DEBRA THANA SAHID KSHUDIRAM SMRITI MAHAVIDYALAYA (AUTONOMOUS)

Gangaram Chak, Chak Shyampur, Debra, West Bengal

PROPOSED SYLLABUS OF

Post – Graduate Programme
in
MATHEMATICS

Under Choice Based Credit System (CBCS)

(w.e.f. Academic Year 2025 – 2026)

Preamble

The Department of Mathematics offers post-graduate (M.Sc.) and Doctoral programs aimed at developing a deep understanding of advanced areas of mathematics and its wide applications. The M.Sc. program, of two years' duration, was introduced under the Faculty of Science, Vidyasagar University, at the very inception of the University in 1985. The Ph.D. program was subsequently launched in 1998, and since then, around 120 scholars have successfully completed their doctoral research. To modernize and enrich the curriculum, the Choice-Based Credit System (CBCS) was adopted in 2018.

The syllabus has been designed to give students a balanced exposure to both pure and applied mathematics, while also preparing them for national-level competitive examinations such as CSIR-NET, UGC-NET, and GATE, as well as the State Eligibility Test (SET). Apart from classroom teaching, the course emphasizes problem-solving skills, research aptitude, and communication abilities. A compulsory project in the fourth semester allows students to pursue independent research in their chosen field of interest.

The department is supported by ICT-enabled smart classrooms, virtual classrooms, a well-equipped computer programming laboratory, and a departmental library. It has also received support from the Department of Science and Technology (DST), Government of India, for upgrading its laboratory and classroom facilities.

Students are trained in the use of advanced computational tools and Computer Algebra Systems (CAS) such as Mathematica, MATLAB, and C++, which are integrated into the curriculum to broaden their knowledge and encourage self-learning through practical experience.

The major research thrust areas of the department include Optimization and Operations Research, Fuzzy Mathematics, and other related fields.

Program Outcomes (POs)

On successful completion of the M.Sc. and Ph.D. programs in Mathematics, students will be able to:

1. **PO1 – Knowledge and Understanding**
   Acquire advanced knowledge of both pure and applied mathematics, with a strong conceptual foundation in modern mathematical theories and methods.
2. **PO2 – Problem Solving and Analytical Thinking**
   Develop critical and logical reasoning skills to analyze, model, and solve complex mathematical problems across diverse domains.
3. **PO3 – Research Aptitude**
   Cultivate research skills by engaging in independent project work, enabling them to explore mathematical problems and contribute to the advancement of the discipline.
4. **PO4 – Technical Proficiency**
   Gain hands-on experience in computational tools and Computer Algebra Systems (CAS) such as Mathematica, MATLAB, and C++, enhancing their ability to perform advanced numerical and symbolic computations.

5. **PO5 – Communication and Presentation**

   Demonstrate effective communication of mathematical ideas, both oral and written, through presentations, seminars, and project reports.

6. **PO6 – Employability and Competitiveness**

   Prepare for higher studies, teaching, research, and national-level competitive examinations (CSIR-NET, UGC-NET, GATE, SET), thereby enhancing career opportunities.

7. **PO7 – Ethical and Lifelong Learning**

   Develop professional ethics, teamwork, and a mindset for continuous learning in response to emerging trends in mathematics and related fields.

Programme Specific Outcomes (PSOs)

Graduates of the Mathematics program will be able to:

1. **PSO1 – Mastery of Core Mathematics**

   Demonstrate advanced knowledge in core areas of mathematics including algebra, analysis, topology, optimization, and differential equations.

2. **PSO2 – Applied Mathematical Skills**

   Apply mathematical theories and computational methods to practical fields such as optimization, operations research, fuzzy mathematics, and fluid dynamics.

3. **PSO3 – Computational Expertise**

   Effectively use programming languages and mathematical software (Mathematica, MATLAB, C++) to simulate, model, and solve real-world mathematical problems.

4. **PSO4 – Independent Research and Innovation**

   Undertake independent research projects, apply appropriate mathematical tools, and contribute original findings in specialized areas of mathematics.

5. **PSO5 – Career Preparedness**

   Be well-prepared for careers in academia, research organizations, industry, data science, and other fields requiring strong mathematical and analytical skills.

CONTENT					
Semester	**Course**	**Course Titles**	**Full Marks**	**No. Of Lectures (Hours)**	**Credit (Lecture – Tutorial - Practical)**
Semester I	MTM – 101T	Real Analysis	50	50	5 (4-1-0)
	MTM – 102T	Algebra	50	50	5 (4-1-0)
	MTM – 103T	Ordinary Differential Equations and Special Functions	50	50	5 (4-1-0)
	MTM – 104T	Multivariate Calculus	50	50	5 (4-1-0)
	MTM – 105T	Advanced Python Programming	50	50	5 (4-1-0)
	MTM – 106T	Graph Theory	25	30	3 (3-0-0)
	MTM – 106P	Advanced Python Programming Lab	25	40	2 (0-0-4)
Total			**300**	**240**	**30**
Semester II	MTM – 201T	Complex Analysis	50	50	5 (4-1-0)
	MTM – 202T	Functional Analysis	50	50	5 (4-1-0)
	MTM – 203T	Topology	50	50	5 (4-1-0)
	CMTM – 204T	Statistical and Numerical Methods	50	50	5 (4-1-0)
	MTM – 205T	Numerical Analysis	50	50	5 (4-1-0)
	MTM – 206T	Classical Mechanics	25	30	3 (3-0-0)
	MTM – 206P	Python Programming with Numerical Methods	25	40	2 (0-0-4)
Total			**300**	**240**	**24**
Semester III	MTM – 301T	Partial Differential Equations and Generalized Functions	50	50	5 (4-1-0)
	MTM – 302T	Optimization Techniques	50	50	5 (4-1-0)
	MTM – 303T	Linear Algebra	50	50	5 (4-1-0)
	CMTM – 304T	Discrete Mathematics	50	50	5 (4-1-0)
	Electives (Any two)				
	MTME – 305T	Advanced Complex Analysis	50	50	5 (4-1-0)
	MTME – 306T	Advanced Topology	50	50	5 (4-1-0)
	MTME – 307T	Fluid Dynamics	50	50	5 (4-1-0)
	MTME – 308T	Advanced Optimization Techniques	50	50	5 (4-1-0)
	MTME – 309T	Differential Geometry	50	50	5 (4-1-0)
	MTME – 310T	Machine Learning	25	30	3 (3-0-0)
	MTME – 310P	Machine Learning Lab	25	40	2 (0-0-4)
Total			**300**	**240**	**24**
Semester IV	MTME – 401T	Integral Transforms and Integral Equations	50	50	5 (4-1-0)
	MTME – 402T	Operations Research	50	50	5 (4-1-0)
	MTME – 403T	Fuzzy Mathematics	50	50	5 (4-1-0)
	MTME – 404T	Project Work	50	50	5 (0-0-10)
	Elective 3 and 4 (Any two)				
	MTME – 405T	Advanced Functional Analysis	50	50	5 (4-1-0)
	MTME – 406T	Operator Theory	50	50	5 (4-1-0)
	MTME – 407T	Advanced Operations Research	50	50	5 (4-1-0)
	MTME – 408T	Advanced Algebra	50	50	5 (4-1-0)
	MTME – 409T	Bio Mathematics	50	50	5 (4-1-0)
	MTME – 410T	Data Science	25	30	3 (3-0-0)
	MTME – 410P	Data Science Lab	25	40	2 (0-0-4)
Total			**300**	**240**	**24**
Grand Total			**1200**		**96**

Note

1. Examinations

- Each paper will be evaluated through two examinations:
  - **End-Semester Examination:** 40 marks

- **Internal Assessment (IA):** 10 marks

- The IA marks will be calculated by taking the average of two IA examinations conducted during the semester.

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2. Elective Papers

- Each student must choose **two Elective Papers** from MTM 305, MTM 306, MTM 307, MTM 308, MTM 309 and MTM 310 in the 3rd Semester, and **two Elective Papers** from MTM 405, MTM 406, MTM 407, MTM 408, MTM 409, and MTM 410 in the 4th Semester.
- An Elective Paper will be offered only if the number of enrolled students is **at least 15 and at most 45**.

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3. Open Electives

- The following courses are offered as **Open Electives** (under CBCS) for PG students of disciplines other than Mathematics:
  - C-MTM-204
  - C-MTM-304

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4. Competitive Examination Relevance

- The syllabus is designed to cover topics relevant for national-level competitive examinations such as **CSIR-NET, UGC-NET, and GATE**, as well as the **State Eligibility Test (SET)**.

Detailed Syllabus

SEMESTER – I

CORE COURSE – 1
MTM – 101T: Real Analysis

Course Content	No of Lectures
Unit I: Set Theory and Cardinal Numbers Concept of Cardinal number of an infinite set, order relation of Cardinal numbers, Schroeder-Bernstein theorem, Cantor's Theorem, Cardinal numbers and Cardinal arithmetic, Continuum Hypothesis, Zorn's Lemma, Axioms of Choice, Well-Ordered Sets, Maximum Principle, Ordinal numbers, Cantor set and cantor-like sets.	12
Unit II: Functions of Bounded Variation and Absolute Continuity Monotone functions and their discontinuities, Functions of Bounded Variation and their properties, Differentiation of a function of bounded variation, characterization of a function of bounded variation, Absolutely Continuous Function, Representation of an absolutely continuous function by an integral. Everywhere Continuous but nowhere differentiable function.	12
Unit III: Riemann–Stieltjes Integral Definition, Necessary and sufficient condition for existence of Riemann-Stieltjes integral, Integration by parts, Change of variables in integral, Integral of step functions, First mean value theorem and Second mean value theorem for Riemann-Stieltjes integrals.	6
Unit IV: Measure Theory and Measurable Functions Outer measure, Lebesgue measure, Measurable sets and their properties, sets, sets, Borel sets, Existence of non-measurable sets. Measurable functions and its operations, sequence of measurable functions and their properties, simple functions, almost everywhere property and its application.	14

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. to verify whether a given subset of R is measurable or to examine whether a real valued function is a function of bounded variation, absolutely continuous, measurable, Riemann-Stieltjes integrable etc.
2. to understand the requirement and the concept of the Bounded variation, Double series, measurable sets, measurable function along with its properties
3. to apply the knowledge of Fourier series in solving complex differential equations

4. to demonstrate understanding of the statement and proofs of the different theorems and their applications.

Reference Books:

1. Rudin, W. (1976). *Principles of mathematical analysis* (Vol. 3). New York: McGraw-hill.
2. Rudin, W. (1970). Real and Complex Analysis, International Student Edition, McGraw-Hill.
3. Rana, I. K. (2002). An Introduction to Measure and Integration (2nd ed.), Narosa Publishing House, New Delhi.
4. Apostol, T. (2002). Mathematical Analysis, 2nd ed., Narosa Publishers.
5. Kumaresan, S. (2011). Topology of Metric Spaces, 2nd ed., Narosa Publishers.
6. Halmos, P.R. (2013). Measure Theory, Graduate Text in Mathematics, Springer-Verlag
7. Royden, H.L. (1988). Real Analysis, 3rd ed., Macmillan.

CORE COURSE – 2
MTM – 102T: Abstract Algebra

Course Content	No of Lectures
Unit I: Group Theory Normal and subnormal series, composition series, solvable groups, Jordan-Hölder theorem and its applications. Finitely generated abelian groups, free abelian groups.	16
Unit II: Ring Theory Noetherian ring, Artinian ring, Hilbert Basis Theorem, Cohen's Theorem.	10
Unit III: Field Theory and Extensions Field extension, Algebraic and transcendental extensions, finite extension, algebraically closed field, splitting field, separable extension, impossibility of some constructions by straightedge and compass, finite fields and their properties, normal extension, Galois extension, Galois group, Galois theory, solution of polynomial equations by radicals, insolvability of the general equation of degree 5 (or more) by radicals.	24

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. Utilize the class equation and Sylow theorems to solve different related problems.
2. Identify and analyze different types of algebraic structures such as Solvable groups, Simple groups, Alternate groups to understand and use the fundamental results in Algebra.
3. Know in detail about polynomial rings, fundamental properties of finite field extensions and classification of Finite Fields.
4. Acquaint with the basic concepts of Galois Theory such as the concepts of normal extensions, fixed field, the fundamental theorem of Galois theory etc.
5. Realize the importance of adjoint of a linear transformation, its canonical form and its applications.

Reference Books:

1. D. S. Malik, J. M. Mordeson, M. K. Sen, Fundamentals of abstract algebra, The McGraw-Hill Companies, Inc.
2. J. A. Gallian, Contemporary abstract algebra, Cengage learning India pvt. Ltd.
3. J. B. Fraleigh, A first course in abstract algebra, Pearson education.
4. M. Artin, Algebra, Pearson education.
5. T. W. Hungerford, Algebra, Springer-Verlag.
6. D. S. Dummit, R. M. Foote, Abstract algebra, Wiley.
7. I. N. Herstein, Topics in algebra, Wiley.
8. N. Jacobson, Basic Algebra I & II (2nd edition), Dover Publications, Inc.
9. Gilbert Strang, Linear Algebra and its Applications (2nd edition), (2014), Elsevier.
10. Kenneth Hoffman & Ray Kunze, Linear Algebra (2nd edition), (2015), Prentice-Hall.

CORE COURSE – 3
MTM – 103T: Ordinary Differential Equations and Special Functions

Course Content	No of Lectures
Unit I: Eigenvalue Problems and Sturm–Liouville Theory	10

Ordinary differential equations of the Strum- Liouville type, Properties of Strum Liouville type, Application to Boundary Value Problems, Eigen values and Eigen functions, Orthogonality theorem, Expansion theorem.	
Unit II: Green's Function and Boundary Value Problems Green's Function and its properties, Green's function for ordinary differential equations, Application to Boundary Value Problems.	8
Unit III: System of Linear Differential Equations Systems of First order equations and the Matrix form, Representation of nth order equations as a system, Existence and uniqueness of solutions of system of equations, Wronskian of vector functions, Autonomous System of Equations, Critical Points and its Stability.	10
Unit IV: Hypergeometric and Confluent Hypergeometric Functions. Hypergeometric functions, Series solution near zero, one and infinity, Integral formula for the hypergeometric function, Differentiation of hypergeometric function, The confluent hypergeometric function, Integral representation of confluent hypergeometric function.	12
Unit V: Legendre Equation: Legendre functions, Generating function, Legendre functions of first kind and second kind, Laplace integral, Orthogonal properties of Legendre polynomials, Rodrigue's formula, Schlaefli's integral	6
Unit VI: Bessel Equation: Bessel function, Series solution of Bessel equation, Generating function, Integrals representations of Bessel's functions, Hankel functions, Recurrence relations, Asymptotic expansion of Bessel functions.	6

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. In ODEs, there are three topics such as Sturm Liouville Problem, Green's Function and Systems of Linear Differential Equations.
2. Many real-life problems are designed based on the ordinary differential equations where eigen values and eigen functions play major roles.
3. On solving the SL problem, a broad idea can be carried on eigen value and eigen function which helps a lot to solve real-life problems.
4. Green's function is an effective technique for solving complex initial and boundary value problems involving differential equations.
5. Nowadays complex real-life problems cannot be designed only single differential equation, so a system of linear differential equations is very much essential for modelling this type of problem.
6. Learners achieve the overall concept for solving system of differential equations which have a great impact to extract the solutions for real-life problems.
7. In SFs, there are three types such as Hypergeometric differential equation, Legendre differential equation and Bessel's function.
8. In this content, learners mainly achieve the solution procedure of special type differential equations which have many applications in engineering design problems and these are more related with real-life complex problems also.

Reference Books:

1. Eastham, M.S.P. (1970) Theory of Ordinary Differential Equations, Van Nostrand, London.
2. Braun, M. Differential Equations and Their Applications; An Introduction to Applied Mathematics, 3rd Edition, Springer-Verlag.
3. Rainville, E.D. and Bedient, P.E. (1969) Elementary Differential Equations, McGraw Hill, NewYork.
4. Coddington, E.A. and Levinson, N. (1955) Theory of ordinary differential equations, McGraw Hill.
   King,A.C., Billingham, J. & Otto, S.R. (2006) Differential equations, Cambridge University Press.

CORE COURSE – 4

MTM – 104T: Multivariate Calculus

Course Content	**No of Lectures**
Unit I: Topology and Continuity in $\mathbb{R}^n$ Points in $\mathbb{R}^n$, norm and inner product on $\mathbb{R}^n$, subsets of $\mathbb{R}^n$, limit and continuity of functions $f: \mathbb{R}^n \to \mathbb{R}^m$.	10
Unit II: Differentiation in $\mathbb{R}^n$	12

Differentiability of function $f: \mathbb{R}^n \rightarrow \mathbb{R}^m$, chain rule, mean value theorem, partial derivatives, inverse function theorem (local and global), implicit function theorem.	
Unit III: Integration in $\mathbb{R}^n$ Integrability of function $f: \mathbb{R}^n \rightarrow \mathbb{R}^m$, Fubini's theorem, partitions of unity, change of variables.	10
Unit IV: Multilinear Algebra, Vector Fields, and Differential Forms Multilinear function, tensor product, vector field, differential form, Poincare lemma, singular n-cube, curve, Stokes' theorem.	10
Unit V: Manifolds and Integral Theorems k-dimensional manifold in $\mathbb{R}^n$, fields and forms on manifolds, Stokes' theorem, Green's theorem and divergence theorem on manifolds.	8

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. Understand the differentiation and integration of multivariate functions
2. Realize the structure of manifolds
3. Apply multivariable calculus in various optimization problems
4. Learn the applications of multivariable calculus in different fields like Physics, Economics, Medical Sciences, Animation & Computer Graphics, etc

Reference Books:

1. M. Spivak, Calculus on Manifolds, Addision-wiseley publishing company
2. G.B. Thomas and R.L. Finney, Calculus, 9th Ed., Pearson Education, Delhi, 2005.
3. M.J. Strauss, G.L. Bradley and K. J. Smith, Calculus, 3rd Ed., Dorling Kindersley (India) Pvt. Ltd. (Pearson Education), Delhi, 2007.
4. E. Marsden, A.J. Tromba and A. Weinstein, Basic Multivariable Calculus, Springer (SIE), Indian reprint, 2005.
5. James Stewart, Multivariable Calculus, Concepts and Contexts, 2nd Ed., Brooks Cole, Thomson Learning,USA, 2001
6. Tom M. Apostol, Mathematical Analysis, Narosa Publishing House, 2nd Ed.,2002

CORE COURSE – 5
MTM – 105T: Advanced Python Programming

Course Content	No of Lectures
Unit I: Python Fundamentals Features of Python, Different Methods to Run Python, Python basics such as syntax, variables, and data types, Comments, Indentation in Python, Input and Output in Python, import function, Operators in Python, loops, conditionals, Branching, Iteration, range and enumerate functions	12
Unit II: Data Structures Data Structures – Definition, Linear Data Structures, Non-Linear Data Structures Python Specific Data Structures: List, Tuples, Set, Dictionaries, Comprehensions and its Types, Strings, Slicing. Arrays - Overview, Types of Arrays, Operations on Arrays	14
Unit III: Object-Oriented Programming Oops Concepts- Class, Object, Constructors, Types of Variables, Types of Methods. Inheritance: Single, Multiple, Multi-Level, Hierarchical, Hybrid, Polymorphism: With Functions and Objects, With Class Methods, With Inheritance, Abstraction: Abstract Classes Encapsulation and Polymorphism in Python.	4
Unit IV: Visualization & Networking Visualization - The Matplotlib Module, Plotting Simple Mathematical Functions-Famous Curves Power Series-Fourier Series-2d Plot Using Colors, Python and The Web, Cgi, Twisted (Networking Framework for Python), Some Popular Python Modules: Smtplib, Httplib, Poplib	10

Course Outcomes (COs)

Upon successful completion of this course, students will learn the following:

1. Learn advanced python concepts
2. Understand data structures using python
3. Familiarize object-oriented concepts using python
4. Understand web programming concepts using python

References Books:

1. Lutz, M. (2013) Learning Python. O'Reilly Media.
2. Kurama, V. (2020) Python Programming: A Modern Approach. Pearson Education.
3. Severance, C.R. (2016) Python for Everybody. CreateSpace Independent Publishing.
4. Chun, W.J. (2006) Core Python Programming. Prentice Hall.
5. Dawson, M. (2010) Python Programming for the Absolute Beginner. Cengage Learning.
6. Downey, A.B. (2015) Think Python: How to Think Like a Computer Scientist. Green Tea Press.
7. Sweigart, A. (2019) Automate the Boring Stuff with Python. No Starch Press.
8. Tosi, S. (2009) Matplotlib for Python Developers. Packt Publishing.

CORE COURSE – 6
MTM – 106T: Graph Theory

Course Content	No of Lectures
Unit I: Basic Concepts and Structures Definitions: graphs, multigraphs, simple graphs, Degree of vertices, paths, and cycles, Subgraphs, connected and disconnected graphs, Isomorphic graphs and examples	5
Unit II: Connectivity, Trees, and Special Graphs Connectivity, components, and cut vertices, Trees and spanning trees, Spanning subgraphs and bipartite graphs, Hamiltonian and Euler paths and cycles	6
Unit III: Distance, Cuts, and Colouring Distance, eccentricity, radius, and centre, Cut sets, bridges, and articulation points, Vertex colouring and chromatic number, Chromatic polynomial and four-colour theorem (statement only)	5
Unit IV: Planar and Directed Graphs Planar graphs and Kuratowski's theorem, Dual graphs and examples, Directed graphs (digraphs) and weighted graphs, Matrix representation of graphs: adjacency, incidence, and path matrices	6
Unit V: Graph Algorithms and Applications Shortest path algorithms: Dijkstra's and Floyd–Warshall, Spanning tree algorithms: Prim's and Kruskal's, Applications: Traveling Salesman Problem, Intersection graphs and practical examples (1 hr)	8

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:
1. Understand and apply the fundamental concepts in graph theory.
2. Describe and solve some real time problems using concepts of graph theory.
3. Discuss the concept of graph, tree, Euler graph, cut set and Combinatorics.
4. Apply graph theory-based tools in solving practical problems in science, business and industry.

Reference Books:

1. Chartrand, G. (2006). Introduction to graph theory. Tata McGraw-Hill Education.
2. Gross, J. L., & Yellen, J. (2005). Graph theory and its applications. CRC press.
3. Deo, N. (2017). Graph theory with applications to engineering and computer science. Courier Dover Publications.
4. West, D. B. (2001). Introduction to graph theory, Upper Saddle River: Prentice Hall.

CORE COURSE – 6
MTM – 106P: Advanced Python Programming Lab
Problem: 20 marks, Lab Note Book and Viva-Voce: 05 marks

Course Content	No of Lectures
Unit I: Python Fundamentals and Control Structures • Installation and configuration of Python IDE (IDLE, Jupyter, PyCharm, Anaconda). Writing first Python program to display messages. • Programs using arithmetic, relational, logical, and bitwise operators. • Programs demonstrating conditional statements (if, if-else, nested if). • Programs demonstrating looping statements (for, while, nested loops). • Programs using range() and enumerate(), combining conditionals and loops for pattern printing or series generation.	10
Unit II: Python Data Structures and Arrays	10

• Programs to create, access, update, delete elements of a List. • Programs to create, access, update, delete elements of a Tuple. • Programs to create, access, update, delete elements of a Set; perform set operations (union, intersection). • Programs to create, access, update, delete elements of a Dictionary; looping through dictionary elements. • Programs for array operations and basic matrix manipulations (addition, multiplication, transpose) using array or numpy.	
Unit III: Object-Oriented Programming in Python • Programs to create simple classes and objects (e.g., Student class with name, roll, marks). • Program using constructors (e.g., Rectangle class for area and perimeter). • Program differentiating class variables and instance variables. • Program demonstrating class method and static method (e.g., Company class). • Programs implementing various inheritance types: single, multiple, multilevel, hierarchical, hybrid. • Programs demonstrating polymorphism, abstraction, and encapsulation using abstract base classes and overridden methods.	12
Unit IV: Visualization, Networking, and Web Programming • Plot simple mathematical functions (e.g., $y = x^2, y = \sin x, y = e^x$) with legends using Matplotlib. • Plot famous curves (Lissajous, Archimedean spiral), Fourier series approximation, or power series comparison. • Create 2D color plots (e.g., heatmap for $z = \sin(X^2 + Y^2)$ using imshow() or contourf()). • Simple CGI script to take user input via web form and display result on webpage. • Implement networking programs using Twisted, and work with SMTP, HTTP, and POP3 modules (smtplib, httplib, poplib).	8

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. Install, configure, and operate Python development environments and write basic Python programs using variables, operators, conditionals, and loops.
2. Implement and manipulate Python data structures such as Lists, Tuples, Sets, Dictionaries, Strings, and Arrays for solving computational problems.
3. Apply Object-Oriented Programming (OOP) concepts such as Classes, Objects, Inheritance, Polymorphism, Abstraction, and Encapsulation using Python.
4. Create and visualize data using Python's Matplotlib library and implement basic web and networking programs using standard Python modules (CGI, Twisted, smtplib, httplib, poplib).
5. Develop integrated Python applications demonstrating problem-solving skills, logical thinking, and real-world data processing through hands-on laboratory exercises.

Reference Books:

1. Lutz, M. (2013) Learning Python. O'Reilly Media.
2. Kurama, V. (2020) Python Programming: A Modern Approach. Pearson Education.
3. Severance, C.R. (2016) Python for Everybody. CreateSpace Independent Publishing.
4. Chun, W.J. (2006) Core Python Programming. Prentice Hall.
5. Dawson, M. (2010) Python Programming for the Absolute Beginner. Cengage Learning.
6. Downey, A.B. (2015) Think Python: How to Think Like a Computer Scientist. Green Tea Press.
7. Sweigart, A. (2019) Automate the Boring Stuff with Python. No Starch Press.
8. Tosi, S. (2009) Matplotlib for Python Developers. Packt Publishing.

SEMESTER – II

CORE COURSE – 7
MTM – 201T: Complex Analysis

Course Content	No of Lectures
Unit I: Complex Integration and Fundamental Theorems	12

Integration along a contour, fundamental theorem of calculus, homotopy, Goursat's theorem, Cauchy's theorem, Cauchy's integral formula, Liouville's theorem, Cauchy's inequalities and other consequences, winding number, open mapping theorem.	
Unit II: Singularities, Laurent Series, and Residue Theory Singularities of a holomorphic function, residues, Laurent series, Cauchy's residue theorem, Cassoratti-Weierstrass theorem, argument principle, Rouche's theorem and its applications.	12
Unit III: Advanced Theorems and Analytic Continuation Maximum modulus theorem, Schwarz's lemma, automorphisms of unit disc, Schwarz reflection principle, Open mapping theorem, Analytic continuation along path.	12
Unit IV: Function Spaces and Harmonic Functions Space of continuous functions, space of analytic functions, space of meromorphic functions. Basic properties of harmonic functions, harmonic functions on a disc, subharmonic and superharmonic functions, Dirichlet's problem, Green's functions.	14

Course Outcomes: After completion of this course, students will be able to
1. visualize the complex plane and the extended complex plane
2. integrate complex valued functions along a curve and find the Laurent series of certain functions.
3. apply Schwarz's lemma in the geometry of unit disc.
4. Solve Dirichlet's problem and apply Green's function to different branches of applied mathematics.

Reference Books:
1. Ponnusamy, S. (1995) Foundations of Complex Analysis, Narosa.
2. Brown, J. W. and Churchill, R. V. Complex Variable and Applications, 8th Edition, McGraw Hill.
3. Nayak, P. K. and Seikh, M. R. (2018) A Text Book of Complex Analysis, Universities Press

CORE COURSE – 8
MTM – 202T: Functional Analysis

Course Content	No of Lectures
Unit I: Metric spaces Completion of Metric space. Equi continuous family of Functions. Compactness in C[0,1] (Arzela-Ascoli's Theorem), Baire category theorem.	10
Unit II: Normed linear spaces Norm, continuity of norm function, Banach spaces with examples, quotient space. Linear operator, boundedness and continuity, examples of bounded and unbounded linear operators. Properties of normed linear spaces, Riesz's Lemma, and its application in Banach spaces. Series and its convergence in normed linear spaces, equivalence of two norms in a linear space, some properties of a finite dimensional normed linear space.	12
Unit III: Banach spaces Hahn-Banach theorems and its consequences, dual and 2nd dual of a normed linear space, separability and reflexivity of normed linear space, Open mapping theorem, closed graph theorem and uniform boundedness principle, some applications of these theorems.	14
Unit IV: Hilbert spaces Hilbert space, orthonormality, orthogonal complement, orthonormal basis, Bessel's inequality, Parseval's equation, Gram-Schmidt orthonomalisation process, Riesz representation theorem, reflexivity of Hilbert space, separable and non-separable Hilbert space.	14

Course Outcomes (COs)
After completion of this course, students will be able to
1. Realize the importance of Baire category theorem, The Arzela-Ascoli theorem etc. and apply them in other related areas.
2. Realize the concepts of bounded operators, normed spaces, Hilbert spaces and utilize them in science and engineering.
3. Distinguish between Banach spaces and Hilbert spaces
4. Apply the Hahn-Banach theorem, the open mapping theorem, the closed graph theorem and uniform boundedness theorem to different related fields.

References Books:
1. Simmons, G.F., Introduction to Topology and Modern analysis, McGraw-Hill, 1963.

2. Kreyszig, E., Introductory Functional Analysis with Applications, John Wiley and Sons (Asia) Pvt. Ltd., 2006.
3. Aliprantis, C.D., Burkinshaw, O., Principles of Real Analysis, 3rd Edition, Harcourt Asia Pvt Ltd.
4. Goffman, C., Pedrick, G., First Course in Functional Analysis, PHI, New Delhi, 1987.
5. Bachman, G., Narici, L., Functional Analysis, Academic Press, 1966.
6. Taylor, A.E. Introduction to Functional Analysis, John Wiley and Sons, New York, 1958.
7. Conway, J.B., A course in Functional Analysis, Springer Verlag, New York, 1990.

CORE COURSE – 9
MTM – 203T: Topology

Course Content	No of Lectures
Unit I: Fundamentals of Topological Spaces Definition and examples of topological spaces, Open sets, Neighbourhoods, Neighbourhood systems, Neighbourhood operator, Generation of a topology using neighbourhood operators, Bases, Subbases, Limit points, Derived sets, Closure of a set, closed sets, Kuratowski closure operator, Interior of a set, Continuous functions, Open maps, Closed maps, Homeomorphism and topological invariants	12
Unit II: Product and Quotient Topologies Product topological spaces, quotient topological space, Examples and application	6
Unit III: Separation Axioms (T_0–T_4 Spaces) T_0 spaces, T_1 spaces, T_2 spaces, Regular spaces, T_3 spaces, Normal spaces, T_4 spaces, Uryshon's lemma (Statement only), Completely regular spaces and $T_{3.5}$ spaces, their properties, characterizations and relationships. Tietze's extension theorem (Statement only).	10
Unit IV: Countability Axioms and Related Spaces First and second countable spaces, Separable spaces, Lindelof space, Examples and relation, Properties on continuity and subspaces of the above spaces.	8
Unit V: Compactness Compact spaces, compact subspaces, characterizations in terms of finite intersection property, Alexander subbase theorem, compactness and separation axioms, compactness and continuous functions, sequentially, Fréchet and countably compact spaces, subspaces and their mutual relationship, locally compact spaces.	8
Unit VI: Connectedness and Path Connectedness Connected spaces and their characterizations, connected subspaces, Connectedness of the real line, Components, totally disconnected spaces, locally connected spaces, Path connectedness, Path components, locally path connected spaces.	6

Course Outcomes: After successful completion of the course the student would be able to
1. Demonstrate knowledge and understanding of concepts such as open and closed sets, interior, closure and boundary.
2. Check whether a collection of subsets is a basis for a given topological space or not, and determine the topology generated by a given basis.
3. Understand separation axioms and find their differences.
4. Determine the connectedness, path connectedness, compactness etc. of the product of an arbitrary family of spaces.
5. Create new topological spaces by using subspace, product and quotient topologies.

Reference Books:
1. Munkers, J.R., Topology, Pearson.
2. Simmons, G.F., Introduction to Topology and Modern analysis, McGraw-Hill, 1963.
3. Kelley, J.L., General topology, Van Nostrand Reinhold Co., New York, 1995.
4. Joshi, K.D., Introduction to General Topology, New age International Publishers, 1983.
5. Hocking, J., Young, G., Topology, Addison-Wesley Reading, 1961.
6. Steen, L., Seebach, J., Counter Examples in Topology, Holt, reinhart and Winston, New York.

CORE COURSE – 10
CMTM – 204T: Statistical and Numerical Methods (CBCS)

Course Content	No of Lectures
Unit I: Descriptive Statistics Mean, median, mode, Correlation (Karl Pearson, rank) and regression, Simple numerical problems	6
Unit II: Hypothesis Testing and ANOVA Null and alternative hypotheses, Chi-square test, t-test and F-test, One-way ANOVA (1 hr)	6
Unit III: Numerical Errors and Interpolation Sources and types of errors, Lagrange and Newton's interpolation (no derivation)	5
Unit IV: Solution of Equations Bisection method, Newton–Raphson method and rate of convergence	5
Unit V: Linear Systems and Integration Cramer's rule, Gauss elimination, Trapezoidal and Simpson's 1/3 rule	6
Unit VI: Differential Equations (Numerical Solutions) Euler's method, Runge–Kutta 2nd and 4th order	4

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. Apply method of interpolation and extrapolation for prediction, recognize elements and variable in statistics and summarize qualitative and quantitative data.
2. Recognize the error in the number generated by the solution, compute solution of algebraic and transcendental equation by numerical methods like Bisection method and Newton-Rapshon method.
3. Process to calculate and apply measures of location and measures of dispersion - grouped and ungrouped data cases, learn non-parametric test such as the Chi-Square test for independence as well as goodness of fit.
4. Compute and interpret the results of bivariate and multivariate regression and correlation analysis, for forecasting.

Reference Books:

1. Goon, A.M., Gupta, M.K. & Dasgupta, B. (1968) Fundamentals of Statistics, Vol. 1 & 2, Calcutta: The World Press Private Ltd.
2. Biswas, S., Sriwastav, G. L. (2011) Mathematical Statistics: A Textbook, Narosa.
3. Pal, M. (2007) Numerical Analysis for Scientists and Engineers: Theory and C Programs, Narosa.
4. Medhi, J. (1984) Stochastic Process, New Age International Publisher, 2ed.
5. Jain, M.K., Iyengar, S.R.K. and Jain, R.K. (1984) Numerical Methods for Scientific and Engineering Computation, New Age International (P) Limited, New Delhi.
6. Krishnamurthy, E.V. and Sen, S.K. (1986) Numerical Algorithms, Affiliated East-West Press Pvt. Ltd., New Delhi.
7. Mathews, J.H. (1992) Numeical Methods for Mathematics, Science, and Engineering, 2nd ed., Prentice-Hall, Inc., N.J., U.S.A.
8. Volkov, E.A. (1986) Numerical Methods, Mir Publishers, Moscow.

CORE COURSE – 11
MTM – 205T: Numerical Analysis

Course Content	No of Lectures
Unit I: Advanced Interpolation and Approximation Cubic Spline Interpolation – concept, construction, and examples. Lagrange's Bivariate Interpolation – formula and applications. Curve Fitting by Least Squares Method – linear and polynomial cases. Approximation of Functions – introduction, minimization of error, concept of Chebyshev polynomials (definition only).	8
Unit II: Numerical Integration Newton–Cotes Formulas (Open Type) – trapezoidal and Simpson rules as special cases. Gaussian Quadrature – Gauss–Legendre formula (derivation and examples). Monte Carlo Integration – basic idea and simple applications.	6
Unit III: Solution of Algebraic and Transcendental Equations	6

Roots of Polynomial Equations – Bairstow's method (concept and examples). Systems of Linear Equations: Pivoting and Matrix Inversion, LU Decomposition Method, Tridiagonal System (Thomas Algorithm)	
Unit IV: Non-linear Systems and Eigenvalue Problems System of Nonlinear Equations: Fixed Point and Newton Methods, Convergence and Rate of Convergence Eigenvalue Problems: Power Method, Jacobi's Method (concept and application examples only)	8
Unit V: Numerical Solution of Differential Equations Ordinary Differential Equations (ODEs): Runge–Kutta Methods (2^{nd} and 4^{th} order), Predictor–Corrector Method (Milne's Method), Shooting Method and Finite Difference Method for 2nd Order Boundary Value Problems, Stability and Convergence Concepts Partial Differential Equations (PDEs): Finite Difference Schemes, Explicit and Implicit Methods for Parabolic and Hyperbolic Equations, Crank–Nicolson Method and Basic Stability Idea	12

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. Interpolation using spline interpolation.
2. Approximate a function by least square method, orthogonal polynomials and Gaussian quadrature.
3. Solve the ordinary differential equations (RK methods, predictor-corrector method, finite difference method, finite element method)
4. Solve a system of linear and non-linear equations and matrix inversion with pivoting.
5. Determine the eigenvalues and eigenvectors of a matrix.
6. Solve the partial differential equations (finite difference method) and analyse of stability of the methods to solve ODEs and PDEs.
7. Students will understand the theory behind these methods. Their programming skills will increase after this course and hence they can write computer programs for any mathematical and logical problems.

Reference Books:

1. Pal, M. (2007) Numerical Analysis for Scientists and Engineers: Theory and C Programs, Narosa.
2. Jain, M.K., Iyengar, S.R.K. and Jain, R.K. (1984) Numerical Methods for Scientific and Engineering Computation, New Age International (P) Limited, New Delhi.
3. Krishnamurthy, E.V. and Sen, S.K. (1986) Numerical Algorithms, Affiliated East-West Press Pvt. Ltd., New Delhi.
4. Mathews, J.H. (1992) Numerical Methods for Mathematics, Science, and Engineering, 2^{nd} ed., Prentice-Hall, Inc., N.J., U.S.A..

CORE COURSE – 12
MTM – 206T: Classical Mechanics

Course Content	No of Lectures
Unit I: System of Particles and Constraints Motion of a system of particles, Constraints and types (holonomic & non-holonomic), Generalized coordinates, Principle of virtual work and D'Alembert's principle	6
Unit II: Lagrangian and Hamiltonian Formulations Lagrange's equations and applications (plane pendulum), Hamiltonian and Hamilton's equations, Cyclic coordinates and conservation laws, Routhian (concept only)	8
Unit III: Variational Principles Principle of stationary action (Hamilton's principle), Derivation of Lagrange's equations from Hamilton's principle, Brachistochrone problem	6
Unit IV: Canonical Transformations and Poisson Brackets Canonical transformations and generating functions, Poisson bracket (definition, properties, and examples)	4
Unit V: Special Theory of Relativity Postulates of special relativity, Lorentz transformation, Time dilation and length contraction, Relativistic momentum, force, and energy equations	6

Course Outcomes (COs)

Upon successful completion of this course, the students can do the following:

1. The student will be able to apply the Lagrangian formalism to analyze problems in Mechanics; and dissect and describe the dynamics of systems of particles, rigid bodies, and systems in non inertial reference frames.
2. The student will deconstruct complex problems into their building blocks. Translate physical problems into appropriate mathematical language and apply appropriate mathematical tools to analyze and solve the resulting equations.
3. Students will demonstrate the ability to apply basic methods of classical mechanics towards solutions of various problems, including the problems of complicated oscillatory systems, the motion of rigid bodies, etc.
4. Able to solve some mathematical problems using variational principle.
5. Using Lorentz transformation, the student will describe the physical situations in inertial frames of reference.

Reference Books:

1. Goldstein, H. (1950) Classical Mechanics, Addison-Wesley, Cambridge.
2. Pal, M. (2009) A Course on Classical Mechanics, Narosa, New Delhi, & Alpha Science, Oxford, London.
3. Gupta, A.S. (2005) Calculus of Variations with Applications, Prentice-Hall of India, New Delhi.
4. Gupta, B.D. and Prakash, S. (1985) Classical Mechanics, KedarNath Ram Nath, Meerut.
5. Kibble, T.W.B. (1985) Classical Mechanics, Orient Longman, London.
6. Rana, N.C. and Joag, P.S. (2004) Classical Mechanics, Tata McGraw-Hill Publishing Company Limited, New Delhi.
7. Symon, K.R. (1971) Mechanics, Addison-Wesley Publ. Co., Inc., Massachusetts.

Takwale, R.G. and Puranik, S. (1980) Introduction to Classical Mechanics, Tata McGraw-Hill Publ. Co. Ltd., New Delhi.

CORE COURSE – 12

MTM – 206P: Python Programming with Numerical Methods

Problem: 20 marks; Lab. Note Book and Viva-Voce: 05 marks.

(Programs will be written on the following problems using pointers, data files, structures, etc.)

Course Content	No of Lectures
Unit I: Python Fundamentals for Numerical Computation - Python syntax, loops, functions - NumPy arrays and matrix operations - Use of SciPy and Matplotlib for numerical visualization	6
Unit II: Solution of Linear Systems - Gaussian elimination - Matrix inversion by partial pivoting - Gauss–Seidel method - LU decomposition	9
Unit III: Interpolation and Numerical Integration - Lagrange interpolation - Newton forward and backward interpolation - Cubic spline interpolation - Gaussian quadrature rule	8
Unit IV: Differential Equations and Roots - Roots of polynomial equations - Runge–Kutta 4th order method for ODEs - Milne's predictor–corrector method - Basic finite difference method for 1D PDE (concept only)	10
Unit V: Eigenvalue Problem (Optional / Short Introduction) - Power method - Jacobi's method (concept and example)	7

Course Outcomes (COs)

Upon successful completion of this course, students will learn the following:

1. Interactive examples and hands-on problem-solving environment.
2. The course is to demonstrate searching, sorting and strings manipulation problems.

3. Demonstrate numerical problems in Python.
4. Applications in various disciplines such as engineering, science, and economics.

Reference Books:

1. Rajaraman, V. Computer Orientated Numerical Methods, 3rd ed., PHI.
2. Pal, M. (2007) Numerical Analysis for Scientists and Engineers: Theory and C Programs Narosa.
3. Jain, M K. (2019) Numerical Methods: For Scientific and Engineering Computation,7th ed., New Age International Private Limited.
4. Kanetkar, V. (2017) Let Us C, 16th ed., BPB Publications

SEMESTER – III

CORE COURSE – 13

MTM – 301T: Partial Differential Equations and Generalized Functions

Course Content	No of Lectures
Unit I: First-Order Partial Differential Equations Formation of PDEs and Cauchy problem, Semi-linear and quasi-linear equations in two variables, Method of characteristics, Applications and examples	8
Unit II: Second-Order Linear PDE and Classification General second-order linear PDEs, Adjoint and self-adjoint equations, Classification: elliptic, parabolic, hyperbolic, Reduction to canonical form	8
Unit III: Fundamental Equations of Mathematical Physics Laplace, Wave, and Heat equations, Equation of vibration of a string and D'Alembert's solution, Domain of dependence and uniqueness, Heat conduction in finite and infinite rods	10
Unit IV: Boundary Value Problems and Separation of Variables Separation of variables for Laplace, Heat, and Wave equations, Dirichlet's and Neumann's boundary value problems, Solutions for a disc and a sphere, Poisson's integral formula	10
Unit V: Harmonic Functions and Green's Functions Fundamental solution of Laplace's equation in 2D, Harmonic function and mean value property, Green's functions for Laplace's equation	7
Unit VI: Generalized Functions (Distributions) Test functions and generalized functions, Regular and singular distributions, Dirac delta function and its properties, Operations and derivatives of generalized functions, Fourier transform of generalized functions	7

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. Use the knowledge of first and second order partial differential equations (PDEs),the general structure of solutions, and analytic methods for solutions.
2. Classify PDEs, apply analytical methods, and physically interpret the solutions.
3. Solve practical PDE problems (Wave, Heat & Laplace equations) with the methods of separation of variables, and analyse the stability and convergence properties of this method.
4. Find solution of Dirichlet's and Neumann's problem for some typical problems like adisc and a sphere.

Reference Books:

1. Pinchover, Y. and Rubinstein, J. (2005) An Introduction to Partial Differential Equations, Cambridge University Press.
2. Rao, S. (2011) Introduction to Partial Differential Equations, 3rd Edition, PHI Learning Private Limited, New Delhi.
3. Duistermaat, J. J. and Kolk, J. A. C. (2010) Distributions Theory and Applications, Birkhäuser Basel.
4. John, F. (1978) Partial Differential Equations, Springer-Verlag, New York. Gelfand, I. M. and Shilov, G.E. (2016) Generalized Functions, AMS, Recent Edition.

CORE COURSE – 14

MTM – 302T: Advanced Optimization Techniques

Course Content	No of Lectures
Unit I: Revised Simplex Method Standard form of Revised Simplex Method, Computational procedure and table formulation, Comparison with Simplex Method, Numerical examples and computational steps	8

Unit II: Sensitivity Analysis Effect of change in cost coefficients and resource availability, change in input-output coefficients, Addition and deletion of variables and constraints, Bounded variable technique and computational procedure	8
Unit III: Convex and Concave Functions: Definition and geometric interpretation, Properties and basic theorems, Differentiable convex/concave functions, twice differentiable cases, strict convexity/concavity theorems	8
Unit IV: Unconstrained Optimization: Search methods: Fibonacci & Golden Section, Interpolation: Quadratic and Cubic methods, Gradient methods: Steepest descent, Damped Newton's method, Davidson–Fletcher–Powell (DFP) method, Line search and projection methods	10
Unit V: Constrained Optimization: Lagrange's multiplier method and interpretation, Nonlinear programming with equality constraints, Kuhn–Tucker conditions for inequality constraints, Applications and examples	8
Unit VI: Computational Optimization: Conventional vs. evolutionary algorithms, Fundamentals of Genetic Algorithms: operators, fitness, selection, Particle Swarm Optimization (PSO): concept and algorithm, Comparative discussion and hybrid approaches	8

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:
1. Solve linear programming problem by revised simplex method
2. Conduct sensitivity analysis of linear programming problems
3. Use classical optimization techniques for nonlinear programming problems
4. Apply different evolutionary algorithms for solving large scale real-world problems

Reference Books:

1. S. S. Rao. Engineering optimization: theory and practice. John Wiley & Sons, 2009.
2. Belegundu, Ashok D., and Tirupathi R. Chandrupatla. Optimization concepts and applications in engineering. Cambridge University Press, 2011.
3. Mokhtar S. Bazaraa, Hanif D. Sherali, and C. M. Shetty, Nonlinear Programming: Theory and Algorithms, Second Edition, John Wiley & Sons, New York 1993.
4. Ruhul Amin Sarker and Charles S. Newton, Optimization Modelling: A practical Approach, CRC Press, 2008.
5. C. Mohan & K. Deep, Optimization Techniques, New Age Science, 2009.
6. Achille Messac, Optimization in Practice with MATLAB, Cambridge University Press, 2015.
7. Michel Gendreau, Jean -Yves Potvin, Handbook of Metaheuristics, Springer, 2019.
8. Convex Optimization By S. Boyd Pub: Cambridge University Press
9. D.E.Goldberg, Genetic algorithms in Search, Optimization, and Machine learning, Addison-Wesley Publishers.
10. Andrea E. Olsson, Particle Swarm Optimization: Theory, Techniques and Applications, Nova Science Publishers, 2011.

CORE COURSE – 15
MTM – 303T: Linear Algebra

Course Content	No of Lectures
Unit I: Dual Spaces and Linear Functionals Linear functional and dual space, Dual basis and double dual, Results on duality, Transpose of a linear transformation, Matrix representation of transpose	8
Unit II: Canonical Forms and Decomposition Theorems Characteristic and minimal polynomial, similarity of linear operator, invariant sub-spaces, primary decomposition theorem, diagonalizable form, triangular canonical form, nilpotent operator, invariants of a nilpotent operator, generalized eigenvectors, Jordan blocks and Jordan canonical form, rational canonical form.	12
Unit III: Inner Product Spaces and Linear Operators	10

Linear transformations on inner product spaces, adjoint of a linear operator, matrix representation of the adjoint, normal and self-adjoint operators, unitary and orthogonal operators and their matrices, orthogonal projections, spectral theorems and consequences.	
Unit IV: Bilinear and Quadratic Forms Bilinear forms, symmetric and skew-symmetric forms, Real quadratic forms, Sylvester's Law of Inertia, Positive definiteness and canonical reduction	8
Unit V: Generalized and Matrix Factorizations Generalized inverse of rectangular matrices, Moore–Penrose inverse, Singular value decomposition (SVD) of matrices	7
Unit VI: Applications and Illustrations Computation of Jordan, rational, and SVD forms using examples, Applications in differential equations and data analysis	5

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. Understand and apply concepts of linear functionals, dual spaces, and transpose operators.
2. Analyze linear operators using characteristic polynomials, invariant subspaces, and canonical forms.
3. Study inner product spaces and properties of adjoint, normal, self-adjoint, unitary, and orthogonal operators.
4. Evaluate bilinear and quadratic forms with Sylvester's law of inertia and positive definiteness.

Apply generalized inverses, Moore–Penrose inverse, and singular value decomposition in linear systems.

References Books:

1. Kenneth Hoffman and Ray Kunze, Linear Algebra, Prentice-Hall International, 2010.
2. P. Lax, Linear Algebra, John Wiley & Sons, 1997.
3. H.E. Rose, Linear Algebra, Birkhauser, 2002.
4. S. Lang, Algebra, 3rd Edition, Springer (India), 2004.
5. Roger A. Horn, Charles R. Johnson., Matrix Analysis, 2nd edition, CUP, 2013.
6. Sheldon Axler, Linear Algebra Done Right, 3rd edition, Springer, 2015.
7. N. Jacobson, Basic algebra I, 2nd edition, Dover Publications, 2012.
8. N. Jacobson, Basic algebra II, 2nd edition, Dover Publications, 2012.
9. T. S. Blyth & E. F. Robertson, Further Linear Algebra, Springer.
10. S. Roman, Advanced Linear Algebra, 3rd edition, Springer, 2007.
11. J. H. Kwak and S. Hong, Linear Algebra, 2nd edition, Birkhauser, 2006.

CORE COURSE – 16

MTM – 304T: Discrete Mathematics (CBCS)

Course Content	No of Lectures
Unit I: Boolean Algebra and Logic Introduction, definitions, and duality, Basic theorems of Boolean algebra, Lattice representation theorem, Sum-of-products form for sets and Boolean algebra, Propositional logic, tautologies, and truth tables	9
Unit II: Sets, Counting, and Induction Sets, propositions, and cardinality, Mathematical induction, Principle of inclusion and exclusion, Discrete numeric functions and generating functions	7
Unit III: Computability and Formal Languages Ordered sets and Hasse diagrams, Languages and grammars, Types of grammars and languages, Finite state machines (FSMs) and equivalent machines	8
Unit IV: Lattices and Order Relations Partial order relations, chains, and antichains, Lattices: definitions and examples, Relation between Boolean algebra and lattices	8
Unit V: Graph Theory Definitions: walks, paths, connected graphs, Regular and bipartite graphs, cycles, and circuits, Trees, rooted trees, spanning trees, Eccentricity, radius, and diameter of graphs, Centres of trees, Hamiltonian and Eulerian graphs, Planar graphs	12
Unit VI: Analysis of Algorithms	6

Definition and importance of algorithm analysis, Time complexity and Big-O notation, Classes of problems and computational limits	

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. Simplify and evaluate basic logic statements including compound statements, implications, inverses, converses, and contra positives using truth tables and the properties of logic, analyze the growth of elementary functions.
2. Represent a graph using an adjacency list and an adjacency matrix and apply graph theory to application problems such as computer networks.
3. Determine if a graph is a binary tree, Euler or a Hamilton path or circuit, N-ary tree, or not a tree.
4. Evaluate Boolean functions and simplify expression using the properties of Boolean algebra and use finite-state machines to model computer operations.

Reference Books:

1. Rosen, K. H. (2007) Discrete Mathematics and its Applications, McGraw-Hill.
2. Deo, N. (2017) Graph theory with applications to engineering and computer science. Courier Dover Publications.
3. Wilson, R. J. & Watkins, J. J. (1990) Graphs: an introductory approach: a first course in discrete mathematics. John Wiley & Sons Inc.

Elective Course – 1 / Elective Course – 2

MTM – 305T: Advanced Complex Analysis

Course Content	No of Lectures
Unit I: Theorems on Zeros and Analytic Functions Fundamental theorems related to zeros of analytic functions, Argument (Counting) Principle, Rouche's Theorem and its applications, Fundamental Theorem of Algebra, Morera's Theorem, Hurwitz's Theorem, and normal limits	6
Unit II: Open and Inverse Mapping Theorems Open Mapping Theorem, Inverse Function Theorem, Univalent functions and their nonvanishing derivatives, Analytic isomorphisms and implicit function theorem	8
Unit III: Riemann Surfaces and Multi-Valued Functions Concept of a Riemann Surface, Construction for the complex logarithm and m-th root, Functional inverses of analytic mappings at critical points, Algebraic nature and local structure	
Unit IV: Analytic Continuation and Harmonic Functions Direct and indirect analytic continuation, Lipschitz nature of the radius of convergence, Analytic continuation along paths and Monodromy Theorem, Harmonic functions and Maximum Principles, Schwarz's Lemma and uniqueness of Riemann mappings	10
Unit V: Hyperbolic Geometry on the Unit Disc Pick's Lemma and differential Schwarz's Lemma, Hyperbolic arc lengths and metric on the unit disc, Geodesics for the hyperbolic metric, Schwarz–Pick Lemma and applications	8
Unit VI: Compactness, Normal Families, and Riemann Mapping Theorem Arzelà–Ascoli Theorem: equivalence of conditions, Montel's Theorem and normal families, Candidate for a Riemann mapping, Proof and implications of the Riemann Mapping Theorem	8

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

6. Identify the zeros and critical points of different analytic functions
7. Construct Riemann surfaces
8. Extend the domain of analytic functions
9. Apply Hurwitz's theorem, Rouche's theorem, Open Mapping theorem, Inverse and Implicit Function theorems, Riemann mapping theorem.

References:

1. S. Ponnusamy and H. Silverman, Complex Variables with Applications, 2006, Birkhaeuser, Boston.
2. T. Gamelin Complex Analysis (UTM) by, Springer, 2003.
3. J. B. Conway, Functions of one complex variable, 2nd Ed., Springer international student edition.
4. James Ward Brown and Ruel V. Churchill, Complex Variables and Applications, 8th Ed., McGraw – Hill International Edition, 2009.

5. Joseph Bak and Donald J. Newman, Complex Analysis, 2nd Ed., Undergraduate Texts in Mathematics, Springer-Verlag New York, Inc., New York, 1997.
6. E.M.Stein and R. Shakrachi, Complex Analysis, Princeton University Press, 2010.

Elective Course – 1 / Elective Course – 2
MTM – 306T: Advanced Topology

Course Content	No of Lectures
Unit I: Nets and Filters Directed sets and definition of nets, Convergence and cluster points of nets, Subnets and their convergence, Characterization of topological properties via nets, Introduction to filters, base and subbase of a filter	10
Unit II: Filters and Ultrafilters Filters associated with nets and vice versa, Filters in topology, Ultrafilters and their properties, Ultrafilter characterization of compactness	8
Unit III: Product Spaces Product of arbitrary family of topological spaces, Productive properties: compactness and connectedness, Separation and countability axioms in product spaces, Embedding lemma and Tychonoff Embedding Theorem (Statement only)	10
Unit IV: Compactification One-point (Alexandroff) compactification, Stone–Čech compactification, Hausdorff compactification and examples, Relationships among compactifications	10
Unit V: Separation and Metrization Urysohn's Lemma and Tietze Extension Theorem, Pseudometric spaces and equicontinuity, Urysohn's embedding theorem, Urysohn's metrization theorem, Paracompactness and its relation to normality	12

Course Outcomes (COs)
Upon successful completion of this course, the students will learn the following:
1. Describe basic properties of Nets and filters.
2. Explain product spaces and the productive properties of compactness and connectedness, Urysohn's Metrization theorems.
3. Establish the relationship between Nets associated with filters and filter associated with nets.
4. Construct different types of compactifications.

Reference Books:
1. Munkers, J.R., Topology, Pearson
2. Dugundji, J., Topology, Allyn and Bacon, 1966.
3. Simmons, G.F., Introduction to Topology and Modern analysis, McGraw-Hill, 1963.
4. Kelley, J.L., General topology, Van Nostrand Reinhold Co., New York, 1995.
5. Hocking, J., Young, G., Topology, Addison-Wesley Reading, 1961.
6. Steen, L., Seebach, J., Counter Examples in Topology, Holt, reinhart and Winston, New York.

Elective Course – 1 / Elective Course – 2
MTM – 307T: Fluid Dynamics

Course Content	No of Lectures
Unit I: Kinematics of Fluid Motion Lagrange's and Euler's methods in fluid motion, Equation of motion and continuity, Streamlines, pathlines, boundary surfaces, Rotational and irrotational flows, velocity potential	8
Unit II: Dynamics of Ideal Fluids Bernoulli's equation and its applications, Impulsive action, Equation of motion and continuity in curvilinear coordinates, Euler's momentum theorem and D'Alembert's paradox, Boundary conditions and uniqueness theorem	8
Unit III: Irrotational Motion and Circulation Flow, circulation, and permanence of irrotational motion, Connectivity of regions, cyclic/acyclic motion, cyclic constant, Kinetic energy and Kelvin's minimum energy theorem, Irrotational motion in two and three dimensions	9
Unit IV: Complex Potential and Motion of Cylinders	10

Complex potential, sources, sinks, and doublets, Image systems and circle theorem, Blasius theorem, motion of circular and elliptic cylinders, Circulation, steady streaming, and Kutta–Joukowski theorem, Conformal and Joukowski transformations, Schwarz–Christoffel theorem	
Unit V: Vortex Motion Vortex line and filament, Equation of surfaces formed by streamlines and vortex lines, Strength, velocity field, and kinetic energy of vortex systems, Rectilinear vortex, vortex pair, and doublet, Image of a vortex, Kármán vortex street	9
Unit VI: Waves and Stream Functions Stokes stream function, Source, sinks, and doublets with respect to a plane and sphere, Surface waves and particle paths, Energy, group velocity, and long wave motion	6

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. Will be able to identify Lagrange's and Euler's methods in fluid motion
2. Identify Velocity field and kinetic energy of a vortex system
3. Identify how to derive basic equations and know the related assumptions.

Reference Books:

1. Ramsay, A.S., Hydrodynamics (Bell).
2. Lamb, H., Hydrodynamics (Cambridge)
3. Landau, L.D., Lifchiz, E.M., Fluid Mechanics (Pergamon), 1959
4. Milne-Thomson, I.M., Theoretical Hydrodynamics
5. Chorlton, F., Textbook of Fluid Dynamics.

Elective Course – 1 / Elective Course – 2

MTM – 308T: Advance Optimization Techniques

Course Content	No of Lectures
Unit I: Geometric Programming Introduction to geometric programming and its structure, Posynomial form and duality principle, Unconstrained geometric programming, Constrained geometric programming and applications	8
Unit II: Stochastic Programming Concepts of stochastic programming and random variables in optimization, Chance constrained programming, Stochastic linear and nonlinear programming, Two-stage stochastic programming and examples	10
Unit III: Game Theory and Strategic Decision Making Matrix and bi-matrix games, Nash equilibrium, Solution of bi-matrix games using quadratic programming, Strategic games and leadership theory in games, Game problems under fuzzy systems	10
Unit IV: Multi-Objective Optimization (MOO) Concept of multi-objective optimization problems, Pareto optimality and dominance, Multi-Objective Decision Making (MODM), Evolutionary algorithms for MOOPs (MOEA, NSGA-II), Applications and examples	10
Unit V: Multi-Attribute Decision Making (MADM) Decision model construction and normalization, Weight assignment and preference modeling, SAW, WP, and MAVT methods, Basics of AHP, total weight calculation, and consistency, Distance-based methods: TOPSIS, VIKOR, Outranking methods: PROMETHEE, ELECTRE	12

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. understand the theory of geometric and stochastic programming problems
2. learn the solution algorithm of bimatrix games
3. utilize several techniques to solving multi-attribute decision making problems
4. apply different optimization techniques to solve various real-life problems

Reference Books:

1. Taha, Hamdy A. Operations research: An introduction. Pearson Education India, 2004.
2. Belegundu, Ashok D., and Tirupathi R. Chandrupatla. Optimization concepts and applications in engineering. Cambridge University Press, 2011.

3. Ruhul Amin Sarker and Charles S. Newton, Optimization Modelling: A practical Approach, CRC Press, 2008.
4. Michel Gendreau, Jean -Yves Potvin, Handbook of Metaheuristics, Springer, 2019.
5. Kalyanmoy Deb, Multi-Objective Optimization using Evolutionary Algorithms, Wiley.
6. Tzeng, G-H. & Huang, J-J. Multiple Attribute Decision Making: Methods and Applications, Chapman and Hall/CRC, 2011
7. Figueira, J. Greco, S. & Ehrgott, M. Multiple Criteria Decision Analysis: State of the Art Surveys, Springer, 2007

Elective Course – 1 / Elective Course – 2
MTM – 309T: Differential Geometry

Course Content	No of Lectures
Unit I: Curves in Space Curves, level curves, and parametrized curves, Arc length, reparametrization, closed curves, Curvature of plane and space curves, Simple closed curves and isoperimetric inequality	8
Unit II: Surfaces and Their Geometry Surfaces, smooth surfaces, smooth maps, Tangents, derivatives, normals, orientability, Level surfaces, ruled and quadric surfaces, Compact and regular surfaces	9
Unit III: First and Second Fundamental Forms First fundamental form, length of curves on surfaces, Isometries, conformal and equiareal maps, Second fundamental form, Gauss and Weingarten maps, Normal and geodesic curvature	10
Unit IV: Curvatures and Global Properties of Surfaces Third fundamental form, Gaussian and mean curvature, Principal curvatures, Meusnier's theorem, Surfaces of constant Gaussian and mean curvature, Flat and compact surfaces, total curvature	10
Unit V: Geodesics and Intrinsic Geometry Geodesics and geodesic equations, Geodesics on surfaces of revolution, Geodesics as shortest paths, geodesic coordinates, Gauss and Codazzi–Mainardi equations, Gauss' Theorem Egregium	8
Unit VI: Non-Euclidean Geometry Spherical geometry, Idea of hyperbolic geometry, Upper half-plane model, Poincaré disc and Beltrami–Klein models	5

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:
1. give an idea of curves and surfaces.
2. identify smooth surfaces, orientable surfaces.
3. find length and curvature of curves on different surfaces.
4. apply the above concepts in different fields of Mathematics.

Reference Books:

1. Pressely, Andrew, Elementary differential Geometry, Springer.
2. Carmo, M. P. do: Differential geometry of curves and surfaces, Prentice-Hall Inc.
3. Singer, I. M. and Thorpe, J. A., Lecture notes on elementary topology and geometry, Springer.
4. Spivak, M., A comprehensive introduction to differential geometry, Vol. I, Publish or Perish Inc., Houston.
5. Eisenhert, L.P., An introduction to Differential Geometry, Princeton University Press.
6. Willmore, T.J., An Introduction to Differential Geometry, Oxford University Press.

Elective Course – 1 / Elective Course – 2
MTME – 310T: Machine Learning

Course Content	No of Lectures
Unit I: Introduction to Machine Learning Concept of Machine Learning, Applications of Concept and definition of ML, Applications of ML, Key elements of ML, Supervised vs. Unsupervised Learning, Statistical Learning: Bayesian approach, Naive Bayes Classifier	
Unit II: Linear Algebra for Machine Learning Review of matrices, vectors, transpose, and inverse, Vectorization and matrix operations, Plotting and data representation in MATLAB/Python, Matrix multiplication in model formulation	
Unit III: Linear Regression	

Prediction using Linear Regression, Cost function and gradient descent, Linear Regression with one and multiple variables, Polynomial Regression, Feature scaling and feature selection	
Unit IV: Logistic Regression and Classification Logistic Regression and sigmoid hypothesis, Comparison with Linear Regression, Binary and multiclass classification, Logistic Regression with multiple variables, Decision boundaries and performance evaluation	
Unit V: Regularization Overfitting and underfitting, Regularization concept and need, Regularization in Linear Regression (Ridge/Lasso), Regularization in Logistic Regression	
Unit VI: Neural Networks Introduction to Artificial Neural Networks, Model representation and architecture, Perceptron training and Gradient Descent, Stochastic Gradient Descent, Multilayer perceptron and backpropagation, Multi-class classification and softmax overview	

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. **Understand and explain** the fundamental concepts, models, and algorithms of supervised, unsupervised, and reinforcement learning.
2. **Apply appropriate machine learning techniques** to solve real-world problems using tools such as Python, Scikit-learn, TensorFlow, or PyTorch.
3. **Analyze and evaluate** the performance of machine learning models using suitable metrics and validation strategies.
4. **Design and implement** machine learning solutions for classification, regression, clustering, and dimensionality reduction tasks.
5. **Develop critical thinking and research skills** to explore emerging trends in machine learning and apply them to interdisciplinary domains.

Reference Books:

1. Ethem Alpaydin, "Introduction to Machine Learning" 2nd Edition, The MIT Press, 2009.
2. Tom M. Mitchell, "Machine Learning", First Edition by Tata McGraw-Hill Education, 2013.
3. Christopher M. Bishop, "Pattern Recognition and Machine Learning" by Springer, 2007.Mevin P. Murphy, "Machine Learning: A Probabilistic Perspective" by The MIT Press, 2012.

Elective Course – 1 / Elective Course – 2

MTME – 310P: Machine Learning

For practical Labs for Machine Learning, students must use software like MABLAB/Octave or Python.

Course Content	No of Lectures
Unit I: MATLAB/Octave/Python Basics - Perform basic arithmetic and logical operations (addition, multiplication, exponentiation, OR, AND, NOT, XOR). - Create and display simple variables and strings. - Format outputs using built-in functions (disp, fprintf, etc.).	6
Unit II: Arrays and Matrices - Create 1D and 2D arrays. - Use built-in functions (zeros, ones, rand, eye, diag). - Load/store matrix data from/to text files. - Compute size, length, and use workspace commands.	6
Unit III: Matrix Operations and Data Handling - Addition, subtraction, multiplication of matrices. - Display specific rows/columns. - Operations: absolute value, negation, removing/adding rows. - Find max, min, sum, mean for rows/columns/matrices.	7
Unit IV: Visualization and Plotting Plot basic data and mathematical functions (sin, cos, etc.). - Create histograms and labeled plots.	6

- Generate subplots and color-coded graphs.	
Unit V: Control Statements and Vectorization - Implement for, while, and if-else structures. - Write vectorized code for matrix operations (transpose, addition, multiplication).	5
Unit VI: Machine Learning Applications – Regression and Classification - Linear Regression: Predict house prices based on area (simple regression). - Multiple Linear Regression: Predict price using multiple features. - Logistic Regression: Classification of binary outcomes (e.g., student eligibility or email spam detection). - Regularization: Apply simple L2 regularization to regression model. - Neural Network (Intro): Use built-in/stochastic gradient descent or backpropagation for prediction.	10

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

6. **Understand and explain** the fundamental concepts, models, and algorithms of supervised, unsupervised, and reinforcement learning.
7. **Apply appropriate machine learning techniques** to solve real-world problems using tools such as Python, Scikit-learn, TensorFlow, or PyTorch.
8. **Analyze and evaluate** the performance of machine learning models using suitable metrics and validation strategies.
9. **Design and implement** machine learning solutions for classification, regression, clustering, and dimensionality reduction tasks.
10. **Develop critical thinking and research skills** to explore emerging trends in machine learning and apply them to interdisciplinary domains.

Reference Books:

4. Ethem Alpaydin, "Introduction to Machine Learning" 2nd Edition, The MIT Press, 2009.
5. Tom M. Mitchell, "Machine Learning", First Edition by Tata McGraw-Hill Education, 2013.

Christopher M. Bishop, "Pattern Recognition and Machine Learning" by Springer, 2007.Mevin P. Murphy, "Machine Learning: A Probabilistic Perspective" by The MIT Press, 2012.

SEMESTER – IV

CORE COURSE – 17

MTM – 401T: Transformations and Integral Equations

Course Content	No of Lectures
Unit I: Fourier Transform Definition and basic properties, Linearity, shifting, scaling, and differentiation properties, Inversion formula, Convolution and Parseval's relation, Multiple Fourier transforms and Bessel's inequality, Applications to Heat, Wave, and Laplace equations	12
Unit II: Laplace Transform Definition and standard transforms, Properties of Laplace transform, Inversion formula (Bromwich integral), Convolution theorem, Applications to ODEs and PDEs	10
Unit III: Wavelet Transform Introduction and need for time-frequency analysis, Multi-resolution analysis, scaling and wavelet functions, Spline and orthogonal wavelets, Applications to signal and image processing	8
Unit IV: Integral Equations – Basic Theory Formation and examples, Fredholm and Volterra equations, Successive substitutions and approximations, Degenerate and convolution kernels, Abel's integral equation	8
Unit V: Integral Equations – Advanced Methods Resolvent kernel method, Fredholm's theorems, Symmetric kernel, Eigenvalues and Eigenfunctions, Fredholm alternative, Applications of integral equations in boundary value problems	12

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. In this course there are four topics namely Laplace Transform, Fourier Transform, Wavelet Transform and Integral Equation.
2. A large number of realistic problems in sciences and engineering involve the solution of linear ordinary and partial differential equations.
3. Laplace and Fourier transforms are the powerful tools for solving realistic problems of ODE and PDE, particularly IVP or BVP.
4. PDE is very difficult to solve directly but using these transforms, PDE is reduced to an ODE and then ODE is reduced to an algebraic equation, which is very easy to find the solution.
5. Wavelet transform is another transform technique with the special advantage that it provides a more accurate solution which helps to determine the exact location of the solution.
6. Specifically, scientist and engineers use the wavelet transform for determining the exact location of an area where the natural gases such as oil and various minerals exist.
7. Integral equation is an important concept in Applied Mathematics to find the unknown function within the integral sign.
8. Many dynamical problems and applied-based practical problems can be solved with the help of Integral equations.

Reference Books:

1. Dyke, P.P.G. (2001) An Introduction to Laplace Transforms and Fourier Series, Springer, Springer-Verlag London Limited.
2. Debnath, L. (1995) Integral Transforms and Their Applications, CRC Press.
3. Walnut, D. F. (2002) An introduction to Wavelet Analysis, Birkhauser.
4. Kanwal, R.P. (1971) Linear Integral Equations; Theory & Techniques, Academic Press, NewYork.
5. Sneddon, I.N. (1974). The use of Integral Transforms, Tata McGraw Hill, Publishing Company Ltd, New Delhi.
6. Davis, H.T. (1962). Introduction to Nonlinear Differential and Integral Equations, Dover Publications.
7. Krasnov, M.L. (1971) Problems and Exercises Integral Equations, Mir Publication Moscow.
8. Hildebrand, F. B. (1992). Methods of Applied Mathematics, Dover Publication.

CORE COURSE – 18
MTM – 402T: Operations Research

Course Content	No of Lectures
Unit I: Integer Programming Standard form of Integer Programming, Cutting plane concept, Gomory's Cutting Plane Method, Gomory's All-Integer Method, Branch and Bound Algorithm for general integer programs	12
Unit II: Quadratic and Convex Programming Formulation of Quadratic Programming Problems, Wolfe's Modified Simplex Method, Beale's Method, Convex Programming and properties	8
Unit III: Optimal Control Theory Concept of performance indices, Basic methods in calculus of variations, Euler–Lagrange equation and necessary conditions, Simple optimal control problems in mechanics	8
Unit IV: Inventory Control – Deterministic Models Introduction, nature, and features of inventory systems, Definition and model building, Deterministic models with no shortage, Deterministic models with shortage, multi-item inventory with constraints, Inventory with deterioration and inflation	12
Unit V: Inventory Control – Probabilistic Models Probabilistic single-period models, Models with and without setup cost, Newsvendor problem, Periodic and continuous review systems, Probabilistic inventory management and simulation overview	10

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:
1. Identify job sequencing problems and able to solve
2. Formulate real-world problems as nonlinear programming model
3. Understand the various selective inventory control techniques and its applications.

Reference Books:

1. Hadley, G., Nonlinear and Dynamic Programming, Pearson.

2. Rao, S.S., Optimization Theory and Application, Wiley Eastern.
3. Taha, H.A., Operations Research-An Introduction, Pearson.
4. Dano, S., Nonlinear and Dynamic Programming.
5. Edward A. Silver, David F. Pyke, Douglas J. Thomas, Inventory and Production Management in Supply Chains, Fourth Edition, CRC Press, 2016.
6. Edwin K.P. Chong and Stanislaw H. Zak, An Introduction to Optimization, Second Edition 2001, John Wiley & Sons, INC.
7. Singiresu S. Rao, Engineering Optimization: Theory and Practice , Wiley, 2009.
8. Mangasarian O.L., Non-linear Programming, McGraw Hill, New York.
9. Mokhtar S. Bazara and C.M. Shetty, Non-linear Programming-Theory and Algorithms, Weiley, New York.
10. Mordecai Auriel, Non-linear Programming – Analysis and Methods, Prentice Hall Inc. Englewood Cliffs, New Jersey.

CORE COURSE – 19
MTM – 403T: Fuzzy Mathematics

Course Content	No of Lectures
Unit I: Fundamentals of Fuzzy Sets Basic concept and definition of fuzzy sets, Standard fuzzy set operations: union, intersection, complement, Properties of fuzzy set operations, Terminologies: support, α-cut, height, normality, convexity	10
Unit II: Fuzzy Relations and Extension Principle Fuzzy relations and examples, Properties of α-cuts, Zadeh's extension principle, Interval numbers and their arithmetic	8
Unit III: Fuzzy Numbers and Arithmetic Fuzzy numbers: triangular, trapezoidal, Gaussian, Representation and membership functions, Arithmetic of fuzzy numbers: addition, subtraction, multiplication, division, Applications in uncertainty modeling	8
Unit IV: Fuzzy Measures and Possibility Theory Fuzzy measures and their properties, Possibility and necessity measures, Possibility distributions, Evidence theory and Dempster–Shafer framework, Introduction to Sugeno and Choquet integrals	9
Unit V: Defuzzification and Decision Making Defuzzification techniques: center of area, center of maxima, mean of maxima, Individual, multi-person, multi-criteria, and multi-stage decision-making, Fuzzy ranking methods and fuzzy ordering	8
Unit VI: Fuzzy Optimization Fuzzy linear programming: formulation and solution concepts, Applications in resource allocation and production systems, Overview of fuzzy control and fuzzy inference systems	7

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. Some fundamental knowledge of fuzzy sets, numbers, matrix, ordinary differential equation and programming, etc.
2. Acquire knowledge of various operations on above fuzzy sets.
3. Solving some multi-person, multi-criteria, multi-stage decision making problems.
4. Some fundamental uncertain programming solving skill which occur almost all decision-making problems.

Reference Books:

1. Klir, G.J. and Yuan, B. (1995) Fuzzy sets and fuzzy logic, Prentice-Hall of India, New Delhi.
2. Dubois, D.J. (1980) Fuzzy sets and systems: theory and applications, Academic press.
3. Bector, C.R. and Chandra, S. (2005) Fuzzy mathematical programming and fuzzy matrix games, Berlin: Springer.
4. Zimmermann, H. J. (1991) Fuzzy set theory and its Applications, Allied Publishers Ltd, New Delhi.

CORE COURSE – 24
MTM – 404T: Project Work

Course Content	No of Lectures
Dissertation Project will be performed on Tutorial/ Review Work on Research Papers. For Project Work one class will be held in every week. Marks are divided as the following: Project Work-25, Presentation-15, and Viva-voce-10. Project Work of each student will be evaluated by the concerned internal teacher/ supervisor and one External Examiner. The external examiner must be present in the day of evaluation.	

Elective Course – 3 / Elective Course – 4

MTM – 405T: Advanced Functional Analysis

Course Content	No of Lectures
Unit 1: Introduction to Topological Vector Spaces (TVS) Definition and examples of TVS, Local base and properties, Separation properties and Hausdorff condition, Symmetric, balanced, absorbing, and convex sets, Bounded sets in a TVS	9
Unit II: Linear Operators and Metrization Definition and properties of linear operators, Locally compact TVS and finite-dimensional results, Metrization theorems, Boundedness and continuity of linear operators	8
Unit III: Local Convexity and Seminorms Definition and examples of locally convex TVS, Seminorms and Minkowski functional, Generating families of seminorms, Criterion for normability, Quotient spaces and examples	10
Unit IV: Fundamental Theorems on TVS Equicontinuity and uniform boundedness, Banach–Steinhaus theorem and consequences, Open mapping theorem, Closed graph theorem, Hahn–Banach theorem and consequences	10
Unit V: Weak Topologies Weak and weak* topologies, Convergence and closure, Compact convex sets, Banach–Alaoglu theorem, Applications in locally convex TVS	7
Unit VI: Barreled and Bornological Spaces Definition and examples of barreled spaces, Definition and examples of bornological spaces, Criteria for locally convex TVS to be barreled or bornological	6

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. Understand basic properties of topological vector spaces and know relevant examples.
2. Realize that existence of convex local base at zero vector is strong enough for metrizablity of a topological vector space.
3. Explain the fundamental concepts of functional analysis and their role in modern mathematics and applied contexts
4. Demonstrate accurate and efficient use of functional analysis techniques
5. Apply problem-solving method using functional analysis techniques applied to diverse situations in physics, engineering and other mathematical contexts

Reference Books:

1. Rudin, W., Functional Analysis, TMG Publishing Co. Ltd., New Delhi, 1973
2. Kelly J. L.& Namioka I., Linear Topological spaces, Springer-Verlag, New York, Heidelberg, Berlin.
3. Schaffer, A.A., Topological Vector Spaces, Springer, 2nd Edn., 1991
4. Bachman, G., Narici, L., Functional Analysis, Academic Press, 1966
5. Diestel, Application of Geometry of Banach Spaces
6. Narici & Beckerstein, Topological Vector spaces, Marcel Dekker Inc, New York and Basel, 1985
7. Simmons, G. F., Introduction to topology and Modern Analysis, Mc Graw Hill, New York, 1963

Elective Course – 3 / Elective Course – 4

MTM – 406T: Operator Theory

Course Content	No of Lectures
Unit I: Bounded and Continuous Linear Operators Definition, Examples, Basic properties of linear operators, Inverse operator, Product of inverse operators, Definition, Example of Bounded linear operator, Norm of an operator, norm space of operators, boundedness and dimension, boundedness and continuity, bounded linear extension, unbounded operator, weak, strong and uniform convergence of operators.	15

Unit II: Adjoint Operator Adjoint operators over normed linear spaces, their algebraic properties, compact operators on normal linear spaces, sequence of compact operators and its convergence, compact extensions, weakly compact-operators, Operator equation involving compact operators, Fredhölm alternative.	15
Unit III: Spectral Theory Resolvent Set, Spectrum, Point spectrum, Continuous spectrum, Residual spectrum, Approximate point spectrum, Spectral radius, Spectral properties of a bounded linear operator, Spectral mapping theorem for polynomials. Numerical range, Numerical radius, Relation between the numerical radius and norm of a bounded linear operator.	15
Unit IV: Banach Algebra Definition of normed and Banach algebra and examples, Singular and non-singular elements, The spectrum of an element, The spectral radius.	5

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. Define different special types of spectrums and state their relations.
2. Determine the spectral radius of different types of operators.
3. Test the behavior of an operator.
4. Apply different standard theorems involving bounded linear operators.

Reference Books:

1. Kreyszig, E., Introductory Functional Analysis with Appliactions, John Wiley and Sons.
2. Bachman, G., and Narici, L., Functional Analysis, Dover Publications.
3. Taylor, A.E. Introduction to Functional Analysis, John Wiley and Sons, New York, 1958.
4. Dunford, N., and Schwarts, J.T., Linear Operators-3, John Willey and Sons.
5. Halmos, P.R., Introduction to Hilbert Space and the theory of Spectral Multiplicity, Chelsea Publishing Co., N.Y.

Elective Course – 3 / Elective Course – 4
MTM – 407T: Advanced Operation Research

Course Content	No of Lectures
Unit I: Goal Programming (GP) Introduction and need for Goal Programming, Comparison between LP and GP approaches, Graphical solution method, Modified Simplex method for Goal Programming, Simple numerical illustrations and interpretation of deviational variables	8
Unit II: Dynamic Programming (DP) Characteristics of dynamic programming problems, Bellman's Principle of Optimality – formulation and interpretation, Additively and multiplicatively separable returns, shortest route problem and resource allocation, Multistage decision process – forward and backward recursion, DP approach for linear and nonlinear programming, Applications in scheduling and inventory	14
Unit III: Replacement and Maintenance Models Introduction and failure mechanism of items, Replacement of items deteriorating with time, Replacement policy considering money value, Replacement of completely failed items (individual and group), Other models: staffing and equipment renewal problems	10
Unit IV: Queuing Theory – Basics and Markovian Models ntroduction, features, and queue disciplines, Poisson process and its properties, Exponential service times and Markovian property, Kendall's notation, Derivation of steady-state probabilities, Solution of basic models: $\{(M/M/1):(\infty\|FCFS)\},\{(M/M/1):(n\|FCFS)\}$	10
Unit 5: Advanced Queuing Models Multi-server models: $\{(M/M/s):(\infty\|FCFS)\},\{(M/M/s):(n\|FCFS)\}$.	8

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. Able to acquire skills in handling replacement and maintenance models
2. Able to apply basic techniques to analyze in networking
3. Understand and characterize the phenomena of dynamic programming problems
4. Expose the basic characteristic features of a queuing system and acquire skills in analyzing real world queuing models.

5. Deep understanding of the theoretical background of queueing systems.

Reference Books:
1. Hadley, G., Nonlinear and Dynamic Programming, Pearson.
2. Rao, S.S., Optimization Theory and Application, Wiley Eastern.
3. Joshi, M.C., and Moudgalya, K.M., Optimization theory and Practice, Narosa Pub.
4. John F Shortle, James M Thompson, Donald Gross, Carl M Harris, *Fundamentals of Queueing Theory*, Fifth Edition, Wiley.
5. T. L. Saaty, *Elements of Queueing Theory, with Applications*, Dover Publications Inc.
6. Bector, C.R., Chandra, S., and Dutta, J., Principles of Optimization Therory, Narosa Pub.
7. Frederick S. Hillier, Gerald J. Lieberman, *Introduction to Operations Research*, McGraw Hill Education.

Elective Course – 3 / Elective Course – 4
MTM – 408T: Advanced Algebra

Course Content	No of Lectures
Unit I: Modules and Homomorphisms Definition and examples of modules, Submodules and quotient modules, Module homomorphisms and isomorphism theorems, Free modules and basis of free modules, Finitely generated modules over PID; structure theorem	10
Unit II: Exact Sequences and Tensor Products Exact, short exact, and split exact sequences, Definition and construction of tensor product of modules, Universal mapping property, Properties and examples of tensor products, Applications to module isomorphisms	10
Unit III: Projective, Injective, and Flat Modules Definition and examples of projective modules, Injective and flat modules, Direct sum of projective modules, Direct product of injective modules, Characterizations of projective, injective, and flat modules	8
Unit IV: Structure of Rings Noetherian and Artinian rings, Hilbert Basis Theorem and Cohen’s Theorem, Primary decomposition theorem, Nilradical and Jacobson radical, Nakayama’s lemma and prime avoidance	9
Unit V: Localization and Fraction Rings Rings and modules of fractions, Local ring and its characterization, Localization of rings and modules, Examples and applications	7
Unit VI: Subdirect Sums and Representations of Rings Prime and semiprime rings, Subdirect sum of rings and representation, Subdirectly irreducible rings and Birkhoff’s theorem, Stone representation theorem for Boolean rings	6

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:
1. Understand modules, submodules, quotient modules, and module homomorphisms with properties of free and finitely generated modules.
2. Analyze exact and split exact sequences, tensor products, and study projective, injective, and flat modules.
3. Explore structural properties of Noetherian and Artinian rings, Hilbert Basis Theorem, and Primary Decomposition Theorem.
4. Apply concepts of radicals, Nakayama’s Lemma, prime avoidance, Chinese Remainder Theorem, and localization in ring theory.

Examine prime and semiprime rings, subdirect sums, subdirectly irreducible rings, and representation theorems including Stone’s theorem.

Reference Books:
1. Dummit, D.S. and Foote, R. M., Abstract Algebra, Second Edition, John Wiley & Sons, Inc., 1999.
2. Atiyah, M., MacDonald, I. G., Introduction to Commutative Algebra, Addison-Wesley, 1969.
3. Lang, S., Algebra, Addison-Wesley, 1993.
4. Lam, T. Y., A First Course in Non-Commutative Rings, Springer Verlag.
5. Hungerford, T. W., Algebra, Springer.
6. Jacobson, N., Basic Algebra, II, Hindusthan Publishing Corporation, India.
7. Gopalakrishnan, N. S., Commutative Algebra, 2nd edition, Orient Blackswan, 2015.

Balwant Singh, Basic Commutative Algebra, World Scientific Publishing Co Pte Ltd,

Elective Course – 3 / Elective Course – 4
MTM – 409T: Bio Mathematics

Course Content	No of Lectures
Unit I: Introduction to Mathematical Modeling in Biology Nature of mathematical models, Deterministic vs. stochastic models, Modeling assumptions and biological interpretation, Review of basic differential and difference equations used in population models	6
Unit II: Single-Species Population Models Exponential and logistic growth models, Logistic model with time delay, Stability of equilibrium with general delay, Stability for discrete time lag, Linear birth–death–immigration–emigration processes	10
Unit III: Age-Structured and Multi-Species Models Age-structured population model formulation, Interaction between two species, Host–parasite type interactions, Competitive type interactions and trajectories, Effect of migration in host–parasite models, Lotka–Volterra and generalized L-V systems	10
Unit IV: Stochastic Population Models Pure birth process, Pure death process, Birth–death process and Kolmogorov forward equations, Transition probabilities and limiting behavior	8
Unit V: Mathematical Theory of Epidemics – Deterministic Models Basic definitions and model assumptions, Simple epidemic (SIS model), General epidemic (SIR model), Kermack–McKendrick threshold theorem, Recurring epidemics and control measures	8
Unit VI: Stochastic Epidemic Models Stochastic epidemic model without removal, With removal, immigration, and emigration, Epidemics with multiple infections, Epidemic model with carriers	8

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. Understand the modelling of exponentially-growing or -declining population.
2. Use the model to recommend appropriate action for population management.
3. Acquire basic knowledge of mathematical theory of Epidemic

Reference Books:

1. J. D. Murray, Mathematical Biology, Springer and Verlag.
2. J. N. Kapur, Mathematical Models in Biology and Medicine, East West Press Pvt. Ltd
3. D. A. MacDonald, Blood Flow in Arteries,Williams and Wilkins Company, Baltimore.
4. Y.C. Fung, Biomechanics of Soft Biological Tissues, Springer Verlag.
5. R. Habermann, , Mathematical Models, Prentice Hall.
6. R. W., Poole, An Introduction to Quantitative Ecology, McGraw- Hill.
7. E. C. Pielou, An Introduction to Mathematical Ecology, Wiley, New York.
8. R. Rosen, Foundation of Mathematical Biology (Vol I & II), Academic Press

Elective Course – 3 / Elective Course – 4
MTME – 410T: Data Science

Course Content	No of Lectures
Unit I: Data Scientist's Toolbox What is Data Science? Turning data → knowledge, Concept of reproducibility in data science, Theory behind version control: Git concepts (repository, commit, push, pull), Markdown and R Markdown theory (syntax, structure), Introduction to R and RStudio interface (conceptual)	5
Unit II: R Programming – Concepts R data types & data structures (theory), Data input/output methods (conceptual overview), Theory of control structures (if/else, loops), Functions and scoping rules (lexical scoping), Theory of loop functions (apply family), Debugging concepts (traceback, error handling), Simulation ideas (random numbers, distributions)	6
Unit III: Getting and Cleaning Data	6

Sources of data (web, APIs, databases), Types of data formats (CSV, JSON, XML), Principles of data cleaning, Missing values: conceptual handling approaches, Tidy data principles (wide vs long format, tidiness rules)	
Unit IV: Exploratory Data Analysis (EDA) Purpose of EDA (conceptual), Summary statistics (mean, median, variance, quantiles), Outlier detection theory, Visualization theory: histograms, boxplots, scatterplots, Introduction to multivariate visualization (PCA conceptually), Identifying patterns, trends, clusters (conceptual)	6
Unit V: Reproducible Research (Theory) Conceptual foundation of reproducible research, Structure & elements of R Markdown (theoretical), knitr workflow (concepts only), The idea of literate statistical programming, Structuring a reproducible scientific analysis project	6

Course Outcomes (COs)

Upon successful completion of this course, the students will learn the following:

1. **Understand and explain** the fundamental concepts of data science, including data collection, preprocessing, visualization, and statistical analysis.
2. **Apply appropriate tools and techniques** (such as Python, R, SQL, and data visualization libraries) for handling, analyzing, and interpreting structured and unstructured data.
3. **Analyze datasets critically** using statistical and machine learning methods to derive meaningful insights and patterns.
4. **Design and implement** end-to-end data-driven solutions for real-world applications in business, science, and social domains.
5. **Demonstrate teamwork, communication, and ethical responsibility** in managing and presenting data-driven projects.

Reference Books:

1. Rachel Schutt, Cathy O'Neil, "Doing Data Science: Straight Talk from the Frontiline" by Schroff/O'Reilly, 2013.
2. Foster Provost, Tom Fawcett, "Data Science for Business" What You Need to Know About Data Mining and Data-Analytic Thinking" by O'Reilly, 2013.
3. John W. Foreman, "Data Smart: Using data Science to Transform Information into Insight" by John Wiley & Sons, 2013.
4. Ian Ayres, "Super Crunchers: Why Thinking-by-Numbers Is the New Way to Be Smart" 1st Edition by Bantam, 2007.
5. Eric Seigel, "Predictive Analytics: The Power to Predict who Will Click, Buy, Lie, or Die", 1st Edition, by Wiley, 2013.
6. Matthew A. Russel, "Mining the Social Web: Data mining Facebook, Twitter, Linkedln, Goole+, GitHub, and More", Second Edition, by O'Reilly Media, 2013.

Elective Course – 3 / Elective Course – 4

MTME – 410P: Data Science Lab

Course Content	No of Lectures
List of Practical	
1. Write a program that prints ‗Hello World‘to the screen. 2. Write a program that asks the user for a number n and prints the sum of the numbers 1to n 3. Write a program that prints a multiplication table for numbers up to 12. 4. Write a function that returns the largest element in a list. 5. Write a function that computes the running total of a list. 6. Write a function that tests whether a string is a palindrome. 7. Implement linear search. 8. Implement binary search. 9. Implement matrices addition, subtraction and Multiplication 10. Fifteen students were enrolled in a course. There ages were: 20 20 20 20 20 21 21 21 22 22 22 22 23 23 23 i. Find the median age of all students under 22 years ii. Find the median age of all students	40

iii. Find the mean age of all students

iv. Find the modal age for all students

v. Two more students enter the class. The age of both students is 23. t is now mean, Whamode and median?

11. Following table gives a frequency distribution of systolic blood pressure. Compute all the measures of dispersion.

Median	95.5	105.5	125.5	135.5	145.5	155.5	165.5	175.5
Number	5	8	22	17	9	5	5	2

12. Obtain probability distribution of, where X is number of spots showing when a six- sided symmetric die (i.e. all six faces of the die are equally likely) is rolled. Simulate random samples symmetric die (i.e. all six faces of the die are equally likely) is rolled. Simulate random samples of sizes 40, 70 and 100 respectively and verify the frequency interpretation of probability.
13. Make visual representations of data using the base, lattice, and ggplot2 plotting systems in Rapply basic principles of data graphics to create rich analytic graphics from available datasets
14. Use Git / Github software to create Github account. Also, create a repo using Github.