

*Model Curriculum for Three/Four Year
Degree Course (With Multiple Entry /Exit
Option)*

Based on NEP-2020

(w.e.f. 2024-25)

Mathematics and Computing

(Four Year Hons. With Research)

COURSE STRUCTURE FOR
B.Sc. (HONS.) IN MATHEMATICS AND COMPUTING,
INSTITUTE OF MATHEMATICS AND APPLICATIONS, BHUBANESWAR
(Four Year Hons. With Research)

MAJOR-I (CORE): MATHEMATICS		MINOR-I: COMPUTING-I	MINOR-II: COMPUTING-II	MEDIUM: ENGLISH
1st Semester				
SN	Course Code	Paper Code	Course Name	Credit
1	Major-I-P1	Core-I	Calculus & Analytical Geometry	4
2	Major-I-P2	Core-I	Introduction to Algebra & Number Theory	4
3	Minor-I-1	Core-II	Programming and Data Structures with Lab	4
4	MDC-1	Multidisciplinary	Discrete Mathematics	3
5	AEC-1	AEC	Odia/ Hindi/ Sanskrit/ Urdu	4
6	VAC-1	VAC	Environmental Studies and Disaster Management	3
Total Credit				22
2nd Semester				
SN	Course No	Paper Code	Course Name	Credit
1	Major-I-P3	Core-I	Real Analysis-I	4
2	Major-I-P4	Core-I	Algebra-I	4
3	Minor-II-1	Core-III	Computer Organization & Operating System	4
4	MDC-2	Multidisciplinary	Operation Research	3
5	AEC-2	AEC	English	4
6	SEC-1	SEC	Analytical Thinking and Logical Reasoning/ Introduction to Python	3
Total Credit				22
3rd Semester				
SN	Course No	Paper Code	Course Name	Credit
1	Major-I-P5	Core-I	Algebra-II	4
2	Major-I-P6	Core-I	Ordinary Differential Equations	4
3	Major-I-P7	Core-I	Analysis-II (Functions of Several Variables)	4
4	Minor-I-2	Core-II	Design and Analysis of Algorithms with Lab	4
5	MDC-3	Multidisciplinary	Probability	3
6	VAC-2	VAC	Understanding India	3
Total Credit				22
4th Semester				
SN	Course No	Paper Code	Course Name	Credit
1	Major-I-P8	Core-I	Numerical Methods with Lab	4

2	Major-I-P9	Core-I	Number Theory and Cryptography	4
3	Major-I-P10	Core-I	Partial Differential Equations	4
4	Minor-II-2	Core-III	Database Management System with Lab	4
5	CES/FW	Community Engagement and Services/Field Work/Internship	Field Work/Internship	4
Total Credit				20
5th Semester				
SN	Course No	Paper Code	Course Name	Credit
1	Major-I-P11	Core-I	Statistics	4
2	Major-I-P12	Core-I	Complex Analysis	4
3	Major-I-P13	Core-I	Optimization Theory	4
4	Minor-I-3	Core-II	Theory of Computation & Compiler Design	4
5	SEC-2	SEC	Computer Network and Software Engineering	3
6	VAC-3	VAC	Understanding Odisha	3
Total Credit				22
6th Semester				
SN	Course No	Paper Code	Course Name	Credit
1	Major-I-P14	Core-I	Differential Geometry (Curves & Surfaces)	4
2	Major-I-P15	Core-I	Topology	4
3	Minor-II-3	Core-III	Machine Learning with Lab	4
4	SEC-3	SEC	IoT with Lab	3
5	VAC-4	VAC	Ethics and Values	3
Total Credit				18
7th Semester				
SN	Course No	Paper Code	Course Name	Credit
1	Major-I-P16	Core-I	Computational Linear Algebra with Lab	4
2	Major-I-P17	Core-I	Probability & Stochastic Processes	4
3	Major-I-P18	Core-I	Lebesgue Measure & Integration	4
4	Minor-I-4	Core-II	Fluid Dynamics	4
5	Minor-I-5	Core-II	Advanced Data Structures with Lab/ Simulation Modeling/ Numerical Solutions of Partial Differential Equations	4
Total Credit				20
8th Semester				
SN	Course No	Paper Code	Course Name	Credit
1	Major-I-P19	Core-I	Functional Analysis	4
2	Major-I-P20	Core-I	Algebraic Geometry/ Solid Mechanics/	4

			Advanced Machine Learning with Lab	
3	Major-I-P21	Community Engagement and Services/Field Work/Internship	Research	12
Total Credit				20

Detailed Syllabus

Semester-I

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P1	Core-I	Calculus & Analytical Geometry	4	60 Hours

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.
- Calculate 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 $e^{ax+b}\sin x$, $e^{ax+b}\cos x$, $(ax + b)^n\sin x$, $(ax + b)^n\cos x$, 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 $\int \sin^n x dx$, $\int \cos^n x dx$, $\int \tan^n x dx$, $\int \sec^n x dx$, $\int (\log x)^n dx$, $\int \sin^n x \cos^n x dx$, 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

The real number System: Finite and infinite sets, countable and uncountable sets, examples, algebraic and order Properties of \mathbb{R} , uncountability of \mathbb{R} , completeness property of \mathbb{R} , applications of the supremum property, Intervals, nested interval property, density of rationals in \mathbb{R} , Introduction to sequence and series of real numbers with basic examples.

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>*

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P2	Core-I	Introduction to Algebra & Number Theory	4	60 Hours

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.*
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Course Code	Course Category	Course Name	Credit	Hours of Instruction
Minor-I-1	Core-II	Programming and Data Structures with Lab	4	60 Hours

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. M. A. Weiss, Data Structures and Algorithm Analysis in C++, Pearson Addison-Wesley, 2006.
10. B. Stroustrup, The C++ Programming Language, 3rd Ed., Addison Welsley, 2010.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
MDC-1	Multidisciplinary	Discrete Mathematics	3	45 Hours

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, propositional 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, 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>*

Course Code	Course Category	Course Name	Credit	Hours of Instruction
AEC-1	AEC	Odia/Hindi/Sanskrit/Urdu	4	60 Hours

Common Syllabus as prescribed by NEP-2020.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
VAC-1	VAC	Environmental Science & Disaster Management	4	60 Hours

Common Syllabus as prescribed by NEP-2020.

Semester-II

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P3	Core-I	Real Analysis-I	4	60 Hours

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

Sequence of real numbers 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.

Infinite series of real numbers, convergence and divergence of infinite series, Cauchy criterion, Tests for convergence: comparison test, limit comparison test, ratio test, Cauchy's

n^{th} root test, Raabe's test, integral test, alternating series, Leibniz test, absolute and conditional convergence.

Unit II

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.

Unit III

Differentiability of a function at a point and in an interval, Caratheodory's theorem, algebra of differentiable functions, relative extrema, interior extremum theorem. Rolle's theorem, Mean value theorems, Cauchy's mean value theorem, Lagrange mean value theorem, intermediate value property of derivatives, Darboux's theorem, applications of mean value theorem, Taylor's theorem and applications.

Unit IV

Riemann integration: partitions, conditions of integrability, definition of Riemann integral properties of the Riemann integral, Riemann integral as limit of a sum, mean value theorem for integrals, integration by parts, Fundamental theorems of calculus, Taylor theorem with remainder. Improper integrals, absolutely convergent integral, tests of convergence, convergence of Beta and Gamma functions.

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.*
- ✓ *S. R. Ghorpade & B.V. Limaye: A Course in Calculus and Real Analysis, Springer.*

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.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P4	Core-I	Algebra-I	4	60 Hours

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 $\mathbb{Z}[x]$, 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 I. 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>*

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Minor-II-1	Core-III	Computer Organization & Operating System	4	60 Hours

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.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
MDC-2	Multidisciplinary	Operation Research	3	45 Hours

COURSE OUTCOME

After completion of this course, students will be able to

- Understand the concept and scope of Operation Research
- Apply Big M method for solving Linear Programming Problems(LLP)
- Identify various phases of Operations Research
- Solve Transportation problems by using NWC and LCM methods
- Appreciate the necessities to know constraints and objectives of a project

Learning Outcome

- . Understanding the importance and characteristics of operation research.
- . Formulating Linear Programming to solve Operation Research Problems.
- . Learning Outcome: Using graphs to solve LPP.
- . Applying NWC and LCM methods to solve Transportation problems.
- . Designing decision flow in an organizations for optimizing individual efficiencies.

UNIT I: INTRODUCTION TO OPERATIONS RESEARCH [10 Hours]

Definition and Scope of Operations Research, Historical Development and Characteristics, Phases of Operations Research. Historical development and importance of OR in decision making

UNIT II: LINEAR PROGRAMMING AND TRANSPORTATION PROBLEM

Formulation of Linear Programming Problems. Linear inequalities in two variables. Their graphs as half planes. **[15 Hours]**

UNIT III: ASSIGNMENT PROBLEM AND QUEUING THEORY [8 Hours]

Graphical Solution of Linear Programming Problems, Simplex Method including two phase methods. Big M Method as a method of solution of LPP

UNIT IV: NETWORK ANALYSIS AND DECISION THEORY [12 Hours]

Transportation Problem: Structure, Basic Feasible Solution. Solution Methods (NWC Method, LCM).

INVENTORY CONTROL: Network Analysis: PERT and CPM, Construction. Critical Path, Time Analysis, Decision Theory: Bayes' Theorem, Probability, Decision Trees

Text Books

1. Introduction to Operational Research by V.K. Kapoor (Sultan Chand & Sons)
2. Operations Research by P.K. Gupta & Man Mohan (Sultan Chand & Sons)

Suggested Reading

1. Operations Research by P.R. Vittal & V. Malini (Margham Publications)
2. Operations Research Theory and Applications by Sharma J. K (Laxmi Publications)
3. Operations Research by Sridhar Bhat K (Himalaya Publishing House)
4. Operations Research by Hillier F.S. and Lieberman G.J. (McGraw Hill)
5. Operations Research: An Introduction by Hamdy A.T (Pearson)
6. Operations Research by Sharma S. D (Kedar Nath Ram Nath)

Course Code	Course Category	Course Name	Credit	Hours of Instruction
AEC-2	AEC	English	4	60 Hours

Common Syllabus as prescribed by NEP-2020.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
SEC-1	SEC	Analytical Thinking and Logical Reasoning/ Introduction to Python	3	45 Hours

Common Syllabus as prescribed by NEP-2020.

Second Year

Semester III

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P5	Core-I	Algebra-II	4	60 Hours

Course Objective:

The objective of this course is to acquaint students with matrix operations, solution of system of equations, vector spaces and linear transformations. In addition, the student will learn about eigenvalues, diagonalization, canonical forms, etc., which has many applications in almost all areas of science and engineering.

Learning Outcomes:

After completing the course the student will be able to

- Determine basis and the dimension of a finite-dimensional vector space, know the relation between rank and nullity of a linear transformation.
- The relation between matrix and linear transformation.
- To find solution of system of linear equations, compute eigenvalues, eigenvectors of a matrix and linear transformation.
- About orthogonality of vectors and application of it to different form of matrix, introduced to different operators.

Unit I

Vector spaces, subspaces, span of a set, more about subspaces, linear dependence, independence, product and quotient space, dimension and basis, linear transformations, range and kernel of a linear map, rank and nullity of linear map.

Unit II

Inverse of linear transformation, consequences of rank – nullity theorem, the space $L(U, V)$, composition of linear maps, matrix associated with linear map, linear map associated with

matrix, rank and nullity of a matrix, determinant minors and rank of a matrix, transpose of a matrix and special type of matrices, elementary row operations

Unit III

System of linear equations, matrix inversion, application of determinant to linear equations, eigenvalues and eigenvectors, similarity of matrices, invariant subspaces, minimal polynomial (eigenvalues and the minimal polynomial), upper triangular matrices, diagonalizable operators (diagonal matrices, conditions for diagonalizability).

Unit IV

Inner product space: inner products and norms, orthonormal bases, orthogonal complements, self-adjoint and normal operators, spectral theorems, isometries, unitary operators, characteristic polynomial, Cayley – Hamilton theorem, Jordan form, trace, quadratic form, application to reduction of quadrics.

Books Recommended:

- ✓ *V. Krishnamurthy, V.P. Mainra, J. L. Arora, An introduction to linear algebra, Affiliated East – West press Pvt. Ltd., New Delhi, 1976.*
- ✓ *Sheldon Axler, Linear algebra done right (Fourth edition), Springer, 2024.*

Books for References:

- ✓ *Seymour Lipschutz and Marc Lars Lipson, Linear Algebra (Schaum's outlines, Fourth Edition), McGraw Hill, New York, 2009.*
- ✓ *A. Ramachandra Rao and P. Bhimsankaram, Linear Algebra (Second Edition), Hindustan Book Agency, 2000.*
- ✓ *Stephen H. Friedberg, Arnold J. Insel, Lawrence E. Spence, Linear Algebra (Fourth Edition), Prentice-Hall of India Pvt. Ltd., New Delhi, 2004.*
- ✓ *Gilbert Strang, Linear Algebra and its Applications, Thomson, 2007.*
- ✓ *S. Kumaresan, Linear Algebra- A Geometric Approach, Prentice Hall of India, 1999.*
- ✓ *Suggested digital platform: NPTEL/SWAYAM/MOOCs.*

e-Learning Source <http://ndl.iitkgp.ac.in> ; <http://ocw.mit.edu> ; <http://mathforum.org> ; <https://linear.axler.net>; and <https://library.oapen.org/handle/20.500.12657/85067>

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P6	Core-I	Ordinary Differential Equations	4	60 Hours

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: Basic concept and definitions. First order Equations: Separation of variables, Homogeneous functions, Exact differential equations, Reducible to exact, First order linear equations, integrating factor, Bernoullis and Riccati equations, Existence and Uniqueness of the solution. Orthogonal Trajectories.

Unit II: Second order ODEs, Homogeneous ODE with constant coefficients and variable coefficients, Non-homogeneous ODEs: Solution by the method of undetermined coefficients and variation of parameters.

Unit III: Series solutions and special functions: Basic concept of power series, Radius of convergence, Legendre equations and polynomials, Solution at Regular Singular point, Frobenius method, Bessel Equation, Gamma and Beta function and their properties.

Unit IV: Laplace Transform: Properties of Laplace transform, convolution theorem, Applications to solve differential equations

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.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P7	Core-I	Analysis-II (Functions of Several Variables)	4	60 Hours

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

Pointwise and uniform convergence of sequence of functions, Cauchy criterion for uniform convergence and Weierstrass M-test, uniform convergence and continuity, term by term integration and differentiation of a series, power series, Abel's theorem, Weierstrass approximation theorem, Taylor series.

Unit-II: 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.

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: Triple product, 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, Tangent and normal components of acceleration, Applications and properties.

Unit-IV

Multiple integrals: Line integral, change of variable, change of order of integration, Jacobian, double and triple integrals, Surface integrals, Green's theorem, Stokes and Gauss divergence theorem with plenty of examples.

Recommended Texts:

1. T. M. Apostol: *Calculus vol. I & II*
2. W. Rudin: *Principles of Mathematical Analysis*
3. T. M. Apostol: *Mathematical Analysis*
4. EM Stein & Rami Shakarchi: *Fourier Analysis: An introduction.*

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Minor-I-2	Core-II	Design and Analysis of Algorithms with Lab	4	60 Hours

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. Leiserson, 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.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
MDC-3	Multidisciplinary	Probability	4	60 Hours

Course Objective:

The objective of the course is to make the student understand basics of probability which is of use in everyday life.

Learning Outcomes:

After completing the course the student will be able to

- Learn the basics of probability and random variables with axioms of probability.
- Know the discrete and continuous distributions and learn how to calculate mean, variance and moments of them.
- Learn on limit theorems with their applications and know about the conditional expectations.
- Learn on Markov chains and their applications.

Unit I

Sample space and events, probability axioms, probability defined on events, conditional probabilities, Independent events, Bayes formula, real random variables, discrete and continuous random variables, probability distribution function, probability mass/density functions, mathematical expectation, and properties, variance and standard deviation.

Unit II

Discrete distributions: uniform, binomial, Poisson, geometric, negative binomial, continuous distributions: uniform, normal, exponential, their expectations and variance, moments, moment generating function, characteristic function and computation of these for the distributions, joint distribution function and its properties, joint probability density functions, marginal and conditional distributions, independent random variables.

Unit III

Limit theorems: Markov inequality, Chebyshev's inequality, statement and interpretation of (weak) law of large numbers and strong law of large numbers, application to problems, conditional probability and conditional expectation, discrete case, continuous case,

applications, expectation of function of two random variables, conditional expectations, bivariate normal distribution, correlation coefficient, joint moment generating function and calculation of covariance, linear regression for two variables.

Unit IV

Central limit theorem for independent and identically distributed random variables with finite variance, Markov chains, Chapman-Kolmogorov equations, classification of states, Gambler Ruin problem.

Book Recommended

1. Sheldon Ross, *Introduction To Probability Models (9th Edition)*, Academic Press, Indian Reprint, 2007.
2. Robert V. Hogg, Joseph W. Mckean And Allen T. Craig, *Introduction To Mathematical Statistics*, Pearson Education, Asia, 2007.
3. Kai Lai Chung, *Elementary Probability Theory With Stochastics Process*, Springer International Students Edition, (Narosa Publ.)

Book for Reference

- ✓ Alexander M. Mood, Franklin A. Graybill and Duane C. Boes, *Introduction to the Theory of Statistics*, (3rd Edition), Tata McGraw- Hill, Reprint 2007.
- ✓ Chow Y S, Teicher H *Probability theory* Springer International edition
- ✓ Irwin Miller and Marylees Miller, *John E. Freund's Mathematical Statistics with Applications (7th Edition)*, Pearson Education, Asia, 2006.
- ✓ e-Learning Source <http://ndl.iitkgp.ac.in>; <http://ocw.mit.edu>; <http://mathforum.org>
- ✓ Suggested digital platform: NPTEL/SWAYAM/MOOCs.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
VAC-2	VAC	Understanding India	3	45 Hours

Common Syllabus as prescribed by NEP-2020.

Semester-IV

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P8	Core-I	Numerical Methods with Lab	4	60 Hours

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

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P9	Core-I	Number Theory and Cryptography	4	60 Hours

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 be 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, version 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.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P10	Core-I	Partial Differential Equations	4	60 Hours

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.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Minor-II-2	Core-III	Database Management System with Lab	4	60 Hours

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.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
CES/FW	Community Engagement and Services/Field Work/Internship	Field Work/Internship	4	60 Hours

Common Syllabus as prescribed by NEP-2020.

Third Year

Semester V

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P11	Core-I	Statistics	4	60 Hours

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.
- 1) S. C. Gupta, Fundamentals of Statistics, Himalaya Publishing House, 7th edition.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P12	Core-I	Complex Analysis	4	60 Hours

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.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P13	Core-I	Optimization Theory	4	60 Hours

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: Introduction to Optimization (Univariate and multivariate optimization, constrained optimization). One Dimensional Optimization (Function comparison methods, Polynomial interpolation, Iterative methods).

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

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. Duality theory for LPP.

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.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Minor-I-3	Core-II	Theory of Computation & Compiler Design	4	60 Hours

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,*

Course Code	Course Category	Course Name	Credit	Hours of Instruction
SEC-2	SEC	Computer Network and Software Engineering	3	45 Hours

Languages and Computation, 2nd Edition, Pearson Education, 2001.

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.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
VAC-3	VAC	Understanding Odisha	3	45 Hours

Common Syllabus as prescribed by NEP-2020.

Semester VI

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P14	Core-I	Differential Geometry (Curves and Surfaces)	4	60 Hours

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.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P15	Core-I	Topology	4	60 Hours

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.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Minor-II-3	Core-III	Machine Learning with Lab	4	60 Hours

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.

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.

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

Unit-IV: 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.

Lab work

Implementation of following methods using Python or R:

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.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
SEC-3	SEC	IoT with Lab	3	45 Hours

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)

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

Course Code	Course Category	Course Name	Credit	Hours of Instruction
VAC-4	VAC	Understanding Odisha	3	45 Hours

Common Syllabus as prescribed by NEP-2020.

Fourth Year

Semester VII

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P16	Core-I	Computational Linear Algebra with Lab	4	60 Hours

Objectives: The objective of this course is to acquaint students with various matrix multiplication 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.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P17	Core-I	Probability and Stochastic Processes	4	60 Hours

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.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P18	Core-I	Lebesgue Measure & Integration	4	60 Hours

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 R_n .

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, $L_p(R_n)$ spaces (completeness, dense subsets, notion of separability).

Unit-III: Product sigma algebras, Product measures, Fubini's theorem in R^n (at least statement with examples). Characterization of continuous linear functionals on L_p 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, Modern techniques and their applications.
4. H.L. Royden: Real Analysis
5. R. Wheeden and A. Zygmund: Measure and Integral: An introduction to Real Analysis.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Minor-I-4	Core-II	Fluid Dynamics	4	60 Hours

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, stream 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 vortices, 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.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Minor-I-5	Core-II	Advanced Data Structures with Lab/ Simulation Modeling/ Numerical Solutions of Partial Differential Equations	4	60 Hours

Advanced Data Structures with Lab

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: String Operations, Brute-Force Pattern Matching, The Boyer-Moore 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 et al. Computational Geometry: Algorithms and Applications, 3rd Edition, Springer.

Simulation Modeling

Course Objective:

The course objectives for Simulation Modeling are to equip students with the skills and mathematical knowledge necessary to effectively model and analyze complex non-linear systems.

Course Outcome:

-Explain mathematical modeling and simulation types, entities, objectives, and benefits.

-Recognize the simulation types and steps for variety of complex systems.

-Study both discrete time and continuous time non-linear models.

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 Recommended:

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

Numerical Solutions of Partial Differential Equations

Course Objective:

To provide the numerical methods of solving the non linear equations, interpolation, differentiation, and integration.

To improve the student's skills in numerical methods by using the numerical analysis software and computer facilities.

A major advantage of numerical method is that a numerical solution can be obtained for problems, where an analytical solution does not exist. An additional advantage is, that a numerical method only uses evaluation of standard functions and the operations: addition, subtraction, multiplication and division.

Course Outcome:

1. Apply a range of techniques to find solutions of standard Partial Differential Equations (PDE).
2. Understand basic properties of standard PDE's.
3. Demonstrate capacity to model physical phenomena using PDE's (in particular using the heat and wave equations).
4. Apply problem-solving using concepts and techniques from PDE's and Fourier analysis applied to diverse situations in physics, engineering, financial mathematics and in other mathematical contexts.

Unit I: Introduction to finite differences (finite difference approximation of partial differential equations (PDE), derivation of difference equations), convergence and consistency of difference schemes for Initial-Value problems and initial-boundary value problems.

Stability of difference schemes for initial-value problems and initial-boundary value problems, The lax theory, Implicit schemes, Analysis of stability, Finite Fourier series and stability. **12 hours**

Unit II: Finite Difference Method (FDM) for Parabolic Equations: Difference schemes for two dimensional parabolic equation, Convergence, Consistency and Stability, Alternating direction implicit schemes (Peaceman-Rachford scheme, Stability, consistency and implementation; Douglas-Rachford scheme and its stability)

FDM for Elliptic Equations: Solvability and convergence of elliptic difference schemes with Dirichlet boundary conditions, solutions of schemes for elliptic difference equations, residual correction methods. **18 hours**

Unit-III : FDM for Hyperbolic equations: Initial-value problems, Explicit & implicit difference schemes for IVP(one sided, centred, Lax-windroff and crank Nicolson schemes), Initial-Boundary-value problem and their difference schemes, Two dimensional hyperbolic equations and difference schemes, CFL

The finite volume method for diffusion problems, Finite volume method for one-dimensional steady state diffusion, the finite volume method for convection-diffusion problems, steady one-dimensional convection and diffusion, the central differencing scheme, properties of discretization scheme, The upwind and hybrid difference schemes. **15 hours**

Unit-IV : Finite element method(FEM) for elliptic problems: variational formulation of a model problem,, FEM for the model problem with piecewise linear functions, an error estimate for FEM for the model problem, FEM for the Poisson equation, geometric interpretation of FEM, A Neumann Problem, Programming FEM. **15 hours**

Books Recommended

1. J. W. Thomas: Numerical Partial Differential Equation , Springer Verlag, 1995. Chapters : 1, 2, 3, 4, 5(Vol.1), 10(vol.2)
- 2.H. K.Versteeg and W.MaLa Lasakera, An Introduction to Computational Fluid Dynamics, The finite volume method. Addison Wesley Longman,1995, Chs 4 and 5.

3. C. Johnson, Numerical Solution of Partial Differential Equations by the Finite Element Method, Cambridge University Press, 1990. Chapter : 1

Books for Reference

1. D. Braess: Finite Elements, Cambridge University Press, 1997. Chapters : IV, V.
2. K.W. Morton and D.F.Mayers: Numerical Solution of Partial Differential Equations, Cambridge University Press, 1994.
3. Numerical Methods for Partial Differential Equations by G.Evans, J.Blackledge and P.Yardley. Springer,2000
4. S. C. Brenner and L. R. Scott: The Mathematical Theory of Finite Element Methods, Springer Verlag, 1994.
- 5.Vitoriano Ruas, Numerical Methods for Partial Differential Equations,Wiley, 2016.

Semester VIII

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P19	Core-I	Functional Analysis	4	60 Hours

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 , L_p 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.

Course Code	Course Category	Course Name	Credit	Hours of Instruction
Major-I-P20	Core-I	Algebraic Geometry/ Solid Mechanics/ Advanced Machine Learning with Lab	4	60 Hours

Algebraic Geometry

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: Definition and examples of rings, subrings, integral domains, fields, ring homomorphisms, kernels and images, ideals, quotient rings, First Isomorphism Theorem for rings, prime and maximal ideals, maximal ideals in polynomial rings, operations on ideals (sum, product, intersection), radical of an ideal, primary ideals, primary decomposition of ideals in a Noetherian ring.

Unit II: Polynomial rings in several variables, Noetherian rings and modules, Ascending Chain Condition (ACC), Hilbert Basis Theorem, Affine algebraic sets, vanishing ideals, the correspondence between algebraic sets and ideals, Zariski topology, coordinate rings, integral extensions of rings, Noether Normalization Theorem.

Unit III: Hilbert's Nullstellensatz (Weak and Strong), radical ideals and algebraic sets, polynomial maps, morphisms of affine varieties, rational functions, introduction to projective space, homogeneous coordinates, projective algebraic sets, homogeneous ideals, projective closure of affine varieties.

Unit IV: Elementary dimension theory (Krull dimension), algebraic curves in the affine and projective plane, singularities and the Jacobian criterion, tangent spaces, Bezout's theorem for plane curves.

Recommended Texts:

1. M. Reid, Undergraduate Algebraic Geometry, Cambridge.
2. Cox, Little and O'Shea: Ideals, Varieties and Algorithms, Springer.
3. K. Smith et al., An Invitation to Algebraic Geometry, Springer.
4. Dummit and Foote, Abstract Algebra, Wiley (Chapters 7, 8, 9, and 15).

Solid Mechanics

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) Strength 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.

Advanced Machine Learning with Lab

Objectives: The objective of this course is to provide students with an in-depth understanding of advanced machine learning concepts grounded in probabilistic modeling, statistical inference, kernel methods, graphical models, and neural networks. The course aims to develop the ability to design, analyze, and implement machine learning algorithms for complex real-world problems involving classification, regression, clustering, dimensionality reduction, and structured prediction. Through hands-on laboratory sessions, students will gain practical experience in applying advanced machine learning techniques using modern computational tools and datasets.

Course Outcomes: After successful completion of this course, the student will be able to:

CO1: Understand and analyze generative and discriminative machine learning models, including Bayesian learning, linear models, and exponential family distributions.

CO2: Apply probabilistic inference techniques such as Gaussian models, Bayesian regression, mixture models, and the Expectation–Maximization algorithm for data modeling and prediction.

CO3: Design and implement kernel-based methods, Support Vector Machines, and Gaussian Process models for classification and regression tasks.

CO4: Model complex dependencies using probabilistic graphical models, including Bayesian Networks, Markov Models, Hidden Markov Models, Markov Random Fields, and Conditional Random Fields, and perform exact inference.

CO5: Develop neural network models including perceptrons and multilayer neural networks, and apply learning algorithms such as backpropagation with convergence acceleration techniques.

CO6: Apply dimensionality reduction, clustering, and collaborative filtering techniques to high-dimensional datasets for visualization, feature extraction, and recommendation systems.

CO7 (Lab-oriented): Implement and evaluate advanced machine learning algorithms using programming tools and libraries, analyze experimental results, and interpret model performance on real-world datasets.

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.

Course Code	Course Category	Course Name	Credit
Major-I-P21	Community Engagement and Services/Field Work/Internship	Research	12

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