theorem for Curves, Non-Unit Speed Curves.

[15 Lectures] Surfaces in R^3: Basic Definitions and Examples, Tangents and Derivatives, Normals and Orientability, Ruled Surfaces and Surfaces of Revolution, First Fundamental Form, Christoffel Symbols, Arc Length of Curves on Surfaces, Isometries of Surfaces, Second Fundamental Form, Gauss and Weingarten Maps, Curvatures of Surfaces (Normal, Geodesic, Gaussian, Mean, Principal), Meusnier and Euler Theorems, Parallel Transport, Geodesics with Examples, Gauss' Theorema Egregium and Gauss-Bonnet Theorem.

Textbooks

1. T. M. Apostol, Mathematical Analysis, Narosa Publishing House, Addison-Wesley, 1974.
2. A. Pressley, Elementary Differential Geometry, Springer, 2010.
3. M. P. do Carmo, Differential Geometry of Curves and Surfaces, Prentice-Hall, New Jersey, 1976.

Reference Books

1. W. Rudin, Principles of Mathematical Analysis, McGraw-Hill, 1976.
2. B. O'Neill, Elementary Differential Geometry, Elsevier, 2006.
3. T. M. Apostol, Calculus Vol. II, John Wiley & Sons, 1969.

Online Course Material

1. S. Dutta, Curves and Surfaces, NPTEL Course Material, Department of Mathematics and Statistics, IIT Kanpur, https://nptel.ac.in/courses/111104095/
2. A. Pal, Geometry of Curves and Surfaces, NPTEL Course Material, Department of Mathematics and Statistics, IIT Kanpur, https://nptel.ac.in/courses/111104765/

Course Title	**Programming Lab**	Course Number	MAL6XXX
Department	Mathematics	L-T-P (C)	0-0-4 (2)
Offered for	M.Sc.	Type	Core
Prerequisite			

Objectives

1. To introduce the basics of computer programming.
2. To equip students with the ability to develop well-structured programs in a high-level programming language.
3. To introduce fundamental algorithms and data structures and their use in solving computational problems.

Learning Outcomes

The students will have the ability to:

1. Write well-structured programs in a high-level programming language.
2. Analyze the time and space complexity of basic algorithms.
3. Implement and apply fundamental searching, sorting, and data-structure techniques to solve problems.

Contents

Basic features of Programming [9 lab sessions]: Computer systems, the von Neumann architecture, machine language, CPU, ALU, compiler, Data types (including strings), variables, operators, expressions, control structures, functions, parameter passing conventions.

Advanced Features of Programming [14 lab sessions]: Arrays, Multi-dimensional arrays, recursions, operation on data (Insert, delete, search, traverse and modify), structures, memory management, files, input/output, standard library functions, programming tools and pointers.

Introduction to object-oriented programming [3 lab sessions]: Abstract data types, classes, access control, class implementation, constructor, destructors

The above programing concepts will be studied with implementation of various numerical methods: Bisection method, false position method, Newton-Raphson method, secant method, matrix operations, Gauss-Seidel method, Gauss-Jacobi method (For all these methods, only implementation of algorithm is discussed, theory will be covered in the course of Numerical Analysis.)

Textbooks

1. Kanetkar, Let Us C++, BPB Publications, New Delhi., 2019
2. Smith, E., Introduction to the Tools of Scientific Computing, Springer, 2020.
3. Chapra, S., Applied Numerical Methods wih MATLAB for Engineers and Scientists. Tata McGraw Hill Publications, 2012.

Reference Books

1. Goodrich, M. T., Tamassia, R., and Goldwasser, M. H. (2013) Data Structures and Algorithms in Python. Wiley.
2. Lafore, R., Object-Oriented Programming in C++, Fourth Edition, Pearson, 2002.

Online Course Material

1. Narayanaswamy, Programming and Data Structures (in C), IIT Madras. NPTEL. https://nptel.ac.in/courses/106106130

Course Title	**Topology**	Course Number	MAL6XXX
Department	Mathematics	L-T-P (C)	3-1-0 (4)
Offered for	M.Sc., B.S. M&C	Type	Core
Prerequisite			

Objectives

1. To train the students in the domain of Topology.
2. To give sufficient knowledge of the subject which can be used by students for further applications in their respective domains of interest.

Learning Outcomes

1. Topological spaces, order topology and product topology.
2. Separation axioms, countability axioms Urysohn's metrization theorem.
3. Function spaces, pointwise and uniform convergence, Stone-Weierstrass theorem.

Contents

Basic Topology [14 Lectures]: Topological spaces, basis and sub-basis, order topology, product topology, subspace topology, convergence, closed sets, continuous functions, quotient topology

Properties of Topological Spaces [16 Lectures]: Connected spaces, components, local connectedness, compact spaces, limit point compactness, local compactness, countability axioms, separation axioms, normal spaces, Tychonoff spaces, Urysohn's metrization theorem, Tietze extension theorem, Tychonoff theorem, Stone-Cech compactification

Special Topics [09 Lectures]: Function spaces, pointwise and uniform convergence, compact-open topology, uniform convergence on compact sets, Ascoli's theorem, Stone-Weierstrass theorem.

Textbooks

1. Munkres, J., Topology, second edition, Pearson Publications, 2000.
2. Willard, S., General Topology, Dover Publications, 2004.

Reference Books

1. Pervin, W. J. and Boas, R. P., Foundations of general topology, Academic Press.
2. Simmons, G. F., Introduction to topology and modern analysis, Tata McGraw-Hill, 2004.

Online Course Material

1. Veeramani, P., Topology, NPTEL Course Material, Department of Mathematics, IIT Madras, https://nptel.ac.in/courses/111106054/.

Detailed Course Content of Elective Courses

Course Title	**Partial Differential Equations**	Course Number	MAL6XXX
Department	Mathematics	L-T-P (C)	3-0-0 (3)
Offered for	M.Sc., B.S. M&C	Type	Elective
Prerequisite			

Objectives

1. Introduce the concepts of existence and uniqueness of solution of partial differential equations.
2. Develop analytical techniques to solve partial differential equations.
3. Understand the properties of the solution of partial differential equations.

Learning Outcomes

1. Understanding existence, uniqueness, and other properties of a solution of partial differential equations.
2. Solving partial differential equations with Fourier series method, Green's function method, Laplace transform method, and Fourier transform method.

Contents

Motivation and origin [3 Lectures]: PDEs of engineering and physics (Heat, wave, and Laplace equations).

First order partial differential equations [9 Lectures]: Linear, quasi-linear and fully nonlinear equations, Lagrange method, the Cauchy problem, Cauchy method of characteristics, compatible systems, Charpit method.

Second order partial differential equations [11 Lectures]: Classification and Canonical forms, Adjoint operators, Riemann's method, solving linear partial differential equations with constant coefficients.

Elliptic, parabolic and hyperbolic equations[16 Lectures]: Variable separation method for Laplace/Poisson equation, heat conduction equation, wave equation, Burger equation, D'Alembert's solution, Maximum-Minimum principles, Duhamel's principle, solutions by Green's function method.

Text Books

1. Rao, K. S., Introduction to partial differential equations, 3rd Edition, PHI, 2011.
2. Logan, J. D., Applied partial differential equations, 3rd Ed., Springer, 2015.
3. Pinchover, Y. and Rubinstein, J., An introduction to partial differential equations, Cambridge University Press, 2005.

Reference Books

1. Sneddon, I. N., Elements of Partial Differential Equations, McGraw-Hill, New York,1986.
2. Prasad, P. and Ravindran, R., Partial differential equations, New Age International Publisher, 2005.
3. Mattheij, R. M. M., Rienstra, S. W., and ten Thije Boonkkamp, J. H. M., Partial Differential Equations: Modeling, Analysis, Computation, SIAM Publication, 2005.

Online Course Material

1. Agrawal, P. N. and Pandey D.N., Ordinary and partial differential equations and applications, NPTEL Course Material, Department of Mathematics, IIT Roorkee, https://nptel.ac.in/courses/111107111/
2. Sinha, R. K., Partial differential equations, NPTEL Course Material, Department of Mathematics, IIT Guwahati, https://nptel.ac.in/courses/111103021/

Course Title	**Dynamical Systems**	Course Number	MAL6XXX
Department	Mathematics	L-T-P (C)	3-0-0 (3)
Offered for	M.Sc.	Type	Elective
Prerequisite			

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 10]: 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 11]: 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.

Textbooks

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 Kharagpur https://nptel.ac.in/courses/108105054/

Course Title	**Optimization**		Course Number	MAL7XXX
Department	Mathematics		L-T-P(C)	3-0-0(3)
Offered for	M.Sc., Ph.D.		Type	Elective
Prerequisite	Linear Algebra, One variable and Multivariable Calculus			

Objectives

1. To train the student in the domain of Foundations of Optimization Theory.
2. To understand convexity, duality, and its role in optimization.
3. To introduce sufficient tools for solving optimization problems that can be used by students for further applications in different areas of interest.

Learning Outcomes

1. Understand basic concepts of optimization and optimality conditions.
2. Understand convex set, convex function, KKT, and Fritz John condition.
3. Understand Lagrange duality.
4. Solve optimization problems using numerical algorithms.

Contents

Linear Programming [15 lectures]*:* Linear programming problem formulation, Convex set, Convex Hull, Convex Polyhedral Sets and Cones, Linear Inequalities, Projection onto a Finite-Dimensional Closed Convex Set, Separation of Convex Sets in Finite-Dimensional Vector Spaces, Proper Separation of a Convex Set and a Convex Polyhedron, Farkas's Lemma, Gordon's alternative theorem, Feasible solution and basic feasible solution of LPP, Simplex method Charne's M method, Two phase method, Duality, Complementary Slackness, Weak and Strong Duality, Dual simplex algorithm, Sensitivity analysis, Integer Programming, Gomory's cut-constraint method, Branch and Bound method, Transportation problem, Assignment problem, Applications.

Nonlinear Programming [24 lectures]:

Unconstrained Optimization[12]: Unconstrained Optimization, Basic Results on the Existence of Optimizers, First-Order and Second-Order Optimality Conditions, Quadratic Forms, Convex Functions, Differentiable Convex Functions, Important consequences of convexity, Iterative methods, Line search methods, Global convergence of descent algorithms, Gradient Descent, Newton's method, Conjugate direction method, Quasi-Newton Method, Applications.

Constrained optimization[12]: First-Order Necessary Conditions (Fritz John Optimality Conditions), Lagrange Multipliers, Karush-Kuhn-Tucker conditions, Constraint Qualifications, Regular points, Perspectives on Duality, Saddle Points and Their Properties, Nonlinear Programming Duality, Strong Duality in Convex Programming, Examples of Dual Problems, Projected gradient method, Penalty function method, Barrier Function method, Interior Point method, Augmented Lagrangian Methods, Sequential quadratic programming.

Textbooks

1. Luenberger, D. G., Linear and Nonlinear Programming, Yinyu Ye, Third Edition, Springer, 2008.
2. Stephen Boyd & Lieven Vandenberghe, Convex Optimization, 1st Ed., Cambridge University Press, 2009.
3. Mokhtar S. Bazaraa, Hanif D. Sherali, and C. M. Shetty, Nonlinear Programming: Theory and Algorithms, 3rd Edition, John Wiley & Sons, 2006.

Reference Books

1. Osman Güler, Foundations of Optimization, 1st Edition, Springer [Graduate Text in Mathematics], 2010.
2. Jorge Nocedal and Stephen J. Wright: Numerical Optimization, 2nd Edition, Springer, 2006.
3. Amir Beck, Introduction to Nonlinear Optimization: Theory, Algorithms, and Applications with MATLAB, 1st Edition, SIAM, 2014.

Online Course Material

1. Joydeep Dutta, Foundations of Optimization, NPTEL Course Material, IIT Kanpur, https://nptel.ac.in/courses/111104071

Course Title	**Galois theory**	Course Number	MAL6XXX
Department	Mathematics	L-T-P (C)	3-0-0 (3)
Offered for	M.Sc.	Type	Elective
Prerequisite	Abstract Algebra		

Objectives

1. To train the student in the domain of field extensions, including algebraic extensions, splitting fields, and algebraic closures.
2. To analyze the solvability of polynomial equations by radicals and understand historical applications like classical straightedge and compass constructions.
3. Recognize and apply groups and rings in different mathematical contexts, utilizing advanced concepts like cyclotomic polynomials, cyclic extensions, and Hilbert's Theorem 90.

Learning Outcomes

The student will be able to:

1. Construct and evaluate various types of field extensions, determining whether they are separable, inseparable, or normal.
2. Compute Galois groups for different extensions and apply the Fundamental Theorem of Galois Theory to both composite and simple extensions.
3. Assess the solvability of equations by radicals and formally demonstrate the insolvability of the quintic.

Contents

Field extensions: Review of Algebraic Extensions, Splitting Field, Algebraic Closure, Symmetric polynomials, Separable and Inseparable extensions, Primitive Element Theorem, Normal extensions **[15 lectures]**

Galois Theory: Galois group, Fundamental Theorem of Galois Theory and its applications, Composite extensions and Simple extensions, Finite fields **[12 lectures]**

Applications of Galois Theory: Cyclotomic polynomials and extensions, Cyclic extensions, Solvable groups and solvability of equations by radicals, Insolvability of Quintic, Norm and trace, Hilbert's Theorem 90 **[12 lectures]**

Textbooks

1. Dummit, D.S. and Foote, R.M., Abstract Algebra, 3rd Edition, John Wiley and Sons, 2003.
2. Bhattacharya, P.B., Jain, S.K. and Nagpaul, S.R., Basic Abstract Algebra, 2nd Edition, Cambridge University Press, 1994.

Reference Books

1. Rotman, J., Galois Theory, 2nd Edition, Springer, 1998.
2. Stewart, I., Galois Theory, Third Edition, Chapman and Hall, 2003.

Online Course Material

1. NPTEL, Introduction to Galois Theory, Prof. Krishna Hanumanthu, Chennai Mathematical Institute. https://onlinecourses.nptel.ac.in/noc21_ma15/preview

Course Title	**Analytic Number Theory**	Course Number	MAL6XXX
Department	Mathematics	L-T-P (C)	3-0-0 (3)
Offered for	M.Sc., B.S. M&C	Type	Elective
Prerequisite			

Objectives

1. Develop a strong foundation in arithmetic functions and prime distribution.
2. Apply analytic techniques, including the theories of Dirichlet series and L-functions, to study number-theoretic problems.
3. Introduce modular forms and explicate their role in modern analytic number theory.

Learning Outcomes

After successful completion of the course students will be able to:

1. Apply analytical methods to study partial sums and the distribution of primes.
2. Define fundamental objects such as the Gamma function, Theta functions, the Riemann Zeta function, Dirichlet L-functions, and study their properties.
3. Demonstrate knowledge of basics of modular forms and their applications in number theory.

Contents

Arithmetic Functions and Distribution of Primes (12 Lectures): Introduction and definitions, Multiplicative functions, Dirichlet convolution, Möbius inversion formula, Big-O notation, Average orders and partial sums of arithmetic functions, Euler-Maclaurin summation formula, Chebyshev functions, Prime Number Theorem and its equivalent forms, and Ikehara-Weiner Tauberian theorem (without proof).

Special Functions (5 Lectures): Gamma function, Bernoulli polynomials, Mellin and Inverse Mellin transform, Bessel functions (definitions + basic properties only), Theta Functions and Perron's formula.

Dirichlet Series and Euler Products (14 Lectures): Character Groups, Dirichlet Characters, Dirichlet Series, Primes in Arithmetic Progressions, Multiplication of Dirichlet Series, Euler Products, Theory of Riemann Zeta Functions (Location of Poles and Zeros, Functional Equation, Special Values, analytic continuation via Poisson or Euler-Meclaurin summation formula).

Modular Forms (8 Lectures): Modular group, Basic definitions, Eisenstein series, q-expansions, and Space of modular forms.

Textbooks

1. Apostol, T. M., Introduction to Analytic Number Theory, Springer-Verlag, 1976.
2. Apostol, T. M. Modular Functions and Dirichlet Series in Number Theory (2nd ed.). Graduate Texts in Mathematics, Vol. 41. Springer-Verlag New York, 1990.

Reference Books

1. Iwaniec, H., Kowalski, E. Analytic Number Theory. American Mathematical Society Colloquium Publications, Vol. 53. Providence, RI: American Mathematical Society, 2004.

Course Title	**Numerical Analysis**	Course Number	MAL7XXX
Department	Mathematics	L-T-P (C)	3-0-0 (3)
Offered for	M.Sc.	Type	Elective
Antirequisite	Any course done in Numerical methods/analysis		

Objectives

1. Learn numerical techniques for a variety of mathematical problems.
2. Analyze the validity and error in the numerical results.

Learning Outcomes

After successful completion of the course students will be able to:

1. Develop an understanding of numerical error and applicability of a particular method.
2. Solve numerically algebraic equations, linear systems of equations, ordinary differential equations and eigenvalue problems.
3. Carry out numerical differentiation, integration, and interpolation

Contents

Errors analysis [3 Lectures]: Numerical Algorithms and errors, Floating point systems, Types of error, Propagation of Error, the stability of algorithms.

Root Finding Methods [8 Lectures]: Bisection method, Secant method, the method of false position, Newton-Raphson Method, Fixed-Point Iteration Method, Muller's method, criterion for acceptance of a root, Rates of Convergence.

Solving linear system of equations [8 Lectures]: Direct methods (Gauss elimination, Gauss-Jordan method, LU decomposition, Crout's Method, Do-little Method, and Cholesky decomposition), Ill-conditioned systems, iterative methods (Gauss-Seidel method, Gauss-Jacobi method), matrix inversion, Rate of Convergence, Rayleigh Quotient, Min-max principle, the power and inverse power methods for eigenvalue problems.

Interpolation [6 Lectures]: Errors in polynomial interpolation, finite differences, Newton's formulae for interpolation, Lagrange interpolation formula, Hermite interpolation, Spline interpolation.

Numerical Integration and Differentiation [6 Lectures]: Newton-Cotes integration formulae, Difference Formulae, Method of Undetermined Coefficients.

Numerical IVPs for Ordinary Differential Equations [8 Lectures]: Taylor series method, Euler's Method, Modified Euler's Methods, Runge-Kutta Methods.

Textbooks

1. Süli, E. and Mayers, D.F., An Introduction to Numerical Analysis, Cambridge Uni. Press, 2006.
2. Sastry, S.S., Introductory Methods of Numerical Analysis, Prentice Hall of India Pvt. Ltd., 2007.
3. Chapra, S.C., Applied Numerical Methods with MATLAB for Engineers and Scientists, 3 Ed., McGraw Hill, 2012

Reference Books

1. Burden, R. L., Numerical Analysis, 9th Edition, Cengage Learning India, 2012
2. Conte, S.D. and Boor, C., Elementary Numerical Analysis: An Algorithmic Approach, Third Edition, McGraw-Hill Publication, 1980.

Online course Material

1. Lal, R. and Banerjee S., Numerical Analysis, NPTEL Course Material, Department of Mathematics, IIT Roorkee, https://nptel.ac.in/courses/111107062/
2. Usha, R., Numerical Analysis, NPTEL Course Material, Department of Mathematics, IIT Madras, https://nptel.ac.in/courses/111106101/

Course Title	**Module Theory**	Course Number	MAL7XXX
Department	Mathematics	L-T-P (C)	3-0-0 (3)
Offered for	M.Sc.	Type	Elective
Prerequisite	Basic knowledge of Linear Algebra, groups and Rings		

Objectives
1. To introduce the theory of modules over commutative rings.
2. To apply the classification of finitely generated modules over PID to prove the fundamental theorem of finite abelian groups
3. To apply the theory of modules to understand Jordan and Rational canonical forms of matrices

Learning Outcomes

The students are expected to learn:
1. Canonical forms of Matrices up to similarity with proof.
2. Classification of finitely generated modules over a PID.
3. Classification of finite Abelian groups.

Contents

Modules over Commutative rings [12 Lectures]: Review of Vector Spaces, Rings, Principal Ideal domains, and Examples, Definition and Examples of Modules, Quotient Modules and Module homomorphisms, Isomorphism Theorems, direct sums, finitely generated Modules, Free Modules and bases, Tensor Product of Modules, Exact sequences - Projective, Injective and Flat modules.

Modules with chain conditions [9 Lectures]: Noetherian and Artinian modules. Noetherian and Artinian rings. Hilbert basis theorem, Nil and Jacobson Radicals.

Modules over a Principal Ideal Domain [9 Lectures]: Structure of finitely generated modules over PID : Cyclic Decomposition, Equivalence of matrices over PID, Finitely generated torsion modules, Classification of finitely generated modules over PID, Classification of Abelian groups.

Modules over k[x] and linear operators [9 Lectures]: Review of linear operators on finite-dimensional vector spaces, Canonical forms: Jordan Canonical form and Rational Canonical Form, and Applications.

Textbooks

1. Musili, C., (1994), Introduction to rings and modules, 2nd Edition, Narosa.
2. Dummit ,D.S., Foote, R.M. (2004), Abstract algebra, 3rd Edition, Wiley.

Reference Books

1. Luther, I.S., Passi, I.B.S., (2013), Algebra; Volume 3: Modules, 1st Edition, Narosa.
2. Roman, S., (2008), Advanced linear algebra, 3rd Edition, Springer.
3. Lang, S., (2002), Algebra, Revised Third Edition, Springer.

Online Course Material

1. Mandal, M., Nanduri, R., Rings and Modules, Department of Mathematics, IIT Kharagpur, https://nptel.ac.in/courses/111105161

Course Title	**Statistical Models and Regression**	Course Number	MAL7XXX
Department	Mathematics	L-T-P (C)	3-0-0 (3)
Offered for	M.Sc., B.S. M&C	Type	Elective
Prerequisite	Probability, Statistics and Random Processes		

Objectives

The Instructor will discuss the following aspects:

1. Statistical Modelling
2. Linear and Non-linear Regression
3. ANOVA and Analysis of Categorical Data

Learning Outcomes

The students are expected to have the ability to:

1. Understand applications of regression and assumptions
2. Formation of Contingency Tables and Its Analysis
3. Use of R for Analysis of Real Data

Contents

Introduction to Statistical Modeling [4 Lectures]: Model Diagnostics, Transformations, Multicollinearity, Influence, Model Building, Variable Selection.

Linear regression [8 Lectures]: Bi-variate Gaussian Distribution, Assumptions for linear regression, Estimation of Parameters by Least Square Approximation, Hypothesis Test and Confidence Intervals for Model Parameters, Multiple Linear Regression with data examples, Residual Analysis

Regression Cont [14 Lectures]: Introduction to Logistic Regression and Poisson Regression Within the More General Regression Approach, Exponential Family of Distributions, Generalized Linear Model With Data Examples. Introduction to Multiple Approaches to Variable Selection Illustrated with an Extensive Data Analysis Example

Analysis of Variance [6 Lectures]: One way and Two way ANOVA with applications

Analysis of Categorical Data [7 Lectures] : Contingency Table, Log-linear Modeling, Measures of Association, Testing of Hypotheses of associations for 2-way and 3-way tables

Lab R Programing: Reading in Data, Tables, Linear regression and basic plotting, One way ANOVA and QQ-norm plots, Two way ANOVA and Box Plots, Logistic and Poisson regression, Analysis of contingency table, demonstration of the tools for some data

Textbooks

1. Montgomery D. C., Peck, E. A. and Vining, G. G. (2013) Introduction to Linear Regression Analysis, Wiley.
2. Althem, P. M. E. (2015) Introduction to Statistical Modelling in R, Cambridge University Press

Reference Books

1. Draper, N.R. and Smith, H. (2011). Applied Regression Analysis, Wiley Series.
2. Rohatgi, V.K. and Saleh, A.K.M.E. (2008). An Introduction to Probability and Statistics, Wiley.

Self-Learning Material

Salabh, Linear Regression Analysis and Forecasting**,** NPTEL Course Material, Department of Mathematics and Statistics, IIT Kanpur, https://nptel.ac.in/courses/111/104/111104098/

Course Title	**Time Series Analysis**	Course Number	MAL7XXX
Department	Mathematics	L-T-P (C)	3-0-0 (3)
Offered for	M.Sc., B.S. M&C	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[7 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 [7 Lectures]ARMA (p, q) processes, ACF and PACF, Modeling using ARMA processes, estimation of parameters, testing model adequacy, Order estimation.

Univariate Forecasting Models [7 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, 4thed.

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

1. 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/

Course Title	**Machine Learning and Pattern Recognition**	Course Number	MAL7XXX
Department	Mathematics	L-T-P (C)	3-0-0 (3)
Offered for	M.Sc.(MA)/M.Tech.(DCS)/PhD (MA)	Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Introduce the mathematical and statistical techniques used in pattern recognition.
2. Impart knowledge on differentiate among various pattern recognition techniques.

Learning Outcomes

The students are expected to have the ability to:

1. Formulate high dimensional feature vectors from observations.
2. Select an appropriate pattern analysis tool for analysing data in a given feature space.
3. Apply pattern analysis tools to practical applications and detect patterns in the data.

Contents

Introduction [2 Lectures]: Definitions, data sets for Pattern Recognition, Different Paradigms of Pattern Recognition.

Bayes Decision Theory [7 Lectures]: Bayes Decision Theory: Bayes decision rule, Minimum error rate classification, Normal density and discriminant functions, Bayesian networks.

Generative Methods [7 Lectures]: Maximum Likelihood and Bayesian Parameter Estimation, Nonparametric techniques.

Discriminative Methods [7 Lectures]: Distance-based methods, Linear Discriminant Functions, Artificial Neural Networks, Support Vector Machines.

Clustering and Principal Component Analysis [8 Lectures]: k-means clustering, Gaussian Mixture Modeling, EM-algorithm, PCA, Kernel PCA, Probabilistic PCA.

Combining Classifiers [8 Lectures]: Bagging and Boosting, Adaboost, Bayesian Model Averaging.

Textbook

1. 1.Duda, R. O., Hart, P. E. and Stork, D., Pattern Classification 2/e, Wiley, 2002.
2. Bishop, C., Pattern Recognition and Machine Learning, Springer, 2006.

Reference Books

1. Theodoridis, S. and Koutroumbas, K. (2008) Pattern Recognition, Edition 4. Academic Press.
2. MacKay, D.J.C. (2004) Information Theory, Inference and Learning Algorithms, Cambridge University Press.
3. Cristianini, N. and Taylor, J. S. (2000) An Introduction to Support Vector Machines, Cambridge University Press.

Online Course Material

1. Das, S. and Murthy, C.A. (IIT Madras) *Pattern Recognition*, https://nptel.ac.in/courses/106106046/

Course Title	**Statistical Inference**	Course Number	MAL7XXX
Department	Mathematics	L-T-P (C)	3-0-0 (3)
Offered for	M.Sc.	Type	Elective
Prerequisite	Basics of Probability and Statistics		

Objectives

The Instructor will:

1. Provide background in the area of Statistics.
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. Provide basic understanding of the Point and Interval Estimation, Testing of Hypotheses, Non-parametric Estimation.
2. Impart knowledge in Random Sampling, Unbiased Estimation, Bias-Variance Tradeoff, Goodness of Fit.

Contents

Random Sampling & Sampling Distributions [5 lectures]: Random sampling, exact sampling distributions: Chi-square, t and F distributions, large sample theory.

Point and Interval Estimations [16 lectures]: Point estimator, properties of an estimator, factorization, MVUE, maximum likelihood method of estimation, Cramer-Rao bound, confidence interval estimation.

Tests of Hypotheses [18 lectures]: Review of hypotheses testing, Neyman-Pearson theory, general linear hypothesis, method of least squares, analysis of variance (one way and two way), analysis of categorical data, Chi-square test for goodness of fit, test of independence, non-parametric tests.

Text Books

1. Rohatgi, V. K. (2003), Statistical Inference, Dover Publications Inc.
2. Hogg, R. V., McKean, J. W., Craig, A. T. (2009), Introduction to Mathematical Statistics, Pearson.

Reference Books

1. Casella, G. and Berger, R. L. (1990), Statistical Inference, Brooks/ Cole Publishing Company.
2. Rao, C. R. (2006), Linear Statistical Inference and Its Applications, Wiley.
3. Gibbons, J.D. and Chakroborti, S., Nonparametric Statistical Inference, CRC Press, 2010.

Online Course material

1. Zhou Fan, Introduction to Statistical Inference, Stanford University, http://web.stanford.edu/class/stats200/.
2. Kumar, S., Department of Mathematics, IIT Kharagpur, NPTEL Course on "Statistical Inference", https://nptel.ac.in/courses/111105124/

Course Title	**Graph Theory and its Applications**	Course Number	CSL7XXX
Department	Computer Science and Engineering	L-T-P (C)	3-0-0 (3)
Offered for	B.Tech., M.Tech., Ph.D. (CSE, AI), M.Sc. (Maths), B.S. M&C	Type	Elective
Prerequisite	Maths for Computing (or Discrete Mathematics)		

Objectives
The course aims to introduce the basic concepts and results of Graph Theory with special focus on those topics and techniques that are useful in theoretical computer science and in practice.

Learning Outcomes
Students will learn about fundamentals and advanced topics of Graph Theory. Students should have a deep understanding of graph theory concepts, be able to analyze complex graph-related problems, and appreciate the wide range of applications of graph theory in various domains after taking this course.

Contents
Basics [10 lectures]: Graphs, Degree, Paths, Connectivity, Trees and Forests, Bipartite Graphs, Contractions and Minors, Euler Tour

Matching and Connectivity [11 lectures]: Matchings in bipartite graphs and general graphs, 2-connected and 3-connected graphs, Menger's theorem

Planar Graphs and Colouring [9 lectures]: Planar Graphs, Kurtowaski's theorem, Colouring maps and planar graphs, Colouring vertices, Colouring edges

Extremal Graph Theory, Ramsey Theory for Graphs and Optimization [12 lectures]: Subgraphs and minors, Hadwiger's conjecture, Ramsey's Original Theorem, Ramsey numbers, Ramsey properties and connectivity, Hamiltonian Cycles, Optimization Problems in Graph Theory.

Textbooks
1. Reinhardt Diestel (2016), Graph Theory, Springer.
2. Douglas West (2000), Introduction to Graph Theory, Pearson.

Self Learning Material
1. https://nptel.ac.in/courses/111106102