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1The latest version of this file can be found at https://www.math.iitb.ac.in/\[ Academic Programs\[Curriculum Booklet. Created and maintained by Shri Ashutosh R. Mulik and Professor Ronnie Sebastian. Please write to ronnie@iitb.ac.in if you find any errors.
# Chapter 1

## B.S. program in Mathematics (for those who joined in July 2022 or later)

### 1.1 Curriculum

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### 1.2 List of Electives

(click on the link)
Chapter 2

Integrated M.Sc. program in Mathematics

2.1 Minimum Requirements

The minimum requirements for students to obtain a 5-year Integrated M.Sc. degree are as follows:

(1) Number of core courses: 2 HSS courses + HSS Environmental Science + CESE Environmental Science + 10 MA courses (excludes MA 1xx courses) = 14.

(2) Compulsory Project in the 5th year.

(3) Number of Credits in core courses (counted as above): 92

(4) Number of credits for the project: 30

(5) Minimum number of Department electives: 9

(6) Minimum no of credits in department electives (including the Advanced Electives): 54

(7) Minimum no of Institute electives: 2

(8) Minimum No of credits in institute electives: 12

(9) Minimum No of credits: 330
### 2.2 Curriculum for students switching after first year

#### Third Semester

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#### Fourth Semester

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#### Fifth Semester

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Total credits for eight semesters = 264.
2.2. CURRICULUM FOR STUDENTS SWITCHING AFTER FIRST YEAR

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.

Department Electives may include any Department Elective offered or Ph.D. course offered in the relevant semester. The existing departmental rules for prerequisites for these courses will apply.

The Advanced Elective listed in Semesters 9 and 10 must be one of the core Ph.D. courses (that is, not a “Topics” course). These are:

For Semester 9 (Advanced Elective): MA 813 (Algebra I), MA 819 (Measure Theory), MA 815 (Differential Topology), MA 817 (Partial Differential Equations), MA 833 (Weak Convergence and Martingale Theory), MA 821 (Theory of Estimation)

For Semester 10 (Advanced Elective): MA 812 (Algebra II), MA 814 (Complex Analysis), MA 816 (Algebraic Topology), MA 818 (Partial Differential Equations II), MA 820 (Stochastic Processes), MA 822 (Testing of Hypothesis), MA 824 (Functional Analysis
2.3 Curriculum for students switching after second year

2.3.1 Eligibility

The department will use its discretion to admit students who apply for a branch change after their second year. Students will not be admitted after their second year unless they have already completed MA 403 (Real Analysis) and at least one of MA 406 (General Topology), MA 410 (Multivariable calculus), MA 412 (Complex Analysis), MA 419 (Basic Algebra) or MA 414 (Algebra I). Other criteria, such as performance in these courses, may also be used to determine eligibility.

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*In Semester 6, it is expected that the student will take 4 out of the 5 MA courses.

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Total credits for six semesters = 220.
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.

Department Electives may include any Department Elective offered or Ph.D. course offered in the relevant semester. The existing departmental rules for prerequisites for these courses will apply.

The Advanced Elective listed in Semesters 9 and 10 must be one of the core Ph.D. courses (that is, not a “Topics” course). These will be courses with numbers MA8xx.

For Semester 9 (Advanced Elective): MA 813 (Algebra I), MA 819 (Measure Theory), MA 815 (Differential Topology), MA 817 (Partial Differential Equations), MA 833 (Weak Convergence and Martingale Theory), MA 821 (Theory of Estimation)

For Semester 10 (Advanced Elective): MA 812 (Algebra II), MA 814 (Complex Analysis), MA 816 (Algebraic Topology), MA818 (Partial Differential Equations II), MA 820 (Stochastic Processes), MA 822 (Testing of Hypothesis), MA 824 (Functional Analysis)

2.4 List of Electives

(click on the link)
CHAPTER 2. INTEGRATED M.SC. PROGRAM IN MATHEMATICS
Chapter 3

Two year M.Sc. program in Mathematics

3.1 Curriculum

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### 3.2 List of Electives for Mathematics programs

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Apart from the above listed electives, a student may also opt for a Ph.D. level course as an elective subject to the approvals from the course instructor and the faculty advisor. The list of Ph.D. courses offered in the department are as follows:
## List of Electives for Mathematics Programs

### Odd Semester Electives

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Chapter 4

Two year M.Sc. program in Statistics

4.1 Curriculum

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<table>
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<td>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.</td>
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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).

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<td>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).</td>
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**Text Reference**


**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.


Applications: space filling curve, nowhere differentiable continuous function.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>MA 408</th>
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<tbody>
<tr>
<td>Course Name</td>
<td>Measure Theory</td>
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### 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


#### 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.


Two Dimensional Autonomous Systems and Phase Space Analysis: critical points, proper and improper nodes, spiral points and saddle points.


Boundary Value Problems for Second Order Equations: Green’s function, Sturm comparison theorems and oscillations, eigenvalue problems.
<table>
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<p>| Description | Continued on next page ... |</p>
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<tbody>
<tr>
<td>Course Name</td>
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</table>
| Description | Review of basics: Equivalence relations, partitions, division algorithm for integers, primes, unique factorization, congruences, Chinese Remainder Theorem, Euler $\varphi$-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.
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**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.
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<thead>
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**Description**

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<td>Operators on Hilbert Spaces</td>
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**Text Reference**


**Description**

### List of Mathematics Courses

**Course Code**: MA 510  
**Course Name**: Introduction to Algebraic Geometry  
**Total Credits**: 6  
**Type**: T  
**Lecture**: 2  
**Tutorial**: 1  
**Practical**: 0  
**Selfstudy**: 0  
**Half Semester**: N  

**Prerequisite**: MA 414 (Algebra 1)

| Text Reference |  
|----------------|---|

**Description**: Varieties: Affine and projective varieties, coordinate rings, morphisms and rational maps, local ring of a point, function fields, dimension of a variety. Curves: Singular points and tangent lines, multiplicities and local rings, intersection multiplicities, Bezout's theorem for plane curves, Max Noether's theorem and some of its applications, group law on a nonsingular cubic, rational parametrization, branches and valuations.
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<tr>
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<td>Course Name</td>
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### Text Reference

### Description
### Course Code
MA 518

### Course Name
Spectral Approximation

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#### Text Reference

#### Description
- Convergence of operators: norm, collectively compact and $\nu$ convergence. Error estimates. Finite rank approximations based on projections and approximations for integral operators.
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<tr>
<th>Course Code</th>
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<tbody>
<tr>
<td>Course Name</td>
<td>Theory of Analytic Functions</td>
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### Text Reference


### Description

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<th>Course Code</th>
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<td>Course Name</td>
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**Text Reference**


**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 \( \pi \). Diophantine equations: Brahmagupta’s equation (also known as Pell’s equation), The equation, Fermat’s method of descent, discussion of the Mordell equation.
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**Text Reference**

2. S. Lang, Algebraic Number Theory, Addison-Wesley, 1970.

**Description**

### 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)

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**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.
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### Text Reference

### Description
Faces, flats, cones, lunes. Distance functions Birkhoff monoid, Tits monoid and Janus monoid Lie and Zie elements Eulerian idempotents, Dynkin idempotents, Joyal-Klyachko-Stanley theorem Orlik-Solomon algebra Incidence algebras and operads.
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**Text Reference**


**Description**

Fixed Point Theorems with Applications: Banach contraction mapping theorem, Brouwer fixed point theorem, Leray-Schauder 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.
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**Text Reference**


**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.
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<tr>
<td>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.</td>
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**Description**

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<td>MA 562</td>
<td><strong>The Mathematical Theory of Finite Elements</strong></td>
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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.)
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<tr>
<td>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.</td>
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<tr>
<td>Prerequisite</td>
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**Text Reference**


**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 non-linear 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, Kratchoukw 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.
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<tr>
<td>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.</td>
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**Text Reference**


**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.
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<tr>
<td>Wedderburn-Artin Theory: semisimple rings and modules, Wedderburn and Artin’s structure theorem of semisimple rings.</td>
</tr>
<tr>
<td>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.</td>
</tr>
<tr>
<td>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.</td>
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<tr>
<td>Introduction to division rings: Wedderburn’s (little) theorem, algebraic division algebras over reals (Frobenius theorem), construction of division algebras, polynomials over division rings.</td>
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<tr>
<td>Ordered structures in rings: orderings and preorderings in rings, formally real ring, ordered division rings.</td>
</tr>
<tr>
<td>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.</td>
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<td>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.</td>
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Description

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<tr>
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<td>Course Name</td>
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**Text Reference**


**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.
<table>
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<tr>
<th>Course Code</th>
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<tbody>
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<tbody>
<tr>
<td>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</td>
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### Course Code
MA 5118

### Course Name
Category Theory 2

| Total Credits | 6 |
| Lecture       | 3 |
| Tutorial      | 0 |
| Practical     | 0 |
| Selfstudy     | 6 |
| Half Semester | N |

### Prerequisite
Nil

#### Text Reference


#### 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.
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<tr>
<td>1. J.Humphreys, Reflection groups and Coxeter groups, CUP, 1990</td>
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<tr>
<td>Reflection arrangement and reflection group, Coxeter diagram, Coxeter complex, Bruhat order, Root system, Classification of Coxeter groups, Poincare polynomial and related enumeration. Connection to related topics such as buildings, geometric group theory, Coxeter bialgebras, depending on the interest of the instructor and students.</td>
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<table>
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<tbody>
<tr>
<td>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]</td>
</tr>
<tr>
<td>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]</td>
</tr>
<tr>
<td>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]</td>
</tr>
<tr>
<td>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]</td>
</tr>
<tr>
<td>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]</td>
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### Course Code
MA 813

### Course Name
Measure Theory

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**Description**

## CHAPTER 5. LIST OF ALL MATHEMATICS COURSES

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### Text Reference


### 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.
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**Description**

### Course Code: MA 824

#### Course Name: Functional Analysis

| Total Credits | 6 |
| Lecture | 3 |
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| **Tutorial**      | **0** |
| **Practical**     | **0** |
| **Selfstudy**     | **0** |
| **Half Semester** | **N** |
| **Prerequisite**  | **Nil** |

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**Text Reference**


**Description**

A selection of topics from the following:
- Hensel’s Lemma, Newton’s 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.
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**Text Reference**


**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.
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<tr>
<td>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.</td>
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Text Reference

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<tbody>
<tr>
<td>MA 844</td>
<td>Topics in Analysis 2</td>
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Description
A selection of topics from the following:


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


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.

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**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.
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**Text Reference**


**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.
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**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.
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<td>Affine and projective varieties, rational maps, nonsingularity.</td>
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<td>Algebraic Curves, Riemann Roch Theorem.</td>
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<td>Sheaves and Schemes. Basic properties. Divisors and Differentials.</td>
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<td>Cohomology of sheaves, Serre Duality Theorem.</td>
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**Text Reference**


**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.
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**Text Reference**


**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.
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**Text Reference**


**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.
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<td>Description</td>
<td>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.</td>
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### Text Reference


### Description

A selection of topics from the following:
- 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.
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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.


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.

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**Text Reference**


**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.
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**Text Reference**


**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.
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**Text Reference**

5. Modern Graph theory - Bollobas, Graduate Texts in Mathematics, Springer.

**Description**

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<tr>
<td>2. Extremal Combinatorics With Applications in Computer Science - Stasys Jukna, Springer, 2nd Edition</td>
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<td>7. Linear Algebra methods in Coombinatorics - Babai/Frankl, lecture notes.</td>
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<td>8. The Polynomial method in Combinatorics - survey paper by T. Tao</td>
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#### Text Reference

2. Additional Texts:
   
   (a) Theoretical Statistics, D.R. Cox, D.V. Hinkley CRC Press

#### 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]
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<th><strong>Course Code</strong></th>
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<td><strong>Course Name</strong></td>
<td>Topics in Category Theory 1</td>
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<td>8. Mac Lane, Categories for the working mathematician, Springer, 1998</td>
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<table>
<thead>
<tr>
<th><strong>Description</strong></th>
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<tbody>
<tr>
<td>Categories, functors, natural transformations.</td>
</tr>
<tr>
<td>Limits, colimits, complete and cocomplete categories.</td>
</tr>
<tr>
<td>Adjoint functors, universal constructions, free and cofree objects.</td>
</tr>
<tr>
<td>Functor categories, comma categories, quotient categories, derived categories.</td>
</tr>
<tr>
<td>Representable functors, Yoneda lemma.</td>
</tr>
<tr>
<td>Cauchy completeness, Karoubi envelopes.</td>
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<tr>
<td>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.</td>
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### Chapter 5. List of All Mathematics Courses

<table>
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<th>Course Code</th>
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<tbody>
<tr>
<td>8. Mac Lane, Categories for the working mathematician, Springer, 1998</td>
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</table>

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.
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<tr>
<th>Course Code</th>
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**Text Reference**

   Other

**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)
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**Text Reference**

5. Purdue Online Writing Lab (OWL), https://owl.purdue.edu/

**Description**

Continued on next page ...
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<td>Communication Skills</td>
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Chapter 6

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<tbody>
<tr>
<td>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.</td>
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**Text Reference**


**Description**

Random phenomena, sample spaces, events, sigma algebra, probability space, properties of probability, conditional probability, independence, Bayes formula, Polyà’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).
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**Text Reference**


**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/pmf s 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 (q-q plot), 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).
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## Text Reference


## Description

### CHAPTER 6. LIST OF ALL STATISTICS COURSES

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<th>Course Code</th>
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**Text Reference**


**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.
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<p>| <strong>Description</strong> | Nonlinear regression, Nonparametric regression, generalized additive models, Bootstrap methods, kernel methods, neural network, Artificial Intelligence, a few topics from machine learning. |</p>
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<tr>
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# CHAPTER 6. LIST OF ALL STATISTICS COURSES

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7. Lecture Notes based on selected recent papers on Big Data Modeling and Analysis. |

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**Text Reference**


**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
### Course Name
SI 539
Random graphs

| Total Credits | 6 |
| Lecture | 2 |
| Tutorial | 1 |
| Practical | 0 |
| Selfstudy | 0 |
| Half Semester | N |
| Prerequisite | Nil |

### Text Reference

### Description
Review of probabilistic tools: Markov inequality, Chebyshev's inequality, concentration inequalities: Hoeffding, Efron-Stein, Azuma-Hoeffding, Mcdiarmid (statements only). Modes of convergences. Some real life examples, two basic models of random graphs (Erdos-Renyi model $G(n, M)$ and Erdos-Renyi-Gilbert model $G(n, p)$) and relationship between them, monotonicity, thresholds and sharp thresholds, evolution: sub-critical phase, super-critical phase, phase transition, connectivity, threshold for connectivity, dense and sparse random graphs, degree sequence and asymptotic distribution of degrees, sub-graph counts, its asymptotic distribution and thresholds for sub-graph containment. Introduction to other random graph models: Generalized binomial model, Exponential random graph models, Configuration model, Preferential attachment model, Stochastic block model, examples.
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**Text Reference**


**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.
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**Text Reference**


**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.
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**Text Reference**


**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.

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**Text Reference**


**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

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