Model Curriculum

(With Multiple Entry /Exit Option)

Based on NEP-2020

5 Year Integrated M. Sc in Mathematics and Computing

COURSE STRUCTURE FOR
5 YEAR INTEGRATED M.Sc. IN MATHEMATICS AND COMPUTING,
INSTITUTE OF MATHEMATICS AND APPLICATIONS, BHUBANESWAR

Semester-I				
SN	**Course No**	**Paper Code**	**Course Name**	**Credit**
1	S1-C1-P1	Core-I	Calculus & Analytical Geometry	4
2	S1-C1-P2	Core-I	Introduction to Algebra & Number Theory	4
3	S1-C2-P1	Core-II	Programming and Data Structures with Lab	4
4	S1-MD-P1	Multidisciplinary	Discrete Mathematics	3
5	S1-AEC-P1	AEC	Odia/ Hindi/ Sanskrit/Urdu	4
6	S1-VAC-P1	VAC	Environmental Studies and Disaster Management	3
			Total Credit	22
Semester-II				
SN	**Course No**	**Paper Code**	**Course Name**	**Credit**
1	S2-C1-P1	Core-I	Real Analysis-I	4
2	S2-C1-P2	Core-I	Algebra-I	4
3	S2-C3-P1	Core-III	Computer Organization & Operating System	4
4	S2-MD-P1	Multidisciplinary	Operation Research	3
5	S2-AEC-P1	AEC	English	4
6	S2-SEC-P1	SEC	Analytical Thinking and Logical Reasoning/ Introduction to Python	3
			Total Credit	22
Semester-III				
SN	**Course No**	**Paper Code**	**Course Name**	**Credit**
1	S3-C1-P1	Core-I	Algebra-II	4
2	S3-C1-P2	Core-I	Ordinary Differential Equations	4
3	S3-C1-P3	Core-I	Analysis-II (Functions of Several Variables)	4
4	S3-C2-P1	Core-II	Design and Analysis of Algorithms with Lab	4
5	S3-MD-P1	Multidisciplinary	Probability	3
6	S3-VAC-P1	VAC	Understanding India	3
			Total Credit	22
Semester-IV				
SN	**Course No**	**Paper Code**	**Course Name**	**Credit**
1	S4-C1-P1	Core-I	Numerical Methods with Lab	4
2	S4-C1-P2	Core-I	Number Theory and Cryptography	4
3	S4-C1-P3	Core-I	Partial Differential Equations	4
4	S4-C2-P1	Core-III	Database Management System with Lab	4
5	S4-FW-P1	Community	Field Work/Internship	4

		Engagement and Services/Field Work/Internship		
			Total Credit	20
		Semester-V		
SN	**Course No**	**Paper Code**	**Course Name**	**Credit**
1	S5-C1-P1	Core-I	Statistics	4
2	S5-C1-P2	Core-I	Complex Analysis	4
3	S5-C1-P3	Core-I	Optimization Theory	4
4	S5-C2-P1	Core-II	Theory of Computation & Compiler Design	4
5	S5-SEC-P1	SEC	Computer Network and Software Engineering	3
6	S5-VAC-P1	VAC	Understanding Odisha	3
			Total Credit	22
		Semester-VI		
SN	**Course No**	**Paper Code**	**Course Name**	**Credit**
1	S6-C1-P1	Core-I	Differential Geometry (Curves & Surfaces)	4
2	S6-C1-P2	Core-I	Topology	4
3	S6-C3-P1	Core-III	Machine Learning with Lab	4
4	S6-SEC-P1	SEC	IoT with Lab	3
5	S6-VAC-P1	VAC	Ethics and Values	3
			Total Credit	18
		Semester-VII		
SN	**Course No**	**Paper Code**	**Course Name**	**Credit**
1	S7-C1-P1	Core-I	Computational Linear Algebra with Lab	4
2	S7-C1-P2	Core-I	Probability, Statistics, and Stochastic Processes with Lab (in R)	4
3	S7-C1-P3	Core-I	Principles of Programming (Python and C++)	4
4	S7-C1-P4	Core-I	Advanced Optimization with Lab	4
5	S7-C2-P1	Core-II	Fluid Dynamics	4
			Total Credit	20
		Semester-VIII		
SN	**Course No**	**Paper Code**	**Course Name**	**Credit**
1	S8-C1-P1	Core-I	Functional Analysis	4
2	S8-C1-P2	Core-I	Artificial Intelligence	4
3	S8-C1-P3	Core-I	Advanced Data Structures with Lab	4
4	S8-C1-P4	Core-I	Numerical Solution of Partial Differential Equations	4
5	S8-C2-P1	Core-II	Project/Any one course from NPTEL not overlap with existing courses	4
			Total Credit	20
		Semester-IX		

SN	Course No	Paper Code	Course Name	Credit
1	S9-C1-P1	Core-I	Advanced Machine Learning with Lab	4
2	S9-C1-P2	Core-I	Algebraic Geometry	4
3	S9-C1-P3	Core-I	Simulation Modeling	4
4	S9-C1-P4	Core-I	Elective I (To be chosen from a Group A)	4
5	S9-C2-P1	Core-II	Solid Mechanics	4
			Total Credit	20
		Semester-X		
SN	**Course No**	**Paper Code**	**Course Name**	**Credit**
1	S10-C1-P1	Core-I	Lebesgue Measure & Integration	4
2	S10-C1-P2	Core-I	Elective II (To be chosen from a Group B)	4
3	S10-FW-P1	Community Engagement and Services/Field Work/Internship	Research/ Any two courses from NPTEL not overlap with existing courses + one reading course	12
			Total Credit	20

For Allied Elective papers a student can choose any two of the following courses from each group depending on the availability

Elective Papers Group-A S9-C1-P4		**Elective Papers Group-B** S10-C1-P2	
A1	Bioinformatics	B1	Cyber Security
A2	Computational Fluid Dynamics	B2	Deep Learning and Reinforcement Learning with Lab
A3	Computational Finance	B3	Discrete Dynamical Systems
A4	Computational Modelling of Financial Derivatives	B4	High Performance Computing
A5	Computer Vision	B5	Natural Language Processing
A6	Finite Elements: Theory and Algorithms	B6	Quantum Computing
A7	Image & Video Processing	B7	Soft Computing Methods
A8	Probabilistic Graphical Models	B8	Time Series Analysis and Forecasting

Detailed Syllabus

First Year

Semester-I

Core I: Calculus & Analytical Geometry 4 credit

Course Objective:

The main emphasis of this course is to equip the student with necessary analytic and technical skills to handle problems of mathematical nature as well as practical problems. More precisely, main target of this course is to explore the different tools for higher order derivatives to plot the various curves and to solve the problems associated with differentiation and integration of vector functions.

Learning Outcomes:

After completing the course the student will be able to

- Trace a curve and find asymptotes.
- Talculate integrals of typical type using reduction formulae, etc.
- Calculate arc length, surface of revolution and know about conics
- Calculate triple products, gradient divergence, curl, etc.

Unit I

Hyperbolic functions, higher order derivatives, Leibnitz rule and its applications to problems of the type $e^{ax+b}sinx$, $e^{ax+b}cosx$, $(ax + b)^n sinx$, $(ax + b)^n cosx$, concavity and inflection points, asymptotes, curve tracing in Cartesian coordinates, tracing in polar coordinates of standard curves, L'Hospital rule, application in business, economics and life sciences.

Unit II

Riemann integration as a limit of sum, integration by parts, reduction formulae, derivations and illustrations of reduction formulae of the type $\int sin^n x dx$,$\int cos^n x dx$,$\int tan^n x dx$,$\int sec^n x dx$, $\int (logx)^n dx$,$\int sin^n x cos^n x dx$, definite integral, integration by substitution.

Unit III

Volumes by slicing, disks and washers methods, volumes by cylindrical shells, parametric equations, parameterizing a curve, arc length, arc length of parametric curves, area of surface of revolution, techniques of sketching conics, reflection properties of conics, rotation of axes and second degree equations, classification into conics using the discriminant, polar equations of conics.

Unit IV

Triple product, introduction to vector functions, operations with vector-valued functions, limits and continuity of vector functions, differentiation, partial differentiation, div, curl and integration of vector functions, tangent and normal components of acceleration.

Books Recommended:

✓ *H. Anton, I. Bivens and S. Davis: Calculus,10th Ed., John Wiley and Sons (Asia) Pvt. Ltd., Singapore, 2002.*

- ✓ *Shanti Narayan, P. K. Mittal: Differential Calculus, S. Chand, 2014.*
- ✓ *R. J. T Bell: An elementary Treatise on coordinate geometry, MacMillan and Company Limited, 2005.*

Books for Reference:

- ✓ *James Stewart: Single Variable Calculus, Early Transcendental, 8th edition, Cengage Learning, 2016.*
- ✓ *G.B. Thomas and R. L. Finney: Calculus, 9th Ed., Pearson Education, Delhi, 2005.*
- ✓ *M. J. Strauss, G. L. Bradley and K. J. Smith: Calculus, 3rd edition, Dorling Kindersley (India) Pvt. Ltd. (Pearson Education), Delhi, 2007.*
- ✓ *Suggested digital platform: NPTEL/SWAYAM/MOOCs.*
- ✓ *e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org*

Core I: Introduction to Algebra & Number Theory 4 credit

Course Objectives:

To present a systematic introduction to number theory and a basic course on algebra.

Learning Outcomes:

After completing the course the student will be able to

- Understand the equivalence relations and concept of group with different examples.
- Understand the properties of cyclic groups, rings, and integral domain.
- Know divisibility and division algorithm and find *gcd* using Euclidean Algorithm.
- Solve linear Diophantine equations, find least common multiples,solve linear congruence applying the Chinese remainder theorem.

Unit I

Integers and equivalence relations**,** properties of integers, modular arithmetic, mathematical inductions, equivalence relations, Introduction to groups**,** symmetries of a square, the dihedral groups, definitions and examples of groups, elementary properties of groups, subgroups, examples of subgroups.

Unit II

Cyclic groups, properties of cyclic groups, classification of subgroups of cyclic groups, definitions and examples of normal subgroups, Introduction to rings, definition and examples of rings, properties of rings, subrings, definition and examples of integral domain and fields.

Unit III

Divisibility**,** division algorithms, prime and composite numbers, Fibonacci and Lucas numbers, Fermat numbers, greatest common divisor, Euclidean algorithm.

Unit IV

Fundamental theorem of arithmetic, least common multiple, linear Diophantine equations, congruence, linear congruence, Chinese remainder theorem, Wilson’s theorem, Fermat little theorem, Euler’s theorem.

Books Recommended:

- ✓ *Joseph A. Gallian, Contemporary Abstract Algebra (4th Edition), Narosa Publishing House, New Delhi, 1999.(IX Edition 2010).*
- ✓ *Thomas Koshy, Elementary Number Theory with Applications (2nd Edition), Academic Press, 2007.*

Books for Reference:

- ✓ *I. N. Herstein: Topics in Algebra, Wiley Eastern Limited, India, 1975.*
- ✓ *David M. Burton: Elementary Number Theory (6th Edition), Tata McGraw-Hill Edition, Indian Reprint, 2007.*
- ✓ *Suggested digital platform: NPTEL/SWAYAM/MOOCs.*
- ✓ *e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org.*

Core II: Programming and Data Structures with Lab 4 credit

Objective: The objective of the course is to learn the basics about C and C++ programming languages such as variables, data types, arrays, pointers, functions and classes etc. It also covers the concept of linear data structures like linked list, stack and queue.

Expected Outcome: On successful completion of the course, students should have a good understanding about the concept of C, object-oriented programming using C++ and be able to write basic C and C++ code. Students can also implement the linked list, stack and queue using both C and C++.

Unit I: Programming in C: Programming methodology, overview of C, Lexical elements, syntax rules, basic data types, operators, expressions, flow of control, function definitions, conditional execution, loops.

Unit II: One dimensional array, two dimensional arrays, sparse matrix, recursion, pointers, strings, preprocessor, file input/ output.

Unit III: Introduction to C++, variables and constant declarations, expressions, input using the extraction operator >> and cin, output using the insertion operator << and cout, Preprocessor directives, increment(++) and decrement(--) operators, operators, if-else statement, switch and break statements, loops, Continue statement, nested control statement. Functions, arrays.

Unit-IV: Data Structures: ADTs, linear data structures, linked list, stacks and queues, applications.

Lab Work: Execution of simple programmes using C and C++.

Recommended Texts:

1. Brian W. Kernighan and Dennis M. Ritchie: The C Programming Language.
2. Bruce Eckel: Thinking in C++.
3. Byron S. Gottfried: Theory and Problems of Programming with C.
4. A. Kelly, I. Pohl, A book on C, Pearson Education, 2000.
5. D. S. Malik: C++ Programming Language, Course Technology, Cengage Learning, India Edition, 2009.
6. E. Balaguruswami: Object oriented programming with C++, fifth edition, Tata McGraw Hill Education Pvt. Ltd.,2008.
7. R. Johnsonbaugh and M. Kalin-Applications Programming in ANSI C, Pearson Education.
8. S. B. Lippman and J. Lajoie, C++ Primer, 3rd Ed., Addison Wesley, 2000.
9. Bjarne Stroustrup, The C++ Programming Language, 3rd Ed., Addison Welsley, 2010.

Multidisciplinary: Discrete Mathematics 3 credit

Course Objectives:

The main objectives of this course are to introduce topics and techniques of counting principles, combinatorics, and graph theory to understand problems in almost all areas of knowledge.

Learning Outcomes: On the completion of this course, students will be able to

- Learn core ideas in logic and relations.
- Know the concept of the Pigeon-hole principle and solve recurrence relations.
- Learn lattices and Boolean algebra.
- Get a good knowledge of the basics of Graph theory.

UNIT-I

Propositional logic, proportional equivalences, predicates and quantifiers, nested quantifiers, rules of inference, methods of proof, relations and their properties, n- ary relations and their applications.

UNIT-II

The basic counting principle, The Pigeon-hole principle, generalized permutations and combinations, recurrence relations, counting using recurrence relations, solving linear homogeneous recurrence relations with constant coefficients, generating functions, solving recurrence relations using generating functions.

UNIT-III

Partially ordered sets, Hasse diagram of partially ordered sets, maps between ordered sets, duality principle, lattices, Boolean algebra .

UNIT-IV

Graphs, basic concepts and graph terminology, representing graphs and graph isomorphism, distance in a graph, cut vertices and cut edges, connectivity, Trees and Properties, Euler and Hamiltonian path, shortest-path problems, planar graphs and graph coloring.

Books Recommended:

- ✓ *Kenneth H. Rosen, Discrete Mathematics and Applications (Sixth Edition), Tata McGraw Hill Publications, 2007.*
- ✓ *Edgar G. Goodaire and Michael M. Parmenter, Discrete Mathematics with Graph Theory (2nd Edition), Pearson Education (Singapore) Pte. Ltd., Indian Reprint 2003.*

Books for Reference:

- ✓ *1. B A. Davey and H. A. Priestley, Introduction to Lattices and Order, Cambridge University Press, Cambridge, 1990.*
- ✓ *2. Rudolf Lidl and Gnter Pilz, Applied Abstract Algebra (2nd Edition), Undergraduate Texts in Mathematics, Springer (SIE), Indian reprint, 2004.*
- ✓ *3. Kevin Ferland-Discrete Mathematical Structures, Cengage Learning India Pvt. Ltd.,2009.*
- ✓ *Suggested digital platform: NPTEL/SWAYAM/MOOCs*
- ✓ *e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org*

AEC: Odia/Hindi/Sanskrit/Urdu 4 credit

Common Syllabus as prescribed by NEP-2020.

VAC: Environmental Science & Disaster Management 4 credit

Common Syllabus as prescribed by NEP-2020.

Semester-II

Core-I: Real Analysis-I 4 credit

Course Objective:

The objective of the course is to introduce the basics of real number system and the properties of sequence and series of real numbers. The ideas of completeness, least upper bound property, denseness, limit, continuity and uniform continuity will also be introduced. This is one of the core courses essential to start doing mathematics.

Learning Outcomes:

On successful completion of this course, students will be able to

- Learn basics of real number system and test countability of a set.
- Know on sequence of real numbers and their basic properties.
- Test convergence of an infinite series.
- Find limit and continuity of functions and test uniform continuity of functions.

Unit I

Finite and infinite sets, countable and uncountable sets, examples, algebraic and order Properties of R, uncountability of R, completeness property of **R,** applications of the supermom property, Intervals, nested interval property, denseness of rationals in R.

Unit II

Sequence and their limits, limit theorems, monotone sequences, monotone Convergence theorem, subsequences, divergence criteria, monotone subsequence theorem, Bolzano Weierstrass theorem for sequences, Cauchy sequence, Cauchy's convergence criterion.

Unit III

Infinite series, convergence and divergence of infinite series, Cauchy criterion, Tests for convergence: comparison test, limit comparison test, ratio test, Cauchy's nth root test, Raabe's test, integral test, alternating series, Leibniz test, absolute and conditional convergence.

Unit IV

Limits of functions, limit theorems, some extensions of limit concept, continuous functions and their combinations, continuous functions on intervals, boundedness theorem, maximum minimum theorem, intermediate value theorem, uniform continuity, examples, uniform continuity theorem.

Books Recommended:

- ✓ *R. G. Bartle and D. R. Sherbert, Introduction to Real Analysis, 3rd Edn., John Wiley and Sons (Asia) Pvt. Ltd., Singapore, 2002.*
- ✓ *G. Das and S. Pattanayak, Fundamentals of Mathematical Analysis, TMH Publishing Co., 30th reprints, 2021.*

Books for Reference:

- ✓ S. *C. Mallik and S. Arora, Mathematical Analysis, New Age International Publications.*
- ✓ *A. Kumar, S. Kumaresan, A basic course in Real Analysis, CRC Press, 2014.*
- ✓ *Brian S. Thomson, Andrew. M. Bruckner, and Judith B. Bruckner, Elementary Real Analysis, Prentice Hall, 2001.*
- ✓ *Gerald G. Bilodeau , Paul R. Thie, G. E. Keough, An Introduction to Analysis, Jones & Bartlett, Second Edition, 2010.*
- ✓ *e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org*
- ✓ *Suggested digital platform: NPTEL/SWAYAM/MOOCs.*

Core-I: Algebra-I 4 credit

Course Objectives:

To present a systematic and rigorous study on algebraic structures like groups, rings and some important results with their applications. After pursuing this course, one can opt for advanced topics in groups, rings and their applications to problems in physics, computer science and engineering.

Learning Outcomes:

After completing this course, students will able to

- Understand permutation groups with some results and application in Rubik's cube.

- Understand the concept of homomorphisms, isomorphisms, normal subgroups and factor groups.
- Explore more properties of rings and ideals rigorously.
- Get introduced to the concept of reducibility and irreducibility of polynomials and concept of unique factorization domain.

Unit I

Permutation groups, definition and notations, cyclic notation, properties of permutations, isomorphisms, definition and examples, Cayley's theorem, properties of isomorphisms, automorphisms, cosets, properties of cosets, Lagrange's theorem and consequences, an application of cosets to permutation groups, an application of cosets to Rubik's cube.

Unit II

External direct products, definition and examples, properties of external direct products, the group of units modulo n as an external direct product, applications, normal subgroups, factor groups, application of factor groups, internal direct products, group homomorphisms, definition and examples, properties of homomorphisms, the first isomorphism theorem.

Unit III

Characteristic of a ring, ideals, factor rings, prime ideals and maximal ideals, ring homomorphisms, definition and examples, the field of quotients, polynomial rings, notations and terminology, division algorithm and consequences.

Unit IV

Factorization of polynomials, reducibility test, irreducibility test, unique factorization in Z[x], divisibility in integral domains, irreducible, primes, unique factorization domain, Euclidean domain.

Books Recommended:

- ✓ *Joseph A. Gallian, Contemporary Abstract Algebra (9th Edition), Narosa Publishing House, New Delhi, 2010.*
- ✓ *I. N. Herstein, Topics in Algebra, Wiley Eastern Limited, India, 1975.*

Books for Reference:

- ✓ *John B. Fraleigh, A First Course in Abstract Algebra, 7th Ed., Pearson, 2002.*
- ✓ *D. S. Dummit, R. M. Foote, Abstract Algebra, Wiley-India edition, 2013.*
- ✓ *Joseph 1. Rotman, An Introduction to the Theory of Groups, 4th Ed., Springer Verlag, 1995.*
- ✓ *M. Artin, Abstract Algebra, 2nd Ed., Pearson, 2011.*

- ✓ *Suggested digital platform: NPTEL/SWAYAM/MOOCs.*
- ✓ *e-Learning Source http://ndl.iitkgp.ac.in ; http://ocw.mit.edu ; http://mathforum.org*Yu.

Core III: Computer Organization & Operating System 4 credit

Objectives: This course will discuss the basic concepts of computer architecture and organization that can help the students to have a clear view as to how a computer system works. Starting from the basics, the students will be introduced to the state-of-the-art in this field. Operating System is a computer software that manages the hardware components. It acts as an intermediary between the users and the hardware. It is responsible for managing the system resources and providing a smooth working environment for the users.

Expected Outcomes: This course will address all the fundamental points, starting from the foundations to the architectural issues to correlation with existing commercial operating systems. Students shall learn process management, processor management, memory management, storage management, user management, protection and security. As a subject, it is an amalgamation of the fields like computer architecture, and operating system. A course on operating systems is essential to equip the students for taking up the challenges in understanding and designing of computer systems.

Computer Organization

Unit-I: Introduction to computer architecture, Instruction set, Instruction set principles and trade offs, Computer arithmetic, ALU design, Assessing computer system performance, Amdahl's Law.

Unit-II: Pipelining, Pipeline control, pipeline hazards, Basics of caching, Cache mapping, virtual memory, Main memory, Disks and buses, Interfacing Input/ output devices to the memory, processor and operating system.

Operating System

Unit-III: Process Management (Processes, CPU Scheduling, critical section problem, semaphore, Dead lock- prevention and avoidance & detection & recovery).

Unit-IV: Storage Management (Memory management- paging & segmentation, virtual memory, file system interface), I/ O system, secondary - storage structure, protection and security. Case study of UNIX/ LINUX system.

Recommended Texts:

1. J. L. Hennessy, and D. A .Patterson, Computer Organization: The Hardware/Software Interface, Morgan Kaufman Publishers 1994.
2. J. L. Hennessy, and D. A .Patterson, Computer Architecture: A Quantitative Approach, Morgan Kaufman Publishers 1990.
3. A. Silberschatz & P. B. Galvin, Operating System concepts, John Wiley.
4. P. C. Bhatt, An Introduction to operating systems, PHI.

Multidisciplinary: Operation Research 3 credit

Course Objective: The Objective of the course is to introduce the basic concepts of Operational Research and linear programming to the students.

Unit I: Basics of Operational Research: Origin & Development of Operational Research, Definition and Meaning of Operational Research, Different Phases of an Operational Research Study, Scope and Limitations of Operational Research, Mathematical Modeling of Real Life Problems.

Unit II: Linear Programming: Introduction to Linear algebra. Solution of a system of Linear Equations, Linear independence and dependence of vectors, Concept of Basis, Basic Feasible solution, Convex sets. Extreme points, Hyperplanes and Halfspaces, Convex cones, Polyhedral sets and cones.

Unit III: Linear Programming Problem Formulation, solution by Graphical Method, Theory of Simplex Method, Simplex Algorithm, Two phase Method, Charnes-M Method, Degeneracy, Theory of Duality, Dual-simplex method.

References:

1. G. Hadley: Linear Programming. Narosa, Reprint, 2002.
2. Hamdy A. Taha: Operations Research-An Introduction, Prentice Hall, 9th Edition, 2010.
3. A. Ravindran, D. T. Phillips and James J. Solberg: Operations Research- Principles and Practice, John Wiley & Sons, 2005.
4. F.S. Hillier. G.J. Lieberman: Introduction to Operations Research- Concepts and Cases, 9th Edition, Tata Mc-Graw Hill, 2010.

AEC : English 4 credit

Common Syllabus as prescribed by NEP-2020.

SEC : Analytical Thinking and Logical Reasoning/ Introduction to Python 3 credit

Common Syllabus as prescribed by NEP-2020.

Second Year

Semester-III

Core-I Algebra-II 4 credit

Objectives: This course deals with group theory, ring theory and field. Some basics of ring theory like rings, subrings, ideals, ring homomorphisms and their properties are covered.This course is an integral part of any course on modern algebra.

Expected Outcomes: After completing this course, this will help students to continue more courses in advanced Ring theory modules, Galois groups.

Unit I: Groups: Symmetrics: Motivation for the definition of a group, dihedral groups, Binary operation on a set, axiomatic definition of a group and examples, the group of units of integers modulo n and connection with Euler's ϕ –function. **Elementary properties:** Uniqueness of identity and inverse, cancellation, etc; subgroups, order of a group, order of an element, finite groups. Homomorphisms, isomorphisms, Normal subgroups, kernels and images; kernels and normal subgroups. Quotient groups. Conjugation, linear and outer automorphisms. **Cyclic groups:** Classification; the structure of subgroups of a cyclic group. **Cosets:** Lagrange's theorem, theorems of Fermat and Euler.

Unit II: Permutation groups: Definition, cycle notation, representation as a product of disjoint cycles, generation by transposition, sign of a permutation, alternating group, Cayley's theorem.

Group actions on sets: Orbit, stabilizer, transitivity, orbit as a quotient space, orbits form a partition, class equation and its application to continuing problems, nilpotent and solvable groups, p-groups are nilpotent. Cauchy's theorem. Examples of GL(n,R) and its subgroups.

Unit III: Ring & Field: Motivation, definition, examples, basic properties, subrings. Ideals and factor rings: One-and two-sided ideals, factor rings: prime and maximal ideals in commutative rings: characterization in terms of properties of quotients. Ring homomorphisms: Kernels are ideals, first isomorphism theorem. Zero divisors: Integral domains, fields, finite domains are fields, the finite field Z/pZ. Field of quotients of an Integral domain. Polynomial ring over a ring: Division algorithm; remainder theorem; polynomial in F[X] of degree n has at most n roots. Principal ideal domains : Z and F[X]; prime ideals an maximal ideals in PIDs.

Unit IV: Factorization of polynomials: irreducible and reducibles, Z[X]: content of a polynomial, primitive polynomials, Gauss's lemma: product of primitives is primitive, primitive and irreducible over Q is irreducible, Irreducibility tests: reading modulo primes; Einsteins criterion, cyclotomic polynomials; irreducibility of a polynomial over F[X] being equivalent to it generating a prime ideal; Unique factorization in Z[X].

Recommended Texts:

1. J. A. Gallian, *Contemporary Abstract Algebra*, 4th edition, Narosa, Chapters 1-11.
2. M. Artin, *Algebra, Prentice-Hall of India*, Chapters 2, 5, 6.
3. I. N. Herstein, *Topics in algebra*, 2nd edition, 1975, Chapters 1,2.

Core-I: Ordinary Differential Equations 4 credit

Objectives: Differential Equations introduced by Leibnitz can model almost all Physical, Biological, Chemical systems in nature. The objective of this course is to familiarize the students with various methods of solving differential equations and to have a qualitative applications through models. The students have to solve problems to understand the methods.

Expected Outcomes: A student completing the course is able to solve differential equations and is able to model problems in nature using Ordinary Differential Equations. This is also prerequisite for studying the course in Partial Differential Equations and models dealing with Partial Differential Equations.

Unit-I: First order Ordinary differential equations: Basic concepts of DEs. Geometrical significant, Existance and Uniqueness of the solution, IVP and BVP, 1st order, 1st degree DEs, methods of solutions: Variable separable, Homogeneous, Reducible to homogeneous, exact, reducible to exact, linear, Bernolli, Riccali Equation.

Unit-II: Applications: Orthogonal trajectories and modeling, Various real world problems.

Unit-III: Second order ODEs, Homogeneous ODE with constant coefficients and variable coefficient, Nonhomogeneous ODEs: Solution by method of undetermined coefficient and variation of parameters.

Unit-IV: Series solution and special functions: Basic concept of power series, Radius of convergence, Legendre Equation and polynomials Bessel Equation and polynomials, Gamma & Beta function and their properties.

Recommended Texts:

1. E.A. Coddington, *An introduction to Ordinary Differential equations*, (Prentice Hall).
2. G. F. Simmons, *Differential equations*, (MCGraw Hill).
3. W. Hurewicz: *Lectures on Ordinary Differential Equations* (Dover Publications).
4. Martin Braun, *Differential Equations and their Applications*, Springer.
5. J Sinha Roy and S.Padhy, *Ordinary and Partial Differential Equation*, Kalyani Publisher.

6. G.F.Simmons and J.S.Robertson, *Differential Equations with Applications and Historical Notes*, 2nd Edition, (McGraw Hill).
7. R.V. Churchill & J.W.Brown, Complex variables and applications, MCGraw Hill.

Core-I: Analysis-II (Functions of Several Variables) 4 credit

Objectives: It represents the extension of calculus in one variable to calculus with functions of several variables. This course treats topics related to differential calculus in several variables, integration in several variables and vector calculus. Multivariate calculus has many applications in various areas such as pure mathematics, engineering and physics.

Expected Outcomes: Perform differential calculus operations on functions of several variables including continuity, partial derivatives and directional derivatives. Estimate multiple integrals in different coordinate systems including Cartesian, polar, cylindrical and spherical coordinates. Perform calculus operations on vector-valued functions. Study the use of the most important theorems of vector calculus, such as the Fundamental Theorem of Line Integrals, Green's Theorem, the Divergence Theorem, and Stokes' Theorem, etc.

Unit-I: Functions of several variables: Functions from $\mathbb{R}^m$ to $\mathbb{R}$ and from $\mathbb{R}^m$ to $\mathbb{R}^n$, Open set, Neighbourhood, Limit, Iterated limits, Continuity, Geometrical Interpretation and properties.

Unit-II: Partial derivatives: Geometrical Interpretation, Higher order partial derivatives, Clairaut's theorem, Chain rule, Directional derivatives and applications, Differentiability, Sufficient conditions for differentiability, Optimization, Stationary points, Local maxima and minima, Lagrange's method of multipliers.

Unit-III: Vector Calculus: Gradient of scalar field, Geometrical interpretation and applications, properties of gradient, Divergence of a vector field, Geometrical interpretation and properties, Curl of a vector field, Applications and properties.

Unit-IV: Multiple integrals: Line integral, change of variable, Jacobian, double and triple integrals, Reverse order, Surface integrals, Green's theorem, Stokes and Gauss divergence theorem.

Recommended Texts:

1. S. R. Ghorpade & B.V. Limaye: *A Course in Calculus and Real Analysis*, Springer.
2. T. M. Apostol: *Calculus vol. I & II*
3. W. Rudin: *Principles of Mathematical Analysis*
4. T. M. Apostol: *Mathematical Analysis*
5. EM Stein & Rami Shakarchi: *Fourier Analysis: An introduction*.

Core-II: Design and Analysis of Algorithms with Lab 4 credit

Objectives: To understand the importance of algorithm and its complexity. To analyze the complexity of an algorithm in terms of time and space complexities. To design and implement various programming paradigms and its complexity.

Course Outcome: Ability to analyze the time and space complexity, given an algorithm. Apply the techniques of algorithm in solving real world problems. Systematic development of an algorithm for solving a problems.

Unit I: Data structures: Binary trees, binary search trees, heaps, sets and disjoint sets union, graphs (representation, BFS, DFS).

Unit-II: Algorithms: The role of algorithms in computing, Introduction to design and analysis of algorithms, functions. Asymptotic notations, recurrences. Divide and conquer: (Heap sort, Quick sort, Lower bounds for sorting, counting sort, FFT, Strassen's matrix multiplications).

Unit-III: Dynamic programming: (Matrix Chain Multiplication, Floyd Warshall algorithm, Longest common subsequence), Greedy method: Fractional knapsack problem, (Huffman codes, Kruskal and Prim's algorithm for finding minimum spanning tree, Dijkstra's algorithm).

Unit-IV: Backtracking (8-queens problem, sum of subsets), Max flow, min cuts, Ford Fulkerson method, string matching (Rabin-Karp algorithm), NP-Completeness and approximation algorithms.

Lab Work: Implementation of the algorithms using C or C++.

Recommended Texts:

1. Dexter Kozen, *Algorithms*, Springer Verlag, 1992.
2. Thomas H. Cormen, Charles E. Leiesersen, Ronald L. Rivest, *Introduction to Algorithms*, MIT press, 2000.
3. Jon Kleinberg and Eva Tardos, *Algorithm Design*, Pearson/ Addison-wesley, 2006.
4. E. Horowitz, S. Sahni, and S. Rajasekharan, *Fundamental of Computer Algorithms*, Galgotia Publications, 2002.
5. A. Aho, J. Hopcroft and J. Ullman: *Data Structures and Algorithms*.
6. T. A. Standish: *Data Structure Techniques*, Addison Wesley.

Multidisciplinary: Probability 3 credit

Objectives:

1) To learn basic concepts of probability, conditional probability and independence, probability distribution of a discrete random variable.
2) To acquaint students with basic concepts of mathematical expectation for univariate and bivariate random variable and various standard discrete and continuous probability distributions such as discrete uniform, Bernoulli, Binomial and hypergeometric, normal, Beta, Gamma, Cauchy etc.

Expected outcomes:

1) Acquire ability to distinguish between random and non-random experiments.
2) Knowledge to conceptualize the probability of events including frequentist and axiomatic approach.
3) Knowledge related to concept discrete random variable and its probability distribution including expectation and moment.
4) Knowledge of important discrete and continuous probability distributions such as uniform, Bernoulli, Binomial, Poisson and hypergeometric., Norma, Gamma, Beta, Cauchy, Chi-square distribution.

Unit-I: Introduction to probability, Basic terminology, Classical definition of Probability and its limitations, Statistical (or empirical) definition of Probability, Kolmogorov's Axiomatic approach to Probability, Conditional probability and Bayes Theorem, Independent of events and related problems.

Unit-II: Introduction, definition and types of random variables, Distribution function, Mass and density functions, Expectation and its properties, Some inequalities based on expectation, Variance and Covariance and moment generating function, Standard discrete distributions: Bernoulli, Binomial, Poisson, Geometric and Hypergeometric.

Unit-III: Continuous probability distribution: Rectangular or uniform distribution, Triangular distribution, Normal distribution, Gamma distribution, Beta distribution of first and second kinds, Exponential distribution, Chi-square distribution, Cauchy distribution and related problems.

Unit-IV: Moment generating function, Cumulants, Chebychev's inequality, the weak law of large numbers, Central Limit Theorem, Probability generating function (p. g. f) and related problems.

Reference Book:

1. J.A. Rice, Mathematical Statistics with Data Analysis, Cengage Learning.

2. K. L. Chung : Elementary probability Theory, Narosa Publisher.

3. W. Feller: Introduction to Probability Theory and its Applications Vol 1

4. Sheldon Ross: A first course in Probability

5. V. K. Rohatgi: Introduction to Probability Theory and Mathematical Statistics.

6. R.A. Johnson, Miller & Freund, Probability and Statistics for Engineers, PHI learning.

VAC: Understanding India 3 credit

Common Syllabus as prescribed by NEP-2020.

Semester-IV

Core I: Numerical Methods with Lab 4 credit

Objectives: To explore complex systems, physicists, engineers, financiers and mathematicians require computational methods since mathematical models are only rarely solvable algebraically. Numerical methods, based upon sound computational mathematics, are the basic algorithms underpinning computer predictions in modern systems science. Such methods include techniques for simple solution of nonlinear equations, interpolation from the known to the unknown, linear algebra underlying systems of equations, solutions to ordinary differential equations to simulate systems, etc.

Expected Outcomes: Demonstrate the effect of error propagation, and the steps for its minimization Use numerical methods and how they are used to obtain approximate solutions. Apply numerical methods to obtain approximate solutions to mathematical problems. Derive numerical methods for various mathematical operations and tasks, such as interpolation, differentiation, integration, the solution of linear and nonlinear equations, and the solution of differential equations. Analyse and evaluate the accuracy of common numerical methods. Implement numerical methods in computer programming languages.

Unit-I: Nature of numerical computations: Significant digits, Errors and propagation, convergence and stability of numerical algorithms, efficiency and arithmetic:- complexity. **Solution of non-linear equations:** Iterative methods, Bisection, Newton, secant, Regula-Falsi methods, acceleration of convergence, Newton's methods for polynomials, quotient- difference algorithms.

Unit-II: Interpolation: Interpolation and interpolating polynomial and its construction using Lagrangian method and methods of differences, Iterated interpolation, Method of divided differences, Difference operators and relations, Inverse interpolation, Spline functions and their use.

Unit-III: Numerical integration and numerical solution to ODEs: Numerical integration, Newtonian and Gaussian quadrature method, integration formulae using finite differences, Romberg integration.

Unit-IV: Matrix computations-Numerical solutions of systems of linear equations, computation of inverse and eigenvalues of a matrix. Solutions of ordinary differential equations.

Lab Work: Programming Assignments

Recommended Texts:

1. K. Atkinsons: Numerical Analysis
2. Comte de Boor: Numerical Analysis

Core-I: Number Theory and Cryptography 4 credit

Objectives: The main objective of this course is to build up the basic theory of the integers, prime numbers and their primitive roots, the theory of congruence, quadratic reciprocity law and number theoretic functions, Fermat's last theorem, to acquire knowledge in cryptography specially in RSA encryption and decryption.

Expected Outcomes: Upon successful completion of this course students will able to know the basic definitions and theorems in number theory, to identify order of an integer, primitive roots, Euler's criterion, the Legendre symbol, Jacobi symbol and their properties, to understand modular arithmetic number-theoretic functions and apply them to cryptography.

Unit-I: Basic number theory: Divisibility, and primality, Greatest Common Divisor, Unique factorization and its consequences, Congruences(Basic properties, solving linear congruences, residue classes, Euler's phi function, Fermat's little theorem), Computing with large integers (basic integer arithmetic, integer exponentiation, computing in Z_n, Faster integer arithmetic), Euclid's algorithm (basic and extended), Computing modular inverses and Chinese remainder theorem, Hensel lifting, orders and primitive roots.

Unit-II: Overview of Cryptography, Affine cipher and its cryptanalysis, Shannon ciphers and perfect security, Computational ciphers and semantic security.
Stream ciphers: Pseudorandom generators(PRG), encryption with a PRG, linear generators, and the cryptanalysis of stream cipher.

Unit III: Block Ciphers: Basic definitions and properties, constructing block ciphers in practice-Data Encryption Standard(DES)(Algorithm, Challenges, drawbacks), triple DES, Advanced Encryption Standard(AES)(algorithm and its security), Using Block ciphers(pseudo random permutations(CRP) and functions (CRF)—definition and properties, security against chosen plain text attack (CPA).

Unit-IV: Principles of Public-Key Cryptosystems, The RSA cryptosystem, Primality testing, Discrete Logarithm Problem(DLP), ElGamal Crypto System, The digital signature, Elliptic curve over the reals, Finite fields, Elliptic curves modulo a prime, Properties of Elliptic curves.

Texts:
1.Victor Shoup, A Computational introduction to number theory and algebra,Cambridge University Press, 2005.
2. Dan Boneh and Victor Shoup, A Graduate Course in Applied Cryptography, verson 0.5, 2020,
3. Douglas Stinson , Cryptography : Theory and Practice, CRC Press, 2006, Chapters: 5, 6, 7.

References:
1. J. Katz, and Y. Lindell, Introduction to Modern Cryptography, Chapman and Hall/CRC, second edition.
2. A. Menezes, P. C. Van Oorschot, and S. A. Vanstans – Handbook of Applied Cryptography, CRC Press, 1997.
3. N. Koblitz – A Course in Number Theory and Cryptography, Springer Verlag
4. A. DAS, Computational Number Theory, CRC press.
5. D. M. Burton, Elementary Number Theory, McGrawHill Education, 2012.
6. A. Das, C. E.VENI Madhavan, Public Key Cryptography-Theory and Practice, Dorling Kindersley, 2009.

Core-I: Partial Differential Equations 4 credit

Objectives: Provide how to solve linear Partial Differential with different methods. Derive heat and wave equations in 2D and 3D, and obtain the solutions. Determine the solutions of PDEs subject to conditions at the boundary of the spatial domain and initial conditions.

Expected Outcome: Use the knowledge of partial differential equations (PDEs), modelling, the general structure of solutions, and analytic and numerical methods for solutions. Formulate physical problems as PDEs using conservation laws. Understand analogies between mathematical descriptions of different (wave) phenomena in physics and engineering. Classify PDEs, apply analytical methods, and physically interpret the solutions. Solve practical PDE problems with finite difference methods, implemented in code, and analyse the consistency, stability and convergence properties of such numerical methods.

Unit I: Introduction: Periodic function, Fourier series, even and odd functions, Half range expansions, Fourier series for arbitrary period, Applications, Fourier transform, PDEs, Types, Quasilinear PDEs, Solution of PDEs, Lagrange's multiplier method.

Unit II: Wave Equation: One dimension wave equation(modeling), solution by method of separation of variables, Eigenvalues and eigen functions, Normal forms, D'Alembert solution of wave equation, two dimensional wave equations and its solution.

Unit III: Heat Equation: One dimension heat equation(modeling), solution by method of separation of variables under laterally insulated and adiabatic conditions, Solution by using Fourier transform, Two dimensional heat equation and solution. **Laplace Equation:** Laplace equation in polar form, Harmonic functions, Solution of Laplace equation by method of separation of variable, Solution for a circular disk.

Unit IV: Linear Integral Equations: Linear integral equation of the first and second kind of Fredholm and Volterra type, Solutions with separable kernels. Characteristic numbers and eigenfunctions, resolvent kernel.

Recommended Texts:

1. Fritz John, *Partial Differential Equations*.
2. Phoolan Prasad and Renuka Ranindam, *Partial Differential Equations*.
3. J. Sinha Roy, S. Padhy, A Course on Ordinary and Partial Differential Equations, Kalyani Publishers.
4. Tyn Mint-U, Lokenath Debnath, Linear Partial Differential Equations for Scientists and Engineers, Fourth Edition, Birkhauser.

5. Lawrence Evans, Partial Differential Equations, Second Edition, Graduate Studies in Mathematics, AMS.
6. Abdul J. Jerry, Introduction to Integral Equations with Applications, 2nd Ed., Clarkson University Wiley Publishers, 1999.
7. Chambers, Ll. G., Integral Equations: A short Course,International Text Book Company Ltd., 1976.
8. R. P. Kanwal, Linear Integral Equations,2nd Ed., Birkhauser Bosten,1997.
9. Hochstadt Harry, Integral Equations, John Wiley & Sons,1989.

Core-III: Database Management System with Lab 4 credit

Objectives: At the end of the course, the students will be able to: Understand the basic concepts and the applications of database systems. Master the basics of SQL and construct queries using SQL. Understand the relational database design principles. Familiar with the basic issues of transaction processing and concurrency control. Familiar with database storage structures and access techniques.

Expected Outcomes: After completing this course the student must demonstrate the knowledge and ability to: Demonstrate the basic elements of a relational database management system.Identify the data models for relevant problems. Design entity relationship and convert entity relationship diagrams into RDBMS and formulate SQL queries on the respect data into RDBMS and formulate SQL queries on the data. Demonstrate their understanding of key notions of query evaluation and optimization techniques. Extend normalization for the development of application software‘s.

Unit-I: Overview of database systems, Introduction to database design, The relational model, Relational algebra and calculus, SQL (queries, constrains, Triggers).

Unit-II: Overview of storage and indexing, storing data - disks & files, Tree - structured indexing, overview of query evaluation, Evaluating relational operators, A typical relational query optimizer, schema refinement,

Unit-III: Functional dependencies, Normal forms, Physical database design and tuning, security and authorization.

Unit-IV: Laboratory work SQL

Recommended Texts:

1. R. Ramakrishnan and J. Gehrke - Database Management Systems - MC Grawhill - 3rd Edition 2003.

2. Elmarsi, Navathe: Fundamentals of Database System, Addison Wesley.

3. A. Silberschata, H. Korth, S. Sudarshan, Database System Concepts, Mc Grawhill.

Community Engagement and Services/Field Work/Internship: Field Work/Internship 4 credit

Semester-V

Core I: Statistics 4 credit

Objectives:

 -To understand point and interval estimations and characteristics of good estimators

 - Construct the confidence intervals for mean, variance and proportions

 -To familiar with confidence interval for different cases

 -Understand the probabilities of error for testing of hypothesis.

Expected Outcomes:

 -Explain the need to study the sampling distribution of a statistic

 -Use sampling distribution of mean and proportion to draw inferences about the population mean and population proportion

 -Calculate the error in sampling using sampling distribution, use central limit theorem to make inferences

 -Use chi-square, F and t-distributions to solve some problems of statistical inference

Unit-I: Sampling Theory: Introduction to sampling theory, types of sampling: purposive sampling, random sampling, stratified sampling, systematic sampling, parameter and statistic: sampling distribution of a statistic, standard error, utility of standard error, tests of significance: null and alternative hypotheses, errors in sampling, critical region and level of significance, procedure for testing of hypothesis, hypotheses concerning one mean, confidence intervals, inference concerning two means and related problems.

Unit-II- Inference concerning variance and proportions: The estimation of variances, hypotheses concerning one variance, two variances, confidence interval, estimation proportions, hypotheses concerning one proportion, two proportion, several proportions, analysis of rxc tables, goodness of fit, Analysis of Variance(ANOVA).

Unit-III-Statistical Inference: Introduction, characteristics of estimators: unbiasedness, consistency, efficiency and sufficiency. Minimum variance unbiased estimator, Cramer-Rao inequality, Complete family of distributions, Rao-Blackwell theorem, Methods of estimation and related problems.

Unit-IV: Theory of Attributes-Introduction, Notations and terminology, classes and class frequencies, consistency of data, Independence attributes, association of attributes and related problems.

Reference Text:

1) Miller and Freund: Probability and Statistics for Engineer, PHI Learning.
2) V. K. Rohatgi and A. K. Md. Ehsanes Saleh, An introduction to probability theory and statistics, 2nd edition, Wiley publisher.
3) S. C. Gupta, Fundamentals of Statistics, Himalaya Publishing House, 7th edition.

Core-I	Complex Analysis	4 credit

Objectives:

- To study the techniques of complex variables and functions together with their derivatives, contour integration and transformations.

- To study complex power series, classification of singularities, calculus of residues and its applications in the evaluation of integrals, and other concepts and properties.

Expected Outcomes:

- Students will be equipped with the understanding of the fundamental concepts of complex variable theory and skill of contour integration to evaluate complicated real integrals via residue calculus.

- Apply problem-solving using complex analysis techniques applied to diverse situations in physics, engineering and other mathematical contexts.

Unit-I: Regions in the complex plane, Function of complex variable, mapping, limit, continuity, differentiability, analytic functions, Cauchy-Riemann Equations, examples of analytic functions, harmonic functions, properties of analytic functions. Elementary functions: exponential function, trigonometric functions, hyperbolic functions, multivalued functions and its branches, logarithmic functions, complex exponents and inverse trigonometric and hyperbolic functions and related problems.

Unit-II: Contour integral, simply and multiply connected domain, Cauchy theorem, Cauchy integral formula, winding number, derivative of an analytic functions, Cauchy's inequality, Morera's theorem, Liouville's theorem, fundamental theorem of algebra, maximum Modulus principle with applications.

Unit-III: Power series: multiplication, division, Integration and differentiation of power series, radius of convergence, Taylor series and related problems. Conformal mapping: Introduction, conformality theorem, linear fractional transformations, Exponential transformation, trigonometric transformation and other related mapping.

Unit-IV: Zeros and singularities, Isolated and non-isolated singularities, Laurent series, Removable singularities, Poles and Essential Singularities, Laurent Expansion around an Isolated Singularity , Concept of residue and Residue Theorem. Evaluation of real integrals using Contour integrals.

Recommended Texts:

1. John B. Conway, Functions of one complex variable, Springer.
2. E. M. Stein & Rami Shakarchi, Complex Analysis, Vol.2.
3. T. W. Gamelin, Complex Analysis.

Core I: Optimization Theory 4 credit

Objectives: To understand the theory of optimization methods and algorithms developed for solving various types of optimization problems. To develop and promote research interest in applying optimization techniques in problems of Engineering and Technology. To apply the mathematical results and numerical techniques of optimization theory to concrete Engineering problems

Expected outcomes: Comprehend the techniques and applications of optimization technique. Analyse characteristics of a general linear programming problem. Apply basic concepts of mathematics to formulate an optimization problem. Analyse various methods of solving the unconstrained minimization problem. Analyse and appreciate variety of performance measures for various optimization problems.

Unit-I: Elementary Optimization: Univariate and multivariate optimization, constrained optimization. Linear programming: motivation and brief history, its formulation including examples from real life problems, graphical solution of LPP of two variables. Basic feasible solutions, extreme points and basic feasible solutions relationship, standard form of LPP, Simplex method, examples, artificial variables, Big M method (penalty method), two phase method.

Unit-II: Duality theory for LPP: Motivation to study duality in LPP, duality theorems and their economic interpretations, examples, complementary slackness theorem, finding solution of one problem from another, dual simplex method.

Applications of linear programming framework: Transportation problem, North West corner rule, Matrix minima method, Row minima method, column minima method, Vogel's Approximation Method (VAM), Optimal solution method, Modi method, stepping stone method, Assignment problem, Hungarian method, Travelling salesman Problem, examples, role of duality theory in attaining optimal solutions for both TP and AP problems.

Unit-III: Nonlinear programming problems: Unconstrained scalar differentiable nonlinear programming problems in R^n, steepest descent direction method, illustrations, and numerical difficulties associated with this technique, convergence analysis for example convex quadratic optimization problems. Introduction to nonlinear programming, concept of feasible solution, Lagrangian method, Karush-Kuhn Tucker conditions, constraint qualifications, highlight the role of convexity. Numerical implementation of simplex method and steepest descent method.

Unit-IV: Game Theory: formulation of two person zero sum games, solving two person zero sum games, games with mixed strategies, graphical solution procedure and related problems.

Recommended Texts:

1. D. G. Luenberger, *Linear and Nonlinear programming*, 3rd ed, Springer 2008.
2. Hamdy A. Taha, Operations Research, An Introduction, 8th Ed., Prentice-Hall India, 2006.
3. K. Lange, *Optimization*, Springer Verlag, 2004.
4. S. Chandra, Jayadeva, A. Mehra, *Numerical Optimization with Applications*, Narosa, 2009.
5. R. J. Venderbei, *Linear programming: Foundation and extensions*, 2nd ed, Springer, 2001.
6. G. Hadley, *Linear programming*, Narosa, 2002.
7. Mokhtar S. Bazaraa, John J. Jarvis and Hanif D. Sherali, Linear Programming and Network Flows, 2nd Ed., John Wiley and Sons, India, 2004.
8. F. S. Hillier and G. J. Lieberman, Introduction to Operations Research, 9th Ed., Tata McGraw Hill, Singapore, 2009.

Core-II: Theory of Computation & Compiler Design 4 credit

Objectives: This course covers the theory of Computation. Topics include fundamental concepts in automata theory and formal languages including finite automaton, regular expression, grammar, formal language, pushdown automaton, and Turing machine. Not only do they form basic models of computation, they are also the foundation of many branches of computer science, e.g. compilers, software engineering, pattern recognition, NLP, AI, game design, IOT, etc. The properties of these models will be studied and various rigorous techniques for analyzing and comparing them will be discussed.

Expected Outcomes: On completion of this course, students will be able to: Learn the theoretical foundation of computer science to be useful in real life applications. Know to design lexical analyzer which is the first step in the compiler or interpreter of every programming language, which reads a file and produces sequence of tokens by using DFA. To develop different mathematical and statistical models to be useful in the field of machine learning, robotics, image and video processing etc. Simulations of these models using C, Python or any programming language are also interesting and useful.

Unit-I: Regular Languages: Finite automata, Nondeterminism, regular expressions, Non regular Languages. Application in Compiler Design.

Unit-II: Context-Free Languages: Context free grammars, Push down automata, Non-context-free languages. Application in Compiler Design.

Unit-III: The church Turing Thesis: Turing machines, Variants of Turing machines, the definition of algorithm. Decidability: Decidable languages, The Halting problem. Reducibility: Undecidable problems from language theory, Mapping reducibility.

Unit-IV: Complexity Theory: Measuring complexity, The P and NP completeness.

Recommended Texts:

1. M. Sipser - *Introduction to the theory of computation* - Thomson Learning - 2001, Chapter: 1, 2, 3, 4, 5, 7.
2. J. E. Hopcroft, Motwani, J. D. Ullman - *Introduction to Automata Theory, Languages and Computation*, 2nd Edition, Pearson Education, 2001.

SEC: Computer Network and Software Engineering 3 credit

Objectives: To introduce the concept, terminologies, and technologies used in modern data communication and computer networking. To identify importance of OSI and TCP/IP models. To make students to get familiarized with different protocols and network components. Able to analyze the concept of local area networks, their topologies, protocols and applications. Be able to evaluate the performance of competing network technologies and protocols. Develop an ability to use the techniques, skills, and modern engineering tools and processes necessary for software engineering.

Course Outcomes: Illustrate the working principle of different protocols at different layers. The student installs and configures workstations, servers and networked printers, inter networking devices such as switches and routers. Analyze the requirements for a given organizational structure and select the most appropriate networking architecture and technologies. Practice and building the skills of subnetting and routing mechanisms. To be familiar with contemporary issues in networking technologies, network tools and network programming. Allow the student to gain expertise in some specific areas of networking such as the design and maintenance of individual networks. Analyze, specify and design the topological and routing strategies for an IP based networking infrastructure. Specify and identify deficiencies in existing protocols, and then go onto formulate new and better protocols. Develop an ability to apply software engineering perspective through software design and construction, requirements analysis, verification, and validation, to develop solutions to modern problems such as security, data science, and systems engineering.

Computer Networks

Unit I: Introduction, Network models, Physical layer (Signals, digital and analogue transmission, Multiplexing, circuit switching), Data Link Layer (Error detection and correction, Data link control and Protocols, PPP, Local area networks, connecting LANS, Cellular telephone and satellite network), Network Layer (Host-to-host delivery - inter networking, addressing, and routing), Network layer protocols),

Unit-II: Transport Layer (Process to process Delivery : VDP and TCP, Congestions control and quality of service), Application Layer (Client server models, Domain name system, SMTP, FTP, HTTP and WWW), Security (Cryptography, Manage security, user authentication and key management).

Software Engineering

Unit III: Introduction, Software life cycle modules, Requirements Analysis and specification, software design, Function oriented software design. Coding and Testing, Software reliability and quality management, Computer Aided Software Engineering, Software maintenance. Introduction to object oriented Analysis and Design, Iterative Development and the unified process, case study-The next-Gen POS, Inception, Understanding Requirements, Use case Model, Identifying other requirements, Elaboration, Use case Model.

Unit-IV: Drawing system sequence diagrams, Visualizing concepts, Adding Associations, Adding attributes, Adding details with operation contracts, Interaction diagram notation. PATTERNS, GRASP, Creating design class diagrams, GOF Design pattern Planning and project queues comments on iterative development and the UP, Rational Unified Process.

Text Book:

1. Crag Larman: Applying UML and Patterns-An introduction OOAP & D and the Unified process, Pearson Education Asia.
2. Rajib Mail: Fundamentals of software Engineering, PHI.

Recommended Texts:

1. B. A. Forouzan- *Data Communications and Networking*, TMH, 3rd Edition, 2004.
2. A. S. Tanenbaum, *Computer Networks*, Prentice Hall
3. W. Stallings, *Computer Networking with Internet Protocols and Technology* Prentice Hall.

VAC: Understanding Odisha	3 credit

Common Syllabus as prescribed by NEP-2020.

Semester-VI

Core-I: Differential Geometry (Curves and Surfaces)	4 credit

Objective: To study of geometry of curves, surfaces, and their higher dimensional analogues using the methods of calculus. Introduce the concepts such as regular curves, arc length, and parametrization, etc. Also to study the concepts of Simple surfaces, tangent vectors and tangent spaces, and first and second fundamental forms.

Expected Outcome: Describe the basic concepts of geometry and topology of curves, surfaces, and their higher dimensional analogues. Examine local and global properties of a solid body.

Unit-I: Introduction to differential geometry-curves, curves in $\mathbb{R}^2$ and $\mathbb{R}^3$, Parametrization, Regular curve, Arc length, Properties of Cycloid, Cissoid, Folium of descartes, Logarithmic spiral, Curvature, Radius of curvature, Osculating plane, Torsion of a space curve.

Unit-II: Serret-Frenet formula for space curves, existence theorem for space curves, Involute, Evolute, Inverse and implicit function theorems.

Unit-III: Surfaces in $\mathbb{R}^3$, Regular surface, Two dimensional manifolds, Change of parameters, Jacobian, tangent spaces, Diffiomorphism, Reparametrization Theorem, First fundamental form and related problems.

Unit-IV: Orientation of a surfaces, Second fundamental form and the Gauss map, Mean curvature and scalar curvature, Stokes formula, Gauss-Bonnet Theorem.

Recommended Texts:

1. Do Carmo, Differential Geometry, Academic Press.
2. T. J. Willmore, Differential Geometry.
3. A. N. Pressley, Elementary Differential Geometry, Springer.

Core-I: Topology 4 credit

Objectives: The objective of this course is to impart knowledge on opensets, closed sets, continuous functions, connectedness and compactness.

Expected Outcomes: On successful completion of the course students will learn to work with abstract topological spaces. This is a foundation course for all analysis course in future.

Unit-I: Infinite sets and Axiom of Choice, Well-ordered sets, Well-ordering theorem, Topological Spaces Basis and sub-basis for a topology, Order and product topologies, Closed sets, limit and interior points, Continuous functions.

Unit-II: The metric topology, Connected spaces, Connected subspaces of the real line, Components and local connectedness, Arc wise connectedness, Arc wise connectedness in Euclidean spaces. Compact spaces, Compact subspaces of the real line.

Unit-III: Compactness and finite intersection properties, Compactness in metric spaces, Limit point compactness, Sequential compactness and its equivalence in metric spaces,Local compactness and One point compactification. Separation and Countability axioms.

Unit-IV: Topological spaces based on these axioms such as T_0, T_1, T_2 etc., Lindeloff space, Separable space and Normal spaces and their basic properties. The Uryshon Lemma, The Uryshonmetrization theorem, The Tychonoff theorem, Completely regular spaces.

Prescribed Text Book:

1. James R. Munkres: Topology, Second Edition, Prentice-Hall. (Relevant topics prescribed above from chapters 1, 2, 3, 4, and 5.)

Reference Books:

2. W. J. Pervin: Foundations of General Topology, Academic Press 1964.
3. J. Dugundji: Topology, UBS, 1999.
4. G. F. Simmons: Introduction to Topology and Modern Analysis, Tata McGraw-Hill, 1963.
5. M. A. Armstrong: Basic Topology, Springer, 1983.
6. G. E. Bredon: Topology and Geometry, Springer GTM 139, 1995.

Core-III: Machine Learning with Lab 4 credit

Objectives:

1. Differentiate between supervised,unsupervised machine learning approaches
2. Ability to choose appropriate machine learning algorithm for solving a problem
3. Design and adapt existing machine learning algorithms to suit applications
4. Understand the underlying mathematical relationships across various machine learning algorithms
5. Design and implement machine learning algorithms to real world applications

Expected Outcomes: Upon successful completion of this course students will able to understand the concepts and can implement simple and multiple linear regression, Logistic regression, Linear discriminate analysis, Ridge regression, Cross-validation and boot strap, Fitting classification and regression trees, K-nearest neighbours, Principal component analysis and K-means clustering algorithm.

<u>Predictive Analytics</u>

Unit-I: Linear Methods for Regression and Classification: Overview of supervised learning, Linear regression models and least squares, Multiple regression, Multiple outputs, Subset selection, Ridge regression, Lasso regression, Linear Discriminant Analysis, Logistic regression, Principal Component Analysis.

Unit-II: Model Assesment and Selection: Bias, Variance, and model complexity, Bias-variance trade off, Estimate of In-sample prediction error, Effective number of parameters, Bayesian approach and BIC, Cross- validation, Boot strap methods, conditional or expected test error.

Additive Models, Trees, and Boosting: Generalized additive models, Regression and classification trees, Boosting methods-exponential loss and AdaBoost, Random forests and analysis.

Unit-III: Neural Networks(NN), Support Vector Machines(SVM), and K-nearest Neighbor: Fitting neural networks, Back propagation, Issues in training NN, SVM for classification, Reproducing Kernels, SVM for regression, K-nearest –Neighbour classifiers, clustering and K-means.

<u>Inferential Statistics and Prescriptive analytics</u>

Unit-IV: Assessing Performance of a classification Algorithm(t-test, McNemar's test, Paired ttest, paired F-test), Analysis of Variance.

<u>Lab work</u>

Implementation of following methods using Python or Matlab:

Simple and multiple linear regression, Logistic regression, Linear discriminate analysis, Ridge regression, Cross-validation and boot strap, Fitting classification and regression trees, K-nearest neighbours, Principal component analysis, K-means clustering.

Recommended Texts:

1. Trevor Hastie, Robert Tibshirani, Jerome Friedman , The Elements of Statistical Learning-Data Mining, Inference, and Prediction, Second Edition , Springer Verlag, 2009.

2. G. James, D. Witten, T. Hastie, R. Tibshirani-An introduction to statistical learning with applications in R,Springer,2013.

3. E. Alpaydin, Introduction to Machine Learning, Prentice Hall Of India, 2010.

References:

1. C. M. Bishop –Pattern Recognition and Machine Learning, Springer, 2006 2. L. Wasserman-All of statistics Texts 1 and 2 and reference 2 are available on line.
2. Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow 3rd Edition, Kindle Edition by Aurélien Géron.
3. Machine Learning with PyTorch and Scikit-Learn, 2022 by Sebastian Raschka.
4. Practical Machine Learning for Computer Vision: End-to-End Machine Learning for Images by Valliappa Lakshmanan, Martin Görner, Ryan Gillard.

SEC: IoT with Lab 3 credit

Objectives: "IoT for Mathematicians" is designed to bridge the gap between mathematical principles and real-world applications by exploring the exciting intersection of the Internet of Things (IoT) and mathematics. This course aims to empower mathematicians with the knowledge and skills to leverage IoT technologies for solving complex problems, conducting data-driven research, and building innovative applications.

Expected Outcomes: The lectures will include a mix of presentations, hands-on exercises, group discussions, and collaborative projects. Students will have the opportunity to work with IoT hardware, analyze data, and gain practical experience in applying mathematical concepts to IoT scenarios.

By the end of the course, students will have a solid foundation in IoT concepts, hands-on experience with IoT devices, and insights into the role of mathematics in shaping the future of IoT applications.

Unit-I: Introduction to IoT: Sensing, Actuation, Basics of Networking, Communication Protocols, Sensor Networks, Machine-to-Machine Communications, Interoperability in IoT,

Unit-II: Introduction to Arduino Programming, Integration of Sensors and Actuators with Arduino, Introduction to Python programming.

Unit-III: Introduction to Raspberry Pi, Implementation of IoT with Raspberry Pi, Introduction to SDN, SDN for IoT, Data Handling and Analytics, Cloud Computing, Sensor-Cloud, Fog Computing,

Unit-IV: Smart Cities and Smart Homes, Connected Vehicles, Smart Grid, Industrial IoT, Case Study: Agriculture, Healthcare, Activity Monitoring.

Books Recommended:

1. "The Internet of Things: Enabling Technologies, Platforms, and Use Cases", by Pethuru Raj and Anupama C. Raman (CRC Press)

"Internet of Things: A Hands-on Approach", by Arshdeep Bahga and Vijay Madisetti (Universities Press)

VAC: Ethics and Values 3 credit

Common Syllabus as prescribed by NEP-2020.

Fourth Year

Semester-VII

Core I: Computational Linear Algebra with Lab 4 credit

Objectives: The objective of this course is to acquaint students with various matrix multiplcation algorithms, numerical methods of finding solution of different system of linear equations, matrix factorizations, pseudo inverse etc. which arises in different branches of science.

Expected Outcome: The student will use this knowledge wherever he/she goes after undergraduate program. It has applications in data science, finance mathematics, industrial mathematics, bio mathematics and students can handle physical problems to find an approximated solution.

Unit-I: Matrix Multiplication: Basic algorithm and notations, Structure and efficiency, Block matrices and algorithms, Fast matrix - vector products, Vectorization and locality, Parallel matrix multiplication. Kronecker Product, Triangular systems, Diagonal Dominance and symmetry, Banded systems, Symmetric indefinite systems, Block tridiagonal systems, Vandermonde systems, Visualization of different matrix computations and their Applications in Data Science.

Unit-II: Vector Space & Subspaces, Solving AX = 0 & AX = b, Linear Independence, Basis and Dimension, The Four Fundamental Subspaces, Linear Transformation, Orthogonal Vectors, Projections to a line, Projections and Least Squares, Orthogonal Bases & Gram-Schmidt.

Eigenvalues and eigenvectors, Diagonalization of a Matrix, Complex Matrices, Similarity Transformation, Test for positive definiteness, Vector norms, Matrix norms, Singular Value Decomposition.

Unit-III: Errors in Computations, Computing Norm, Inner product and solution of Triangular System, Efficiency and stability of an Algorithm, Conditioning, Perturbation Analysis, Perturbation Analysis of linear system.

LU Factorization Methods, Scaling, Effects of the condition number on accuracy, computing and estimating the condition number, Parallel LU, Orthogonalization and Least Square, Householder's matrices and QR factorization, Classical and Modified Gram-Schmidt Algorithm for QR factorization, Solution of AX = b using QR Factorization, Projections Using QR Factorization, SVD and its computation.

Unit-IV: Existence and uniqueness of least square solutions, Pseudoinverse and the least square problem, sensitivity of the least square problem, Computational Methods for Over determined Problems, Computing selected eigenvalues and eigenvectors, Jacobi, Gauss-Seidel and SOR methods.

Functions of Matrices: Eigen value methods, Approximation methods, The matrix exponential, The sign, Square root and Log of a matrix, Tensors.

Texts:

1. Gene. H. Golub, Charles F. Van Loan, Matrix Computations, Fourth Edition, The Johns Hopkins University Press, Baltimore 2013.
2. G. Strang, Linear Algebra for Everyone, Wellesley-Cambridge Press, 2020.

Reference Books:

1. G. Strang, Linear Algebra and Its Applications, 4th Edition, Cengage Learning, 2006.
2. J. W. Demmel, Applied Numerical Linear Algebra, SIAM, 1997.
3. P. G. Ciarlet, Introduction to numerical linear algebra and optimization.
4. William Ford, Numerical linear algebra with applications, AP.
5. Richard Bronson, G.B. Costa, Matrix Methods: Applied Linear Algebra, Third Edition, AP.

Core I: Probability Statistics, and Stochastic Processes with Lab (in R) 4 credit

Objectives:

- To acquaint students with basic concepts of bivariate probability distribution.
- To manage situations involving more than one random variable and function of random variable in engineering applications.
- To understand the concept of characteristic function and their properties
- To understand the concept of mode of stochastic convergence, law of large numbers and its application to i.i.d cases.

Expected Outcomes:

- Solve the problems involving multiple random variables.
- Explain the concept of stochastic convergence and check for the convergence of a given sequences of random variables.
- Find the expressions for the characteristic function of a random variable and verify its properties.
- Apply the various laws of large numbers to sequences of random variables.

Unit-I: Two-dimensional random variables: Joint probability mass function, marginal probability function, conditional probability function, distribution function, conditional distribution function, conditional probability mass and density function, stochastic independence, generalization to n-dimensional random variable and related problem, moments on bivariate probability distribution, condition expectation and variance.

Unit-II: Characteristic function (c.f.) : concept, definition, elementary properties, uniform continuity and non-negative definiteness of characteristic function. Uniqueness theorem, Inversion theorem (without proof), Fourier inversion theorem, Convolution theorem, Levy's continuity theorem (without proof) and Bochners theorem (without proof).

Unit-III: Stochastic convergence of sequence of random variables: Convergence distribution, convergence in probability, almost sure convergence, convergence in rth mean, weak and complete convergence of distribution functions and their interrelations. Slutsky's theorem and its applications. Helly-Bray lemma (statement only) and related problems.

Unit-IV: Stochastic series of sequence of random variables: - Law of large numbers, weak law of large numbers due to Bernoulli, Markov, Khintchin. Strong law of large numbers- Kolmogorov's strong law of large numbers for independent and i.i.d random variables (statement and applications only). Classical Central limit theorem: De- Moivre Laplace Central limit theorem, Statement of Liaponouff's Central limit theorem and Lindberg-Levy Central limit theorem. Applications of various central limit theorems.

Reference Text:

1) B. R. Bhat : Modern Probability Theory, 2nd Edn., Wiley Eastern Ltd., New Delhi (1991).
2) R. G. Laha and V. K. Rohatgi: Probability Theory, John Wiley, New York (1979).
3) V. K. Rohatgi and Ehsanes Saleh: An Introduction to Probability Theory and Mathematical Statistics, Wiley Eastern Ltd (2014).
4) W. Feller: Introduction to Probability Theory and Its Applications Vol. 1 and 2, John Wiley, New York (1968).
5) Miller and Freund: Probability and Statistics for Engineer, PHI Learning.

Core-I: Principles of Programming (Python and C++) 4 credit

Unit I: Getting Started with Python and C++: Introduction, Basic data types, Control Structures: if, if-elif-else, for, while, break, continue. Data Structures: Lists, Tuples, Sets, and Dictionaries.

Unit II: Functions: Defining functions, Calling functions, Passing arguments, Keyword arguments, Default arguments, Variable-length arguments, Anonymous functions, Function returning values, Scope of the variables in a function - global & local variables, User defined functions.Modules & Packages: Creating modules, Import statement, from import statement, name spacing; Creating user defined packages.

Unit III: File Handling: Handling of csv file.Object Oriented Programming: Features, classes and objects, creating class and object, Using a class & its methods; Exception Handling: Errors, Types of exception, try, except and finally, assertion.

Unit IV: Numpy: Introduction, Creating of arrays and matrices;Introduction to Panda: Creating a data frame, Dealing with row & columns, Indexing & selection data, Working with missing data, Iterating over rows and columns; Merging and joining DataFrame objects, Concatenation, Reshaping DataFrame objects, Pivoting, Data transformation, permutation & sampling, Data aggregation and GroupBy operations; Creating data frame from CSV file; Matplotlib: Creating effective visual representations of your data, Avoiding common pitfalls.

Text Books:

1. Donal.E.Knuth, Art of Computer Programming,Volume-1, Third Edition, 1997

2. R. N. Rao, Core Python Programming, 2nd Edition, Dreamtech Press, 2018.

3. J. V. Guttag, Introduction to Computation and Programming Using Python, with Application to Understanding Data, 2nd Edition, PHI Learning, 2016.

4. W. McKinney, Python for Data Analysis: Data Wrangling with Pandas, NumPy, and Ipython, 2nd Edition, O'Reilly Media, 2017.

Reference Books:

1. P. Barry, Head First Python, 2nd Edition, O'Reilly Media, 2010.

2. A. Downey, Think Python : How to Think Like a Computer Scientist, 2nd Edition, Green Tea Press, 2015.

3. J. Zelle, Python Programming : An Introduction To Computer Science, 3rd Edition, Franklin, Beedle & Associates, 2016.

4. Brian W. Kernighan and Dennis M. Ritchie: The C Programming Language.

5. Bruce Eckel: Thinking in C++

Core-I: Advanced Optimization with Lab 4 Credit

Unit-I: One Dimensional Optimization: Function comparison methods, Polynomial interpolation, Iterative methods. Gradient Based Optimization Methods (I): Calculus on R^n , Method of steepest descend, Stochastic gradient descent, Conjugate gradient method, Conjugate gradient for non quadratic objective function, The generalized reduced gradient method, Gradient projection method.

Unit-II: Gradient Based Optimization Methods (II): Newton type methods(Newton's method, Marquardt's method), The Quasi-Newton method, BFGS, L-BFGS.

UNIT-III: Convex sets, convex functions, First and second order conditions for convexity, Jensen`s inequality, Convex optimization problems, Characterization of optimal solutions, Necessary optimal conditions for constrained optimization problems(Fritz John and KKT), Lagrange multiplier method.

Unit-IV: Sufficient conditions for optimality, KKT sufficient conditions, Constraint qualification, Second order optimality conditions, KKT second order optimality necessary conditions, Penalty function techniques, Primal dual method.

Books Recommended

Texts

1. M. C. Joshi, K. M. Moudgalya, Optimization: Theory and Practice, Narosa Publishing House, 2004.

2. Stephen Boyd, Lieven Vandenberghe, Convex Optimization, Cambridge University Press

References

1. J. A. Snyman, Practical Mathematical Optimization, Springer Sciences, 2005.

2. Nocedal J, Wright S.J., Numerical Optimization, Springer.

3. Convex Optimization Overview, Lecture notes by Zico Kotler, Stanford University.

4. Optimality Conditions for Constrained Optimization Problems, Lecture notes by Robert M. Freund, MIT.

5. Vivek S Borkar: Elementary Convexity with Optimization, Hindustan Book Agency.

Core-II: Fluid Dynamics 4 credit

Objectives: The ability to identify, reflect upon, evaluate and apply different types of information and knowledge to form independent judgments. Analytical, logical thinking and conclusions based on quantitative information will be the main objective of learning this subject.

Course Outcomes: At the end of the course, learners would acquire competency in the following skills.

1. Define Real Fluids, Ideal Fluids, Streamlines, Path lines, Vortex Lines, Source, Sinks, Doublets, Potential Flow, Irrotational Flow, 2D Flow, 3D Flow, Impulsive Motion .

2. Derive Equation of Continuity, Euler's equation of motion, Bernoulli's equation, Milne Thomson Circle Theorem, Theorem of Blasius. Explain Axisymmetric flows, Karman Vortex Street.

3. Prepare Conditions at boundary of two inviscid Immiscible Fluid, Two-Dimensional Image system. Application of Circle Theorem.

4. Analyze fluid motion in General. Discuss Steady & Unsteady Flow, Compressible & Incompressible Fluid, Viscous & Inviscid Fluid, Sources, sinks & doublets.

5. Evaluate the velocity potential, streamlines, path lines, equi-potential surface, steam function, complex potential for two dimensional, irrotational, incompressible flow.

6. Determine the relation between local and particle rate of change, Develop Stokes stream function, Determine the flow characteristics, hydrodynamical aspects of Conformal transformation, pressure at a point in a fluid.

UNIT I: KINEMATICS Kinematics of fluids in motion: Real fluids and ideal fluids, velocity of a fluid at a point, streamlines and path lines, Steady and unsteady flows. The velocity potential, the vorticity vector, Local and particle rates of change, the equation of continuity, worked examples, acceleration of a point of a fluid.

UNIT II: MOTION OF A FLUID Equations of motion of a fluid: pressure at a point in a fluid at rest, Pressure at a point in a moving fluid, Conditions at a boundary of two inviscid Immiscible fluids, Euler's equations of motion, Bernoulli's equation, worked examples, some flows involving axial symmetry, Some special two-dimensional flows, Impulsive motion.

UNIT III: TWO DIMENSIONAL FLOWS Some two-dimensional flows: Meaning of two-dimensional flow, use of cylindrical polar coordinates, The stream function. The complex potential for two-dimensional irrotational, incompressible flow, complex velocity potential for standard two dimensional flows, uniform stream, line sources and line sinks, line doublets, line vertices, worked examples. Two- dimensional image systems, The Milne Thomson circle theorem, some application of the circle theorem, extension of the circle theorem, the theorem of blasius, the use of conformal transformation – some hydro dynamical aspects of conformal transformation worked example, vortex rows – single infinite rows of line vortices, The karman vortex street.

UNIT IV: THREE DIMENSIONAL FLOWS Some three-dimensional flows: Introduction, sources, sinks and doublets, Images in a rigid infinite plane, Axi-symmetric flows, stokes stream function, some special form of the stream function for axi-symmetric irrotational motions.

REFERENCE BOOKS:

1. F. Chorlton, Textbook of Fluid Dynamics, CBS Publication and Distribution, 2004.

2. M. D. Raisinghania, Fluid Dynamics, S. Chand, 2008.

3. G. K. Batchelor, An Introduction to Fluid Mechanics, Foundation Books,1984.

Semester-VIII

Core-I: Functional Analysis 4 Credit

Objectives: Functional Analysis has wide ranging applications in several areas of mathematics, especially in the modern approach to the study of partial differential equations. The proposed course will cover all the material usually dealt with in any basic course of Functional Analysis. Starting from normed linear spaces, we will study all the important theorems, with applications, in the theory of Banach and Hilbert spaces. One important feature of the proposed course is the detailed treatment of weak topologies.

Course Outcomes: Students will learn Hilbert spaces and Banach spaces. Students will be able to understand the concept of dimension of a Hilbert space, bounded linear transformations, norms, inner products, dual spaces and their difference from the finite dimensional cases. Students should know about p, Lp spaces, dual spaces and their properties. Students should understand the fundamental theorems as mentioned in the syllabus.

Unit-I: Normed linear spaces, Riesz lemma, characterization of finite-dimensional spaces, Banach spaces. Operator norm, continuity and boundedness of linear maps on a normed linear space. Baire's theorem and its consequence.

Unit-II: Hahn-Banach theorems, uniform boundedness principle, divergence of Fourier series, closed graph theorem, open mapping theorem and some applications.

Unit-III: Duals spaces, weak and weak* convergence, adjoint of an operator. Inner product spaces, orthonormal set, Gram-Schmidt ortho-normalization, Bessel's inequality, orthonormal basis, separable Hilbert spaces. Orthonormal complements, orthogonal projections, projection theorem, Riesz representation theorem.

Unit-IV: Adjoint, normal, unitary, self-adjoint operators, compact operators. Spectral theorem for compact self-adjoint operators, statement of the spectral theorem for bounded self-adjoint operators.

Text Book:

1. B. V. Limaye, Functional Analysis, 2nd edition, Wiley Eastern, 1996.
2. Rajendra Bhatia: Notes on Functional Analysis, Hindustan Book Agency.

Reference Books:

1. J. B. Conway: A course in functional analysis, Graduate Texts in Mathematics, 96., Springer-Verlag, 1990.
2. Erwin Kreyszig: Introductory functional analysis with applications, Wiley India.
3. Christopher Heil: Metrics, Norms, Inner Products, and Operator Theory, Birkhäuser.
4. W. Rudin: Functional analysis, McGraw-Hill, Inc., 1991.
5. George Bachman and Lawrence Narici: Functional Analysis, Dover Publications
6. K. Yosida: Functional analysis, Grundlehren der Mathematischen Wissenschaften, Springer-Verlag, 1980.

Core-I: Artificial Intelligence 4 Credit

Unit I: Artificial Intelligence: Introduction, Intelligent Agents: Agents & Environments, Concept of Rationality, Nature & Structure of Agents.

Unit II: Problem Solving: Solving Problems by Searching, Classical Search, Adversarial Search, Constraint Satisfaction Problems. Knowledge, Reasoning and planning: Logical agents.

Unit III: First order logic, Inference in First order logic. Classical planning, Knowledge Representation: Uncertain Knowledge and Reasoning: Probabilistic Reasoning, Learning from Examples, Knowledge in learning;

Unit IV: Types of AI, Generative AI, Language models, Latest AI topics.

Prescribed Text Books

1. Stuart Russell and Peter Norving, "Artificial Intelligence: A Modern Approach", Third Edition, 2010, Pearson Education, New Delhi.

Reference Books

1. Elanie A. Rich and Kevin Knight, "*Artificial Intelligence*", 3rd Edition, 2009, McGraw-Hill Education (India), New Delhi.

2. Nills J. Nilsson, "*Artificial Intelligence: A New Synthesis*" 2nd Edition, 2000,Elsiver India Publications, New Delhi.

3. Michael Negnevitsky, "*Artificial Intelligence: A Guide to Intelligent Systems*", Second Edition, 2005, Pearson Education, Inc. New Delhi.

4. Dan W. Patterson, "*Introduction to Artificial Intelligence and Expert Systems*",1st Edition, 1996, PHI Learning Pvt. Ltd., New Delhi.

5. Ben Coppin, "*Artificial Intelligence Illuminated*", 2005, Narosa Publication, New Delhi. ISBN: 978-81-7319-671-3.

Core-I: Advanced Data Structures with Lab 4 Credit

Course Objective:

• The student should be able to choose appropriate data structures, understand the ADT/libraries, and use it to design algorithms for a specific problem.

• To familiarize students with advanced paradigms and data structure used to solve algorithmic problems.

• Introduce students to the advanced methods of designing and analysing algorithms and recent developments in algorithmic design.

• The student should be able to understand different classes of problems concerning their computation difficulties, choose appropriate algorithms and use it for a specific problem.

Course Outcome: Upon successful completion of this course, the student should learn:

• Develop and analyse algorithms for symbol table, red-black trees, B-trees and Splay trees.

• Develop algorithms for text processing applications and identify suitable data structures and develop algorithms for computational geometry problems.

• Determine the appropriate data structure for solving a particular set of problems.

• Categorize the different problems in various classes according to their complexity and develop an insight of recent activities in the field of the advanced data structure and algorithms.

Unit I: Dictionaries: Definition, Dictionary Abstract Data Type, Implementation of Dictionaries. Skip Lists: Need for Randomizing Data Structures and Algorithms, Search and Update Operations on Skip Lists, Probabilistic Analysis of Skip Lists, Deterministic Skip Lists. Trees: Red Black Trees, 2-3 Trees, B-Trees, Splay trees, Fibonacci Heaps, Van Emde Boas Priority Queues.

Unit II: Text Processing: Sting Operations, Brute-Force Pattern Matching, The BoyerMoore Algorithm, The Knuth-Morris-Pratt Algorithm, Rabin-Karp Fingerprinting Algorithm, Standard Tries, Compressed Tries, Suffix Tries, The Huffman Coding Algorithm. Computational Geometry: One

Dimensional Range Searching, Two Dimensional) 2 Range Searching, constructing a Priority Search Tree, Searching a Priority Search Tree, Priority Range Trees, Quadtrees, k-D Trees, Convex Hull, Line-segment Intersection. Sweep Lines.

Unit-III: Graph Matching: Algorithm to compute maximum matching. Characterization of maximum matching by augmenting paths, Edmond's Blossom algorithm to compute augmenting path. Flow-Networks: Maxflow-mincut theorem, Ford-Fulkerson Method to compute maximum flow, Edmond-Karp maximum-flow algorithm. Matrix Computations: Strassen's algorithm and introduction to divide and conquer paradigm, inverse of a triangular matrix, relation between the time complexities of basic matrix operations, LUP-decomposition.

Unit-IV: Linear Programming: Geometry of the feasibility region and Simplex algorithm, Formulation of Problems as Linear Programs. Duality. Simplex, Interior Point, Ellipsoid Algorithms. Number Theory and Algebra: Preliminaries, Polynomial roots and factors, Primality testing (Proof of PRIMALITY NP) NP-completeness: Examples, proof of NP-hardness and NP-completeness. Approximation algorithms: Greedy Approximation Algorithms, Vertex Cover, Wiring, TSP.

Books:

1. Thomas H. Cormen, Charles E. Leiserson, R.L. Rivest.. Introduction to Algorithms, Prentice Hall of India Publications.

2. Mark Allen Weiss, Data Structures and Algorithm Analysis in C++, 2nd Edition, Pearson, 2004.

3. Algorithm Design by Kleinberg and Tardos, Pearson.

4. The Design and Analysis of Computer Algorithms" by Aho, Hopcroft, Ullman.

5. Merc De-Berg eta al. Computational Geometry: Algorithms and Applications, 3rd Edition, Springer.

Core-I: Numerical Solution of Partial Differential Equations 4 Credit

Unit I: Solution of first order ordinary differential equations Approximate Solution: Picard Iteration Method, Taylor Series method.

Unit II: Numerical Solution: Euler method; Algorithm; Example; analysis.

Unit III: Modified Euler Method: Algorithm; Example; analysis

Unit IV: Runge Kutta methods, Second Order methods, Fourth Order Runge Kutta methods, Higher Order Runge Kutta methods

References:

1. Bradie B A Friendly Introduction to Numerical Anaysis Pearson Education,2007

2. Burden RL, Faires J D Numerical Analysis Cengage Learning, 2007

3. Chapra SC, Canale, R P Numerical Methods for Engineers Tata McGraw Hill, 2003

4. Gerald C.F., Wheatley P O Applied Numerical analysis, Addison Wesley, 1998

Core-II: Project/ Any one course from NPTEL not overlap with existing courses 4 Credit

Fifth Year

Semester-IX

Core I: Advanced Machine Learning with Lab 4 Credit

Unit-I: Generative models for discrete data (Bayesian concept learning, Naïve Bayes classifier), Gaussian discriminant analysis, Inference in jointly Gaussian distributions, Bayesian statistics, Bayesian linear regression, General linear models and exponential family. Softmax regression.

Unit-II: Mixture models and EM algorithm, Sparse linear models, Review of SVM for classification and regression, Multiclass SVM, Basic kernels, Kernels for texts and strings. Kernels for generative models, Gaussian Processes for regression.

Unit-III: Probabilistic Graphical Models: DIRECTED Graphical models(Bayesian networks), Markov and Hidden Markov Models, Markov Random fields, Conditional Random fields, Exact inference for graphical models-variable elimination.

Unit-IV: Neural Network: Model of a neuron, Least Mean Square Algorithm, Perceptron(Learning algorithm, Convergence theorem), Multilayer Perceptron and back propagation(BPA) , Methods of acceleration of convergence of BPA.

Dimensionality reduction (Kernel PCA, Independent Component analysis, LLE, t-SNE, Feature selection), Spectral clustering. Collaborative filtering methods.

Lab work

Implementation of the following using python:

1. Naïve Bayes classifier
2. Softmax regression
3. EM algorithm and Gaussian mixture model for anomaly detection ,and clustering
4. SVM for multiclass classification (ex. Document classification, sequence classification, etc.)
5. SVM for non-linear regression
6. Bayesian networks
7. Hidden Markov models
8. Sum-product variable elimination algorithm
9. Perceptron learning algorithm
10. Back propagation algorithm
11. Kernel PCA and feature selection algorithm
12. Spectral clustering
13. Collaborative filtering method.

Books Recommended:

1. Kevin P. Murphy, Probabilistic Machine Learning – an Introduction , MIT Press, 2022.

2. Kevin P. Murphy, Probabilistic Machine Learning – advanced topics, MIT Press, 2022.
3. Christopher Bishop, Pattern Recognition and Machine Learning, Springer, 2007.
4. Simon Haykin, Neural Network – a comprehensive foundation, Pearson Education-1994.
5. Tom Mitchel, Machine Learning – McGraw Hill Science,1997.

Core I: Algebraic Geometry 4 credit

Objectives: Algebraic geometry is a branch of mathematics which uses abstract algebraic techniques, mainly from commutative algebra, to solve geometrical problems. Classically, it studies zeros of multivariate polynomials; the modern approach generalizes this in a few different aspects.

Course Outcomes: Algebraic geometry occupies a central place in modern mathematics and learners can grasp its multiple conceptual connections with such diverse fields as complex analysis, topology and number theory.

Unit I: Introduction to algebraic geometry, prime ideals and primary decompositions.

Unit II: Ideals in polynomial rings, Hilbert basis theorem, Noether normalization theorem.

Unit III: Hilbert's Nullstellensatz, Projective varieties.

Unit IV: Algebraic curves, Bezout's theorem, Elementary dimension theory.

Recommended Texts:

1. M. Reid, Undergraduate Algebraic Geometry, Cambridge.

2. Cox, Little and O'Shea: Ideals, Varieties and Algorithms, Springer.

Core I: Simulation Modeling 4 credit

Unit I: Overview of mathematical modeling, types of mathematical models and methods to solve the same; Discrete time linear models – Fibonacci rabbit model, cell-growth model, prey-predator model; Analytical solution methods and stability analysis of system of linear difference equations; Graphical solution – cobweb diagrams; Discrete time age structured model – Leslie Model; Jury's stability test; Numerical methods to find eigen values – power method and LR method.

Unit II: Discrete time non-linear models- different cell division models, prey-predator model; Stability of non-linear discrete time models; Logistic difference equation; Bifurcation diagrams. Introduction to continuous time models – limitations & advantage of discrete time model, need of continuous time models.

Unit III: Continuous time single species model – Allee effect; Continuous time models – Lotka Volterra competition model, prey predator models, Epidemic model, Rumor model, Varying Gravity model, Tumor model, Vegetation in a desert model etc.

Unit IV: Discrete models: Difference Equation, Stability Analysis, Population models, Bank account models, Economic model, Pollutant model, Mathematical model of the Dynamics of Alcohol, Linear predator-prey model, Forensic model, Drug delivery model, Lanchester's combat model, Two species completion model

Books and references

1. Sandip Banerjee, Mathematical Modeling: Models, Analysis and Applications (second edition), CRC Press, Routledge, Taylor & Francis Group (2022).

Elective I (To be chosen from Group A) 4 credit

To be chosen from Group A

Core II: Solid Mechanics 4 credit

Objectives: This is the course where deformation of solid bodies and the underlying concepts are introduced to undergraduate students. The course begins by building foundation of the concepts of stress and strain in three-dimensional deformable bodies. It further uses these concepts to study extension, torsion and bending of beams. The one-dimensional theory of beams are also introduced. Also discusses various theories of failure which are critical for design of machine elements in industry.

Course Outcomes: At the end of the course, learners would acquire competency in various theories and application of the topic Solid Mechanics.

Unit I: Mathematical preliminaries and notation; Concept of Traction vector; Concept of Stress tensor, Stress tensor and its representation in Cartesian coordinate system; Transformation of stress matrix; Equations of equilibrium; Symmetry of stress tensor, State of stress in simple cases; Principal stress components and principal planes; Maximizing shear component of traction; Mohr's circle.

Unit II: Stress invariants; Octahedral Plane; Decomposition of stress tensor; Concept of strain and strain tensor, Longitudinal, shear and volumetric strains; Local infinitesimal rotation; Strain compatibility condition, Linear stress-strain relation for isotropic bodies.

Unit III: Relation between material constants, Stress and strain matrices in cylindrical coordinate system; Equations of equilibrium in cylindrical coordinate system. Axisymmetric deformations: combined extension-torsion-inflation of a cylinder, Bending of beams having symmetrical and non-symmetrical cross-section.

Unit IV: Shear center, Shear flow in thin and open cross-section beams; Euler Bernouli and Timoshenko beam theories; beam buckling, Energy methods, Reciprocal relations, Castigliano's theorem, Deflection of straight and curved beams using energy method, Various theories of failure and their application.

Texts:
1. Advanced Mechanics of Solids (LS Srinath) Stength of Materials, Parts I & II (S. Timoshenko)

References:
1. E. P. Popov, Engineering Mechanics of Solids, Prentice Hall, 1998.

1. F. P. Beer, E. R. Johnston (Jr.) and J.T. DeWolf, Mechanics of Materials, Tata McGraw Hill, 2005.

2. S. H. Crandall, N. C. Dahl, and T. J. Lardner, An Introduction to The Mechanics Of Solids, 2nd Ed., Tata McGraw Hill, 2008.

3. S. P. Timoshenko, Strength of Materials, Vols. 1 & 2, CBS Publishers, 1986.

4. H. Shames and J. M. Pitarresi, Introduction to Solid Mechanics, Prentice Hall of India, 2003.

5. J. M. Gere, Mechanics of Materials, Thomson Brooks/Cole, 2006.

Semester-X

Core-I: Lebesgue Measure & Integration 4 credit

Objectives: Lebesgue Measure & Integration is an advanced topic in mathematics. The proposed course will cover all the abstract concepts of Lebesgue measure, Measurable functions, Lebesgue integration etc.

Course Outcomes: Students will learn Riemann integration and Lebesgue integration. Students will be able to understand the concept of Product sigma algebras, Product measures, Fubini's theorem in Rn.

Unit-I: Construction of Lebesgue measure, Measurable functions, Lebesgue integration.Monotone convergence theorem, dominated convergence theorem, Fatou's lemma.

Unit-II: Comparison of Riemann integration and Lebesgue integration, Lp(Rn) spaces (completeness, dense subsets, notion of separability).

Unit-III: Product sigma algebras, Product measures, Fubini's theorem in Rn(at least statement with examples). Characterization of continuous linear functionals on Lp spaces, Functions of bounded variation.

Unit-IV: Absolutely continuous functions, Fundamental theorem of Calculus. Abstract measures and integration, signed measure, Radon Nikodym theorem, complex measures, Riesz representation theorem.

Reference Texts:

1. Stein and Shakarchi: Real analysis (Measure theory and integration.
2. W. Rudin: Real and Complex Analysis
3. G. B. Folland: Real Analysis, Modem techniques and their applications.
4. H.L. Royden: Real Analysis
5. R. Wheeden and A. Zygmund: Measure and Integral: An introduction to Real Analysis.

Elective II (To be chosen from Group B) 4 credit

To be chosen from Group B

Community Engagement and Services/Field Work/Internship 12 credit

Research/Any two courses from NPTEL not overlap with existing courses + one Reading course

S9-C1-P4: Core-I: Elective Papers Group-A

A1. Bioinformatics 4 credit

Unit I: Molecular Biology Primer. Restriction mapping algorithm, Motif finding problem, Algorithms for motif finding (brute force, branch-and-bound and greedy)

Unit II: Edit distance and alignment, Global and local sequence alignment, multiple sequence alignment, Gene Prediction.

Unit III: DNA sequencing, shortest superstring problem, sequencing by hybridization (SBH), SBH as Hamiltonian and Eulerian path problem, Fragment Assembly problem.

Unit IV: Distance and character based methods for phylogenetics.

Recommended Texts:

1. N. C. Jones and P. A. Bavzner, An introduction to Bioinformatic algorithms, MIJ Press,2004. Relevant parts of chapters 2,4,5,6,8 and 10.
2. Dan E Krane, M. L. Baymer, Fundamental concepts of Bioinformatics, Pearson Education, 2003.
3. D. Gusfied, Algorithms on strings, Tress and sequences, Computer Science and computational Biology, Cambridge University Press, 1997.
4. M. S. Waterman, Introduction to computational Biology, Chapman Hall, 19995.

A2. Computational Fluid Dynamics 4 credit

Unit I: Introduction: Conservation equation; mass; momentum and energy equations; convective forms of the equations and general description.

Classification and Overview of Numerical Methods: Classification into various types of equation; parabolic elliptic and hyperbolic; boundary and initial conditions; over view of numerical methods.

Unit II: Finite Difference Technique: Finite difference methods; different means for formulating finite difference equation; Taylor series expansion, integration over element, local function method; treatment of boundary conditions; boundary layer treatment; variable property; interface and free surface treatment; accuracy of f.d. method.

Finite Volume Technique: Finite volume methods; different types of finite volume grids; approximation of surface and volume integrals; interpolation methods; central, upwind and hybrid formulations and comparison for convection-diffusion problem.

Unit III: Finite Element Methods: Finite element methods; Rayleigh-Ritz, Galerkin and Least square methods; interpolation functions; one and two dimensional elements; applications.

Methods of Solution:Solution of finite difference equations; iterative methods; matrix inversion methods;ADI method; operator splitting; fast Fourier transform.

Time integration Methods: Single and multilevel methods; predictor corrector methods; stability analysis;Applications to transient conduction and advection diffusion problems.

Unit IV: Numerical Grid Generation: Numerical grid generation; basic ideas; transformation and mapping.

Navier-Stokes Equations:Explicit and implicit methods;SIMPLE type methods; fractional step methods.

Turbulence modeling: Reynolds averaged Navier-Stokes equations, RANS modeling, DNS and LES.

Text Books:

1. Ferziger, J. H. and Peric, M.(2003). Computational Methods for Fluid Dynamics. Third Edition,SpringerVerlag,Berlin.

2. Versteeg, H.K. and Malalasekara, W.(2008). Introduction to Computational Fluid Dynamics: The Finite Volume Method.Second Edition (Indian Reprint) Pearson Education.
3. Anderson, D.A., Tannehill, J.C. and Pletcher, R.H.(1997). Computational Fluid Mechanics and Heat Transfer. Taylor & Francis.

A3. Computational Finance 4 credit

Unit-I: Introduction: Investment and markets, Typical investment problems; MeanVariance Portfolio Theory: Asset return, random variables, random returns, portfolio mean and variance, the feasible set, the Markowitz model, the two-fund theorem, inclusion of risk-free asset, the one fund theorem.

Unit-II: Capital Asset Pricing Model: Market equilibrium, the capital market line, Pricing Model, Security Market Line, Divestment implications, Performance evaluation, CAPM pricing formula; Models and Data: Factor model, CAPM as a Factor Model, Arbitrage Pricing theory, data and statistics.

Forwards and Futures: Forward contracts, Forward prices, Value of forward contract, Basics of futures contracts, Futures prices, Relation to expected spot price, Perfect hedge, Minimum variance hedge. Options, The No Arbitrage Principle, option and futures market. Option Pricing by Monte Carlo Simulation.

Unit-III: Stochastic Differential Equations: Stochastic Ito Processes, Wiener Process, Stochastic differential equation, Ito integral, Ito Lemma, and Applications in Stock Market, The Black-Scholes Equation: Derivation of the Black-Scholes Equation, Solution of the Black-Scholes Equation, Closed Form Solutions of European Call and Put Options, Hedging Portfolios: The Greeks, hedging, Implied Volatility.

Unit-IV: Option Pricing by Partial Differential Equations: Classification of PDEs, Finite Difference Methods for Parabolic Equations (An Explicit Method, An Implicit method, Crank-Nicolson Method), Option Pricing by the Heat Equation, Pricing American Options (Projected SOR Method for American Options).

Lab Work

Implementations of the following:

I. (a) Markowitz model

(b) Computing the minimum variance portfolio using two fund theorem.

(c) Computing the minimum variance portfolio using one fund theorem.

II.(a) Computing the beta of a portfolio CAPM and hence draw the security market line.

(b) Computing the market return using Multi factor model

(c) Computing the price of an asset using arbitrage pricing theory.

III. (a) Computing the value of forwards and futures using appropriate data.

(b) Computing the option price using Monte Carlo Option pricing model.

IV. (a) Computing the price of European put and call option using Black-Scholes(BS) formula

(b) Computing implied volatility using BS formula

(c) Computing the Greeks and using those hedging a portfolio.

V. (a) Computing the pricing of a European option using explicit finite difference method.

(b) Computing the pricing of a European option using implicit finite difference method.

(c) Computing the pricing of a European option using Crank-Nicholson finite difference method.

(d) Computing the pricing of an American option using projected SOR method.

Text Books:

(For Units 1, 2)

T1: D. G. Luenberger, Investment Science, 2nd Edition, Oxford University Press, 2014.

For unit 3 : T1 and T2 :

T2: J. C. Hull and S. Basu, Options, Future and Other Derivatives, 10th Edition, Pearson, 2018.

(For units 4 and 5)

T3: O. Ugur, An Introduction to Computational Finance, 1st Edition, Imperial College Press, 2009.

Reference Books:

R1. E. J. Elton, M. J. Gruber, S. J. Brown, and W. N. Goetzmann, Modern Portfolio Theory and Investment Analysis, 7th Edition, John Wiley & Sons, 2007.

R2. Z. Bodie, A. Kane, A. J. Marcus, and P. Mohanty, Investments, 11th Edition, McGraw-Hill Education, 2019.

R3. A. Hirsa, Computational Methods in Finance, Chapman & Hall/CRC Press, 2013.

R4. P. Wilmott, Option Pricing : Mathematical Models and Computation, 1st Edition, Oxford Financial Press, 1993.

R5. L. Clewlow and C. Strickland, Implementing Derivative Models, John Wiley & Sons, 1998.

A4. Computational Modelling of Financial Derivatives 4 credit

Unit-I: Construction of finite difference schemes for Laplace and heat equation. Solution of Tri diagonal system of linear equations, iterative methods (Jacobi Successive over relaxation) Introduction to stability and convergence of finite difference method, crank Nicholson and ADI methods.

Unit-II: The Black Scholes (B.S.) Model: Derivation of B.S. equation using no arbitrage argument, options dividend paying equities, Derivation of B.S. formula for calls, Puts and simple digitals, obtaining formulae for Greeks and their numerical computation, Finite Difference method for solution of B.S. equation.

Unit-III: Simple generalization of B. S. model (Dividend payments, time dependent parameters), Early exercise and American options (Perpetual American call and put, general payoff, local solutions), American option problem as free boundary problems, Finite difference method for American options, Monte-Carlo simulation.

Unit-IV: Exotic and path dependent options: General introduction, Barrier options, Strongly path dependent options, Asian options, Look back options, Multi Asset options, Numerical implementation. Extensions of B-S. Model: Defects in B-S Models, Discrete hedging, Transaction costs, stochastic volatility. Jump diffusion, Crash modelling.

Books Recommended:

Text: Paul Wilmott: Paul Wilmott on quantitative finance John Wiley – 2006

Reference Books:

1. *Quantitative Methods in Derivative pricing - an introduction to computational Finance, D. A. Tavella , John Wiley – 2002.*
2. *The concepts and practice of mathematical finance, M. S. Joshi, Cambridge Univ. Press - 2003.*
3. *Derivative Securities and Difference Methods, Y. Zhu, X. Wu, F. Chern, Springer Verlag- 2004.*
4. *Numerical Solution of PDE, G.D. Smith, CUP.*

A5. Computer Vision 4 credit

Unit-I Introduction to computer vision, Human vision, color spaces, and transformations, Image formation: Geometric primitives, 2D transformations, 3D transformations, 3D rotations, 3D to 2D projections, Lens distortions, Parametric transformations, Mesh-based warping, Image processing: Point operators, Linear filtering, More neighborhood operators, Fourier transformations.

Unit-II Interpolation and Optimization: Pyramids and wavelets, Image blending, Model fitting and optimization: Scattered data interpolation, Varational methods and regularization, Markov random field and application. Convolutional neural networks: Application to digit classification, Network architectures, model zoos, Visualizing weights and activations, Adversarial examples, self-supervised learning. Recognition: Object detection, Semantic segmentation.

Unit-III Feature detection and matching: Points and patches, Edges and contours with applications, Lines and vanishing points: Hough transformation, Segmentation: Graph-based segmentation, Mean shift, Image alignment and stitching: Pairwise alignment and application, Image stitching and application.

Motion estimation: Translational alignment, parametric motion and application, Spline-based motion and application, Optical flow: deep learning approaches and application, Layered motion and application. Depth estimation: Epipolar geometry, Sparse correspondence, Dense correspondence, Local methods, Global optimization, Deep neural networks, Multi-view stereo.

Unit-IV Structure from motion and SLAM : Geometric intrinsic calibration, Pose estimation, Two-frame structure from motion, Multi-frame structure from motion, simultaneous localization and mapping(SLAM) , 3D reconstruction: Shape from X , 3D scanning, Computational photography: Photometric calibration, High dynamic range imaging, Super-resolution, denoising, and blur removal. Image matting and composing, Hole filling and inpainting.

Text Books:

1. R Szeliski, **Computer vision: algorithms and applications**, 2nd edition,2021,springer, szeliski.org/book

Reference Books:

1. D.A. Forsyth, J Ponce, **Computer vision: a modern approach,** 2nd Edition, Pearson, 2012.
2. R Hartley, A Zisserman, **Multiple view geometry in Computer vision**, 2nd Edition, Cambridge University Press, 2005.
3. R. C. Gonzalez, R.E. Woods, R.E., Digital **image processing**, 3rd Edition, Pearson Education, 2002.

Online Reference Material(s):

1. https://www.cs.cornell.edu/courses/cs6670/2011sp/lectures/lectures.html
2. http://www.cs.cmu.edu/~16385/
3. http://web.stanford.edu/class/cs223b/syllabus.html
4. https://www2.eecs.berkeley.edu/Research/Projects/CS/vision/classes/cs280_s99/
5. https://onlinecourses.nptel.ac.in/noc21_ee23/preview

A6. Finite Elements: Theory and Algorithms 4 credit

Unit I: Generalized (weak) derivatives, Sobolev norms and associated spaces, inner-product spaces,

Unit II: Hilbert spaces, construction of finite element spaces, mapped finite elements, two- and three-dimensional finite elements, Interpolation and discretization error, variational formulation of second order elliptic boundary value problems,

Unit III: Finite element algorithms and implementation for linear elasticity, Mindlin-Reissner plate problem,

Unit IV: Two-dimensional stationary incompressible Navier-Stokes equations systems in fluid mechanics.

References:

1. Sashikumaar Ganesan, Lutz Tobiska: Finite elements: Theory and Algorithms, Cambridge-IISc Series, Cambridge University Press, 2017.

2. Dietrich Braess, Finite Elements: Theory, Fast Solvers, and Applications in Solid Mechanics, Cambridge University Press, 3rd ed., 2007.

3. Susanne C. Brenner, Ridgway Scott, The Mathematical Theory of Finite Element Methods, Springer-Verlag, 3rd ed., 2008.

A7. Image & Video Processing 4 Credit

Unit I: Computer Graphics: Development of computer Graphics: Raster Scan and Random Scan graphics storages, displays processors and character generators, colour display techniques, interactive input/output devices. Points, lines and curves: Scan conversion, line-drawing algorithms. Circle and ellipse generation, polygon filling anti aliasing.

Unit II: Two-dimensional viewing: Coordinate systems, linear transformations, line and polygon clipping algorithms. Image Processing: Fundamentals of Image processing and Image Transforms: Basic steps of Image processing system sampling and quantization of an Image – Basic relationship between pixels Image Transforms: 2 – D Discrete Fourier Transform, Discrete Cosine Transform (DCT), Discrete Wavelet transforms. Image Processing Techniques: Image Enhancement: Spatial Domain methods: Histogram Processing, Fundamentals of Spatial Filtering, Smoothing Spatial filters, Sharpening Spatial filters Frequency Domain methods: Basics of filtering in frequency domain, image smoothing, image sharpening, selective filtering

Unit III: Image Segmentation: Segmentation concepts, point, line and Edge detection, Thresholding, region based segmentation Image Compression Image compression fundamentals – coding Redundancy, spatial and temporal redundancy. Compression models : Lossy and Lossless, Huffmann coding, Arithmetic coding, LZW coding, run length coding, Bit Plane coding, transform coding, predictive coding , wavelet coding, JPEG standards

Unit IV: Video Processing: Basic Steps of Video Processing: Analog video, Digital Video, Time varying Image Formation models : 3D motion models, Geometric Image formation , Photometric Image formation, sampling of video signals, filtering operations 2-D Motion Estimation: Optical flow, general methodologies, pixel based motion estimation, Block matching algorithm, Mesh based motion Estimation, global Motion Estimation, Region based motion estimation, multi resolution motion estimation. Waveform based coding, Block based transform coding, predictive coding, Application of motion estimation in video coding.

Books Recommended:

1. D. Hearn and M. P. Baker, Computer Graphics, 2nd Ed., Prentice–Hall of India, 2004.
2. J. D. Foley, A van Dam, S. K. Feiner and J. F. Hughes, Computer Graphics: Principles and ractices, 2nd Ed., Addison-Wesley, MA, 1990.
3. D. F. Rogers, Procedural Elements in Computer Graphics, 2nd Ed., McGraw Hill Book Company, 2001.
4. D. F. Rogers and A. J. Admas, Mathematical Elements in Computer Graphics, 2nd Ed., McGraw Hill Book Company, 1990.
5. Gonzaleze and Woods ,"Digital Image Processing ", 3rd edition , Pearson.
6. Yao Wang, Jorn Ostermann, Ya-Qin Zhang, 'Video Processing and Communications', Prentice Hall, 2002.
7. Alan C.Bovik, 'The Essential Guide to Video Processing', Elsevier Science, edition 2, 2009.
8. A. Murat Tekalp, 'Digital Video Processing', Prentice Hall, edition 1, 1996.
9. M. Tekalp ,"Digital video Processing", Prentice Hall International
10. Relf, Christopher G.,"Image acquisition and processing with LabVIEW", CRC press
11. Aner ozdemi R, "Inverse Synthetic Aperture Radar Imaging with MATLAB Algorithms", John Wiley & Sons
12. Chris Solomon, Toby Breckon, "Fundamentals of Digital Image Processing A Practical Approach with Examples in Matlab", John Wiley & Sons.

A8. Probabilistic Graphical Models 4 Credit

Unit I: Introduction, Probability Theory, Bayesian Networks.

Unit II: Undirected models, Learning Bayes Nets, Exact Inference, Message Passing.

Unit-III: Sampling, MAP Inference, Structured prediction.

Unit-IV: Parameter Learning, Bayesian Learning; Structure Learning, Exponential families; variational inference.

Recommended Text Books:
1. Probabilistic Graphical Models: Principles and Techniques by Daphne Koller and Nir Friedman. MIT Press.

References:

1. *Modeling and Reasoning with Bayesian networks* by Adnan Darwiche.
2. *Pattern Recognition and Machine Learning* by Chris Bishop.
3. *Machine Learning: a Probabilistic Perspective* by Kevin P. Murphy.
4. *Information Theory, Inference, and Learning Algorithms* by David J. C. Mackay.
5. *Bayesian Reasoning and Machine Learning* by David Barber.
6. *Graphical models, exponential families, and variational inference* by Martin J. Wainwright and Michael I. Jordan.

S10-C1-P2: Core-I: Elective Papers Group-B

B1. Cyber Security 4 Credit

Unit I: Introduction - Introduction to cyber security, Confidentiality, integrity, and availability. Foundations - Fundamental concepts, CIA, CIA triangle, data breach at target.Security management, Governance, risk, and compliance (GRC)- GRC framework, security standards.

Unit II: Contingency planning - Incidence response, Disaster Recovery, BCP. Cyber security policy - ESSP, ISSP, SYSSP. Risk Management - Cyber Risk Identification, Assessment, and Control.

Unit III: Cyber security: Industry perspective - Defense Technologies, Attack, Exploits. Cyber security technologies - Access control, Encryption, Standards. Foundations of privacy - Information privacy, Measurement, Theories.

Unit IV: Privacy regulation - Privacy, Anonymity, Regulation, Data Breach. Privacy regulation in Europe, Privacy: The Indian Way - Data Protection, GDPR, DPDP, Aadhar. Information privacy: Economics and strategy, Economic value of privacy, privacy valuation, WTA and WTC, Business strategy and privacy, espionage, Privacy vs safety.

References Text:

1. Michael E. Whitman, Herbert J. Mattord, (2018). Principles of Information Security, 6th edition, Cenage Learning, N. Delhi.

2. Darktrace, “Technology” https://www.darktrace.com/en/technology/#machine-learning, accessed November 2018.
3. Van Kessel, P. Is cyber security about more than protection? EY Global Information Security Survey 2018-2019.
4. Johnston, A.C. and Warkentin, M. Fear appeals and information security behaviors: An empirical study. MIS Quarterly, 2010.
5. Arce I. et al. Avoiding the top 10 software security design flaws. IEEE Computer Society Center for Secure Design (CSD), 2014.
6. Smith, H. J., Dinev, T., & Xu, H. Information privacy research: an interdisciplinary review. MIS Quarterly, 2011.
7. Subramanian R. Security, privacy and politics in India: a historical review. Journal of Information Systems Security (JISSec), 2010.
8. Acquisti, A., John, L. K., & Loewenstein, G. What is privacy worth? The Journal of Legal Studies, 2013.
9. Xu H., Luo X.R., Carroll J.M., Rosson M.B. The personalization privacy paradox: An exploratory study of decision making process for location-aware marketing. Decision Support Systems, 2011.

B2. Deep Learning & Reinforcement Learning with Lab 4 Credit

Unit I: Exact inference for graphical models, Variational inference,Monte Carlo inference,MCMC inference,Learning undirected Gaussian graphical models. **Reinforcement learning and control-** MDP, Bellman equations,value iterations and policy iteration, Linear quadratic regulation, LQG, Q-learningValue function approximation, Policy search, Reinforce POMDPs.

Unit II: Review of backpropagation. **Regularization for Deep Learning**: Parameter Norm Penalties, Norm Penalties as Constrained Optimization, Regularization and Under-Constrained Problems, Dataset Augmentation, Noise Robustness, Semi-Supervised Learning, Multitask Learning, Early Stopping, Parameter Tying and Parameter Sharing, Sparse Representations, Bagging and Other Ensemble Methods, Dropout, Adversarial Training, Tangent Distance, Tangent Prop and Manifold Tangent Classifier. **Optimization for Training Deep Models**: How Learning Differs from Pure Optimization, Challenges in Neural Network Optimization, Basic Algorithms, Parameter Initialization Strategies, Algorithms with Adaptive Learning Rates, Approximate Second-order Methods, Optimization Strategies and Meta-Algorithms.

Unit III: Convolutional Networks: The Convolution Operation, Motivation, Pooling, convolution and Pooling as an infinitely strong prior, Variants of the Basic Convolution Function, Structured Outputs, Data Types, Efficient convolution Algorithms, Random or Unsupervised Features, The Neuroscientific Basis for Convolutional Networks, Convolutional Networks and the History of Deep Learning. **Sequence Modeling : Recurrent and Recursive Nets** : Unfolding Computational Graphs, Recurrent Neural Networks, Bidirectional RNNs, Encoder-Decoder Sequence-to-Sequence Architecture, Deep recurrent Networks, Recursive Neural Networks, The Challenge of Long-Term Dependencies, Echo State Networks, Leaky Units and Other Strategies for Multiple Time Scales, The Long Short-Term Memory and Other Gated RNNs, Optimization for Long-Term Dependencies, Explicit Memory.

Unit IV: Practical Methodology: Performance Metrics, Default Baseline Models, Determining Whether to Gather More Data, Selecting Hyperparameters, Debugging Strategies, Example-Multi-Digit Number Recognition.

Linear Factor Models: Slow Feature Analysis, Sparse Coding, **Autoencoders**: Undercomplete Autoencoders, Regularized Autoendcoders, Representational Power, Layer Size and Depth, Stochastic Encoders and Decoders, DenoisingAutoencoders, Learning Manifolds with Autoencoders, Contractive Autoencoders, Predictive Sparse Decomposition, Applications of Autoencoders, **Deep Generative Models** : Boltzmann Machines, Restricted Boltzmann Machines, Deep Belief Networks.

Implementaion of the following algorithms:

i. Convolution Neural network (CNN)
ii. Recurrent Neural Network (RNN)
iii. Autoencoder
iv. Deep Belief Network

Books for reference:

1.Ian Goodfellow, YoshuaBengio, and Aaron Courville, Deep Learning, The MIT Press, 2016

2. Kevin P. Murphy, Machine Learning-a probabilistic prospective, MIT Press, 2012

3. Tom Mitchel, Machine Learning, McGraw Hill.

B3. Discrete Dynamical Systems 4 Credit

Unit-I: Representations of Dynamical Systems, Dynamical systems with discrete time. Types of trajectories, fixed and periodic points, Attracting, repelling and saddle fixed and periodic points and Chaos, Lyapunov Exponent.

Unit-II: Logistic Map, Hennon Map, Lorenz Model, Rossler Map, Horseshoe map, Complex Quadratic Map, Tent Map, Duffing Map. Fractals: Cantor Set, Sierpinski Triangle, Koch Curve, Fractal dimension, Similarity Dimension, Box-counting dimension.

Unit-III: Cellular Automata: Components of Cellular Automata, Basic types, Space time diagram and state transition diagram of CA rules, Rule Space, Boolean functions, Matrix and Polynomial representation of Cellular Automata rules, Classification of Cellular Automata rules, Density Classification Task, Relation of Cellular Automata with other areas.

Unit-IV: L-System, Tilings, Iterated Function System, Mathematical Morphological Operations: Erosion, Delition, Opening and Closing and Integral Value Transformations. Pattern Formation, Pattern Recognition, Pattern Classification and Pattern Analysis, & Applications.

Lab work

Implementation of following methods using R or Python or Matlab:

1. Program for Fractal formation and calculating its fractal dimension.

2. Program for obtaining the space time diagram and STD for CA rules.

3. Program for finding patterns for different IVTs.

4. Any other program recommended by the instructor.

Recommended Text

1. Barnsley, Michael F.; and Rising, Hawley; Fractals Everywhere. Boston: Academic Press Professional, 1993. ISBN 0-12-079061-0
2. Mandelbrot, Benoit B.; The Fractal Geometry of Nature. New York: W. H. Freeman and Co., 1982. ISBN 0-7167-1186-9
3. S. Wolfram, A New kind of Science, Wolfram Publisher, 2002.
4. Grzegorz Rozenberg and Arto Salomaa. The mathematical theory of L systems (Academic Press, New York, 1980). ISBN 0-12-597140-0.
5. Grzegorz Rozenberg, Arto Salomaa – Lindenmayer Systems: Impacts on Theoretical Computer Science, Computer Graphics, and Developmental Biology ISBN 978-3-540-55320-5
6. Mathematical morphology: from theory to applications, Laurent Najman and Hugues Talbot (Eds). ISTE-Wiley. ISBN 978-1-84821-215-2. (520 pp.) June 2010.
7. Image Analysis and Mathematical Morphology, Volume 2: Theoretical Advances by Jean Serra, ISBN 0-12-637241-1 (1988)
8. Discrete Dynamical Systems, Oded Galor, Springer.
9. *Nonlinear Dynamics and Chaos with Applications to Physics, Biology, Chemistry and Engineering* by Steven H. Strogatz, published by Addison Wesley (1994).

B4. High Performance Computing 4 Credit

Unit I: Program execution: Program, Compilation, Object files, Function call and return, Address space, Data and its representation. Computer organization: Memory, Registers, Instruction set architecture, Instruction processing

Unit II: Pipelined processors: Pipelining, Structural, data and control hazards, Impact on programming. Virtual memory: Use of memory by programs, Address translation, Paging, Cache memory: Organization, impact on programming, virtual caches.

Unit III: Operating systems: Processes and system calls, Process management, Program profiling. File systems: Disk management, Name management, Protection.

Unit IV: Parallel architecture: Inter-process communication, Synchronization, Mutual exclusion, Basics of parallel architecture, Parallel programming with message passing using MPI.

References Text:

1. J. L. Hennessy and D. A. Patterson, Computer Architecture: A Quantitative Approach, Morgan Kaufmann.
2. A. Silberschatz, P. B. Galvin, G. Gagne, Operating System Concepts, John Wiley.
3. R. E. Bryant and D. R. O'Hallaron, Computer Systems: A Programmer's Perspective, Prentice Hall.

B5. Natural Language Processing 4 Credit

Unit-I: Introduction to Natural Language Processing, various applications, issues and processing complexities, Regular Expressions, Text Normalization, Edit Distance, N-gram Language Models, Smoothing techniques. Naive Bayes and Sentiment Classification, Other text classification task and logistic regression.

Unit-II: Vector Semantics and Embeddings, Sequence Labeling for Parts of Speech and Named Entities. Deep Learning Architectures for Sequence Processing, Recurrent neural networks applied to language problem, Contextual Embeddings, Machine Translation and Encoder-Decoder Models.

Unit-III: Constituency Grammars, Constituency Parsing, Dependency Parsing, Logical Representations of Sentence Meaning, Computational Semantics and, Semantic Parsing, Information Extraction.

Unit-IV: Word Senses and WordNet, Coreference Resolution, Discourse Coherence, Question Answering, Chatbots & Dialogue Systems, Automatic Speech Recognition, Text-to-Speech.

Text Books:

1. D. Jurafsky and J. H. Martin, ***Speech and Language Processing – An introduction to language processing, computational linguistics, and speech recognition***, Pearson Education, 3rd Edition, Dec, 2020 (Draft Copy: https://web.stanford.edu/~jurafsky/slp3/ed3book.pdf)
2. Christopher D. Manning and Hinrich Schütze, ***Foundations of Statistical Natural Language Processing***, MIT Press, 2nd Edition, 2000

Reference Books:

1. T. Siddiqui and U. S. Tiwary, ***Natural language Processing and Information Retrieval***, Oxford University Press, 1st Edition, 2008
2. Charu C. Aggarwal, ***Machine Learning for Text***, Springer, 1st Edition, 2018
3. J. Allen, ***Natural Language Understanding***, Pearson Education, 2nd Edition, 2008

Online Reference Material(s):

1. https://nptel.ac.in/courses/106/101/106101007/ : by Prof. P. Bhattacharyya, IIT Bombay
2. https://nptel.ac.in/courses/106/105/106105158/: by Prof. P. Goyal, IIT Kharagpur

https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-863j_naturallanguage-and-the-computer-representation-of-knowledge-spring-2003/lecture-notes/

B6. Quantum Computing 4 Credit

Unit I: Introduction to Quantum Computing, Postulates of Quantum Mechanics, Qubits and Bloch Sphere, Basic Quantum Gates, Quantum Circuits. Quantum No Cloning Theorem and Teleportation.

Unit II: Dense coding, Density Matrix, Projective measurement, POVM, EPR and Bell's Inequalities. Deutsch Algorithm, Deutsch-Jozsa Algorithm, Simon Problem, Grover's Search Algorithm, Quantum Fourier Transform, Period Finding, Method of Continued Fraction.

Unit III: Shor's Factorization Algorithm, Quantum Error Correction Codes. Classical Information Theory, Shannon entropy, Von Neumann Entropy,

Unit IV: Classical Cryptography, RSA Algorithm, Quantum Cryptography, BB 84 protocol, B-92 and Eckart protocol, Practical realization of a quantum computer.

References Text:

1. MichaelA. Nielsen and Issac L. Chuang,"Quantum Computation and Information, Cambridge (2002).
2. Mikio Nakahara and Tetsuo Ohmi,"Quantum Computing", CRC Press (2008).
3. N. David Mermin,"Quantum Computer Science",Cambridge (2007).

B7. Soft Computing Methods 4 Credit

Unit-I Neural Network topologies, activation functions and learning methods, perceptron training algorithm, The multilayer perceptron (MLP), Back Propagation learning algorithm, financial applications.

Unit-II Self organization maps, Support vector machine for classification and regression, application to finance. Genetic algorithm (GA), MLP-GA, SVM-GA hybrid methods and financial applications.

Unit-III Elements of fuzzy set theory, Fuzzy logic and approximate reasoning, Neuro-fuzzy and Fuzzy–GA hybrid methods, Rough set theory financial applications.

Unit-IV The particle swarm optimization algorithm, Discrete PSO, MLP-Swarm Hybrids, Ant colony optimization methods, financial applications.

Books Recommended:

1. S. Haykin-Neural Networks: a comprehensive foundation, Pearson Education, 2001

2. Brabazan, M. O' Neill-Biologically Inspired Algorithm for Financial ModellingSpringer-2006

3. R. A. Aliev, B. Fazlollahi, R.R. Aliev-Soft Computing and its Applications in Bussines and Economic, Springer Verlag, 2004.

4. Relevant research papers an use of soft computing methods for financial problems.

B8. Time Series Analysis and Forecasting 4 Credit

Unit-I: Linear Time Series Analysis and its Applications: Stationary, Correlation and Autocorrelation Function. White Noise and Linear Time Series, Simple Autoregressive Models, Simple Autoregressive Models.

Unit-II: Conditional Heteroscedastic Models: Characteristic of Volatility, Structure of a Model, Model Building, The Arch MODEL, The GARCH Model, The Integrated GARCH Model, The GARCH-M Model, The Exponential GARCH Model, The threshold GARCH Model, The CHARAM Model, Random Coefficient Autoregressive Models, The stochastic Volatility Model, Application.

Unit-III: Nonlinear Models and Their Applications: Nonlinear Models, Nonlinearity Tests, Modelling, Forecasting, Applications. High- Frequency Data Analysis and Market Microstructure: Nonsynchronous Trading, Bid-Ask Spread, Empirical Characteristics of Transactions Data, Models for price changes, Duration Models, Nonlinear Duration Models, Bivariate Models for Price Change and Duration.

Unit-IV: Principle Component Analysis and Factor Models: A Factor Model, Macro econometric Factor Models, Fundamental Factor Models, Principal Component Analysis, Statistical Factor Analysis, Asymptotic Principal Component Analysis.

Recommended Book:

1. Analysis of Financial Time Series, by Ruey S. Tsay, Wiley Series in Probability and Statistics.

2. Introduction to Time Series and Forecasting, Second Edition, P. J. Brockwell and R. A. Davis, Springer.