List of Courses[1]
Department of Mathematics, IIT Bombay

27th May 2023

Mathematics Courses
Statistics Courses

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[1]Created and maintained by Shri Ashutosh R. Mulik and Professor Ronnie Sebastian

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Mathematics Courses

Course Code	**MA 001**
Course Name	**Preparatory Mathematics 1**
Total Credits	0
Type	T
Lecture	3
Tutorial	2
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. nil
Description	Complex numbers as ordered pairs. Argand's diagram. Triangle inequality. De Moivre's Theorem. Algebra: Quadratic equations and expressions. Permutations and combinations. Binomial theorem for a positive integral index. Coordinate Geometry: Locus, Straight lines. Equations of circle, parabola, ellipse and hyperbola in standard forms. Parametric representation. Vectors: Addition of vectors. Multiplication by a scalar. Scalar product, cross product and scalar triple product with geometrical applications. Matrices and Determinants: Algebra of matrices. Determinants and their properties. Inverse of a matrix. Cramer's rule.

Course Code	**MA 002**
Course Name	**Preparatory Mathematics 2**
Total Credits	0
Type	T
Lecture	3
Tutorial	2
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1.
Description	Function, Inverse function, Elementary functions and their graphs, Limit, Continuity, Derivative and its geometrical significance. Differentiability. Derivatives of sum, difference, product and quotient of functions. Derivatives of polynomial, rational, trigonometric, logarithmic, exponential, hyperbolic, inverse trigonometric and inverse hyperbolic functions. Differentiation of composite and implicit functions. Tangents and Normals, Increasing and decreasing functions. Maxima and Minima. Integrations as the inverse process of differentiation, Integration by parts and by substitution. Definite integrals and its application to the determination of areas.

Course Code	**MA 106**
Course Name	**Linear Algebra**
Total Credits	4
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	Y
Prerequisite	Nil
Text Reference	1. H. Anton, Elementary Linear Algebra with Applications (8th Edition), John Wiley, 1995. 2. G. Strang, Linear Algebra and its Applications (4th Edition), Thomson, 2006. 3. S. Kumaresan, Linear algebra - A Geometric Approach, Prentice Hall of India, 2000. 4. E. Kreyszig, Advanced Engineering Mathematics (8th Edition), John Wiley, 1999.
Description	Vectors in $\mathbb{R}^n$, linear independence and dependence, linear span of a set of vectors, vector subspaces of $\mathbb{R}^n$, basis of a vector subspace. Systems of linear equations, matrices and Gauss elimination, row space, null space, and column space, rank of a matrix. Determinants and rank of a matrix in terms of determinants. Abstract vector spaces, linear transformations, matrix of a linear transformation, change of basis and similarity, rank-nullity theorem. Inner product spaces, Gram-Schmidt process, orthonormal bases, projections and least squares approximation. Eigenvalues and eigenvectors, characteristic polynomials, eigenvalues of special matrices (orthogonal, unitary, hermitian, symmetric, skew-symmetric, normal), algebraic and geometric multiplicity, diagonalization by similarity transformations, spectral theorem for real symmetric matrices, application to quadratic forms.

Course Code	**MA 108**
Course Name	**Differential Equations**
Total Credits	4
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	Y
Prerequisite	Nil
Text Reference	1. E. Kreyszig, Advanced Engineering Mathematics (8th Edition), John Wiley, 1999. 2. W. E. Boyce and R. DiPrima, Elementary Differential Equations (8th Edition), John Wiley, 2005. 3. T. M. Apostol, Calculus, Volume 2 (2nd Edition), Wiley Eastern, 1980.
Description	Exact equations, integrating factors and Bernoulli equations. Orthogonal trajectories. Lipschitz condition, Picard's theorem, examples of non-uniqueness. Linear differential equations generalities. Linear dependence and Wronskians. Dimensionality of space of solutions, Abel-Liouville formula. Linear ODE with constant coefficients, characteristic equations. Cauchy-Euler equations. Method of undetermined coefficients. Method of variation of parameters. Laplace transform generalities. Shifting theorems.

Course Code	**MA 109**
Course Name	**Calculus 1**
Total Credits	4
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	Y
Prerequisite	Nil
Text Reference	1. Hughes-Hallett et al., Calculus - Single and Multivariable (3rd Edition), John-Wiley, 2003 2. James Stewart, Calculus (5th Edition), Thomson, 2003. 3. T. M. Apostol, Calculus, Volumes 1 & 2 (2nd Edition), Wiley Eastern, 1980. 4. G. B. Thomas and R. L. Finney, Calculus and Analytic Geometry (9th Edition), ISE Reprint, Addison-Wesley, 1998.
Description	Review of limits, continuity, differentiation. Mean value theorem, Taylor's theorem, maxima and minima. Riemann integrals, fundamental theorem of calculus. Improper integrals, applications to area and volume. Convergence of sequences and series: power series. Partial derivatives, gradient and directional derivatives, chain rule, maxima and minima, Lagrange multipliers.

Course Code	**MA 111**
Course Name	**Calculus 2**
Total Credits	4
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	Y
Prerequisite	Nil
Text Reference	1. Hughes-Hallett et al., Calculus - Single and Multivariable (3rd Edition), John-Wiley, 2003. 2. James Stewart, Calculus (5th Edition), Thomson, 2003. 3. T. M. Apostol, Calculus, Volumes 1 & 2 (2nd Edition), Wiley Eastern, 1980. 4. G. B. Thomas and R. L. Finney, Calculus and Analytic Geometry (9th Edition), ISE Reprint, Addison-Wesley, 1998.
Description	Double and triple integration, Jacobians and change of variables formula. Parametrization of curves and surfaces, vector fields, line and surface integrals. Divergence and curl. Theorems of Green, Gauss, and Stokes.

Course Code	**MA 113**
Course Name	**Mathematics and Its History**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. (JB) The Ascent of Man, by Jacob Bronowski; BBC Books 2. (BS) The Ascent of Science, by Brian L. Silver; Oxford University Press. 3. (EM) This is Biology, by Ernst Mayr; Harvard University Press. 4. (Stillwell) Mathematics and its History, by John Stillwell; Springer (Undergraduate Texts in Mathematics). 5. (PCM) The Princeton Companion to Mathematics, edited by Timothy Gowers, June Barrow Green, and Imre Leader; Princeton University Press. 6. (Burton) Elementary number theory, by D. M. Burton; 6th edition, McGraw-Hill, 2007. 7. (Goldberg) Methods of real analysis, by R. R. Goldberg; Oxform & IBH Pub. (Indian Edition), 1970. 8. (JJ) Elementary number theory, by G. A. Jones and J. M. Jones; Springer Math Undergrad Series, 1998.
Description	Continued on next page ...

Course Code	MA 113 (... continued from previous page)
Course Name	**Mathematics and Its History**
Description	Part I 1. Copernican revolution, Galileo versus Church, Kepler and Newton (JB – Chapter 6 and 7). 2. Enlightenment movement and Romantic movement and further professionalisation (BS – Chapter 6, 7 and 11). 3. Industrial revolution and engines (JB – Chapter 8) 4. Electromagnetism (BS – Chapter 8) 5. Darwin and Mendel (JB – Chapter 9 and 12; BS – Chapter 23). Part II 1. History of Algebra: Quadratic equations, solutions to cubics and quartics, higher degree equations and insolvability. algebra and geometry of complex numbers, fundamental theorem of algebra (Stillwell – Chapters 6 and 14). 2. History of Calculus and Geometry: The regular polyhedra, conic sections, coordinate geometry (Stillwell – Chapter 2 and 7). Early results on areas and volumes, maxima, minima and tangents, infinite series, Leibniz's calculus (Stillwell – Chapter 9). The isoperimetric inequality (PCM – III.94 , IV.26 and V.19). 3. History of Number Theory and Combinatorics: Pythagorean triples, prime numbers, Euclidean algorithm, chinese remainder theorem, Pell's equation (Stillwell – Chapters 3, and 5). Divisibility, Bezout's identity, prime factorisation, fundamental theorem of arithmetic, division algorithms, GCD and LCM (Burton – Chapter 2, JJ – Chapter 1 and 2). Pigeonhole principle, Konigsberg problem (Stillwell – Chapter 25). 4. Elementary Concepts: Statements and quantifiers, sets, functions and methods of proofs (Goldberg – Chapter 1, Burton – Chapter 1, Jones and Jones – Appendix A). Relations, equivalence, partitions, modular arithmetic (JJ – Appendix B, Section 3.1, 5.1-5.3, 6.1, 8.2-8.5). Uncountability of R (Goldberg – Chapter 1). Double and triple integration, Jacobians and change of variables formula. Parametrization of curves and surfaces, vector fields, line and surface integrals. Divergence and curl. Theorems of Green, Gauss, and Stokes.

Course Code	**MA 114**
Course Name	**An Introduction to Mathematical Concepts**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. T. M. Apostol, Mathematical Analysis, (2nd edition) Narosa Publicating House, 1974. 2. D. M. Burton, Elementary number theory, 6th edition, McGraw-Hill, 2007. 3. J. B. Conway, Functions of one complex variable, 2nd edition, Springer, 1978. 4. J. P. D'Angelo and D. B. West, Mathematical thinking: Problem-solving and Proofs, 2nd edition,Prentice Hall, 1997. 5. R. R. Goldberg, Methods of real analysis, Oxform & IBH Pub. (Indian Edition), 1970. 6. P. R. Halmos, Naive set theory, Springer 1960 (Reprint 2017). 7. G. A. Jones and J. M. Jones, Elementary number theory, Springer Math Undergrad Series, 1998 (Indian edition available). 8. A. Kumar and S. Kumerasan, A Basic course in real analysis, CRC Press, 2014.
Description	Elementary Concepts: Statements and Quantifiers, Sets, Functions and Methods of proofs (Goldberg, Ch 1) (Burton, Ch 1) (Jones and Jones Appendix A). Basic Real Analysis: Least upper bound and applications, Archimedean property, Density of $\mathbb{Q}$, $\mathbb{R}\setminus\mathbb{Q}$, Greatest integer function, Nested Interval Theorem, Uncountability of $\mathbb{R}$ (Goldberg, Ch 1). Sequence of Real numbers: (Goldberg, Ch 2). Operations, Monotone sequences, Cauchy sequences. Convergence of Series: Convergence and divergence, Test for absolute convergence (Goldberg, Ch 3). Basic Algebra: Divisibility, Bezout's Identity, Prime Factorisation, Fundamental Theorem of Arithmetic, Division Algorithms, GCD and LCM (Burton, Ch. 2) (Jones and Jones Ch. 1 and 2). Relations, Equivalence, Partitions, Modular Arithmetic, Euler and Mobius functions and inversion. Groups and Subgroups (basic properties and examples) (Jones and Jones Appendix B, Sec 3.1, 5.1-5.3, 6.1, 8.2-8.5). Complex Plane: Polar representation and roots of unity, lines and half planes in $\mathbb{C}$, $\mathbb{C}$ as a vector space over $\mathbb{R}$, conjugation as a linear map over $\mathbb{R}$, extended complex plane and its spherical representation (Conway, Ch. 1).

Course Code	**MA 205**
Course Name	**Complex Analysis**
Total Credits	4
Type	T
Lecture	3
Tutorial	0
Practical	1
Selfstudy	0
Half Semester	Y
Prerequisite	Nil
Text Reference	1. R. V. Churchill and J. W. Brown, Complex variables and applications (7th Edition), McGraw-Hill (2003) 2. J. M. Howie, Complex analysis, Springer-Verlag (2004) 3. M. J. Ablowitz and A. S. Fokas, Complex Variables- Introduction and Applications, Cambridge University Press, 1998 (Indian Edition) 4. E. Kreyszig, Advanced engineering mathematics (8th Edition), John Wiley (1999).
Description	Definition and properties of analytic functions. Cauchy-Riemann equations, harmonic functions. Power series and their properties. Elementary functions. Cauchy's theorem and its applications. Taylor series ans Laurent expansions. Residues and the Cauchy residue formula. Evaluation of improper integrals. Conformal mappings. Inversion of Laplace transforms.

Course Code	**MA 207**
Course Name	**Differential Equations 2**
Total Credits	4
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	Y
Prerequisite	Nil
Text Reference	1. E. Kreyszig, Advanced engineering mathematics (8th Edition), John Wiley (1999). 2. W. E. Boyce and R. DiPrima, Elementary Differential Equations (8th Edition), John Wiley (2005) 3. R. V. Churchill and J. W. Brown, Fourier series and boundary value problems (7th Edition), McGraw-Hill (2006).
Description	Review of power series and series solutions of ODE's. Legendre's equation and Legendre polynomials. Regular and irregular singular points, method of Frobenius. Bessel's equation and Bessel's functions. Sturm-Liouville problems. Fourier series. D'Alembert solution to the Wave equation. Classification of linear second order PDE in two variables. Laplace, Wave, and Heat equations using separation of variables. Vibration of a circular membrane. Heat equation in the half space.

Course Code	**MA 214**
Course Name	**Introduction to Numerical Analysis**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. S. D. Conte and Carl de Bo or, Elementary Numerical Analysis- An Algorithmic Approach (3rd Edition), McGraw-Hill, 1980. 2. C. E. Froberg, Introduction to Numerical Analysis (2nd Edition), Addison-Wesley, 1981. 3. E. Kreyszig, Advanced engineering mathematics (8th Edition), John Wiley (1999).
Description	Interpolation by polynomials, divided differences, error of the interpolating polynomial, piecewise linear and cubic spline interpolation. Numerical integration, composite rules, error formulae. Solution of a system of linear equations, implementation of Gaussian elimination and Gauss-Seidel methods, partial pivoting, row echelon form, LU factorization Cholesky's method, ill-conditioning, norms. Solution of a nonlinear equation, bisection and secant methods. Newton's method, rate of convergence, solution of a system of nonlinear equations, numerical solution of ordinary differential equations, Euler and Runge-Kutta methods, multistep methods, predictor-corrector methods, order of convergence, finite difference methods, numerical solutions of elliptic, parabolic, and hyperbolic partial differential equations. Eigenvalue problem, power method, QR method, Gershgorin's theorem. Exposure to software packages like IMSL subroutines, MATLAB.

Course Code	**MA 401**
Course Name	**Linear Algebra**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. K. Hoffman and R. Kunze, Linear Algebra, Pearson Education (India), 2003. 2. S. Lang, Linear Algebra, Undergraduate Texts in Mathematics, Springer-Verlag, New York, 1989. 3. P. Lax, Linear Algebra, John Wiley & Sons, 1997. 4. H.E. Rose, Linear Algebra, Birkhauser, 2002.
Description	Vector spaces over fields, subspaces, bases and dimension. Systems of linear equations, matrices, rank, Gaussian elimination. Linear transformations, representation of linear transformations by matrices, rank-nullity theorem, duality and transpose. Determinants, Laplace expansions, cofactors, adjoint, Cramer's Rule. Eigenvalues and eigenvectors, characteristic polynomials, minimal polynomials, Cayley-Hamilton Theorem, triangulation, diagonalization, rational canonical form, Jordan canonical form. Inner product spaces, Gram-Schmidt ortho-normalization, orthogonal projections, linear functionals and adjoints, Hermitian, self-adjoint, unitary and normal operators, Spectral Theorem for normal operators. Bilinear forms, symmetric and skew-symmetric bilinear forms, real quadratic forms, Sylvester's law of inertia, positive definiteness.

Course Code	**MA 403**
Course Name	**Real Analysis**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. T. Apostol, Mathematical Analysis, 2nd Edition, Narosa, 2002. 2. K. Ross, Elementary Analysis: The Theory of Calculus, Springer Int. Edition, 2004. 3. W. Rudin, Principles of Mathematical Analysis, 3rd Edition, McGraw-Hill, 1983.
Description	Review of basic concepts of real numbers: Archimedean property, Completeness. Metric spaces, compactness, connectedness, (with emphasis on $\mathbb{R}^n$). Continuity and uniform continuity. Monotonic functions, Functions of bounded variation; Absolutely continuous functions. Derivatives of functions and Taylor‘s theorem. Riemann integral and its properties, characterization of Riemann integrable functions. Improper integrals, Gamma functions. Sequences and series of functions, uniform convergence and its relation to continuity, differentiation and integration. Fourier series, pointwise convergence, Fejer‘s theorem, Weierstrass approximation theorem.

Course Code	**MA 406**
Course Name	**General Topology**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 403 (Real Analysis)
Text Reference	1. M. A. Armstrong, Basic Topology, Springer (India), 2004. 2. K. D. Joshi, Introduction to General Topology, New Age International, 2000. 3. J. L. Kelley, General Topology, Van Nostrand, 1955.J. R. Munkres, Topology, 2nd Edition, Pearson Education (India), 2001. 4. G. F. Simmons, Introduction to Topology and Modern Analysis, McGraw-Hill, 1963.
Description	Topological Spaces: open sets, closed sets, neighbourhoods, bases, sub bases, limit points, closures, interiors, continuous functions, homeomorphisms. Examples of topological spaces: subspace topology, product topology, metric topology, order topology. Quotient Topology: Construction of cylinder, cone, Moebius band, torus, etc. Connectedness and Compactness: Connected spaces, Connected subspaces of the real line, Components and local connectedness, Compact spaces, Heine-Borel Theorem, Local -compactness. Separation Axioms: Hausdorff spaces, Regularity, Complete Regularity, Normality, Urysohn Lemma, Tychonoff embedding and Urysohn Metrization Theorem, Tietze Extension Theorem. Tychnoff Theorem, One-point Compactification. Complete metric spaces and function spaces, Characterization of compact metric spaces, equicontinuity, Ascoli-Arzela Theorem, Baire Category Theorem. Applications: space filling curve, nowhere differentiable continuous function. Optional Topics: Topological Groups and orbit spaces, Paracompactness and partition of unity, Stone-Cech Compactification, Nets and filters.

Course Code	**MA 408**
Course Name	**Measure Theory**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 403 (Real Analysis)
Text Reference	1. P.R. Halmos, Measure Theory, Graduate Text in Mathematics, Springer-Verlag, 1979. 2. Inder K. Rana, An Introduction to Measure and Integration (2nd Edition), Narosa Publishing House, New Delhi, 2004. 3. H.L. Royden, Real Analysis, 3rd Edition, Macmillan, 1988.
Description	Semi-algebra, Algebra, Monotone class, Sigma-algebra, Monotone class theorem. Measure spaces. Outline of extension of measures from algebras to the generated sigma-algebras, Measurable sets, Lebesgue Measure and its properties. Measurable functions and their properties, Integration and Convergence theorems. Introduction to L^p-spaces, Riesz-Fischer theorem, Riesz Representation theorem for L^2-spaces. Absolute continuity of measures, Radon-Nikodym theorem. Dual of L^p-spaces. Product measure spaces, Fubini's theorem. Fundamental Theorem of Calculus for Lebesgue Integrals (an outline).

Course Code	**MA 410**
Course Name	**Multivariable Calculus**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 403 (Real Analysis)
Text Reference	1. W. Fleming, Functions of Several Variables, 2nd Edition, Springer-Verlag, 1977. 2. J.R. Munkres, Analysis on Manifolds, Addison-Wesley,1991. 3. W. Rudin, Principles of Mathematical Analysis, 3rd Edition, McGraw-Hill, 1984. 4. M. Spivak, Calculus on Manifolds, A Modern Approach to Classical Theorems of Advanced Calculus, W. A. Benjamin, Inc., 1965.
Description	Functions on Euclidean spaces, continuity, differentiability, partial and directional derivatives, Chain Rule, Taylor's Theorem, Inverse Function Theorem, Implicit Function Theorem, Regular and critical values, Applications. Riemann Integral of real-valued functions on Euclidean spaces, measure zero sets, Fubini's Theorem, Partition of unity, change of variables, Integration by parts. Partition of unity, change of variables, Integration by parts. Integration on chains, tensors, differential forms, Poincare Lemma, singular chains, Stokes' Theorem for integrals of differential forms on chains (general version), Fundamental theorem of calculus.

Course Code	**MA 412**
Course Name	**Complex Analysis**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. J.B. Conway, Functions of One Complex Variable, 2nd Edition, Narosa, New Delhi, 1978. 2. T.W. Gamelin, Complex Analysis, Springer International Edition, 2001. 3. R. Remmert, Theory of Complex Functions, Springer Verlag, 1991. 4. A.R. Shastri, An Introduction to Complex Analysis, Macmilan India, New Delhi, 1999.
Description	Complex numbers and the point at infinity. Analytic functions. Cauchy-Riemann conditions. Mappings by elementary functions. Riemann surfaces. Conformal mappings. Contour integrals, Cauchy-Goursat Theorem. Uniform convergence of sequences and series. Taylor and Laurent series. Isolated singularities and residues. Evaluation of real integrals. Zeroes and poles, Maximum Modulus Principle, Argument Principle, Rouche's theorem.

Course Code	**MA 414**
Course Name	**Algebra 1**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 401 (Linear Algebra), MA 419 (Basic Algebra)
Text Reference	1. M. Artin, Algebra, Prentice Hall of India, 1994. 2. D.S. Dummit and R. M. Foote, Abstract Algebra, 2nd Edition, John Wiley, 2002. 3. J.A. Gallian, Contemporary Abstract Algebra, 4th Edition, Narosa, 1999. 4. N. Jacobson, Basic Algebra I, 2nd Edition, Hindustan Publishing Co., 1984, W.H. Freeman, 1985.
Description	Fields, Characteristic and prime subfields, Field extensions, Finite, algebraic and finitely generated field extensions, Classical ruler and compass constructions, Splitting fields and normal extensions, algebraic closures. Finite fields, Cyclotomic fields, Separable and inseparable extensions. Galois groups, Fundamental Theorem of Galois Theory, Composite extensions, Examples (including cyclotomic extensions and extensions of finite fields). Norm, trace and discriminant. Solvability by radicals, Galois' Theorem on solvability. Cyclic extensions, Abelian extensions, Polynomials with Galois groups S_n. Transcendental extensions.

Course Code	**MA 417**
Course Name	**Ordinary Differential Equations**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. M. Hirsch, S. Smale and R. Deveney, Differential Equations, Dynamical Systems and Introduction to Chaos, Academic Press, 2004 2. L. Perko, Differential Equations and Dynamical Systems, Texts in Applied Mathematics, Vol. 7, 2nd Edition, Springer Verlag, New York, 1998. 3. M. Rama Mohana Rao, Ordinary Differential Equations: Theory and Applications. Affiliated East-West Press Pvt. Ltd., New Delhi, 1980. 4. D. A. Sanchez, Ordinary Differential Equations and Stability Theory: An Introduction, Dover Publ. Inc., New York, 1968.
Description	Review of solution methods for first order as well as second order equations, Power Series methods with properties of Bessel functions and Legendre polynomials. Existence and Uniqueness of Initial Value Problems: Picard's and Peano's Theorems, Gronwall's inequality, continuation of solutions and maximal interval of existence, continuous dependence. Higher Order Linear Equations and linear Systems: fundamental solutions, Wronskian, variation of constants, matrix exponential solution, behaviour of solutions. Two Dimensional Autonomous Systems and Phase Space Analysis: critical points, proper and improper nodes, spiral points and saddle points. Asymptotic Behavior: stability (linearized stability and Lyapunov methods). Boundary Value Problems for Second Order Equations: Green's function, Sturm comparison theorems and oscillations, eigenvalue problems.

Course Code	**MA 419**
Course Name	**Basic Algebra**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. M. Artin, Algebra, Prentice Hall of India, 1994. 2. D. S. Dummit and R. M. Foote, Abstract Algebra, 2nd Edition, John Wiley, 2002. 3. J. A. Gallian, Contemporary Abstract Algebra, 4th Edition, Narosa, 1999. 4. K. D. Joshi, Foundations of Discrete Mathematics, Wiley Eastern, 1989. 5. T. T. Moh, Algebra, World Scientific, 1992. 6. S. Lang, Algebra, 3rd Edition, Springer (India), 2004. 7. J. Stillwell, Elements of Algebra, Springer, 1994.
Description	Continued on next page ...

Course Code	**MA 419 (... continued from previous page)**
Course Name	**Basic Algebra**
Description	Review of basics: Equivalence relations, partitions, division algorithm for integers, primes, unique factorization, congruences, Chinese Remainder Theorem, Euler φ-function. Permutations, sign of a permutation, inversions, cycles and transpositions. Rudiments of rings, fields, elementary properties, polynomials in one, several variables, divisibility, irreducible polynomials, Division algorithm, Remainder Theorem, Factor Theorem, Rational Zeros Theorem, Relation between the roots and coefficients, Newton's Theorem on symmetric functions, Newton's identities, Fundamental Theorem of Algebra. Rational functions, partial fraction decomposition, unique factorization of polynomials in several variables, Resultants and discriminants. Groups, subgroups, factor groups, Lagrange's Theorem, homomorphisms, normal subgroups. Quotients of groups, Basic examples of groups: symmetric groups, matrix groups, group of rigid motions of the plane and finite groups of motions. Cyclic groups, generators and relations, Cayley's Theorem, group actions, Sylow Theorems. Direct products, Structure Theorem for finite abelian groups. Simple groups and solvable groups, nilpotent groups, simplicity of alternating groups, composition series, Jordan-Holder Theorem. Semidirect products. Free groups, free abelian groups. Rings, Examples (including polynomial rings, formal power series rings, matrix rings and group rings), ideals, prime and maximal ideals, rings of fractions, Chinese Remainder Theorem for pairwise comaximal ideals. Euclidean Domains, Principal Ideal Domains and Unique Factorization Domains. Polynomial rings over UFD's.

Course Code	**MA 450**
Course Name	**Independent Study**
Total Credits	6
Type	S
Lecture	0
Tutorial	0
Practical	6
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	
Description	Independent Study: The student should pursue a topic of his or her choice for one semester under the supervision of a faculty member. The course is the analogue of the Seminar courses that undergraduate students were required to take in previous years. The Independent Study should end with a presentation to the supervising faculty member and the preparation of a brief report of about ten pages.

Course Code	**MA 503**
Course Name	**Functional Analysis**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 401 (Linear Algebra), MA 408 (Measure Theory)
Text Reference	1. J.B. Conway, A Course in Functional Analysis, 2nd Edition, Springer, Berlin, 1990. 2. C. Goffman and G. Pedrick, A First Course in Functional Analysis, Prentice-Hall, 1974. 3. E. Kreyzig, Introduction to Functional Analysis with Applications, John Wiley & Sons, New York, 1978. 4. B.V. Limaye, Functional Analysis, 2nd Edition, New Age International, New Delhi, 1996. 5. A. Taylor and D. Lay, Introduction to Functional Analysis, Wiley, New York, 1980.
Description	Normed spaces. Continuity of linear maps. Hahn-Banach Extension and Separation Theorems. Banach spaces. Dual spaces and transposes. Uniform Boundedness Principle and its applications. Closed Graph Theorem, Open Mapping Theorem and their applications. Spectrum of a bounded operator. Examples of compact operators on normed spaces. Inner product spaces, Hilbert spaces. Orthonormal basis. Projection theorem and Riesz Representation Theorem.

Course Code	**MA 504**
Course Name	**Operators on Hilbert Spaces**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 503 (Functional Analysis)
Text Reference	1. B.V. Limaye, Functional Analysis, 2nd Edition, New Age International, 1996. 2. J.B. Conway, A Course in Functional Analysis, 2nd Edition, Springer, 1990. 3. C. Goffman and G. Pedrick, First Course in Functional Analysis, Prentice Hall, 1974. 4. I. Gohberg and S. Goldberg, Basic Operator Theory, Birkhauser, 1981. 5. E. Kreyzig, Introduction to Functional Analysis with Applications, John Wiley & Sons, 1978.
Description	Adjoints of bounded operators on a Hilbert space, Normal, self-adjoint and unitary operators, their spectra and numerical ranges. Compact operators on Hilbert spaces. Spectral theorem for compact self-adjoint operators. Application to Sturm-Liouville Problems.

Course Code	**MA 515**
Course Name	**Partial Differential Equations**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 410 (Multivariable Calculus), MA417 (Ordinary Differential Equations)
Text Reference	1. E. DiBenedetto, Partial Differential Equations, Birkhauser, 1995. 2. L.C. Evans, Partial Differential Equations, Graduate Studies in Mathematics, Vol. 19, American Mathematical Society, 1998. 3. F. John, Partial Differential Equations, 3rd Edition, Narosa, 1979. 4. E. Zauderer, Partial Differential Equations of Applied Mathematics, 2nd Edition, John Wiley and Sons, 1989.
Description	Cauchy Problems for First Order Hyperbolic Equations: method of characteristics, Monge cone. Classification of Second Order Partial Differential Equations: normal forms and characteristics. Initial and Boundary Value Problems: Lagrange-Green‘s identity and uniqueness by energy methods. Stability theory, energy conservation and dispersion. Laplace equation: mean value property, weak and strong maximum principle, Green‘s function, Poisson‘s formula, Dirichlet‘s principle, existence of solution using Perron’s method (without proof). Heat equation: initial value problem, fundamental solution, weak and strong maximum principle and uniqueness results. Wave equation: uniqueness, D‘Alembert‘s method, method of spherical means and Duhamel’s principle. Methods of separation of variables for heat, Laplace and wave equations.

Course Code	**MA 521**
Course Name	**Theory of Analytic Functions**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 403 (Real Analysis), MA412 (Complex Analysis)
Text Reference	1. L. Ahlfors, Complex Analysis, 3rd Edition, McGraw-Hill, 1979. 2. J.B. Conway, Functions of One Complex Variable, 2nd Edition, Narosa, 1978. 3. T.W. Gamelin, Complex Analysis, Springer International, 2001. 4. R. Narasimhan, Theory of Functions of One Complex Variable, Springer (India), 2001. 5. W. Rudin, Real and Complex Analysis, 3rd Edition, Tata McGraw-Hill, 1987.
Description	Maximum Modulus Theorem. Schwarz Lemma. Phragmen-Lindelof Theorem. Riemann Mapping Theorem. Weierstrass Factorization Theorem. Runge's Theorem. Simple connectedness. Mittag-Leffler Theorem. Schwarz Reflection Principle. Basic properties of harmonic functions. Picard Theorems.

Course Code	**MA 523**
Course Name	**Basic Number Theory**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 419 (Basic Algebra)
Text Reference	1. W.W. Adams and L.J. Goldstein, Introduction to the Theory of Numbers, 3rd Edition, Wiley Eastern, 1972. 2. A. Baker, A Concise Introduction to the Theory of Numbers, Cambridge University Press, 1984. 3. I. Niven and H.S. Zuckerman, An Introduction to the Theory of Numbers, 4th Edition, Wiley, 1980.
Description	Infinitude of primes, discussion of the Prime Number Theorem, infinitude of primes in specific arithmetic progressions, Dirichlet‘s theorem (without proof). Arithmetic functions, Mobius inversion formula. Structure of units modulo n, Euler's phi function. Congruences, theorems of Fermat and Euler, Wilson's theorem, linear congruences, quadratic residues, law of quadratic reciprocity. Binary quadratics forms, equivalence, reduction, Fermat's two square theorem, Lagrange's four square theorem. Continued fractions, rational approximations, Liouville's theorem, discussion of Roth's theorem, transcendental numbers, transcendence of e and π. Diophantine equations: Brahmagupta's equation (also known as Pell's equation), The equation, Fermat's method of descent, discussion of the Mordell equation.

Course Code	**MA 524**
Course Name	**Algebraic Number Theory**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 414 (Algebra 1)
Text Reference	1. K. Ireland and M. Rosen, A Classical Introduction to Modern Number Theory, 2nd Edition, Springer-Verlag, Berlin, 1990. 2. S. Lang, Algebraic Number Theory, Addison- Wesley, 1970. 3. D. A. Marcus, Number Fields, Springer-Verlag, 1977.
Description	Algebraic number fields. Localisation, discrete valuation rings. Integral ring extensions, Dedekind domains, unique factorisation of ideals. Action of the Galois group on prime ideals. Valuations and completions of number fields, discussion of Ostrowski's theorem, Hensel's lemma, unramified, totally ramified and tamely ramified extensions of p-adic fields. Discriminants and Ramification. Cyclotomic fields, Gauss sums, quadratic reciprocity revisited. The ideal class group, finiteness of the ideal class group, Dirichlet units theorem.

Course Code	**MA 525**
Course Name	**Dynamical Systems**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 417 (Ordinary Differential Equations)
Text Reference	1. L. Perko, Differential Equations and Dynamical Systems, Springer Verlag, 1991. 2. M. W. Hirsch and S. Smale, Differential Equations, Dynamical Systems and Linear Algebra, Academic Press, 174. 3. P. Hartman, Ordinary Differential Equations, 2nd edition, SIAM 2002. 4. C. Chicone, Ordinary Differential Equations with Applications, 2nd Edition, Springer, 2006.
Description	**Linear Systems**: Review of stability for linear systems of two equations. **Local Theory for Nonlinear Planar Systems**: Flow defined by a differential equation, Linearization and stable manifold theorem, Hartman-Grobman theorem, Stability and Lyapunov functions, Saddles, nodes, foci, centers and nonhyperbolic critical points. Gradient and Hamiltonian systems. **Global Theory for Nonlinear Planar Systems**: Limit sets and attractors, Poincare map, Poincare Benedixson theory and Poincare index theorem. **Bifurcation Theory for Nonlinear Systems**: Structural stability and Peixoto's theorem, Bifurcations at nonhyperbolic equilibrium points.

Course Code	**MA 526**
Course Name	**Commutative Algebra**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 5101 (Algebra 2)
Text Reference	1. D. Eisenbud, Commutative Algebra (with a view toward algebraic geometry), Graduate Texts in Mathematics 150, Springer-Verlag, 2003. 2. H. Matsumura, Commutative ring theory, Cambridge Studies in Advanced Mathematics No. 8, Cambridge University Press, 1980. 3. W. Bruns and J. Herzog, Cohen-Macaulay Rings, Revised edition, Cambridge Studies in Advanced Mathematics No. 39, Cambridge University Press, 1998.
Description	Dimension theory of affine algebras: Principal ideal theorem, Noether normalization lemma, dimension and transcendence degree, catenary property of affine rings, dimension and degree of the Hilbert polynomial of a graded ring, Nagata's altitude formula, Hilbert's Nullstellensatz, finiteness of integral closure. Associated primes of modules, degree of the Hilbert polynomial of a graded module, Hilbert series and dimension, Dimension theorem, Hilbert-Samuel multiplicity, associativity formula for multiplicity, Complete local rings: Basics of completions, Artin-Rees lemma, associated graded rings of filtrations, completions of modules, regular local rings Basic Homological algebra: Categories and functors, derived functors, Hom and tensor products, long exact sequence of homology modules, free resolutions, Tor and Ext, Koszul complexes. Cohen-Macaulay rings: Regular sequences, quasi-regular sequences, Ext and depth, grade of a module, Ischebeck's theorem, Basic properties of Cohen-Macaulay rings, Macaulay's unmixed theorem, Hilbert-Samuel multiplicity and Cohen-Macaulay rings, rings of invariants of finite groups.Optional Topics: Face rings of simplicial complexes, shellable simplicial complexes and their face rings. Dedekind Domains and Valuation Theory.

Course Code	**MA 528**
Course Name	**Hyperplane Arrangements**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. P. Orlik and H. Terao, Arrangements of hyperplanes, Springer, 1992. 2. C. De Concini and C. Procesi,.Topics in hyperplane arrangements, polytopes and boxsplines. Springer, 2011. 3. A. Dimca Hyperplane arrangements. An introduction. Springer, 2017. 4. M. Aguiar and S. Mahajan. Topics in hyperplane arrangements. AMS, 2017.
Description	Faces, flats, cones, lunes. Distance functions Birkhoff monoid, Tits monoid and Janus monoid Lie and Zie elements Eulerian idempotents, Dynkin idempotents, JoyalKlyachko-Stanley theorem Orlik-Solomon algebra Incidence algebras and operads.

Course Code	**MA 530**
Course Name	**Nonlinear Analysis**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 503 (Functional Analysis)
Text Reference	1. M.C. Joshi and R.K. Bose, Some Topics in Nonlinear Functional Analysis, Wiley Eastern Ltd., New Delhi, 1985. 2. E. Zeilder, Nonlinear Functional Analysis and Its Applications, Vol. I (Fixed Point Theory), Springer Verlag, Berlin, 1985.
Description	Fixed Point Theorems with Applications: Banach contraction mapping theorem, Brouwer fixed point theorem, LeraySchauder fixed point theorem. Calculus in Banach spaces: Gateaux as well as Frechet derivatives, chain rule, Taylor's expansions, Implicit function theorem with applications, subdifferential. Monotone Operators: maximal monotone operators with properties, surjectivity theorem with applications. Degree theory and condensing operators with applications.

Course Code	**MA 532**
Course Name	**Analytic Number Theory**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 414 (Algebra I), MA 412 (Complex Analysis)
Text Reference	1. S. Lang, Algebraic Number Theory, AddisonWesley, 1970. 2. J.P. Serre, A Course in Arithmetic, SpringerVerlag, 1973. 3. T. Apostol, Introduction to Analytic Number Theory, Springer-Verlag, 1976.
Description	The Wiener-Ikehara Tauberian theorem, the Prime Number Theorem. Dirichlet's theorem for primes in an Arithmetic Progression. Zero free regions for the Riemann-zeta function and other L-functions. Euler products and the functional equations for the Riemann zeta function and Dirichlet L-functions. Modular forms for the full modular group, Eisenstein series, cusp forms, structure of the ring of modular forms. Hecke operators and Euler product for modular forms. The L-function of a modular form, functional equations. Modular forms and the sums of four squares. Optional topics: Discussion of L-functions of number fields and the Chebotarev Density Theorem. Phragmen-Lindelof Principle, Mellin inversion formula, Hamburger's theorem. Discussion of Modular forms for congruence subgroups. Discussion of Artin's holomorphy conjecture and higher reciprocity laws. Discussion of elliptic curves and the Shimura-Taniyama conjecture (Wiles' Theorem)

Course Code	**MA 533**
Course Name	**Advanced Probability Theory**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	6
Half Semester	N
Prerequisite	Nil
Text Reference	1. P. Billingsley, Probability and Measure, 3rd Edition, John Wiley and Sons, New York, 1995. 2. J. Rosenthal, A First Look at Rigorous Probability, World Scientific, Singapore, 2000. 3. A.N. Shiryayev, Probability, 2 nd Edition, Springer, New York, 1995. 4. K.L. Chung, A Course in Probability Theory, Academic Press, New York, 1974.
Description	Probability measure, probability space, construction of Lebesgue measure, extension theorems, limit of events, Borel-Cantelli lemma. Random variables, Random vectors, distributions, multidimensional distributions, independence. Expectation, change of variable theorem, convergence theorems. Sequence of random variables, modes of convergence. Moment generating function and characteristics functions, inversion and uniqueness theorems, continuity theorems, Weak and strong laws of large number, central limit theorem. Radon Nikodym theorem, definition and properties of conditional expectation,

Course Code	**MA 534**
Course Name	**Modern Theory of PDE**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 503 (Functional Analysis), MA 515 (Partial Differential Equations)
Text Reference	1. S. Kesavan, Topics in Functional Analysis Wiley Eastern Ltd., New Delhi, 1989. 2. M. Renardy and R.C. Rogers, An Introduction to Partial Differential Equations,2nd Edition, Springer Verlag International Edition, New York, 2004. 3. L.C. Evans, Partial Differential Equations, American Mathematical Society, Providence, 1998.
Description	Theory of distributions: supports, test functions, regular and singular distributions, generalised derivatives. Sobolev Spaces: definition and basic properties, approximation by smooth functions, dual spaces, trace and imbedding results (without proof). Elliptic Boundary Value Problems: abstract variational problems, Lax-Milgram Lemma, weak solutions and wellposedness with examples, regularity result, maximum principles, eigenvalue problems. Semigroup Theory and Applications: exponential map, C_0-semigroups, Hille-Yosida and Lummer-Phillips theorems, applications to heat and wave equations.

Course Code	**MA 538**
Course Name	**Representation Theory of Finite Groups**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 414 (Algebra 1)
Text Reference	1. M. Burrow, Representation Theory of Finite Groups, Academic Press, 1965. 2. N. Jacobson, Basic Algebra II, Hindustan Publishing Corporation, 1983. 3. S. Lang, Algebra, 3rd Edition, Springer (India), 2004. 4. J.-P. Serre, Linear Representation of Groups, Springer-Verlag, 1977.
Description	Representations, Subrepresentations, Tensor products, Symmetric and Alternating Squares.Characters, Schur's lemma, Orthogonality relations, Decomposition of regular representation, Number of irreducible representations, canonical decomposition and explicit decompositions. Subgroups, Product groups, Abelian groups. Induced representations.Examples: Cyclic groups, alternating and symmetric groups. Integrality properties of characters, Burnside's pq theorem. The character of induced representation, Frobenius Reciprocity Theorem, Meckey's irreducibility criterion, Examples of induced representations, Representations of supersolvable groups.

Course Code	**MA 539**
Course Name	**Spline Theory and Variational Methods**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. C. De Boor, A Practical Guide to Splines, Springer-Verlag, Berlin, 1978. 2. H.N. Mhaskar and D.V. Pai, Fundamentals of Approximation Theory, Narosa Publishing House, New Delhi, 2000. 3. P.M. Prenter, Splines and Variational Methods, Wiley-Interscience, 1989.
Description	Even Degree and Odd Degree Spline Interpolation, end conditions, error analysis and order of convergence. Hermite interpolation, periodic spline interpolation. B-Splines, recurrence relation for B-splines, curve fitting using splines, optimal quadrature. Tensor product splines, surface fitting, orthogonal spline collocation methods.

Course Code	**MA 540**
Course Name	**Numerical Methods for Partial Differential Equations**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 515 (Partial Differential Equations), SI 517 (Numerical Analysis)
Text Reference	1. K. W. Morton and D. Mayers, Numerical Solution for Partial Differential Equations, 2nd edition, Cambridge, 2005. 2. G. D. Smith, Numerical Solutions of Partial Differential Equations, 3rd Edition, Calrendorn Press, 1985. 3. J. C. Strikwerda, Finite difference Schemes and Partial Differential Equations, Wadsworth and Brooks/ Cole, 1989. 4. J. W. Thomas, Numerical Partial Differential Equations : Finite Difference Methods, Texts in Applied Mathematics, Vol. 22, Springer Verlag, 1999. 5. J. W. Thomas, Numerical Partial Differential Equations: Conservation Laws and Elliptic Equations, Texts in Applied Mathematics, Vol. 33, Springer Verlag, 1999. 6. R. Mitchell and S. D. F. Griffiths, The Finite Difference Methods in Partial Differential Equations, Wiley and Sons, NY, 1980.
Description	Finite differences: Grids, Finite-difference approximations to derivatives. Linear Transport Equation: Upwind, Lax-Wendroff and Lax-Friedrich schemes, von-Neumann stability analysis, CFL condition, Lax-Richtmyer equivalence theorem, Modified equations, Dissipation and dispersion. Heat Equation: Initial and boundary value problems (Dirichlet and Neumann), Explicit and implicit methods (Backward Euler and Crank-Nicolson schemes) with consistency and stability, Discrete maximum principle, ADI methods for two dimensional heat equation (including LOD algorithm). Poisson‘s Equation: Finite difference scheme for initial and boundary value problems, Discrete maximum principle, Iterative methods for linear systems (Jacobi, Gauss-Seidel, SOR methods and Conjugate Gradient method), Peaceman-Rachford algorithm (ADI) for linear systems. Wave Equation: Explicit schemes and their stability analysis, Implementation of boundary conditions.Lab Component: Exposure to MATLAB and computational experiments based on the algorithms discussed in the course.

Course Code	**MA 556**
Course Name	**Differential Geometry**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 410 (Multivariable Calculus)
Text Reference	1. M. doCarmo, Differential Geometry of Curves and Surfaces, Prentice Hall, 1976. 2. B. O'Neill, Elementary Differential Geometry, Academic Press, 1966. 3. J.J. Stoker, Differential Geometry, Wiley-Interscience, 1969. 4. J. A. Thorpe, Elementary Topics in Differential Geometry, Springer (India), 2004.
Description	Graphs and level sets of functions on Euclidean spaces, vector fields, integral curves of vector fields, tangent spaces. Surfaces in Euclidean spaces, vector fields on surfaces, orientation, Gauss map. Geodesics, parallel transport, Weingarten map. Curvature of plane curves, arc length and line integrals, Curvature of surfaces. Parametrized surfaces, local equivalence of surfaces. Gauss-Bonnet Theorem, Poincare-Hopf Index Theorem.

Course Code	**MA 562**
Course Name	**The Mathematical Theory of Finite Elements**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 515 (Partial Differential Equations), MA 503 (Functional Analysis)
Text Reference	1. K. E. Brenner and R. Scott, The Mathematical Theory of Finite Element Methods, Springer- Verlag, 1994. 2. P.G. Ciarlet, The Finite Element Methods for Elliptic Problems, North Holland, 1978. 3. C. Johnson, Numerical solutions of Partial Differential Equations by Finite Element Methods, Cambridge University Press, 1987. 4. C. Mercier, Lectures on Topics in Finite Element Solution of Elliptic Problems, TIFR Lectures on Mathematics and Physics Vol. 63, Narosa, 1979.
Description	Sobolev Spaces: basic elements, Poincare inequality. Abstract variational formulation and elliptic boundary value problem. Galerkin formulation and Cea's Lemma. Construction of finite element spaces. Polynomial approximations and interpolation errors. Convergence analysis: Aubin-Nitsche duality argument; non-conforming elements and numerical integration; computation of finite element solutions. Parabolic initial and boundary value problems: semidiscrete and completely discrete schemes with convergence analysis. Lab component: Implementation of algorithms and computational experiments using MATLAB

Course Code	**MA 581**
Course Name	**Elements of Differential Topology**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 410 (Multivariable Calculus)
Text Reference	1. B. A. Dubrovin, A. T. Fomenko, and S. P. Novikov, Modern Geometry Methods and Applications Part II: The Geometry and Topology of Manifolds, Springer-Verlag, 1985. 2. V. Guillemin and A Pollack, Differential Topology Prentice-Hall Inc., Englewood Cliffs, New Jersey, 1974. 3. J. Milnor, Topology from the Differential View-point, University Press of Virginia, Charlottsville 1990. 4. A. R. Shastri, Elements of Differential Topology, CRC Press, 2011.
Description	Differentiable Manifolds in $\mathbb{R}^n$: Review of inverse and implicit function theorems; tangent spaces and tangent maps; immersions; submersions and embeddings. Regular Values: Regular and critical values; regular inverse image theorem; Sard's theorem; Morse lemma. Transversality: Orientations of manifolds; oriented and mod 2 intersection numbers; degree of maps. Application to the Fundamental Theorem of Algebra. *Lefschetz theory of vector fields and flows: Poincare-Hopf index theorem; Gauss-Bonnet theorem. *Abstract manifolds: Examples such as real and complex projective spaces and Grassmannian varieties; Whitney embedding theorems. (*indicates expository treatment intended for these parts of the syllabus.)

Course Code	**MA 593**
Course Name	**Project (Optional)**
Total Credits	4
Type	
Lecture	
Tutorial	
Practical	
Selfstudy	
Half Semester	
Prerequisite	
Text Reference	1.
Description	

Course Code	**MA 598**
Course Name	**Project 2 (Optional)**
Total Credits	6
Type	
Lecture	
Tutorial	
Practical	
Selfstudy	
Half Semester	
Prerequisite	
Text Reference	1.
Description	

Course Code	**MA 5101**
Course Name	**Algebra 2**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 414 (Algebra 1)
Text Reference	1. M. F. Atiyah and I. G. Macdonald, Introduction to Commutative Algebra, Addison Wesley, 1969. 2. D. S. Dummit and R. M. Foote, Abstract Algebra, 2nd Edition, John Wiley, 2002. 3. N. Jacobson, Basic Algebra I and II, 2nd Edition, W. H. Freeman, 1985 and 1989. 4. S. Lang, Algebra, 3rd Edition, Springer (India), 2004. 5. O. Zariski and P. Samuel, Commutative Algebra, Vol. I, Springer, 1975.
Description	Modules, submodules, quotient modules and module homomorphisms. Generation of modules, direct sums and free modules. Tensor products of modules. Exact sequences. Hom and Tensor duality. Finitely generated modules over principal ideal domains, invariant factors, elementary divisors, rational canonical forms. Applications to finitely generated abelian groups and linear transformations. Noetherian rings and modules, Hilbert basis theorem, Primary decomposition of ideals in noetherian rings. Integral extensions, Going-up and Going-down theorems, Extension and contraction of prime ideals, Noether's Normalization Lemma, Hilbert's Nullstellensatz.

Course Code	**MA 5102**
Course Name	**Basic Algebraic Topology**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 406 (General Topology)
Text Reference	1. M. J. Greenberg and J. R. Harper, Algebraic Topology, Benjamin, 1981. 2. W. Fulton, Algebraic topology: A First Course, Springer-Verlag, 1995. 3. A. Hatcher, Algebraic Topology, Cambridge Univ. Press, Cambridge, 2002. 4. W. Massey, A Basic Course in Algebraic Topology, Springer-Verlag, Berlin, 1991. 5. J. R. Munkres, Elements of Algebraic Topology, Addison-Wesley, 1984. 6. J. J. Rotman, An Introduction to Algebraic Topology, Springer (India), 2004. 7. H. Seifert and W. Threlfall, A Textbook of Topology, translated by M. A. Goldman, Academic Press, 1980. 8. J. W. Vick, Homology Theory: An Introduction to Algebraic Topology, 2nd Edition, Springer-Verlag, 1994.
Description	Paths and homotopy, homotopy equivalence, contractibility, deformation retracts. Basic constructions: cones, mapping cones, mapping cylinders, suspension. Fundamental groups. Examples (including the fundamental group of the circle) and applications (including Fundamental Theorem of Algebra, Brouwer Fixed Point Theorem and Borsuk-Ulam Theorem, both in dimension two). Van Kampen‘s Theorem, Covering spaces, lifting properties, deck transformations. Universal coverings (existence theorem optional). Singular Homology. Mayer-Vietoris Sequences. Long exact sequence of pairs and triples. Homotopy invariance and excision theorem (without proof). Applications of homology: Jordan-Brouwer separation theorem, invariance of dimension, Hopf's Theorem for commutative division algebras with identity, Borsuk-Ulam Theorem, Lefschetz Fixed Point Theorem.

Course Code	**MA 5103**
Course Name	**Algebraic Combinatorics 2 1 0 6**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 401 (Linear Algebra)
Text Reference	1. N. Alon, Combinatorial Nullstellensatz, Combinatorics, Probability, and Computing, Vol. 8 (1999), pp. 7-29. 2. R. P. Stanley, Algebraic Combinatorics: Walks, Trees, Tableaux, and More, Springer, 2013. 3. C. Godsil and G. F. Royle, Algebraic Graph Theory, Springer, 2001. 4. F. Chung, Spectral Graph Theory, CBMS Regional Conference Series in Math., No. 92, American Mathematical Society, 1991. 5. L. Babai and P. Frankl, Linear Algebra Methods in Combinatorics, Department of Computer Science, University of Chicago, Preliminary version, 1992.
Description	A selection of topics from the following: Algebraic Graph theory: adjacency and Laplacian matrices of a graph, Matrix-Tree theorem, Cycle space and Bond space. Algebraic Sperner theory: Sperner property of posets, algebraic characterization of strong Sperner property, unimodality of q-binomial coefficients. Young Tableaux: Up-Down operators on the Young lattice and counting tableaux, RSK correspondence. Enumeration under group action: Burnside's lemma, Polya theory. Spectral Graph theory: Isoperimetric problems, Flows and Cheeger constants, Quasirandomness, expanders, and eigenvalues, random walks on graphs. The Combinatorial Nullstellensatz and some of its applications. Linear Algebra methods in Combinatorics. Association Schemes. Electrical Networks and resistances. Connections to Graph sparsification.

Course Code	**MA 5104**
Course Name	**Hyperbolic Conservation Laws**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 515 Partial Differential Equations
Text Reference	1. L. C. Evans, Partial Differential Equations, American Mathematical Society, 2010. 2. E. Godlewski and P.-A. Raviart, Numerical Approximation of Hyperbolic Systems of Conservation Laws, Springer, 1996. 3. A. Bressan, Hyperbolic Systems of Conservation Laws – The One-Dimensional Cauchy Problem, Oxford University Press, 2000. 4. J. Smoller, Shock Waves and ReactionDiffusion Equations, Springer, 1994
Description	Basic Concepts: Definition and examples, Loss of regularity, Weak solution, Rankine-Hugoniot jump condition, Entropy solution. Scalar Conservation Laws: Existence of an entropy solution, Uniqueness of the entropy solution, Asymptotic behavior of the entropy solution, The Riemann problem. System of Conservation Laws: Linear hyperbolic system with constant coefficients, Nonlinear case, Simple waves and Riemann invariants, Shock waves and contact discontinuities, Characteristic curves and entropy conditions, Solution of the Riemann problem, The Riemann problem for the psystem.

Course Code	**MA5105**
Course Name	**Coding Theory**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 401 (Linear Algebra)
Text Reference	1. J. H. van Lint, Introduction to Coding Theory, Springer, 1999. 2. W. C. Huffman and V. Pless, Fundamentals of Error Correcting Codes, Cambridge University Press, 2003. 3. J. MacWilliams and N. J. A. Sloane, The Theory of Error Correcting Codes, North-Holland, 1977. 4. S. Ling and C. Xing, Coding Theory: A First Course, Cambridge University Press, 2004.
Description	Basic Concepts: Idea behind use of codes, block codes and linear codes, repetition codes, nearest neighbour decoding, syndrome decoding, requisite basic ideas in probability, Shannon's theorem (without proof). Good linear and nonlinear codes: Binary Hamming codes, dual of a code, constructing codes by various operations, simplex codes, Hadamard matrices and codes constructed from Hadamard and conference matrices, Plotkin bound and various other bounds, Gilbert-Varshamov bound. Reed-Muller and related codes: First order Reed-Muller codes, RM code of order r, Decoding and Encoding using the algebra of finite field with characteristic two. Perfect codes: Weight enumerators, Kratchouwk polynomials, Lloyd's theorem, Binary and ternary Golay codes, connections with Steiner systems. Cyclic codes: The generator and the check polynomial, zeros of a cyclic code, the idempotent generators, BCH codes, Reed-Solomon codes, Quadratic residue codes, generalized RM codes. Optional topics; Codes over $\mathbb{Z}_4$: Quaternary codes over $\mathbb{Z}_4$, binary codes derived from such codes, Galois rings over $\mathbb{Z}_4$, cyclic codes over $\mathbb{Z}_4$. Goppa codes: the minimum distance of Goppa codes, generalized BCH codes, decoding of Goppa codes and their asymptotic behaviour.Algebraic geometry codes: algebraic curves and codes derived from them, Riemann-Roch theorem (statement only) and applications to algebraic geometry codes.

Course Code	MA5106
Course Name	**Introduction to Fourier Analysis**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 403 (Real Analysis)
Text Reference	1. R. S. Strichartz, A Guide to Distributions and Fourier Transforms, CRC Press, 1994. 2. E. M. Stein and R. Shakarchi, Fourier Analysis: An Introduction, Princeton University Press, 2003. 3. I. Richards and H. Youn, Theory of Distributions: A Nontechnical Introduction, Cambridge University Press, 1990.
Description	Basic Properties of Fourier Series: Uniqueness of Fourier Series, Convolutions, Cesaro and Abel Summability, Fejer's theorem, Poisson Kernel and Dirichlet problem in the unit disc. Mean square Convergence, Example of Continuous functions with divergent Fourier series. Distributions and Fourier Transforms: Calculus of Distributions, Schwartz class of rapidly decreasing functions, Fourier transforms of rapidly decreasing functions, Riemann Lebesgue lemma, Fourier Inversion Theorem, Fourier transforms of Gaussians. Tempered Distributions: Fourier transforms of tempered distributions, Convolutions, Applications to PDE's (Laplace, Heat and Wave Equations), Schrodinger-Equation and Uncertainty principle. Paley-Wienner Theorems, Poisson Summation Formula: Radial Fourier transforms and Bessel's functions. Hermite functions.

Course Code	**MA 5107**
Course Name	**Continuum Mechanics**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 417 (Ordinary Differential Equations) and MA 410 (Multivariable Calculus)
Text Reference	1. O. Gonzalez and A. M. Stuart, A First Course in Continuum mechanics, Cambridge University Press, 2008. 2. M. Gurtin, An Introduction to Continuum Mechanics, Academic press, 1981. 3. J. N. Reddy, An Introduction to Continuum Mechanics with Applications, Cambridge University Press, 2008. 4. J. N. Reddy, Principles of Continuum Mechanics: A Study of Conservation Principles with Applications, Cambridge University Press, 2010. 5. Y. R. Talpaert, Tensor analysis and Continuum Mechanics, Springer, 2003. 6. R. Temam and A. Miranville, Mathematical Modelling in Continuum Mechanics, Cambridge University Press, 2005.
Description	Preliminaries: Tensor algebra and calculus, Continuum mass and force concepts. Kinematics of Continuous Media: Deformation, Changes in distance, angles, volume, area, Particle derivatives, Measures of strain: Cauchy-Green strain tensor. Balance Laws of motion: Lagrangean and Eulerian forms of Conservation laws for mass, linear and angular momentum, and energy, Frame-indifference. Constitutive relations: Constitutive laws for solids and fluids, principle of material frame indifference, discussion of isotropy, linearized elasticity, fluid mechanics. indifference, discussion of isotropy, linearized elasticity, fluid mechanics.

Course Code	**MA 5108**
Course Name	**Lie Groups and Lie Algebras**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 401 (Linear Algebra) and MA 403 (Real Analysis)
Text Reference	1. J.Stillwell, Naive Lie Theory, Springer, 2008. 2. A. Kirillov Jr., Introduction to Lie Groups and Lie Algebras, Cambridge University Press, 2008.
Description	Introduction, Examples: Rotations of the plane, Quaternions and space rotations, SU(2) and SO(3), The Cartan-Dieudonné Theorem, Quaternions and rotations in R4, SU(2)xSU(2) and SO(4). Matrix Lie groups: definitions and examples. The symplectic, orthogonal and unitary groups, connectedness, compactness. Maximal tori. centres and discrete subgroups The exponential map, Lie algebras The matrix exponential, tangent spaces, the Lie algebra of a Lie group. Complexification, the matrix logarithm, the exponential map, One parameter subgroups, the functor from Lie groups to Lie algebras The adjoint mapping, normal subgroups and Lie algebras The Campbell-Baker-Hausdorff Theorem, simple connectivity, simply connected Lie groups and their characterization by Lie algebras, covering groups.

Course Code	**MA5109**
Course Name	**Graph Theory**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. D.B. West, Introduction to Graph Theory, Prentice Hall of India, 2001. 2. J. A. Bondy and U. S. R. Murty, Graph Theory with Applications, Springer-Verlag, 2008. 3. R. Diestel, Introduction to Graph Theory, Springer-Verlag, 2010.
Description	Basic Concepts: various kinds of graphs, simple graphs, complete graph, walk, tour, path and cycle, Eulerian graph, bipartite graph (characterization), Havel-Hakimi theorem and Erdos-Gallai theorem (statement only), hypercube graph, Petersen graph, trees, forests and spanning subgraphs, distances, radius, diameter, center of a graph, the number of distinct spanning trees in a complete graph. Trees: Kruskal and Prim algorithms with proofs of correctness, Dijkstra's a algorithm, Breadth first and Depth first search trees, rooted and binary trees, Huffman's algorithm Matchings: augmenting path, Hall's matching theorem, vertex and edge cover, independence number and their connections, Tutte's theorem for the existence of a 1-factor in a graph, Connectivity k-vertex and edge connectivity, blocks, characterizations of 2- connected graphs, Menger's theorem and applications, Network flows, Ford- Fulkerson algorithm, Supply-demand theorem and the Gale-Ryser theorem on degree sequences of bipartite graphs Graph Colourings chromatic number, Greedy algorithm, bounds on chromatic numbers, interval graphs and chordal graphs (with simplicial elimination ordering), Brook's theorem and graphs with no triangles but large chromatic number, chromatic polynomials. Hamilton property Necessary conditions, Theorems of Dirac and Ore, Chvatal's theorem and toughness of a graph, Non-Hamiltonian graphs with large vertex degrees. Planar graphs Embedding a graph on plane, Euler's formula, non-planarity of K5 and K3,3, classification of regular polytopes, Kuratowski's theorem (no proof), 5-colour theorem. Ramsey theory Bounds on R(p, q), Bounds on Rk(3): colouring with k colours and with no monochromatic K3, application to Schur's theorem, Erdos and Szekeres theorem on points in general position avoiding a convex m-gon.

Course Code	**MA5110**
Course Name	**Non-commutative Algebra**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 419 (Basic Algebra)
Text Reference	1. N. Jacobson, Basic Algebra, Vol. I and II, Dover Publications, 2009. 2. S. Lang, Algebra, 3rd Edition, Springer Verlag, 2002 3. T. Y. Lam, A First Course in Noncommutative Rings, 2nd edition, Springer, 2001. 4. A. Knapp, Advanced Algebra, Birkhauser, 2007.
Description	Wedderburn-Artin Theory: semisimple rings and modules, Weddereburn and Artin's structure theorem of semisimple rings. Jacobson radical theory: Jacobson radical, Jacobson semisimple rings (or semiprimitive rings), nilpotent ideal, Hopkins and Levitzki theorem, Jacobson radical under base change, semisimplicity of group rings. Prime and primitive rings: prime and semiprime ideal (and ring), primitive ring and ideal, Jacobson-Chevalley's density theorem, Structure theorem for left primitive rings, Jacobson-Herstein's commutativity theorem. Introduction to division rings: Wedderburn's (little) theorem, algebraic division algebras over reals (Frobenius theorem), construction of division algebras, polynomials over division rings. Ordered structures in rings: orderings and preorderings in rings, formally real ring, ordered division rings. Local rings, semilocal rings and idempotents: Krull-Schmidt-Azumaya theorem on uniqueness of indecomposable summands of a module, stable range of a ring and cancellation of modules. Brauer group and Clifford algebras.

Course Code	**MA 5111**
Course Name	**Theory of Finite Semigroups**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	
Text Reference	1. P. Grillet. Semigroups. an introduction to the structure theory, Marcel Dekker Inc., 1995 2. J. Rhodes and B. Steinberg, The q-theory of finite semigroups. Springer, 2009 3. B. Steinberg.Representation theory of finite monoids. Springer, 2016 4. M. Aguiar and S. Mahajan. Topics in hyperplane arrangements. AMS, 2017
Description	Monoids and their linearized algebras Bands, left regular bands Hyperplane arrangements Birkhoff monoid, Tits monoid and Janus monoid Idempotents and simple modules Quivers of band algebras Noncommutative zeta and Mobius functions Karoubi envelopes of semigroups.

Course Code	**MA5112**
Course Name	**Introduction to Mathematical Methods**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	MA 515 (Partial Differential Equations)
Text Reference	1. C. M. Bender and S. A. Orszag, Advanced Mathematical Methods for Scientists and Engineers, McGraw-Hill Book Co., 1978. 2. R. Courant & D. Hilbert, Methods of Mathematical Physics, Vol. I & II, Wiley Eastern, 1975. 3. J. Kevorkian and J.D. Cole, Perturbation Methods in Applied Mathematics, Springer Verlag, 1985. 4. S. G. Mikhlin, Variation Methods in Mathe-matical Physics, Pergaman Press, Oxford 1964. 5. J. A. Murdock, Perturbations Theory and Methods, John Wiley and Sons, 1991. 6. P. D. Miller, Applied asymptotic analysis, American Mathematical Society, 2006. 7. M. L. Krasnov et.al., Problems and exercises in the calculus of variations, Mir Publishers, 1975. 8. M. Krasnov et. al., Problems and exercises in integral equations, Mir Publishers, 1971.
Description	Asymptotic expansions: Watson's lemma, method of stationary phase and saddle point method. Applications to differential equations. Behaviour of solutions near an irregular singular point, Stoke's phenomenon. Method of strained coordinates and matched asymptotic expansions, Lindstedt expansions. Calculus of variations: Classical methods.Integral equations: Volterra integral equations of first and second kind. Iterative methods and Neumann series.

Course Code	**MA 5113**
Course Name	**Category Theory 1**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Aguiar and Mahajan, Monoidal functors, species and Hopf algebras, American Mathematical Society, 2010. 2. Awodey, Category theory, Oxford University Press, 2010. 3. Borceau, Handbook of categorical algebra, Volumes 1, 2, 3, Cambridge University Press, 1994. 4. Leinster, Higher categories, Higher operads, Cambridge University Press, 2004. 5. Leinster, Basic category theory, Cambridge University Press, 2014. 6. Mac Lane, Categories for the working mathematician, Springer, 1998. 7. Riehl, Category theory in context, Aurora, Dover Publications, 2016.
Description	Categories, functors, natural transformations. Limits and colimits. Adjoint functors and universal constructions. Functor categories, comma categories, quotient categories. Cauchy completeness, Karoubi envelopes. Cartesian categories, group objects. The above concepts can be motivated and discussed by connecting them to other areas of mathematics depending on the interests of the instructor and students.

Course Code	**MA 5115**
Course Name	**Hopf Algebras**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. M. Sweedler, Hopf algebras, W.A.Benjamin, Inc, NewYork, 1969. 2. E. Abe, Hopf algebras, CUP, 1980. 3. C. Kassel, Quantum groups, Springer, 1995. 4. M.Aguiar, S. Mahajan. Bimonoids for hyperplane arrangements, CUP, 2020 5. D.Radford. Hopf algebras, World Scientific, 2012. 6. R. Underwood. Fundamentals of Hopf algebras, Springer, 2015. 7. M.Aguiar, S. Mahajan. Monoidal functors, species and Hopf algebras, AMS, 2010
Description	Algebras, coalgebras and bialgebras, Convolution algebra, antipode and Hopf algebras, Universal constructions, Tensor algebra, Symmetric and exterior algebras, universal enveloping algebras, Group-likes, primitives and coradical filtration, Structure results. Borel-Hopf and Carter-MilnorMoore theorems, Hopf algebras for hyperplane arrangements, Connection to affine group schemes and quantum groups.

Course Code	**MA 5116**
Course Name	**Species and Operads**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. F.Bergeron, G.Labelle, P.Leroux. Combinatorial species and tree-like structures. CUP, 1998. 2. M.Markl, S.Shnider, J. Stasheff. Operads in Algebra, Topology and Physics, AMS, 2002. 3. M.Aguiar, S. Mahajan. Bimonoids for hyperplane arrangements, CUP, 2020. 4. J-L.Loday, B.Vallette. Algebraic operads, Springer, 2012 5. T.Leinster. Higher operads, Higher categories. CUP, 2004. 6. M.Aguiar and S.Mahajan. Monoidal Functors, species and Hopf algebras, AMS, 2010.
Description	Species. Exponential Species, species of linear orders and other examples. Cauchy, Hadamard and substitution products on species and universal constructions. Power series/Generating function of species Operads. Commutative, associative and Lie operads and other examples, Algebras over operads, Koszul theory of Operads, Species and operads for hyperplane arrangements

Course Code	**MA 5118**
Course Name	**Category Theory 2**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	6
Half Semester	N
Prerequisite	Nil
Text Reference	1. Aguiar and Mahajan, Monoidal functors, species and Hopf algebras, American Mathematical Society, 2010. 2. Awodey, Category theory, Oxford University Press, 2010. 3. Borceau, Handbook of categorical algebra, Volumes 1, 2, 3, Cambridge University Press, 1994. 4. Leinster, Higher categories, Higher operads, Cambridge University Press, 2004. 5. Leinster, Basic category theory, Cambridge University Press, 2014. 6. Mac Lane, Categories for the working mathematician, Springer, 1998. 7. Riehl, Category theory in context, Aurora, Dover Publications, 2016.
Description	Monoidal categories, monoids, comonoids. Symmetric monoidal categories, braidings, Hopf monoids. Higher monoidal categories. 2-categories, bicategories, higher categories. Monads, distributive laws, higher monads. The above concepts can be motivated and discussed by connecting them to other areas of mathematics depending on the interests of the instructor and students.

Course Code	**MA 811**
Course Name	**Algebra 1**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Dummit, Foote: Abstract algebra, second edition, Wiley student editions, 2005. 2. Jacobson: Basic algebra, I, Dover publications, 2009. 3. Jacobson: Basic algebra, II, Dover publications, 2009. 4. Lang: Algebra, third edition, Springer-Verlag, GTM 211, 2002
Description	Review of field and Galois theory: solvable and radical extensions, Kummer theory, Galois cohomology and Hilbert's Theorem 90, Normal Basis theorem. Infinite Galois extensions: Krull topology, projective limits, profinite groups, Fundamental Theorem of Galois theory for infinite extensions. Review of integral ring extensions: integral Galois extensions, prime ideals in integral ring extensions, decomposition and inertia groups, ramification index and residue class degree, Frobenius map, Dedekind domains, unique factorisation of ideals. Categories and functors: definitions and examples. Functors and natural transformations, equivalence of categories. Products and coproducts, the hom functor, representable functors, universals and adjoints. Direct and inverse limits. Free objects. Homological algebra: Additive and abelian categories, Complexes and homology, long exact sequences, homotopy, resolutions, derived functors, Ext, Tor, cohomology of groups, extensions of groups.

Course Code	**MA 812**
Course Name	**Algebra 2**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. (DF) Dummit, Foote: Abstract algebra, second edition, Wiley student editions, 2005. 2. (J1)Jacobson: Basic algebra, I, Dover publications, 2009. 3. (J2) Jacobson: Basic algebra, II, Dover publications, 2009. 4. (L) Lang: Algebra, third edition, Springer-Verlag, GTM 211, 2002
Description	A review of modules over a PID. [DF-12, J1-3, L-III.7] Noetherian modules and rings: Primary decomposition, Nakayama's lemma, filtered and graded modules, the Hilbert polynomial, Artinian modules and rings. [DF-15, J2-3, L-X] Semisimple and simple rings: Semisimple modules, Jacobson density theorem, semisimple and simple rings, Wedderburn-Artin structure theorems, Jacobson radical, the effect of a base change on semisimplicity. [DF-18, J2-3, J2-4, L-XVII] Representations of finite groups: Basic definitions, characters, class functions, orthogonality relations, induced representations and induced characters, Frobenius reciprocity, decomposition of the regular representation, supersolvable groups, representations of symmetric groups. [DF-18, DF-19, J2-5, L-XVIII] Categories and functors: Definitions and examples, functors and natural transformations, the equivalence of categories, products and coproducts, the Hom functor, representable functors, universals and adjoints, direct and inverse limits, free objects. [DF-Appendix II, J2-1, L-I.11] Homological algebra: Additive and abelian categories, complexes and homology, long exact sequences, homotopy, resolutions, derived functors, Ext, Tor, cohomology of groups, extensions of groups. [DF-17, J2-6, L-XX]

Course Code	**MA 813**
Course Name	**Measure Theory**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. K. Chandrasekharan, A Course on Topological Groups, Hindustan Book Agency, 1996. 2. L. Nachbin, The Haar Integral, van Nostrand, 1965. 3. I. K. Rana, An Introduction to Measure and Integration, 2nd Ed., American Mathematical Society, 2002. 4. H. L. Royden, Real Analysis, 3rd Ed., Prentice Hall of India, 1988. 5. W. Rudin, Real and Complex Analysis, McGraw-Hill, 1987.
Description	Review of measure theory: monotone convergence theorem, dominated convergence theorem, complete measures. Borel measures: Riesz representation theorem, Lebesgue measure on $\mathbb{R}^k$, L^p-spaces, Complex measures: total variation, absolute continuity, Radon-Nikodym theorem, polar and Hahn decompositions, bounded linear functionals on L^p, generalised Riesz representation theorem. Differentiation: Maximal function, Lebesgue points, absolute continuity of functions, fundamental theorem of calculus, Jacobian of a differentiable transformation, change of variable formula. Product measures: Fubini's theorem, completion of product measures, convolutions, Fourier transform, Riemann-Lebesgue lemma, inversion theorem, Plancherel theorem, L^1 as a Banach algebra. Content on a locally compact Hausdorff space, existence and uniqueness of the Haar measure on a locally compact group.

Course Code	**MA 814**
Course Name	**Complex Analysis**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. L. V. Ahlfors, Complex Analysis, McGraw-Hill, 1996. 2. S. Lang, Complex Analysis, 4th Ed., Springer, 1999. 3. D. H. Luecking and L. A. Rubel, Complex Analysis: A Functional Analysis Approach, Springer-Verlag, 1984. 4. R. Narasimhan and Y. Nievergelt, Complex Analysis in One Variable, Birkhäuser, 2001. 5. R. Remmert, Theory of Complex Functions, Springer (India), 2005. 6. W. Rudin, Real and Complex Analysis, McGraw Hill, 1987.
Description	Review of basic complex analysis: Cauchy's theorem, Liouville's theorem, power series representation, open mapping theorem, calculus of residues. Harmonic functions, Poisson integral, Harnack's theorem, Schwarz reflection principle. Maximum modulus principle, Schwarz lemma, Phragmen-Lindelof method. Runge's theorem, Mittag-Leffler theorem, Weierstrass theorem, conformal equivalence, Riemann mapping theorem, characterisation of simply connected regions, Jensen's formula. Analytic continuation, monodromy theorem, Little Picard theorem.

Course Code	**MA 815**
Course Name	**Differential Topology**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. R. Bott and L. W. Tu , Differential Forms in Algebraic Topology, Springer-Verlag, New York, 1982. 2. L. Conlon, Differentiable manifolds, 2nd Ed., Birkhäuser, Boston, 2001. 3. G. E Bredon, Topology and Geometry, Springer-Verlag, New York, 1997.
Description	Review of differentiable manifolds, tangent and cotangent bundles, tensors. DeRham complex, Poincare's Lemma, Mayer-Vietoris sequences, cohomology with compact supports, degree of a map, Poincare duality. Vector bundles, cohomology with vertical compact supports, Thom isomorphism, twisted DeRham complex, Poincare duality for non-orientable manifolds.

Course Code	**MA 816**
Course Name	**Algebraic Topology**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. M.J. Greenberg and J. R. Harper, Algebraic Topology, Benjamin, 1981. 2. W. Fulton, Algebraic topology: A First Course, Springer-Verlag, 1995. 3. A. Hatcher, Algebraic Topology, Cambridge Univ. Press, Cambridge, 2002. 4. W. Massey, A Basic Course in Algebraic Topology, Springer-Verlag, Berlin, 1991. 5. J.R. Munkres, Elements of Algebraic Topology, Addison Wesley, 1984. 6. J.J. Rotman, An Introduction to Algebraic Topology, Springer (India), 2004. 7. H. Seifert and W. Threlfall, A Textbook of Topology, Academic Press, 1980.
Description	Paths and homotopy, homotopy equivalence, contractibility, deformation retracts. Basic constructions: cones, mapping cones, mapping cylinders, suspension. Cell complexes, subcomplexes, CW pairs. Fundamental groups. Examples (including the fundamental group of the circle) and applications (including Fundamental Theorem of Algebra, Brouwer Fixed Point Theorem and Borsuk-Ulam Theorem, both in dimension two). Van Kampen's Theorem. Covering spaces, lifting properties, deck transformations, universal coverings. Simplicial complexes, barycentric subdivision, stars and links, simplicial approximation. Simplicial Homology. Singular Homology. Mayer-Vietoris sequences. Long exact sequence of pairs and triples. Homotopy invariance and excision. Degree. Cellular Homology. Applications of homology: Jordan-Brouwer separation theorem, Invariance of dimension, Hopf's Theorem for commutative division algebras with identity, Borsuk-Ulam Theorem, Lefschetz Fixed Point Theorem. Optional Topics: Outline of the theory of: cohomology groups, cup products, Kunneth formulas, Poincare duality.

Course Code	**MA 817**
Course Name	**Partial Differential Equations 1**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. S. Kesavan, Topics in Functional Analysis and Applications, New Age International Pvt. Ltd., 1989. 2. L C. Evans, Partial Differential Equation, American Mathematical Society, 1998. 3. M. Renardy and R. C. Rogers, An Introduction to Partial Differential Equations, Springer-Verlag, 2004. 4. G. B. Folland, Introduction to Partial Differential Equations, 2nd Ed., Prentice-Hall of India, 1995. 5. R. C. McOwen, Partial Differential Equations: Methods and Applications, 2nd Ed., Pearson Education, Inc., 2003.
Description	Distribution Theory and Sobolev Spaces: Distributional derivatives, Definitions and elementary properties of Sobolev Spaces, Approximations by smooth functions, Traces, Imbedding Theorems (without proof), Rellich-Kondrachov Compactness Theorem. Second Order Linear Elliptic Equations: Weak Solutions, Lax-Milgram Theorem, Existence and Regularity Results, Maximum Principles, Eigenvalue Problems. Second Order Linear Parabolic Equations: Existence of weak solutions and Regularity Results, Maximum Principles. Second Order Linear Hyperbolic Equations: Existence of weak solutions and Regularity Results, Maximum Principles, Propagation of Disturbance

Course Code	**MA 818**
Course Name	**Partial Differential Equations 2**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. L C. Evans, Partial Differential Equations, American Mathematical Society, 1998. 2. M. Renardy and R. C. Rogers, An Introduction to Partial Differential Equations, Springer, 2004. 3. M. Defermos, Hyperbolic Conservation Laws in Continuum Physics, Springer, 2000. 4. B. Dacorogna, Direct Methods in Calculus of Variation, Springer 1989. 5. P. Prasad and R. Ravindran, Partial Differential Equations, Wiley Eastern, 1985. 6. J. Smoller, Shock Waves and Reaction-Diffusion Equations, Springer, 1993.
Description	Nonlinear First-Order Scalar Equations: Method of Characteristics, Weak Solutions and Uniqueness for Hamilton-Jacobi Equations, Scalar Conservation Laws: shocks and entropy condition, weak solutions and uniqueness, and long time behavior. Calculus of Variations: Euler-Lagrange Equation, Second Variations, Existence of Minimizers: Coercivity, Lower-Semicontinuity, Convexity, and Constrained Minimization Problems. Hamilton-Jacobi Equations: Viscosity Solutions, Uniqueness, Applications to Control Theory and Dynamic Programming. System of Conservation Laws: Theory of Shock Waves, Travelling Waves, Entropy Criteria, Riemann Problem, Glimm Existence Result for System of Two Conservation Laws.

Course Code	**MA 820**
Course Name	**Stochastic Processes**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Norris J. R. Markov chains, Cambridge University press, Cambridge, 1997. 2. Hoel, Port and Stone, Introduction to Stochastic Processes, Houghton Mifflin Company, USA, 1972. 3. David A. Levin, Yuval Peres and Elizabeth L. Wilmer, Markov chains and mixing times, AMS Providence, 2008. 4. William Feller, An introduction to probability and its applications, Vol. I, 3 rd edition, John Wiley and Sons, Singapore, 1968. 5. K B Athreya and S N Lahiri, Probability Theory, TRIM 41, Hindustan Book Agency, New Delhi, 2006.
Description	Discrete time Markov Chains: Definition and basic properties, class structure, hitting time and absorption probabilities, strong Markov property, recurrence and transience, invariant distributions, convergence to equilibrium, time reversal, ergodic theorem. Markov chain mixing: Coupling and total variation distance, Mixing time, upper bound and lower bound on mixing time. Continuous time Markov chains- definition and examples, embedded Markov chain, Kolmogorov forward and backward equations, classification of states, limit theorems. Random walk – in dimension one, two and three, The Reflection Principle, hitting probabilities of a finite sets, Last visits and Long leads, Maxima and first passages, Duality, position of maxima. Poisson Process - definition and properties, inter arrival and waiting time distributions, conditional distribution of arrival times.

Course Code	**MA 823**
Course Name	**Probability**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. K L Chung, A course in probability theory, 3rd edition, Academic Press, San Dieago, 2001. 2. P. Billingsley, Probability and measure, 3rd edition, John Wiely and Sons, New York, 1995. 3. Robert B. Ash, Probability and measure theory, 2nd edition, Academic Press, San Diego, 2008. 4. K B Athreya and S N Lahiri, Probability Theory, TRIM 41, Hindustan Book Agency, New Delhi, 200
Description	Review of probability space. Random variables in $\mathbb{R}$ and $\mathbb{R}^n$, distribution of random variables, Expectation of a R-valued random variable, Change of variable formula, Fatou's lemma, monotone convergence theorem, dominated convergence theorem, Markov inequality, Jensen's inequality, notion of independence of sigma-fields and random variables, product of distributions, Fubini's theorem. Convergence almost surely, in probability, in law, convergence in moments, Borel-Cantelli lemma, Uniform integrability of sequence of random variables. Characteristic functions, convolution of distributions, Uniqueness theorem, inversion theorem. Weak law of large numbers, strong law of large numbers, Lindberg-Feller central limit theorem, Law of iterated logarithms. Radon Nikodym theorem (reading exercise), Condition expectation definition, existence and its properties, regular conditional law

Course Code	**MA 824**
Course Name	**Functional Analysis**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. M. Ahues, A. Largillier and B. V. Limaye, Spectral Computations for Bounded Operators, Chapman & Hall/CRC, 2001. 2. J. B. Conway, Functional Analysis, 2nd Ed., Springer-Verlag, 1990. 3. S. Lang, Complex Analysis, 4th Ed., Springer, 1999. 4. B. V. Limaye, Functional Analysis, 2nd Ed., New Age International Publishers, 1996. 5. F. Riesz and B. SzNagy, Functional Analysis, Dover Publications, 1990. 6. W. Rudin, Functional Analysis, Tata McGraw Hill, 1974. 7. K. Yosida, Functional Analysis, 5th Ed., Narosa, 1979.
Description	Review of normed linear spaces, Hahn-Banach theorems, uniform boundedness principle, open mapping theorem, closed graph theorem, Riesz representation theorem on Hilbert spaces. Weak and weak* convergence, reflexivity in the setting of normed linear spaces. Compact operators, Sturm-Liouville problems. Spectral projections, spectral decomposition theorem, spectral theorem for a bounded normal operator, unbounded operators, spectral theorem for an unbounded normal operator.

Course Code	**MA 833**
Course Name	**Weak Convergance and Martingale Theory**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. P. Billingsley, Convergence of Probability Measures, Wiley, 1999. 2. R.J. Elliot, Stochastic Calculus and Applications, Springer-Verlag, 1982. 3. K.R. Parthasarathy, Probability Measures on Metric Spaces, Academic Press, 1967. 4. A.W. Van-der-Vaart and J.A. Wellner, Weak Convergence and Empirical Processes: With Applications to Statistics, Springer-Verlag, 1996. 5. D. Williams, Probability with Martingales, Cambridge Mathematical Textbooks, 1991.
Description	Review of conditional expectations. Martingales in discrete and continuous time. Square integrable Martingales. Weak convergence in metric spaces with special reference to C([0,1]) space. Dependent variables. Diffusion processes and mixing. Martingale Central Limit Theorem.

Course Code	**MA 839**
Course Name	**Advanced Commutative Algebra**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. W.Bruns and J. Herzog, Cohen-Macaulay rings, Cambridge University Press, 1992. J. Herzog and T. Hibi, Monomial Ideals, Springer 2011.
Description	Face rings of simplical complexes, rings of invariants of finite groups, local cohomology of modules and its applications to Cohen-Macaulay Gorenstein rings and face rings of simplicial complexes

Course Code	**MA 841**
Course Name	**Topics in Algebra 1**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. S. S. Abhyankar, Lectures on Algebra, Vol. I, World Scientific, Hackensack, NJ, 2006. 2. W. Bruns and J. Herzog, Cohen-Macaulay Rings, Revised second edition, Cambridge University Press, 1998 3. H. Matsumura, Commutative Ring Theory, Cambridge University Press, 1989.
Description	A selection of topics from the following: Regular sequences, grade and depth. Projective dimension, Auslander-Buchsbaum formula. Koszul complex. Rank of modules. Buchsbaum-Eisenbud acyclicity criterion. Graded rings and modules. Basic properties of graded modules: associated primes, dimension etc. Hensel's Lemma, Newton' Theorem and Weierstrass Preparation Theorem. Chevalley's Theorem on invariants of a finite pseudo-reflection group acting on the polynomial ring. The Jacobian criterion for regularity. Divisor class group of a noetherian normal domain and its properties under ring extensions etc. Applications to unique factorization. Cohen-Macaulay rings. Homological characterization of regular local rings. Injective hulls, Matlis Duality. Local cohomology. Basic properties. Invariance under flat and finite base changes. Canonical module: Existence and basic properties. Local duality and applications. Canonical module of graded rings.

Course Code	**MA 842**
Course Name	**Topics in Algebra 2**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. S. S. Abhyankar, Lectures on Algebra, Vol. I, World Scientific, Hackensack, NJ, 2006. 2. W. Bruns and J. Herzog, Cohen-Macaulay Rings, Revised second edition, Cambridge University Press, 1998 3. H. Matsumura, Commutative Ring Theory, Cambridge University Press, 1989.
Description	A selection of topics from the following: Cohen-Macaulay rings and modules, Canonical Module, Gorenstein rings. Hilbert functions and multiplicities, Macaulay's Theorem Stanley-Reisner rings, shellability. Semigroup rings and rings of invariants Determinantal rings, Straightening law. Big Cohen-Macaulay modules, Hochster's finiteness theorem.

Course Code	MA 843
Course Name	**Topics in Analysis 1**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. R.C. Gunning, Introduction to holomorphic functions of several variables. Vol. I. Function theory, Wadsworth and Brooks/Cole, 1990. 2. A.W. Knapp, Advanced real analysis, Birkhauser, 2005. 3. S. Lang and W. Cherry, Topics in Nevanlinna theory, Springer-Verlag, 1990. 4. R. Narasimhan, Several complex variables, University of Chicago Press, 1995. 5. E.M. Stein, Harmonic Analysis: Real Variable Methods,Orthogonality, and Oscillatory Integrals, Princeton University Press, 1993. 6. S. Thangavelu, An Introduction to the Uncertainty Principle: Hardy's Theorem on Lie Groups, Birkhauser, 2004.
Description	A selection of topics from the following: Singular Integrals (Calderon-Zygmund theory), the Kakeya problem, the Uncertainty Principle, the almost everywhere convergence of Fourier series, multilinear operators between Lp spaces. Pseudodifferential operators, Index theorems. Advanced complex analysis in one variable: Nevanlina theory, the existence of quasi-conformal maps, iterated polynomial maps, complex dynamics, compact Riemann surfaces, the Corona theorem. Holomorphic functions in several complex variables: elementary properties of functions of several complex variables, analytic continuation, subharmonic functions, Hartog's theorem, automorphisms of bounded domains.

Course Code	**MA 844**
Course Name	**Topics in Analysis 2**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. M. Ahues, A. Largillier, B.V. Limaye, Spectral Computation for bounded operators, Chapman and Hall/CRC, 2001. 2. K.E. Atkinson, The Numerical Solution of Integral Equations of the Second Kind, Cambridge University Press, 1997. 3. G. Bachman, L. Narici and E. Beckenstein, Fourier and Wavelet Analysis, Springer-Verlag, 2000. 4. S. K. Berberian, Lectures in Functional Analysis and Operator Theory, Narosa Publishing House, 1979. 5. F. Chatelin, Spectral Approximation of Linear Operators, Academic Press, 1983. 6. J.B. Conway, A Course in Functional Analysis, Springer-Verlag, 1985. 7. P.L. Duren, Theory of Hp spaces, Dover Publications, 2000. 8. W. Hackbusch, Integral Equations: Theory and Numerical Treatment, Birkhauser, 1995. 9. T. Kato, Perturbation Theory for Linear Operators, Springer-Verlag, 1995. 10. R. Kress, Linear Integral Equations, Second Edition, Springer-Verlag, 1999. 11. P. Koosis, Introduction to Hp spaces, 2nd Edition, Cambridge University Press, 1999. 12. C.S. Kubrusly, An Introduction to Models and Decompositions in Operator Theory, Birkhauser, 1997.

Course Code	MA 844 (... continued from previous page)
Course Name	**Topics in Analysis 2**
Text Reference	13. G.J. Murphy, C*-Algebras and Operator Theory, Academic Press Inc., 1990. 14. W. Rudin, Real and Complex Analysis, McGraw-Hill, 1987. 15. W. Rudin, Functional Analysis, McGraw Hill, 1991. 16. A. Vretblad, Fourier Analysis and its Applications, Springer-Verlag, 2005.
Description	A selection of topics from the following: Fourier Series and Fourier Transforms: Orthonormal Sequences in Inner Product Spaces, Fourier Series, Riemann-Lebesgue Lemma, Convergence/Divergence of Fourier Series, Fejer Theory, Fourier Transform, Inversion Theorem, Approximate Identities, Plancherel Theorem Hp spaces: Harmonic and Subharmonic Functions, Hp spaces, Nevanlinna Class of Functions, Boundary Values, Non-tangential Limits, F. and M. Riesz Theorem, Inner Functions, Outer Functions, Factorization Theorems, Beurling's Theorem Banach Algebras: Examples of Banach Algebras, Spectrum, Gelfand Representation, C*-Algebras, Positive Linear Functionals, Gelfand-Naimark Representation Elements of Operator Theory: Hilbert Space Operators, Parts of Spectrum, Orthogonal Projections, Invariant Subspaces, Reducing Subspaces, Shifts, Decompositions of Operators Perturbation Theory for Linear Operators: Analyticity of the resolvent operator, spectral projection and the weighted mean of the eigenvalues, The method of majorizing series, Spectral Decomposition Theorem. Spectral Approximation: Norm and nu- convergence, Iterative refinement methods such as the Rayleigh-Schrodinger series and methods based on the fixed point techniques, error estimates. Approximate solutions of Operator Equations: Galerkin, Iterated Galerkin and Nystrom methods, Condition Numbers, Two Grid Methods.

Course Code	**MA 845**
Course Name	**Topics in Combinatorics 1**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. C. Berge, Principles of Combinatorics, Academic Press, 1972. 2. I.G. Macdonald, Symmetric functions and Hall polynomials. Second edition, Oxford University Press, 1995. 3. R.P. Stanley, Enumerative Combinatorics, Vol. I, Wadsworth and Brooks/Cole, 1986.
Description	A selection of topics from the following: Basic Combinatorial Objects : Sets, multisets, partitions of sets, partitions of numbers, finite vector spaces, permutations, graphs etc. Basic Counting Coefficients: The twelve fold way, binomial, q-binomial and the Stirling coefficients, permutation statistics, etc. Sieve Methods : Principle of inclusion-exclusion, permutations with restricted positions, Sign-reversing involutions, determinants etc. Combinatorial reciprocity. Theory of Symmetric functions.

Course Code	**MA 846**
Course Name	**Topics in Combinatorics 2**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. M. Aigner, Combinatorial Theory, Springer-Verlag, New York, 1979. 2. I. G. Macdonald, Symmetric functions and Hall polynomials. Second edition, Oxford University Press, New York, 1995. 3. B.E. Sagan, The Symmetric Group: Representations, Combinatorial Algorithms and Symmetric Functions, Wadsworth and Brooks/Cole, 1991. 4. R. P. Stanley, Enumerative Combinatorics, Vol. I, Wadsworth and Brooks/Cole, Monterey, CA, 1986. 5. R. P. Stanley, Enumerative Combinatorics, Vol. II, Cambridge University Press, Cambridge, 1999.
Description	A selection of topics from the following: Partially ordered sets, Mobius inversion. Rational generating functions: P-partitions and linear Diophantine equations. Polya theory and representation theory of the symmetric group. Combinatorial algorithms, and symmetric functions. Generating functions: Single and multivariable Lagrange inversion. Young tableaux and plane partitions

Course Code	**MA 847**
Course Name	**Topics in Geometry 1**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. J. M. Lee, Riemannian Manifolds: An Introduction to Curvature, Springer-Verlag, New York, 1997. 2. W. M. Boothby, An Introduction to Differentiable Manifolds and Riemannian Geometry, 2nd edition, Academic Press, 2002. 3. M. Do Carmo, Differential Geometry of Curves and Surfaces, Prentice Hall, 1976. 4. S. Kumaresan, A Course in Differential Geometry and Lie Groups, Hindustan Book Agency, 2002. 5. J. Milnor, Morse Theory, Princeton University Press, 1963.
Description	A selection of topics from the following: Review of the theory of curves and surfaces in the Euclidean 3-space. Differentiable manifolds, and Riemannian structures. Connections, and curvature tensor. The theorems of Bonnet-Meyers and Hadamard. Manifolds of constant curvature.

Course Code	**MA 848**
Course Name	**Topics in Geometry 2**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. S. S. Abhyankar, Algebraic Geometry for Scientists and Engineers, American Mathematical Society, Providence, RI, 1990. 2. D. Eisenbud and J. Harris, The Geometry of Schemes, Springer-Verlag, 2000. 3. R. Hartshorne, Algebraic Geometry, Springer-Verlag, 1977. 4. I. R. Shafarevich, Basic Algebraic Geometry, Vol. 1 and 2, Second edition, Springer-Verlag, 1994.
Description	A selection of topics from the following: Affine and projective varieties, rational maps, nonsingularity. Algebraic Curves, Riemann Roch Theorem. Sheaves and Schemes. Basic properties. Divisors and Differentials. Cohomology of sheaves, Serre Duality Theorem.

Course Code	**MA 849**
Course Name	**Topics in Topology 1**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. B. Gray, Homotopy Theory, Academic Press, 1975. 2. A. Hatcher, Algebraic Topology, Cambridge University Press 2002. 3. G. W. Whitehead, Elements of Homotopy Theory, Springer Verlag, 1978. 4. P. Hilton, Homotopy Theory and Duality, Gordon and Beach Sc. Publishers, 1965. 5. N. Steenrod, The Topology of Fibre Bundles, 7th reprint, Princeton University Press, 1999. 6. R. M. Switzer, Algebraic topology: Homotopy and Homology, Springer Verlag, 2002.
Description	A selection of topics from the following: CW complexes, Homotopy groups, Cellular Approximation. Whitehead‘s theorem, Hurewicz theorem. Excision, Fibre bundles, Long exact sequences. Postnikov Towers, Obstruction Theory. Stable homotopy groups. Spectral Sequences, Serre Class of abelian groups.

Course Code	**MA 850**
Course Name	**Topics in Topology 2**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. G. E. Bredon, Introduction to Compact Transformation Groups, Academic Press 1972. 2. T. Brocker and T. tom Dieck, Representations of Compact Lie Groups, Springer-Verlag, New York, 1985. 3. W. Y. Hsiang, Cohomology Theory of Topological Transformation Groups, Springer-Verlag, 1975.
Description	Basics of Topological groups, Lie group. Group actions, homogeneous spaces examples. G-spaces, existence of slice and tubes Covering homotopy theorem, Classification of G-Spaces. Finite group actions, homology spheres G-coverings, Cech theory Locally smooth actions, orbit types, principal orbits Actions of tori. Cohomology structure of fixed point sets, $\mathbb{Z}_p$-actions, projective spaces and product of spheres.

Course Code	**MA 851**
Course Name	**Topics in Number Theory 1**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. S. Lang, Algebraic number theory., Second edition, Springer-Verlag, New York, 1994. 2. D. Bump, Automorphic forms and representations, Cambridge University Press, Cambridge, 1997. 3. H. Iwaniec and E. Kowalski, Analytic number theory, American Mathematical Society, Providence, RI, 2004. 4. H. Hida, Modular forms and Galois cohomology, Cambridge University Press, Cambridge, 2000.
Description	A selection of topics from the following: Algebraic number theory, abelian and non-abelian reciprocity laws, the Langlands programme, automorphic forms and representations. The arithmetic of algebraic groups. Arithmetic algebraic geometry: counting rational points of varieties over finite fields Galois representations and galois cohomology. Additive number theory: partitions, compositions, Goldbach problem.

Course Code	**MA 852**
Course Name	**Topics in Number Theory 2**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. S. Lang, Algebraic number theory., Second edition, Springer-Verlag, New York, 1994. 2. D. Bump, Automorphic forms and representations, Cambridge University Press, Cambridge, 1997. 3. H. Iwaniec and E. Kowalski, Analytic number theory, American Mathematical Society, Providence, RI, 2004. 4. H. Hida, Modular forms and Galois cohomology, Cambridge University Press, Cambridge, 2000.
Description	A selection of topics from the following: Harmonic analysis on Lie groups, L-functions, l-adic representations and motives. Diophantine equations and the applications of K-theory to number theory. Analytic number theory and transcendental methods. Applications of ergodic theory to number theory.

Course Code	**MA 853**
Course Name	**Topics in Differential Equations 1**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. D. Gilbarg and N.S. Trudinger, Elliptic Partial Differential Equations of Second Order, Springer-Verlag, 1983. 2. P. Grisvard, Elliptic Problems in Nonsmooth Domains, Pitman, 1984. 3. D. Serre, Systems of Conservation Laws, Vols. 1, 2, Cambridge University Press, 2000. 4. L. Evans, Weak Convergence Methods for Nonlinear PDEs, CBMS Regional Conference series in Math., American Mathematical Society, Providence RI, 1990 5. A. Bensoussan, J.L. Lions and G. Papanicolaou, Asymptotic Analysis for Periodic Structures, North Holland, 1978. 6. M. Struwe, Variational Methods: Applications to nonlinear PDEs and Hamiltonian systems, Springer-Verlag, 1990.
Description	A selection of topics from the following: 1. Schauder theory, regularity for second order elliptic equations. Nonlinear analysis and its applications to nonlinear PDEs: Fixed point methods, variational methods, monotone iteration, degree theory. 2. Evolution equations: Existence via semigroup theory 3. Nonlinear Hyperbolic systems: Theory of well posedness, compensated compactness, 4. Young measures; propagation of oscillations, weakly nonlinear geometric optics.

Course Code	**MA 854**
Course Name	**Topics in Differential Equations 2**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. D. K. Arrowsmith, C. M. Place: An Introduction to Dynamical Systems, Cambridge University Press, 1990. 2. C. Chicone, Ordinary Differential Equations. Springer-Verlag, 1999. 3. J. Guckenheimer and P. Holmes, Nonlinear Oscillations, Dynamical Systems, and Bifurcations of Vector Fields. Springer-Verlag, 2002. 4. P.Glendinning, Stability, instability and chaos: An Introduction to the Theory of Nonlinear Differential Equations, Cambridge University Press, 1994. 5. J. Palis and W. C. de Melo, Geometric Theory of Dynamical Systems, Springer-Verlag, 1982. 6. R. Grimshaw, Nonlinear Ordinary Differential Equations. CRC press, 1991. 7. N.A. Magnitskii and S.V. Sidorov, New Methods for Chaotic Dynamics, World Scientific, 2006. 8. L. Perko, Differential Equations and Dynamical Systems, Springer-Verlag, 2001.
Description	Continued on next page ...

Course Code	**MA 854 (... continued from previous page)**
Course Name	**Topics in Differential Equations 2**
Description	A selection of topics from the following: Diffeomorphisms and flows: Elementary dynamics of diffeomorphisms, flows and differential equations, conjugacy, equivalence of flows, Sternberg's theorem on smooth conjugacy (statement only), Hamiltonian flows and Poincare maps. Local properties of flows and diffeomorphisms: Hyperbolic fixed points, Hartman-Grobman theorems for maps and flows, Normal forms for vector fields, Centre manifolds. Structural stability and hyperbolicity: Structural stability for linear systems, Flows on 2-dimensional manifolds, Peixoto's characterisation of structural stability on unit disc, Anosov and Horseshoe diffeomorphisms, Homoclinic points, Melnikov function. Bifurcations and Perturbations: Saddle-node and Hopf bifurcations, Andronov-Hopf bifurcation, The logistic map, Arnold's circle map; Perturbation theory: Melnikov's method for the study of perturbation of completely integrable systems. Floquet theory and Hill's equation and some of its applications. Two dimensional systems: Poincare-Bendixon theorem, Index of planar vector fields and the Poincare Hopf index theorem for two dimensional manifolds. Van der Pol's equation, Duffing's equation, Lorenz's equation. First integrals and functional independence of first integrals, notion of complete integrability, Jacobi multipliers, Liouville's theorem on preservation of phase volume, Jacobi's last multiplier theorem and its applications.

Course Code	**MA 855**
Course Name	**Topics in Numerical Analysis 1**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Axelsson, O. Iterative Solution Methods, Cambridge University Press, 1994. 2. Briggs, W. L., Henson, V. E. and McCormick, S. F. A Multigrid tutorial, SIAM, 2000. 3. Godlewski, E. and Raviart, P. –A. Numerical Approximation of Hyperbolic Systems of Conservation Laws, Springer, 1995. 4. Kroner, D. Numerical Schemes for Conservation Laws. John Wiley, 1997. 5. LeVeque, R. J. Finite Volume Methods for Hyperbolic Problems, Cambridge University Press, 2002. 6. LeVeque, R. J. Numerical Methods for Conservation Laws. Birkhauser, 1992. 7. Quarteroni, A. and Valli, A. Numerical Approximation of Partial Differential Equations, Springer, 1997. 8. Ueberrhuber, C. W. Numerical Computation: Methods, Software and Analysis, Springer-Verlag, 1997.
Description	A selection of topics from the following: Review of finite difference methods for elliptic, parabolic and hyperbolic problems. Stability, consistency and convergence theory. Finite difference schemes for scalar conservation laws (Lax-Friedrichs, Upwind, Lax-Wendroff, etc.), Conservative schemes and their numerical flux functions, Consistency, Lax-Wendroff Theorem, CFL Condition, Nonlinear Stability and TVD property, Monotone Difference schemes, Numerical entropy condition, Convergence result. Finite difference Schemes for one-dimensional system of conservation laws, approximate Riemann solvers, Godunov's method, High resolution methods, Multidimensional approaches. Large Scale Scientific Computing: Classical Iterative Methods for solving Linear systems, Large Sparse Linear Systems, Storage Schemes, GMRES algorithm, Preconditioned Conjugate Gradient method and Multi-grid method, Newton's Method and some of its variations for solving nonlinear systems.

Course Code	MA 856
Course Name	**Topics in Numerical Analysis II**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Z. Chen, Finite Element Methods And Their Applications, Springer-Verlag, New York, 2005. 2. S. C. Brenner and R. L. Scott, The Mathematical Theory of Finite Element Methods, 2nd Edition, Springer-Verlag, New York, 2002. 3. M. Ainsworth and J. T. Oden, A Posteriori Error Estimation in Finite Element Analysis, John Wiley and Sons, 2000. 4. V. Thomee, Galerkin Finite Element Methods for Parabolic Problems, 2nd Edition, Springer-Verlag, Berlin, 2006.
Description	A selection of topics from the following: Mixed Finite Element Methods: Examples of mixed variational formulations-primal, dual formulations; abstract mixed formulations, discrete mixed formulations, existence-uniqueness of solutions, convergence analysis, implementation procedures. Adaptive FEM: A study of -Explicit A posteriori error estimators, Implicit A posteriori estimators, Recovery based error estimators, Goal Oriented adaptive mesh refinement for second order elliptic boundary value problems. Discontinuous Galerkin Methods for second order elliptic boundary value problems: Global element methods, Symmetric Interior Penalty Method, Discontinuous hp- Galerkin Method, Non-symmetric interior penalty method: Consistency, approximation properties, existence and uniqueness of solutions, error estimates, implementation procedures. FEM for parabolic problems: The standard Galerkin method, semi-discretization in space. discretization in space and time, the discontinuous Galerkin Method, a mixed method, implementation procedures. Elements of Multigrid Methods: Multigrid Components - Interpolation, restriction Coarse-grid correction, V, W, and FMG cycles, Implementation, Convergence analysis, Performance diagnostics.

Course Code	**MA 858**
Course Name	**Topics in Probability II**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. V.S. Borkar, Optimal control of diffusion processes, Longman Scientific and Technical, Harlow (copublished by John Wiley), 1989. 2. D. Nualart, The Malliavin calculus and related topics, Springer-Verlag, 1995.
Description	A selection of topics from the following: Stochastic optimal control: compactness of laws, dynamic programming principle. Malliavin calculus and applications to finance: Wiener-Ito chaos expansion, Shorohod integral, Integration by parts formula, Clark- Ocone formula and application to finance.

Course Code	**MA 859**
Course Name	**Topics in Statistics I**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. J. George Shanthikumar and Moshe Shaked (1994) Stochastic Orders and their Applications, Academic press. 2. C.D. Lai and M. Xie (2006) Stochastic Ageing and Dependence for Reliability, Springer Verlag.
Description	A selection of topics from the following: Univariate Stochastic Orders-hazard rate order, likelihood ratio order, mean residual rate order. Univariate variability orders- convex order, dispersive order, peakedness order. Univariate monotone convex and related orders. Multivariate stochastic orders. Multivariate variability and related orders. Statistical Inference for stochastic ordering. Applications in reliability theory, biology, economics and scheduling.

Course Code	**MA 860**
Course Name	**Topics in Statistics II**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. A. W. Van der Vaart, Asymptotic Statistics, Cambridge University Press, 2000. 2. U. Grenander, Abstract Inference, John Wiley, 1981. 3. P. McCullagh and J. A. Nelder, Generalized Linear Models, 2nd Edition, Chapman and Hall/CRC, 1994. 4. L. Fahrmeir and G. Tutz, Multivariate Statistical Modeling based on Generalized Linear Models, 2nd Edition, Springer-Verlag, 1994. 5. R. H. Myers, D. C. Montgomery and G. Geoffrey Vining, Generalized Linear Models with applications in Engineering and Sciences, Wiley-Interscience, 2001.
Description	A selection of topics from the following: Inference in Semi-parametric models: Models with infinite imensional parameters, Efficient estimation and the delta method, Score and information operators, Estimating equations, Maximum Likelihood estimation, Testing. Generalized linear models: Components of a GLM, estimation techniques, diagnostics, continuous response models, Binomial response models, Poisson response models, overdispersion, multivariate GLMs, quasi likelihoods, generalized estimating equations, generalized linear mixed models, programming in R and SAS.

Course Code	**MA 861**
Course Name	**Combinatorics 1**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Enumerative Combinatorics - Stanley, Vol.1 (2nd Edition) and 2, Cambridge University Press. 2. Extremal Combinatorics With Applications in Computer Science - Stasys Jukna, Springer, 2nd Edition. 3. Computing the Continuous Discretely : Integer-point Enumeration in Polyhedra - Beck and Robbins, Springer, 2nd edition. 4. Combinatorics of Finite Sets - Anderson, Dover Books on Mathematics. 5. Modern Graph theory - Bollobas, Graduate Texts in Mathematics, Springer.
Description	Extremal Set Theory: Sperner's Theorem, Theorems of Erdos-Ko-Rado, Kruskal-Katona, Dilworth's theorem, Kleitman's lemma for ideals and correlation inequalities. Graph theory: Matching theory, Hamiltonicity, Extremal graph theory, Graph colorings, Ramsey theory. Basic Enumerative Combinatorics: Generating Functions, Quasi-polynomials and applications to Ehrhart theory, Transfer Matrix Method, Stanley's Reciprocity Theorem, Exponential Structures, Trees, Lagrange inversion Theorem.

Course Code	**MA 862**
Course Name	**Combinatorics 2**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Enumerative Combinatorics - Stanley, Vol.1 (2nd Edition) and 2, Cambridge University Press. 2. Extremal Combinatorics With Applications in Computer Science - Stasys Jukna, Springer, 2nd Edition 3. The Symmetric Group : Representations, Combinatorial Algorithms, and symmetric functions - Bruce Sagan, Graduate texts in Mathematics, Springer, 2nd ed. 4. Representation Theory : A combinatorial Viewpoint - A. Prasad, Cambridge University Press 5. Combinatorics of Coxeter Groups : Bjorner and Brenti, Graduate Texts in Mathematics, Springer. 6. Symmetric Functions and Hall Polynomials - Macdonald, Oxford Mathematical monographs. 7. Linear Algebra methods in Coombinatorics - Babai/Frankl, lecture notes. 8. The Polynomial method in Combinatorics - survey paper by T. Tao 9. Incidence Theorems and Their Applications - Z. Dvir, Foundations and Trends in Theoretical Computer Science, Now Publishers Inc.
Description	Advanced Enumeration: Permutation Statistics and generalizations to Coxeter groups, Enumeration with Symmetric Functions, RSK Algorithm, Frobenius characteristic, The Jacobi-Trudi identity, Murnaghan-Nakayama Lemma, Littlewood-Richardson rule. Linear algebra methods in Combinatorics, The polynomial method, combinatorial Nullstellensatz and applications.

Course Code	**MA 863**
Course Name	**Theoretical Statistics 1**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Main text: Jun Shao, Mathematical Statistics, 2nd Ed., Springer, 2003. 2. Additional Texts: (a) Theoretical Statistics, D.R. Cox, D.V. Hinkley CRC Press (b) E. L. Lehmann, Theory of Statistical Inference, Wiley, 1983. (c) E. L. Lehmann, Testing Statistical Hypotheses, Wiley, 1986.
Description	1. Parametric models, exponential and location-scale family, Sufficiency, Minimal Sufficiency, Complete Statistic, Decision Rule, Loss Function and Risk, Point estimators, consistency, asymptotic bias, variance and MSE, asymptotic inference.[Chapter 2] 2. UMVUE, U-statistics, Asymptotic Unbiased estimator, V-statistics [Chapter 3] 3. Bayes Decision and Bayes estimators, Invariance, Minimaxity and admissibility, MLE and efficient estimation method. [Chapter 4] 4. The NP Lemma, monotone likelihood ratio, UMP test for one sided and two sided hypothesis, UMP Unbiased test, UMP invariant test, likelihood ratio test, chi-squared test, Sign, permutation and rank test, Kolmogorov- Smirnov and Cramer-von Mises test and asymptotic test [Chapter 6.]

Course Code	**MA 864**
Course Name	**Topics in Category Theory 1**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Aguiar and Mahajan, Monoidal functors, species and Hopf algebras, American Mathematical Society, 2010. 2. Awodey, Category theory, Oxford University Press, 2010. 3. Borceau, Handbook of categorical algebra, Volumes 1, 2 and 3, Cambridge University Press, 1994. 4. Goerss and Jardine, Simplicial homotopy theory, Birkhauser, 1997. 5. Hirschhorn, Model categories and their localizations, American Mathematical Society, 2003. 6. Leinster, Higher categories, Higher operads, Cambridge University Press, 2004. 7. Leinster, Basic category theory, Cambridge University Press, 2014. 8. Mac Lane, Categories for the working mathematician, Springer, 1998
Description	Categories, functors, natural transformations. Limits, colimits, complete and cocomplete categories. Adjoint functors, universal constructions, free and cofree objects. Functor categories, comma categories, quotient categories, derived categories. Representable functors, Yoneda lemma. Cauchy completeness, Karoubi envelopes. Cartesian categories, group objects. The above concepts can be motivated and discussed by connecting them to other areas of mathematics depending on the interests of the instructor and students.

Course Code	**MA 865**
Course Name	**Topics in Category Theory 2**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Aguiar and Mahajan, Monoidal functors, species and Hopf algebras, American Mathematical Society, 2010. 2. Awodey, Category theory, Oxford University Press, 2010. 3. Borceau, Handbook of categorical algebra, Volumes 1, 2 and 3, Cambridge University Press, 1994. 4. Goerss and Jardine, Simplicial homotopy theory, Birkhauser, 1997. 5. Hirschhorn, Model categories and their localizations, American Mathematical Society, 2003. 6. Leinster, Higher categories, Higher operads, Cambridge University Press, 2004. 7. Leinster, Basic category theory, Cambridge University Press, 2014. 8. Mac Lane, Categories for the working mathematician, Springer, 1998
Description	Monoidal categories, monoids, comonoids. Symmetric monoidal categories, braidings, Hopf monoids. Higher monoidal categories. Enriched categories, 2-categories, bicategories, higher categories. Monads, distributive laws, higher monads. The above concepts can be motivated and discussed by connecting them to other areas of mathematics depending on the interests of the instructor and students.

Course Code	**MA 867**
Course Name	**Statistical Modelling - 1**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Main Text: Linear Models by S.R. Searle (1971) Wiley & SonsOther 2. Additional Reference: Linear Model Methodology by A. I. Khuri (2009) CRC Press
Description	1. Full rank model (Chapters 3 and 4) 2. Models with rank deficiency (Chapter 5: Sections 5.1,5.2,5.3,5.4,5.5) 3. One-way classification model (Chapter 6: Sections 6.1,6.2,6.3,6.4) 4. Two-way Crossed Classification model (Chapter 7: Sections 7.1,7.2) 5. Fixed, Random and Mixed models for Balanced Data (Chapter 9.1-9.5, 9.8, 9.9)

Course Code	**MA 899**
Course Name	**Communication Skills**
Total Credits	6
Type	N
Lecture	1
Tutorial	2
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Alley, Michael The Craft of ScientificPresentations, Springer (2003). 2. Booth, Wayne C., Gregory G. Colomb, and JosephM. Williams, The Craft of Research, The Universityof Chicago Press, 3rd edition, (2008). 3. Keshav. S, How to read a paper. ACM SIGCOMM Comp. Commun. Rev., 37, 2007. 4. Monippally, M. M., Pawar, B.S. Academic Writing:A Guide for Management Students and Researchers,Response Books, (2010). 5. Purdue Online Writing Lab (OWL),https://owl.purdue.edu/ 6. Strunk Jr., William; E. B. White, The Elements of Style, Fourth Edition, Longman; 4th edition (1999). 7. Truss, Lynne Eats, Shoots & Leaves: The ZeroTolerance Approach to Punctuation Gotham;(2006). 8. Whitesides, George M. Whitesides Group: Writing a Paper, Advanced Materials 16 (2004).
Description	Continued on next page ...

Course Code	MA 899 (... continued from previous page)
Course Name	**Communication Skills**
Description	Context of communication: Recognizing our capability and roles as professionals. Scientific Method: Question and answer aspects of technical communication; Scientific Methodology and its relationship to technical communication;Surveying literature: Categories; reading and organizing scientific literature; search engines and tools. Listening and Note taking: 5-R method and mind-mapping.Technical writing: Report organization; Journal selection; Introduction, conclusion, and abstract writing. Speaking & Presentation skills: Organization of presentation slides (number, content, and formatting); Oral presentations; Audience/context dependent practices; Nonverbal aspects: body language, eye-contact, personal appearance, facing large audience. Elevator pitch: Pitches for technical audience and policymakers. Workplace communication: Sensitivity towards gender and diversity; Email communication and netiquettes.Ethics in academic communication: Intellectual Property,copyrights and plagiarism; Authorship; Data ethics; Biases and balanced criticism of literature;Suggested additional topics relevant to disciplines: Data representation, Group discussion and interviews; accessible scientific writing, report writing using LaTeX, Proofreading, etc

Course Code	**MAS801**
Course Name	**Seminar**
Total Credits	4
Type	S
Lecture	0
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1.
Description	

Course Code	**MAS802**
Course Name	**Seminar**
Total Credits	4
Type	S
Lecture	0
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1.
Description	

Statistics Courses

Course Code	**SI 404**
Course Name	**Applied Stochastic Processes**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. U. N. Bhat, Elements of Applied Stochastic Processes, Wiley, 1972. 2. V.G. Kulkarni, Modeling and Analysis of Stochastic Systems, Chapman and Hall,London, 1995. 3. J. Medhi, Stochastic Models in Queuing Theory, Academic Press, 1991. 4. R. Nelson, Probability, Stochastic Processes,and Queuing Theory: The Mathematics of Computer Performance Modelling, Springer-Verlag, New York, 1995.
Description	Stochastic processes: description and definition. Markov chains with finite and countably infinite state spaces. Classification of states, irreducibility, ergodicity. Basic limit theorems. Statistical Inference. Applications to queuing models. Markov processes with discrete and continuous state spaces. Poisson process, pure birth process, birth and death process. Brownian motion. Applications to queuing models and reliability theory. Basic theory and applications of renewal processes, stationary processes. Branching processes. Markov Renewal and semiMarkov processes, regenerative processes.

Course Code	SI 416
Course Name	**Optimization**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Beale, E.M.L., and Mackley, L. , Introduction to Optimization, John Wiley & Sons, Hoboken, 1988. 2. Chavatal, V., Linear Programming, W.H. Reeman and Company, New York, 1983. 3. Chong, E.P.K. and Zak, S.H., An Introduction to Optimization, 4th Edition, John Wiley & Sons, Hoboken, 2013. 4. Joshi, M.C., and Moudgalya, K., Optimization: Theory and Practice, Narosa, New Delhi, 2004. 5. Nocedal, J. and Wright, S. J., Numerical Optimization, 2nd Edition, Springer, New York, 2006. 6. Vanderbei, R.J., Linear Programming Foundations and Extensions, 3rd Edition, Springer, New York, 2008.
Description	Unconstrained optimization using calculus (Taylor‘s theorem, convex functions, coercive functions). Unconstrained optimization via iterative methods (Newton‘s method, Gradient/ conjugate gradient based methods, Quasi-Newton methods). Constrained optimization (Penalty methods, Lagrange multipliers, Karush-Kuhn-Tucker conditions). Introduction to Linear Programming: Lines and hyperplanes, Convex sets, Convex hull, Formulation of a Linear Programming Problem, Theorems dealing with vertices of feasible regions and optimality, Graphical solution. Simplex method (including Big M method and two-phase method), Dual problem, Duality theory, Dual simplex method, Revised simplex method

Course Code	**SI 419**
Course Name	**Combinatorics**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Bona, M. A walk through Combinatorics, 4th edition, World Scientific, 2017. 2. Nesetril, J,. and Matousek, J. Invitation to Discrete Mathematics, 2nd edition, Oxford University Press, 2009. 3. Lehman, E., Leighton, F. T., and Meyer, A. R. (2019) Mathematics for Computer science, (Freely available online), 2019.
Description	Counting Basic Combinatorial objects: Sets, Multisets, Partitions of sets, Partitions of numbers, Permutations, Trees, Partially ordered sets.Generating functions, Recurrence relations, Principle of Inclusion-Exclusion.Graph Theory Graphs and Directed graphs, Paths, Walks, Connectivity, Matchings in bipartite graphs, Network flows, Dilworths theorem.

Course Code	**SI 422**
Course Name	**Regression Analysis**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	SI 427 (Probability 1)
Text Reference	1. Draper, N. and Smith,H. Applied Regression Analysis, 3rd Edition, John Wiley and Sons Series in Probability and Statistics, New York, 1998. 2. Montgomery, D., Peck, E., Vining, G. Introduction to Linear Regression Analysis, 5th Edition, John Wiley, New York, 2012. 3. Sen, A. and Srivastava, M. Regression Analysis Theory, Methods & Applications, 1st Edition, Springer-Verlag Berlin Heidelberg, New York, 1990. 4. Kutner, M., Nachtsheim, C., Neter, J. and Li, W. Applied Linear Statistical Models, 5th Edition, McGraw-Hill Companies, Boston, 2005.
Description	Simple and multiple linear regression models – estimation, tests and confidence regions. Simultaneous testing methods- Bonferroni method etc. Analysis of Variance for simple and multiple regression models. Analysis of residuals. Lack of fit tests. Checks (graphical procedures and tests) for model assumptions: Normality, homogeneity of errors, independence, correlation of covariates and errors. Multicollinearity, outliers, leverage and measures of influence. Model selection (stepwise, forward and backward, best subset selection) and model validation. Discussion of algorithms for model selection. Regression models with indicator variables. Polynomial regression models. Regression models with interaction terms. Transformation of response variables and covariates. Variance stabilizing transformations, Box-Cox method. Ridge‘s regression. Weighted Regression.

Course Code	**SI 423**
Course Name	**Linear Algebra and its Applications**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Rao, A.R., and Bhimashankaram, P., Linear algebra, 2nd edition, Hindustan book agencey, New Delhi, 2000. 2. Friedberg, S.H., Insel, A.J., and Spence, L.E., Linear algebra, 4th edition, PHI learning, New Delhi, 2011. 3. Strang, G., Linear algebra and its applications, 4th edition, Thomson Learning, Toronto, 2006.
Description	Vector spaces (with emphasis over $\mathbb{R}$ and $\mathbb{C}$): Subspaces, linear dependence and independence, basis and dimension. Linear transformations: Rank-nullity theorem, matrix representation of a linear transformation, invertibility and isomorphism, effect of change of basis on the matrix representation of a linear transformation, dual spaces. Review of elementary properties of determinants, Cramer‘s rule. Diagonalization: Eigenvalues and eigenvectors, algebraic and geometric multiplicities of an eigenvalue, diagonalizability, invariant subspaces and Cayley-Hamilton theorem. Inner product spaces: Gram-Schmidt orthogonalization, adjoint of a linear operator, normal and self-adjoint operator, orthogonal projections and the spectral theorem, singular value decomposition and pseudo-inverse, bilinear and quadratic forms. Canonical forms: Jordan canonical form (with emphasis on computation).

Course Code	**SI 424**
Course Name	**Statistical Inference 1**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Casella, G. and Berger, R. Statistical Inference, 1st Edition, Duxbury Press, Pacific Grove, 2002. 2. Hogg, R., McKean. J. and Craig, A., Introduction to Mathematical Statistics, 8th Edition, Pearson, Boston, 2019. 3. Lehmann, E. Theory of Point Estimation, 1st Edition, John Wiley & Sons, New York, 1983. 4. Lehmann, E and Romano, J. Testing Statistical Hypotheses, 3rd Edition, Springer-Verlag New York, 2005. 5. DeGroot, M. and Schervish, M. Probability and Statistics, 4th Edition, Addison Wesley, Boston, 2002.
Description	Distributions of functions of random variables, Sampling distributions, Order statistics, Sufficiency and completeness, exponential family of distributions, Methods of estimation (Method of Moments, MLE and Bayesian), Unbiased estimators, Evaluating estimators, UMVUEs, Testing, Likelihood Ratio tests, UMP tests, unbiased tests, Interval estimation, Consistent and efficient estimators.

Course Code	**SI 426**
Course Name	**Algorithms**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Dasgupta, S., Papadimitriou, C., and Vazirani, U. Algorithms, Tata McGraw-Hill, 2008. 2. Kleinberg, J. and Tardos, E. Algorithm design, Pearson, 2006. 3. Cormen, T., Leiserson, C., Rivest, R., and Stein, C. Introduction to Algorithms, 3rd edition, MIT Press, 2009.
Description	Basics: Algorithm analysis and asymptotic notation, Linked lists. Graphs: Breadth first search, Depth first search, Strongly connected components. Divide and Conquer: Merge sort, Fast Fourier transform. Greedy Algorithms: Dijkstra's algorithm, Minimum spanning tree algorithms, Huffman codes and data compression. Dynamic programming: Longest increasing sequences, edit distance, shortest paths. Network flows: Maxflow Mincut theorem, max flow algorithms, application to bipartite matchings. Introduction to Randomized algorithms: randomized quick sort, global mincut, hashing.

Course Code	**SI 427**
Course Name	**Probability 1**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Athreya K.B. and Lahiri S. N., Probability Theory, Hindustan Book Agency, 2006. 2. Billingsley, P., Probability and Measure, 2nd edition, John Wiley & Sons, New York, 1995. 3. Hoel, P.G., Port, S.C., and Stone, C.J., Introduction to Probability Theory, Universal Book Stall, New Delhi, 1998. 4. Karr, A.F., Probability, Springer-Verlag, New York, 2003. Rosenthal, J.S., A first look at rigorous Probability theory, 2nd edition, World Scientific, 2006. 5. Ross, S., A first course in Probability, 9th Edition, Pearson, Delhi, 2019.
Description	Random phenomena, sample spaces, events, sigma algebra, probability space, properties of probability, conditional probability, independence, Bayes formula, Polya's urn model. Discrete random variable, probability mass function, independent random variables, sum of random variables, random vector, expectation of discrete random variable, properties of expectation and variance. Continuous random variable, distribution function, density of a continuous random variable, expectation, change of variable formula, random vector, joint distribution of random variables, joint density, distribution of sums and products of random variables, conditional density, conditional expectation, order statistics, moment generating function, characteristic function, brief introduction to moment problem. Inequalities: Markov, Chebyshev, Schwarz and Chernoff bound. Convergence in probability, almost sure convergence, convergence in distribution, relation between these three modes of convergences, weak law of large numbers (WLLN), strong law of large numbers (SLLN), central limit theorem (CLT).

Course Code	**SI 429**
Course Name	**Real analysis**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Ajit kumar, and Kumaresan, S., A basic course in Real analysis, CRC Press, Boca Raton, 2014. 2. Apostol, T.M., Mathematical analysis, 2nd edition, Narosa Publishers, New Delhi, 2002. 3. Bartle, R.G., and Sherbert, D. R., Introduction to Real analysis, 4th edition, John Wiley, New York, 2011. 4. Ghorpade, S.R., and Limaye, B.V., A course in Calculus and Real analysis, Springer (India), New Delhi, 2006. 5. Ross, K.A., Elementary analysis: The theory of Calculus, 2nd edition, Springer (India), New Delhi, 2013. 6. Tao T., Analysis I, 3rd Edition, Hindustan Book Agency, New Delhi, 2006.
Description	Review of sequences and series of real numbers. Limit superior and limit inferior, Cauchy sequences and completeness of $\mathbb{R}$. Tests for convergence of series of real numbers. Basic notions of Metric Spaces with emphasis on $\mathbb{R}^n$. Heine Borel Theorem. Continuity and Uniform continuity. Derivatives. Mean Value Theorem and applications. Functions of bounded variation. Riemann-Stieltjes integral. Improper integrals and Gamma function. Sequences and series of functions. Uniform convergence, interchanging limits with integrals and derivatives. Arzela-Ascoli theorem (statement only). Functions of several variables: Partial derivative, directional derivative, total derivative; Mean value theorem, Taylor's theorem.

Course Code	**SI 431**
Course Name	**Introduction to Data Analysis using R**
Total Credits	6
Type	T
Lecture	2
Tutorial	0
Practical	2
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. FOSSEE, Spoken tutorials at https://r.fossee.in/ James, G., Witten, D., Hastie, T., and Tibshirani, R., An introduction to statistical learning with applications in R, Springer, New York, 2013. 2. Wickham, H., Advanced R, CRC press, New York, 2.Wickham, H., and Grolemund, G., R for Data Science, O'Reilly Media Inc, Canada, 2017.
Description	Overview of R software, Data Frames, R Scripts, creating, importing/exporting and merging of data sets, creating matrices and basic matrix operations in R, 2d/3d plotting, programming in R (for, if else, do and while loops), functions, creating report using R markdown. Exploring data using R, Scatter plot, histogram, bar chart, pie chart, box plot, basic statistics computation (mean, median, variance etc.) Generating random samples from standard distributions (such as Bernoulli, Poisson, Normal, Exponential etc.) and comparing theoretical pdfs/pmfs using histograms/frequency distributions, quantiles of sampling distributions (t, chi and F distribution) Maximization/minimization of functions in R (some algorithm), MLE estimation. Polynomial fitting of scatter plot, introducing regression line, least squares estimates, residual plots, testing normality of residuals (qqplot), goodness of fit measures and tests, testing of regression parameters, simulation of regression model, empirical distribution of least square estimator and its comparison with theoretical distribution. Simulation of multivariate normal random vectors, estimation of mean and covariance matrix, eigen values and eigen vector of variance covariance matrix, spectral decomposition covariance matrix. Generating dependent random variables with some models like (random walk, AR(1), MA(1) etc).

Course Code	**SI 503**
Course Name	**Categorical Data Analysis**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. A. Agresti, Categorical Data Analysis, 3rd Edition, Wiley, November 2012. 2. A. Agresti, An Introduction to Categorical Data Analysis,2nd Edition, Wiley, March 2007. 3. E.B. Andersen, The Statistical Analysis of Categorical Data, Springer for Science, 1997. 4. R.F. Gunst and R.L. Mason, Regression Analysis and its Applications – A Data Oriented Approach, Marcel Dekkar, 1980. 5. T.J. Santner and D. Duffy, The Statistical Analysis of Discrete Data, Springer-Verlag, 1989. 6. A.A. Sen and M. Srivastava, Regression Analysis – Theory, Methods and Applications, Springer-Verlag, 1990
Description	Two-way contingency tables: Table structure for two dimensions. Ways of comparing proportions. Measures of associations. Sampling distributions. Goodness-of-fit tests, testing of independence. Exact and large sample inference. Models of binary response variables. Logistic regression. Logistic models for categorical data. Probit and extreme value models. Log-linear models for two and three dimensions. Fitting of logit and log-linear models. Log-linear and logit models for ordinary variables. Regression: Simple, multiple, non-linear regression, likelihood ratio test, confidence intervals and hypotheses tests, tests for distributional assumptions Collinearity, outliers, analysis of residuals. Model building, Principal component and ridge regression. Lab component: Relevant real life problems to be done using statistical Software Packages such as SAS etc.

Course Code	**SI 505**
Course Name	**Multivariate Analysis**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	SI 424 (Statistical Inference 1)
Text Reference	1. T.W. Anderson, An Introduction to Multivariate Statistical Analysis, 3rd Ed., Wiley, July 2003. 2. R. Gnanadesikan, Methods for Statistical Data Analysis of Multivariate Observations, John Wiley, New York, 1997. 3. R.A. Johnson and D.W. Wicheran, Applied Multivariate Statistical Analysis, 6th Edition, Wiley, April 2007. 4. M.S. Srivastava and E.M. Carter, An Introduction to Multivariate Statistics, North Holland, 1983.
Description	K-variate normal distribution. Estimation of the mean vector and dispersion matrix. Random sampling from multivariate normal distribution. Multivariate distribution theory. Discriminant and canonical analysis. Factor analysis. Principal components.Distribution theory associated with the analysis.

Course Code	**SI 507**
Course Name	**Numerical Analysis**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. K.E. Atkinson, An Introduction to Numerical Analysis, Wiley, 1989. 2. S.D. Conte and C. De Boor, Elementary Numerical Analysis An Algorithmic Approach, McGraw-Hill, 1981. 3. K. Eriksson, D. Estep, P. Hansbo and C. Johnson, Computational Differential Equations, Cambridge Univ. Press, Cambridge, 1996. 4. G.H. Golub and J.M. Ortega, Scientific Computing and Differential Equations: An Introduction to Numerical Methods, Academic Press, 1992. 5. J. Stoer and R. Bulirsch, Introduction to Numerical Analysis, 2nd ed., Texts in Applied Mathematics, Vol. 12, Springer Verlag, New York, 1993.
Description	Principles of floating point computations and rounding errors. Systems of Linear Equations: factorization methods, pivoting and scaling, residual error correction method. Iterative methods: Jacobi, Gauss-Seidel methods with convergence analysis, conjugate gradient methods. Eigenvalue problems: only implementation issues. Nonlinear systems: Newton and Newton like methods and unconstrained optimization. Interpolation: review of Lagrange interpolation techniques, piecewise linear and cubic splines, error estimates. Approximation : uniform approximation by polynomials, data fitting and least squares approximation. Numerical Integration: integration by interpolation, adaptive quadratures and Gauss methods. Initial Value Problems for Ordinary Differential Equations: Runge-Kutta methods, multi-step methods, predictor and corrector scheme, stability and convergence analysis. Two Point Boundary Value Problems : finite difference methods with convergence results. Lab Component: Implementation of algorithms and exposure to public domain packages like LINPACK and ODEPACK.

Course Code	**SI 509**
Course Name	**Time Series Analysis**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	SI 424 (Statistical Inference 1)
Text Reference	1. Brockwell P. and Davis R., Introduction to Time Series and Forecasting, Springer, New York, 2000. 2. Brockwell P. and Davis R., Time Series: Theory and Methods, Springer, New York, 1991. 3. Box G.E.P., Jenkins G., Reinsel G. and Ljung, Time Series Analysis-Forecasting and Control, 5th Edition, Wiley, New York, 2016. 4. Chatfield C., The Analysis of Time Series - An Introduction, 6th Edition, Chapman and Hall / CRC, New York, 2016. 5. Shumway R.H. and Soffer D.S., Time Series Analysis and Its Applications, 4th Edition, Springer, New York, 2016. 6. Weiss C. H., An Introduction to Discrete-Valued Time Series Data, John Wiley & Sons, Inc., Chichester, 2018.
Description	Stationary processes – strong and weak, linear processes, estimation of mean and covariance functions. Wald decomposition Theorem. Modeling using ARMA processes, estimation of parameters testing model adequacy, Order estimation. Prediction in stationary processes, with special reference to ARMA processes. Frequency domain analysis – spectral density and its estimation, transfer functions. Nonlinear ARCH and GARCH models. Discrete-Valued time series models.

Course Code	**SI 513**
Course Name	**Theory of Sampling**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Chaudhuri, A. and Stenger, H., Survey Sampling: Theory and Methods, Chapman and Hall/CRC, Boca Raton, 2005. 2. Cochran, W.G., Sampling Techniques, 3rd Edition, John Wiley and Sons, New York, 1977. 3. Des Raj, Sampling Theory, McGraw-Hill Book Co., New York, 1978. 4. Mukhopadhyay, P., Theory and Methods of Survey Sampling, Prentice-Hall of India New Delhi, 1998.
Description	Principals of sample survey, Probability sampling, Non-probability sampling, Simple random sampling, Estimation of population total, Variance estimation, finite population correction, Random sampling with replacement, linear estimators of population mean, Sampling for proportions and percentages, sample size estimation for proportion as well as continuous data in random sampling. Stratified random sampling, Estimator of population total and its variance, Optimum allocation, comparison between stratified and simple random sampling, Stratified sampling for proportion and sample size estimation, construction of strata, Number of strata, Quota sampling. Ratio estimator, estimation of variance from sample, comparison between ratio estimator and best linear unbiased estimator, bias of ratio estimates, ratio estimates in stratified sampling. Regression estimators, Large sample comparison with ratio estimate. Single stage cluster sampling with equal and unequal cluster sizes, Sampling with probability proportion to size, selection with unequal probabilities with and without replacement, the Horvitz Thompson estimator, Brewer's method, Murthy's method, Rao, Hartley and Cochran method. Two stage sampling with units of equal and unequal sizes. Introduction to randomized response techniques with examples and estimation.

Course Code	**SI 514**
Course Name	**Statistical Modeling**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. T. Hastie, and R. Tibshirani, Generalized Additive Models, Chapman and Hall, London, 1990. 2. G.A.F. Seber, and C.J. Wild, Nonlinear Regression, John Wiley & Sons, 1989. 3. W. Hardle, Applied Nonparametric Regression, Cambridge University Press, London, 1990.
Description	Nonlinear regression, Nonparametric regression, generalized additive models, Bootstrap methods, kernel methods, neural network, Artificial Intelligence, a few topics from machine learning.

Course Code	**SI 515**
Course Name	**Statistical Techniques in Data Mining**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. L. Breiman, J.H. Friedman, R.A. Olschen and C.J. Stone, Classification of Regresion Trees, Wadsowrth Publisher, Belmont, CA, 1984. 2. D.J. Hand, H. Mannila and P. Smith, Principles of Data Minng, MIT Press,Cambridge, MA 2001. 3. M.H. Hassoun, Fundamentals of Artificial Neural Networks, Prentice-Hall of India,New Delhi January 2003. 4. T. Hastie, R. Tibshirani & J. H. Friedman, The elements of Statistical Learning: Data Mining, Inference & Prediction, 2nd Edition, Springer Series in Statistics, Springer-Verlag, New York February 2009. 5. R.A. Johnson and D.W. Wichern, Applied Multivariate Statistical 6th Edition Pearson April 2007. 6. S. James Press, Subjective and Objective Bayesian Statistics: Principles, Models, and Applications, 2nd Edition, Wiley, 2002.
Description	Introduction to Data Mining and its Virtuous Cycle. Cluster Analysis: Hierarchical and Non-hierarchical techniques. Classification and Discriminant Analysis Tools: CART, Random forests, Fisher's discriminant functions and other related rules, Bayesian classification and learning rules. Dimension Reduction and Visualization Techniques: Multidimensional scaling, Principal Component Analysis, Chernoff faces, Sun-ray charts.Algorithms for data-mining using multiple nonlinear and non-parametric regression. Neural Networks: Multi-layer perceptron, predictive ANN model building using back-propagation algorithm. Exploratory data analysis using Neural Networks self organizing maps. Genetic Algorithms, Neuro-genetic model building. Discussion of Case Studies.

Course Code	**SI 526**
Course Name	**Experimental Designs**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	SI 424 (Statistical Inference 1)
Text Reference	1. A.M. Kshirsagar, A First Course in Linear Models, Marcel Dekker, 1983. 2. D.C. Montgomery, Design and Analysis of Experiments, 8th Ed., John Wiley & Sons, 2012. 3. C.F.J. Wu and M. Hamada, Experiments: Planning Analysis, and Parameter Design Optimization, John Wiley & Sons, 2nd Edition 2009.
Description	Linear Models and Estimators, Estimability of linear parametric functions. Gauss-Markoff Theorem. One-way classification and two-way classification models and their analyses. Standard designs such as CRD, RBD, LSD, BIBD. Analysis using the missing plot technique. Fctorial designs. Confounding. Analysis using Yates‘ algorithm. Fractional factorial. A brief introduction to Random Effects models and their analyses. A brief introduction to special designs such as split-plot, strip-plot, cross-over designs. Response surface methodology. Applications using SAS software.

Course Code	**SI 527**
Course Name	**Introduction to Derivative Pricing**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	SI 427 (Probability 1) and SI 537 (Probability 2)
Text Reference	1. D. G. Luenberger, Investment Science, Oxford University Press, 1998. 2. J. C. Hull, Options, Futures and Other Derivatives, 4th Edition, Prentice-Hall, 2000. 3. J. C. Cox and M. Rubinstein, Options Market, Englewood Cliffs, N.J.: Prentice Hall, 1985. 4. C. P Jones, Investments, Analysis and Measurement, 5th Edition, John Wiley and Sons, 1996.
Description	Basic notions – Cash flow, present value of a cash flow, securities, fixed income securities, types of markets. Forward and futures contracts, options, properties of stock option prices, trading strategies involving options, option pricing using Binomial trees, Black – Scholes model, Black – Scholes formula, Risk-Neutral measure, Delta – hedging, options on stock indices, currency options.

Course Code	**SI 534**
Course Name	**Nonparametric Statistics**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	SI 424 (Statistical Inference 1)
Text Reference	1. W.W. Daniel, Applied Nonparametric Statistics, 2nd ed., Boston: PWS-KENT, 1990. 2. M. Hollandor, and D.A. Wolfe, Non-parametric Statistical Inference, McGraw-Hill, 1973. 3. E.L. Lehmann, Nonparametric Statistical Methods Based on Ranks, McGraw-Hill, 1975. 4. J.D. Gibbons, Nonparametric Statistical Inference Marcel Dekker, NewYork, 1985. 5. R.H. Randles and D.A. Wolfe, Introduction to the Theory of Nonparametric Statistics,Wiley, New York, 1979. 6. P. Sprent, Applied Nonparametric Statistical Methods, Chapman and Hall, London, 1989. 7. B.C. Arnold, N. Balakrishnan and H. N. Nagaraja, First Course in Order Statistics. John Wiley, NewYork, 1992. 8. J.K. Ghosh and R.V. Ramamoorthi, Bayesian Nonparametrics, Springer Verlag, NY, 2003.
Description	Kolmogorov-Smirnov Goodness of Fit Test. The empirical distribution and its basic properties. Order Statistics. Inferences concerning Location parameter based on one-sample and two-sample problems. Inferences concerning Scale parameters. General Distribution Tests based on Two or More Independent Samples. Tests for Randomness and equality of distributions. Tests for Independence. The one-sample regression problem. Asymptotic Relative Efficiency of Tests. Confidence Intervals and Bounds.

Course Code	**SI 536**
Course Name	**Analysis of Multi-Type and Big Data**
Total Credits	6
Type	T
Lecture	3
Tutorial	0
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Bollen K.A. Structural Equations with Latent Variables, New York: John Wiley, 1989. 2. Bollen K.A. Latent Curve Models: A Structural Equation Perspective. Hoboken: John Wiley, 2006. 3. Hastie, T., Tibshirani, R. and Friedman, J. The Elements of Statistical Learning. Berlin: Springer, 2009. 4. B Ühlmann, P. and van de Geer, S. Statistics for High-Dimensional Data: Methods, Theory and Applications. Berlin: Springer, 2011. 5. Cressie, N., Statistics for Spatial Data, Revised Edition. NJ: Wiley Classics, 2015. 6. Gamerman, D., Hedibert, F. L. Markov Chain Monte Carlo: Stochastic Simulation for Bayesian Inference, 2nd ed. FL: Chapman and Hall/CRC, 2006. 7. Lecture Notes based on selected recent papers on Big Data Modeling and Analysis.
Description	Overview of Spatial Data, Structured Data. Structural Equation Modeling. Introduction to Big Data. Large dimension small size multivariate data analysis; tackling the problems of estimation and inference. Classification of Big Data; Screening and Variable Selection. Lasso Regression; Projection Methods. Introduction to Markov Chain Monte Carlo (MCMC) Simulations; MCMC techniques for Bayesian Modeling of Big Data.

Course Code	**SI 537**
Course Name	**Probability 2**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Athreya, K.B. and Lahiri, S. N., Measure Theory and Probability Theory, Springer, New York, 2006. 2. Ash, R. B., Probability and measure theory, Second edition, Academic Press, Burlington, 2000. 3. Billingsley, P., Probability and Measure, Anniversary Edition, John Wiley & Sons, Hoboken, 2012. 4. Chung, K. L., A Course in Probability Theory, Third edition, Academic Press, San Diego, 2001. 5. Durret, R., Probability: Theory and Examples, Fifth edition, Cambridge University Press, Cambridge, 2019. 6. Pollard, D., A user's guide to Measure Theoretic Probability, Cambridge University Press, Cambridge, 2002.
Description	Probability space, random variables $(\mathbb{R}, \mathbb{R}^d)$ valued, distributions of random variables, change of variables formula, expectation of $\mathbb{R}$ valued random variable, Jensen's inequality, Holder's inequality, Chebyshev's inequality, Fatou's lemma, monotone convergence theorem, dominated convergence theorem, product measure, Fubini's theorem, notion of independence of sigma-fields and random variables, Kolmogorov's consistency theorem. Convergence in probability, almost sure convergence, convergence in distribution, convergence in L^p, relation between different modes of convergence, Borel-Cantelli lemma, characteristic function, inversion formula, continuity theorems, Scheffe's lemma, uniform integrability, tightness, Helly's selection principle, moment problem. Weak law of large numbers, strong law of large numbers, central limit theorem. Radon Nikodym theorem (statement only), conditional expectation: definition and its properties.

Course Code	**SI 541**
Course Name	**Statistical Epidemiology**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Lawson, A. Statistical Methods in Spatial Epidemiology, 2nd Edition, Wiley, New York, 2006. 2. Gordis, L. Epidemiology, 5th Edition, Elsevier Saunders, Philadelphia, 2014. 3. Kalbfleisch, J. and Prentice, R. The Statistical Analysis of Failure Time Data, 2nd Edition, Wiley, New York, 2002. 4. Lee, E. and Wang, J. Statistical methods for survival data analysis, 3rd Edition, John Wiley & Sons., Hoboken, 2003.
Description	Epidemiologic approach to clinical trials: observational studies, cross-sectional studies, designing a case control study, bias in a case-control study, matching issues, cohort studies, design of a cohort study, biases in a cohort study, comparing case and cohort studies, randomized trials, selection of subjects, crossover trials, issues on sample size, recruitment. Case studies to explore above topics. Spatial Epidemiology: Geographical Representation and Mapping, Spatial Interpolation and Smoothing Methods, Estimation and Inference, Spatial Proximity Indices, Disease Clustering, Spatial Regression, Infectious disease modelling. Survival Analysis in Epidemiology: Functions of survival time, censoring mechanisms, nonparametric estimators of survival function, Cox's proportional hazards model, Cases studies using survival analysis methods in health research.

Course Code	**SI 543**
Course Name	**Asymptotic Statistics**
Total Credits	8
Type	T
Lecture	3
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	SI 427 (Probability 1) and SI 424 (Statistical Inference 1)
Text Reference	1. DasGupta A., Asymptotic Theory of Statistics and Probability, Springer, New York, 2008. 2. Serfling R.J., Approximation Theorems of Mathematical Statistics, Wiley, New York, 2009. 3. van der vaart A. W. and Wellner J. A., Weak Convergence and Empirical Processes, Springer, New York, 1996.
Description	Review of modes of stochastic convergences: Almost sure convergence, convergence in probability, convergence in the p-th moment and their relations. Convergence in distribution Additional topics in stochastic convergence: Portmanteau theorem (Statement only). Convergence in total variation (Scheffe's theorem). Skorohod representation theorem. HallyBray theorems (Statement only). Uniform tightness and Prohorov's theorem for random vectors. Characteristic function. Levy's continuity theorem (statement only). Strong law of large numbers (i.i.d. random variables with finite mean). Weak law of large numbers (finite variance). Levy-Lindeberg central limit theorem. Delta method and variance stabilizing transformations. Asymptotic properties of moment estimators, M-estimators and Z-estimators. Strong consistency and asymptotic normality of the MLE. Berry-Essen Theorem (without proof). Argmax theorem (statement without proof). Convergence of U-statistics (without proof) and its applications to linear rank statistics. Glivenko-Cantelli lemma. Convergence of the Kolmogorov-Smirnov statistics to the Brownian bridge (statement only without proof). Convergence of the quantile process. Almost sure and weak convergence results for maximum of i.i.d. random variables. Order statistics. Renyi's representation theorem for the order statistics of the i.i.d. exponential random variables. Bahadur-Rao representation theorem for the sample quantiles. Efficiency of tests: Asymptotic power function, consistency and asymptotic relative efficiency

Course Code	**SI 544**
Course Name	**Martingale theory**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	SI 427 (Probability 1) and SI 537 (Probability 2)
Text Reference	1. Athreya, K.B. and Lahiri, S.N., Probability Theory, Hindustan Book Agency, 2006. 2. Billingsley, P., Probability and Measure, Anniversary Edition, John Wiley and Sons, Hoboken, 2012. 3. Chung, K. L., A Course in Probability Theory, Third edition, Academic Press, San Diego, 2001. 4. Williams, D., Probability with martingales, Cambridge University Press, Cambridge, 1991.
Description	Review of conditional expectation: Conditional expectation and conditional probability, properties of conditional expectation, regular conditional distributions, disintegration, conditional independence. Martingales and Stopping times: Stopping times, random time change, martingale property, optional sampling theorem, maximum and up-crossing inequalities, martingale convergence theorem, Martingale central limit theorem.

Course Code	**SI 546**
Course Name	**Statistical Inference II**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	SI 424 (Statistical Inference 1)
Text Reference	1. Casella G. and Berger R.L., Statistical Inference, Wadsworth, a part of Cengage Learning, Delhi, 2002. 2. Dasgupta A., Asymptotic Theory of Statistics and Probability, Springer, New York, 2008. 3. Jurečková J., Sen P.K. and Picek J., Methodology in Robust and Nonparametric Statistics, CRC press, Boca Raton, 2012. 4. Lehmann E.L., Theory of Point Estimation, Springer, New York, 1998. 5. Lehmann E.L. and Romano J.P. , Testing of Statistical Hypotheses, Springer, New York, 2011. 6. Huber P. J. and Ronchetti E.M., Robust Statistics, Wiley, New York, 2009. 7. Shao J., Mathematical Statistics, Springer, New York, 2003.
Description	Minimaxity and admissibility: Minimax estimation, admissibility and minimaxity in exponential families, admissibility and minimaxity in group families, Simultaneous estimation. Maxmin tests and invariance, Hunt-stein Theorem, Most stringent tests. Multiple testing via Maximin procedures and Scheffé's S-method. U-statistics: Variance computation and projection method. Convergence of U statistics (one sample and two samples). Linear rank statistics. Asymptotic normality under null hypothesis. Pitman's Asymptotic relative efficiency, Noether's theorem for evaluating asymptotic relative efficiency. Bahadur's efficiency. Resampling techniques. Robust inference: Break-down point in finite sample, Influence curve. M-estimator, L-estimator, Restimator, minimum distance estimator and Pitman's estimator. Relations to minimax estimator and equivariant estimators. Robust tests and confidence sets.

Course Code	**SI 548**
Course Name	**Computational Statistics**
Total Credits	6
Type	T
Lecture	2
Tutorial	1
Practical	0
Selfstudy	0
Half Semester	N
Prerequisite	Nil
Text Reference	1. Efron B. and Tibshirani R.J., An Introduction to the Bootstrap, Chapman and Hall, New York, 1993. 2. Gentle J.E., Elements of Computational Statistics (ECS), Springer-Verlag, New York, 2002. 3. Gentle J.E., Computational Statistics, Statistics and Computing Series, Springer-Verlag, New York, 2009. 4. Gelman A., Carlin J. B., Stern H. S., and, Dunson D. B., Vehtari A., and Rubin D.B., Bayesian Data Analysis, 3rd Edition, CRC Press, Taylor and Francis Group, Boca Raton, 2014. 5. Givens G. H. and Hoeting J. A., Computational Statistics, 2nd Edition, John Wiley and Sons, Inc., Hoboken, New Jersey, 2013. 6. Lange K., Numerical Analysis for Statisticians, 2nd Edition, Springer-Verlag, New York, 2002. 7. Little R.J.A. and Rubin D.B., Statistical Analysis with Missing Data, 2nd Edition, Wiley, New York, 2019. 8. Liu J., Monte Carlo Strategies in Scientific Computing, Springer-Verlag, New York, 2001. 9. Rice J.A., Mathematical Statistics and Data Analysis, 2nd Edition, Duxbury Press, Belmont, California, 1995.
Description	Introduction to Bayesian Theory and methods; non-informative priors and conjugate priors; posterior inference (with special reference to one parameter exponential family)-credible intervals and hypothesis testing; hierarchical and empirical Bayesian models; computational techniques for use in Bayesian analysis, especially the use of simulation from posterior distributions, with emphasis on the WinBUGS package as a practical tool. MCMC simulation (Markov chains; Metropolis-Hastings algorithm; Gibbs sampling; convergence), EM algorithm, Bootstrap (Bootstrapping; jackknife resampling; percentile confidence intervals). Permutation tests.

Course Code	**SI 593**
Course Name	**Project 1 (Optional)**
Total Credits	4
Type	
Lecture	
Tutorial	
Practical	
Selfstudy	
Half Semester	
Prerequisite	
Text Reference	1.
Description	

Course Code	**SI 598**
Course Name	**Project 2 (Optional)**
Total Credits	6
Type	
Lecture	
Tutorial	
Practical	
Selfstudy	
Half Semester	
Prerequisite	
Text Reference	1.
Description	