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University of Delhi

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CNC-II/093/1/EC-1282/26/2
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NOTIFICATION

Sub: Amendment to Ordinance V

(ECR 4-1-2/ dated 29.04.2026)

Following addition be made to Annexure-II-A to the Ordinance V (2-A) of the Ordinances of the University;

Add the following:

The syllabi of following Departments under the Faculty of Mathematical Sciences based on Postgraduate Curriculum Framework 2024 are notified herewith for the information of all concerned:

Department	Syllabi	Annexure
Mathematics	(i) One year M.Sc. Mathematics for semester I/II and 2 year M.Sc. Mathematics for Semester III/IV	1
Computer Science	(i) Master of Computer Applications (MCA) for Semester III/IV	2
	(ii) 2 year M.Sc. Computer Science for Semester III/ IV and One year M.Sc. Computer Science for semester I/II	3
	(iii) The minor modifications/ revision of the First Year of Two-Year M.Sc. Computer Science: 1. Minor Changes in Syllabus of DSC103: Mathematical Foundations of Computer Science 2. Addition of DSE 208: Research Methodology	4

Rajni Abbi
REGISTRAR

Annexure-1

Curricular Structure and Syllabi of Courses in Second Year of Two-year M.Sc. Mathematics and One-year M.Sc. Mathematics

(Post Graduate Curriculum Framework (PGCF) -2024 based on NEP-2020)

Department of Mathematics
Faculty of Mathematical Sciences
University of Delhi
Delhi – 110007

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Programme Objectives and Outcomes

Programme Objectives

The two-year M.Sc. Mathematics programme's main objectives are to nurture a student to:

- inculcate and develop mathematical aptitude and the ability to think abstractly.
- develop computational abilities and programming skills.
- develop the ability to read, follow and appreciate mathematical text.
- train them to communicate mathematical ideas in a lucid and effective manner.
- orient them to apply their theoretical knowledge to solve real-life problems.
- prepare them for higher education and research in mathematics.

Programme Outcomes

On successful completion of the two-year M.Sc. Mathematics programme, a student will:

- have a strong foundation in core areas of Mathematics, both pure and applied.
- be able to apply mathematical skills and logical reasoning for problem solving.
- communicate mathematical ideas effectively, in writing as well as orally.
- have sound knowledge of mathematical modelling, programming and computational techniques as required for employment in industry.

Details of Courses in First Year of Two-year M.Sc. Mathematics

Semester	Discipline Specific Core (DSC)	Discipline Specific Elective (DSE)	Skill-Based Course (SBC)	Generic Elective (GE) Courses (offered by the Department of Mathematics)
Semester-I	**DSC-1:** Field Theory **DSC-2**: Introduction to Topology **DSC-3**: Ordinary Differential Equations	**DSE-1:** (i) Matrix Analysis (ii) Numerical Analysis **DSE-2*:** (i) Advanced Group Theory (ii) Nonlinear Optimization *Student will opt for DSE-2 or GE-1	Communicating Mathematics	**GE-1:** (i) Matrix Analysis (ii) Nonlinear Optimization
Semester-II	**DSC-4**: Module Theory **DSC-5**: Functional Analysis **DSC-6**: Complex Analysis	**DSE-3:** (i) Algebraic Number Theory (ii) General Topology **DSE-4#:** (i) Fourier Analysis (ii) Integral Equations #Student will opt for DSE-4 or GE-2	Appreciating Mathematics via Workshops and Seminars	**GE-2**: (i) Fourier Analysis (ii) Integral Equations

Curricular Structure for Second Year of Two-year PG Programme under Structure-1 (Only Course work)

Semester	DSC	DSE	2 Credit Course	Dissertation/ Academic Project/ Entrepreneurship	Total Credits
Semester-III	**DSC-7** **DSC-8** (8 Credits)	**DSE-5** **DSE-6** **DSE-7** OR **DSE-3, DSE-4 & GE-3** (12 Credits)	**Skill-based course/ Workshop/ Specialized laboratory/ Internship/ Apprenticeship/ Hands on learning** (2 Credits)	**NIL**	**22**
Semester-IV	**DSC-9** **DSC-10** (8 Credits)	**DSE-8** **DSE-9** **DSE-10** OR **DSE-5, DSE-6 & GE-4** (12 Credits)	**Skill-based course/ Workshop/ Specialized laboratory/ Internship/ Apprenticeship/ Hands on learning** (2 Credits)	**NIL**	**22**

Details of Courses in Second Year of Two-year M.Sc. Mathematics

Semester	DSC	DSE	SBC	GE
Semester-III	**DSC-7**: Fluid Dynamics **DSC-8**: Measure and Integration	**DSE-5:** (i) Algebraic Topology (ii) Commutative Algebra (iii) Dynamical Systems (iv) Theory of Bounded Operators **DSE-6:** (i) Advanced Complex Analysis (ii) Numerical Methods for Ordinary Differential Equations (iii) Representation of Finite Groups (iv) Topological Dynamics **DSE-7*:** (i) Advanced Functional Analysis (ii) Algebraic Coding Theory (iii) Differential Geometry (iv) Finite Element Methods *Student will opt for DSE-7 or GE-3	Developing Mathematical Ideas	**GE-3:** (i) Dynamical Systems (ii) Numerical Methods for Ordinary Differential Equations

Semester	DSC	DSE	SBC	GE
Semester-IV	**DSC-9**: Partial Differential Equations **DSC-10**: Analysis of Several Variables	**DSE-8:** (i) Advanced Fluid Dynamics (ii) Probability Theory (iii) Simplicial Homology Theory (iv) Theory of Unbounded Operators **DSE-9:** (i) Banach and C*-Algebras (ii) Chaos Theory (iii) Character Theory of Finite Groups (iv) Nonsmooth Optimization **DSE-10[#]:** (i) Computational Fluid Dynamics (ii) Differential Topology (iii) General Measure Theory (iv) Theory of Non-commutative Rings [#]Student will opt for DSE-10 or GE-4	Workshops and Seminars on Advanced Topics	**GE-4:** (i) Nonsmooth Optimization (ii) Probability Theory

Curricular Structure for Second Year of Two-year PG Programme under Structure-2 (Course work + Research)

Semester	DSC	DSE	2 Credit Course	Dissertation/ Academic Project/ Entrepreneurship	Total Credits
Semester-III	**DSC-7** **DSC-8** (8 Credits)	**DSE-5** **DSE-6** OR **DSE-3 & GE-3** (8 Credits)	**NIL**	(6 Credits)	**22**
Semester-IV	**DSC-9** **DSC-10** (8 Credits)	**DSE-7** **DSE-8** OR **DSE-4 & GE-4** (8 Credits)	**NIL**	(6 Credits)	**22**

Details of Courses in Second Year of Two-year M.Sc. Mathematics

Semester	DSC	DSE	Dissertation	GE
Semester-III	**DSC-7**: Fluid Dynamics **DSC-8**: Measure and Integration	**DSE-5 and DSE-6* (Select two papers, each from a different group)** **Group-1:** (i) Algebraic Topology (ii) Commutative Algebra (iii) Dynamical Systems (iv) Theory of Bounded Operators **Group-2:** (i) Advanced Complex Analysis (ii) Numerical Methods for Ordinary Differential Equations (iii) Representation of Finite Groups (iv) Topological Dynamics **Group-3:** (i) Advanced Functional Analysis (ii) Algebraic Coding Theory (iii) Differential Geometry (iv) Finite Element Methods *Student will opt for DSE-6 or GE-3	(6 Credits)	**GE-3:** (i) Dynamical Systems (ii) Numerical Methods for Ordinary Differential Equations

Semester	DSC	DSE	Dissertation	GE
Semester-IV	**DSC-9**: Partial Differential Equations **DSC-10**: Analysis of Several Variables	**DSE-7 and DSE-8[#] (Select two papers, each from a different group)** **Group-1:** (i) Advanced Fluid Dynamics (ii) Probability Theory (iii) Simplicial Homology Theory (iv) Theory of Unbounded Operators **Group-2:** (i) Banach and C*-Algebras (ii) Chaos Theory (iii) Character Theory of Finite Groups (iv) Nonsmooth Optimization **Group-3:** (i) Computational Fluid Dynamics (ii) Differential Topology (iii) General Measure Theory (iv) Theory of Non-commutative Rings [#]Student will opt for DSE-8 or GE-4	(6 Credits)	**GE-4:** (i) Nonsmooth Optimization (ii) Probability Theory

Curricular Structure for Second Year of Two-year PG Programme under Structure-3 (Research)

Semester	DSC	DSE (related to identified research field)	Research Methods/ Tools/ Writing	One Intensive Problem-based Research	Total Credits
Semester-III	**1 DSC** (course related to the area identified for research) **(4 Credits)**	**1 DSE** (course related or allied to the area identified for research) **(4 Credits)**	**(2 x 2 =4 Credits)**	**(10 Credits)**	**22**
Semester-IV	**-**	**1 DSE** Or a DSE of an allied subject related to the area identified for research **(4 Credits)**		**(16 Credits)**	**22**

Details of Courses in Second Year of Two-year M.Sc. Mathematics

Semester	DSC	DSE	Research Methods/ Tools/ Writing	One Intensive Problem-based Research
Semester-III	**DSC**: Matrix Groups	**Any one of the following** (course related or allied to the area identified for research): (i) Advanced Complex Analysis (ii) Advanced Functional Analysis (iii) Algebraic Coding Theory (iv) Algebraic Topology (v) Commutative Algebra (vi) Differential Geometry (vii) Dynamical Systems (viii) Finite Element Methods (ix) Numerical Methods for Ordinary Differential Equations (x) Representation of Finite Groups (xi) Theory of Bounded Operators (xii) Topological Dynamics		(10 Credits)

Semester	DSC	DSE	Research Methods/ Tools/ Writing	One Intensive Problem-based Research
Semester-IV	**-**	**Any one of the following (**course related or allied to the area identified for research)**:** (i) Advanced Fluid Dynamics (ii) Banach and C*-Algebras (iii) Chaos Theory (iv) Character Theory of Finite Groups (v) Computational Fluid Dynamics (vi) Differential Topology (vii) General Measure Theory (viii) Nonsmooth Optimization (ix) Probability Theory (x) Simplicial Homology Theory (xi) Theory of Non-commutative Rings (xii) Theory of Unbounded Operators		(16 Credits)

Programme Objectives and Outcomes

Programme Objectives

The one-year M.Sc. Mathematics programme's main objectives are to nurture a student to:

- inculcate and develop mathematical aptitude and the ability to think abstractly.
- develop computational abilities and programming skills.
- develop the ability to read, follow and appreciate mathematical text.
- train them to communicate mathematical ideas in a lucid and effective manner.
- orient them to apply their theoretical knowledge to solve real-life problems.
- prepare them for higher education and research in mathematics.

Programme Outcomes

On successful completion of the one-year M.Sc. Mathematics programme, a student will:

- have a strong foundation in core areas of Mathematics, both pure and applied.
- be able to apply mathematical skills and logical reasoning for problem solving.
- communicate mathematical ideas effectively, in writing as well as orally.
- have sound knowledge of mathematical modelling, programming and computational techniques as required for employment in industry.

Curricular Structure for One-year PG Programme under Structure-1 (Only Course work)

Semester	DSC	DSE	2 Credit Course	Total Credits
Semester-I	**DSC-1** **DSC-2** (8 Credits)	**DSE-1** **DSE-2** **DSE-3** OR **DSE-1, DSE-2 & GE-1** (12 Credits)	**Skill-based course/ Workshop/ Specialized laboratory/ Internship/ Apprenticeship/ Hands on Learning** (2 Credits)	**22**
Semester-II	**DSC-3** **DSC-4** (8 Credits)	**DSE-4** **DSE-5** **DSE-6** OR **DSE-3, DSE-4 & GE-2** (12 Credits)	**Skill-based course/ Workshop/ Specialized laboratory/ Internship/ Apprenticeship/ Hands on Learning** (2 Credits)	**22**

Details of Courses in One-year M.Sc. Mathematics

Semester	DSC	DSE	SBC	GE
Semester-I	**DSC-1**: Fluid Dynamics **DSC-2**: Measure and Integration	**DSE-1:** (i) Commutative Algebra (ii) Dynamical Systems (iii) Introduction to Topology[@] (iv) Theory of Bounded Operators **DSE-2:** (i) Numerical Methods for Ordinary Differential Equations (ii) Ordinary Differential Equations[@] (iii) Representation of Finite Groups (iv) Topological Dynamics **DSE-3*:** (i) Advanced Functional Analysis (ii) Algebraic Coding Theory (iii) Differential Geometry (iv) Finite Element Methods *Student will opt for DSE-3 or GE-1 [@]Student is advised to opt for these papers, if not studied earlier	Developing Mathematical Ideas	**GE-1:** (i) Dynamical Systems (ii) Numerical Methods for Ordinary Differential Equations

Semester	DSC	DSE	SBC	GE
Semester-II	**DSC-3**: Partial Differential Equations **DSC-4**: Analysis of Several Variables	**DSE-4:** (i) Advanced Fluid Dynamics (ii) Module Theory[@] (iii) Probability Theory (iv) Theory of Unbounded Operators **DSE-5:** (i) Banach and C*-Algebras (ii) Chaos Theory (iii) Complex Analysis[@] (iv) Nonsmooth Optimization **DSE-6[#]:** (i) Computational Fluid Dynamics (ii) Differential Topology (iii) General Measure Theory (iv) Theory of Non-commutative Rings [#]Student will opt for DSE-6 or GE-2 [@]Student is advised to opt for these papers, if not studied earlier	Workshops and Seminars on Advanced Topics	**GE-2:** (i) Nonsmooth Optimization (ii) Probability Theory

Curricular Structure for One-year PG Programme under Structure-2 (Course work + Research)

Semester	DSC	DSE	2 Credit Course	Dissertation/ Academic Project/ Entrepreneurship	Total Credits
Semester-I	**DSC-1** **DSC-2** (8 Credits)	**DSE-1** **DSE-2** OR **DSE-1 & GE-1** (8 Credits)	**NIL**	(6 Credits)	**22**
Semester-II	**DSC-3** **DSC-4** (8 Credits)	**DSE-3** **DSE-4** OR **DSE-1 & GE-2** (8 Credits)	**NIL**	(6 Credits)	**22**

Details of Courses in One-year M.Sc. Mathematics

Semester	DSC	DSE	Dissertation	GE
Semester-I	**DSC-1**: Fluid Dynamics **DSC-2**: Measure and Integration	**DSE-1/ DSE-2* (Select two papers, each from a different group)** **Group-1:** (i) Commutative Algebra (ii) Dynamical Systems (iii) Introduction to Topology[@] (iv) Theory of Bounded Operators **Group-2:** (i) Numerical Methods for Ordinary Differential Equations (ii) Ordinary Differential Equations[@] (iii) Representation of Finite Groups (iv) Topological Dynamics **Group-3:** (i) Advanced Functional Analysis (ii) Algebraic Coding Theory (iii) Differential Geometry (iv) Finite Element Methods *Student will opt for DSE-2 or GE-1 [@]Student is advised to opt for these papers, if not studied earlier	(6 Credits)	**GE-1:** (i) Dynamical Systems (ii) Numerical Methods for Ordinary Differential Equations

Semester	DSC	DSE	Dissertation	GE
Semester-II	**DSC-3**: Partial Differential Equations **DSC-4**: Analysis of Several Variables	**DSE-3/ DSE-4[#] (Select two papers, each from a different group)** **Group-1:** (i) Advanced Fluid Dynamics (ii) Module Theory[@] (iii) Probability Theory (iv) Theory of Unbounded Operators **Group-2:** (i) Banach and C*-Algebras (ii) Chaos Theory (iii) Complex Analysis[@] (iv) Nonsmooth Optimization **Group-3:** (i) Computational Fluid Dynamics (ii) Differential Topology (iii) General Measure Theory (iv) Theory of Non-commutative Rings [#]Student will opt for DSE-4 or GE-2 [@]Student is advised to opt for these papers, if not studied earlier	(6 Credits)	**GE-2:** (i) Nonsmooth Optimization (ii) Probability Theory

Curricular Structure for One-year PG Programme under Structure-3 (Research)

Semester	DSC	DSE (related to identified research field)	Research Methods/ Tools/ Writing	One Intensive Problem-based Research	Total Credits
Semester-I	**1 DSC** (course related to the area identified for research) **(4 Credits)**	**1 DSE** (course related or allied to the area identified for research) **(4 Credits)**	**(2 x 2 =4 Credits)**	**(10 Credits)**	**22**
Semester-II	**-**	**1 DSE** Or a DSE of an allied subject related to the area identified for research **(4 Credits)**		**(16 Credits)**	**22**

Details of Courses in One-year M.Sc. Mathematics

Semester	DSC	DSE	Research Methods/ Tools/ Writing	One Intensive Problem-based Research
Semester-I	**DSC**: Matrix Groups	**Any one of the following (**course related or allied to the area identified for research)**:** (i) Advanced Functional Analysis (ii) Algebraic Coding Theory (iii) Commutative Algebra (iv) Differential Geometry (v) Dynamical Systems (vi) Finite Element Methods (vii) Numerical Methods for Ordinary Differential Equations (viii) Representation of Finite Groups (ix) Theory of Bounded Operators (x) Topological Dynamics		(10 Credits)

Semester	DSC	DSE	Research Methods/ Tools/ Writing	One Intensive Problem-based Research
Semester-II	-	**Any one of the following (**course related or allied to the area identified for research)**:** (i) Advanced Fluid Dynamics (ii) Banach and C*-Algebras (iii) Chaos Theory (iv) Computational Fluid Dynamics (v) Differential Topology (vi) General Measure Theory (vii) Nonsmooth Optimization (viii) Probability Theory (ix) Theory of Non-commutative Rings (x) Theory of Unbounded Operators		(16 Credits)

Syllabi of Courses in Semester-III of M.Sc. Mathematics under Structure-1 (Only Course work)

Discipline Specific Core (DSC) Courses

DISCIPLINE SPECIFIC CORE – 7: FLUID DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC-7: Fluid Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Calculus and Partial Differential Equations

Learning Objectives

The objective of this course is to:

- prepare a mathematical foundation to study the motion of fluids.
- develop concepts, models, and techniques to solve problems of fluid flow.
- develop the ability to conduct advanced studies and research in the broad field of fluid dynamics.

Learning Outcomes

After studying this course, the student will be able to:

- understand the concept of fluids, their classification, flow lines, models and approaches to study fluid flow.
- formulate mass and momentum conservation principles and obtain their solution for non-viscous flow.
- know potential flow, Bernoulli's equation, Kelvin's minimum energy and circulation theorems.
- understand two- and three-dimensional motion, complex potential, circle theorem, Blasius theorem, Weiss's and Butler's sphere theorems.
- apply the concept of stress and strain in viscous flow to derive Navier–Stokes equation of motion and energy equation.

Syllabus

Unit – 1 **(10 hours)**

Classification of fluids, Continuum model, Eulerian and Lagrangian approach of description, Differentiation following the fluid motion, Flow lines, vorticity and circulation, Conservation of mass: Equation of continuity, Boundary surface.

Unit – 2 **(12 hours)**

Forces in fluid motion, Conservation of momentum: Euler's equation of motion, Theory of irrotational motion: Integration of Euler's equation under different conditions, Bernoulli's equation, Impulsive motion, Kelvin's minimum energy and circulation theorems, Potential theorem.

Unit – 3 **(13 hours)**

Two-dimensional motion: Complex potential, Line sources, sinks, doublets and vortices, Two-dimensional image system, Milne–Thomson circle theorem, Images with respect to a plane and cylinder, Blasius theorem. Three-dimensional flows, Weiss's sphere theorem, Images with respect to sphere, Axi-symmetric flow, Stokes stream function, Butler's sphere theorem, Flow past spheres and cylinders.

Unit – 4 **(10 hours)**

Stress and strain analysis, Newton's law of viscosity, Laminar flow, Navier–Stokes equation of motion, Steady flow between parallel planes and Poiseuille flow, Constitutive equation, Energy equation.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] F. Chorlton, *Text Book of Fluid Dynamics*, CBS Publisher, 2005.
[2] R. W. Fox, P. J. Pritchard and A. T. McDonald, *Introduction to Fluid Mechanics*, Seventh Edition, John Wiley & Sons, 2009.
[3] P. K. Kundu, I. M. Cohen and D. R. Dowling, *Fluid Mechanics*, Sixth Edition, Academic Press, 2016.

Suggested Readings

(i) L. M. Milne-Thomson, *Theoretical Hydrodynamics*, The Macmillan company, USA, 1969.
(ii) D. E. Rutherford, *Fluid Dynamics*, Oliver and Boyd Ltd., 1978.

DISCIPLINE SPECIFIC CORE – 8: MEASURE AND INTEGRATION

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC-8: Measure and Integration	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Real Analysis and Riemann Integration

Learning Objectives

The primary objective of this course is to:

- extend the notion of length of an interval with the introduction of the concept of Lebesgue outer measure for any subset of real line.
- investigate the properties of Lebesgue measurable sets and functions.
- familiarize students with the Lebesgue integration of functions and its comparison with Riemann integration.
- generalize the concepts of measure and integration to an abstract space.

Learning Outcomes

This course will enable the students to:

- verify whether a given subset of $\mathbb{R}$ or a real valued function is measurable.
- understand the requirement and the concept of the Lebesgue integral (a generalization of the Riemann integration) along with its properties.
- understand the statements and proofs of the fundamental integral convergence theorems and demonstrate their applications.
- carry out a comprehensive study of functions of bounded variation and their utility in understanding differentiation and integration.
- apply Hölder and Minkowski inequalities in L^p-spaces and understand completeness of L^p-spaces.

Syllabus

Unit – 1 **(14 hours)**

Lebesgue outer measure, Measurable sets, Lebesgue measure, Borel sets, Regularity, Measurable functions, Borel and Lebesgue measurability, Non-measurable sets.

Unit – 2 **(13 hours)**

Integration of nonnegative functions, General integral, Integration of series, Riemann and Lebesgue integrals.

Unit – 3 **(8 hours)**

Functions of bounded variation, Lebesgue's differentiation theorem, Differentiation and integration, Absolute continuity of functions.

Unit – 4 **(10 hours)**

Measures and outer measures, Measure spaces, Integration with respect to a measure, L^p-spaces, Hölder's and Minkowski's inequalities, Completeness of L^p-spaces.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. de Barra, *Measure Theory and Integration*, Ellis Horwood Ltd., Chichester, John Wiley & Sons, Inc., New York, 1981 (Indian Reprint, 2014).

Suggested Readings

(i) M. Capinski and P. E. Kopp, *Measure, Integral and Probability*, Springer, 2005.
(ii) E. Hewitt and K. Stromberg, *Real and Abstract Analysis: A Modern Treatment of the Theory of Functions of a Real Variable*, Springer, Berlin, 1975.
(iii) H. L. Royden and P. M. Fitzpatrick, *Real Analysis*, Fourth Edition, Pearson, 2015.

Discipline Specific Elective (DSE) Courses

DISCIPLINE SPECIFIC ELECTIVE – 5 (i): ALGEBRAIC TOPOLOGY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-5 (i): Algebraic Topology	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- understand the concepts of homotopic maps, homotopy type, retracts, and deformation retracts, and their role in algebraic topology.
- compute fundamental groups of basic topological spaces.
- acquire knowledge of covering projections, lifting properties, Borsuk–Ulam theorem, and classification techniques of covering spaces.
- learn free groups and free products to understand and apply the Seifert–Van Kampen theorem.

Learning Outcomes

This course will enable the students to:

- distinguish between spaces with the same homotopy type.
- compute fundamental groups of standard spaces such as n-sphere $\mathbb{S}^n$ and punctured planes.
- apply the concept of fundamental groups to prove Brouwer's fixed-point theorem and the Fundamental theorem of Algebra.
- explain the lifting theorems and their implications in topology.
- classify covering spaces for given base spaces.
- apply Seifert–Van Kampen theorem to compute fundamental groups of glued spaces.

Syllabus

Unit – 1 **(11 hours)**

Homotopic maps, Homotopy type, Retract and deformation retract.

Unit – 2 **(12 hours)**

Fundamental group, Calculation of fundamental groups of n-sphere $\mathbb{S}^n$ and punctured plane, Brouwer's fixed-point theorem, Fundamental theorem of Algebra.

Unit – 3 **(12 hours)**

Covering projections, Lifting theorems, Borsuk–Ulam theorem, Classification of covering spaces.

Unit – 4 **(10 hours)**

Free products, Free groups, Seifert–Van Kampen theorem and its applications.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. R. Munkres, *Elements of Algebraic Topology*, Addison-Wesley Publishing Company, 1984.
[2] T. B. Singh, *Introduction to Topology*, Springer Nature Singapore, 2019.

Suggested Readings

(i) G. E. Bredon, *Geometry and Topology*, Springer, 2014.
(ii) A. Hatcher, *Algebraic Topology*, Cambridge University Press, 2002.
(iii) W. S. Massey, *A Basic Course in Algebraic Topology*, World Publishing Corporation, 2009.
(iv) J. J. Rotman, *An Introduction to Algebraic Topology*, Springer, 2011.
(v) E. H. Spanier, *Algebraic Topology*, Springer-Verlag, 1989.

DISCIPLINE SPECIFIC ELECTIVE – 5 (ii): COMMUTATIVE ALGEBRA

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-5 (ii): Commutative Algebra	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra and Field Theory

Learning Objectives

The objective of this course is to:

- develop a solid understanding of the structure of commutative rings, ideals, their radicals, extension, contraction etc.
- study important constructions such as total quotient rings, localizations.
- develop basic foundation in other areas of mathematics such as algebraic geometry, algebraic number theory.

Learning Outcomes

This course will enable the students to:

- know the localization of rings at a prime ideal that is an algebraic analogue of the geometric notion concentrating attention near a point.
- know more closely the polynomial rings, power series rings in one or more variables over a commutative ring and their prime spectrum.
- define, identify, and elaborate integral closure of rings, valuations rings, discrete valuation rings, structure theorem of Artin rings.

Syllabus

Unit – 1 **(12 hours)**

Radical of an ideal, Prime avoidance lemma, Chinese remainder theorem, Extension and contraction of ideals, Jacobson radical of a ring, Nakayama lemma, Tensor product of modules.

Unit – 2 **(13 hours)**

Rings and modules of fractions, Localization, Local properties, Primary decomposition, First and second uniqueness theorem of primary decomposition, Associated prime ideals of decomposable ideals.

Unit – 3 **(10 hours)**

Integral ring extensions, Going up theorem, Going down theorem, Integrally closed domains, Valuation rings, Hilbert's Nullstellensatz theorem.

Unit – 4 **(10 hours)**

Noetherian rings, Primary decomposition in Noetherian rings, Artin rings, Structure theorem for Artin rings, Discrete valuation rings.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. F. Atiyah and I. G. MacDonald, *Introduction to Commutative Algebra*, CRC Press, Taylor & Francis, 2018.

Suggested Readings

(i) D. Eisenbud, *Commutative Algebra with a View Towards Algebraic Geometry*, Springer, 2004.
(ii) R. Y. Sharp, *Steps in Commutative Algebra*, Cambridge University Press, 2000.
(iii) B. Singh, *Basic Commutative Algebra*, World Scientific, 2011.
(iv) O. Zariski and P. Samuel, *Commutative Algebra*, Volume I & II, Springer, 1975.

DISCIPLINE SPECIFIC ELECTIVE – 5 (iii): DYNAMICAL SYSTEMS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-5 (iii): Dynamical Systems	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology and Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- understand discrete and continuous systems with case studies to study nonlinear systems of ordinary differential equations and dynamical systems.
- understand the concepts, models and techniques to realize the real-world problems and stability of the systems along with the chaotic dynamic behaviour of models by understanding bifurcations.

Learning Outcomes

This course will enable the students to learn:

- formulation of mathematical models with the stability analysis near the equilibrium points.
- how the concept of phase portraits helps to analyse mathematical model graphically.
- the qualitative behaviour of the solution set of a given system of differential equations including the invariant sets and limiting behaviour of the dynamical system or flow defined by the system of differential equations.
- how different bifurcations explain the chaotic behaviour of the system.

Syllabus

Unit – 1 **(13 hours)**

Linear systems: Jordan forms, Stability theory; Nonlinear systems: Fundamental existence-uniqueness theorem, Dependence on initial conditions and parameters, Flow of a differential equation, Linearization, Stable manifold theorem, Hartman–Grobman theorem.

Unit – 2 **(10 hours)**

Stability and Lyapunov functions, Saddle points, Nodes, Foci, Centers and nonhyperbolic critical points, Center manifold theorem.

Unit – 3 **(12 hours)**

Limit sets and attractors, Periodic orbits and limit cycles, Poincaré map, Stable manifold theorem for periodic orbits, Poincare-Bendixson theorem.

Unit – 4 **(10 hours)**

Bifurcations at nonhyperbolic equilibrium points, Saddle node, Transcritical and Pitchfork bifurcations, Hopf bifurcation.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. W. Hirsch, S. Smale and R. L. Devaney, *Differential Equations, Dynamical Systems, and an Introduction to Chaos*, Third Edition, Academic Press, 2013.
[2] L. Perko, *Differential Equations and Dynamical Systems*, Third Edition, Springer Verlag, 2001.

Suggested Readings

(i) R. L. Devaney, *A First Course in Chaotic Dynamical Systems: Theory and Experiment*, CRC Press, Taylor & Francis, 2018.
(ii) S. H. Strogatz, *Nonlinear Dynamics and Chaos*, Second Edition, CRC Press, Taylor & Francis, 2018.
(iii) S. Wiggins, *Introduction to Applied Nonlinear Dynamical Systems and Chaos*, TAM Volume 2, Springer-Verlag, NY, 1990.

DISCIPLINE SPECIFIC ELECTIVE – 5 (iv): THEORY OF BOUNDED OPERATORS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-5 (iv): Theory of Bounded Operators	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis

Learning Objectives

The primary objective of this course is to:

- introduce some classes of bounded linear operators which play a central role in both pure and applied mathematics.
- study the properties and spectral theory of these operators.

Learning Outcomes

This course will enable the students to understand:

- the spectrum and sub-divisions of spectrum of standard operators like shifts and multiplication.
- the spectral theorem for some classes of bounded linear operators.
- the concepts of compactness, self-adjointness and positivity of bounded linear operators.
- trace class and Hilbert–Schmidt operators.

Syllabus

Unit – 1 **(11 hours)**

Properties of spectrum and resolvent of bounded operators, Subdivision of the spectrum including point, approximate and compression spectrum.

Unit – 2 **(10 hours)**

Operators on Hilbert spaces, Adjoint operator, Projections and idempotents, Operations with projections, Invariant and reducing subspaces.

Unit – 3 **(14 hours)**

Compact operators on Hilbert spaces, Diagonalisation of compact self-adjoint operators, Spectral theorem and functional calculus for Compact normal operators, Positive operators, Compact operators on Banach spaces, Spectral theory of compact operators.

Unit – 4 **(10 hours)**

Polar decomposition, Singular values, Trace class operators, Trace norm and Hilbert Schmidt operators.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] R. Bhatia, *Notes on Functional Analysis*, Hindustan Book Agency, 2009.
[2] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.

Suggested Readings

(i) E. Kreyszig, *Introductory Functional Analysis with Applications*, John Wiley & Sons, 2006.
(ii) B. Simon, *Operator Theory: A Comprehensive Course in Analysis*, Part 4, American Mathematical Society, 2015.
(iii) S. R. Garcia, J. Mashregi and W. T. Ross, *Operator Theory by Example*, Oxford University Press, 2023.

DISCIPLINE SPECIFIC ELECTIVE – 6 (i): ADVANCED COMPLEX ANALYSIS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-6 (i): Advanced Complex Analysis	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Complex Analysis

Learning Objectives

The primary objective of this course is to:

- explore the metric space structure of the spaces of continuous and analytic functions, through Arzela–Ascoli, Hurwitz and Montel theorems.
- investigate various characterizations of simply connected regions, with a special focus on the Riemann mapping theorem.
- use Runge's and Mittag–Leffler's theorems to approximate and interpolate analytic and meromorphic functions.
- analyze the range of analytic functions using Bloch's/ Landau's constants and Picard's theorem.

Learning Outcomes

This course will enable the students to:

- apply various variants of maximum modulus theorem, encompassing Hadamard's three circles theorem and Phragmen–Lindelöf theorem.
- comprehend the notions of normality, compactness, equicontinuity and local boundedness for the spaces of continuous and analytic functions.
- construct and factorize entire functions using infinite products, including special functions like gamma and zeta.
- analyze the harmonic functions on a disk using Poisson kernel, which in turn, solves the Dirichlet problem for a unit disk.

Syllabus

Unit – 1 **(12 hours)**

Convex functions and Hadamard's three circles theorem, Maximum-Modulus theorem (third version), Phragmen–Lindelöf theorem, Spaces of continuous functions, Normal and equicontinuous families, Arzela–Ascoli theorem.

Unit – 2 **(11 hours)**

Spaces of analytic functions, Hurwitz's theorem, Montel's theorem, Riemann mapping theorem, Infinite products, Weierstrass factorization theorem, Factorization of sine function.

Unit – 3 **(10 hours)**

Gamma and Riemann zeta function, Runge's theorem, Characterizations of simple connectedness, Mittag–Leffler's theorem.

Unit – 4 **(12 hours)**

Harmonic functions, Mean value property, Maximum and minimum principles, Harmonic function on a disk, Harnack's theorem, Range of an analytic function, Bloch's theorem, Bloch's and Landau's constants, Picard's theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. B. Conway, *Functions of One Complex Variable*, Second Edition, Narosa Publishing House, New Delhi, 2002.

Suggested Readings

(i) L. V. Ahlfors, *Complex Analysis*, Mc Graw Hill Co., Indian Edition, 2017.
(ii) L. Hahn and B. Epstein, *Classical Complex Analysis*, Jones and Bartlett, 1996.
(iii) E. M. Stein and R. Shakarchi, *Complex Analysis*, Princeton University Press, 2003.
(iv) D. Ullrich, *Complex Made Simple*, Volume 97, American Mathematical Society, 2008.

DISCIPLINE SPECIFIC ELECTIVE – 6 (ii): NUMERICAL METHODS FOR ORDINARY DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-6 (ii): Numerical Methods for Ordinary Differential Equations	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- develop the basic theory underlying the numerical solution of differential equations.
- introduce the concepts of consistency, stability and convergence of finite difference methods.
- execute the numerical schemes for the solution of differential equations.

Learning Outcomes

This course will enable the students to:

- gain a thorough understanding of the fundamental concepts involved in the construction and analysis of finite difference schemes for solving ordinary differential equations (ODEs).
- apply various numerical methods based on finite difference approaches to obtain approximate solutions for both initial value problems (IVPs) and boundary value problems (BVPs).
- develop the ability to select appropriate finite difference methods for specific types of problems and effectively apply them to real world applications.

Syllabus

Unit – 1 **(11 hours)**

Initial value problems: Existence and uniqueness of solution, Finite difference equation, Truncation error, Single step methods for first order IVPs and system of IVPs- Family of explicit and implicit Runge–Kutta methods, Taylor series methods, Derivation, Truncation error, Consistency, Stability and convergence analysis.

Unit – 2 **(12 hours)**

IVPs for the system of ODEs, Consistency, Zero stability and convergence of linear multistep methods, Routh–Hurwitz criterion, Order and error constant, First Dahlquist Barrier, Local truncation error and global truncation error, Error bounds, Local error, Linear stability theory, Higher order differential equations.

Unit – 3 **(12 hours)**

Derivation of explicit and implicit multistep methods for IVPs and system of IVPs, Truncation error, Stability and convergence analysis of family of Nystrom method, Adams–Bashforth method,

Adams–Moulton method, Milne–Simpson method, Predictor corrector method, and Modified predictor corrector method, Hybrid method, Multistep methods for second order IVPs.

Unit – 4 **(10 hours)**

Linear BVPs for second order ordinary differential equations, Shooting method, Finite difference method, Collocation method, Derivative boundary conditions, Nonlinear two-point BVPs, Higher order finite difference methods, Stability, Truncation error and convergence analysis.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. K. Jain, S. R. K. Iyenger and R. K. Jain, *Numerical Methods for Scientific and Engineering Computations*, Seventh Edition, New Age International Publisher, 2019.

[2] J. D. Lambert, *Numerical Methods for Ordinary Differential Systems: The Initial Value Problem*, John Wiley & Sons, 1991.

Suggested Readings

(i) K. E. Atkinson, W. Han and D. E. Stewart, *Numerical Solution of Ordinary Differential Equations*, John Wiley & Sons, 2009.

(ii) J. C. Butcher, *The Numerical Analysis of Ordinary Differential Equations*, Second Edition, Wiley, New York, 2008.

(iii) L. Collatz, *The Numerical Treatment of Differential Equations*, Springer-Verlag, 1966.

DISCIPLINE SPECIFIC ELECTIVE – 6 (iii): REPRESENTATION OF FINITE GROUPS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-6 (iii): Representation of Finite Groups	**4**	**3**	**1**	**0**	**Same as for entry to M.Sc. Mathematics**	**Basics of Linear Algebra and Group Theory**

Learning Objectives

The primary objective of this course is to:

- represent finite groups as groups of matrices (via homomorphisms) and apply the tools of linear algebra to study the group structure.
- introduce the notion of Group algebra, which plays an essential role in classifying representations of groups.
- to discuss some applications of representations of finite groups, such as the Burnside's theorem.

Learning Outcomes

This course will enable the students to:

- define and construct examples of group representations, FG-modules, group algebras.
- grasp key concepts and tools of representation theory and establish a link between FG-modules and group representations.
- prove and apply Maschke's theorem and Schur's lemma to describe all irreducible representations of finite groups over the field of complex numbers.
- apply the theory of characters and group representations to gain insight into group structure, such as normal subgroups, and the solubility of groups.

Syllabus

Unit – 1 **(11 hours)**

Representation of groups, FG-modules and FG-submodules, and reducibility, Permutation modules, FG-modules and equivalent representations, Reducible and irreducible FG-modules, Group algebra of G, Regular FG-module and regular representations, FG-homomorphisms, Direct sum of FG-modules.

Unit – 2 **(11 hours)**

Maschke's theorem for FG-modules and consequences. Schur's lemma and its converse, Application of Schur's lemma, Irreducible modules and group algebra, Structure of group algebra and space of CG-homomorphisms.

Unit – 3 **(10 hours)**

Characters and their properties, Permutation and regular characters, Inner product, Number of irreducible characters, Orthogonality relations and finding normal subgroups.

Unit – 4 **(13 hours)**

Algebraic numbers, Algebraic integers and their properties, Character values, The Burnside's *(p,q)*-theorem and solubility of some particular groups.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. James and M. Liebeck, *Representations and Characters of Groups*, Second Edition, Cambridge University Press, 2005.

Suggested Readings

(i) C. W. Curtis and I. Reiner, *Representation Theory of Finite Groups and Associative Algebras*, American Mathematical Society, 2006.
(ii) W. Fulton and J. Harris, *Representation Theory - A First Course*, Springer-Verlag, 2004.
(iii) I. M. Issacs, *Character Theory of Finite Groups*, American Mathematical Society reprint, 2006.

DISCIPLINE SPECIFIC ELECTIVE – 6 (iv): TOPOLOGICAL DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-6 (iv): Topological Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- provide a strong background of topological dynamical systems including their applications.
- develop some useful and interesting dynamical properties like expansivity, shadowing and topological stability with supporting examples and results from symbolic and topological dynamics.
- introduce the celebrated Sarkovskii's theorem.

Learning Outcomes

This course will enable the students to:

- construct interesting examples of dynamical systems and topological conjugacy.
- visualize stable sets, omega sets and alpha limit sets.
- understand the applications of Sarkovskii's theorem.
- use subshifts of finite type to characterize irreducible matrices.
- prove key results on expansivity and shadowing regarding existence/non-existence, product, subspace and their different characterizations etc.
- find the class of topologically stable homeomorphisms.

Syllabus

Unit – 1 **(10 hours)**

Definition and examples (including real life examples) of dynamical systems, Orbits, Types of orbits, Topological conjugacy and orbits, Phase portrait-graphical analysis of orbit, Periodic points and stable sets, Omega and alpha limit sets and their properties.

Unit – 2 **(10 hours)**

Sarkovskii's theorem, Shift spaces and subshift, Subshift of finite type, Subshift represented by a matrix, Characterizations of irreducible matrices.

Unit – 3 **(13 hours)**

Definition and examples of expansive homeomorphisms, Properties of expansive homeomorphisms, Non-existence of expansive homeomorphism on the unit interval and unit circle, Generators and weak generators, Generators and expansive homeomorphisms.

Unit – 4 **(12 hours)**

Converging semi-orbits for expansive homeomorphisms, Definition, examples and properties of maps having shadowing property, Topological Anosov homeomorphisms and topological stability.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] N. Aoki and K. Hiraide, *Topological Theory of Dynamical Systems: Recent Advances*, North Holland Publications, 1994.
[2] M. Brin and G. Stuck, *Introduction to Dynamical Systems*, Cambridge University Press, 2004.

Suggested Readings

(i) D. C. Hanselman and B. Little field, *Mastering MATLAB*, Pearson, 2012.
(ii) D. Lind and B. Marcus, *An Introduction to Symbolic Dynamics and Coding*, Cambridge University Press, 1996.
(iii) C. Robinson, *Dynamical Systems*, *Stability, Symbolic Dynamics and Chaos*, Second Edition, CRC Press, Taylor & Francis, 1998.
(iv) J. de. Vries, *Elements of Topological Dynamics*, Springer, 1993.

DISCIPLINE SPECIFIC ELECTIVE – 7 (i): ADVANCED FUNCTIONAL ANALYSIS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-7 (i): Advanced Functional Analysis	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis and Topology

Learning Objectives

The primary objective of this course is to:

- define and explain the structure of a topological vector space and its fundamental properties.
- differentiate between normed, metrizable, locally convex and Hausdorff topological vector spaces.
- introduce the foundational theorems of functional analysis, including the Hahn–Banach, Banach–Steinhaus, Open mapping, and Closed graph theorems in the context of locally convex spaces.
- explain some applications of Banach–Alaoglu theorem and Krein–Milman theorem.

Learning Outcomes

This course will enable the students to:

- appreciate types of topological vector spaces and their separation properties.
- understand quotient spaces, weak topology and weak*-topology.
- analyze concepts of continuity, boundedness, and convergence for linear operators and functionals on topological vector spaces.
- understand the notion of local convexity and the role of seminorms in defining locally convex topologies.

Syllabus

Unit – 1 **(12 hours)**

Topological vector spaces, Types of Topological vector spaces, Separation properties, Linear mappings, Finite dimensional spaces, Metrization, Boundedness and continuity, Seminorms and local convexity, Normability.

Unit – 2 **(11 hours)**

Quotient spaces, Seminorms and quotient spaces, Examples, Baire category theorem, Banach–Steinhaus theorem, The open mapping theorem and the closed graph theorem on topological vector spaces.

Unit – 3 **(11 hours)**

Hahn–Banach separation theorem on topological vector spaces, Continuous extension theorem, Weak topologies, Weak topology and convexity, Weak topology and metrizability, Weak*-topology of a dual space, Compact convex sets, Banach–Alaoglu theorem and applications, Goldstine theorem.

Unit – 4 **(11 hours)**

Extreme points, Krein–Milman theorem, Convex hull of compact sets, Applications of Krein–Milman theorem: Stone–Weierstrass theorem, Markov–Kakutani fixed point theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.
[2] W. Rudin, *Functional Analysis*, Second Edition, Tata Mc Graw-Hill, 2011.

Suggested Readings

(i) V. I. Bogachev and O. G. Smolyanov, *Topological Vector Spaces and Their Applications*, Springer, 2017.
(ii) S. Kantorovitz, *Introduction to Modern Analysis*, Oxford Graduate Texts in Mathematics, Oxford University Press, 2006.
(iii) J. Voigt, *A Course on Topological Vector Spaces*, Birkhäuser, 2020.

DISCIPLINE SPECIFIC ELECTIVE – 7 (ii): ALGEBRAIC CODING THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-7 (ii): Algebraic Coding Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra, Groups and Rings

Learning Objectives

The primary objective of this course is to:

- provide an introduction to algebraic coding theory, particularly linear codes.
- discuss bounds on the parameters along with cyclic codes.
- describe some well-known codes, such as Reed–Muller and Golay codes.
- explore the algebraic structure of Cyclic and Quadratic residue codes over fields and rings.

Learning Outcomes

This course will enable the students to:

- get an insight into the matrix representation of a code, as well as encoding and decoding.
- understand Hamming, MDS and Reed–Muller codes.
- describe cyclic codes and their generator polynomial.
- learn about special cyclic codes, such as Quadratic residue codes, and their properties over the ring $\mathbb{Z}_4$.

Syllabus

Unit – 1 **(10 hours)**

Error detecting and error correcting codes, Maximum likelihood decoding, Hamming distance, Linear codes, Hamming weight, Generator matrix, Parity check matrix, Equivalence of linear codes, Encoding and decoding of linear codes, Syndrome decoding.

Unit – 2 **(11 hours)**

Bounds on codes, Sphere covering bound, Hamming bound, Perfect codes, Binary Hamming codes, Binary Golay codes, Singleton bound and MDS codes. Propagation rules, Reed–Muller codes.

Unit – 3 **(12 hours)**

Cyclic codes, Cyclic codes as ideals, Generator polynomial of cyclic codes, Generator and parity-check matrices of cyclic codes**,** Decoding of cyclic codes, Burst error correcting codes.

Unit – 4 **(12 hours)**

Quadratic residue codes: QR codes over fields of characteristic 2 and 3, Cyclic codes and their generating polynomial over $\mathbb{Z}_4$, QR codes over $\mathbb{Z}_4$.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] S. Ling and C. Xing, *Coding Theory: A First Course*, Cambridge University Press, 2004.
[2] W. C. Huffman and V. Pless, *Fundamentals of Error Correcting Codes*, Cambridge University Press, 2010.

Suggested Readings

(i) R. Hill, *A First Course in Coding Theory*, Oxford University Press, 1986.
(ii) F. J. Mac William and N. J. A. Sloane, *Theory of Error Correcting Codes, Part I & II,* Elsevier/North-Holland, Amsterdam, 1977.

DISCIPLINE SPECIFIC ELECTIVE – 7 (iii): DIFFERENTIAL GEOMETRY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-7 (iii): Differential Geometry	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra, Multivariate Calculus and Differential Equations

Learning Objectives

The primary objective of this course is to introduce:

- surfaces and parametrized surfaces.
- orientation on connected surfaces.
- geodesics on surfaces.
- Weingarten maps on oriented surfaces.
- arc length and curvature of oriented plane curves.
- curvatures of oriented surfaces.

Learning Outcomes

This course will enable the students to:

- understand the concepts of level sets and graphs of functions, smooth vector fields, tangent spaces of level sets.
- appreciate surfaces and parametrized surfaces, Gauss map, geodesics and parallel transport on oriented surfaces.
- know what the Weingarten map of an oriented surface is, realize it as shape operator and use it to compute curvature of oriented plane curves.
- find global parametrization and hence arc length of an oriented plane curve.
- compute various types of curvatures of surfaces.

Syllabus

Unit – 1 **(10 hours)**

Level sets in $\mathbb{R}^{n+1}$ and graphs of functions, Smooth vector fields and existence and uniqueness of their integral curves, Tangent spaces of level sets at regular points, Surfaces in $\mathbb{R}^{n+1}$ as inverse images of regular values of smooth functions, Necessary condition for extrema of functions on surfaces-Lagrange multipliers, Existence of a normal vector field on a connected surface, Orientation, Gauss map.

Unit – 2 **(13 hours)**

The notion of a geodesic on a surface, Existence and uniqueness of a geodesic on a surface through a given point with a given velocity vector thereof, Covariant derivative of a smooth vector field, Parallel vector field along a curve, Existence and uniqueness of a parallel vector field along a curve with a given initial vector, Weingarten map of a surface at a point, Local parametrization and curvature of a plane curve.

Unit – 3 **(10 hours)**

Global parametrization and arc length of an oriented plane curve, Differential 1-forms, Line integral of 1-forms over parametrized curves.

Unit – 4 **(12 hours)**

Parametrized surfaces with examples, Curvature of surfaces, Normal curvature of a surface at a point in a given direction, Principal curvatures, First and second fundamental forms, Gauss-Kronecker curvature and mean curvature.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] A. Pressley, *Elementary Differential Geometry*, Springer-Verlag London Limited, 2012.
[2] J. A. Thorpe, *Elementary Topics in Differential Geometry*, Springer (India) Pvt. Limited, 2004.

Suggested Readings

(i) W. Kuhnel, *Differential Geometry: Curves-Surfaces-Manifolds*, Third Edition, American Mathematical Society, 2015.
(ii) B. O' Neill, *Elementary Differential Geometry*, Second Edition, Academic Press INC., Academic Press, New York, 2006.

DISCIPLINE SPECIFIC ELECTIVE – 7 (iv): FINITE ELEMENT METHODS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-7 (iv): Finite Element Methods	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Differential Equations

Learning Objectives

The primary objective of this course is to:

- introduce basic aspects of finite element methods (FEM) including domain discretization, polynomial interpolation, application of boundary conditions, assembly of global arrays, and solution of the resulting algebraic systems.
- discuss the use of finite element methods in solving engineering problems in the domain of solid mechanics, fluid mechanics, heat transfer and electromagnetism.

Learning Outcomes

This course will enable the students to:

- use integral statement to deduce finite element approximations for the underlying linear partial differential equations.
- write special-purpose finite element programs within a procedural programming environment.
- use finite element methods to solve engineering problems in solids mechanics, fluid mechanics, heat transfer, and electromagnetism.
- assess the accuracy and reliability of finite element solutions and troubleshoot problems arising from errors in a given finite element analysis.

Syllabus

Unit – 1 **(12 hours)**

Basic concepts of weak formulation, Variational formulation of a one dimensional model equation, Basis function and finite element solutions, Collocation method, Ritz method, Least square method, Standard Galerkin method, FEM for model problem, Error estimate for FEM for model equation, Convergence analysis.

Unit – 2 **(11 hours)**

Various shapes of finite element, Higher order basis functions, Finite element methods for elliptic problems: Variational methods, Standard Galerkin method, Error estimate for FEM for elliptic problem, FEM for Poisson equation.

Unit – 3 **(12 hours)**

Finite element methods for parabolic problems: One dimensional model problems, Semi-discretization in space, Error estimates, Discretization in space and time, Galerkin method, Finite element methods for hyperbolic problems: Standard Galerkin method, Standard Galerkin method with strongly and weakly imposed boundary conditions.

Unit – 4 **(10 hours)**

Applications of the FEM to second order BVPs in one dimension, Applications of the FEM to linear elliptic, parabolic and hyperbolic equations.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. Evans, J. Blackledge and P. Yardley, *Numerical Methods for Partial Differential Equations*, Springer-Verlag, London, 2000.
[2] C. Johnson, *Numerical Solutions of Partial Differential Equations by Finite Element Methods*, *Cambridge University Press*, Cambridge, 1987.
[3] J. Whiteley, *Finite Element Methods - A Practical Guide*, Springer, 2016.

Suggested Readings

(i) Z. Chen, *Finite Element Methods and Their Applications*, Springer-Verlag, New York, 2005.
(ii) V. Thomee, *Galerkin Finite Element Methods for Parabolic Problems*, Second Edition, Springer-Verlag, Berlin, 2006.

Skill-Based Course (SBC)

DEVELOPING MATHEMATICAL IDEAS

Course Title	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Developing Mathematical Ideas	2	0	0	2	Same as for entry to M.Sc. Mathematics	NIL

Learning Objectives

This course will train students

- to develop skills to create new mathematical ideas independently.
- to present these ideas adeptly.

Learning Outcomes

Students will be able to

- hone their analytical skills and their ability to think critically.
- learn to work collaboratively.
- acquire skills that help them to create and develop new mathematical ideas.

Methodology

We plan to form groups of students, say of 5-6 each, who will be assigned a piece of mathematical work (article/ paper published in reputed journals/ periodicals/book chapters). The designated groups will be required to read and understand this mathematical work under the supervision of a faculty member. They will be further encouraged to pose meaningful questions/problems in the context of the mathematics they have read and possibly offer solutions. Presentations will be conducted for these groups as a part of their assessment process.

Appropriate material for the study will be provided by the department/faculty. Papers/articles for example, may be chosen from resources like *Involve* (Link: https://msp.org/involve/), *SIAM Undergraduate Research Online* (Link: https://www.siam.org/publications/siuro), *The American Mathematical Monthly* (Mathematical Association of America, Taylor and Francis, Link: https://www.tandfonline.com/journals/uamm20), *Mathematics Magazine* (Mathematical Association of America, Taylor and Francis, Link: https://www.tandfonline.com/journals/umma20), *The Mathematics Student* (Indian Mathematical Society, Link: https://www.indianmathsoc.org/MS.html) and *The Mathematical Intelligencer* (Springer Nature, Link: https://link.springer.com/journal/283). Advanced topics beyond the prescribed syllabus from textbooks/ research monographs may also be chosen.

Generic Elective (GE) Courses

GENERIC ELECTIVE – 3 (i): DYNAMICAL SYSTEMS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
GE-3 (i): Dynamical Systems	4	3	1	0	Class XII pass with Mathematics	Basics of Topology and Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- understand discrete and continuous systems with case studies to study nonlinear systems of ordinary differential equations and dynamical systems.
- understand the concepts, models and techniques to realize the real-world problems and stability of the systems along with the chaotic dynamic behaviour of models by understanding bifurcations.

Learning Outcomes

This course will enable the students to learn:

- formulation of mathematical models with the stability analysis near the equilibrium points.
- how the concept of phase portraits helps to analyse mathematical model graphically.
- the qualitative behaviour of the solution set of a given system of differential equations including the invariant sets and limiting behaviour of the dynamical system or flow defined by the system of differential equations.
- how different bifurcations explain the chaotic behaviour of the system.

Syllabus

Unit – 1 **(13 hours)**

Linear systems: Jordan forms, Stability theory; Nonlinear systems: Fundamental existence-uniqueness theorem, Dependence on initial conditions and parameters, Flow of a differential equation, Linearization, Stable manifold theorem, Hartman–Grobman theorem.

Unit – 2 **(10 hours)**

Stability and Lyapunov functions, Saddle points, Nodes, Foci, Centers and nonhyperbolic critical points, Center manifold theorem.

Unit – 3 **(12 hours)**

Limit sets and attractors, Periodic orbits and limit cycles, Poincaré map, Stable manifold theorem for periodic orbits, Poincare–Bendixson theorem.

Unit – 4 **(10 hours)**

Bifurcations at nonhyperbolic equilibrium points, Saddle node, Transcritical and Pitchfork bifurcations, Hopf bifurcation.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. W. Hirsch, S. Smale and R. L. Devaney, *Differential Equations, Dynamical Systems, and an Introduction to Chaos*, Third Edition, Academic Press, 2013.
[2] L. Perko, *Differential Equations and Dynamical Systems*, Third Edition, Springer Verlag, 2001.

Suggested Readings

(i) R. L. Devaney, *A First Course in Chaotic Dynamical Systems: Theory and Experiment*, CRC Press, Taylor & Francis, 2018.
(ii) S. H. Strogatz, *Nonlinear Dynamics and Chaos*, Second Edition, CRC Press, Taylor & Francis, 2018.
(iii) S. Wiggins, *Introduction to Applied Nonlinear Dynamical Systems and Chaos*, TAM Volume 2, Springer-Verlag, NY, 1990.

GENERIC ELECTIVE – 3 (ii): NUMERICAL METHODS FOR ORDINARY DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
GE-3 (ii): Numerical Methods for Ordinary Differential Equations	4	3	1	0	Class XII pass with Mathematics	Basics of Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- develop the basic theory underlying the numerical solution of differential equations.
- introduce the concepts of consistency, stability and convergence of finite difference methods.
- execute the numerical schemes for the solution of differential equations.

Learning Outcomes

This course will enable the students to:

- gain a thorough understanding of the fundamental concepts involved in the construction and analysis of finite difference schemes for solving ordinary differential equations (ODEs).
- apply various numerical methods based on finite difference approaches to obtain approximate solutions for both initial value problems (IVPs) and boundary value problems (BVPs).
- develop the ability to select appropriate finite difference methods for specific types of problems and effectively apply them to real world applications.

Syllabus

Unit – 1 **(11 hours)**

Initial value problems: Existence and uniqueness of solution, Finite difference equation, Truncation error, Single step methods for first order IVPs and system of IVPs- Family of explicit and implicit Runge–Kutta methods, Taylor series methods, Derivation, Truncation error, Consistency, Stability and convergence analysis.

Unit – 2 **(12 hours)**

IVPs for the system of ODEs, Consistency, Zero stability and convergence of linear multistep methods, Routh–Hurwitz criterion, Order and error constant, First Dahlquist Barrier, Local truncation error and global truncation error, Error bounds, Local error, Linear stability theory, Higher order differential equations.

Unit – 3 **(12 hours)**

Derivation of explicit and implicit multistep methods for IVPs and system of IVPs, Truncation error, Stability and convergence analysis of family of Nystrom method, Adams–Bashforth method,

Adams–Moulton method, Milne–Simpson method, Predictor corrector method, and Modified predictor corrector method, Hybrid method, Multistep methods for second order IVPs.

Unit – 4 **(10 hours)**

Linear BVPs for second order ordinary differential equations, Shooting method, Finite difference method, Collocation method, Derivative boundary conditions, Nonlinear two-point BVPs, Higher order finite difference methods, Stability, Truncation error and convergence analysis.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. K. Jain, S. R. K. Iyenger and R. K. Jain, *Numerical Methods for Scientific and Engineering Computations*, Seventh Edition, New Age International Publisher, 2019.

[2] J. D. Lambert, *Numerical Methods for Ordinary Differential Systems: The Initial Value Problem*, John Wiley & Sons, 1991.

Suggested Readings

(i) K. E. Atkinson, W. Han and D. E. Stewart, *Numerical Solution of Ordinary Differential Equations*, John Wiley & Sons, 2009.

(ii) J. C. Butcher, *The Numerical Analysis of Ordinary Differential Equations*, Second Edition, Wiley, New York, 2008.

(iii) L. Collatz, *The Numerical Treatment of Differential Equations*, Springer-Verlag, 1966.

Syllabi of Courses in Semester-IV of M.Sc. Mathematics under Structure-1 (Only Course work)

Discipline Specific Core (DSC) Courses

DISCIPLINE SPECIFIC CORE – 9: PARTIAL DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC-9: Partial Differential Equations	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Multivariate Calculus and Differential Equations

Learning Objectives

The main objective of this course is to introduce:

- well-posedness, fundamental solutions, existence and uniqueness of solutions for Laplace equation, Poisson equation and heat equation.
- solution for wave equation by spherical means.
- characteristics, complete integrals, envelopes and conservation laws for first-order nonlinear partial differential equations.
- classical solution techniques such as Green's function, similarity solutions and transform methods.

Learning Outcomes

This course will enable the students to:

- understand Laplace equation, Poisson equation, and Heat equation, their fundamental solutions, uniqueness principles, mean value properties, and Green's function.
- apply the method of spherical means to solve homogeneous and nonhomogeneous wave equations.
- use characteristics to solve nonlinear partial differential equations, construct complete integrals and envelopes, and understand conservation laws.
- implement various techniques such as similarity solutions and transform methods to derive solutions of different types of partial differential equations.

Syllabus

Unit – 1 **(12 hours)**

Well-posed problems, Classical solution, Laplace equation, Poisson equation, Fundamental solution, Strong maximum principle and uniqueness of solution, Mean value formulas, Representation formula, Green's function, Poisson's formula.

Unit – 2 **(10 hours)**

Heat equation, Fundamental solution for homogeneous and nonhomogeneous initial-value problems, Mean value formula, Strong maximum principle and uniqueness of solution, Local estimates for the solution.

Unit – 3 **(13 hours)**

Wave equation: Solution of homogeneous and nonhomogeneous problems by spherical means,

Nonlinear first order partial differential equations: Complete integrals and envelopes, Characteristics, Introduction to conservation laws.

Unit – 4 **(10 hours)**

Other solution methods: Similarity solutions, Fourier transform and Laplace transform, Cole–Hopf transformation, Potential function, Hodograph and Legendre transform.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] L. C. Evans, *Partial Differential Equations*, American Mathematical Society, Providence, RI, 1998.
[2] F. John, *Partial Differential Equations*, Fourth Edition, Springer-Verlag, New York, 1982.

Suggested Readings

(i) P. R. Garabedian, *Partial Differential Equations*, John Wiley & Sons, Inc., New York- London-Sydney, 1964.
(ii) A. K. Nandakumaran and P. S. Datti, *Partial Differential Equations: Classical Theory with a Modern Touch*, Cambridge University Press, 2020.

DISCIPLINE SPECIFIC CORE – 10: ANALYSIS OF SEVERAL VARIABLES

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC-10: Analysis of Several Variables	**4**	**3**	**1**	**0**	**Same as for entry to M.Sc. Mathematics**	**Basics of Calculus, Real Analysis including Riemann Integration**

Learning Objectives

The primary objective of this course is to:

- introduce differentiation of vector valued functions on $\mathbb{R}^n$ and their properties.
- familiarize students with integration of functions over rectangles and bounded sets in $\mathbb{R}^n$.
- extend integration of functions to unbounded sets in $\mathbb{R}^n$.
- study change of variables and its applications.

Learning Outcomes

This course will enable the students to:

- check differentiability of vector valued functions on $\mathbb{R}^n$, understand the relation between directional derivative and differentiability, apply chain rule, mean value theorems, inverse and implicit function theorems.
- understand higher order derivatives and be able to apply Taylor's formulas with integral remainder, Lagrange's remainder and Peano's remainder.
- master the concepts of integration over rectangles and bounded sets in $\mathbb{R}^n$.
- generalize the integration theory to unbounded sets in $\mathbb{R}^n$.
- grasp the effect of change of variables in integration.

Syllabus

Unit– 1 **(12 hours)**

The differentiability of functions from $\mathbb{R}^n$ to $\mathbb{R}^m$, Partial derivatives and differentiability, Directional derivatives and differentiability, Chain rule, Mean value theorems, Inverse function theorem and Implicit function theorem.

Unit– 2 **(11 hours)**

Derivatives of higher order, Taylor's formulas with integral remainder, Lagrange's remainder and Peano's remainder, Integral over a rectangle, Existence of the integral.

Unit– 3 **(10 hours)**

Evaluation of the integral, Fubini's theorem, Integral over a bounded set.

Unit– 4 **(12 hours)**

Rectifiable sets, Improper integrals**,** Change of variable theorem, Applications of change of variables.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. Giaquinta and G. Modica, *Mathematical Analysis: An Introduction to Functions of Several Variables*, Birkhäuser, 2009.
[2] J. R. Munkres, *Analysis on Manifolds*, CRC Press, Taylor & Francis, 2018.

Suggested Readings

(i) W. Rudin, *Principles of Mathematical Analysis*, Third Edition, Mc Graw Hill, 1986.
(ii) M. Spivak, *Calculus on Manifolds: A Modern Approach to Classical Theorems of Advanced Calculus*, Taylor & Francis, 2018.

Discipline Specific Elective (DSE) Courses

DISCIPLINE SPECIFIC ELECTIVE – 8 (i): ADVANCED FLUID DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-8 (i): Advanced Fluid Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Calculus and Partial Differential Equations

Learning Objectives

The primary objective of this course is to:

- prepare a foundation for advanced studies in compressible flow, boundary layer theory and magnetohydrodynamics.
- develop concepts, models, and techniques that enable problem-solving in compressible flow, boundary layer theory and magnetohydrodynamics.
- equip students with concepts and techniques to conduct research in the above mentioned domains.

Learning Outcomes

This course will enable the students to:

- learn conservation laws, first and second laws of thermodynamics, internal energy and entropy, different forms of energy equations and dimensional analysis.
- know about compressibility in real fluids, wave motion, sound waves, hyperbolic and dispersive waves, shock waves, their formation, properties and elementary analysis.
- know the concepts of boundary layer, boundary layer equations and their solutions, measurements of boundary layer thickness.
- understand the interaction between hydrodynamic processes and electromagnetic phenomena.
- formulate the basic equations of motion in inviscid and viscous conducting fluid flow and explain Alfven's theorem and magnetohydrodynamic (MHD) waves and MHD shocks.

Syllabus

Unit – 1 **(11 hours)**

Flow characteristics, Conservation laws, Equation of state of a substance, First and second law of thermodynamics, Internal energy and entropy, Energy equation, Nondimensionalizing the basic equations of incompressible viscous fluid flow, Nondimensional numbers.

Unit – 2 **(12 hours)**

Compressibility effects in real fluids, Equations of motion, Sound wave, Hyperbolic and dispersive waves, Isentropic gas flow, Flow through a nozzle, Method of characteristics, Shock jump conditions, Non-linear plane waves, Shock waves and their elementary analysis, Similarity solutions.

Unit – 3 **(11 hours)**

Boundary layer concept, Estimation of boundary layer thickness and friction forces, Prandtl's boundary layer equations, Boundary layer along a flat plate, Boundary layer thickness, General properties of the boundary layer equations, Similar solutions, Momentum and energy integral equations for the boundary layer.

Unit – 4 **(11 hours)**

Maxwell's electromagnetic field equations, Magnetohydrodynamic (MHD) approximations, Magnetic field equation, Magnetic Reynolds number, Magnetic body force, Equations of Motions of conducting fluid, Alfven's theorem, MHD waves, MHD shock waves.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] F. Chorlton, *Text Book of Fluid Dynamics*, CBS Publisher, 2005.
[2] H. Schlichting and K. Gersten, *Boundary Layer Theory*, Ninth Edition, Springer, 2017.
[3] G. B. Witham, *Linear and Nonlinear Waves*, John Wiley & Sons, 1999.

Suggested Readings

(i) K. R. Cramer and S. I. Pai, *Magnetofluid Dynamics for Engineers and Applied Physics*, McGraw Hill Book Co., New York, 1973.
(ii) Y. Shao-Wen, *Foundations of Fluid Mechanics*, PHI, New Delhi, 1960.

DISCIPLINE SPECIFIC ELECTIVE – 8 (ii): PROBABILITY THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-8 (ii): Probability Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Measure Theory

Learning Objectives

The primary objective of this course is to introduce:

- probability space as a measure space and random variables as measurable functions.
- expectation and moments of random variables.
- notion of convergence in probability.
- conditioning on sub-σ-algebra.

Learning Outcomes

This course will enable the students to learn:

- about probability or uncertainty in abstract setting.
- moments and expectation of random variables which help to understand applications of probability in industry.
- how to apply the idea of convergence in probability.
- weak law and strong law of large numbers and their applications.

Syllabus

Unit – 1 **(11 hours)**

Probability: σ-algebra, Constructing probability triples, The extension theorem, Random variables, Independence of events, Continuity of probabilities, Limit events, The Borel–Cantelli lemma.

Unit – 2 **(10 hours)**

Expected values: Simple, general non-negative and arbitrary random variables, Moment generating functions, Markov's inequality, Chebyshev's inequality.

Unit – 3 **(12 hours)**

Convergence of random variables: Convergence almost surely, Convergence in probability, Weak law of large numbers, Strong law of large numbers.

Unit – 4 **(12 hours)**

Distributions of random variables: Examples of distributions, Characteristic functions, The central limit theorem, Conditional probability, Conditioning on random variable, Conditioning on a sub-σ-algebra, Conditional variance.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. S. Rosenthal, *A First Look at Rigorous Probability Theory*, Second Edition, World Scientific, Singapore, 2006.

Suggested Readings

(i) W. Feller, *An Introduction to Probability Theory and its Applications*, Volume 1, Third Edition, Wiley, 2008.
(ii) J. E. Michael and J. S. Rosenthal, *Probability and Statistics: The Science of Uncertainty*, Second Edition, W. H. Freeman & Co Ltd., 2009.
(iii) S. Ross, *A First Course in Probability*, Tenth Edition, Pearson Education, 2022.
(iv) D. W. Stroock, *Probability Theory, An Analytic View*, Cambridge University Press, 2024.

DISCIPLINE SPECIFIC ELECTIVE – 8 (iii): SIMPLICIAL HOMOLOGY THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-8 (iii): Simplicial Homology Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- introduce the foundations of simplicial complexes and homology theory.
- develop an understanding of chain mappings and induced homomorphisms.
- apply these concepts to establish fundamental results in topology such as Euler–Poincaré theorem, Brouwer's and Lefschetz fixed-point theorems.

Learning Outcomes

This course will enable the students to:

- identify hyperplanes, simplexes and finite simplicial complexes as subsets of a Euclidean space.
- learn the idea of compact triangulable spaces as geometric carriers of finite simplicial complexes (polyhedra).
- learn the use of homological algebra to associate simplicial homology groups and illustrate it by computing simplicial homology groups of some well-known compact polyhedral.
- prove important applications of simplicial homology theory like invariance of dimension, Euler's formula, Lefschetz and Brouwer's fixed point theorems.

Syllabus

Unit – 1 **(11 hours)**

Geometric simplexes, Geometric complexes and polyhedra, Simplicial maps, Simplicial approximation of continuous maps between two polyhedral.

Unit – 2 **(12 hours)**

Orientation of geometric complexes, Chain complexes, Simplicial homology groups, Structure of homology groups, Relative homology groups, Computation of homology groups, Homology groups of n-sphere.

Unit – 3 **(12 hours)**

Chain mappings, Chain derivation, Chain homotopy, Contiguous maps, Homomorphism induced by continuous maps between two polyhedra, Functorial property of induced homomorphisms, Topological and homotopy invariance of homology groups.

Unit – 4 **(10 hours)**

Euler–Poincaré theorem and Euler's formula, Invariance of dimension, Brouwer's fixed point theorem, Degree of self-mappings of $\mathbb{S}^n$, Brouwer's degree theorem, Existence of eigen values, Lefschetz fixed point theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] F. H. Croom, *Basic Concepts of Algebraic Topology*, Springer, 1978.

Suggested Readings

(i) M. K. Agoston, *Algebraic Topology: A First Course*, Marcel Dekker, 1976.
(ii) M. A. Armstrong, *Basic Topology*, Springer, 1983.
(iii) S. Deo, *Algebraic Topology - A Primer*, Second Edition, Hindustan Book Agency, 2018.

DISCIPLINE SPECIFIC ELECTIVE – 8 (iv): THEORY OF UNBOUNDED OPERATORS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-8 (iv): Theory of Unbounded Operators	**4**	**3**	**1**	**0**	**Same as for entry to M.Sc. Mathematics**	**Basics of Functional Analysis and Bounded Operators**

Learning Objectives

The primary objective of this course is to:

- introduce the notion of unbounded operators.
- develop the theory of operator semigroups and understand their role in applications, particularly for solving differential equations.

Learning Outcomes

This course will enable the students to:

- identify closed and closable linear operators on Banach spaces.
- compute adjoints of unbounded linear operators.
- understand spectral properties of some unbounded operators.
- comprehend the role unbounded operators and semigroups play in applications, particularly in studying solutions of differential equations.

Syllabus

Unit – 1 **(10 hours)**

Unbounded linear operators, Hilbert adjoints, Hellinger–Toeplitz theorem, Hermitian, symmetric and self-adjoint linear operators, Closed linear operators, Closable operators and their closures on Banach spaces.

Unit – 2 **(12 hours)**

Cayley transform, Deficiency indices, Spectral properties of self-adjoint operators, Multiplication and differentiation operators and their spectra.

Unit – 3 **(11 hours)**

Analytic properties of exponential functions, Matrix Semigroups, Uniformly continuous semigroups, Semigroups on Hilbert spaces, Strongly continuous semigroups.

Unit – 4 **(12 hours)**

Generators of semigroups and their resolvents, Hille–Yosida theorem (for contraction semigroup), Dissipative operators and their properties, Lumer–Phillips theorem, Generators of Group, Stone's theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] K. J. Engle and R. Nagel, *One-parameter Semigroups for Linear Evolution Equations*, Springer-Verlag, New York, 2000.
[2] E. Kreyszig*, Introductory Functional Analysis with Applications*, John Wiley & Sons, 2006.

Suggested Readings

(i) S. Goldberg, *Unbounded Linear Operators: Theory and Applications*, Dover Publications, 2006.
(ii) E. Hille and R. S. Phillips, *Functional Analysis and Semi-groups*. American Mathematical Society, Providence, RI, 1957.
(iii) A. Pazy*, Semigroups of Linear Operators and Applications to Partial Differential Equations*, Springer, 1983.
(iv) M. Schechter, *Principles of Functional Analysis*, Second Edition, American Mathematical Society, 2001.
(v) J. Weidmann, *Linear Operators in Hilbert Spaces, Graduate Texts in Mathematics*, Springer, New York, 1980.

DISCIPLINE SPECIFIC ELECTIVE – 9 (i): BANACH AND C*-ALGEBRAS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-9 (i): Banach and C*-Algebras	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis and Topology

Learning Objectives

The primary objective of this course is to introduce:

- Banach algebras and C*-algebras.
- various ways to construct new operator algebras using given ones.
- spectrum of elements in Banach algebras and to study its properties.
- Gelfand representations of commutative Banach algebras and of C*-algebras.

Learning Outcomes

This course will enable the students to:

- familiarize with the representations of operator algebras.
- realize commutative Banach algebras and abelian C*-algebras as space of continuous functions on locally compact groups.
- understand the powerful tool of functional calculus.
- identify any C*-algebra as closed *-subalgebra of space of bounded linear operators on a Hilbert space.

Syllabus

Unit – 1 **(11 hours)**

Elementary properties and examples of Banach algebras, Ideals and quotients, Invertible elements, Spectrum and spectral radius, Spectral radius formula, Spectral mapping theorem (for polynomials), Gelfand–Mazur theorem.

Unit – 2 **(11 hours)**

Multiplicative linear functionals, Commutative Banach algebra, w*-topology, Gelfand transform of an element, Structure space, Gelfand representation.

Unit – 3 **(12 hours)**

Elementary properties and examples of C*-algebras, Unitization, Gelfand–Naimark representation of commutative C*-algebras, Continuous functional calculus, Spectral mapping theorem for normal elements, Positive elements of C*-algebras.

Unit – 4 **(11 hours)**

Ideals in C*-algebras, Approximate units, Quotients, Positive linear functionals, Gelfand–Naimark–Segal representation of C*-algebras.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.
[2] G. J. Murphy, *C*-algebras and Operator Theory*, Academic Press Inc., 1990.

Suggested Readings

(i) J. B. Conway, *A Course in Operator Theory, Graduate Texts in Mathematics*, Springer, 2007.
(ii) J. Dixmier, *C*-algebras*, North-Holland Publishing Company, 1977.
(iii) R. G. Douglas, *Banach Algebra Techniques in Operator Theory, Graduate Texts in Mathematics*, Springer, 1998.
(iv) E. Kaniuth, *A Course on Commutative Banach Algebras*, Graduate Texts in Mathematics, Springer, 2009.
(v) S. Kantorovitz, *Introduction to Modern Analysis*, Oxford Graduate Texts in Mathematics, Oxford University Press, 2006.
(vi) M. Takesaki, *Theory of Operator Algebras I*, Springer, 2002.

DISCIPLINE SPECIFIC ELECTIVE – 9 (ii): CHAOS THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-9 (ii): Chaos Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- introduce some useful and interesting notions like Topological Transitivity and Sensitive dependence on initial conditions.
- study different types of chaos including Devaney's chaos and finding their interrelationships.
- know classical result that period three implies chaos on intervals.
- relate chaos and decomposition theorems.
- study Topological entropy through open covers and also Bowen's definition of entropy, equivalence of these two definitions on compact metric spaces.
- study various interesting results related to topological entropy.

Learning Outcomes

This course will enable the students to:

- construct interesting examples of Topological transitive maps, Topological mixing maps etc.
- know classical examples of Devaney's chaotic maps like tent map, shift maps, logistic maps.
- study and compare different types of chaos.
- find relation between transitivity and chaos on intervals.
- relate chaos theory and classical decomposition theorems.
- study very useful notion of Topological entropy including its properties.
- calculate entropy of any homeomorphism of closed unit interval and of unit circle.

Syllabus

Unit – 1 **(12 hours)**

Topological Transitivity, Locally eventually onto maps, Topological mixing, Sensitive dependence on initial conditions, Devaney's definition of chaos, Transitivity and limit sets for continuous interval maps.

Unit – 2 **(11 hours)**

Characterizing topological mixing in terms of topological transitivity for continuous interval maps, Topological Weakly Mixing, Totally Transitive maps, Relation between transitivity and chaos on intervals, Logistic maps and shift maps as chaotic maps.

Unit – 3 **(12 hours)**

Various other definitions of chaos and their interrelationships. Period three implies chaos, Chaos and decomposition theorems including Bowen's decomposition theorem, Topological Entropy:

Definition using open covers, Examples and properties, Bowen's definition of topological entropy, Equivalence of two definitions, Topological version of Kolmogorov–Sinai theorem.

Unit – 4 **(10 hours)**

Topological Entropy of maps on a compact metric space, Topological Entropy of product maps, of iterations of a map, Topological entropy of an expansive homeomorphism on a compact metric space, of the two-sided shift, of any homeomorphism of the unit interval and of the unit circle.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] N. Aoki and K. Hiraide, *Topological Theory of Dynamical Systems: Recent Advances*, North Holland Publications, 1994.
[2] R. L. Devaney, *A First Course in Chaotic Dynamical Systems*, CRC Press, 2018.
[3] S. Ruette, *Chaos for Continuous Interval Maps: A Survey of Relationship Between Various Kinds of Chaos*, 2018.
[4] Peter Walters, *An Introduction to Ergodic Theory*, Springer, 2000.

Suggested Readings

(i) L. Alsedà, J. Llibre and M. Misiurewicz, *Combinatorial Dynamics and Entropy in Dimension One*, Advanced Series in Nonlinear Dynamics, World Scientific, 2000.
(ii) L. S. Block and W. A. Coppel, *Dynamics in One Dimension*, Springer, 2014.
(iii) M. Brin and G. Stuck, *Introduction to Dynamical Systems*, Cambridge University Press, 2015.

DISCIPLINE SPECIFIC ELECTIVE – 9 (iii): CHARACTER THEORY OF FINITE GROUPS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-9 (iii): Character Theory of Finite Groups	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra and Group Theory

Learning Objectives

The primary objective of this course is to:

- introduce characters of finite groups, class functions, and find the number of irreducible characters.
- find character tables of S_5, using characters of tensor products of CG-modules and powers of characters.
- define restricted characters and prove Clifford's theorem and its application to find the character table of A_5.
- explore some arithmetic properties of character values and introduce real characters.

Learning Outcomes

This course will enable the students to:

- define and construct examples of characters, prove some fundamental properties of characters, and calculate character tables of some small groups and symmetric groups, etc.
- construct new characters from given characters and understand the notion of induced and restricted characters.
- prove the Frobenius reciprocity theorem and the Frobenius–Schur count of involutions.

Syllabus

Unit – 1 **(10 hours)**

Group characters and their properties, Inner product of characters, Class functions and number of irreducible characters, Character tables and some orthogonality relations, Normal subgroups and lifted characters, Linear characters, Character tables of D_6, S_4, A_4.

Unit – 2 **(11 hours)**

Character of tensor products of CG-modules, Powers of characters, Decomposition of power of a character, Character table of symmetric group S_5, Character table of direct product of groups, Restricted characters, Constituents of a restricted character, Clifford's theorem, Restriction of symmetric groups to alternate groups in general normal subgroups of index two, Character table of A_5.

Unit – 3 **(12 hours)**

Induced CG-modules and their characters: Homomorphisms, Transitivity of induction, Frobenius reciprocity theorem, Values of induced characters. Algebraic integers, Some properties of degrees of irreducible characters and arithmetic properties of character values.

Unit – 4 **(12 hours)**

Real representations, Real conjugacy classes and real characters, Characters which can be realized over the reals, RG-modules and CG-modules, G-invariant symmetric bilinear form, Indicator function, The Frobenius–Schur count of involutions**.**

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. James and M. Liebeck, *Representations and Characters of Groups*, Second Edition, Cambridge University Press, 2005.

Suggested Readings

(i) I. M. Issacs, *Character Theory of Finite Groups*, American Mathematical Society reprint, 2006.
(ii) W. Ledermann, *Introduction to Group Characters*, Second Edition, Cambridge University Press, 1987.

DISCIPLINE SPECIFIC ELECTIVE – 9 (iv): NONSMOOTH OPTIMIZATION

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-9 (iv): Nonsmooth Optimization	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Nonlinear Optimization

Learning Objectives

The primary objective of this course is to:

- understand the tools to deal with nonsmooth convex functions.
- study conjugate duality in terms of conjugate functions for constrained nonlinear optimization problems.
- introduce numerical techniques to solve constrained nonlinear optimization problems.

Learning Outcomes

This course will enable the students to learn:

- the notions of subgradients and subdifferentials for nonsmooth convex functions.
- the use of conjugate functions to develop the theory of conjugate duality.
- about numerical methods like gradient descent method, gradient projection method, Newton's method and conjugate gradient method.
- penalty approach technique to solve constrained nonlinear optimization problems.

Syllabus

Unit – 1 **(11 hours)**

Extended real valued functions, Proper convex functions, Closure of convex functions, Differential derivatives, Subgradients and subdifferentials.

Unit – 2 **(12 hours)**

Conjugate functions, Biconjugate functions, Perturbation functions, Closure of convex functions, Directional derivatives, Subgradients and subdifferentials.

Unit – 3 **(12 hours)**

Gradient descent method, Gradient projection method, Newton's method, Conjugate gradient method.

Unit – 4 **(10 hours)**

Penalty function methods, Exterior penalty function, Interior penalty functions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. Avriel, *Nonlinear Programming: Analysis and Methods*, Dover Publications, 2003.

[2] O. Güler, *Foundations of Optimization*, Springer, 2010.

Suggested Readings

(i) A. Bagirov, N. Karitsa and M. M. Makela, *Introduction to Nonsmooth Optimization: Theory, Practice and Software*, Springer, 2014.
(ii) M. S. Bazaraa, H. D. Sherali and C. M. Shetty, *Nonlinear Programming: Theory and Algorithms,* Third Edition, John Wiley & Sons, 2013.
(iii) D. G. Luenberger and Y. Ye, *Linear and Nonlinear Programming*, Springer, 2008.

DISCIPLINE SPECIFIC ELECTIVE – 10 (i): COMPUTATIONAL FLUID DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-10 (i): Computational Fluid Dynamics	**4**	**3**	**1**	**0**	**Same as for entry to M.Sc. Mathematics**	**Basics of Partial Differential Equation (Undergraduate level)**

Learning Objectives

The primary objective of this course is to teach:

- various numerical schemes on finite difference and finite volume methods for solving PDEs.
- discretization errors and grid dependence.
- some real-world applications of PDEs and fluid dynamics.
- discretization of governing equations of diffusion, convection-diffusion, fluid flow and thereby computing the numerical solutions using the flow variables using algorithms.

Learning Outcomes

This course will enable the students to learn:

- techniques for solving the PDEs along with some initial and boundary conditions by using the finite difference and finite volume methods.
- the basic conservation principles of mass, momentum, energy, discretization of governing equations.
- discretization techniques.
- some popular algorithms like SIMPLE and SIMPLER used to obtain the solutions of steady and unsteady flow problems by finite volume methods.

Syllabus

Unit – 1 **(12 hours)**

Basics of discretization using finite differences, Various single and multi-step explicit and implicit finite difference schemes for 1-D and 2-D parabolic and hyperbolic initial boundary value problems, Alternating Direction Implicit schemes (ADI) for 2-D parabolic and hyperbolic equations, Order of accuracy, Consistency, Stability and convergence of a finite difference scheme, Courant Friedrich Lewy condition.

Unit – 2 **(12 hours)**

Finite difference schemes for second and fourth order 2-D elliptic boundary value problem and applications, Finite volume method for diffusion and convection-diffusion equations, Discretization of one and two-dimensional steady state diffusion and convection-diffusion equations, Central difference, Upwind, Exponential, Hybrid, Power-law and QUICK schemes and their properties.

Unit – 3 **(11 hours)**

Flow field calculation, Pressure-velocity coupling, Vorticity-stream function approach, Primitive variables, Staggered grid, Pressure and velocity corrections, Pressure correction equation, SIMPLE and SIMPLER algorithms.

Unit – 4 **(10 hours)**

Finite volume methods for unsteady flows, Discretization of one-dimensional transient heat conduction, Explicit, fully implicit and Crank–Nicolson schemes, Implementation of boundary conditions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. C. Strikweda, *Finite Difference Schemes and Partial Differential Equations*, Second Edition, SIAM, 2004.

[2] H. K. Versteeg and W. Malalasekera, *An Introduction to Computational Fluid Dynamics: The Finite Volume Method*, Second Edition, Pearson, 2008.

Suggested Readings

(i) J. D. Anderson, *Computational Fluid Dynamics*, McGraw-Hill, 1995.

(ii) S. V. Patankar, *Numerical Heat Transfer and Fluid Flow*, CRC Press, Taylor and Francis, Indian Edition, 2017.

(iii) R. H. Pletcher, J. C. Tannehill and D. A. Anderson, *Computational Fluid Mechanics and Heat Transfer*, CRC Press, Taylor and Francis, 2013.

(iv) J. W. Thomas, *Numerical Partial Differential Equations: Finite Difference Methods*, Springer, 2013.

DISCIPLINE SPECIFIC ELECTIVE – 10 (ii): DIFFERENTIAL TOPOLOGY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-10 (ii): Differential Topology	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- introduce the concepts of topological manifolds, smooth structures, smooth manifolds, and manifolds with boundary.
- develop an understanding of smooth functions, smooth maps, diffeomorphisms, and tangent spaces.
- explain the Inverse function theorem, immersions and submersions.
- develop the fundamental concepts of 2-manifolds and distinguish between orientable and non-orientable surfaces.
- explore the properties of compact and connected surfaces.

Learning Outcomes

This course will enable the students to:

- identify and construct examples of topological manifolds, smooth structures and manifolds with and without boundary.
- demonstrate understanding of diffeomorphisms and tangent spaces.
- apply the Inverse function theorem, immersions and submersions.
- define key concepts such as 2-manifolds, orientability, compactness, connectedness and boundary of a surface.
- differentiate between orientable and non-orientable surfaces using examples such as the sphere, torus, Möbius strip and Klein bottle.

Syllabus

Unit – 1 **(12 hours)**

Topological manifolds, Topological properties of manifolds, Smooth structures, Examples of smooth manifolds, Manifolds with boundary.

Unit – 2 **(11 hours)**

Smooth functions and smooth maps, Lie groups, Diffeomorphisms.

Unit – 3 **(10 hours)**

Derivatives and tangents, Inverse function theorem, Immersions and submersions.

Unit – 4 **(12 hours)**

Complexes, Connected sum of two surfaces, Non-orientable surfaces (2- Manifolds), Compact and connected surfaces, Classification of compact and connected surfaces with and without boundary.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] V. Guillemin and Alan Pollack, *Differential Topology*, Prentice-Hall, 1974.
[2] L. C. Kinsey, *Topology of Surfaces*, Springer Verlag, 1997.
[3] J. M. Lee, *Introduction to Smooth Manifolds*, Second Edition, Springer, 2013.

Suggested Readings

(i) L. Conlon, *Differentiable Manifolds*, Second Edition, Birkhäuser Advanced Texts, 2001.
(ii) M. Spivak, *A Comprehensive Introduction to Differential Geometry*, Volume 1, Third Edition, Publish or Perish, Huston, Texas, 1999.
(iii) L. W. Tu, *Introduction to Manifolds*, Second Edition, Springer, 2011.
(iv) F. W. Warner, *Foundations of Differentiable Manifolds and Lie Group*, Springer-Verlag, 1983.

DISCIPLINE SPECIFIC ELECTIVE – 10 (iii): GENERAL MEASURE THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-10 (iii): General Measure Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Measure Theory and Topology

Learning Objectives

The primary objective of this course is to introduce:

- real valued and complex valued measures.
- decomposition of measure spaces and of measures.
- extension of a premeasure to a measure, Lebesgue measure on Euclidean spaces.
- representation of measures and functionals in terms of integrals.
- product measures.

Learning Outcomes

This course will enable the students to:

- appreciate signed measures and complex measures, mutual singularity of measures, Hahn and Jordan decompositions, Lebesgue decomposition, Radon–Nikodym theorem.
- verify conditions under which a set function defined on a collection of subsets of a set has an extension to a measure on a sigma-algebra.
- apply Riesz representation theorem for bounded linear functionals on L^p-spaces.
- understand product measure and the results of Fubini and Tonelli, and express the Lebesgue measure on Euclidean spaces as a product measure.
- apply Riesz–Markov representation theorem for the bounded linear functionals on the space of continuous functions.

Syllabus

Unit – 1 **(13 hours)**

Signed measures, Hahn and Jordan decompositions, Mutually singular measures, Radon–Nikodym theorem, Lebesgue decomposition, Complex measure.

Unit – 2 **(10 hours)**

The Carathéodory extension theorem, Lebesgue measure on $\mathbb{R}^n$, Regularity and translation invariance of Lebesgue measure on $\mathbb{R}^n$.

Unit – 3 **(10 hours)**

Riesz representation theorem for the dual of L^p-spaces, Product measures, Fubini's theorem, Tonelli's theorem.

Unit – 4 **(12 hours)**

Locally compact Hausdorff spaces and construction of Radon measure, Riesz–Markov

representation theorem for positive linear functionals on $C_c(X)$, Riesz representation theorem for the dual of $C(X)$.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] H. L. Royden and P. M. Fitzpatrick, *Real Analysis*, Fourth Edition, Pearson, 2015.
[2] M. E. Taylor, *Measure Theory and Integration*, American Mathematical Society, 2006.

Suggested Readings

(i) G. B. Folland, *Real Analysis: Modern Techniques and Their Applications*, Second Edition, Wiley, New York, 1999.
(ii) P. R. Halmos, *Measure Theory*, Springer Science + Business Media, LLC, 2014.
(iii) E. M. Stein and R. Shakarchi, *Real Analysis: Measure Theory, Integration and Hilbert Spaces*, New Age International Publishers, New Delhi, 2010.

DISCIPLINE SPECIFIC ELECTIVE – 10 (iv): THEORY OF NON-COMMUTATIVE RINGS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-10 (iv): Theory of Non-commutative Rings	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Groups and Rings

Learning Objectives

The primary objective of this course is to:

- give students an understanding of Wedderburn–Artin theory of semisimple rings.
- develop Jacobson's general theory of radicals, prime and semiprime rings, and primitive and semiprimitive rings.
- introduce the structure of primitive rings as a generalisation of the Wedderburn–Artin theorem on Artinian simple rings.

Learning Outcomes

This course will enable the students to:

- know about an extensive variety of rings, including free rings, Weyl algebra, Hilbert twist and triangular ring.
- understand the module theoretic definition of semisimple rings and how it leads to the Wedderburn–Artin structure theorem on their complete classification.
- know Jacobson's general theory of radicals, semiprime rings, prime, primitive and semiprimitive rings and their structures.
- understand the significance of the fundamental result 'Density Theorem' and its consequences on the structure of primitive rings.

Syllabus

Unit – 1 **(11 hours)**

Simple rings, Reduced rings, Dedekind-finite rings, Algebra, Quaternions, Free k-rings, Rings with generators and relations, Weyl algebra, Formal power series ring, Hilbert's twist ring, Differential polynomial rings, Derivation and inner derivation on a ring, Triangular rings, Characterization of one-sided and two-sided ideals in such rings.

Unit – 2 **(11 hours)**

Noetherian and Artinian rings, Examples of one-sided Noetherian and Artinian triangular rings, Twisted polynomial ring and Quotient of free $\mathbb{Z}$-ring, Semisimple rings, Structure of semisimple rings: Wedderburn–Artin's theorem.

Unit – 3 **(10 hours)**

Structure theorem of simple left Artinian rings, Jacobson radical, J-semisimple rings, Nil and nilpotent ideals, Connection between semisimple and J-semisimple rings, Hopkins–Levitzki theorem, Nakayama's lemma.

Unit – 4 **(13 hours)**

Prime radical, Characterisation of prime and semiprime ideals, Prime and semiprime rings, Structure theorem of primitive rings, Density theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] T.-Y. Lam, *A First Course in Noncommutative Rings*, Springer, 2001.

Suggested Readings

(i) I. N. Herstein, *Noncommutative Rings*, The Mathematical Association of America, 2005.
(ii) T. W. Hungerford, *Algebra*, Springer-Verlag, New York, 1981.
(iii) L. H. Rowen, *Ring Theory*, Student Edition, Academic Press, 1991.

Skill-Based Course (SBC)

WORKSHOPS AND SEMINARS ON ADVANCED TOPICS

Course Title	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Workshops and Seminars on Advanced Topics	2	0	0	2	Same as for entry to M.Sc. Mathematics	NIL

Learning Objectives

In this course, we aim to train students to

- understand and assimilate mathematical ideas and techniques presented and discussed in workshops and seminars on varied advanced topics in mathematics.
- communicate mathematical ideas succinctly.

Learning Outcomes

This course will enable students to

- efficiently identify the core ideas in any mathematical discourse, particularly outside the classroom setting.
- write a concise summary of these ideas.

Methodology

The students will attend a requisite number of workshops and seminars organized by the Department through the semester. The workshops and seminars will be on advanced topics, building on the classroom courses offered by the Department. The students will be expected to prepare and submit summaries of a few of these (as mandated by the Department) and also give presentations for assessment.

Generic Elective (GE) Courses

GENERIC ELECTIVE – 4 (i): NONSMOOTH OPTIMIZATION

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
GE-4 (i): Nonsmooth Optimization	4	3	1	0	Class XII pass with Mathematics	Basics of Nonlinear Optimization

Learning Objectives

The primary objective of this course is to:

- understand the tools to deal with nonsmooth convex functions.
- study conjugate duality in terms of conjugate functions for constrained nonlinear optimization problems.
- introduce numerical techniques to solve constrained nonlinear optimization problems.

Learning Outcomes

This course will enable the students to learn:

- the notions of subgradients and subdifferentials for nonsmooth convex functions.
- the use of conjugate functions to develop the theory of conjugate duality.
- about numerical methods like gradient descent method, gradient projection method, Newton's method and conjugate gradient method.
- penalty approach technique to solve constrained nonlinear optimization problems.

Syllabus

Unit – 1 **(11 hours)**

Extended real valued functions, Proper convex functions, Closure of convex functions, Differential derivatives, Subgradients and subdifferentials.

Unit – 2 **(12 hours)**

Conjugate functions, Biconjugate functions, Perturbation functions, Closure of convex functions, Directional derivatives, Subgradients and subdifferentials.

Unit – 3 **(12 hours)**

Gradient descent method, Gradient projection method, Newton's method, Conjugate gradient method.

Unit – 4 **(10 hours)**

Penalty function methods, Exterior penalty function, Interior penalty functions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. Avriel, *Nonlinear Programming: Analysis and Methods*, Dover Publications, 2003.
[2] O. Güler, *Foundations of Optimization*, Springer, 2010.

Suggested Readings

(i) A. Bagirov, N. Karitsa and M. M. Makela, *Introduction to Nonsmooth Optimization: Theory, Practice and Software*, Springer, 2014.
(ii) M. S. Bazaraa, H. D. Sherali and C. M. Shetty, *Nonlinear Programming: Theory and Algorithms,* Third Edition, John Wiley & Sons, 2013.
(iii) D. G. Luenberger and Y. Ye, *Linear and Nonlinear Programming*, Springer, 2008.

GENERIC ELECTIVE – 4 (ii): PROBABILITY THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
GE-4 (ii): Probability Theory	4	3	1	0	Class XII pass with Mathematics	Basics of Integration

Learning Objectives

The primary objective of this course is to introduce:

- probability space as a measure space and random variables as measurable functions.
- expectation and moments of random variables.
- notion of convergence in probability.
- conditioning on sub-σ-algebra.

Learning Outcomes

This course will enable the students to learn:

- about probability or uncertainty in abstract setting.
- moments and expectation of random variables which help to understand applications of probability in industry.
- how to apply the idea of convergence in probability.
- weak law and strong law of large numbers and their applications.

Syllabus

Unit – 1 **(11 hours)**

Probability: σ-algebra, Constructing probability triples, The extension theorem, Random variables, Independence of events, Continuity of probabilities, Limit events, The Borel–Cantelli lemma.

Unit – 2 **(10 hours)**

Expected values: Simple, general non-negative and arbitrary random variables, Moment generating functions, Markov's inequality, Chebyshev's inequality.

Unit – 3 **(12 hours)**

Convergence of random variables: Convergence almost surely, Convergence in probability, Weak law of large numbers, Strong law of large numbers.

Unit – 4 **(12 hours)**

Distributions of random variables: Examples of distributions, Characteristic functions, The central limit theorem, Conditional probability, Conditioning on random variable, Conditioning on a sub-σ-algebra, Conditional variance.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. S. Rosenthal, *A First Look at Rigorous Probability Theory*, Second Edition, World Scientific, Singapore, 2006.

Suggested Readings

(i) W. Feller, *An Introduction to Probability Theory and its Applications*, Volume 1, Third Edition, Wiley, 2008.
(ii) J. E. Michael and J. S. Rosenthal, *Probability and Statistics: The Science of Uncertainty*, Second Edition, W. H. Freeman & Co Ltd., 2009.
(iii) S. Ross, *A First Course in Probability*, Tenth Edition, Pearson Education, 2022.
(iv) D. W. Stroock, *Probability Theory, An Analytic View*, Cambridge University Press, 2024.

Syllabi of Courses in Semester-III of M.Sc. Mathematics under Structure-2 (Course work + Research)

Discipline Specific Core (DSC) Courses

DISCIPLINE SPECIFIC CORE – 7: FLUID DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC-7: Fluid Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Calculus and Partial Differential Equations

Learning Objectives

The objective of this course is to:

- prepare a mathematical foundation to study the motion of fluids.
- develop concepts, models, and techniques to solve problems of fluid flow.
- develop the ability to conduct advanced studies and research in the broad field of fluid dynamics.

Learning Outcomes

After studying this course, the student will be able to:

- understand the concept of fluids, their classification, flow lines, models and approaches to study fluid flow.
- formulate mass and momentum conservation principles and obtain their solution for non-viscous flow.
- know potential flow, Bernoulli's equation, Kelvin's minimum energy and circulation theorems.
- understand two- and three-dimensional motion, complex potential, circle theorem, Blasius theorem, Weiss's and Butler's sphere theorems.
- apply the concept of stress and strain in viscous flow to derive Navier–Stokes equation of motion and energy equation.

Syllabus

Unit – 1 **(10 hours)**

Classification of fluids, Continuum model, Eulerian and Lagrangian approach of description, Differentiation following the fluid motion, Flow lines, vorticity and circulation, Conservation of mass: Equation of continuity, Boundary surface.

Unit – 2 **(12 hours)**

Forces in fluid motion, Conservation of momentum: Euler's equation of motion, Theory of irrotational motion: Integration of Euler's equation under different conditions, Bernoulli's equation, Impulsive motion, Kelvin's minimum energy and circulation theorems, Potential theorem.

Unit – 3 **(13 hours)**

Two-dimensional motion: Complex potential, Line sources, sinks, doublets and vortices, Two-dimensional image system, Milne–Thomson circle theorem, Images with respect to a plane and cylinder, Blasius theorem. Three-dimensional flows, Weiss's sphere theorem, Images with respect to sphere, Axi-symmetric flow, Stokes stream function, Butler's sphere theorem, Flow past spheres and cylinders.

Unit – 4 **(10 hours)**

Stress and strain analysis, Newton's law of viscosity, Laminar flow, Navier–Stokes equation of motion, Steady flow between parallel planes and Poiseuille flow, Constitutive equation, Energy equation.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] F. Chorlton, *Text Book of Fluid Dynamics*, CBS Publisher, 2005.
[2] R. W. Fox, P. J. Pritchard and A. T. McDonald, *Introduction to Fluid Mechanics*, Seventh Edition, John Wiley & Sons, 2009.
[3] P. K. Kundu, I. M. Cohen and D. R. Dowling, *Fluid Mechanics*, Sixth Edition, Academic Press, 2016.

Suggested Readings

(i) L. M. Milne-Thomson, *Theoretical Hydrodynamics*, The Macmillan company, USA, 1969.
(ii) D. E. Rutherford, *Fluid Dynamics*, Oliver and Boyd Ltd., 1978.

DISCIPLINE SPECIFIC CORE – 8: MEASURE AND INTEGRATION

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC-8: Measure and Integration	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Real Analysis and Riemann Integration

Learning Objectives

The primary objective of this course is to:

- extend the notion of length of an interval with the introduction of the concept of Lebesgue outer measure for any subset of real line.
- investigate the properties of Lebesgue measurable sets and functions.
- familiarize students with the Lebesgue integration of functions and its comparison with Riemann integration.
- generalize the concepts of measure and integration to an abstract space.

Learning Outcomes

This course will enable the students to:

- verify whether a given subset of $\mathbb{R}$ or a real valued function is measurable.
- understand the requirement and the concept of the Lebesgue integral (a generalization of the Riemann integration) along with its properties.
- understand the statements and proofs of the fundamental integral convergence theorems and demonstrate their applications.
- carry out a comprehensive study of functions of bounded variation and their utility in understanding differentiation and integration.
- apply Hölder and Minkowski inequalities in L^p-spaces and understand completeness of L^p-spaces.

Syllabus

Unit – 1 **(14 hours)**

Lebesgue outer measure, Measurable sets, Lebesgue measure, Borel sets, Regularity, Measurable functions, Borel and Lebesgue measurability, Non-measurable sets.

Unit – 2 **(13 hours)**

Integration of nonnegative functions, General integral, Integration of series, Riemann and Lebesgue integrals.

Unit – 3 **(8 hours)**

Functions of bounded variation, Lebesgue's differentiation theorem, Differentiation and integration, Absolute continuity of functions.

Unit – 4 **(10 hours)**

Measures and outer measures, Measure spaces, Integration with respect to a measure, L^p-spaces, Hölder's and Minkowski's inequalities, Completeness of L^p-spaces.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. de Barra, *Measure Theory and Integration*, Ellis Horwood Ltd., Chichester, John Wiley & Sons, Inc., New York, 1981 (Indian Reprint, 2014).

Suggested Readings

(i) M. Capinski and P. E. Kopp, *Measure, Integral and Probability*, Springer, 2005.
(ii) E. Hewitt and K. Stromberg, *Real and Abstract Analysis: A Modern Treatment of the Theory of Functions of a Real Variable*, Springer, Berlin, 1975.
(iii) H. L. Royden and P.M. Fitzpatrick, *Real Analysis*, Fourth Edition, Pearson, 2015.

Discipline Specific Elective (DSE) Courses

DSE-5 and DSE-6

Group-1

DISCIPLINE SPECIFIC ELECTIVE: ALGEBRAIC TOPOLOGY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Algebraic Topology	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- understand the concepts of homotopic maps, homotopy type, retracts, and deformation retracts, and their role in algebraic topology.
- compute fundamental groups of basic topological spaces.
- acquire knowledge of covering projections, lifting properties, Borsuk–Ulam theorem, and classification techniques of covering spaces.
- learn free groups and free products to understand and apply the Seifert–Van Kampen theorem.

Learning Outcomes

This course will enable the students to:

- distinguish between spaces with the same homotopy type.
- compute fundamental groups of standard spaces such as n-sphere $\mathbb{S}^n$ and punctured planes.
- apply the concept of fundamental groups to prove Brouwer's fixed-point theorem and the Fundamental theorem of Algebra.
- explain the lifting theorems and their implications in topology.
- classify covering spaces for given base spaces.
- apply Seifert–Van Kampen theorem to compute fundamental groups of glued spaces.

Syllabus

Unit – 1 **(11 hours)**

Homotopic maps, Homotopy type, Retract and deformation retract.

Unit – 2 **(12 hours)**

Fundamental group, Calculation of fundamental groups of n-sphere $\mathbb{S}^n$ and punctured plane, Brouwer's fixed-point theorem, Fundamental theorem of Algebra.

Unit – 3 **(12 hours)**

Covering projections, Lifting theorems, Borsuk–Ulam theorem, Classification of covering spaces.

Unit – 4 **(10 hours)**

Free products, Free groups, Seifert–Van Kampen theorem and its applications.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. R. Munkres, *Elements of Algebraic Topology*, Addison-Wesley Publishing Company, 1984.
[2] T. B. Singh, *Introduction to Topology*, Springer Nature Singapore, 2019.

Suggested Readings

(i) G. E. Bredon, *Geometry and Topology*, Springer, 2014.
(ii) A. Hatcher, *Algebraic Topology*, Cambridge University Press, 2002.
(iii) W. S. Massey, *A Basic Course in Algebraic Topology*, World Publishing Corporation, 2009.
(iv) J. J. Rotman, *An Introduction to Algebraic Topology*, Springer, 2011.
(v) E. H. Spanier, *Algebraic Topology*, Springer-Verlag, 1989.

DISCIPLINE SPECIFIC ELECTIVE: COMMUTATIVE ALGEBRA

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Commutative Algebra	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra and Field Theory

Learning Objectives

The objective of this course is to:

- develop a solid understanding of the structure of commutative rings, ideals, their radicals, extension, contraction etc.
- study important constructions such as total quotient rings, localizations.
- develop basic foundation in other areas of mathematics such as algebraic geometry, algebraic number theory.

Learning Outcomes

This course will enable the students to:

- know the localization of rings at a prime ideal that is an algebraic analogue of the geometric notion concentrating attention near a point.
- know more closely the polynomial rings, power series rings in one or more variables over a commutative ring and their prime spectrum.
- define, identify, and elaborate integral closure of rings, valuations rings, discrete valuation rings, structure theorem of Artin rings.

Syllabus

Unit – 1 **(12 hours)**

Radical of an ideal, Prime avoidance lemma, Chinese remainder theorem, Extension and contraction of ideals, Jacobson radical of a ring, Nakayama lemma, Tensor product of modules.

Unit – 2 **(13 hours)**

Rings and modules of fractions, Localization, Local properties, Primary decomposition, First and second uniqueness theorem of primary decomposition, Associated prime ideals of decomposable ideals.

Unit – 3 **(10 hours)**

Integral ring extensions, Going up theorem, Going down theorem, Integrally closed domains, Valuation rings, Hilbert's Nullstellensatz theorem.

Unit – 4 **(10 hours)**

Noetherian rings, Primary decomposition in Noetherian rings, Artin rings, Structure theorem for Artin rings, Discrete valuation rings.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. F. Atiyah and I. G. MacDonald, *Introduction to Commutative Algebra*, CRC Press, Taylor & Francis, 2018.

Suggested Readings

(i) D. Eisenbud, *Commutative Algebra with a View Towards Algebraic Geometry*, Springer, 2004.
(ii) R. Y. Sharp, *Steps in Commutative Algebra*, Cambridge University Press, 2000.
(iii) B. Singh, *Basic Commutative Algebra*, World Scientific, 2011.
(iv) O. Zariski and P. Samuel, *Commutative Algebra*, Volume I & II, Springer, 1975.

DISCIPLINE SPECIFIC ELECTIVE: DYNAMICAL SYSTEMS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Dynamical Systems	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology and Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- understand discrete and continuous systems with case studies to study nonlinear systems of ordinary differential equations and dynamical systems.
- understand the concepts, models and techniques to realize the real-world problems and stability of the systems along with the chaotic dynamic behaviour of models by understanding bifurcations.

Learning Outcomes

This course will enable the students to learn:

- formulation of mathematical models with the stability analysis near the equilibrium points.
- how the concept of phase portraits helps to analyse mathematical model graphically.
- the qualitative behaviour of the solution set of a given system of differential equations including the invariant sets and limiting behaviour of the dynamical system or flow defined by the system of differential equations.
- how different bifurcations explain the chaotic behaviour of the system.

Syllabus

Unit – 1 **(13 hours)**

Linear systems: Jordan forms, Stability theory; Nonlinear systems: Fundamental existence-uniqueness theorem, Dependence on initial conditions and parameters, Flow of a differential equation, Linearization, Stable manifold theorem, Hartman–Grobman theorem.

Unit – 2 **(10 hours)**

Stability and Lyapunov functions, Saddle points, Nodes, Foci, Centers and nonhyperbolic critical points, Center manifold theorem.

Unit – 3 **(12 hours)**

Limit sets and attractors, Periodic orbits and limit cycles, Poincaré map, Stable manifold theorem for periodic orbits, Poincare-Bendixson theorem.

Unit – 4 **(10 hours)**

Bifurcations at nonhyperbolic equilibrium points, Saddle node, Transcritical and Pitchfork bifurcations, Hopf bifurcation.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. W. Hirsch, S. Smale and R. L. Devaney, *Differential Equations, Dynamical Systems, and an Introduction to Chaos*, Third Edition, Academic Press, 2013.
[2] L. Perko, *Differential Equations and Dynamical Systems*, Third Edition, Springer Verlag, 2001.

Suggested Readings

(i) R. L. Devaney, *A First Course in Chaotic Dynamical Systems: Theory and Experiment*, CRC Press, Taylor & Francis, 2018.
(ii) S. H. Strogatz, *Nonlinear Dynamics and Chaos*, Second Edition, CRC Press, Taylor & Francis, 2018.
(iii) S. Wiggins, *Introduction to Applied Nonlinear Dynamical Systems and Chaos*, TAM Volume 2, Springer-Verlag, NY, 1990.

DISCIPLINE SPECIFIC ELECTIVE: THEORY OF BOUNDED OPERATORS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Theory of Bounded Operators	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis

Learning Objectives

The primary objective of this course is to:

- introduce some classes of bounded linear operators which play a central role in both pure and applied mathematics.
- study the properties and spectral theory of these operators.

Learning Outcomes

This course will enable the students to understand:

- the spectrum and sub-divisions of spectrum of standard operators like shifts and multiplication.
- the spectral theorem for some classes of bounded linear operators.
- the concepts of compactness, self-adjointness and positivity of bounded linear operators.
- trace class and Hilbert–Schmidt operators.

Syllabus

Unit – 1 **(11 hours)**

Properties of spectrum and resolvent of bounded operators, Subdivision of the spectrum including point, approximate and compression spectrum.

Unit – 2 **(10 hours)**

Operators on Hilbert spaces, Adjoint operator, Projections and idempotents, Operations with projections, Invariant and reducing subspaces.

Unit – 3 **(14 hours)**

Compact operators on Hilbert spaces, Diagonalisation of compact self-adjoint operators, Spectral theorem and functional calculus for Compact normal operators, Positive operators, Compact operators on Banach spaces, Spectral theory of compact operators.

Unit – 4 **(10 hours)**

Polar decomposition, Singular values, Trace class operators, Trace norm and Hilbert Schmidt operators.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] R. Bhatia, *Notes on Functional Analysis*, Hindustan Book Agency, 2009.
[2] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.

Suggested Readings

(i) E. Kreyszig, *Introductory Functional Analysis with Applications*, John Wiley & Sons, 2006.
(ii) B. Simon, *Operator Theory: A Comprehensive Course in Analysis*, Part 4, American Mathematical Society, 2015.
(iii) S. R. Garcia, J. Mashregi and W. T. Ross, *Operator Theory by Example*, Oxford University Press, 2023.

Group-2

DISCIPLINE SPECIFIC ELECTIVE: ADVANCED COMPLEX ANALYSIS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Advanced Complex Analysis	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Complex Analysis

Learning Objectives

The primary objective of this course is to:

- explore the metric space structure of the spaces of continuous and analytic functions, through Arzela–Ascoli, Hurwitz and Montel theorems.
- investigate various characterizations of simply connected regions, with a special focus on the Riemann mapping theorem.
- use Runge's and Mittag–Leffler's theorems to approximate and interpolate analytic and meromorphic functions.
- analyze the range of analytic functions using Bloch's/ Landau's constants and Picard's theorem.

Learning Outcomes

This course will enable the students to:

- apply various variants of maximum modulus theorem, encompassing Hadamard's three circles theorem and Phragmen–Lindelöf theorem.
- comprehend the notions of normality, compactness, equicontinuity and local boundedness for the spaces of continuous and analytic functions.
- construct and factorize entire functions using infinite products, including special functions like gamma and zeta.
- analyze the harmonic functions on a disk using Poisson kernel, which in turn, solves the Dirichlet problem for a unit disk.

Syllabus

Unit – 1 **(12 hours)**

Convex functions and Hadamard's three circles theorem, Maximum-Modulus theorem (third version), Phragmen–Lindelöf theorem, Spaces of continuous functions, Normal and equicontinuous families, Arzela–Ascoli theorem.

Unit – 2 **(11 hours)**

Spaces of analytic functions, Hurwitz's theorem, Montel's theorem, Riemann mapping theorem, Infinite products, Weierstrass factorization theorem, Factorization of sine function.

Unit – 3 **(10 hours)**

Gamma and Riemann zeta function, Runge's theorem, Characterizations of simple connectedness, Mittag–Leffler's theorem.

Unit – 4 **(12 hours)**

Harmonic functions, Mean value property, Maximum and minimum principles, Harmonic function on a disk, Harnack's theorem, Range of an analytic function, Bloch's theorem, Bloch's and Landau's constants, Picard's theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. B. Conway, *Functions of One Complex Variable*, Second Edition, Narosa Publishing House, New Delhi, 2002.

Suggested Readings

(i) L. V. Ahlfors, *Complex Analysis*, Mc Graw Hill Co., Indian Edition, 2017.
(ii) L. Hahn and B. Epstein, *Classical Complex Analysis*, Jones and Bartlett, 1996.
(iii) E. M. Stein and R. Shakarchi, *Complex Analysis*, Princeton University Press, 2003.
(iv) D. Ullrich, *Complex Made Simple*, Volume 97, American Mathematical Society, 2008.

DISCIPLINE SPECIFIC ELECTIVE: NUMERICAL METHODS FOR ORDINARY DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Numerical Methods for Ordinary Differential Equations	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- develop the basic theory underlying the numerical solution of differential equations.
- introduce the concepts of consistency, stability and convergence of finite difference methods.
- execute the numerical schemes for the solution of differential equations.

Learning Outcomes

This course will enable the students to:

- gain a thorough understanding of the fundamental concepts involved in the construction and analysis of finite difference schemes for solving ordinary differential equations (ODEs).
- apply various numerical methods based on finite difference approaches to obtain approximate solutions for both initial value problems (IVPs) and boundary value problems (BVPs).
- develop the ability to select appropriate finite difference methods for specific types of problems and effectively apply them to real world applications.

Syllabus

Unit – 1 **(11 hours)**

Initial value problems: Existence and uniqueness of solution, Finite difference equation, Truncation error, Single step methods for first order IVPs and system of IVPs- Family of explicit and implicit Runge–Kutta methods, Taylor series methods, Derivation, Truncation error, Consistency, Stability and convergence analysis.

Unit – 2 **(12 hours)**

IVPs for the system of ODEs, Consistency, Zero stability and convergence of linear multistep methods, Routh–Hurwitz criterion, Order and error constant, First Dahlquist Barrier, Local truncation error and global truncation error, Error bounds, Local error, Linear stability theory, Higher order differential equations.

Unit – 3 **(12 hours)**

Derivation of explicit and implicit multistep methods for IVPs and system of IVPs, Truncation error, Stability and convergence analysis of family of Nystrom method, Adams–Bashforth method,

Adams–Moulton method, Milne–Simpson method, Predictor corrector method, and Modified predictor corrector method, Hybrid method, Multistep methods for second order IVPs.

Unit – 4 **(10 hours)**

Linear BVPs for second order ordinary differential equations, Shooting method, Finite difference method, Collocation method, Derivative boundary conditions, Nonlinear two-point BVPs, Higher order finite difference methods, Stability, Truncation error and convergence analysis.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. K. Jain, S. R. K. Iyenger and R. K. Jain, *Numerical Methods for Scientific and Engineering Computations*, Seventh Edition, New Age International Publisher, 2019.

[2] J. D. Lambert, *Numerical Methods for Ordinary Differential Systems: The Initial Value Problem*, John Wiley & Sons, 1991.

Suggested Readings

(i) K. E. Atkinson, W. Han and D. E. Stewart, *Numerical Solution of Ordinary Differential Equations*, John Wiley & Sons, 2009.

(ii) J. C. Butcher, *The Numerical Analysis of Ordinary Differential Equations*, Second Edition, Wiley, New York, 2008.

(iii) L. Collatz, *The Numerical Treatment of Differential Equations*, Springer-Verlag, 1966.

DISCIPLINE SPECIFIC ELECTIVE: REPRESENTATION OF FINITE GROUPS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Representation of Finite Groups	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra and Group Theory

Learning Objectives

The primary objective of this course is to:

- represent finite groups as groups of matrices (via homomorphisms) and apply the tools of linear algebra to study the group structure.
- introduce the notion of Group algebra, which plays an essential role in classifying representations of groups.
- to discuss some applications of representations of finite groups, such as the Burnside's theorem.

Learning Outcomes

This course will enable the students to:

- define and construct examples of group representations, FG-modules, group algebras.
- grasp key concepts and tools of representation theory and establish a link between FG-modules and group representations.
- prove and apply Maschke's theorem and Schur's lemma to describe all irreducible representations of finite groups over the field of complex numbers.
- apply the theory of characters and group representations to gain insight into group structure, such as normal subgroups, and the solubility of groups.

Syllabus

Unit – 1 **(11 hours)**

Representation of groups, FG-modules and FG-submodules, and reducibility, Permutation modules, FG-modules and equivalent representations, Reducible and irreducible FG-modules, Group algebra of G, Regular FG-module and regular representations, FG-homomorphisms, Direct sum of FG-modules.

Unit – 2 **(11 hours)**

Maschke's theorem for FG-modules and consequences. Schur's lemma and its converse, Application of Schur's lemma, Irreducible modules and group algebra, Structure of group algebra and space of CG-homomorphisms.

Unit – 3 **(10 hours)**

Characters and their properties, Permutation and regular characters, Inner product, Number of irreducible characters, Orthogonality relations and finding normal subgroups.

Unit – 4 **(13 hours)**

Algebraic numbers, Algebraic integers and their properties, Character values, The Burnside's *(p,q)*-theorem and solubility of some particular groups.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. James and M. Liebeck, *Representations and Characters of Groups*, Second Edition, Cambridge University Press, 2005.

Suggested Readings

(i) C. W. Curtis and I. Reiner, *Representation Theory of Finite Groups and Associative Algebras*, American Mathematical Society, 2006.
(ii) W. Fulton and J. Harris, *Representation Theory - A First Course*, Springer-Verlag, 2004.
(iii) I. M. Issacs, *Character Theory of Finite Groups*, American Mathematical Society reprint, 2006.

DISCIPLINE SPECIFIC ELECTIVE: TOPOLOGICAL DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Topological Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- provide a strong background of topological dynamical systems including their applications.
- develop some useful and interesting dynamical properties like expansivity, shadowing and topological stability with supporting examples and results from symbolic and topological dynamics.
- introduce the celebrated Sarkovskii's theorem.

Learning Outcomes

This course will enable the students to:

- construct interesting examples of dynamical systems and topological conjugacy.
- visualize stable sets, omega sets and alpha limit sets.
- understand the applications of Sarkovskii's theorem.
- use subshifts of finite type to characterize irreducible matrices.
- prove key results on expansivity and shadowing regarding existence/non-existence, product, subspace and their different characterizations etc.
- find the class of topologically stable homeomorphisms.

Syllabus

Unit – 1 **(10 hours)**

Definition and examples (including real life examples) of dynamical systems, Orbits, Types of orbits, Topological conjugacy and orbits, Phase portrait-graphical analysis of orbit, Periodic points and stable sets, Omega and alpha limit sets and their properties.

Unit – 2 **(10 hours)**

Sarkovskii's theorem, Shift spaces and subshift, Subshift of finite type, Subshift represented by a matrix, Characterizations of irreducible matrices.

Unit – 3 **(13 hours)**

Definition and examples of expansive homeomorphisms, Properties of expansive homeomorphisms, Non-existence of expansive homeomorphism on the unit interval and unit circle, Generators and weak generators, Generators and expansive homeomorphisms.

Unit – 4 **(12 hours)**

Converging semi-orbits for expansive homeomorphisms, Definition, examples and properties of maps having shadowing property, Topological Anosov homeomorphisms and topological stability.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] N. Aoki and K. Hiraide, *Topological Theory of Dynamical Systems: Recent Advances*, North Holland Publications, 1994.
[2] M. Brin and G. Stuck, *Introduction to Dynamical Systems*, Cambridge University Press, 2004.

Suggested Readings

(i) D. C. Hanselman and B. Little field, *Mastering MATLAB*, Pearson, 2012.
(ii) D. Lind and B. Marcus, *An Introduction to Symbolic Dynamics and Coding*, Cambridge University Press, 1996.
(iii) C. Robinson, *Dynamical Systems*, *Stability, Symbolic Dynamics and Chaos*, Second Edition, CRC Press, Taylor & Francis, 1998.
(iv) J. de. Vries, *Elements of Topological Dynamics*, Springer, 1993.

Group-3

DISCIPLINE SPECIFIC ELECTIVE: ADVANCED FUNCTIONAL ANALYSIS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Advanced Functional Analysis	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis and Topology

Learning Objectives

The primary objective of this course is to:

- define and explain the structure of a topological vector space and its fundamental properties.
- differentiate between normed, metrizable, locally convex and Hausdorff topological vector spaces.
- introduce the foundational theorems of functional analysis, including the Hahn–Banach, Banach–Steinhaus, Open mapping, and Closed graph theorems in the context of locally convex spaces.
- explain some applications of Banach–Alaoglu theorem and Krein–Milman theorem.

Learning Outcomes

This course will enable the students to:

- appreciate types of topological vector spaces and their separation properties.
- understand quotient spaces, weak topology and weak*-topology.
- analyze concepts of continuity, boundedness, and convergence for linear operators and functionals on topological vector spaces.
- understand the notion of local convexity and the role of seminorms in defining locally convex topologies.

Syllabus

Unit – 1 **(12 hours)**

Topological vector spaces, Types of Topological vector spaces, Separation properties, Linear mappings, Finite dimensional spaces, Metrization, Boundedness and continuity, Seminorms and local convexity, Normability.

Unit – 2 **(11 hours)**

Quotient spaces, Seminorms and quotient spaces, Examples, Baire category theorem, Banach–Steinhaus theorem, The open mapping theorem and the closed graph theorem on topological vector spaces.

Unit – 3 **(11 hours)**

Hahn–Banach separation theorem on topological vector spaces, Continuous extension theorem, Weak topologies, Weak topology and convexity, Weak topology and metrizability, Weak*-

topology of a dual space, Compact convex sets, Banach–Alaoglu theorem and applications, Goldstine theorem.

Unit – 4 **(11 hours)**

Extreme points, Krein–Milman theorem, Convex hull of compact sets, Applications of Krein–Milman theorem: Stone–Weierstrass theorem, Markov–Kakutani fixed point theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.
[2] W. Rudin, *Functional Analysis*, Second Edition, Tata Mc Graw-Hill, 2011.

Suggested Readings

(i) V. I. Bogachev and O. G. Smolyanov, *Topological Vector Spaces and Their Applications*, Springer, 2017.
(ii) S. Kantorovitz, *Introduction to Modern Analysis*, Oxford Graduate Texts in Mathematics, Oxford University Press, 2006.
(iii) J. Voigt, *A Course on Topological Vector Spaces*, Birkhäuser, 2020.

DISCIPLINE SPECIFIC ELECTIVE: ALGEBRAIC CODING THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Algebraic Coding Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra, Groups and Rings

Learning Objectives

The primary objective of this course is to:

- provide an introduction to algebraic coding theory, particularly linear codes.
- discuss bounds on the parameters along with cyclic codes.
- describe some well-known codes, such as Reed–Muller and Golay codes.
- explore the algebraic structure of Cyclic and Quadratic residue codes over fields and rings.

Learning Outcomes

This course will enable the students to:

- get an insight into the matrix representation of a code, as well as encoding and decoding.
- understand Hamming, MDS and Reed–Muller codes.
- describe cyclic codes and their generator polynomial.
- learn about special cyclic codes, such as Quadratic residue codes, and their properties over the ring $\mathbb{Z}_4$.

Syllabus

Unit – 1 **(10 hours)**

Error detecting and error correcting codes, Maximum likelihood decoding, Hamming distance, Linear codes, Hamming weight, Generator matrix, Parity check matrix, Equivalence of linear codes, Encoding and decoding of linear codes, Syndrome decoding.

Unit – 2 **(11 hours)**

Bounds on codes, Sphere covering bound, Hamming bound, Perfect codes, Binary Hamming codes, Binary Golay codes, Singleton bound and MDS codes. Propagation rules, Reed–Muller codes.

Unit – 3 **(12 hours)**

Cyclic codes, Cyclic codes as ideals, Generator polynomial of cyclic codes, Generator and parity-check matrices of cyclic codes**,** Decoding of cyclic codes, Burst error correcting codes.

Unit – 4 **(12 hours)**

Quadratic residue codes: QR codes over fields of characteristic 2 and 3, Cyclic codes and their generating polynomial over $\mathbb{Z}_4$, QR codes over $\mathbb{Z}_4$.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] S. Ling and C. Xing, *Coding Theory: A First Course*, Cambridge University Press, 2004.
[2] W. C. Huffman and V. Pless, *Fundamentals of Error Correcting Codes*, Cambridge University Press, 2010.

Suggested Readings

(i) R. Hill, *A First Course in Coding Theory*, Oxford University Press, 1986.
(ii) F. J. Mac William and N. J. A. Sloane, *Theory of Error Correcting Codes, Part I & II,* Elsevier/North-Holland, Amsterdam, 1977.

DISCIPLINE SPECIFIC ELECTIVE: DIFFERENTIAL GEOMETRY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Differential Geometry	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra, Multivariate Calculus and Differential Equations

Learning Objectives

The primary objective of this course is to introduce:

- surfaces and parametrized surfaces.
- orientation on connected surfaces.
- geodesics on surfaces.
- Weingarten maps on oriented surfaces.
- arc length and curvature of oriented plane curves.
- curvatures of oriented surfaces.

Learning Outcomes

This course will enable the students to:

- understand the concepts of level sets and graphs of functions, smooth vector fields, tangent spaces of level sets.
- appreciate surfaces and parametrized surfaces, Gauss map, geodesics and parallel transport on oriented surfaces.
- know what the Weingarten map of an oriented surface is, realize it as shape operator and use it to compute curvature of oriented plane curves.
- find global parametrization and hence arc length of an oriented plane curve.
- compute various types of curvatures of surfaces.

Syllabus

Unit – 1 **(10 hours)**

Level sets in $\mathbb{R}^{n+1}$ and graphs of functions, Smooth vector fields and existence and uniqueness of their integral curves, Tangent spaces of level sets at regular points, Surfaces in $\mathbb{R}^{n+1}$ as inverse images of regular values of smooth functions, Necessary condition for extrema of functions on surfaces-Lagrange multipliers, Existence of a normal vector field on a connected surface, Orientation, Gauss map.

Unit – 2 **(13 hours)**

The notion of a geodesic on a surface, Existence and uniqueness of a geodesic on a surface through a given point with a given velocity vector thereof, Covariant derivative of a smooth vector field, Parallel vector field along a curve, Existence and uniqueness of a parallel vector field along a curve with a given initial vector, Weingarten map of a surface at a point, Local parametrization and curvature of a plane curve.

Unit – 3 **(10 hours)**

Global parametrization and arc length of an oriented plane curve, Differential 1-forms, Line integral of 1-forms over parametrized curves.

Unit – 4 **(12 hours)**

Parametrized surfaces with examples, Curvature of surfaces, Normal curvature of a surface at a point in a given direction, Principal curvatures, First and second fundamental forms, Gauss-Kronecker curvature and mean curvature.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] A. Pressley, *Elementary Differential Geometry*, Springer-Verlag London Limited, 2012.
[2] J. A. Thorpe, *Elementary Topics in Differential Geometry*, Springer (India) Pvt. Limited, 2004.

Suggested Readings

(i) W. Kuhnel, *Differential Geometry: Curves-Surfaces-Manifolds*, Third Edition, American Mathematical Society, 2015.
(ii) B. O' Neill, *Elementary Differential Geometry*, Second Edition, Academic Press INC., Academic Press, New York, 2006.

DISCIPLINE SPECIFIC ELECTIVE: FINITE ELEMENT METHODS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Finite Element Methods	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Differential Equations

Learning Objectives

The primary objective of this course is to:

- introduce basic aspects of finite element methods (FEM) including domain discretization, polynomial interpolation, application of boundary conditions, assembly of global arrays, and solution of the resulting algebraic systems.
- discuss the use of finite element methods in solving engineering problems in the domain of solid mechanics, fluid mechanics, heat transfer and electromagnetism.

Learning Outcomes

This course will enable the students to:

- use integral statement to deduce finite element approximations for the underlying linear partial differential equations.
- write special-purpose finite element programs within a procedural programming environment.
- use finite element methods to solve engineering problems in solids mechanics, fluid mechanics, heat transfer, and electromagnetism.
- assess the accuracy and reliability of finite element solutions and troubleshoot problems arising from errors in a given finite element analysis.

Syllabus

Unit – 1 **(12 hours)**

Basic concepts of weak formulation, Variational formulation of a one dimensional model equation, Basis function and finite element solutions, Collocation method, Ritz method, Least square method, Standard Galerkin method, FEM for model problem, Error estimate for FEM for model equation, Convergence analysis.

Unit – 2 **(11 hours)**

Various shapes of finite element, Higher order basis functions, Finite element methods for elliptic problems: Variational methods, Standard Galerkin method, Error estimate for FEM for elliptic problem, FEM for Poisson equation.

Unit – 3 **(12 hours)**

Finite element methods for parabolic problems: One dimensional model problems, Semi-discretization in space, Error estimates, Discretization in space and time, Galerkin method, Finite element methods for hyperbolic problems: Standard Galerkin method, Standard Galerkin method with strongly and weakly imposed boundary conditions.

Unit – 4 **(10 hours)**

Applications of the FEM to second order BVPs in one dimension, Applications of the FEM to linear elliptic, parabolic and hyperbolic equations.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. Evans, J. Blackledge and P. Yardley, *Numerical Methods for Partial Differential Equations*, Springer-Verlag, London, 2000.
[2] C. Johnson, *Numerical Solutions of Partial Differential Equations by Finite Element Methods*, *Cambridge University Press*, Cambridge, 1987.
[3] J. Whiteley, *Finite Element Methods - A Practical Guide*, Springer, 2016.

Suggested Readings

(i) Z. Chen, *Finite Element Methods and Their Applications*, Springer-Verlag, New York, 2005.
(ii) V. Thomee, *Galerkin Finite Element Methods for Parabolic Problems*, Second Edition, Springer-Verlag, Berlin, 2006.

Generic Elective (GE) Courses

GENERIC ELECTIVE – 3 (i): DYNAMICAL SYSTEMS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
GE-3 (i): Dynamical Systems	4	3	1	0	Class XII pass with Mathematics	Basics of Topology and Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- understand discrete and continuous systems with case studies to study nonlinear systems of ordinary differential equations and dynamical systems.
- understand the concepts, models and techniques to realize the real-world problems and stability of the systems along with the chaotic dynamic behaviour of models by understanding bifurcations.

Learning Outcomes

This course will enable the students to learn:

- formulation of mathematical models with the stability analysis near the equilibrium points.
- how the concept of phase portraits helps to analyse mathematical model graphically.
- the qualitative behaviour of the solution set of a given system of differential equations including the invariant sets and limiting behaviour of the dynamical system or flow defined by the system of differential equations.
- how different bifurcations explain the chaotic behaviour of the system.

Syllabus

Unit – 1 **(13 hours)**

Linear systems: Jordan forms, Stability theory; Nonlinear systems: Fundamental existence-uniqueness theorem, Dependence on initial conditions and parameters, Flow of a differential equation, Linearization, Stable manifold theorem, Hartman–Grobman theorem.

Unit – 2 **(10 hours)**

Stability and Lyapunov functions, Saddle points, Nodes, Foci, Centers and nonhyperbolic critical points, Center manifold theorem.

Unit – 3 **(12 hours)**

Limit sets and attractors, Periodic orbits and limit cycles, Poincaré map, Stable manifold theorem for periodic orbits, Poincare-Bendixson theorem.

Unit – 4 **(10 hours)**

Bifurcations at nonhyperbolic equilibrium points, Saddle node, Transcritical and Pitchfork bifurcations, Hopf bifurcation.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. W. Hirsch, S. Smale and R. L. Devaney, *Differential Equations, Dynamical Systems, and an Introduction to Chaos*, Third Edition, Academic Press, 2013.
[2] L. Perko, *Differential Equations and Dynamical Systems*, Third Edition, Springer Verlag, 2001.

Suggested Readings

(i) R. L. Devaney, *A First Course in Chaotic Dynamical Systems: Theory and Experiment*, CRC Press, Taylor & Francis, 2018.
(ii) S. H. Strogatz, *Nonlinear Dynamics and Chaos*, Second Edition, CRC Press, Taylor & Francis, 2018.
(iii) S. Wiggins, *Introduction to Applied Nonlinear Dynamical Systems and Chaos*, TAM Volume 2, Springer-Verlag, NY, 1990.

GENERIC ELECTIVE – 3 (ii): NUMERICAL METHODS FOR ORDINARY DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
GE-3 (ii): Numerical Methods for Ordinary Differential Equations	4	3	1	0	Class XII pass with Mathematics	Basics of Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- develop the basic theory underlying the numerical solution of differential equations.
- introduce the concepts of consistency, stability and convergence of finite difference methods.
- execute the numerical schemes for the solution of differential equations.

Learning Outcomes

This course will enable the students to:

- gain a thorough understanding of the fundamental concepts involved in the construction and analysis of finite difference schemes for solving ordinary differential equations (ODEs).
- apply various numerical methods based on finite difference approaches to obtain approximate solutions for both initial value problems (IVPs) and boundary value problems (BVPs).
- develop the ability to select appropriate finite difference methods for specific types of problems and effectively apply them to real world applications.

Syllabus

Unit – 1 **(11 hours)**

Initial value problems: Existence and uniqueness of solution, Finite difference equation, Truncation error, Single step methods for first order IVPs and system of IVPs- Family of explicit and implicit Runge–Kutta methods, Taylor series methods, Derivation, Truncation error, Consistency, Stability and convergence analysis.

Unit – 2 **(12 hours)**

IVPs for the system of ODEs, Consistency, Zero stability and convergence of linear multistep methods, Routh–Hurwitz criterion, Order and error constant, First Dahlquist Barrier, Local truncation error and global truncation error, Error bounds, Local error, Linear stability theory, Higher order differential equations.

Unit – 3 **(12 hours)**

Derivation of explicit and implicit multistep methods for IVPs and system of IVPs, Truncation error, Stability and convergence analysis of family of Nystrom method, Adams–Bashforth method,

Adams–Moulton method, Milne–Simpson method, Predictor corrector method, and Modified predictor corrector method, Hybrid method, Multistep methods for second order IVPs.

Unit – 4 **(10 hours)**

Linear BVPs for second order ordinary differential equations, Shooting method, Finite difference method, Collocation method, Derivative boundary conditions, Nonlinear two-point BVPs, Higher order finite difference methods, Stability, Truncation error and convergence analysis.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. K. Jain, S. R. K. Iyenger and R. K. Jain, *Numerical Methods for Scientific and Engineering Computations*, Seventh Edition, New Age International Publisher, 2019.

[2] J. D. Lambert, *Numerical Methods for Ordinary Differential Systems: The Initial Value Problem*, John Wiley & Sons, 1991.

Suggested Readings

(i) K. E. Atkinson, W. Han and D. E. Stewart, *Numerical Solution of Ordinary Differential Equations*, John Wiley & Sons, 2009.

(ii) J. C. Butcher, *The Numerical Analysis of Ordinary Differential Equations*, Second Edition, Wiley, New York, 2008.

(iii) L. Collatz, *The Numerical Treatment of Differential Equations*, Springer-Verlag, 1966.

Syllabi of Courses in Semester-IV of M.Sc. Mathematics under Structure-2 (Course work + Research)

Discipline Specific Core (DSC) Courses

DISCIPLINE SPECIFIC CORE – 9: PARTIAL DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC-9: Partial Differential Equations	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Multivariate Calculus and Differential Equations

Learning Objectives

The main objective of this course is to introduce:

- well-posedness, fundamental solutions, existence and uniqueness of solutions for Laplace equation, Poisson equation and heat equation.
- solution for wave equation by spherical means.
- characteristics, complete integrals, envelopes and conservation laws for first-order nonlinear partial differential equations.
- classical solution techniques such as Green's function, similarity solutions and transform methods.

Learning Outcomes

This course will enable the students to:

- understand Laplace equation, Poisson equation, and Heat equation, their fundamental solutions, uniqueness principles, mean value properties, and Green's function.
- apply the method of spherical means to solve homogeneous and nonhomogeneous wave equations.
- use characteristics to solve nonlinear partial differential equations, construct complete integrals and envelopes, and understand conservation laws.
- implement various techniques such as similarity solutions and transform methods to derive solutions of different types of partial differential equations.

Syllabus

Unit – 1 **(12 hours)**

Well-posed problems, Classical solution, Laplace equation, Poisson equation, Fundamental solution, Strong maximum principle and uniqueness of solution, Mean value formulas, Representation formula, Green's function, Poisson's formula.

Unit – 2 **(10 hours)**

Heat equation, Fundamental solution for homogeneous and nonhomogeneous initial-value problems, Mean value formula, Strong maximum principle and uniqueness of solution, Local estimates for the solution.

Unit – 3 **(13 hours)**

Wave equation: Solution of homogeneous and nonhomogeneous problems by spherical means,

Nonlinear first order partial differential equations: Complete integrals and envelopes, Characteristics, Introduction to conservation laws.

Unit – 4 **(10 hours)**

Other solution methods: Similarity solutions, Fourier transform and Laplace transform, Cole–Hopf transformation, Potential function, Hodograph and Legendre transform.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] L. C. Evans, *Partial Differential Equations*, American Mathematical Society, Providence, RI, 1998.
[2] F. John, *Partial Differential Equations*, Fourth Edition, Springer-Verlag, New York, 1982.

Suggested Readings

(i) P. R. Garabedian, *Partial Differential Equations*, John Wiley & Sons, Inc., New York- London-Sydney, 1964.
(ii) A. K. Nandakumaran and P. S. Datti, *Partial Differential Equations: Classical Theory with a Modern Touch*, Cambridge University Press, 2020.

DISCIPLINE SPECIFIC CORE – 10: ANALYSIS OF SEVERAL VARIABLES

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC-10: Analysis of Several Variables	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Calculus, Real Analysis including Riemann Integration

Learning Objectives

The primary objective of this course is to:

- introduce differentiation of vector valued functions on $\mathbb{R}^n$ and their properties.
- familiarize students with integration of functions over rectangles and bounded sets in $\mathbb{R}^n$.
- extend integration of functions to unbounded sets in $\mathbb{R}^n$.
- study change of variables and its applications.

Learning Outcomes

This course will enable the students to:

- check differentiability of vector valued functions on $\mathbb{R}^n$, understand the relation between directional derivative and differentiability, apply chain rule, mean value theorems, inverse and implicit function theorems.
- understand higher order derivatives and be able to apply Taylor's formulas with integral remainder, Lagrange's remainder and Peano's remainder.
- master the concepts of integration over rectangles and bounded sets in $\mathbb{R}^n$.
- generalize the integration theory to unbounded sets in $\mathbb{R}^n$.
- grasp the effect of change of variables in integration.

Syllabus

Unit– 1 **(12 hours)**

The differentiability of functions from $\mathbb{R}^n$ to $\mathbb{R}^m$, Partial derivatives and differentiability, Directional derivatives and differentiability, Chain rule, Mean value theorems, Inverse function theorem and Implicit function theorem.

Unit– 2 **(11 hours)**

Derivatives of higher order, Taylor's formulas with integral remainder, Lagrange's remainder and Peano's remainder, Integral over a rectangle, Existence of the integral.

Unit– 3 **(10 hours)**

Evaluation of the integral, Fubini's theorem, Integral over a bounded set.

Unit– 4 **(12 hours)**

Rectifiable sets, Improper integrals**,** Change of variable theorem, Applications of change of variables.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. Giaquinta and G. Modica, *Mathematical Analysis: An Introduction to Functions of Several Variables*, Birkhäuser, 2009.
[2] J. R. Munkres, *Analysis on Manifolds*, CRC Press, Taylor & Francis, 2018.

Suggested Readings

(i) W. Rudin, *Principles of Mathematical Analysis*, Third Edition, Mc Graw Hill, 1986.
(ii) M. Spivak, *Calculus on Manifolds: A Modern Approach to Classical Theorems of Advanced Calculus*, Taylor & Francis, 2018.

Discipline Specific Elective (DSE) Courses

DSE-7 and DSE-8

Group-1

DISCIPLINE SPECIFIC ELECTIVE: ADVANCED FLUID DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Advanced Fluid Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Calculus and Partial Differential Equations

Learning Objectives

The primary objective of this course is to:

- prepare a foundation for advanced studies in compressible flow, boundary layer theory and magnetohydrodynamics.
- develop concepts, models, and techniques that enable problem-solving in compressible flow, boundary layer theory and magnetohydrodynamics.
- equip students with concepts and techniques to conduct research in the above mentioned domains.

Learning Outcomes

This course will enable the students to:

- learn conservation laws, first and second laws of thermodynamics, internal energy and entropy, different forms of energy equations and dimensional analysis.
- know about compressibility in real fluids, wave motion, sound waves, hyperbolic and dispersive waves, shock waves, their formation, properties and elementary analysis.
- know the concepts of boundary layer, boundary layer equations and their solutions, measurements of boundary layer thickness.
- understand the interaction between hydrodynamic processes and electromagnetic phenomena.
- formulate the basic equations of motion in inviscid and viscous conducting fluid flow and explain Alfven's theorem and magnetohydrodynamic (MHD) waves and MHD shocks.

Syllabus

Unit – 1 **(11 hours)**

Flow characteristics, Conservation laws, Equation of state of a substance, First and second law of thermodynamics, Internal energy and entropy, Energy equation, Nondimensionalizing the basic equations of incompressible viscous fluid flow, Nondimensional numbers.

Unit – 2 **(12 hours)**

Compressibility effects in real fluids, Equations of motion, Sound wave, Hyperbolic and dispersive waves, Isentropic gas flow, Flow through a nozzle, Method of characteristics, Shock jump conditions, Non-linear plane waves, Shock waves and their elementary analysis, Similarity solutions.

Unit – 3 **(11 hours)**

Boundary layer concept, Estimation of boundary layer thickness and friction forces, Prandtl's boundary layer equations, Boundary layer along a flat plate, Boundary layer thickness, General properties of the boundary layer equations, Similar solutions, Momentum and energy integral equations for the boundary layer.

Unit – 4 **(11 hours)**

Maxwell's electromagnetic field equations, Magnetohydrodynamic (MHD) approximations, Magnetic field equation, Magnetic Reynolds number, Magnetic body force, Equations of Motions of conducting fluid, Alfven's theorem, MHD waves, MHD shock waves.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] F. Chorlton, *Text Book of Fluid Dynamics*, CBS Publisher, 2005.
[2] H. Schlichting and K. Gersten, *Boundary Layer Theory*, Ninth Edition, Springer, 2017.
[3] G. B. Witham, *Linear and Nonlinear Waves*, John Wiley & Sons, 1999.

Suggested Readings

(i) K. R. Cramer and S. I. Pai, *Magnetofluid Dynamics for Engineers and Applied Physics*, McGraw Hill Book Co., New York, 1973.
(ii) Y. Shao-Wen, *Foundations of Fluid Mechanics*, PHI, New Delhi, 1960.

DISCIPLINE SPECIFIC ELECTIVE: PROBABILITY THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Probability Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Measure Theory

Learning Objectives

The primary objective of this course is to introduce:

- probability space as a measure space and random variables as measurable functions.
- expectation and moments of random variables.
- notion of convergence in probability.
- conditioning on sub-σ-algebra.

Learning Outcomes

This course will enable the students to learn:

- about probability or uncertainty in abstract setting.
- moments and expectation of random variables which help to understand applications of probability in industry.
- how to apply the idea of convergence in probability.
- weak law and strong law of large numbers and their applications.

Syllabus

Unit – 1 **(11 hours)**

Probability: σ-algebra, Constructing probability triples, The extension theorem, Random variables, Independence of events, Continuity of probabilities, Limit events, The Borel–Cantelli Lemma.

Unit – 2 **(10 hours)**

Expected values: Simple, general non-negative and arbitrary random variables, Moment generating functions, Markov's inequality, Chebyshev's inequality.

Unit – 3 **(12 hours)**

Convergence of random variables: Convergence almost surely, Convergence in probability, Weak law of large numbers, Strong law of large numbers.

Unit – 4 **(12 hours)**

Distributions of random variables: Examples of distributions, Characteristic functions, The central limit theorem, Conditional probability, Conditioning on random variable, Conditioning on a sub-σ-algebra, Conditional variance.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. S. Rosenthal, *A First Look at Rigorous Probability Theory*, Second Edition, World Scientific, Singapore, 2006.

Suggested Readings

(i) W. Feller, *An Introduction to Probability Theory and its Applications*, Volume 1, Third Edition, Wiley, 2008.
(ii) J. E. Michael and J. S. Rosenthal, *Probability and Statistics: The Science of Uncertainty*, Second Edition, W. H. Freeman & Co Ltd., 2009.
(iii) S. Ross, *A First Course in Probability*, Tenth Edition, Pearson Education, 2022.
(iv) D. W. Stroock, *Probability Theory, An Analytic View*, Cambridge University Press, 2024.

DISCIPLINE SPECIFIC ELECTIVE: SIMPLICIAL HOMOLOGY THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Simplicial Homology Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- introduce the foundations of simplicial complexes and homology theory.
- develop an understanding of chain mappings and induced homomorphisms.
- apply these concepts to establish fundamental results in topology such as Euler–Poincaré theorem, Brouwer's and Lefschetz fixed-point theorems.

Learning Outcomes

This course will enable the students to:

- identify hyperplanes, simplexes and finite simplicial complexes as subsets of a Euclidean space.
- learn the idea of compact triangulable spaces as geometric carriers of finite simplicial complexes (polyhedra).
- learn the use of homological algebra to associate simplicial homology groups and illustrate it by computing simplicial homology groups of some well-known compact polyhedral.
- prove important applications of simplicial homology theory like invariance of dimension, Euler's formula, Lefschetz and Brouwer's fixed point theorems.

Syllabus

Unit – 1 **(11 hours)**

Geometric simplexes, Geometric complexes and polyhedra, Simplicial maps, Simplicial approximation of continuous maps between two polyhedral.

Unit – 2 **(12 hours)**

Orientation of geometric complexes, Chain complexes, Simplicial homology groups, Structure of homology groups, Relative homology groups, Computation of homology groups, Homology groups of n-sphere.

Unit – 3 **(12 hours)**

Chain mappings, Chain derivation, Chain homotopy, Contiguous maps, Homomorphism induced by continuous maps between two polyhedra, Functorial property of induced homomorphisms, Topological and homotopy invariance of homology groups.

Unit – 4 **(10 hours)**

Euler–Poincaré theorem and Euler's formula, Invariance of dimension, Brouwer's fixed point theorem, Degree of self-mappings of $\mathbb{S}^n$, Brouwer's degree theorem, Existence of eigen values, Lefschetz fixed point theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] F. H. Croom, *Basic Concepts of Algebraic Topology*, Springer, 1978.

Suggested Readings

(i) M. K. Agoston, *Algebraic Topology: A First Course*, Marcel Dekker, 1976.
(ii) M. A. Armstrong, *Basic Topology*, Springer, 1983.
(iii) S. Deo, *Algebraic Topology - A Primer*, Second Edition, Hindustan Book Agency, 2018.

DISCIPLINE SPECIFIC ELECTIVE: THEORY OF UNBOUNDED OPERATORS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Theory of Unbounded Operators	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis and Bounded Operators

Learning Objectives

The primary objective of this course is to:

- introduce the notion of unbounded operators.
- develop the theory of operator semigroups and understand their role in applications, particularly for solving differential equations.

Learning Outcomes

This course will enable the students to:

- identify closed and closable linear operators on Banach spaces.
- compute adjoints of unbounded linear operators.
- understand spectral properties of some unbounded operators.
- comprehend the role unbounded operators and semigroups play in applications, particularly in studying solutions of differential equations.

Syllabus

Unit – 1 **(10 hours)**

Unbounded linear operators, Hilbert adjoints, Hellinger–Toeplitz theorem, Hermitian, symmetric and self-adjoint linear operators, Closed linear operators, Closable operators and their closures on Banach spaces.

Unit – 2 **(12 hours)**

Cayley transform, Deficiency indices, Spectral properties of self-adjoint operators, Multiplication and differentiation operators and their spectra.

Unit – 3 **(11 hours)**

Analytic properties of exponential functions, Matrix Semigroups, Uniformly continuous semigroups, Semigroups on Hilbert spaces, Strongly continuous semigroups.

Unit – 4 **(12 hours)**

Generators of semigroups and their resolvents, Hille–Yosida theorem (for contraction semigroup), Dissipative operators and their properties, Lumer–Phillips theorem, Generators of Group, Stone's theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] K. J. Engle and R. Nagel, *One-parameter Semigroups for Linear Evolution Equations*, Springer-Verlag, New York, 2000.
[2] E. Kreyszig, *Introductory Functional Analysis with Applications*, John Wiley & Sons, 2006.

Suggested Readings

(i) S. Goldberg, *Unbounded Linear Operators: Theory and Applications*, Dover Publications, 2006.
(ii) E. Hille and R. S. Phillips, *Functional Analysis and Semi-groups*. American Mathematical Society, Providence, RI, 1957.
(iii) A. Pazy, *Semigroups of Linear Operators and Applications to Partial Differential Equations*, Springer, 1983.
(iv) M. Schechter, *Principles of Functional Analysis*, Second Edition, American Mathematical Society, 2001.
(v) J. Weidmann, *Linear Operators in Hilbert Spaces, Graduate Texts in Mathematics*, Springer, New York, 1980.

Group-2

DISCIPLINE SPECIFIC ELECTIVE: BANACH AND C*-ALGEBRAS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Banach and C*-Algebras	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis and Topology

Learning Objectives

The primary objective of this course is to introduce:

- Banach algebras and C*-algebras.
- various ways to construct new operator algebras using given ones.
- spectrum of elements in Banach algebras and to study its properties.
- Gelfand representations of commutative Banach algebras and of C*-algebras.

Learning Outcomes

This course will enable the students to:

- familiarize with the representations of operator algebras.
- realize commutative Banach algebras and abelian C*-algebras as space of continuous functions on locally compact groups.
- understand the powerful tool of functional calculus.
- identify any C*-algebra as closed *-subalgebra of space of bounded linear operators on a Hilbert space.

Syllabus

Unit – 1 **(11 hours)**

Elementary properties and examples of Banach algebras, Ideals and quotients, Invertible elements, Spectrum and spectral radius, Spectral radius formula, Spectral mapping theorem (for polynomials), Gelfand–Mazur theorem.

Unit – 2 **(11 hours)**

Multiplicative linear functionals, Commutative Banach algebra, w*-topology, Gelfand transform of an element, Structure space, Gelfand representation.

Unit – 3 **(12 hours)**

Elementary properties and examples of C*-algebras, Unitization, Gelfand–Naimark representation of commutative C*-algebras, Continuous functional calculus, Spectral mapping theorem for normal elements, Positive elements of C*-algebras.

Unit – 4 **(11 hours)**

Ideals in C*-algebras, Approximate units, Quotients, Positive linear functionals, Gelfand–Naimark–Segal representation of C*-algebras.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.
[2] G. J. Murphy, *C*-algebras and Operator Theory*, Academic Press Inc., 1990.

Suggested Readings

(i) J. B. Conway, *A Course in Operator Theory, Graduate Texts in Mathematics*, Springer, 2007.
(ii) J. Dixmier, *C*-algebras*, North-Holland Publishing Company, 1977.
(iii) R. G. Douglas, *Banach Algebra Techniques in Operator Theory, Graduate Texts in Mathematics*, Springer, 1998.
(iv) E. Kaniuth, *A Course on Commutative Banach Algebras*, Graduate Texts in Mathematics, Springer, 2009.
(v) S. Kantorovitz, *Introduction to Modern Analysis*, Oxford Graduate Texts in Mathematics, Oxford University Press, 2006.
(vi) M. Takesaki, *Theory of Operator Algebras I*, Springer, 2002.

DISCIPLINE SPECIFIC ELECTIVE: CHAOS THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Chaos Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- introduce some useful and interesting notions like Topological Transitivity and Sensitive dependence on initial conditions.
- study different types of chaos including Devaney's chaos and finding their interrelationships.
- know classical result that period three implies chaos on intervals.
- relate chaos and decomposition theorems.
- study Topological entropy through open covers and also Bowen's definition of entropy, equivalence of these two definitions on compact metric spaces.
- study various interesting results related to topological entropy.

Learning Outcomes

This course will enable the students to:

- construct interesting examples of Topological transitive maps, Topological mixing maps etc.
- know classical examples of Devaney's chaotic maps like tent map, shift maps, logistic maps.
- study and compare different types of chaos.
- find relation between transitivity and chaos on intervals.
- relate chaos theory and classical decomposition theorems.
- study very useful notion of Topological entropy including its properties.
- calculate entropy of any homeomorphism of closed unit interval and of unit circle.

Syllabus

Unit – 1 **(12 hours)**

Topological Transitivity, Locally eventually onto maps, Topological mixing, Sensitive dependence on initial conditions, Devaney's definition of chaos, Transitivity and limit sets for continuous interval maps.

Unit – 2 **(11 hours)**

Characterizing topological mixing in terms of topological transitivity for continuous interval maps, Topological Weakly Mixing, Totally Transitive maps, Relation between transitivity and chaos on intervals, Logistic maps and shift maps as chaotic maps.

Unit – 3 **(12 hours)**

Various other definitions of chaos and their interrelationships. Period three implies chaos, Chaos and decomposition theorems including Bowen's decomposition theorem, Topological Entropy:

Definition using open covers, Examples and properties, Bowen's definition of topological entropy, Equivalence of two definitions, Topological version of Kolmogorov–Sinai theorem.

Unit – 4 **(10 hours)**

Topological Entropy of maps on a compact metric space, Topological Entropy of product maps, of iterations of a map, Topological entropy of an expansive homeomorphism on a compact metric space, of the two-sided shift, of any homeomorphism of the unit interval and of the unit circle.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] N. Aoki and K. Hiraide, *Topological Theory of Dynamical Systems: Recent Advances*, North Holland Publications, 1994.
[2] R. L. Devaney, *A First Course in Chaotic Dynamical Systems*, CRC Press, 2018.
[3] S. Ruette, *Chaos for Continuous Interval Maps: A Survey of Relationship Between Various Kinds of Chaos*, 2018.
[4] Peter Walters, *An Introduction to Ergodic Theory*, Springer, 2000.

Suggested Readings

(i) L. Alsedà, J. Llibre and M. Misiurewicz, *Combinatorial Dynamics and Entropy in Dimension One*, Advanced Series in Nonlinear Dynamics, World Scientific, 2000.
(ii) L. S. Block and W. A. Coppel, *Dynamics in One Dimension*, Springer, 2014.
(iii) M. Brin and G. Stuck, *Introduction to Dynamical Systems*, Cambridge University Press, 2015.

DISCIPLINE SPECIFIC ELECTIVE: CHARACTER THEORY OF FINITE GROUPS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Character Theory of Finite Groups	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra and Group Theory

Learning Objectives

The primary objective of this course is to:

- introduce characters of finite groups, class functions, and find the number of irreducible characters.
- find character tables of S_5, using characters of tensor products of CG-modules and powers of characters.
- define restricted characters and prove Clifford's theorem and its application to find the character table of A_5.
- explore some arithmetic properties of character values and introduce real characters.

Learning Outcomes

This course will enable the students to:

- define and construct examples of characters, prove some fundamental properties of characters, and calculate character tables of some small groups and symmetric groups, etc.
- construct new characters from given characters and understand the notion of induced and restricted characters.
- prove the Frobenius reciprocity theorem and the Frobenius–Schur count of involutions.

Syllabus

Unit – 1 **(10 hours)**

Group characters and their properties, Inner product of characters, Class functions and number of irreducible characters, Character tables and some orthogonality relations, Normal subgroups and lifted characters, Linear characters, Character tables of D_6, S_4, A_4.

Unit – 2 **(11 hours)**

Character of tensor products of CG-modules, Powers of characters, Decomposition of power of a character, Character table of symmetric group S_5, Character table of direct product of groups, Restricted characters, Constituents of a restricted character, Clifford's theorem, Restriction of symmetric groups to alternate groups in general normal subgroups of index two, Character table of A_5.

Unit – 3 **(12 hours)**

Induced CG-modules and their characters: Homomorphisms, Transitivity of induction, Frobenius reciprocity theorem, Values of induced characters. Algebraic integers, Some properties of degrees of irreducible characters and arithmetic properties of character values.

Unit – 4 **(12 hours)**

Real representations, Real conjugacy classes and real characters, Characters which can be realized over the reals, RG-modules and CG-modules, G-invariant symmetric bilinear form, Indicator function, The Frobenius–Schur count of involutions**.**

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. James and M. Liebeck, *Representations and Characters of Groups*, Second Edition, Cambridge University Press, 2005.

Suggested Readings

(i) I. M. Issacs, *Character Theory of Finite Groups*, American Mathematical Society reprint, 2006.
(ii) W. Ledermann, *Introduction to Group Characters*, Second Edition, Cambridge University Press, 1987.

DISCIPLINE SPECIFIC ELECTIVE: NONSMOOTH OPTIMIZATION

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Nonsmooth Optimization	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Nonlinear Optimization

Learning Objectives

The primary objective of this course is to:

- understand the tools to deal with nonsmooth convex functions.
- study conjugate duality in terms of conjugate functions for constrained nonlinear optimization problems.
- introduce numerical techniques to solve constrained nonlinear optimization problems.

Learning Outcomes

This course will enable the students to learn:

- the notions of subgradients and subdifferentials for nonsmooth convex functions.
- the use of conjugate functions to develop the theory of conjugate duality.
- about numerical methods like gradient descent method, gradient projection method, Newton's method and conjugate gradient method.
- penalty approach technique to solve constrained nonlinear optimization problems.

Syllabus

Unit – 1 **(11 hours)**

Extended real valued functions, Proper convex functions, Closure of convex functions, Differential derivatives, Subgradients and subdifferentials.

Unit – 2 **(12 hours)**

Conjugate functions, Biconjugate functions, Perturbation functions, Closure of convex functions, Directional derivatives, Subgradients and subdifferentials.

Unit – 3 **(12 hours)**

Gradient descent method, Gradient projection method, Newton's method, Conjugate gradient method.

Unit – 4 **(10 hours)**

Penalty function methods, Exterior penalty function, Interior penalty functions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. Avriel, *Nonlinear Programming: Analysis and Methods*, Dover Publications, 2003.

[2] O. Güler, *Foundations of Optimization*, Springer, 2010.

Suggested Readings

(i) A. Bagirov, N. Karitsa and M. M. Makela, *Introduction to Nonsmooth Optimization: Theory, Practice and Software*, Springer, 2014.
(ii) M. S. Bazaraa, H. D. Sherali and C. M. Shetty, *Nonlinear Programming: Theory and Algorithms,* Third Edition, John Wiley & Sons, 2013.
(iii) D. G. Luenberger and Y. Ye, *Linear and Nonlinear Programming*, Springer, 2008.

Group-3

DISCIPLINE SPECIFIC ELECTIVE: COMPUTATIONAL FLUID DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Computational Fluid Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Partial Differential Equation (Undergraduate level)

Learning Objectives

The primary objective of this course is to teach:

- various numerical schemes on finite difference and finite volume methods for solving PDEs.
- discretization errors and grid dependence.
- some real-world applications of PDEs and fluid dynamics.
- discretization of governing equations of diffusion, convection-diffusion, fluid flow and thereby computing the numerical solutions using the flow variables using algorithms.

Learning Outcomes

This course will enable the students to learn:

- techniques for solving the PDEs along with some initial and boundary conditions by using the finite difference and finite volume methods.
- the basic conservation principles of mass, momentum, energy, discretization of governing equations.
- discretization techniques.
- some popular algorithms like SIMPLE and SIMPLER used to obtain the solutions of steady and unsteady flow problems by finite volume methods.

Syllabus

Unit – 1 **(12 hours)**

Basics of discretization using finite differences, Various single and multi-step explicit and implicit finite difference schemes for 1-D and 2-D parabolic and hyperbolic initial boundary value problems, Alternating Direction Implicit schemes (ADI) for 2-D parabolic and hyperbolic equations, Order of accuracy, Consistency, Stability and convergence of a finite difference scheme, Courant Friedrich Lewy condition.

Unit – 2 **(12 hours)**

Finite difference schemes for second and fourth order 2-D elliptic boundary value problem and applications, Finite volume method for diffusion and convection-diffusion equations, Discretization of one and two-dimensional steady state diffusion and convection-diffusion equations, Central difference, Upwind, Exponential, Hybrid, Power-law and QUICK schemes and their properties.

Unit – 3 **(11 hours)**

Flow field calculation, Pressure-velocity coupling, Vorticity-stream function approach, Primitive variables, Staggered grid, Pressure and velocity corrections, Pressure correction equation, SIMPLE and SIMPLER algorithms.

Unit – 4 **(10 hours)**

Finite volume methods for unsteady flows, Discretization of one-dimensional transient heat conduction, Explicit, fully implicit and Crank–Nicolson schemes, Implementation of boundary conditions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. C. Strikweda, *Finite Difference Schemes and Partial Differential Equations*, Second Edition, SIAM, 2004.

[2] H. K. Versteeg and W. Malalasekera, *An Introduction to Computational Fluid Dynamics: The Finite Volume Method*, Second Edition, Pearson, 2008.

Suggested Readings

(i) J. D. Anderson, *Computational Fluid Dynamics*, McGraw-Hill, 1995.

(ii) S. V. Patankar, *Numerical Heat Transfer and Fluid Flow*, CRC Press, Taylor and Francis, Indian Edition, 2017.

(iii) R. H. Pletcher, J. C. Tannehill and D. A. Anderson, *Computational Fluid Mechanics and Heat Transfer*, CRC Press, Taylor and Francis, 2013.

(iv) J. W. Thomas, *Numerical Partial Differential Equations: Finite Difference Methods*, Springer, 2013.

DISCIPLINE SPECIFIC ELECTIVE: DIFFERENTIAL TOPOLOGY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Differential Topology	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- introduce the concepts of topological manifolds, smooth structures, smooth manifolds, and manifolds with boundary.
- develop an understanding of smooth functions, smooth maps, diffeomorphisms, and tangent spaces.
- explain the Inverse function theorem, immersions and submersions.
- develop the fundamental concepts of 2-manifolds and distinguish between orientable and non-orientable surfaces.
- explore the properties of compact and connected surfaces.

Learning Outcomes

This course will enable the students to:

- identify and construct examples of topological manifolds, smooth structures and manifolds with and without boundary.
- demonstrate understanding of diffeomorphisms and tangent spaces.
- apply the Inverse function theorem, immersions and submersions.
- define key concepts such as 2-manifolds, orientability, compactness, connectedness and boundary of a surface.
- differentiate between orientable and non-orientable surfaces using examples such as the sphere, torus, Möbius strip and Klein bottle.

Syllabus

Unit – 1 **(12 hours)**

Topological manifolds, Topological properties of manifolds, Smooth structures, Examples of smooth manifolds, Manifolds with boundary.

Unit – 2 **(11 hours)**

Smooth functions and smooth maps, Lie groups, Diffeomorphisms.

Unit – 3 **(10 hours)**

Derivatives and tangents, Inverse function theorem, Immersions and submersions.

Unit – 4 **(12 hours)**

Complexes, Connected sum of two surfaces, Non-orientable surfaces (2- Manifolds), Compact and connected surfaces, Classification of compact and connected surfaces with and without boundary.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] V. Guillemin and Alan Pollack, *Differential Topology*, Prentice-Hall, 1974.
[2] L. C. Kinsey, *Topology of Surfaces*, Springer Verlag, 1997.
[3] J. M. Lee, *Introduction to Smooth Manifolds*, Second Edition, Springer, 2013.

Suggested Readings

(i) L. Conlon, *Differentiable Manifolds*, Second Edition, Birkhäuser Advanced Texts, 2001.
(ii) M. Spivak, *A Comprehensive Introduction to Differential Geometry*, Volume 1, Third Edition, Publish or Perish, Huston, Texas, 1999.
(iii) L. W. Tu, *Introduction to Manifolds*, Second Edition, Springer, 2011.
(iv) F. W. Warner, *Foundations of Differentiable Manifolds and Lie Group*, Springer-Verlag, 1983.

DISCIPLINE SPECIFIC ELECTIVE: GENERAL MEASURE THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: General Measure Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Measure Theory and Topology

Learning Objectives

The primary objective of this course is to introduce:

- real valued and complex valued measures.
- decomposition of measure spaces and of measures.
- extension of a premeasure to a measure, Lebesgue measure on Euclidean spaces.
- representation of measures and functionals in terms of integrals.
- product measures.

Learning Outcomes

This course will enable the students to:

- appreciate signed measures and complex measures, mutual singularity of measures, Hahn and Jordan decompositions, Lebesgue decomposition, Radon–Nikodym theorem.
- verify conditions under which a set function defined on a collection of subsets of a set has an extension to a measure on a sigma-algebra.
- apply Riesz representation theorem for bounded linear functionals on L^p-spaces.
- understand product measure and the results of Fubini and Tonelli, and express the Lebesgue measure on Euclidean spaces as a product measure.
- apply Riesz–Markov representation theorem for the bounded linear functionals on the space of continuous functions.

Syllabus

Unit – 1 **(13 hours)**

Signed measures, Hahn and Jordan decompositions, Mutually singular measures, Radon–Nikodym theorem, Lebesgue decomposition, Complex measure.

Unit – 2 **(10 hours)**

The Carathéodory extension theorem, Lebesgue measure on $\mathbb{R}^n$, Regularity and translation invariance of Lebesgue measure on $\mathbb{R}^n$.

Unit – 3 **(10 hours)**

Riesz representation theorem for the dual of L^p-spaces, Product measures, Fubini's theorem, Tonelli's theorem.

Unit – 4 **(12 hours)**

Locally compact Hausdorff spaces and construction of Radon measure, Riesz–Markov representation theorem for positive linear functionals on $C_c(X)$, Riesz representation theorem for the dual of $C(X)$.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] H. L. Royden and P. M. Fitzpatrick, *Real Analysis*, Fourth Edition, Pearson, 2015.
[2] M. E. Taylor, *Measure Theory and Integration*, American Mathematical Society, 2006.

Suggested Readings

(i) G. B. Folland, *Real Analysis: Modern Techniques and Their Applications*, Second Edition, Wiley, New York, 1999.
(ii) P. R. Halmos, *Measure Theory*, Springer Science + Business Media, LLC, 2014.
(iii) E. M. Stein and R. Shakarchi, *Real Analysis: Measure Theory, Integration and Hilbert Spaces*, New Age International Publishers, New Delhi, 2010.

DISCIPLINE SPECIFIC ELECTIVE: THEORY OF NON-COMMUTATIVE RINGS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Theory of Non-commutative Rings	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Groups and Rings

Learning Objectives

The primary objective of this course is to:

- give students an understanding of Wedderburn–Artin theory of semisimple rings.
- develop Jacobson's general theory of radicals, prime and semiprime rings, and primitive and semiprimitive rings.
- introduce the structure of primitive rings as a generalisation of the Wedderburn–Artin theorem on Artinian simple rings.

Learning Outcomes

This course will enable the students to:

- know about an extensive variety of rings, including free rings, Weyl algebra, Hilbert twist and triangular ring.
- understand the module theoretic definition of semisimple rings and how it leads to the Wedderburn–Artin structure theorem on their complete classification.
- know Jacobson's general theory of radicals, semiprime rings, prime, primitive and semiprimitive rings and their structures.
- understand the significance of the fundamental result 'Density Theorem' and its consequences on the structure of primitive rings.

Syllabus

Unit – 1 **(11 hours)**

Simple rings, Reduced rings, Dedekind-finite rings, Algebra, Quaternions, Free k-rings, Rings with generators and relations, Weyl algebra, Formal power series ring, Hilbert's twist ring, Differential polynomial rings, Derivation and inner derivation on a ring, Triangular rings, Characterization of one-sided and two-sided ideals in such rings.

Unit – 2 **(11 hours)**

Noetherian and Artinian rings, Examples of one-sided Noetherian and Artinian triangular rings, Twisted polynomial ring and Quotient of free $\mathbb{Z}$-ring, Semisimple rings, Structure of semisimple rings: Wedderburn–Artin's theorem.

Unit – 3 **(10 hours)**

Structure theorem of simple left Artinian rings, Jacobson radical, J-semisimple rings, Nil and nilpotent ideals, Connection between semisimple and J-semisimple rings, Hopkins–Levitzki theorem, Nakayama's lemma.

Unit – 4 **(13 hours)**

Prime radical, Characterisation of prime and semiprime ideals, Prime and semiprime rings, Structure theorem of primitive rings, Density theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] T.-Y. Lam, *A First Course in Noncommutative Rings*, Springer, 2001.

Suggested Readings

(i) I. N. Herstein, *Noncommutative Rings*, The Mathematical Association of America, 2005.
(ii) T. W. Hungerford, *Algebra*, Springer-Verlag, New York, 1981.
(iii) L. H. Rowen, *Ring Theory*, Student Edition, Academic Press, 1991.

Generic Elective (GE) Courses

GENERIC ELECTIVE – 4 (i): NONSMOOTH OPTIMIZATION

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
GE-4 (i): Nonsmooth Optimization	4	3	1	0	Class XII pass with Mathematics	Basics of Nonlinear Optimization

Learning Objectives

The primary objective of this course is to:

- understand the tools to deal with nonsmooth convex functions.
- study conjugate duality in terms of conjugate functions for constrained nonlinear optimization problems.
- introduce numerical techniques to solve constrained nonlinear optimization problems.

Learning Outcomes

This course will enable the students to learn:

- the notions of subgradients and subdifferentials for nonsmooth convex functions.
- the use of conjugate functions to develop the theory of conjugate duality.
- about numerical methods like gradient descent method, gradient projection method, Newton's method and conjugate gradient method.
- penalty approach technique to solve constrained nonlinear optimization problems.

Syllabus

Unit – 1 **(11 hours)**

Extended real valued functions, Proper convex functions, Closure of convex functions, Differential derivatives, Subgradients and subdifferentials.

Unit – 2 **(12 hours)**

Conjugate functions, Biconjugate functions, Perturbation functions, Closure of convex functions, Directional derivatives, Subgradients and subdifferentials.

Unit – 3 **(12 hours)**

Gradient descent method, Gradient projection method, Newton's method, Conjugate gradient method.

Unit – 4 **(10 hours)**

Penalty function methods, Exterior penalty function, Interior penalty functions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. Avriel, *Nonlinear Programming: Analysis and Methods*, Dover Publications, 2003.
[2] O. Güler, *Foundations of Optimization*, Springer, 2010.

Suggested Readings

(i) A. Bagirov, N. Karitsa and M. M. Makela, *Introduction to Nonsmooth Optimization: Theory, Practice and Software*, Springer, 2014.
(ii) M. S. Bazaraa, H. D. Sherali and C. M. Shetty, *Nonlinear Programming: Theory and Algorithms,* Third Edition, John Wiley & Sons, 2013.
(iii) D. G. Luenberger and Y. Ye, *Linear and Nonlinear Programming*, Springer, 2008.

GENERIC ELECTIVE – 4 (ii): PROBABILITY THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
GE-4 (ii): Probability Theory	4	3	1	0	Class XII pass with Mathematics	Basics of Integration

Learning Objectives

The primary objective of this course is to introduce:

- probability space as a measure space and random variables as measurable functions.
- expectation and moments of random variables.
- notion of convergence in probability.
- conditioning on sub-σ-algebra.

Learning Outcomes

This course will enable the students to learn:

- about probability or uncertainty in abstract setting.
- moments and expectation of random variables which help to understand applications of probability in industry.
- how to apply the idea of convergence in probability.
- weak law and strong law of large numbers and their applications.

Syllabus

Unit – 1 **(11 hours)**

Probability: σ-algebra, Constructing probability triples, The extension theorem, Random variables, Independence of events, Continuity of probabilities, Limit events, The Borel–Cantelli Lemma.

Unit – 2 **(10 hours)**

Expected values: Simple, general non-negative and arbitrary random variables, Moment generating functions, Markov's inequality, Chebyshev's inequality.

Unit – 3 **(12 hours)**

Convergence of random variables: Convergence almost surely, Convergence in probability, Weak law of large numbers, Strong law of large numbers.

Unit – 4 **(12 hours)**

Distributions of random variables: Examples of distributions, Characteristic functions, The central limit theorem, Conditional probability, Conditioning on random variable, Conditioning on a sub-σ-algebra, Conditional variance.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. S. Rosenthal, *A First Look at Rigorous Probability Theory*, Second Edition, World Scientific, Singapore, 2006.

Suggested Readings

(i) W. Feller, *An Introduction to Probability Theory and its Applications*, Volume 1, Third Edition, Wiley, 2008.
(ii) J. E. Michael and J. S. Rosenthal, *Probability and Statistics: The Science of Uncertainty*, Second Edition, W. H. Freeman & Co Ltd., 2009.
(iii) S. Ross, *A First Course in Probability*, Tenth Edition, Pearson Education, 2022.
(iv) D. W. Stroock, *Probability Theory, An Analytic View*, Cambridge University Press, 2024.

Syllabi of Courses in Semester-III of M.Sc. Mathematics under Structure-3 (Research)

Discipline Specific Core (DSC) Course

DISCIPLINE SPECIFIC CORE: MATRIX GROUPS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC: Matrix Groups	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Calculus and Linear Algebra

Learning Objectives

The primary objective of this course is to:

- introduce the notion of matrix groups which serves as a bridge between algebra, geometry and analysis.
- use exponential and logarithm maps to connect one-parameter subgroups with Lie algebras.
- connect Clifford algebra constructions to orthogonal groups, spin groups and isomorphism questions.

Learning Outcomes

This course will enable the students to:

- distinguish between general linear, orthogonal and special orthogonal groups with explicit examples.
- construct and compute reflection and rotation matrices in $\mathbb{R}^n$and analyze their properties.
- comprehend maximal tori, their coverings and conjugacy results in compact matrix groups.
- appreciate the applications of matrix groups in algebraic geometry, complex analysis, group and ring theory, number theory, quantum physics, Einstein's special relativity, Heisenberg's uncertainty principle, quark theory, Fourier series, combinatorics and many more areas.

Syllabus

Unit – 1 **(10 hours)**

The general linear groups, The orthogonal groups, The isomorphism question, Reflection in $\mathbb{R}^n$, Curves in a vector space, Smooth homeomorphisms, The special orthogonal groups.

Unit – 2 **(11 hours)**

Orthogonal matrices and isometries, Exponential and Logarithm of a matrix, One-parameter subgroups, Lie Algebras, $SO(3)$ and $Sp(1)$.

Unit – 3 **(12 hours)**

Maximal tori, Covering by maximal tori, Reflections in $\mathbb{R}^n$, Monogenic groups.

Unit – 4 **(12 hours)**

Conjugacy of maximal tori, Clifford algebras, $Pin(k)$, $Spin(k)$ and isomorphisms.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. L. Curtis, *Matrix Groups*, Springer, 1984.

Suggested Readings

(i) A. Baker, *Matrix Groups: An Introduction to Lie Group Theory*, Springer Undergraduate Mathematics Series, 2001.

(ii) K. Tapp, *Matrix Groups for Undergraduates*, American Mathematical Society, 2016.

Discipline Specific Elective (DSE) Courses

DISCIPLINE SPECIFIC ELECTIVE: ADVANCED COMPLEX ANALYSIS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Advanced Complex Analysis	**4**	**3**	**1**	**0**	**Same as for entry to M.Sc. Mathematics**	**Basics of Complex Analysis**

Learning Objectives

The primary objective of this course is to:

- explore the metric space structure of the spaces of continuous and analytic functions, through Arzela–Ascoli, Hurwitz and Montel theorems.
- investigate various characterizations of simply connected regions, with a special focus on the Riemann mapping theorem.
- use Runge's and Mittag–Leffler's theorems to approximate and interpolate analytic and meromorphic functions.
- analyze the range of analytic functions using Bloch's/ Landau's constants and Picard's theorem.

Learning Outcomes

This course will enable the students to:

- apply various variants of maximum modulus theorem, encompassing Hadamard's three circles theorem and Phragmen–Lindelöf theorem.
- comprehend the notions of normality, compactness, equicontinuity and local boundedness for the spaces of continuous and analytic functions.
- construct and factorize entire functions using infinite products, including special functions like gamma and zeta.
- analyze the harmonic functions on a disk using Poisson kernel, which in turn, solves the Dirichlet problem for a unit disk.

Syllabus

Unit – 1 **(12 hours)**

Convex functions and Hadamard's three circles theorem, Maximum-Modulus theorem (third version), Phragmen–Lindelöf theorem, Spaces of continuous functions, Normal and equicontinuous families, Arzela–Ascoli theorem.

Unit – 2 **(11 hours)**

Spaces of analytic functions, Hurwitz's theorem, Montel's theorem, Riemann mapping theorem, Infinite products, Weierstrass factorization theorem, Factorization of sine function.

Unit – 3 **(10 hours)**

Gamma and Riemann zeta function, Runge's theorem, Characterizations of simple connectedness, Mittag–Leffler's theorem.

Unit – 4 **(12 hours)**

Harmonic functions, Mean value property, Maximum and minimum principles, Harmonic function on a disk, Harnack's theorem, Range of an analytic function, Bloch's theorem, Bloch's and Landau's constants, Picard's theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. B. Conway, *Functions of One Complex Variable*, Second Edition, Narosa Publishing House, New Delhi, 2002.

Suggested Readings

(i) L. V. Ahlfors, *Complex Analysis*, Mc Graw Hill Co., Indian Edition, 2017.
(ii) L. Hahn and B. Epstein, *Classical Complex Analysis*, Jones and Bartlett, 1996.
(iii) E. M. Stein and R. Shakarchi, *Complex Analysis*, Princeton University Press, 2003.
(iv) D. Ullrich, *Complex Made Simple*, Volume 97, American Mathematical Society, 2008.

DISCIPLINE SPECIFIC ELECTIVE: ADVANCED FUNCTIONAL ANALYSIS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Advanced Functional Analysis	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis and Topology

Learning Objectives

The primary objective of this course is to:

- define and explain the structure of a topological vector space and its fundamental properties.
- differentiate between normed, metrizable, locally convex and Hausdorff topological vector spaces.
- introduce the foundational theorems of functional analysis, including the Hahn–Banach, Banach–Steinhaus, Open mapping, and Closed graph theorems in the context of locally convex spaces.
- explain some applications of Banach–Alaoglu theorem and Krein–Milman theorem.

Learning Outcomes

This course will enable the students to:

- appreciate types of topological vector spaces and their separation properties.
- understand quotient spaces, weak topology and weak*-topology.
- analyze concepts of continuity, boundedness, and convergence for linear operators and functionals on topological vector spaces.
- understand the notion of local convexity and the role of seminorms in defining locally convex topologies.

Syllabus

Unit – 1 **(12 hours)**

Topological vector spaces, Types of Topological vector spaces, Separation properties, Linear mappings, Finite dimensional spaces, Metrization, Boundedness and continuity, Seminorms and local convexity, Normability.

Unit – 2 **(11 hours)**

Quotient spaces, Seminorms and quotient spaces, Examples, Baire category theorem, Banach–Steinhaus theorem, The open mapping theorem and the closed graph theorem on topological vector spaces.

Unit – 3 **(11 hours)**

Hahn–Banach separation theorem on topological vector spaces, Continuous extension theorem, Weak topologies, Weak topology and convexity, Weak topology and metrizability, Weak*-topology of a dual space, Compact convex sets, Banach–Alaoglu theorem and applications, Goldstine theorem.

Unit – 4 **(11 hours)**

Extreme points, Krein–Milman theorem, Convex hull of compact sets, Applications of Krein–Milman theorem: Stone–Weierstrass theorem, Markov–Kakutani fixed point theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.
[2] W. Rudin, *Functional Analysis*, Second Edition, Tata Mc Graw-Hill, 2011.

Suggested Readings

(i) V. I. Bogachev and O. G. Smolyanov, *Topological Vector Spaces and Their Applications*, Springer, 2017.
(ii) S. Kantorovitz, *Introduction to Modern Analysis*, Oxford Graduate Texts in Mathematics, Oxford University Press, 2006.
(iii) J. Voigt, *A Course on Topological Vector Spaces*, Birkhäuser, 2020.

DISCIPLINE SPECIFIC ELECTIVE: ALGEBRAIC CODING THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Algebraic Coding Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra, Groups and Rings

Learning Objectives

The primary objective of this course is to:

- provide an introduction to algebraic coding theory, particularly linear codes.
- discuss bounds on the parameters along with cyclic codes.
- describe some well-known codes, such as Reed–Muller and Golay codes.
- explore the algebraic structure of Cyclic and Quadratic residue codes over fields and rings.

Learning Outcomes

This course will enable the students to:

- get an insight into the matrix representation of a code, as well as encoding and decoding.
- understand Hamming, MDS and Reed–Muller codes.
- describe cyclic codes and their generator polynomial.
- learn about special cyclic codes, such as Quadratic residue codes, and their properties over the ring $\mathbb{Z}_4$.

Syllabus

Unit – 1 **(10 hours)**

Error detecting and error correcting codes, Maximum likelihood decoding, Hamming distance, Linear codes, Hamming weight, Generator matrix, Parity check matrix, Equivalence of linear codes, Encoding and decoding of linear codes, Syndrome decoding.

Unit – 2 **(11 hours)**

Bounds on codes, Sphere covering bound, Hamming bound, Perfect codes, Binary Hamming codes, Binary Golay codes, Singleton bound and MDS codes. Propagation rules, Reed–Muller codes.

Unit – 3 **(12 hours)**

Cyclic codes, Cyclic codes as ideals, Generator polynomial of cyclic codes, Generator and parity-check matrices of cyclic codes**,** Decoding of cyclic codes, Burst error correcting codes.

Unit – 4 **(12 hours)**

Quadratic residue codes: QR codes over fields of characteristic 2 and 3, Cyclic codes and their generating polynomial over $\mathbb{Z}_4$, QR codes over $\mathbb{Z}_4$.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] S. Ling and C. Xing, *Coding Theory: A First Course*, Cambridge University Press, 2004.
[2] W. C. Huffman and V. Pless, *Fundamentals of Error Correcting Codes*, Cambridge University Press, 2010.

Suggested Readings

(i) R. Hill, *A First Course in Coding Theory*, Oxford University Press, 1986.
(ii) F. J. Mac William and N. J. A. Sloane, *Theory of Error Correcting Codes, Part I & II,* Elsevier/North-Holland, Amsterdam, 1977.

DISCIPLINE SPECIFIC ELECTIVE: ALGEBRAIC TOPOLOGY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Algebraic Topology	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- understand the concepts of homotopic maps, homotopy type, retracts, and deformation retracts, and their role in algebraic topology.
- compute fundamental groups of basic topological spaces.
- acquire knowledge of covering projections, lifting properties, Borsuk–Ulam theorem, and classification techniques of covering spaces.
- learn free groups and free products to understand and apply the Seifert–Van Kampen theorem.

Learning Outcomes

This course will enable the students to:

- distinguish between spaces with the same homotopy type.
- compute fundamental groups of standard spaces such as n-sphere $\mathbb{S}^n$ and punctured planes.
- apply the concept of fundamental groups to prove Brouwer's fixed-point theorem and the Fundamental theorem of Algebra.
- explain the lifting theorems and their implications in topology.
- classify covering spaces for given base spaces.
- apply Seifert–Van Kampen theorem to compute fundamental groups of glued spaces.

Syllabus

Unit – 1 **(11 hours)**

Homotopic maps, Homotopy type, Retract and deformation retract.

Unit – 2 **(12 hours)**

Fundamental group, Calculation of fundamental groups of n-sphere $\mathbb{S}^n$ and punctured plane, Brouwer's fixed-point theorem, Fundamental theorem of Algebra.

Unit – 3 **(12 hours)**

Covering projections, Lifting theorems, Borsuk–Ulam theorem, Classification of covering spaces.

Unit – 4 **(10 hours)**

Free products, Free groups, Seifert–Van Kampen theorem and its applications.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. R. Munkres, *Elements of Algebraic Topology*, Addison-Wesley Publishing Company, 1984.
[2] T. B. Singh, *Introduction to Topology*, Springer Nature Singapore, 2019.

Suggested Readings

(i) G. E. Bredon, *Geometry and Topology*, Springer, 2014.
(ii) A. Hatcher, *Algebraic Topology*, Cambridge University Press, 2002.
(iii) W. S. Massey, *A Basic Course in Algebraic Topology*, World Publishing Corporation, 2009.
(iv) J. J. Rotman, *An Introduction to Algebraic Topology*, Springer, 2011.
(v) E. H. Spanier, *Algebraic Topology*, Springer-Verlag, 1989.

DISCIPLINE SPECIFIC ELECTIVE: COMMUTATIVE ALGEBRA

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Commutative Algebra	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra and Field Theory

Learning Objectives

The objective of this course is to:

- develop a solid understanding of the structure of commutative rings, ideals, their radicals, extension, contraction etc.
- study important constructions such as total quotient rings, localizations.
- develop basic foundation in other areas of mathematics such as algebraic geometry, algebraic number theory.

Learning Outcomes

This course will enable the students to:

- know the localization of rings at a prime ideal that is an algebraic analogue of the geometric notion concentrating attention near a point.
- know more closely the polynomial rings, power series rings in one or more variables over a commutative ring and their prime spectrum.
- define, identify, and elaborate integral closure of rings, valuations rings, discrete valuation rings, structure theorem of Artin rings.

Syllabus

Unit – 1 **(12 hours)**

Radical of an ideal, Prime avoidance lemma, Chinese remainder theorem, Extension and contraction of ideals, Jacobson radical of a ring, Nakayama lemma, Tensor product of modules.

Unit – 2 **(13 hours)**

Rings and modules of fractions, Localization, Local properties, Primary decomposition, First and second uniqueness theorem of primary decomposition, Associated prime ideals of decomposable ideals.

Unit – 3 **(10 hours)**

Integral ring extensions, Going up theorem, Going down theorem, Integrally closed domains, Valuation rings, Hilbert's Nullstellensatz theorem.

Unit – 4 **(10 hours)**

Noetherian rings, Primary decomposition in Noetherian rings, Artin rings, Structure theorem for Artin rings, Discrete valuation rings.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. F. Atiyah and I. G. MacDonald, *Introduction to Commutative Algebra*, CRC Press, Taylor & Francis, 2018.

Suggested Readings

(i) D. Eisenbud, *Commutative Algebra with a View Towards Algebraic Geometry*, Springer, 2004.
(ii) R. Y. Sharp, *Steps in Commutative Algebra*, Cambridge University Press, 2000.
(iii) B. Singh, *Basic Commutative Algebra*, World Scientific, 2011.
(iv) O. Zariski and P. Samuel, *Commutative Algebra*, Volume I & II, Springer, 1975.

DISCIPLINE SPECIFIC ELECTIVE: DIFFERENTIAL GEOMETRY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Differential Geometry	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra, Multivariate Calculus and Differential Equations

Learning Objectives

The primary objective of this course is to introduce:

- surfaces and parametrized surfaces.
- orientation on connected surfaces.
- geodesics on surfaces.
- Weingarten maps on oriented surfaces.
- arc length and curvature of oriented plane curves.
- curvatures of oriented surfaces.

Learning Outcomes

This course will enable the students to:

- understand the concepts of level sets and graphs of functions, smooth vector fields, tangent spaces of level sets.
- appreciate surfaces and parametrized surfaces, Gauss map, geodesics and parallel transport on oriented surfaces.
- know what the Weingarten map of an oriented surface is, realize it as shape operator and use it to compute curvature of oriented plane curves.
- find global parametrization and hence arc length of an oriented plane curve.
- compute various types of curvatures of surfaces.

Syllabus

Unit – 1 **(10 hours)**

Level sets in $\mathbb{R}^{n+1}$ and graphs of functions, Smooth vector fields and existence and uniqueness of their integral curves, Tangent spaces of level sets at regular points, Surfaces in $\mathbb{R}^{n+1}$ as inverse images of regular values of smooth functions, Necessary condition for extrema of functions on surfaces-Lagrange multipliers, Existence of a normal vector field on a connected surface, Orientation, Gauss map.

Unit – 2 **(13 hours)**

The notion of a geodesic on a surface, Existence and uniqueness of a geodesic on a surface through a given point with a given velocity vector thereof, Covariant derivative of a smooth vector field, Parallel vector field along a curve, Existence and uniqueness of a parallel vector field along a curve with a given initial vector, Weingarten map of a surface at a point, Local parametrization and curvature of a plane curve.

Unit – 3 **(10 hours)**

Global parametrization and arc length of an oriented plane curve, Differential 1-forms, Line integral of 1-forms over parametrized curves.

Unit – 4 **(12 hours)**

Parametrized surfaces with examples, Curvature of surfaces, Normal curvature of a surface at a point in a given direction, Principal curvatures, First and second fundamental forms, Gauss-Kronecker curvature and mean curvature.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] A. Pressley, *Elementary Differential Geometry*, Springer-Verlag London Limited, 2012.
[2] J. A. Thorpe, *Elementary Topics in Differential Geometry*, Springer (India) Pvt. Limited, 2004.

Suggested Readings

(i) W. Kuhnel, *Differential Geometry: Curves-Surfaces-Manifolds*, Third Edition, American Mathematical Society, 2015.
(ii) B. O' Neill, *Elementary Differential Geometry*, Second Edition, Academic Press INC., Academic Press, New York, 2006.

DISCIPLINE SPECIFIC ELECTIVE: DYNAMICAL SYSTEMS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Dynamical Systems	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology and Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- understand discrete and continuous systems with case studies to study nonlinear systems of ordinary differential equations and dynamical systems.
- understand the concepts, models and techniques to realize the real-world problems and stability of the systems along with the chaotic dynamic behaviour of models by understanding bifurcations.

Learning Outcomes

This course will enable the students to learn:

- formulation of mathematical models with the stability analysis near the equilibrium points.
- how the concept of phase portraits helps to analyse mathematical model graphically.
- the qualitative behaviour of the solution set of a given system of differential equations including the invariant sets and limiting behaviour of the dynamical system or flow defined by the system of differential equations.
- how different bifurcations explain the chaotic behaviour of the system.

Syllabus

Unit – 1 **(13 hours)**

Linear systems: Jordan forms, Stability theory; Nonlinear systems: Fundamental existence-uniqueness theorem, Dependence on initial conditions and parameters, Flow of a differential equation, Linearization, Stable manifold theorem, Hartman–Grobman theorem.

Unit – 2 **(10 hours)**

Stability and Lyapunov functions, Saddle points, Nodes, Foci, Centers and nonhyperbolic critical points, Center manifold theorem.

Unit – 3 **(12 hours)**

Limit sets and attractors, Periodic orbits and limit cycles, Poincaré map, Stable manifold theorem for periodic orbits, Poincare-Bendixson theorem.

Unit – 4 **(10 hours)**

Bifurcations at nonhyperbolic equilibrium points, Saddle node, Transcritical and Pitchfork bifurcations, Hopf bifurcation.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. W. Hirsch, S. Smale and R. L. Devaney, *Differential Equations, Dynamical Systems, and an Introduction to Chaos*, Third Edition, Academic Press, 2013.
[2] L. Perko, *Differential Equations and Dynamical Systems*, Third Edition, Springer Verlag, 2001.

Suggested Readings

(i) R. L. Devaney, *A First Course in Chaotic Dynamical Systems: Theory and Experiment*, CRC Press, Taylor & Francis, 2018.
(ii) S. H. Strogatz, *Nonlinear Dynamics and Chaos*, Second Edition, CRC Press, Taylor & Francis, 2018.
(iii) S. Wiggins, *Introduction to Applied Nonlinear Dynamical Systems and Chaos*, TAM Volume 2, Springer-Verlag, NY, 1990.

DISCIPLINE SPECIFIC ELECTIVE: FINITE ELEMENT METHODS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Finite Element Methods	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Differential Equations

Learning Objectives

The primary objective of this course is to:

- introduce basic aspects of finite element methods (FEM) including domain discretization, polynomial interpolation, application of boundary conditions, assembly of global arrays, and solution of the resulting algebraic systems.
- discuss the use of finite element methods in solving engineering problems in the domain of solid mechanics, fluid mechanics, heat transfer and electromagnetism.

Learning Outcomes

This course will enable the students to:

- use integral statement to deduce finite element approximations for the underlying linear partial differential equations.
- write special-purpose finite element programs within a procedural programming environment.
- use finite element methods to solve engineering problems in solids mechanics, fluid mechanics, heat transfer, and electromagnetism.
- assess the accuracy and reliability of finite element solutions and troubleshoot problems arising from errors in a given finite element analysis.

Syllabus

Unit – 1 **(12 hours)**

Basic concepts of weak formulation, Variational formulation of a one dimensional model equation, Basis function and finite element solutions, Collocation method, Ritz method, Least square method, Standard Galerkin method, FEM for model problem, Error estimate for FEM for model equation, Convergence analysis.

Unit – 2 **(11 hours)**

Various shapes of finite element, Higher order basis functions, Finite element methods for elliptic problems: Variational methods, Standard Galerkin method, Error estimate for FEM for elliptic problem, FEM for Poisson equation.

Unit – 3 **(12 hours)**

Finite element methods for parabolic problems: One dimensional model problems, Semi-discretization in space, Error estimates, Discretization in space and time, Galerkin method, Finite element methods for hyperbolic problems: Standard Galerkin method, Standard Galerkin method with strongly and weakly imposed boundary conditions.

Unit – 4 **(10 hours)**

Applications of the FEM to second order BVPs in one dimension, Applications of the FEM to linear elliptic, parabolic and hyperbolic equations.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. Evans, J. Blackledge and P. Yardley, *Numerical Methods for Partial Differential Equations*, Springer-Verlag, London, 2000.
[2] C. Johnson, *Numerical Solutions of Partial Differential Equations by Finite Element Methods*, *Cambridge University Press*, Cambridge, 1987.
[3] J. Whiteley, *Finite Element Methods - A Practical Guide*, Springer, 2016.

Suggested Readings

(i) Z. Chen, *Finite Element Methods and Their Applications*, Springer-Verlag, New York, 2005.
(ii) V. Thomee, *Galerkin Finite Element Methods for Parabolic Problems*, Second Edition, Springer-Verlag, Berlin, 2006.

DISCIPLINE SPECIFIC ELECTIVE: NUMERICAL METHODS FOR ORDINARY DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Numerical Methods for Ordinary Differential Equations	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- develop the basic theory underlying the numerical solution of differential equations.
- introduce the concepts of consistency, stability and convergence of finite difference methods.
- execute the numerical schemes for the solution of differential equations.

Learning Outcomes

This course will enable the students to:

- gain a thorough understanding of the fundamental concepts involved in the construction and analysis of finite difference schemes for solving ordinary differential equations (ODEs).
- apply various numerical methods based on finite difference approaches to obtain approximate solutions for both initial value problems (IVPs) and boundary value problems (BVPs).
- develop the ability to select appropriate finite difference methods for specific types of problems and effectively apply them to real world applications.

Syllabus

Unit – 1 **(11 hours)**

Initial value problems: Existence and uniqueness of solution, Finite difference equation, Truncation error, Single step methods for first order IVPs and system of IVPs- Family of explicit and implicit Runge–Kutta methods, Taylor series methods, Derivation, Truncation error, Consistency, Stability and convergence analysis.

Unit – 2 **(12 hours)**

IVPs for the system of ODEs, Consistency, Zero stability and convergence of linear multistep methods, Routh–Hurwitz criterion, Order and error constant, First Dahlquist Barrier, Local truncation error and global truncation error, Error bounds, Local error, Linear stability theory, Higher order differential equations.

Unit – 3 **(12 hours)**

Derivation of explicit and implicit multistep methods for IVPs and system of IVPs, Truncation error, Stability and convergence analysis of family of Nystrom method, Adams–Bashforth method,

Adams–Moulton method, Milne–Simpson method, Predictor corrector method, and Modified predictor corrector method, Hybrid method, Multistep methods for second order IVPs.

Unit – 4 **(10 hours)**

Linear BVPs for second order ordinary differential equations, Shooting method, Finite difference method, Collocation method, Derivative boundary conditions, Nonlinear two-point BVPs, Higher order finite difference methods, Stability, Truncation error and convergence analysis.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. K. Jain, S. R. K. Iyenger and R. K. Jain, *Numerical Methods for Scientific and Engineering Computations*, Seventh Edition, New Age International Publisher, 2019.

[2] J. D. Lambert, *Numerical Methods for Ordinary Differential Systems: The Initial Value Problem*, John Wiley & Sons, 1991.

Suggested Readings

(i) K. E. Atkinson, W. Han and D. E. Stewart, *Numerical Solution of Ordinary Differential Equations*, John Wiley & Sons, 2009.

(ii) J. C. Butcher, *The Numerical Analysis of Ordinary Differential Equations*, Second Edition, Wiley, New York, 2008.

(iii) L. Collatz, *The Numerical Treatment of Differential Equations*, Springer-Verlag, 1966.

DISCIPLINE SPECIFIC ELECTIVE: REPRESENTATION OF FINITE GROUPS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Representation of Finite Groups	**4**	**3**	**1**	**0**	**Same as for entry to M.Sc. Mathematics**	**Basics of Linear Algebra and Group Theory**

Learning Objectives

The primary objective of this course is to:

- represent finite groups as groups of matrices (via homomorphisms) and apply the tools of linear algebra to study the group structure.
- introduce the notion of Group algebra, which plays an essential role in classifying representations of groups.
- to discuss some applications of representations of finite groups, such as the Burnside's theorem.

Learning Outcomes

This course will enable the students to:

- define and construct examples of group representations, FG-modules, group algebras.
- grasp key concepts and tools of representation theory and establish a link between FG-modules and group representations.
- prove and apply Maschke's theorem and Schur's lemma to describe all irreducible representations of finite groups over the field of complex numbers.
- apply the theory of characters and group representations to gain insight into group structure, such as normal subgroups, and the solubility of groups.

Syllabus

Unit – 1 **(11 hours)**

Representation of groups, FG-modules and FG-submodules, and reducibility, Permutation modules, FG-modules and equivalent representations, Reducible and irreducible FG-modules, Group algebra of G, Regular FG-module and regular representations, FG-homomorphisms, Direct sum of FG-modules.

Unit – 2 **(11 hours)**

Maschke's theorem for FG-modules and consequences. Schur's lemma and its converse, Application of Schur's lemma, Irreducible modules and group algebra, Structure of group algebra and space of CG-homomorphisms.

Unit – 3 **(10 hours)**

Characters and their properties, Permutation and regular characters, Inner product, Number of irreducible characters, Orthogonality relations and finding normal subgroups.

Unit – 4 **(13 hours)**

Algebraic numbers, Algebraic integers and their properties, Character values, The Burnside's *(p,q)*-theorem and solubility of some particular groups.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. James and M. Liebeck, *Representations and Characters of Groups*, Second Edition, Cambridge University Press, 2005.

Suggested Readings

(i) C. W. Curtis and I. Reiner, *Representation Theory of Finite Groups and Associative Algebras*, American Mathematical Society, 2006.
(ii) W. Fulton and J. Harris, *Representation Theory - A First Course*, Springer-Verlag, 2004.
(iii) I. M. Issacs, *Character Theory of Finite Groups*, American Mathematical Society reprint, 2006.

DISCIPLINE SPECIFIC ELECTIVE: THEORY OF BOUNDED OPERATORS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Theory of Bounded Operators	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis

Learning Objectives

The primary objective of this course is to:

- introduce some classes of bounded linear operators which play a central role in both pure and applied mathematics.
- study the properties and spectral theory of these operators.

Learning Outcomes

This course will enable the students to understand:

- the spectrum and sub-divisions of spectrum of standard operators like shifts and multiplication.
- the spectral theorem for some classes of bounded linear operators.
- the concepts of compactness, self-adjointness and positivity of bounded linear operators.
- trace class and Hilbert–Schmidt operators.

Syllabus

Unit – 1 **(11 hours)**

Properties of spectrum and resolvent of bounded operators, Subdivision of the spectrum including point, approximate and compression spectrum.

Unit – 2 **(10 hours)**

Operators on Hilbert spaces, Adjoint operator, Projections and idempotents, Operations with projections, Invariant and reducing subspaces.

Unit – 3 **(14 hours)**

Compact operators on Hilbert spaces, Diagonalisation of compact self-adjoint operators, Spectral theorem and functional calculus for Compact normal operators, Positive operators, Compact operators on Banach spaces, Spectral theory of compact operators.

Unit – 4 **(10 hours)**

Polar decomposition, Singular values, Trace class operators, Trace norm and Hilbert Schmidt operators.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] R. Bhatia, *Notes on Functional Analysis*, Hindustan Book Agency, 2009.
[2] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.

Suggested Readings

(i) E. Kreyszig, *Introductory Functional Analysis with Applications*, John Wiley & Sons, 2006.
(ii) B. Simon, *Operator Theory: A Comprehensive Course in Analysis*, Part 4, American Mathematical Society, 2015.
(iii) S. R. Garcia, J. Mashregi and W. T. Ross, *Operator Theory by Example*, Oxford University Press, 2023.

DISCIPLINE SPECIFIC ELECTIVE: TOPOLOGICAL DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Topological Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- provide a strong background of topological dynamical systems including their applications.
- develop some useful and interesting dynamical properties like expansivity, shadowing and topological stability with supporting examples and results from symbolic and topological dynamics.
- introduce the celebrated Sarkovskii's theorem.

Learning Outcomes

This course will enable the students to:

- construct interesting examples of dynamical systems and topological conjugacy.
- visualize stable sets, omega sets and alpha limit sets.
- understand the applications of Sarkovskii's theorem.
- use subshifts of finite type to characterize irreducible matrices.
- prove key results on expansivity and shadowing regarding existence/non-existence, product, subspace and their different characterizations etc.
- find the class of topologically stable homeomorphisms.

Syllabus

Unit – 1 **(10 hours)**

Definition and examples (including real life examples) of dynamical systems, Orbits, Types of orbits, Topological conjugacy and orbits, Phase portrait-graphical analysis of orbit, Periodic points and stable sets, Omega and alpha limit sets and their properties.

Unit – 2 **(10 hours)**

Sarkovskii's theorem, Shift spaces and subshift, Subshift of finite type, Subshift represented by a matrix, Characterizations of irreducible matrices.

Unit – 3 **(13 hours)**

Definition and examples of expansive homeomorphisms, Properties of expansive homeomorphisms, Non-existence of expansive homeomorphism on the unit interval and unit circle, Generators and weak generators, Generators and expansive homeomorphisms.

Unit – 4 **(12 hours)**

Converging semi-orbits for expansive homeomorphisms, Definition, examples and properties of maps having shadowing property, Topological Anosov homeomorphisms and topological stability.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] N. Aoki and K. Hiraide, *Topological Theory of Dynamical Systems: Recent Advances*, North Holland Publications, 1994.
[2] M. Brin and G. Stuck, *Introduction to Dynamical Systems*, Cambridge University Press, 2004.

Suggested Readings

(i) D. C. Hanselman and B. Little field, *Mastering MATLAB*, Pearson, 2012.
(ii) D. Lind and B. Marcus, *An Introduction to Symbolic Dynamics and Coding*, Cambridge University Press, 1996.
(iii) C. Robinson, *Dynamical Systems*, *Stability, Symbolic Dynamics and Chaos*, Second Edition, CRC Press, Taylor & Francis, 1998.
(iv) J. de. Vries, *Elements of Topological Dynamics*, Springer, 1993.

Syllabi of Courses in Semester-IV of M.Sc. Mathematics under Structure-3 (Research)

Discipline Specific Elective (DSE) Courses

DISCIPLINE SPECIFIC ELECTIVE: ADVANCED FLUID DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Advanced Fluid Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Calculus and Partial Differential Equations

Learning Objectives

The primary objective of this course is to:

- prepare a foundation for advanced studies in compressible flow, boundary layer theory and magnetohydrodynamics.
- develop concepts, models, and techniques that enable problem-solving in compressible flow, boundary layer theory and magnetohydrodynamics.
- equip students with concepts and techniques to conduct research in the above mentioned domains.

Learning Outcomes

This course will enable the students to:

- learn conservation laws, first and second laws of thermodynamics, internal energy and entropy, different forms of energy equations and dimensional analysis.
- know about compressibility in real fluids, wave motion, sound waves, hyperbolic and dispersive waves, shock waves, their formation, properties and elementary analysis.
- know the concepts of boundary layer, boundary layer equations and their solutions, measurements of boundary layer thickness.
- understand the interaction between hydrodynamic processes and electromagnetic phenomena.
- formulate the basic equations of motion in inviscid and viscous conducting fluid flow and explain Alfven's theorem and magnetohydrodynamic (MHD) waves and MHD shocks.

Syllabus

Unit – 1 **(11 hours)**

Flow characteristics, Conservation laws, Equation of state of a substance, First and second law of thermodynamics, Internal energy and entropy, Energy equation, Nondimensionalizing the basic equations of incompressible viscous fluid flow, Nondimensional numbers.

Unit – 2 **(12 hours)**

Compressibility effects in real fluids, Equations of motion, Sound wave, Hyperbolic and dispersive waves, Isentropic gas flow, Flow through a nozzle, Method of characteristics, Shock jump conditions, Non-linear plane waves, Shock waves and their elementary analysis, Similarity solutions.

Unit – 3 **(11 hours)**

Boundary layer concept, Estimation of boundary layer thickness and friction forces, Prandtl's boundary layer equations, Boundary layer along a flat plate, Boundary layer thickness, General properties of the boundary layer equations, Similar solutions, Momentum and energy integral equations for the boundary layer.

Unit – 4 **(11 hours)**

Maxwell's electromagnetic field equations, Magnetohydrodynamic (MHD) approximations, Magnetic field equation, Magnetic Reynolds number, Magnetic body force, Equations of Motions of conducting fluid, Alfven's theorem, MHD waves, MHD shock waves.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] F. Chorlton, *Text Book of Fluid Dynamics*, CBS Publisher, 2005.
[2] H. Schlichting and K. Gersten, *Boundary Layer Theory*, Ninth Edition, Springer, 2017.
[3] G. B. Witham, *Linear and Nonlinear Waves*, John Wiley & Sons, 1999.

Suggested Readings

(i) K. R. Cramer and S. I. Pai, *Magnetofluid Dynamics for Engineers and Applied Physics*, McGraw Hill Book Co., New York, 1973.
(ii) Y. Shao-Wen, *Foundations of Fluid Mechanics*, PHI, New Delhi, 1960.

DISCIPLINE SPECIFIC ELECTIVE: BANACH AND C*-ALGEBRAS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Banach and C*-Algebras	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis and Topology

Learning Objectives

The primary objective of this course is to introduce:

- Banach algebras and C*-algebras.
- various ways to construct new operator algebras using given ones.
- spectrum of elements in Banach algebras and to study its properties.
- Gelfand representations of commutative Banach algebras and of C*-algebras.

Learning Outcomes

This course will enable the students to:

- familiarize with the representations of operator algebras.
- realize commutative Banach algebras and abelian C*-algebras as space of continuous functions on locally compact groups.
- understand the powerful tool of functional calculus.
- identify any C*-algebra as closed *-subalgebra of space of bounded linear operators on a Hilbert space.

Syllabus

Unit – 1 **(11 hours)**

Elementary properties and examples of Banach algebras, Ideals and quotients, Invertible elements, Spectrum and spectral radius, Spectral radius formula, Spectral mapping theorem (for polynomials), Gelfand–Mazur theorem.

Unit – 2 **(11 hours)**

Multiplicative linear functionals, Commutative Banach algebra, w*-topology, Gelfand transform of an element, Structure space, Gelfand representation.

Unit – 3 **(12 hours)**

Elementary properties and examples of C*-algebras, Unitization, Gelfand–Naimark representation of commutative C*-algebras, Continuous functional calculus, Spectral mapping theorem for normal elements, Positive elements of C*-algebras.

Unit – 4 **(11 hours)**

Ideals in C*-algebras, Approximate units, Quotients, Positive linear functionals, Gelfand–Naimark–Segal representation of C*-algebras.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.
[2] G. J. Murphy, *C*-algebras and Operator Theory*, Academic Press Inc., 1990.

Suggested Readings

(i) J. B. Conway, *A Course in Operator Theory, Graduate Texts in Mathematics*, Springer, 2007.
(ii) J. Dixmier, *C*-algebras*, North-Holland Publishing Company, 1977.
(iii) R. G. Douglas, *Banach Algebra Techniques in Operator Theory, Graduate Texts in Mathematics*, Springer, 1998.
(iv) E. Kaniuth, *A Course on Commutative Banach Algebras*, Graduate Texts in Mathematics, Springer, 2009.
(v) S. Kantorovitz, *Introduction to Modern Analysis*, Oxford Graduate Texts in Mathematics, Oxford University Press, 2006.
(vi) M. Takesaki, *Theory of Operator Algebras I*, Springer, 2002.

DISCIPLINE SPECIFIC ELECTIVE: CHAOS THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Chaos Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- introduce some useful and interesting notions like Topological Transitivity and Sensitive dependence on initial conditions.
- study different types of chaos including Devaney's chaos and finding their interrelationships.
- know classical result that period three implies chaos on intervals.
- relate chaos and decomposition theorems.
- study Topological entropy through open covers and also Bowen's definition of entropy, equivalence of these two definitions on compact metric spaces.
- study various interesting results related to topological entropy.

Learning Outcomes

This course will enable the students to:

- construct interesting examples of Topological transitive maps, Topological mixing maps etc.
- know classical examples of Devaney's chaotic maps like tent map, shift maps, logistic maps.
- study and compare different types of chaos.
- find relation between transitivity and chaos on intervals.
- relate chaos theory and classical decomposition theorems.
- study very useful notion of Topological entropy including its properties.
- calculate entropy of any homeomorphism of closed unit interval and of unit circle.

Syllabus

Unit – 1 **(12 hours)**

Topological Transitivity, Locally eventually onto maps, Topological mixing, Sensitive dependence on initial conditions, Devaney's definition of chaos, Transitivity and limit sets for continuous interval maps.

Unit – 2 **(11 hours)**

Characterizing topological mixing in terms of topological transitivity for continuous interval maps, Topological Weakly Mixing, Totally Transitive maps, Relation between transitivity and chaos on intervals, Logistic maps and shift maps as chaotic maps.

Unit – 3 **(12 hours)**

Various other definitions of chaos and their interrelationships. Period three implies chaos, Chaos and decomposition theorems including Bowen's decomposition theorem, Topological Entropy:

Definition using open covers, Examples and properties, Bowen's definition of topological entropy, Equivalence of two definitions, Topological version of Kolmogorov–Sinai theorem.

Unit – 4 **(10 hours)**

Topological Entropy of maps on a compact metric space, Topological Entropy of product maps, of iterations of a map, Topological entropy of an expansive homeomorphism on a compact metric space, of the two-sided shift, of any homeomorphism of the unit interval and of the unit circle.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] N. Aoki and K. Hiraide, *Topological Theory of Dynamical Systems: Recent Advances*, North Holland Publications, 1994.
[2] R. L. Devaney, *A First Course in Chaotic Dynamical Systems*, CRC Press, 2018.
[3] S. Ruette, *Chaos for Continuous Interval Maps: A Survey of Relationship Between Various Kinds of Chaos*, 2018.
[4] Peter Walters, *An Introduction to Ergodic Theory*, Springer, 2000.

Suggested Readings

(i) L. Alsedà, J. Llibre and M. Misiurewicz, *Combinatorial Dynamics and Entropy in Dimension One*, Advanced Series in Nonlinear Dynamics, World Scientific, 2000.
(ii) L. S. Block and W. A. Coppel, *Dynamics in One Dimension*, Springer, 2014.
(iii) M. Brin and G. Stuck, *Introduction to Dynamical Systems*, Cambridge University Press, 2015.

DISCIPLINE SPECIFIC ELECTIVE: CHARACTER THEORY OF FINITE GROUPS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Character Theory of Finite Groups	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra and Group Theory

Learning Objectives

The primary objective of this course is to:

- introduce characters of finite groups, class functions, and find the number of irreducible characters.
- find character tables of S_5, using characters of tensor products of CG-modules and powers of characters.
- define restricted characters and prove Clifford's theorem and its application to find the character table of A_5.
- explore some arithmetic properties of character values and introduce real characters.

Learning Outcomes

This course will enable the students to:

- define and construct examples of characters, prove some fundamental properties of characters, and calculate character tables of some small groups and symmetric groups, etc.
- construct new characters from given characters and understand the notion of induced and restricted characters.
- prove the Frobenius reciprocity theorem and the Frobenius–Schur count of involutions.

Syllabus

Unit – 1 **(10 hours)**

Group characters and their properties, Inner product of characters, Class functions and number of irreducible characters, Character tables and some orthogonality relations, Normal subgroups and lifted characters, Linear characters, Character tables of D_6, S_4, A_4.

Unit – 2 **(11 hours)**

Character of tensor products of CG-modules, Powers of characters, Decomposition of power of a character, Character table of symmetric group S_5, Character table of direct product of groups, Restricted characters, Constituents of a restricted character, Clifford's theorem, Restriction of symmetric groups to alternate groups in general normal subgroups of index two, Character table of A_5.

Unit – 3 **(12 hours)**

Induced CG-modules and their characters: Homomorphisms, Transitivity of induction, Frobenius reciprocity theorem, Values of induced characters. Algebraic integers, Some properties of degrees of irreducible characters and arithmetic properties of character values.

Unit – 4 **(12 hours)**

Real representations, Real conjugacy classes and real characters, Characters which can be realized over the reals, RG-modules and CG-modules, G-invariant symmetric bilinear form, Indicator function, The Frobenius–Schur count of involutions**.**

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. James and M. Liebeck, *Representations and Characters of Groups*, Second Edition, Cambridge University Press, 2005.

Suggested Readings

(i) I. M. Issacs, *Character Theory of Finite Groups*, American Mathematical Society reprint, 2006.
(ii) W. Ledermann, *Introduction to Group Characters*, Second Edition, Cambridge University Press, 1987.

DISCIPLINE SPECIFIC ELECTIVE: COMPUTATIONAL FLUID DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Computational Fluid Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Partial Differential Equation (Undergraduate level)

Learning Objectives

The primary objective of this course is to teach:

- various numerical schemes on finite difference and finite volume methods for solving PDEs.
- discretization errors and grid dependence.
- some real-world applications of PDEs and fluid dynamics.
- discretization of governing equations of diffusion, convection-diffusion, fluid flow and thereby computing the numerical solutions using the flow variables using algorithms.

Learning Outcomes

This course will enable the students to learn:

- techniques for solving the PDEs along with some initial and boundary conditions by using the finite difference and finite volume methods.
- the basic conservation principles of mass, momentum, energy, discretization of governing equations.
- discretization techniques.
- some popular algorithms like SIMPLE and SIMPLER used to obtain the solutions of steady and unsteady flow problems by finite volume methods.

Syllabus

Unit – 1 **(12 hours)**

Basics of discretization using finite differences, Various single and multi-step explicit and implicit finite difference schemes for 1-D and 2-D parabolic and hyperbolic initial boundary value problems, Alternating Direction Implicit schemes (ADI) for 2-D parabolic and hyperbolic equations, Order of accuracy, Consistency, Stability and convergence of a finite difference scheme, Courant Friedrich Lewy condition.

Unit – 2 **(12 hours)**

Finite difference schemes for second and fourth order 2-D elliptic boundary value problem and applications, Finite volume method for diffusion and convection-diffusion equations, Discretization of one and two-dimensional steady state diffusion and convection-diffusion equations, Central difference, Upwind, Exponential, Hybrid, Power-law and QUICK schemes and their properties.

Unit – 3 **(11 hours)**

Flow field calculation, Pressure-velocity coupling, Vorticity-stream function approach, Primitive

variables, Staggered grid, Pressure and velocity corrections, Pressure correction equation, SIMPLE and SIMPLER algorithms.

Unit – 4 **(10 hours)**

Finite volume methods for unsteady flows, Discretization of one-dimensional transient heat conduction, Explicit, fully implicit and Crank–Nicolson schemes, Implementation of boundary conditions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. C. Strikweda, *Finite Difference Schemes and Partial Differential Equations*, Second Edition, SIAM, 2004.

[2] H. K. Versteeg and W. Malalasekera, *An Introduction to Computational Fluid Dynamics: The Finite Volume Method*, Second Edition, Pearson, 2008.

Suggested Readings

(i) J. D. Anderson, *Computational Fluid Dynamics*, McGraw-Hill, 1995.

(ii) S. V. Patankar, *Numerical Heat Transfer and Fluid Flow*, CRC Press, Taylor and Francis, Indian Edition, 2017.

(iii) R. H. Pletcher, J. C. Tannehill and D. A. Anderson, *Computational Fluid Mechanics and Heat Transfer*, CRC Press, Taylor and Francis, 2013.

(iv) J. W. Thomas, *Numerical Partial Differential Equations: Finite Difference Methods*, Springer, 2013.

DISCIPLINE SPECIFIC ELECTIVE: DIFFERENTIAL TOPOLOGY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Differential Topology	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- introduce the concepts of topological manifolds, smooth structures, smooth manifolds, and manifolds with boundary.
- develop an understanding of smooth functions, smooth maps, diffeomorphisms, and tangent spaces.
- explain the Inverse function theorem, immersions and submersions.
- develop the fundamental concepts of 2-manifolds and distinguish between orientable and non-orientable surfaces.
- explore the properties of compact and connected surfaces.

Learning Outcomes

This course will enable the students to:

- identify and construct examples of topological manifolds, smooth structures and manifolds with and without boundary.
- demonstrate understanding of diffeomorphisms and tangent spaces.
- apply the Inverse function theorem, immersions and submersions.
- define key concepts such as 2-manifolds, orientability, compactness, connectedness and boundary of a surface.
- differentiate between orientable and non-orientable surfaces using examples such as the sphere, torus, Möbius strip and Klein bottle.

Syllabus

Unit – 1 **(12 hours)**

Topological manifolds, Topological properties of manifolds, Smooth structures, Examples of smooth manifolds, Manifolds with boundary.

Unit – 2 **(11 hours)**

Smooth functions and smooth maps, Lie groups, Diffeomorphisms.

Unit – 3 **(10 hours)**

Derivatives and tangents, Inverse function theorem, Immersions and submersions.

Unit – 4 **(12 hours)**

Complexes, Connected sum of two surfaces, Non-orientable surfaces (2- Manifolds), Compact and connected surfaces, Classification of compact and connected surfaces with and without boundary.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] V. Guillemin and Alan Pollack, *Differential Topology*, Prentice-Hall, 1974.
[2] L. C. Kinsey, *Topology of Surfaces*, Springer Verlag, 1997.
[3] J. M. Lee, *Introduction to Smooth Manifolds*, Second Edition, Springer, 2013.

Suggested Readings

(i) L. Conlon, *Differentiable Manifolds*, Second Edition, Birkhäuser Advanced Texts, 2001.
(ii) M. Spivak, *A Comprehensive Introduction to Differential Geometry*, Volume 1, Third Edition, Publish or Perish, Huston, Texas, 1999.
(iii) L. W. Tu, *Introduction to Manifolds*, Second Edition, Springer, 2011.
(iv) F. W. Warner, *Foundations of Differentiable Manifolds and Lie Group*, Springer-Verlag, 1983.

DISCIPLINE SPECIFIC ELECTIVE: GENERAL MEASURE THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: General Measure Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Measure Theory and Topology

Learning Objectives

The primary objective of this course is to introduce:

- real valued and complex valued measures.
- decomposition of measure spaces and of measures.
- extension of a premeasure to a measure, Lebesgue measure on Euclidean spaces.
- representation of measures and functionals in terms of integrals.
- product measures.

Learning Outcomes

This course will enable the students to:

- appreciate signed measures and complex measures, mutual singularity of measures, Hahn and Jordan decompositions, Lebesgue decomposition, Radon–Nikodym theorem.
- verify conditions under which a set function defined on a collection of subsets of a set has an extension to a measure on a sigma-algebra.
- apply Riesz representation theorem for bounded linear functionals on L^p-spaces.
- understand product measure and the results of Fubini and Tonelli, and express the Lebesgue measure on Euclidean spaces as a product measure.
- apply Riesz–Markov representation theorem for the bounded linear functionals on the space of continuous functions.

Syllabus

Unit – 1 **(13 hours)**

Signed measures, Hahn and Jordan decompositions, Mutually singular measures, Radon–Nikodym theorem, Lebesgue decomposition, Complex measure.

Unit – 2 **(10 hours)**

The Carathéodory extension theorem, Lebesgue measure on $\mathbb{R}^n$, Regularity and translation invariance of Lebesgue measure on $\mathbb{R}^n$.

Unit – 3 **(10 hours)**

Riesz representation theorem for the dual of L^p-spaces, Product measures, Fubini's theorem, Tonelli's theorem.

Unit – 4 **(12 hours)**

Locally compact Hausdorff spaces and construction of Radon measure, Riesz–Markov representation theorem for positive linear functionals on $C_c(X)$, Riesz representation theorem for the dual of $C(X)$.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] H. L. Royden and P. M. Fitzpatrick, *Real Analysis*, Fourth Edition, Pearson, 2015.
[2] M. E. Taylor, *Measure Theory and Integration*, American Mathematical Society, 2006.

Suggested Readings

(i) G. B. Folland, *Real Analysis: Modern Techniques and Their Applications*, Second Edition, Wiley, New York, 1999.
(ii) P. R. Halmos, *Measure Theory*, Springer Science + Business Media, LLC, 2014.
(iii) E. M. Stein and R. Shakarchi, *Real Analysis: Measure Theory, Integration and Hilbert Spaces*, New Age International Publishers, New Delhi, 2010.

DISCIPLINE SPECIFIC ELECTIVE: NONSMOOTH OPTIMIZATION

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Nonsmooth Optimization	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Nonlinear Optimization

Learning Objectives

The primary objective of this course is to:

- understand the tools to deal with nonsmooth convex functions.
- study conjugate duality in terms of conjugate functions for constrained nonlinear optimization problems.
- introduce numerical techniques to solve constrained nonlinear optimization problems.

Learning Outcomes

This course will enable the students to learn:

- the notions of subgradients and subdifferentials for nonsmooth convex functions.
- the use of conjugate functions to develop the theory of conjugate duality.
- about numerical methods like gradient descent method, gradient projection method, Newton's method and conjugate gradient method.
- penalty approach technique to solve constrained nonlinear optimization problems.

Syllabus

Unit – 1 **(11 hours)**

Extended real valued functions, Proper convex functions, Closure of convex functions, Differential derivatives, Subgradients and subdifferentials.

Unit – 2 **(12 hours)**

Conjugate functions, Biconjugate functions, Perturbation functions, Closure of convex functions, Directional derivatives, Subgradients and subdifferentials.

Unit – 3 **(12 hours)**

Gradient descent method, Gradient projection method, Newton's method, Conjugate gradient method.

Unit – 4 **(10 hours)**

Penalty function methods, Exterior penalty function, Interior penalty functions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. Avriel, *Nonlinear Programming: Analysis and Methods*, Dover Publications, 2003.

[2] O. Güler, *Foundations of Optimization*, Springer, 2010.

Suggested Readings

(i) A. Bagirov, N. Karitsa and M. M. Makela, *Introduction to Nonsmooth Optimization: Theory, Practice and Software*, Springer, 2014.
(ii) M. S. Bazaraa, H. D. Sherali and C. M. Shetty, *Nonlinear Programming: Theory and Algorithms,* Third Edition, John Wiley & Sons, 2013.
(iii) D. G. Luenberger and Y. Ye, *Linear and Nonlinear Programming*, Springer, 2008.

DISCIPLINE SPECIFIC ELECTIVE: PROBABILITY THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Probability Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Measure Theory

Learning Objectives

The primary objective of this course is to introduce:

- probability space as a measure space and random variables as measurable functions.
- expectation and moments of random variables.
- notion of convergence in probability.
- conditioning on sub-σ-algebra.

Learning Outcomes

This course will enable the students to learn:

- about probability or uncertainty in abstract setting.
- moments and expectation of random variables which help to understand applications of probability in industry.
- how to apply the idea of convergence in probability.
- weak law and strong law of large numbers and their applications.

Syllabus

Unit – 1 **(11 hours)**

Probability: σ-algebra, Constructing probability triples, The extension theorem, Random variables, Independence of events, Continuity of probabilities, Limit events, The Borel–Cantelli Lemma.

Unit – 2 **(10 hours)**

Expected values: Simple, general non-negative and arbitrary random variables, Moment generating functions, Markov's inequality, Chebyshev's inequality.

Unit – 3 **(12 hours)**

Convergence of random variables: Convergence almost surely, Convergence in probability, Weak law of large numbers, Strong law of large numbers.

Unit – 4 **(12 hours)**

Distributions of random variables: Examples of distributions, Characteristic functions, The central limit theorem, Conditional probability, Conditioning on random variable, Conditioning on a sub-σ-algebra, Conditional variance.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. S. Rosenthal, *A First Look at Rigorous Probability Theory*, Second Edition, World Scientific, Singapore, 2006.

Suggested Readings

(i) W. Feller, *An Introduction to Probability Theory and its Applications*, Volume 1, Third Edition, Wiley, 2008.
(ii) J. E. Michael and J. S. Rosenthal, *Probability and Statistics: The Science of Uncertainty*, Second Edition, W. H. Freeman & Co Ltd., 2009.
(iii) S. Ross, *A First Course in Probability*, Tenth Edition, Pearson Education, 2022.
(iv) D. W. Stroock, *Probability Theory, An Analytic View*, Cambridge University Press, 2024.

DISCIPLINE SPECIFIC ELECTIVE: SIMPLICIAL HOMOLOGY THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Simplicial Homology Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- introduce the foundations of simplicial complexes and homology theory.
- develop an understanding of chain mappings and induced homomorphisms.
- apply these concepts to establish fundamental results in topology such as Euler–Poincaré theorem, Brouwer's and Lefschetz fixed-point theorems.

Learning Outcomes

This course will enable the students to:

- identify hyperplanes, simplexes and finite simplicial complexes as subsets of a Euclidean space.
- learn the idea of compact triangulable spaces as geometric carriers of finite simplicial complexes (polyhedra).
- learn the use of homological algebra to associate simplicial homology groups and illustrate it by computing simplicial homology groups of some well-known compact polyhedral.
- prove important applications of simplicial homology theory like invariance of dimension, Euler's formula, Lefschetz and Brouwer's fixed point theorems.

Syllabus

Unit – 1 **(11 hours)**

Geometric simplexes, Geometric complexes and polyhedra, Simplicial maps, Simplicial approximation of continuous maps between two polyhedral.

Unit – 2 **(12 hours)**

Orientation of geometric complexes, Chain complexes, Simplicial homology groups, Structure of homology groups, Relative homology groups, Computation of homology groups, Homology groups of n-sphere.

Unit – 3 **(12 hours)**

Chain mappings, Chain derivation, Chain homotopy, Contiguous maps, Homomorphism induced by continuous maps between two polyhedra, Functorial property of induced homomorphisms, Topological and homotopy invariance of homology groups.

Unit – 4 **(10 hours)**

Euler–Poincaré theorem and Euler's formula, Invariance of dimension, Brouwer's fixed point theorem, Degree of self-mappings of $\mathbb{S}^n$, Brouwer's degree theorem, Existence of eigen values, Lefschetz fixed point theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] F. H. Croom, *Basic Concepts of Algebraic Topology*, Springer, 1978.

Suggested Readings

(i) M. K. Agoston, *Algebraic Topology: A First Course*, Marcel Dekker, 1976.
(ii) M. A. Armstrong, *Basic Topology*, Springer, 1983.
(iii) S. Deo, *Algebraic Topology - A Primer*, Second Edition, Hindustan Book Agency, 2018.

DISCIPLINE SPECIFIC ELECTIVE: THEORY OF NON-COMMUTATIVE RINGS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Theory of Non-commutative Rings	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Groups and Rings

Learning Objectives

The primary objective of this course is to:

- give students an understanding of Wedderburn–Artin theory of semisimple rings.
- develop Jacobson's general theory of radicals, prime and semiprime rings, and primitive and semiprimitive rings.
- introduce the structure of primitive rings as a generalisation of the Wedderburn–Artin theorem on Artinian simple rings.

Learning Outcomes

This course will enable the students to:

- know about an extensive variety of rings, including free rings, Weyl algebra, Hilbert twist and triangular ring.
- understand the module theoretic definition of semisimple rings and how it leads to the Wedderburn–Artin structure theorem on their complete classification.
- know Jacobson's general theory of radicals, semiprime rings, prime, primitive and semiprimitive rings and their structures.
- understand the significance of the fundamental result 'Density Theorem' and its consequences on the structure of primitive rings.

Syllabus

Unit – 1 **(11 hours)**

Simple rings, Reduced rings, Dedekind-finite rings, Algebra, Quaternions, Free k-rings, Rings with generators and relations, Weyl algebra, Formal power series ring, Hilbert's twist ring, Differential polynomial rings, Derivation and inner derivation on a ring, Triangular rings, Characterization of one-sided and two-sided ideals in such rings.

Unit – 2 **(11 hours)**

Noetherian and Artinian rings, Examples of one-sided Noetherian and Artinian triangular rings, Twisted polynomial ring and Quotient of free $\mathbb{Z}$-ring, Semisimple rings, Structure of semisimple rings: Wedderburn–Artin's theorem.

Unit – 3 **(10 hours)**

Structure theorem of simple left Artinian rings, Jacobson radical, J-semisimple rings, Nil and nilpotent ideals, Connection between semisimple and J-semisimple rings, Hopkins–Levitzki theorem, Nakayama's lemma.

Unit – 4 **(13 hours)**

Prime radical, Characterisation of prime and semiprime ideals, Prime and semiprime rings, Structure theorem of primitive rings, Density theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] T.-Y. Lam, *A First Course in Noncommutative Rings*, Springer, 2001.

Suggested Readings

(i) I. N. Herstein, *Noncommutative Rings*, The Mathematical Association of America, 2005.
(ii) T. W. Hungerford, *Algebra*, Springer-Verlag, New York, 1981.
(iii) L. H. Rowen, *Ring Theory*, Student Edition, Academic Press, 1991.

DISCIPLINE SPECIFIC ELECTIVE: THEORY OF UNBOUNDED OPERATORS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Theory of Unbounded Operators	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis and Bounded Operators

Learning Objectives

The primary objective of this course is to:

- introduce the notion of unbounded operators.
- develop the theory of operator semigroups and understand their role in applications, particularly for solving differential equations.

Learning Outcomes

This course will enable the students to:

- identify closed and closable linear operators on Banach spaces.
- compute adjoints of unbounded linear operators.
- understand spectral properties of some unbounded operators.
- comprehend the role unbounded operators and semigroups play in applications, particularly in studying solutions of differential equations.

Syllabus

Unit – 1 **(10 hours)**

Unbounded linear operators, Hilbert adjoints, Hellinger–Toeplitz theorem, Hermitian, symmetric and self-adjoint linear operators, Closed linear operators, Closable operators and their closures on Banach spaces.

Unit – 2 **(12 hours)**

Cayley transform, Deficiency indices, Spectral properties of self-adjoint operators, Multiplication and differentiation operators and their spectra.

Unit – 3 **(11 hours)**

Analytic properties of exponential functions, Matrix Semigroups, Uniformly continuous semigroups, Semigroups on Hilbert spaces, Strongly continuous semigroups.

Unit – 4 **(12 hours)**

Generators of semigroups and their resolvents, Hille–Yosida theorem (for contraction semigroup), Dissipative operators and their properties, Lumer–Phillips theorem, Generators of Group, Stone's theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Syllabi of Courses in Semester-I of One-year M.Sc. Mathematics under Structure-1 (Only Course work)

Discipline Specific Core (DSC) Courses

DISCIPLINE SPECIFIC CORE – 1: FLUID DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC-1: Fluid Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Calculus and Partial Differential Equations

Learning Objectives

The objective of this course is to:

- prepare a mathematical foundation to study the motion of fluids.
- develop concepts, models, and techniques to solve problems of fluid flow.
- develop the ability to conduct advanced studies and research in the broad field of fluid dynamics.

Learning Outcomes

After studying this course, the student will be able to:

- understand the concept of fluids, their classification, flow lines, models and approaches to study fluid flow.
- formulate mass and momentum conservation principles and obtain their solution for non-viscous flow.
- know potential flow, Bernoulli's equation, Kelvin's minimum energy and circulation theorems.
- understand two- and three-dimensional motion, complex potential, circle theorem, Blasius theorem, Weiss's and Butler's sphere theorems.
- apply the concept of stress and strain in viscous flow to derive Navier–Stokes equation of motion and energy equation.

Syllabus

Unit – 1 **(10 hours)**

Classification of fluids, Continuum model, Eulerian and Lagrangian approach of description, Differentiation following the fluid motion, Flow lines, vorticity and circulation, Conservation of mass: Equation of continuity, Boundary surface.

Unit – 2 **(12 hours)**

Forces in fluid motion, Conservation of momentum: Euler's equation of motion, Theory of irrotational motion: Integration of Euler's equation under different conditions, Bernoulli's equation, Impulsive motion, Kelvin's minimum energy and circulation theorems, Potential theorem.

Unit – 3 **(13 hours)**

Two-dimensional motion: Complex potential, Line sources, sinks, doublets and vortices, Two-dimensional image system, Milne–Thomson circle theorem, Images with respect to a plane and cylinder, Blasius theorem. Three-dimensional flows, Weiss's sphere theorem, Images with respect to sphere, Axi-symmetric flow, Stokes stream function, Butler's sphere theorem, Flow past spheres and cylinders.

Unit – 4 **(10 hours)**

Stress and strain analysis, Newton's law of viscosity, Laminar flow, Navier–Stokes equation of motion, Steady flow between parallel planes and Poiseuille flow, Constitutive equation, Energy equation.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] F. Chorlton, *Text Book of Fluid Dynamics*, CBS Publisher, 2005.
[2] R. W. Fox, P. J. Pritchard and A. T. McDonald, *Introduction to Fluid Mechanics*, Seventh Edition, John Wiley & Sons, 2009.
[3] P. K. Kundu, I. M. Cohen and D. R. Dowling, *Fluid Mechanics*, Sixth Edition, Academic Press, 2016.

Suggested Readings

(i) L. M. Milne-Thomson, *Theoretical Hydrodynamics*, The Macmillan company, USA, 1969.
(ii) D. E. Rutherford, *Fluid Dynamics*, Oliver and Boyd Ltd., 1978.

DISCIPLINE SPECIFIC CORE – 2: MEASURE AND INTEGRATION

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC-2: Measure and Integration	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Real Analysis and Riemann Integration

Learning Objectives

The primary objective of this course is to:

- extend the notion of length of an interval with the introduction of the concept of Lebesgue outer measure for any subset of real line.
- investigate the properties of Lebesgue measurable sets and functions.
- familiarize students with the Lebesgue integration of functions and its comparison with Riemann integration.
- generalize the concepts of measure and integration to an abstract space.

Learning Outcomes

This course will enable the students to:

- verify whether a given subset of $\mathbb{R}$ or a real valued function is measurable.
- understand the requirement and the concept of the Lebesgue integral (a generalization of the Riemann integration) along with its properties.
- understand the statements and proofs of the fundamental integral convergence theorems and demonstrate their applications.
- carry out a comprehensive study of functions of bounded variation and their utility in understanding differentiation and integration.
- apply Hölder and Minkowski inequalities in L^p-spaces and understand completeness of L^p-spaces.

Syllabus

Unit – 1 **(14 hours)**

Lebesgue outer measure, Measurable sets, Lebesgue measure, Borel sets, Regularity, Measurable functions, Borel and Lebesgue measurability, Non-measurable sets.

Unit – 2 **(13 hours)**

Integration of nonnegative functions, General integral, Integration of series, Riemann and Lebesgue integrals.

Unit – 3 **(8 hours)**

Functions of bounded variation, Lebesgue's differentiation theorem, Differentiation and integration, Absolute continuity of functions.

Unit – 4 **(10 hours)**

Measures and outer measures, Measure spaces, Integration with respect to a measure, L^p-spaces, Hölder's and Minkowski's inequalities, Completeness of L^p-spaces.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. de Barra, *Measure Theory and Integration*, Ellis Horwood Ltd., Chichester, John Wiley & Sons, Inc., New York, 1981 (Indian Reprint, 2014).

Suggested Readings

(i) M. Capinski and P. E. Kopp, *Measure, Integral and Probability*, Springer, 2005.
(ii) E. Hewitt and K. Stromberg, *Real and Abstract Analysis: A Modern Treatment of the Theory of Functions of a Real Variable*, Springer, Berlin, 1975.
(iii) H. L. Royden and P.M. Fitzpatrick, *Real Analysis*, Fourth Edition, Pearson, 2015.

Discipline Specific Elective (DSE) Courses

DISCIPLINE SPECIFIC ELECTIVE – 1 (i): COMMUTATIVE ALGEBRA

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-1 (i): Commutative Algebra	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra and Field Theory

Learning Objectives

The objective of this course is to:

- develop a solid understanding of the structure of commutative rings, ideals, their radicals, extension, contraction etc.
- study important constructions such as total quotient rings, localizations.
- develop basic foundation in other areas of mathematics such as algebraic geometry, algebraic number theory.

Learning Outcomes

This course will enable the students to:

- know the localization of rings at a prime ideal that is an algebraic analogue of the geometric notion concentrating attention near a point.
- know more closely the polynomial rings, power series rings in one or more variables over a commutative ring and their prime spectrum.
- define, identify, and elaborate integral closure of rings, valuations rings, discrete valuation rings, structure theorem of Artin rings.

Syllabus

Unit – 1 **(12 hours)**

Radical of an ideal, Prime avoidance lemma, Chinese remainder theorem, Extension and contraction of ideals, Jacobson radical of a ring, Nakayama lemma, Tensor product of modules.

Unit – 2 **(13 hours)**

Rings and modules of fractions, Localization, Local properties, Primary decomposition, First and second uniqueness theorem of primary decomposition, Associated prime ideals of decomposable ideals.

Unit – 3 **(10 hours)**

Integral ring extensions, Going up theorem, Going down theorem, Integrally closed domains, Valuation rings, Hilbert's Nullstellensatz theorem.

Unit – 4 **(10 hours)**

Noetherian rings, Primary decomposition in Noetherian rings, Artin rings, Structure theorem for Artin rings, Discrete valuation rings.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. F. Atiyah and I. G. MacDonald, *Introduction to Commutative Algebra*, CRC Press, Taylor & Francis, 2018.

Suggested Readings

(i) D. Eisenbud, *Commutative Algebra with a View Towards Algebraic Geometry*, Springer, 2004.
(ii) R. Y. Sharp, *Steps in Commutative Algebra*, Cambridge University Press, 2000.
(iii) B. Singh, *Basic Commutative Algebra*, World Scientific, 2011.
(iv) O. Zariski and P. Samuel, *Commutative Algebra*, Volume I & II, Springer, 1975.

DISCIPLINE SPECIFIC ELECTIVE – 1 (ii): DYNAMICAL SYSTEMS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-1 (ii): Dynamical Systems	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology and Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- understand discrete and continuous systems with case studies to study nonlinear systems of ordinary differential equations and dynamical systems.
- understand the concepts, models and techniques to realize the real-world problems and stability of the systems along with the chaotic dynamic behaviour of models by understanding bifurcations.

Learning Outcomes

This course will enable the students to learn:

- formulation of mathematical models with the stability analysis near the equilibrium points.
- how the concept of phase portraits helps to analyse mathematical model graphically.
- the qualitative behaviour of the solution set of a given system of differential equations including the invariant sets and limiting behaviour of the dynamical system or flow defined by the system of differential equations.
- how different bifurcations explain the chaotic behaviour of the system.

Syllabus

Unit – 1 **(13 hours)**

Linear systems: Jordan forms, Stability theory; Nonlinear systems: Fundamental existence-uniqueness theorem, Dependence on initial conditions and parameters, Flow of a differential equation, Linearization, Stable manifold theorem, Hartman–Grobman theorem.

Unit – 2 **(10 hours)**

Stability and Lyapunov functions, Saddle points, Nodes, Foci, Centers and nonhyperbolic critical points, Center manifold theorem.

Unit – 3 **(12 hours)**

Limit sets and attractors, Periodic orbits and limit cycles, Poincaré map, Stable manifold theorem for periodic orbits, Poincare-Bendixson theorem.

Unit – 4 **(10 hours)**

Bifurcations at nonhyperbolic equilibrium points, Saddle node, Transcritical and Pitchfork bifurcations, Hopf bifurcation.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. W. Hirsch, S. Smale and R. L. Devaney, *Differential Equations, Dynamical Systems, and an Introduction to Chaos*, Third Edition, Academic Press, 2013.
[2] L. Perko, *Differential Equations and Dynamical Systems*, Third Edition, Springer Verlag, 2001.

Suggested Readings

(i) R. L. Devaney, *A First Course in Chaotic Dynamical Systems: Theory and Experiment*, CRC Press, Taylor & Francis, 2018.
(ii) S. H. Strogatz, *Nonlinear Dynamics and Chaos*, Second Edition, CRC Press, Taylor & Francis, 2018.
(iii) S. Wiggins, *Introduction to Applied Nonlinear Dynamical Systems and Chaos*, TAM Volume 2, Springer-Verlag, NY, 1990.

DISCIPLINE SPECIFIC ELECTIVE – 1 (iii): INTRODUCTION TO TOPOLOGY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-1 (iii): Introduction to Topology	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Metric Spaces

Learning Objectives

The primary objective of this course is to introduce:

- basic principles of point-set topology, including bases and subbases for a topology.
- continuity, homeomorphisms, and different types of topologies, such as product and box topologies.
- key notions of connectedness and local connectedness.
- compactness and its significance in topological spaces.

Learning Outcomes

This course will enable the students to:

- analyze subsets of topological spaces by determining their interior, closure, boundary, and limit points, as well as identifying bases and subbases.
- identify continuous functions between topological spaces, analyze mappings into product spaces, and compare topological properties of different spaces.
- evaluate the connectedness and path connectedness of the product of an arbitrary family of spaces.
- understand key classifications of topological spaces, including Hausdorff spaces, first and second countable spaces, and separable spaces.
- explore advanced concepts such as limit point compactness and Tychonoff's theorem.

Syllabus

Unit – 1 **(10 hours)**

Topological spaces, Basis, Order topology, Subspace topology, Metric topology, Closed set and limit points, Hausdorff spaces.

Unit – 2 **(12 hours)**

Continuous functions, Homeomorphism, The box and product topologies, Metrizability of products of metric spaces**,** Connected and path connected spaces.

Unit – 3 **(12 hours)**

Locally connected and locally path connected spaces, Connectedness of product of spaces, First and second countable spaces, Separable spaces.

Unit – 4 **(11 hours)**

Compact spaces, The Tychonoff theorem, Limit point compactness, Sequential compactness.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. R. Munkres, *Topology*, Updated Second Edition, Pearson, 2021.
[2] T. B. Singh, *Introduction to Topology*, Springer Nature, 2019.

Suggested Readings

(i) G. E. Bredon, *Topology and Geometry*, Springer, 2014.
(ii) J. Dugundji, *Topology*, Allyn and Bacon Inc., Boston, 1978.
(iii) J. L. Kelley, *General Topology*, Dover Publications, 2017.
(iv) G. F. Simmons, *Introduction to Topology and Modern Analysis*, McGraw Hill Education, 2017.
(v) L. A. Steen and J. A. Seebach, *Counterexamples in Topology*, Dover Publications, 2013.
(vi) S. Willard, *General Topology*, Dover Publications, 2004.

DISCIPLINE SPECIFIC ELECTIVE – 1 (iv): THEORY OF BOUNDED OPERATORS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-1 (iv): Theory of Bounded Operators	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis

Learning Objectives

The primary objective of this course is to:

- introduce some classes of bounded linear operators which play a central role in both pure and applied mathematics.
- study the properties and spectral theory of these operators.

Learning Outcomes

This course will enable the students to understand:

- the spectrum and sub-divisions of spectrum of standard operators like shifts and multiplication.
- the spectral theorem for some classes of bounded linear operators.
- the concepts of compactness, self-adjointness and positivity of bounded linear operators.
- trace class and Hilbert–Schmidt operators.

Syllabus

Unit – 1 **(11 hours)**

Properties of spectrum and resolvent of bounded operators, Subdivision of the spectrum including point, approximate and compression spectrum.

Unit – 2 **(10 hours)**

Operators on Hilbert spaces, Adjoint operator, Projections and idempotents, Operations with projections, Invariant and reducing subspaces.

Unit – 3 **(14 hours)**

Compact operators on Hilbert spaces, Diagonalisation of compact self-adjoint operators, Spectral theorem and functional calculus for Compact normal operators, Positive operators, Compact operators on Banach spaces, Spectral theory of compact operators.

Unit – 4 **(10 hours)**

Polar decomposition, Singular values, Trace class operators, Trace norm and Hilbert Schmidt operators.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] R. Bhatia, *Notes on Functional Analysis*, Hindustan Book Agency, 2009.
[2] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.

Suggested Readings

(i) E. Kreyszig, *Introductory Functional Analysis with Applications*, John Wiley & Sons, 2006.
(ii) B. Simon, *Operator Theory: A Comprehensive Course in Analysis*, Part 4, American Mathematical Society, 2015.
(iii) S. R. Garcia, J. Mashregi and W. T. Ross, *Operator Theory by Example*, Oxford University Press, 2023.

DISCIPLINE SPECIFIC ELECTIVE – 2 (i): NUMERICAL METHODS FOR ORDINARY DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-2 (i): Numerical Methods for Ordinary Differential Equations	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- develop the basic theory underlying the numerical solution of differential equations.
- introduce the concepts of consistency, stability and convergence of finite difference methods.
- execute the numerical schemes for the solution of differential equations.

Learning Outcomes

This course will enable the students to:

- gain a thorough understanding of the fundamental concepts involved in the construction and analysis of finite difference schemes for solving ordinary differential equations (ODEs).
- apply various numerical methods based on finite difference approaches to obtain approximate solutions for both initial value problems (IVPs) and boundary value problems (BVPs).
- develop the ability to select appropriate finite difference methods for specific types of problems and effectively apply them to real world applications.

Syllabus

Unit – 1 **(11 hours)**

Initial value problems: Existence and uniqueness of solution, Finite difference equation, Truncation error, Single step methods for first order IVPs and system of IVPs- Family of explicit and implicit Runge–Kutta methods, Taylor series methods, Derivation, Truncation error, Consistency, Stability and convergence analysis.

Unit – 2 **(12 hours)**

IVPs for the system of ODEs, Consistency, Zero stability and convergence of linear multistep methods, Routh–Hurwitz criterion, Order and error constant, First Dahlquist Barrier, Local truncation error and global truncation error, Error bounds, Local error, Linear stability theory, Higher order differential equations.

Unit – 3 **(12 hours)**

Derivation of explicit and implicit multistep methods for IVPs and system of IVPs, Truncation error, Stability and convergence analysis of family of Nystrom method, Adams–Bashforth method,

Adams–Moulton method, Milne–Simpson method, Predictor corrector method, and Modified predictor corrector method, Hybrid method, Multistep methods for second order IVPs.

Unit – 4 **(10 hours)**

Linear BVPs for second order ordinary differential equations, Shooting method, Finite difference method, Collocation method, Derivative boundary conditions, Nonlinear two-point BVPs, Higher order finite difference methods, Stability, Truncation error and convergence analysis.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. K. Jain, S. R. K. Iyenger and R. K. Jain, *Numerical Methods for Scientific and Engineering Computations*, Seventh Edition, New Age International Publisher, 2019.

[2] J. D. Lambert, *Numerical Methods for Ordinary Differential Systems: The Initial Value Problem*, John Wiley & Sons, 1991.

Suggested Readings

(i) K. E. Atkinson, W. Han and D. E. Stewart, *Numerical Solution of Ordinary Differential Equations*, John Wiley & Sons, 2009.

(ii) J. C. Butcher, *The Numerical Analysis of Ordinary Differential Equations*, Second Edition, Wiley, New York, 2008.

(iii) L. Collatz, *The Numerical Treatment of Differential Equations*, Springer-Verlag, 1966.

DISCIPLINE SPECIFIC ELECTIVE – 2 (ii): ORDINARY DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-2 (ii): Ordinary Differential Equations	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Differential Equations and Calculus

Learning Objectives

The objective of this course is to study:

- existence, uniqueness, and continuity of solutions of initial value problems (IVPs)
- homogeneous and non-homogeneous linear systems
- stability of solutions for systems of ordinary differential equations.
- eigenvalues and eigenfunctions of Sturm-Liouville systems and Green's functions
- applications of theory of ordinary differential equations in real world problems.

Learning Outcomes

After studying this course, the student will be able to:

- know about the existence, uniqueness, and continuity of solutions of IVPs.
- apply the matrix method of solution for linear systems of differential equations.
- analyze the stability of solutions for systems of ordinary differential equations.
- understand Green's functions and their applications in the solution of boundary value problems (BVPs).
- comprehend the properties of eigenvalues and eigenfunctions of Sturm-Liouville systems.

Syllabus

Unit – 1 **(12 hours)**

Well-posed problems, Existence, uniqueness, and continuity theorems for the solution of IVPs of the first order, Picard's method, Existence and uniqueness of solution for systems and higher order IVPs , Global existence theorem.

Unit – 2 **(9 hours)**

Homogeneous and non-homogeneous linear systems, Linear systems with constant coefficients and their solution by matrix method, Linear equations with periodic coefficients.

Unit – 3 **(12 hours)**

Stability of autonomous system of differential equations, Critical points of an autonomous system and their classification. Stability of linear systems with constant coefficients, Linear plane autonomous system and phase portrait analysis, Perturbed systems, Method of Lyapunov for nonlinear systems, Limit cycles, Poincare-Bendixson's theorem and its applications.

Unit – 4 **(12 hours)**

Sturm separation and comparison theorems, Adjoint forms and Lagrange's identity, Two-point boundary value problems, Green's functions, Construction of Green's functions, Sturm-Liouville systems, eigenvalues and eigenfunctions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] E. A. Coddington, *An Introduction to Ordinary Differential Equations*, Dover Publications, 2012.
[2] T. Myint-U, *Ordinary Differential Equations*, Elsevier, North-Holland, 1978.
[3] S. L. Ross, *Differential Equation*s, Second Edition, John Wiley & Sons, India, 2007.

Suggested Readings

(i) L. Perko, *Differential Equations and Dynamical Systems,* Springer, 2001.
(ii) G. F. Simmons, *Differential Equations with Applications and Historical Notes*, Third Edition, CRC Press, 2017.

DISCIPLINE SPECIFIC ELECTIVE – 2 (iii): REPRESENTATION OF FINITE GROUPS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-2 (iii): Representation of Finite Groups	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra and Group Theory

Learning Objectives

The primary objective of this course is to:

- represent finite groups as groups of matrices (via homomorphisms) and apply the tools of linear algebra to study the group structure.
- introduce the notion of Group algebra, which plays an essential role in classifying representations of groups.
- to discuss some applications of representations of finite groups, such as the Burnside's theorem.

Learning Outcomes

This course will enable the students to:

- define and construct examples of group representations, FG-modules, group algebras.
- grasp key concepts and tools of representation theory and establish a link between FG-modules and group representations.
- prove and apply Maschke's theorem and Schur's lemma to describe all irreducible representations of finite groups over the field of complex numbers.
- apply the theory of characters and group representations to gain insight into group structure, such as normal subgroups, and the solubility of groups.

Syllabus

Unit – 1 **(11 hours)**

Representation of groups, FG-modules and FG-submodules, and reducibility, Permutation modules, FG-modules and equivalent representations, Reducible and irreducible FG-modules, Group algebra of G, Regular FG-module and regular representations, FG-homomorphisms, Direct sum of FG-modules.

Unit – 2 **(11 hours)**

Maschke's theorem for FG-modules and consequences. Schur's lemma and its converse, Application of Schur's lemma, Irreducible modules and group algebra, Structure of group algebra and space of CG-homomorphisms.

Unit – 3 **(10 hours)**

Characters and their properties, Permutation and regular characters, Inner product, Number of irreducible characters, Orthogonality relations and finding normal subgroups.

Unit – 4 **(13 hours)**

Algebraic numbers, Algebraic integers and their properties, Character values, The Burnside's *(p,q)*-theorem and solubility of some particular groups.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. James and M. Liebeck, *Representations and Characters of Groups*, Second Edition, Cambridge University Press, 2005.

Suggested Readings

(i) C. W. Curtis and I. Reiner, *Representation Theory of Finite Groups and Associative Algebras*, American Mathematical Society, 2006.
(ii) W. Fulton and J. Harris, *Representation Theory - A First Course*, Springer-Verlag, 2004.
(iii) I. M. Issacs, *Character Theory of Finite Groups*, American Mathematical Society reprint, 2006.

DISCIPLINE SPECIFIC ELECTIVE – 2 (iv): TOPOLOGICAL DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-2 (iv): Topological Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- provide a strong background of topological dynamical systems including their applications.
- develop some useful and interesting dynamical properties like expansivity, shadowing and topological stability with supporting examples and results from symbolic and topological dynamics.
- introduce the celebrated Sarkovskii's theorem.

Learning Outcomes

This course will enable the students to:

- construct interesting examples of dynamical systems and topological conjugacy.
- visualize stable sets, omega sets and alpha limit sets.
- understand the applications of Sarkovskii's theorem.
- use subshifts of finite type to characterize irreducible matrices.
- prove key results on expansivity and shadowing regarding existence/non-existence, product, subspace and their different characterizations etc.
- find the class of topologically stable homeomorphisms.

Syllabus

Unit – 1 **(10 hours)**

Definition and examples (including real life examples) of dynamical systems, Orbits, Types of orbits, Topological conjugacy and orbits, Phase portrait-graphical analysis of orbit, Periodic points and stable sets, Omega and alpha limit sets and their properties.

Unit – 2 **(10 hours)**

Sarkovskii's theorem, Shift spaces and subshift, Subshift of finite type, Subshift represented by a matrix, Characterizations of irreducible matrices.

Unit – 3 **(13 hours)**

Definition and examples of expansive homeomorphisms, Properties of expansive homeomorphisms, Non-existence of expansive homeomorphism on the unit interval and unit circle, Generators and weak generators, Generators and expansive homeomorphisms.

Unit – 4 **(12 hours)**

Converging semi-orbits for expansive homeomorphisms, Definition, examples and properties of maps having shadowing property, Topological Anosov homeomorphisms and topological stability.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] N. Aoki and K. Hiraide, *Topological Theory of Dynamical Systems: Recent Advances*, North Holland Publications, 1994.
[2] M. Brin and G. Stuck, *Introduction to Dynamical Systems*, Cambridge University Press, 2004.

Suggested Readings

(i) D. C. Hanselman and B. Little field, *Mastering MATLAB*, Pearson, 2012.
(ii) D. Lind and B. Marcus, *An Introduction to Symbolic Dynamics and Coding*, Cambridge University Press, 1996.
(iii) C. Robinson, *Dynamical Systems*, *Stability, Symbolic Dynamics and Chaos*, Second Edition, CRC Press, Taylor & Francis, 1998.
(iv) J. de. Vries, *Elements of Topological Dynamics*, Springer, 1993.

DISCIPLINE SPECIFIC ELECTIVE – 3 (i): ADVANCED FUNCTIONAL ANALYSIS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-3 (i): Advanced Functional Analysis	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis and Topology

Learning Objectives

The primary objective of this course is to:

- define and explain the structure of a topological vector space and its fundamental properties.
- differentiate between normed, metrizable, locally convex and Hausdorff topological vector spaces.
- introduce the foundational theorems of functional analysis, including the Hahn–Banach, Banach–Steinhaus, Open mapping, and Closed graph theorems in the context of locally convex spaces.
- explain some applications of Banach–Alaoglu theorem and Krein–Milman theorem.

Learning Outcomes

This course will enable the students to:

- appreciate types of topological vector spaces and their separation properties.
- understand quotient spaces, weak topology and weak*-topology.
- analyze concepts of continuity, boundedness, and convergence for linear operators and functionals on topological vector spaces.
- understand the notion of local convexity and the role of seminorms in defining locally convex topologies.

Syllabus

Unit – 1 **(12 hours)**

Topological vector spaces, Types of Topological vector spaces, Separation properties, Linear mappings, Finite dimensional spaces, Metrization, Boundedness and continuity, Seminorms and local convexity, Normability.

Unit – 2 **(11 hours)**

Quotient spaces, Seminorms and quotient spaces, Examples, Baire category theorem, Banach–Steinhaus theorem, The open mapping theorem and the closed graph theorem on topological vector spaces.

Unit – 3 **(11 hours)**

Hahn–Banach separation theorem on topological vector spaces, Continuous extension theorem, Weak topologies, Weak topology and convexity, Weak topology and metrizability, Weak*-topology of a dual space, Compact convex sets, Banach–Alaoglu theorem and applications, Goldstine theorem.

Unit – 4 **(11 hours)**

Extreme points, Krein–Milman theorem, Convex hull of compact sets, Applications of Krein–Milman theorem: Stone–Weierstrass theorem, Markov–Kakutani fixed point theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.
[2] W. Rudin, *Functional Analysis*, Second Edition, Tata Mc Graw-Hill, 2011.

Suggested Readings

(i) V. I. Bogachev and O. G. Smolyanov, *Topological Vector Spaces and Their Applications*, Springer, 2017.
(ii) S. Kantorovitz, *Introduction to Modern Analysis*, Oxford Graduate Texts in Mathematics, Oxford University Press, 2006.
(iii) J. Voigt, *A Course on Topological Vector Spaces*, Birkhäuser, 2020.

DISCIPLINE SPECIFIC ELECTIVE – 3 (ii): ALGEBRAIC CODING THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-3 (ii): Algebraic Coding Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra, Groups and Rings

Learning Objectives

The primary objective of this course is to:

- provide an introduction to algebraic coding theory, particularly linear codes.
- discuss bounds on the parameters along with cyclic codes.
- describe some well-known codes, such as Reed–Muller and Golay codes.
- explore the algebraic structure of Cyclic and Quadratic residue codes over fields and rings.

Learning Outcomes

This course will enable the students to:

- get an insight into the matrix representation of a code, as well as encoding and decoding.
- understand Hamming, MDS and Reed–Muller codes.
- describe cyclic codes and their generator polynomial.
- learn about special cyclic codes, such as Quadratic residue codes, and their properties over the ring $\mathbb{Z}_4$.

Syllabus

Unit – 1 **(10 hours)**

Error detecting and error correcting codes, Maximum likelihood decoding, Hamming distance, Linear codes, Hamming weight, Generator matrix, Parity check matrix, Equivalence of linear codes, Encoding and decoding of linear codes, Syndrome decoding.

Unit – 2 **(11 hours)**

Bounds on codes, Sphere covering bound, Hamming bound, Perfect codes, Binary Hamming codes, Binary Golay codes, Singleton bound and MDS codes. Propagation rules, Reed–Muller codes.

Unit – 3 **(12 hours)**

Cyclic codes, Cyclic codes as ideals, Generator polynomial of cyclic codes, Generator and parity-check matrices of cyclic codes**,** Decoding of cyclic codes, Burst error correcting codes.

Unit – 4 **(12 hours)**

Quadratic residue codes: QR codes over fields of characteristic 2 and 3, Cyclic codes and their generating polynomial over $\mathbb{Z}_4$, QR codes over $\mathbb{Z}_4$.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] S. Ling and C. Xing, *Coding Theory: A First Course*, Cambridge University Press, 2004.
[2] W. C. Huffman and V. Pless, *Fundamentals of Error Correcting Codes*, Cambridge University Press, 2010.

Suggested Readings

(i) R. Hill, *A First Course in Coding Theory*, Oxford University Press, 1986.
(ii) F. J. Mac William and N. J. A. Sloane, *Theory of Error Correcting Codes, Part I & II,* Elsevier/North-Holland, Amsterdam, 1977.

DISCIPLINE SPECIFIC ELECTIVE – 3 (iii): DIFFERENTIAL GEOMETRY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-3 (iii): Differential Geometry	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra, Multivariate Calculus and Differential Equations

Learning Objectives

The primary objective of this course is to introduce:

- surfaces and parametrized surfaces.
- orientation on connected surfaces.
- geodesics on surfaces.
- Weingarten maps on oriented surfaces.
- arc length and curvature of oriented plane curves.
- curvatures of oriented surfaces.

Learning Outcomes

This course will enable the students to:

- understand the concepts of level sets and graphs of functions, smooth vector fields, tangent spaces of level sets.
- appreciate surfaces and parametrized surfaces, Gauss map, geodesics and parallel transport on oriented surfaces.
- know what the Weingarten map of an oriented surface is, realize it as shape operator and use it to compute curvature of oriented plane curves.
- find global parametrization and hence arc length of an oriented plane curve.
- compute various types of curvatures of surfaces.

Syllabus

Unit – 1 **(10 hours)**

Level sets in $\mathbb{R}^{n+1}$ and graphs of functions, Smooth vector fields and existence and uniqueness of their integral curves, Tangent spaces of level sets at regular points, Surfaces in $\mathbb{R}^{n+1}$ as inverse images of regular values of smooth functions, Necessary condition for extrema of functions on surfaces-Lagrange multipliers, Existence of a normal vector field on a connected surface, Orientation, Gauss map.

Unit – 2 **(13 hours)**

The notion of a geodesic on a surface, Existence and uniqueness of a geodesic on a surface through a given point with a given velocity vector thereof, Covariant derivative of a smooth vector field, Parallel vector field along a curve, Existence and uniqueness of a parallel vector field along a curve with a given initial vector, Weingarten map of a surface at a point, Local parametrization and curvature of a plane curve.

Unit – 3 **(10 hours)**

Global parametrization and arc length of an oriented plane curve, Differential 1-forms, Line integral of 1-forms over parametrized curves.

Unit – 4 **(12 hours)**

Parametrized surfaces with examples, Curvature of surfaces, Normal curvature of a surface at a point in a given direction, Principal curvatures, First and second fundamental forms, Gauss-Kronecker curvature and mean curvature.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] A. Pressley, *Elementary Differential Geometry*, Springer-Verlag London Limited, 2012.
[2] J. A. Thorpe, *Elementary Topics in Differential Geometry*, Springer (India) Pvt. Limited, 2004.

Suggested Readings

(i) W. Kuhnel, *Differential Geometry: Curves-Surfaces-Manifolds*, Third Edition, American Mathematical Society, 2015.
(ii) B. O' Neill, *Elementary Differential Geometry*, Second Edition, Academic Press INC., Academic Press, New York, 2006.

DISCIPLINE SPECIFIC ELECTIVE – 3 (iv): FINITE ELEMENT METHODS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-3 (iv): Finite Element Methods	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Differential Equations

Learning Objectives

The primary objective of this course is to:

- introduce basic aspects of finite element methods (FEM) including domain discretization, polynomial interpolation, application of boundary conditions, assembly of global arrays, and solution of the resulting algebraic systems.
- discuss the use of finite element methods in solving engineering problems in the domain of solid mechanics, fluid mechanics, heat transfer and electromagnetism.

Learning Outcomes

This course will enable the students to:

- use integral statement to deduce finite element approximations for the underlying linear partial differential equations.
- write special-purpose finite element programs within a procedural programming environment.
- use finite element methods to solve engineering problems in solids mechanics, fluid mechanics, heat transfer, and electromagnetism.
- assess the accuracy and reliability of finite element solutions and troubleshoot problems arising from errors in a given finite element analysis.

Syllabus

Unit – 1 **(12 hours)**

Basic concepts of weak formulation, Variational formulation of a one dimensional model equation, Basis function and finite element solutions, Collocation method, Ritz method, Least square method, Standard Galerkin method, FEM for model problem, Error estimate for FEM for model equation, Convergence analysis.

Unit – 2 **(11 hours)**

Various shapes of finite element, Higher order basis functions, Finite element methods for elliptic problems: Variational methods, Standard Galerkin method, Error estimate for FEM for elliptic problem, FEM for Poisson equation.

Unit – 3 **(12 hours)**

Finite element methods for parabolic problems: One dimensional model problems, Semi-discretization in space, Error estimates, Discretization in space and time, Galerkin method, Finite element methods for hyperbolic problems: Standard Galerkin method, Standard Galerkin method with strongly and weakly imposed boundary conditions.

Unit – 4 **(10 hours)**

Applications of the FEM to second order BVPs in one dimension, Applications of the FEM to linear elliptic, parabolic and hyperbolic equations.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. Evans, J. Blackledge and P. Yardley, *Numerical Methods for Partial Differential Equations*, Springer-Verlag, London, 2000.

[2] C. Johnson, *Numerical Solutions of Partial Differential Equations by Finite Element Methods*, *Cambridge University Press*, Cambridge, 1987.

[3] J. Whiteley, *Finite Element Methods - A Practical Guide*, Springer, 2016.

Skill-Based Course (SBC)

DEVELOPING MATHEMATICAL IDEAS

Course Title	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Developing Mathematical Ideas	2	0	0	2	Same as for entry to M.Sc. Mathematics	NIL

Learning Objectives

This course will train students

- to develop skills to create new mathematical ideas independently.
- to present these ideas adeptly.

Learning Outcomes

Students will be able to

- hone their analytical skills and their ability to think critically.
- learn to work collaboratively.
- acquire skills that help them to create and develop new mathematical ideas.

Methodology

We plan to form groups of students, say of 5-6 each, who will be assigned a piece of mathematical work (article/ paper published in reputed journals/ periodicals/book chapters). The designated groups will be required to read and understand this mathematical work under the supervision of a faculty member. They will be further encouraged to pose meaningful questions/problems in the context of the mathematics they have read and possibly offer solutions. Presentations will be conducted for these groups as a part of their assessment process.

Appropriate material for the study will be provided by the department/faculty. Papers/articles for example, may be chosen from resources like *Involve* (Link: https://msp.org/involve/), *SIAM Undergraduate Research Online* (Link: https://www.siam.org/publications/siuro), *The American Mathematical Monthly* (Mathematical Association of America, Taylor and Francis, Link: https://www.tandfonline.com/journals/uamm20), *Mathematics Magazine* (Mathematical Association of America, Taylor and Francis, Link: https://www.tandfonline.com/journals/umma20), *The Mathematics Student* (Indian Mathematical Society, Link: https://www.indianmathsoc.org/MS.html) and *The Mathematical Intelligencer* (Springer Nature, Link: https://link.springer.com/journal/283). Advanced topics beyond the prescribed syllabus from textbooks/ research monographs may also be chosen.

Generic Elective (GE) Courses

GENERIC ELECTIVE – 1 (i): DYNAMICAL SYSTEMS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
GE-1 (i): Dynamical Systems	4	3	1	0	Class XII pass with Mathematics	Basics of Topology and Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- understand discrete and continuous systems with case studies to study nonlinear systems of ordinary differential equations and dynamical systems.
- understand the concepts, models and techniques to realize the real-world problems and stability of the systems along with the chaotic dynamic behaviour of models by understanding bifurcations.

Learning Outcomes

This course will enable the students to learn:

- formulation of mathematical models with the stability analysis near the equilibrium points.
- how the concept of phase portraits helps to analyse mathematical model graphically.
- the qualitative behaviour of the solution set of a given system of differential equations including the invariant sets and limiting behaviour of the dynamical system or flow defined by the system of differential equations.
- how different bifurcations explain the chaotic behaviour of the system.

Syllabus

Unit – 1 **(13 hours)**

Linear systems: Jordan forms, Stability theory; Nonlinear systems: Fundamental existence-uniqueness theorem, Dependence on initial conditions and parameters, Flow of a differential equation, Linearization, Stable manifold theorem, Hartman–Grobman theorem.

Unit – 2 **(10 hours)**

Stability and Lyapunov functions, Saddle points, Nodes, Foci, Centers and nonhyperbolic critical points, Center manifold theorem.

Unit – 3 **(12 hours)**

Limit sets and attractors, Periodic orbits and limit cycles, Poincaré map, Stable manifold theorem for periodic orbits, Poincare-Bendixson theorem.

Unit – 4 **(10 hours)**

Bifurcations at nonhyperbolic equilibrium points, Saddle node, Transcritical and Pitchfork bifurcations, Hopf bifurcation.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. W. Hirsch, S. Smale and R. L. Devaney, *Differential Equations, Dynamical Systems, and an Introduction to Chaos*, Third Edition, Academic Press, 2013.
[2] L. Perko, *Differential Equations and Dynamical Systems*, Third Edition, Springer Verlag, 2001.

Suggested Readings

(i) R. L. Devaney, *A First Course in Chaotic Dynamical Systems: Theory and Experiment*, CRC Press, Taylor & Francis, 2018.
(ii) S. H. Strogatz, *Nonlinear Dynamics and Chaos*, Second Edition, CRC Press, Taylor & Francis, 2018.
(iii) S. Wiggins, *Introduction to Applied Nonlinear Dynamical Systems and Chaos*, TAM Volume 2, Springer-Verlag, NY, 1990.

GENERIC ELECTIVE – 1 (ii): NUMERICAL METHODS FOR ORDINARY DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
GE-1 (ii): Numerical Methods for Ordinary Differential Equations	4	3	1	0	Class XII pass with Mathematics	Basics of Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- develop the basic theory underlying the numerical solution of differential equations.
- introduce the concepts of consistency, stability and convergence of finite difference methods.
- execute the numerical schemes for the solution of differential equations.

Learning Outcomes

This course will enable the students to:

- gain a thorough understanding of the fundamental concepts involved in the construction and analysis of finite difference schemes for solving ordinary differential equations (ODEs).
- apply various numerical methods based on finite difference approaches to obtain approximate solutions for both initial value problems (IVPs) and boundary value problems (BVPs).
- develop the ability to select appropriate finite difference methods for specific types of problems and effectively apply them to real world applications.

Syllabus

Unit – 1 **(11 hours)**

Initial value problems: Existence and uniqueness of solution, Finite difference equation, Truncation error, Single step methods for first order IVPs and system of IVPs- Family of explicit and implicit Runge–Kutta methods, Taylor series methods, Derivation, Truncation error, Consistency, Stability and convergence analysis.

Unit – 2 **(12 hours)**

IVPs for the system of ODEs, Consistency, Zero stability and convergence of linear multistep methods, Routh–Hurwitz criterion, Order and error constant, First Dahlquist Barrier, Local truncation error and global truncation error, Error bounds, Local error, Linear stability theory, Higher order differential equations.

Unit – 3 **(12 hours)**

Derivation of explicit and implicit multistep methods for IVPs and system of IVPs, Truncation error, Stability and convergence analysis of family of Nystrom method, Adams–Bashforth method,

Adams–Moulton method, Milne–Simpson method, Predictor corrector method, and Modified predictor corrector method, Hybrid method, Multistep methods for second order IVPs.

Unit – 4 **(10 hours)**

Linear BVPs for second order ordinary differential equations, Shooting method, Finite difference method, Collocation method, Derivative boundary conditions, Nonlinear two-point BVPs, Higher order finite difference methods, Stability, Truncation error and convergence analysis.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. K. Jain, S. R. K. Iyenger and R. K. Jain, *Numerical Methods for Scientific and Engineering Computations*, Seventh Edition, New Age International Publisher, 2019.
[2] J. D. Lambert, *Numerical Methods for Ordinary Differential Systems: The Initial Value Problem*, John Wiley & Sons, 1991.

Suggested Readings

(i) K. E. Atkinson, W. Han and D. E. Stewart, *Numerical Solution of Ordinary Differential Equations*, John Wiley & Sons, 2009.
(ii) J. C. Butcher, *The Numerical Analysis of Ordinary Differential Equations*, Second Edition, Wiley, New York, 2008.
(iii) L. Collatz, *The Numerical Treatment of Differential Equations*, Springer-Verlag, 1966.

Syllabi of Courses in Semester-II of One-year M.Sc. Mathematics under Structure-1 (Only Course work)

Discipline Specific Core (DSC) Courses

DISCIPLINE SPECIFIC CORE – 3: PARTIAL DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC-3: Partial Differential Equations	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Multivariate Calculus and Differential Equations

Learning Objectives

The main objective of this course is to introduce:

- well-posedness, fundamental solutions, existence and uniqueness of solutions for Laplace equation, Poisson equation and heat equation.
- solution for wave equation by spherical means.
- characteristics, complete integrals, envelopes and conservation laws for first-order nonlinear partial differential equations.
- classical solution techniques such as Green's function, similarity solutions and transform methods.

Learning Outcomes

This course will enable the students to:

- understand Laplace equation, Poisson equation, and Heat equation, their fundamental solutions, uniqueness principles, mean value properties, and Green's function.
- apply the method of spherical means to solve homogeneous and nonhomogeneous wave equations.
- use characteristics to solve nonlinear partial differential equations, construct complete integrals and envelopes, and understand conservation laws.
- implement various techniques such as similarity solutions and transform methods to derive solutions of different types of partial differential equations.

Syllabus

Unit – 1 **(12 hours)**

Well-posed problems, Classical solution, Laplace equation, Poisson equation, Fundamental solution, Strong maximum principle and uniqueness of solution, Mean value formulas, Representation formula, Green's function, Poisson's formula.

Unit – 2 **(10 hours)**

Heat equation, Fundamental solution for homogeneous and nonhomogeneous initial-value problems, Mean value formula, Strong maximum principle and uniqueness of solution, Local estimates for the solution.

Unit – 3 **(13 hours)**

Wave equation: Solution of homogeneous and nonhomogeneous problems by spherical means,

Nonlinear first order partial differential equations: Complete integrals and envelopes, Characteristics, Introduction to conservation laws.

Unit – 4 **(10 hours)**

Other solution methods: Similarity solutions, Fourier transform and Laplace transform, Cole–Hopf transformation, Potential function, Hodograph and Legendre transform.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] L. C. Evans, *Partial Differential Equations*, American Mathematical Society, Providence, RI, 1998.
[2] F. John, *Partial Differential Equations*, Fourth Edition, Springer-Verlag, New York, 1982.

Suggested Readings

(i) P. R. Garabedian, *Partial Differential Equations*, John Wiley & Sons, Inc., New York- London-Sydney, 1964.
(ii) A. K. Nandakumaran and P. S. Datti, *Partial Differential Equations: Classical Theory with a Modern Touch*, Cambridge University Press, 2020.

DISCIPLINE SPECIFIC CORE – 4: ANALYSIS OF SEVERAL VARIABLES

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC-4: Analysis of Several Variables	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Calculus, Real Analysis including Riemann Integration

Learning Objectives

The primary objective of this course is to:

- introduce differentiation of vector valued functions on $\mathbb{R}^n$ and their properties.
- familiarize students with integration of functions over rectangles and bounded sets in $\mathbb{R}^n$.
- extend integration of functions to unbounded sets in $\mathbb{R}^n$.
- study change of variables and its applications.

Learning Outcomes

This course will enable the students to:

- check differentiability of vector valued functions on $\mathbb{R}^n$, understand the relation between directional derivative and differentiability, apply chain rule, mean value theorems, inverse and implicit function theorems.
- understand higher order derivatives and be able to apply Taylor's formulas with integral remainder, Lagrange's remainder and Peano's remainder.
- master the concepts of integration over rectangles and bounded sets in $\mathbb{R}^n$.
- generalize the integration theory to unbounded sets in $\mathbb{R}^n$.
- grasp the effect of change of variables in integration.

Syllabus

Unit– 1 **(12 hours)**

The differentiability of functions from $\mathbb{R}^n$ to $\mathbb{R}^m$, Partial derivatives and differentiability, Directional derivatives and differentiability, Chain rule, Mean value theorems, Inverse function theorem and Implicit function theorem.

Unit– 2 **(11 hours)**

Derivatives of higher order, Taylor's formulas with integral remainder, Lagrange's remainder and Peano's remainder, Integral over a rectangle, Existence of the integral.

Unit– 3 **(10 hours)**

Evaluation of the integral, Fubini's theorem, Integral over a bounded set.

Unit– 4 **(12 hours)**

Rectifiable sets, Improper integrals**,** Change of variable theorem, Applications of change of variables.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. Giaquinta and G. Modica, *Mathematical Analysis: An Introduction to Functions of Several Variables*, Birkhäuser, 2009.
[2] J. R. Munkres, *Analysis on Manifolds*, CRC Press, Taylor & Francis, 2018.

Suggested Readings

(i) W. Rudin, *Principles of Mathematical Analysis*, Third Edition, Mc Graw Hill, 1986.
(ii) M. Spivak, *Calculus on Manifolds: A Modern Approach to Classical Theorems of Advanced Calculus*, Taylor & Francis, 2018.

Discipline Specific Elective (DSE) Courses

DISCIPLINE SPECIFIC ELECTIVE – 4 (i): ADVANCED FLUID DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-4 (i): Advanced Fluid Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Calculus and Partial Differential Equations

Learning Objectives

The primary objective of this course is to:

- prepare a foundation for advanced studies in compressible flow, boundary layer theory and magnetohydrodynamics.
- develop concepts, models, and techniques that enable problem-solving in compressible flow, boundary layer theory and magnetohydrodynamics.
- equip students with concepts and techniques to conduct research in the above mentioned domains.

Learning Outcomes

This course will enable the students to:

- learn conservation laws, first and second laws of thermodynamics, internal energy and entropy, different forms of energy equations and dimensional analysis.
- know about compressibility in real fluids, wave motion, sound waves, hyperbolic and dispersive waves, shock waves, their formation, properties and elementary analysis.
- know the concepts of boundary layer, boundary layer equations and their solutions, measurements of boundary layer thickness.
- understand the interaction between hydrodynamic processes and electromagnetic phenomena.
- formulate the basic equations of motion in inviscid and viscous conducting fluid flow and explain Alfven's theorem and magnetohydrodynamic (MHD) waves and MHD shocks.

Syllabus

Unit – 1 **(11 hours)**

Flow characteristics, Conservation laws, Equation of state of a substance, First and second law of thermodynamics, Internal energy and entropy, Energy equation, Nondimensionalizing the basic equations of incompressible viscous fluid flow, Nondimensional numbers.

Unit – 2 **(12 hours)**

Compressibility effects in real fluids, Equations of motion, Sound wave, Hyperbolic and dispersive waves, Isentropic gas flow, Flow through a nozzle, Method of characteristics, Shock jump conditions, Non-linear plane waves, Shock waves and their elementary analysis, Similarity solutions.

Unit – 3 **(11 hours)**

Boundary layer concept, Estimation of boundary layer thickness and friction forces, Prandtl's boundary layer equations, Boundary layer along a flat plate, Boundary layer thickness, General properties of the boundary layer equations, Similar solutions, Momentum and energy integral equations for the boundary layer.

Unit – 4 **(11 hours)**

Maxwell's electromagnetic field equations, Magnetohydrodynamic (MHD) approximations, Magnetic field equation, Magnetic Reynolds number, Magnetic body force, Equations of Motions of conducting fluid, Alfven's theorem, MHD waves, MHD shock waves.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] F. Chorlton, *Text Book of Fluid Dynamics*, CBS Publisher, 2005.
[2] H. Schlichting and K. Gersten, *Boundary Layer Theory*, Ninth Edition, Springer, 2017.
[3] G. B. Witham, *Linear and Nonlinear Waves*, John Wiley & Sons, 1999.

Suggested Readings

(i) K. R. Cramer and S. I. Pai, *Magnetofluid Dynamics for Engineers and Applied Physics*, McGraw Hill Book Co., New York, 1973.
(ii) Y. Shao-Wen, *Foundations of Fluid Mechanics*, PHI, New Delhi, 1960.

DISCIPLINE SPECIFIC ELECTIVE – 4 (ii): MODULE THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-4 (ii): Module Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Groups and Rings

Learning Objectives

The primary objective of this course is to:

- introduce a new algebraic structure, namely, module which is a generalization of a vector space when the underlying field is replaced by an arbitrary ring. The study of modules over a ring also provides an insight into the structure of the ring.
- study free modules, finitely generated modules, projective and injective modules.
- classify the finitely generated modules over a principal ideal domain (PID).

Learning Outcomes

This course will enable the students to:

- identify and construct examples of modules, and apply homomorphism theorems on the same.
- define and characterize Noetherian, Artinian module, and apply the structure theorem of finitely generated modules over PID.
- distinguish between projective, injective, free, and semi simple modules.
- prove universal property of tensor product of modules, and Hilbert basis theorem.

Syllabus

Unit – 1 **(13 hours)**

Basic concepts of module theory, Fundamental theorems of homomorphism, Direct product and direct sum of modules, Exact sequences, Split exact sequences.

Unit – 2 **(10 hours)**

Free modules, Projective and injective modules, Dual basis lemma, Baer's criterion, Divisible modules.

Unit – 3 **(12 hours)**

Tensor product of modules, Chain conditions, Hilbert basis theorem.

Unit – 4 **(10 hours)**

Modules over PID's, Semi simple modules.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. F. Athiyah and I. G. Macdonald, *Introduction to Commutative Algebra*, Addison Wesley, 1969.
[2] P. M. Cohn, *Basic Algebra*, Springer International Edition, 2003.
[3] P. M. Cohn, *Classic Algebra*, John Wiley & Sons Ltd., 2000.

Suggested Readings

(i) D. S. Dummit and R. M. Foote, *Abstract Algebra*, Wiley India Pvt. Ltd., 2011.
(ii) N. Jacobson, *Basic Algebra*, Volume II, Dover Publications Inc., 2009.
(iii) T. W. Hungerford, *Algebra*, Springer-Verlag, 1981.

DISCIPLINE SPECIFIC ELECTIVE – 4 (iii): PROBABILITY THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-4 (iii): Probability Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Measure Theory

Learning Objectives

The primary objective of this course is to introduce:

- probability space as a measure space and random variables as measurable functions.
- expectation and moments of random variables.
- notion of convergence in probability.
- conditioning on sub-σ-algebra.

Learning Outcomes

This course will enable the students to learn:

- about probability or uncertainty in abstract setting.
- moments and expectation of random variables which help to understand applications of probability in industry.
- how to apply the idea of convergence in probability.
- weak law and strong law of large numbers and their applications.

Syllabus

Unit – 1 **(11 hours)**

Probability: σ-algebra, Constructing probability triples, The extension theorem, Random variables, Independence of events, Continuity of probabilities, Limit events, The Borel–Cantelli Lemma.

Unit – 2 **(10 hours)**

Expected values: Simple, general non-negative and arbitrary random variables, Moment generating functions, Markov's inequality, Chebyshev's inequality.

Unit – 3 **(12 hours)**

Convergence of random variables: Convergence almost surely, Convergence in probability, Weak law of large numbers, Strong law of large numbers.

Unit – 4 **(12 hours)**

Distributions of random variables: Examples of distributions, Characteristic functions, The central limit theorem, Conditional probability, Conditioning on random variable, Conditioning on a sub-σ-algebra, Conditional variance.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. S. Rosenthal, *A First Look at Rigorous Probability Theory*, Second Edition, World Scientific, Singapore, 2006.

Suggested Readings

(i) W. Feller, *An Introduction to Probability Theory and its Applications*, Volume 1, Third Edition, Wiley, 2008.
(ii) J. E. Michael and J. S. Rosenthal, *Probability and Statistics: The Science of Uncertainty*, Second Edition, W. H. Freeman & Co Ltd., 2009.
(iii) S. Ross, *A First Course in Probability*, Tenth Edition, Pearson Education, 2022.
(iv) D. W. Stroock, *Probability Theory, An Analytic View*, Cambridge University Press, 2024.

DISCIPLINE SPECIFIC ELECTIVE – 4 (iv): THEORY OF UNBOUNDED OPERATORS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-4 (iv): Theory of Unbounded Operators	**4**	**3**	**1**	**0**	**Same as for entry to M.Sc. Mathematics**	**Basics of Functional Analysis and Bounded Operators**

Learning Objectives

The primary objective of this course is to:

- introduce the notion of unbounded operators.
- develop the theory of operator semigroups and understand their role in applications, particularly for solving differential equations.

Learning Outcomes

This course will enable the students to:

- identify closed and closable linear operators on Banach spaces.
- compute adjoints of unbounded linear operators.
- understand spectral properties of some unbounded operators.
- comprehend the role unbounded operators and semigroups play in applications, particularly in studying solutions of differential equations.

Syllabus

Unit – 1 **(10 hours)**

Unbounded linear operators, Hilbert adjoints, Hellinger–Toeplitz theorem, Hermitian, symmetric and self-adjoint linear operators, Closed linear operators, Closable operators and their closures on Banach spaces.

Unit – 2 **(12 hours)**

Cayley transform, Deficiency indices, Spectral properties of self-adjoint operators, Multiplication and differentiation operators and their spectra.

Unit – 3 **(11 hours)**

Analytic properties of exponential functions, Matrix Semigroups, Uniformly continuous semigroups, Semigroups on Hilbert spaces, Strongly continuous semigroups.

Unit – 4 **(12 hours)**

Generators of semigroups and their resolvents, Hille–Yosida theorem (for contraction semigroup), Dissipative operators and their properties, Lumer–Phillips theorem, Generators of Group, Stone's theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] K. J. Engle and R. Nagel, *One-parameter Semigroups for Linear Evolution Equations*, Springer-Verlag, New York, 2000.
[2] E. Kreyszig*, Introductory Functional Analysis with Applications*, John Wiley & Sons, 2006.

Suggested Readings

(i) S. Goldberg, *Unbounded Linear Operators: Theory and Applications*, Dover Publications, 2006.
(ii) E. Hille and R. S. Phillips, *Functional Analysis and Semi-groups*. American Mathematical Society, Providence, RI, 1957.
(iii) A. Pazy*, Semigroups of Linear Operators and Applications to Partial Differential Equations*, Springer, 1983.
(iv) M. Schechter, *Principles of Functional Analysis*, Second Edition, American Mathematical Society, 2001.
(v) J. Weidmann, *Linear Operators in Hilbert Spaces, Graduate Texts in Mathematics*, Springer, New York, 1980.

DISCIPLINE SPECIFIC ELECTIVE – 5 (i): BANACH AND C*-ALGEBRAS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-5 (i): Banach and C*-Algebras	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis and Topology

Learning Objectives

The primary objective of this course is to introduce:

- Banach algebras and C*-algebras.
- various ways to construct new operator algebras using given ones.
- spectrum of elements in Banach algebras and to study its properties.
- Gelfand representations of commutative Banach algebras and of C*-algebras.

Learning Outcomes

This course will enable the students to:

- familiarize with the representations of operator algebras.
- realize commutative Banach algebras and abelian C*-algebras as space of continuous functions on locally compact groups.
- understand the powerful tool of functional calculus.
- identify any C*-algebra as closed *-subalgebra of space of bounded linear operators on a Hilbert space.

Syllabus

Unit – 1 **(11 hours)**

Elementary properties and examples of Banach algebras, Ideals and quotients, Invertible elements, Spectrum and spectral radius, Spectral radius formula, Spectral mapping theorem (for polynomials), Gelfand–Mazur theorem.

Unit – 2 **(11 hours)**

Multiplicative linear functionals, Commutative Banach algebra, w*-topology, Gelfand transform of an element, Structure space, Gelfand representation.

Unit – 3 **(12 hours)**

Elementary properties and examples of C*-algebras, Unitization, Gelfand–Naimark representation of commutative C*-algebras, Continuous functional calculus, Spectral mapping theorem for normal elements, Positive elements of C*-algebras.

Unit – 4 **(11 hours)**

Ideals in C*-algebras, Approximate units, Quotients, Positive linear functionals, Gelfand–Naimark–Segal representation of C*-algebras.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.
[2] G. J. Murphy, *C*-algebras and Operator Theory*, Academic Press Inc., 1990.

Suggested Readings

(i) J. B. Conway, *A Course in Operator Theory, Graduate Texts in Mathematics*, Springer, 2007.
(ii) J. Dixmier, *C*-algebras*, North-Holland Publishing Company, 1977.
(iii) R. G. Douglas, *Banach Algebra Techniques in Operator Theory, Graduate Texts in Mathematics*, Springer, 1998.
(iv) E. Kaniuth, *A Course on Commutative Banach Algebras*, Graduate Texts in Mathematics, Springer, 2009.
(v) S. Kantorovitz, *Introduction to Modern Analysis*, Oxford Graduate Texts in Mathematics, Oxford University Press, 2006.
(vi) M. Takesaki, *Theory of Operator Algebras I*, Springer, 2002.

DISCIPLINE SPECIFIC ELECTIVE – 5 (ii): CHAOS THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-5 (ii): Chaos Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- introduce some useful and interesting notions like Topological Transitivity and Sensitive dependence on initial conditions.
- study different types of chaos including Devaney's chaos and finding their interrelationships.
- know classical result that period three implies chaos on intervals.
- relate chaos and decomposition theorems.
- study Topological entropy through open covers and also Bowen's definition of entropy, equivalence of these two definitions on compact metric spaces.
- study various interesting results related to topological entropy.

Learning Outcomes

This course will enable the students to:

- construct interesting examples of Topological transitive maps, Topological mixing maps etc.
- know classical examples of Devaney's chaotic maps like tent map, shift maps, logistic maps.
- study and compare different types of chaos.
- find relation between transitivity and chaos on intervals.
- relate chaos theory and classical decomposition theorems.
- study very useful notion of Topological entropy including its properties.
- calculate entropy of any homeomorphism of closed unit interval and of unit circle.

Syllabus

Unit – 1 **(12 hours)**

Topological Transitivity, Locally eventually onto maps, Topological mixing, Sensitive dependence on initial conditions, Devaney's definition of chaos, Transitivity and limit sets for continuous interval maps.

Unit – 2 **(11 hours)**

Characterizing topological mixing in terms of topological transitivity for continuous interval maps, Topological Weakly Mixing, Totally Transitive maps, Relation between transitivity and chaos on intervals, Logistic maps and shift maps as chaotic maps.

Unit – 3 **(12 hours)**

Various other definitions of chaos and their interrelationships. Period three implies chaos, Chaos and decomposition theorems including Bowen's decomposition theorem, Topological Entropy: Definition using open covers, Examples and properties, Bowen's definition of topological entropy,

Equivalence of two definitions, Topological version of Kolmogorov–Sinai theorem.

Unit – 4 **(10 hours)**

Topological Entropy of maps on a compact metric space, Topological Entropy of product maps, of iterations of a map, Topological entropy of an expansive homeomorphism on a compact metric space, of the two-sided shift, of any homeomorphism of the unit interval and of the unit circle.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] N. Aoki and K. Hiraide, *Topological Theory of Dynamical Systems: Recent Advances*, North Holland Publications, 1994.
[2] R. L. Devaney, *A First Course in Chaotic Dynamical Systems*, CRC Press, 2018.
[3] S. Ruette, *Chaos for Continuous Interval Maps: A Survey of Relationship Between Various Kinds of Chaos*, 2018.
[4] Peter Walters, *An Introduction to Ergodic Theory*, Springer, 2000.

Suggested Readings

(i) L. Alsedà, J. Llibre and M. Misiurewicz, *Combinatorial Dynamics and Entropy in Dimension One*, Advanced Series in Nonlinear Dynamics, World Scientific, 2000.
(ii) L. S. Block and W. A. Coppel, *Dynamics in One Dimension*, Springer, 2014.
(iii) M. Brin and G. Stuck, *Introduction to Dynamical Systems*, Cambridge University Press, 2015.

DISCIPLINE SPECIFIC ELECTIVE – 5 (iii): COMPLEX ANALYSIS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-5 (iii): Complex Analysis	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Real Analysis and Metric Spaces

Learning Objectives

The primary objective of this course is to:

- gain insights of well-known classical results in the field of complex analysis.
- investigate various properties of analytic functions, conformal mappings and Möbius transformations.
- derive various forms of Cauchy's theorem, integral formulas and maximum principles.
- represent complex-valued functions as Taylor and Laurent series.

Learning Outcomes

This course will enable the students to:

- construct Möbius transformations using Symmetry and Orientation principles.
- foresee the usage of simply connected regions in the complex plane for the existence of primitives and branch of logarithm.
- understand the behavior of zeros of analytic functions and meromorphic functions through Argument principle and Rouche's theorem.
- evaluate the real integrals involving rational and trigonometric functions by contour integration using Residue theorem.
- apply Schwarz's lemma to characterize the conformal maps of the open unit disk onto itself.

Syllabus

Unit – 1 **(10 hours)**

Extended plane and its spherical representation, Analytic functions, Branch of logarithm, Conformal mappings, Möbius transformations.

Unit – 2 **(10 hours)**

Line integrals, Fundamental theorem of Calculus for line integrals, Power series representation of analytic functions, Zeros of analytic functions, Liouville's theorem.

Unit – 3 **(12 hours)**

Index of a closed curve, Cauchy's theorem and integral formula, Morera's Theorem, Homotopic version of Cauchy's theorem and simple connectivity, Counting Zeros, Open mapping theorem, Goursat's theorem.

Unit – 4 **(13 hours)**

Classification of singularities, Laurent series, Casorati-Weierstrass theorem, Residue theorem with applications, Argument principle, Rouche's theorem, Maximum principles, Schwarz lemma.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. B. Conway, *Functions of One Complex Variable*, Second Edition, Narosa Publishing House, New Delhi, 2002.

Suggested Readings

(i) L. V. Ahlfors, *Complex Analysis*, Mc Graw Hill Co., Indian Edition, 2017.
(ii) T. W. Gamelin, *Complex Analysis*, Springer New York, NY, 2001.
(iii) L. Hahn and B. Epstein, *Classical Complex Analysis*, Jones and Bartlett, 1996.
(iv) E. M. Stein and R. Shakarchi, *Complex Analysis*, Princeton University Press, 2003.

DISCIPLINE SPECIFIC ELECTIVE – 5 (iv): NONSMOOTH OPTIMIZATION

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-5 (iv): Nonsmooth Optimization	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Nonlinear Optimization

Learning Objectives

The primary objective of this course is to:

- understand the tools to deal with nonsmooth convex functions.
- study conjugate duality in terms of conjugate functions for constrained nonlinear optimization problems.
- introduce numerical techniques to solve constrained nonlinear optimization problems.

Learning Outcomes

This course will enable the students to learn:

- the notions of subgradients and subdifferentials for nonsmooth convex functions.
- the use of conjugate functions to develop the theory of conjugate duality.
- about numerical methods like gradient descent method, gradient projection method, Newton's method and conjugate gradient method.
- penalty approach technique to solve constrained nonlinear optimization problems.

Syllabus

Unit – 1 **(11 hours)**

Extended real valued functions, Proper convex functions, Closure of convex functions, Differential derivatives, Subgradients and subdifferentials.

Unit – 2 **(12 hours)**

Conjugate functions, Biconjugate functions, Perturbation functions, Closure of convex functions, Directional derivatives, Subgradients and subdifferentials.

Unit – 3 **(12 hours)**

Gradient descent method, Gradient projection method, Newton's method, Conjugate gradient method.

Unit – 4 **(10 hours)**

Penalty function methods, Exterior penalty function, Interior penalty functions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. Avriel, *Nonlinear Programming: Analysis and Methods*, Dover Publications, 2003.

[2] O. Güler, *Foundations of Optimization*, Springer, 2010.

Suggested Readings

(i) A. Bagirov, N. Karitsa and M. M. Makela, *Introduction to Nonsmooth Optimization: Theory, Practice and Software*, Springer, 2014.
(ii) M. S. Bazaraa, H. D. Sherali and C. M. Shetty, *Nonlinear Programming: Theory and Algorithms,* Third Edition, John Wiley & Sons, 2013.
(iii) D. G. Luenberger and Y. Ye, *Linear and Nonlinear Programming*, Springer, 2008.

DISCIPLINE SPECIFIC ELECTIVE – 6 (i): COMPUTATIONAL FLUID DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-6 (i): Computational Fluid Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Partial Differential Equation (Undergraduate level)

Learning Objectives

The primary objective of this course is to teach:

- various numerical schemes on finite difference and finite volume methods for solving PDEs.
- discretization errors and grid dependence.
- some real-world applications of PDEs and fluid dynamics.
- discretization of governing equations of diffusion, convection-diffusion, fluid flow and thereby computing the numerical solutions using the flow variables using algorithms.

Learning Outcomes

This course will enable the students to learn:

- techniques for solving the PDEs along with some initial and boundary conditions by using the finite difference and finite volume methods.
- the basic conservation principles of mass, momentum, energy, discretization of governing equations.
- discretization techniques.
- some popular algorithms like SIMPLE and SIMPLER used to obtain the solutions of steady and unsteady flow problems by finite volume methods.

Syllabus

Unit – 1 **(12 hours)**

Basics of discretization using finite differences, Various single and multi-step explicit and implicit finite difference schemes for 1-D and 2-D parabolic and hyperbolic initial boundary value problems, Alternating Direction Implicit schemes (ADI) for 2-D parabolic and hyperbolic equations, Order of accuracy, Consistency, Stability and convergence of a finite difference scheme, Courant Friedrich Lewy condition.

Unit – 2 **(12 hours)**

Finite difference schemes for second and fourth order 2-D elliptic boundary value problem and applications, Finite volume method for diffusion and convection-diffusion equations, Discretization of one and two-dimensional steady state diffusion and convection-diffusion equations, Central difference, Upwind, Exponential, Hybrid, Power-law and QUICK schemes and their properties.

Unit – 3 **(11 hours)**

Flow field calculation, Pressure-velocity coupling, Vorticity-stream function approach, Primitive variables, Staggered grid, Pressure and velocity corrections, Pressure correction equation, SIMPLE and SIMPLER algorithms.

Unit – 4 **(10 hours)**

Finite volume methods for unsteady flows, Discretization of one-dimensional transient heat conduction, Explicit, fully implicit and Crank–Nicolson schemes, Implementation of boundary conditions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. C. Strikweda, *Finite Difference Schemes and Partial Differential Equations*, Second Edition, SIAM, 2004.

[2] H. K. Versteeg and W. Malalasekera, *An Introduction to Computational Fluid Dynamics: The Finite Volume Method*, Second Edition, Pearson, 2008.

Suggested Readings

(i) J. D. Anderson, *Computational Fluid Dynamics*, McGraw-Hill, 1995.

(ii) S. V. Patankar, *Numerical Heat Transfer and Fluid Flow*, CRC Press, Taylor and Francis, Indian Edition, 2017.

(iii) R. H. Pletcher, J. C. Tannehill and D. A. Anderson, *Computational Fluid Mechanics and Heat Transfer*, CRC Press, Taylor and Francis, 2013.

(iv) J. W. Thomas, *Numerical Partial Differential Equations: Finite Difference Methods*, Springer, 2013.

DISCIPLINE SPECIFIC ELECTIVE – 6 (ii): DIFFERENTIAL TOPOLOGY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-6 (ii): Differential Topology	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- introduce the concepts of topological manifolds, smooth structures, smooth manifolds, and manifolds with boundary.
- develop an understanding of smooth functions, smooth maps, diffeomorphisms, and tangent spaces.
- explain the Inverse function theorem, immersions and submersions.
- develop the fundamental concepts of 2-manifolds and distinguish between orientable and non-orientable surfaces.
- explore the properties of compact and connected surfaces.

Learning Outcomes

This course will enable the students to:

- identify and construct examples of topological manifolds, smooth structures and manifolds with and without boundary.
- demonstrate understanding of diffeomorphisms and tangent spaces.
- apply the Inverse function theorem, immersions and submersions.
- define key concepts such as 2-manifolds, orientability, compactness, connectedness and boundary of a surface.
- differentiate between orientable and non-orientable surfaces using examples such as the sphere, torus, Möbius strip and Klein bottle.

Syllabus

Unit – 1 **(12 hours)**

Topological manifolds, Topological properties of manifolds, Smooth structures, Examples of smooth manifolds, Manifolds with boundary.

Unit – 2 **(11 hours)**

Smooth functions and smooth maps, Lie groups, Diffeomorphisms.

Unit – 3 **(10 hours)**

Derivatives and tangents, Inverse function theorem, Immersions and submersions.

Unit – 4 **(12 hours)**

Complexes, Connected sum of two surfaces, Non-orientable surfaces (2- Manifolds), Compact and connected surfaces, Classification of compact and connected surfaces with and without boundary.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] V. Guillemin and Alan Pollack, *Differential Topology*, Prentice-Hall, 1974.
[2] L. C. Kinsey, *Topology of Surfaces*, Springer Verlag, 1997.
[3] J. M. Lee, *Introduction to Smooth Manifolds*, Second Edition, Springer, 2013.

Suggested Readings

(i) L. Conlon, *Differentiable Manifolds*, Second Edition, Birkhäuser Advanced Texts, 2001.
(ii) M. Spivak, *A Comprehensive Introduction to Differential Geometry*, Volume 1, Third Edition, Publish or Perish, Huston, Texas, 1999.
(iii) L. W. Tu, *Introduction to Manifolds*, Second Edition, Springer, 2011.
(iv) F. W. Warner, *Foundations of Differentiable Manifolds and Lie Group*, Springer-Verlag, 1983.

DISCIPLINE SPECIFIC ELECTIVE – 6 (iii): GENERAL MEASURE THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-6 (iii): General Measure Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Measure Theory and Topology

Learning Objectives

The primary objective of this course is to introduce:

- real valued and complex valued measures.
- decomposition of measure spaces and of measures.
- extension of a premeasure to a measure, Lebesgue measure on Euclidean spaces.
- representation of measures and functionals in terms of integrals.
- product measures.

Learning Outcomes

This course will enable the students to:

- appreciate signed measures and complex measures, mutual singularity of measures, Hahn and Jordan decompositions, Lebesgue decomposition, Radon–Nikodym theorem.
- verify conditions under which a set function defined on a collection of subsets of a set has an extension to a measure on a sigma-algebra.
- apply Riesz representation theorem for bounded linear functionals on L^p-spaces.
- understand product measure and the results of Fubini and Tonelli, and express the Lebesgue measure on Euclidean spaces as a product measure.
- apply Riesz–Markov representation theorem for the bounded linear functionals on the space of continuous functions.

Syllabus

Unit – 1 **(13 hours)**

Signed measures, Hahn and Jordan decompositions, Mutually singular measures, Radon–Nikodym theorem, Lebesgue decomposition, Complex measure.

Unit – 2 **(10 hours)**

The Carathéodory extension theorem, Lebesgue measure on $\mathbb{R}^n$, Regularity and translation invariance of Lebesgue measure on $\mathbb{R}^n$.

Unit – 3 **(10 hours)**

Riesz representation theorem for the dual of L^p-spaces, Product measures, Fubini's theorem, Tonelli's theorem.

Unit – 4 **(12 hours)**

Locally compact Hausdorff spaces and construction of Radon measure, Riesz–Markov

representation theorem for positive linear functionals on $C_c(X)$, Riesz representation theorem for the dual of $C(X)$.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] H. L. Royden and P. M. Fitzpatrick, *Real Analysis*, Fourth Edition, Pearson, 2015.
[2] M. E. Taylor, *Measure Theory and Integration*, American Mathematical Society, 2006.

Suggested Readings

(i) G. B. Folland, *Real Analysis: Modern Techniques and Their Applications*, Second Edition, Wiley, New York, 1999.
(ii) P. R. Halmos, *Measure Theory*, Springer Science + Business Media, LLC, 2014.
(iii) E. M. Stein and R. Shakarchi, *Real Analysis: Measure Theory, Integration and Hilbert Spaces*, New Age International Publishers, New Delhi, 2010.

DISCIPLINE SPECIFIC ELECTIVE – 6 (iv): THEORY OF NON-COMMUTATIVE RINGS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE-6 (iv): Theory of Non-commutative Rings	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Groups and Rings

Learning Objectives

The primary objective of this course is to:

- give students an understanding of Wedderburn–Artin theory of semisimple rings.
- develop Jacobson's general theory of radicals, prime and semiprime rings, and primitive and semiprimitive rings.
- introduce the structure of primitive rings as a generalisation of the Wedderburn–Artin theorem on Artinian simple rings.

Learning Outcomes

This course will enable the students to:

- know about an extensive variety of rings, including free rings, Weyl algebra, Hilbert twist and triangular ring.
- understand the module theoretic definition of semisimple rings and how it leads to the Wedderburn–Artin structure theorem on their complete classification.
- know Jacobson's general theory of radicals, semiprime rings, prime, primitive and semiprimitive rings and their structures.
- understand the significance of the fundamental result 'Density Theorem' and its consequences on the structure of primitive rings.

Syllabus

Unit – 1 **(11 hours)**

Simple rings, Reduced rings, Dedekind-finite rings, Algebra, Quaternions, Free k-rings, Rings with generators and relations, Weyl algebra, Formal power series ring, Hilbert's twist ring, Differential polynomial rings, Derivation and inner derivation on a ring, Triangular rings, Characterization of one-sided and two-sided ideals in such rings.

Unit – 2 **(11 hours)**

Noetherian and Artinian rings, Examples of one-sided Noetherian and Artinian triangular rings, Twisted polynomial ring and Quotient of free $\mathbb{Z}$-ring, Semisimple rings, Structure of semisimple rings: Wedderburn–Artin's theorem.

Unit – 3 **(10 hours)**

Structure theorem of simple left Artinian rings, Jacobson radical, J-semisimple rings, Nil and nilpotent ideals, Connection between semisimple and J-semisimple rings, Hopkins–Levitzki theorem, Nakayama's lemma.

Unit – 4 **(13 hours)**

Prime radical, Characterisation of prime and semiprime ideals, Prime and semiprime rings, Structure theorem of primitive rings, Density theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] T.-Y. Lam, *A First Course in Noncommutative Rings*, Springer, 2001.

Suggested Readings

(i) I. N. Herstein, *Noncommutative Rings*, The Mathematical Association of America, 2005.
(ii) T. W. Hungerford, *Algebra*, Springer-Verlag, New York, 1981.
(iii) L. H. Rowen, *Ring Theory*, Student Edition, Academic Press, 1991.

Skill-Based Course (SBC)

WORKSHOPS AND SEMINARS ON ADVANCED TOPICS

Course Title	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Workshops and Seminars on Advanced Topics	2	0	0	2	Same as for entry to M.Sc. Mathematics	NIL

Learning Objectives

In this course, we aim to train students to

- understand and assimilate mathematical ideas and techniques presented and discussed in workshops and seminars on varied advanced topics in mathematics.
- communicate mathematical ideas succinctly.

Learning Outcomes

This course will enable students to

- efficiently identify the core ideas in any mathematical discourse, particularly outside the classroom setting.
- write a concise summary of these ideas.

Methodology

The students will attend a requisite number of workshops and seminars organized by the Department through the semester. The workshops and seminars will be on advanced topics, building on the classroom courses offered by the Department. The students will be expected to prepare and submit summaries of a few of these (as mandated by the Department) and also give presentations for assessment.

Generic Elective (GE) Courses

GENERIC ELECTIVE – 2 (i): NONSMOOTH OPTIMIZATION

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
GE-2 (i): Nonsmooth Optimization	4	3	1	0	Class XII pass with Mathematics	Basics of Nonlinear Optimization

Learning Objectives

The primary objective of this course is to:

- understand the tools to deal with nonsmooth convex functions.
- study conjugate duality in terms of conjugate functions for constrained nonlinear optimization problems.
- introduce numerical techniques to solve constrained nonlinear optimization problems.

Learning Outcomes

This course will enable the students to learn:

- the notions of subgradients and subdifferentials for nonsmooth convex functions.
- the use of conjugate functions to develop the theory of conjugate duality.
- about numerical methods like gradient descent method, gradient projection method, Newton's method and conjugate gradient method.
- penalty approach technique to solve constrained nonlinear optimization problems.

Syllabus

Unit – 1 **(11 hours)**

Extended real valued functions, Proper convex functions, Closure of convex functions, Differential derivatives, Subgradients and subdifferentials.

Unit – 2 **(12 hours)**

Conjugate functions, Biconjugate functions, Perturbation functions, Closure of convex functions, Directional derivatives, Subgradients and subdifferentials.

Unit – 3 **(12 hours)**

Gradient descent method, Gradient projection method, Newton's method, Conjugate gradient method.

Unit – 4 **(10 hours)**

Penalty function methods, Exterior penalty function, Interior penalty functions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. Avriel, *Nonlinear Programming: Analysis and Methods*, Dover Publications, 2003.
[2] O. Güler, *Foundations of Optimization*, Springer, 2010.

Suggested Readings

(i) A. Bagirov, N. Karitsa and M. M. Makela, *Introduction to Nonsmooth Optimization: Theory, Practice and Software*, Springer, 2014.
(ii) M. S. Bazaraa, H. D. Sherali and C. M. Shetty, *Nonlinear Programming: Theory and Algorithms,* Third Edition, John Wiley & Sons, 2013.
(iii) D. G. Luenberger and Y. Ye, *Linear and Nonlinear Programming*, Springer, 2008.

GENERIC ELECTIVE – 2 (ii): PROBABILITY THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
GE-2 (ii): Probability Theory	4	3	1	0	Class XII pass with Mathematics	Basics of Integration

Learning Objectives

The primary objective of this course is to introduce:

- probability space as a measure space and random variables as measurable functions.
- expectation and moments of random variables.
- notion of convergence in probability.
- conditioning on sub-σ-algebra.

Learning Outcomes

This course will enable the students to learn:

- about probability or uncertainty in abstract setting.
- moments and expectation of random variables which help to understand applications of probability in industry.
- how to apply the idea of convergence in probability.
- weak law and strong law of large numbers and their applications.

Syllabus

Unit – 1 **(11 hours)**

Probability: σ-algebra, Constructing probability triples, The extension theorem, Random variables, Independence of events, Continuity of probabilities, Limit events, The Borel–Cantelli Lemma.

Unit – 2 **(10 hours)**

Expected values: Simple, general non-negative and arbitrary random variables, Moment generating functions, Markov's inequality, Chebyshev's inequality.

Unit – 3 **(12 hours)**

Convergence of random variables: Convergence almost surely, Convergence in probability, Weak law of large numbers, Strong law of large numbers.

Unit – 4 **(12 hours)**

Distributions of random variables: Examples of distributions, Characteristic functions, The central limit theorem, Conditional probability, Conditioning on random variable, Conditioning on a sub-σ-algebra, Conditional variance.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. S. Rosenthal, *A First Look at Rigorous Probability Theory*, Second Edition, World Scientific, Singapore, 2006.

Suggested Readings

(i) W. Feller, *An Introduction to Probability Theory and its Applications*, Volume 1, Third Edition, Wiley, 2008.
(ii) J. E. Michael and J. S. Rosenthal, *Probability and Statistics: The Science of Uncertainty*, Second Edition, W. H. Freeman & Co Ltd., 2009.
(iii) S. Ross, *A First Course in Probability*, Tenth Edition, Pearson Education, 2022.
(iv) D. W. Stroock, *Probability Theory, An Analytic View*, Cambridge University Press, 2024.

Syllabi of Courses in Semester-I of One-year M.Sc. Mathematics under Structure-2 (Course work + Research)

Discipline Specific Core (DSC) Courses

DISCIPLINE SPECIFIC CORE – 1: FLUID DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC-1: Fluid Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Calculus and Partial Differential Equations

Learning Objectives

The objective of this course is to:

- prepare a mathematical foundation to study the motion of fluids.
- develop concepts, models, and techniques to solve problems of fluid flow.
- develop the ability to conduct advanced studies and research in the broad field of fluid dynamics.

Learning Outcomes

After studying this course, the student will be able to:

- understand the concept of fluids, their classification, flow lines, models and approaches to study fluid flow.
- formulate mass and momentum conservation principles and obtain their solution for non-viscous flow.
- know potential flow, Bernoulli's equation, Kelvin's minimum energy and circulation theorems.
- understand two- and three-dimensional motion, complex potential, circle theorem, Blasius theorem, Weiss's and Butler's sphere theorems.
- apply the concept of stress and strain in viscous flow to derive Navier–Stokes equation of motion and energy equation.

Syllabus

Unit – 1 **(10 hours)**

Classification of fluids, Continuum model, Eulerian and Lagrangian approach of description, Differentiation following the fluid motion, Flow lines, vorticity and circulation, Conservation of mass: Equation of continuity, Boundary surface.

Unit – 2 **(12 hours)**

Forces in fluid motion, Conservation of momentum: Euler's equation of motion, Theory of irrotational motion: Integration of Euler's equation under different conditions, Bernoulli's equation, Impulsive motion, Kelvin's minimum energy and circulation theorems, Potential theorem.

Unit – 3 **(13 hours)**

Two-dimensional motion: Complex potential, Line sources, sinks, doublets and vortices, Two-dimensional image system, Milne–Thomson circle theorem, Images with respect to a plane and cylinder, Blasius theorem. Three-dimensional flows, Weiss's sphere theorem, Images with respect to sphere, Axi-symmetric flow, Stokes stream function, Butler's sphere theorem, Flow past spheres and cylinders.

Unit – 4 **(10 hours)**

Stress and strain analysis, Newton's law of viscosity, Laminar flow, Navier–Stokes equation of motion, Steady flow between parallel planes and Poiseuille flow, Constitutive equation, Energy equation.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] F. Chorlton, *Text Book of Fluid Dynamics*, CBS Publisher, 2005.
[2] R. W. Fox, P. J. Pritchard and A. T. McDonald, *Introduction to Fluid Mechanics*, Seventh Edition, John Wiley & Sons, 2009.
[3] P. K. Kundu, I. M. Cohen and D. R. Dowling, *Fluid Mechanics*, Sixth Edition, Academic Press, 2016.

Suggested Readings

(i) L. M. Milne-Thomson, *Theoretical Hydrodynamics*, The Macmillan company, USA, 1969.
(ii) D. E. Rutherford, *Fluid Dynamics*, Oliver and Boyd Ltd., 1978.

DISCIPLINE SPECIFIC CORE – 2: MEASURE AND INTEGRATION

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC-2: Measure and Integration	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Real Analysis and Riemann Integration

Learning Objectives

The primary objective of this course is to:

- extend the notion of length of an interval with the introduction of the concept of Lebesgue outer measure for any subset of real line.
- investigate the properties of Lebesgue measurable sets and functions.
- familiarize students with the Lebesgue integration of functions and its comparison with Riemann integration.
- generalize the concepts of measure and integration to an abstract space.

Learning Outcomes

This course will enable the students to:

- verify whether a given subset of $\mathbb{R}$ or a real valued function is measurable.
- understand the requirement and the concept of the Lebesgue integral (a generalization of the Riemann integration) along with its properties.
- understand the statements and proofs of the fundamental integral convergence theorems and demonstrate their applications.
- carry out a comprehensive study of functions of bounded variation and their utility in understanding differentiation and integration.
- apply Hölder and Minkowski inequalities in L^p-spaces and understand completeness of L^p-spaces.

Syllabus

Unit – 1 **(14 hours)**

Lebesgue outer measure, Measurable sets, Lebesgue measure, Borel sets, Regularity, Measurable functions, Borel and Lebesgue measurability, Non-measurable sets.

Unit – 2 **(13 hours)**

Integration of nonnegative functions, General integral, Integration of series, Riemann and Lebesgue integrals.

Unit – 3 **(8 hours)**

Functions of bounded variation, Lebesgue's differentiation theorem, Differentiation and integration, Absolute continuity of functions.

Unit – 4 **(10 hours)**

Measures and outer measures, Measure spaces, Integration with respect to a measure, L^p-spaces, Hölder's and Minkowski's inequalities, Completeness of L^p-spaces.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. de Barra, *Measure Theory and Integration*, Ellis Horwood Ltd., Chichester, John Wiley & Sons, Inc., New York, 1981 (Indian Reprint, 2014).

Suggested Readings

(i) M. Capinski and P. E. Kopp, *Measure, Integral and Probability*, Springer, 2005.
(ii) E. Hewitt and K. Stromberg, *Real and Abstract Analysis: A Modern Treatment of the Theory of Functions of a Real Variable*, Springer, Berlin, 1975.
(iii) H. L. Royden and P.M. Fitzpatrick, *Real Analysis*, Fourth Edition, Pearson, 2015.

Discipline Specific Elective (DSE) Courses

DSE-1 and DSE-2

Group-1

DISCIPLINE SPECIFIC ELECTIVE: COMMUTATIVE ALGEBRA

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Commutative Algebra	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra and Field Theory

Learning Objectives

The objective of this course is to:

- develop a solid understanding of the structure of commutative rings, ideals, their radicals, extension, contraction etc.
- study important constructions such as total quotient rings, localizations.
- develop basic foundation in other areas of mathematics such as algebraic geometry, algebraic number theory.

Learning Outcomes

This course will enable the students to:

- know the localization of rings at a prime ideal that is an algebraic analogue of the geometric notion concentrating attention near a point.
- know more closely the polynomial rings, power series rings in one or more variables over a commutative ring and their prime spectrum.
- define, identify, and elaborate integral closure of rings, valuations rings, discrete valuation rings, structure theorem of Artin rings.

Syllabus

Unit – 1 **(12 hours)**

Radical of an ideal, Prime avoidance lemma, Chinese remainder theorem, Extension and contraction of ideals, Jacobson radical of a ring, Nakayama lemma, Tensor product of modules.

Unit – 2 **(13 hours)**

Rings and modules of fractions, Localization, Local properties, Primary decomposition, First and second uniqueness theorem of primary decomposition, Associated prime ideals of decomposable ideals.

Unit – 3 **(10 hours)**

Integral ring extensions, Going up theorem, Going down theorem, Integrally closed domains,

Valuation rings, Hilbert's Nullstellensatz theorem.

Unit – 4 **(10 hours)**

Noetherian rings, Primary decomposition in Noetherian rings, Artin rings, Structure theorem for Artin rings, Discrete valuation rings.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. F. Atiyah and I. G. MacDonald, *Introduction to Commutative Algebra*, CRC Press, Taylor & Francis, 2018.

Suggested Readings

(i) D. Eisenbud, *Commutative Algebra with a View Towards Algebraic Geometry*, Springer, 2004.
(ii) R. Y. Sharp, *Steps in Commutative Algebra*, Cambridge University Press, 2000.
(iii) B. Singh, *Basic Commutative Algebra*, World Scientific, 2011.
(iv) O. Zariski and P. Samuel, *Commutative Algebra*, Volume I & II, Springer, 1975.

DISCIPLINE SPECIFIC ELECTIVE: DYNAMICAL SYSTEMS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Dynamical Systems	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology and Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- understand discrete and continuous systems with case studies to study nonlinear systems of ordinary differential equations and dynamical systems.
- understand the concepts, models and techniques to realize the real-world problems and stability of the systems along with the chaotic dynamic behaviour of models by understanding bifurcations.

Learning Outcomes

This course will enable the students to learn:

- formulation of mathematical models with the stability analysis near the equilibrium points.
- how the concept of phase portraits helps to analyse mathematical model graphically.
- the qualitative behaviour of the solution set of a given system of differential equations including the invariant sets and limiting behaviour of the dynamical system or flow defined by the system of differential equations.
- how different bifurcations explain the chaotic behaviour of the system.

Syllabus

Unit – 1 **(13 hours)**

Linear systems: Jordan forms, Stability theory; Nonlinear systems: Fundamental existence-uniqueness theorem, Dependence on initial conditions and parameters, Flow of a differential equation, Linearization, Stable manifold theorem, Hartman–Grobman theorem.

Unit – 2 **(10 hours)**

Stability and Lyapunov functions, Saddle points, Nodes, Foci, Centers and nonhyperbolic critical points, Center manifold theorem.

Unit – 3 **(12 hours)**

Limit sets and attractors, Periodic orbits and limit cycles, Poincaré map, Stable manifold theorem for periodic orbits, Poincare-Bendixson theorem.

Unit – 4 **(10 hours)**

Bifurcations at nonhyperbolic equilibrium points, Saddle node, Transcritical and Pitchfork bifurcations, Hopf bifurcation.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. W. Hirsch, S. Smale and R. L. Devaney, *Differential Equations, Dynamical Systems, and an Introduction to Chaos*, Third Edition, Academic Press, 2013.
[2] L. Perko, *Differential Equations and Dynamical Systems*, Third Edition, Springer Verlag, 2001.

Suggested Readings

(i) R. L. Devaney, *A First Course in Chaotic Dynamical Systems: Theory and Experiment*, CRC Press, Taylor & Francis, 2018.
(ii) S. H. Strogatz, *Nonlinear Dynamics and Chaos*, Second Edition, CRC Press, Taylor & Francis, 2018.
(iii) S. Wiggins, *Introduction to Applied Nonlinear Dynamical Systems and Chaos*, TAM Volume 2, Springer-Verlag, NY, 1990.

DISCIPLINE SPECIFIC ELECTIVE: INTRODUCTION TO TOPOLOGY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Introduction to Topology	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Metric Spaces

Learning Objectives

The primary objective of this course is to introduce:

- basic principles of point-set topology, including bases and subbases for a topology.
- continuity, homeomorphisms, and different types of topologies, such as product and box topologies.
- key notions of connectedness and local connectedness.
- compactness and its significance in topological spaces.

Learning Outcomes

This course will enable the students to:

- analyze subsets of topological spaces by determining their interior, closure, boundary, and limit points, as well as identifying bases and subbases.
- identify continuous functions between topological spaces, analyze mappings into product spaces, and compare topological properties of different spaces.
- evaluate the connectedness and path connectedness of the product of an arbitrary family of spaces.
- understand key classifications of topological spaces, including Hausdorff spaces, first and second countable spaces, and separable spaces.
- explore advanced concepts such as limit point compactness and Tychonoff's theorem.

Syllabus

Unit – 1 **(10 hours)**

Topological spaces, Basis, Order topology, Subspace topology, Metric topology, Closed set and limit points, Hausdorff spaces.

Unit – 2 **(12 hours)**

Continuous functions, Homeomorphism, The box and product topologies, Metrizability of products of metric spaces**,** Connected and path connected spaces.

Unit – 3 **(12 hours)**

Locally connected and locally path connected spaces, Connectedness of product of spaces, First and second countable spaces, Separable spaces.

Unit – 4 **(11 hours)**

Compact spaces, The Tychonoff theorem, Limit point compactness, Sequential compactness.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. R. Munkres, *Topology*, Updated Second Edition, Pearson, 2021.
[2] T. B. Singh, *Introduction to Topology*, Springer Nature, 2019.

Suggested Readings

(i) G. E. Bredon, *Topology and Geometry*, Springer, 2014.
(ii) J. Dugundji, *Topology*, Allyn and Bacon Inc., Boston, 1978.
(iii) J. L. Kelley, *General Topology*, Dover Publications, 2017.
(iv) G. F. Simmons, *Introduction to Topology and Modern Analysis*, McGraw Hill Education, 2017.
(v) L. A. Steen and J. A. Seebach, *Counterexamples in Topology*, Dover Publications, 2013.
(vi) S. Willard, *General Topology*, Dover Publications, 2004.

DISCIPLINE SPECIFIC ELECTIVE: THEORY OF BOUNDED OPERATORS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Theory of Bounded Operators	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis

Learning Objectives

The primary objective of this course is to:

- introduce some classes of bounded linear operators which play a central role in both pure and applied mathematics.
- study the properties and spectral theory of these operators.

Learning Outcomes

This course will enable the students to understand:

- the spectrum and sub-divisions of spectrum of standard operators like shifts and multiplication.
- the spectral theorem for some classes of bounded linear operators.
- the concepts of compactness, self-adjointness and positivity of bounded linear operators.
- trace class and Hilbert–Schmidt operators.

Syllabus

Unit – 1 **(11 hours)**

Properties of spectrum and resolvent of bounded operators, Subdivision of the spectrum including point, approximate and compression spectrum.

Unit – 2 **(10 hours)**

Operators on Hilbert spaces, Adjoint operator, Projections and idempotents, Operations with projections, Invariant and reducing subspaces.

Unit – 3 **(14 hours)**

Compact operators on Hilbert spaces, Diagonalisation of compact self-adjoint operators, Spectral theorem and functional calculus for Compact normal operators, Positive operators, Compact operators on Banach spaces, Spectral theory of compact operators.

Unit – 4 **(10 hours)**

Polar decomposition, Singular values, Trace class operators, Trace norm and Hilbert Schmidt operators.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] R. Bhatia, *Notes on Functional Analysis*, Hindustan Book Agency, 2009.
[2] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.

Suggested Readings

(i) E. Kreyszig, *Introductory Functional Analysis with Applications*, John Wiley & Sons, 2006.
(ii) B. Simon, *Operator Theory: A Comprehensive Course in Analysis*, Part 4, American Mathematical Society, 2015.
(iii) S. R. Garcia, J. Mashregi and W. T. Ross, *Operator Theory by Example*, Oxford University Press, 2023.

Group-2

DISCIPLINE SPECIFIC ELECTIVE: NUMERICAL METHODS FOR ORDINARY DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Numerical Methods for Ordinary Differential Equations	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- develop the basic theory underlying the numerical solution of differential equations.
- introduce the concepts of consistency, stability and convergence of finite difference methods.
- execute the numerical schemes for the solution of differential equations.

Learning Outcomes

This course will enable the students to:

- gain a thorough understanding of the fundamental concepts involved in the construction and analysis of finite difference schemes for solving ordinary differential equations (ODEs).
- apply various numerical methods based on finite difference approaches to obtain approximate solutions for both initial value problems (IVPs) and boundary value problems (BVPs).
- develop the ability to select appropriate finite difference methods for specific types of problems and effectively apply them to real world applications.

Syllabus

Unit – 1 **(11 hours)**

Initial value problems: Existence and uniqueness of solution, Finite difference equation, Truncation error, Single step methods for first order IVPs and system of IVPs- Family of explicit and implicit Runge–Kutta methods, Taylor series methods, Derivation, Truncation error, Consistency, Stability and convergence analysis.

Unit – 2 **(12 hours)**

IVPs for the system of ODEs, Consistency, Zero stability and convergence of linear multistep methods, Routh–Hurwitz criterion, Order and error constant, First Dahlquist Barrier, Local truncation error and global truncation error, Error bounds, Local error, Linear stability theory, Higher order differential equations.

Unit – 3 **(12 hours)**

Derivation of explicit and implicit multistep methods for IVPs and system of IVPs, Truncation error, Stability and convergence analysis of family of Nystrom method, Adams–Bashforth method, Adams–Moulton method, Milne–Simpson method, Predictor corrector method, and Modified predictor corrector method, Hybrid method, Multistep methods for second order IVPs.

Unit – 4 **(10 hours)**

Linear BVPs for second order ordinary differential equations, Shooting method, Finite difference method, Collocation method, Derivative boundary conditions, Nonlinear two-point BVPs, Higher order finite difference methods, Stability, Truncation error and convergence analysis.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. K. Jain, S. R. K. Iyenger and R. K. Jain, *Numerical Methods for Scientific and Engineering Computations*, Seventh Edition, New Age International Publisher, 2019.

[2] J. D. Lambert, *Numerical Methods for Ordinary Differential Systems: The Initial Value Problem*, John Wiley & Sons, 1991.

Suggested Readings

(i) K. E. Atkinson, W. Han and D. E. Stewart, *Numerical Solution of Ordinary Differential Equations*, John Wiley & Sons, 2009.

(ii) J. C. Butcher, *The Numerical Analysis of Ordinary Differential Equations*, Second Edition, Wiley, New York, 2008.

(iii) L. Collatz, *The Numerical Treatment of Differential Equations*, Springer-Verlag, 1966.

DISCIPLINE SPECIFIC ELECTIVE: ORDINARY DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Ordinary Differential Equations	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Differential Equations and Calculus

Learning Objectives

The objective of this course is to study:

- existence, uniqueness, and continuity of solutions of initial value problems (IVPs)
- homogeneous and non-homogeneous linear systems
- stability of solutions for systems of ordinary differential equations.
- eigenvalues and eigenfunctions of Sturm-Liouville systems and Green's functions
- applications of theory of ordinary differential equations in real world problems.

Learning Outcomes

After studying this course, the student will be able to:

- know about the existence, uniqueness, and continuity of solutions of IVPs.
- apply the matrix method of solution for linear systems of differential equations.
- analyze the stability of solutions for systems of ordinary differential equations.
- understand Green's functions and their applications in the solution of boundary value problems (BVPs).
- comprehend the properties of eigenvalues and eigenfunctions of Sturm-Liouville systems.

Syllabus

Unit – 1 **(12 hours)**

Well-posed problems, Existence, uniqueness, and continuity theorems for the solution of IVPs of the first order, Picard's method, Existence and uniqueness of solution for systems and higher order IVPs , Global existence theorem.

Unit – 2 **(9 hours)**

Homogeneous and non-homogeneous linear systems, Linear systems with constant coefficients and their solution by matrix method, Linear equations with periodic coefficients.

Unit – 3 **(12 hours)**

Stability of autonomous system of differential equations, Critical points of an autonomous system and their classification. Stability of linear systems with constant coefficients, Linear plane autonomous system and phase portrait analysis, Perturbed systems, Method of Lyapunov for nonlinear systems, Limit cycles, Poincare-Bendixson's theorem and its applications.

Unit – 4 **(12 hours)**

Sturm separation and comparison theorems, Adjoint forms and Lagrange's identity, Two-point boundary value problems, Green's functions, Construction of Green's functions, Sturm-Liouville systems, eigenvalues and eigenfunctions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] E. A. Coddington, *An Introduction to Ordinary Differential Equations*, Dover Publications, 2012.
[2] T. Myint-U, *Ordinary Differential Equations*, Elsevier, North-Holland, 1978.
[3] S. L. Ross, *Differential Equation*s, Second Edition, John Wiley & Sons, India, 2007.

Suggested Readings

(i) L. Perko, *Differential Equations and Dynamical Systems,* Springer, 2001.
(ii) G. F. Simmons, *Differential Equations with Applications and Historical Notes*, Third Edition, CRC Press, 2017.

DISCIPLINE SPECIFIC ELECTIVE: REPRESENTATION OF FINITE GROUPS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Representation of Finite Groups	**4**	**3**	**1**	**0**	**Same as for entry to M.Sc. Mathematics**	**Basics of Linear Algebra and Group Theory**

Learning Objectives

The primary objective of this course is to:

- represent finite groups as groups of matrices (via homomorphisms) and apply the tools of linear algebra to study the group structure.
- introduce the notion of Group algebra, which plays an essential role in classifying representations of groups.
- to discuss some applications of representations of finite groups, such as the Burnside's theorem.

Learning Outcomes

This course will enable the students to:

- define and construct examples of group representations, FG-modules, group algebras.
- grasp key concepts and tools of representation theory and establish a link between FG-modules and group representations.
- prove and apply Maschke's theorem and Schur's lemma to describe all irreducible representations of finite groups over the field of complex numbers.
- apply the theory of characters and group representations to gain insight into group structure, such as normal subgroups, and the solubility of groups.

Syllabus

Unit – 1 **(11 hours)**

Representation of groups, FG-modules and FG-submodules, and reducibility, Permutation modules, FG-modules and equivalent representations, Reducible and irreducible FG-modules, Group algebra of G, Regular FG-module and regular representations, FG-homomorphisms, Direct sum of FG-modules.

Unit – 2 **(11 hours)**

Maschke's theorem for FG-modules and consequences. Schur's lemma and its converse, Application of Schur's lemma, Irreducible modules and group algebra, Structure of group algebra and space of CG-homomorphisms.

Unit – 3 **(10 hours)**

Characters and their properties, Permutation and regular characters, Inner product, Number of irreducible characters, Orthogonality relations and finding normal subgroups.

Unit – 4 **(13 hours)**

Algebraic numbers, Algebraic integers and their properties, Character values, The Burnside's *(p,q)*-theorem and solubility of some particular groups.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. James and M. Liebeck, *Representations and Characters of Groups*, Second Edition, Cambridge University Press, 2005.

Suggested Readings

(i) C. W. Curtis and I. Reiner, *Representation Theory of Finite Groups and Associative Algebras*, American Mathematical Society, 2006.
(ii) W. Fulton and J. Harris, *Representation Theory - A First Course*, Springer-Verlag, 2004.
(iii) I. M. Issacs, *Character Theory of Finite Groups*, American Mathematical Society reprint, 2006.

DISCIPLINE SPECIFIC ELECTIVE: TOPOLOGICAL DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Topological Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- provide a strong background of topological dynamical systems including their applications.
- develop some useful and interesting dynamical properties like expansivity, shadowing and topological stability with supporting examples and results from symbolic and topological dynamics.
- introduce the celebrated Sarkovskii's theorem.

Learning Outcomes

This course will enable the students to:

- construct interesting examples of dynamical systems and topological conjugacy.
- visualize stable sets, omega sets and alpha limit sets.
- understand the applications of Sarkovskii's theorem.
- use subshifts of finite type to characterize irreducible matrices.
- prove key results on expansivity and shadowing regarding existence/non-existence, product, subspace and their different characterizations etc.
- find the class of topologically stable homeomorphisms.

Syllabus

Unit – 1 **(10 hours)**

Definition and examples (including real life examples) of dynamical systems, Orbits, Types of orbits, Topological conjugacy and orbits, Phase portrait-graphical analysis of orbit, Periodic points and stable sets, Omega and alpha limit sets and their properties.

Unit – 2 **(10 hours)**

Sarkovskii's theorem, Shift spaces and subshift, Subshift of finite type, Subshift represented by a matrix, Characterizations of irreducible matrices.

Unit – 3 **(13 hours)**

Definition and examples of expansive homeomorphisms, Properties of expansive homeomorphisms, Non-existence of expansive homeomorphism on the unit interval and unit circle, Generators and weak generators, Generators and expansive homeomorphisms.

Unit – 4 **(12 hours)**

Converging semi-orbits for expansive homeomorphisms, Definition, examples and properties of maps having shadowing property, Topological Anosov homeomorphisms and topological stability.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] N. Aoki and K. Hiraide, *Topological Theory of Dynamical Systems: Recent Advances*, North Holland Publications, 1994.
[2] M. Brin and G. Stuck, *Introduction to Dynamical Systems*, Cambridge University Press, 2004.

Suggested Readings

(i) D. C. Hanselman and B. Little field, *Mastering MATLAB*, Pearson, 2012.
(ii) D. Lind and B. Marcus, *An Introduction to Symbolic Dynamics and Coding*, Cambridge University Press, 1996.
(iii) C. Robinson, *Dynamical Systems*, *Stability, Symbolic Dynamics and Chaos*, Second Edition, CRC Press, Taylor & Francis, 1998.
(iv) J. de. Vries, *Elements of Topological Dynamics*, Springer, 1993.

Group-3

DISCIPLINE SPECIFIC ELECTIVE: ADVANCED FUNCTIONAL ANALYSIS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Advanced Functional Analysis	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis and Topology

Learning Objectives

The primary objective of this course is to:

- define and explain the structure of a topological vector space and its fundamental properties.
- differentiate between normed, metrizable, locally convex and Hausdorff topological vector spaces.
- introduce the foundational theorems of functional analysis, including the Hahn–Banach, Banach–Steinhaus, Open mapping, and Closed graph theorems in the context of locally convex spaces.
- explain some applications of Banach–Alaoglu theorem and Krein–Milman theorem.

Learning Outcomes

This course will enable the students to:

- appreciate types of topological vector spaces and their separation properties.
- understand quotient spaces, weak topology and weak*-topology.
- analyze concepts of continuity, boundedness, and convergence for linear operators and functionals on topological vector spaces.
- understand the notion of local convexity and the role of seminorms in defining locally convex topologies.

Syllabus

Unit – 1 **(12 hours)**

Topological vector spaces, Types of Topological vector spaces, Separation properties, Linear mappings, Finite dimensional spaces, Metrization, Boundedness and continuity, Seminorms and local convexity, Normability.

Unit – 2 **(11 hours)**

Quotient spaces, Seminorms and quotient spaces, Examples, Baire category theorem, Banach–Steinhaus theorem, The open mapping theorem and the closed graph theorem on topological vector spaces.

Unit – 3 **(11 hours)**

Hahn–Banach separation theorem on topological vector spaces, Continuous extension theorem,

Weak topologies, Weak topology and convexity, Weak topology and metrizability, Weak*-topology of a dual space, Compact convex sets, Banach–Alaoglu theorem and applications, Goldstine theorem.

Unit – 4 **(11 hours)**

Extreme points, Krein–Milman theorem, Convex hull of compact sets, Applications of Krein–Milman theorem: Stone–Weierstrass theorem, Markov–Kakutani fixed point theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.
[2] W. Rudin, *Functional Analysis*, Second Edition, Tata Mc Graw-Hill, 2011.

Suggested Readings

(i) V. I. Bogachev and O. G. Smolyanov, *Topological Vector Spaces and Their Applications*, Springer, 2017.
(ii) S. Kantorovitz, *Introduction to Modern Analysis*, Oxford Graduate Texts in Mathematics, Oxford University Press, 2006.
(iii) J. Voigt, *A Course on Topological Vector Spaces*, Birkhäuser, 2020.

DISCIPLINE SPECIFIC ELECTIVE: ALGEBRAIC CODING THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Algebraic Coding Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra, Groups and Rings

Learning Objectives

The primary objective of this course is to:

- provide an introduction to algebraic coding theory, particularly linear codes.
- discuss bounds on the parameters along with cyclic codes.
- describe some well-known codes, such as Reed–Muller and Golay codes.
- explore the algebraic structure of Cyclic and Quadratic residue codes over fields and rings.

Learning Outcomes

This course will enable the students to:

- get an insight into the matrix representation of a code, as well as encoding and decoding.
- understand Hamming, MDS and Reed–Muller codes.
- describe cyclic codes and their generator polynomial.
- learn about special cyclic codes, such as Quadratic residue codes, and their properties over the ring $\mathbb{Z}_4$.

Syllabus

Unit – 1 **(10 hours)**

Error detecting and error correcting codes, Maximum likelihood decoding, Hamming distance, Linear codes, Hamming weight, Generator matrix, Parity check matrix, Equivalence of linear codes, Encoding and decoding of linear codes, Syndrome decoding.

Unit – 2 **(11 hours)**

Bounds on codes, Sphere covering bound, Hamming bound, Perfect codes, Binary Hamming codes, Binary Golay codes, Singleton bound and MDS codes. Propagation rules, Reed–Muller codes.

Unit – 3 **(12 hours)**

Cyclic codes, Cyclic codes as ideals, Generator polynomial of cyclic codes, Generator and parity-check matrices of cyclic codes**,** Decoding of cyclic codes, Burst error correcting codes.

Unit – 4 **(12 hours)**

Quadratic residue codes: QR codes over fields of characteristic 2 and 3, Cyclic codes and their generating polynomial over $\mathbb{Z}_4$, QR codes over $\mathbb{Z}_4$.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] S. Ling and C. Xing, *Coding Theory: A First Course*, Cambridge University Press, 2004.
[2] W. C. Huffman and V. Pless, *Fundamentals of Error Correcting Codes*, Cambridge University Press, 2010.

Suggested Readings

(i) R. Hill, *A First Course in Coding Theory*, Oxford University Press, 1986.
(ii) F. J. Mac William and N. J. A. Sloane, *Theory of Error Correcting Codes, Part I & II,* Elsevier/North-Holland, Amsterdam, 1977.

DISCIPLINE SPECIFIC ELECTIVE: DIFFERENTIAL GEOMETRY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Differential Geometry	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra, Multivariate Calculus and Differential Equations

Learning Objectives

The primary objective of this course is to introduce:

- surfaces and parametrized surfaces.
- orientation on connected surfaces.
- geodesics on surfaces.
- Weingarten maps on oriented surfaces.
- arc length and curvature of oriented plane curves.
- curvatures of oriented surfaces.

Learning Outcomes

This course will enable the students to:

- understand the concepts of level sets and graphs of functions, smooth vector fields, tangent spaces of level sets.
- appreciate surfaces and parametrized surfaces, Gauss map, geodesics and parallel transport on oriented surfaces.
- know what the Weingarten map of an oriented surface is, realize it as shape operator and use it to compute curvature of oriented plane curves.
- find global parametrization and hence arc length of an oriented plane curve.
- compute various types of curvatures of surfaces.

Syllabus

Unit – 1 **(10 hours)**

Level sets in $\mathbb{R}^{n+1}$ and graphs of functions, Smooth vector fields and existence and uniqueness of their integral curves, Tangent spaces of level sets at regular points, Surfaces in $\mathbb{R}^{n+1}$ as inverse images of regular values of smooth functions, Necessary condition for extrema of functions on surfaces-Lagrange multipliers, Existence of a normal vector field on a connected surface, Orientation, Gauss map.

Unit – 2 **(13 hours)**

The notion of a geodesic on a surface, Existence and uniqueness of a geodesic on a surface through a given point with a given velocity vector thereof, Covariant derivative of a smooth vector field, Parallel vector field along a curve, Existence and uniqueness of a parallel vector field along a curve with a given initial vector, Weingarten map of a surface at a point, Local parametrization and curvature of a plane curve.

Unit – 3 **(10 hours)**

Global parametrization and arc length of an oriented plane curve, Differential 1-forms, Line integral of 1-forms over parametrized curves.

Unit – 4 **(12 hours)**

Parametrized surfaces with examples, Curvature of surfaces, Normal curvature of a surface at a point in a given direction, Principal curvatures, First and second fundamental forms, Gauss-Kronecker curvature and mean curvature.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] A. Pressley, *Elementary Differential Geometry*, Springer-Verlag London Limited, 2012.
[2] J. A. Thorpe, *Elementary Topics in Differential Geometry*, Springer (India) Pvt. Limited, 2004.

Suggested Readings

(i) W. Kuhnel, *Differential Geometry: Curves-Surfaces-Manifolds*, Third Edition, American Mathematical Society, 2015.
(ii) B. O' Neill, *Elementary Differential Geometry*, Second Edition, Academic Press INC., Academic Press, New York, 2006.

DISCIPLINE SPECIFIC ELECTIVE: FINITE ELEMENT METHODS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Finite Element Methods	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Differential Equations

Learning Objectives

The primary objective of this course is to:

- introduce basic aspects of finite element methods (FEM) including domain discretization, polynomial interpolation, application of boundary conditions, assembly of global arrays, and solution of the resulting algebraic systems.
- discuss the use of finite element methods in solving engineering problems in the domain of solid mechanics, fluid mechanics, heat transfer and electromagnetism.

Learning Outcomes

This course will enable the students to:

- use integral statement to deduce finite element approximations for the underlying linear partial differential equations.
- write special-purpose finite element programs within a procedural programming environment.
- use finite element methods to solve engineering problems in solids mechanics, fluid mechanics, heat transfer, and electromagnetism.
- assess the accuracy and reliability of finite element solutions and troubleshoot problems arising from errors in a given finite element analysis.

Syllabus

Unit – 1 **(12 hours)**

Basic concepts of weak formulation, Variational formulation of a one dimensional model equation, Basis function and finite element solutions, Collocation method, Ritz method, Least square method, Standard Galerkin method, FEM for model problem, Error estimate for FEM for model equation, Convergence analysis.

Unit – 2 **(11 hours)**

Various shapes of finite element, Higher order basis functions, Finite element methods for elliptic problems: Variational methods, Standard Galerkin method, Error estimate for FEM for elliptic problem, FEM for Poisson equation.

Unit – 3 **(12 hours)**

Finite element methods for parabolic problems: One dimensional model problems, Semi-discretization in space, Error estimates, Discretization in space and time, Galerkin method, Finite element methods for hyperbolic problems: Standard Galerkin method, Standard Galerkin method with strongly and weakly imposed boundary conditions.

Unit – 4 **(10 hours)**

Applications of the FEM to second order BVPs in one dimension, Applications of the FEM to linear elliptic, parabolic and hyperbolic equations.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. Evans, J. Blackledge and P. Yardley, *Numerical Methods for Partial Differential Equations*, Springer-Verlag, London, 2000.

[2] C. Johnson, *Numerical Solutions of Partial Differential Equations by Finite Element Methods*, *Cambridge University Press*, Cambridge, 1987.

[3] J. Whiteley, *Finite Element Methods - A Practical Guide*, Springer, 2016.

Generic Elective (GE) Courses

GENERIC ELECTIVE – 1 (i): DYNAMICAL SYSTEMS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
GE-1 (i): Dynamical Systems	4	3	1	0	Class XII pass with Mathematics	Basics of Topology and Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- understand discrete and continuous systems with case studies to study nonlinear systems of ordinary differential equations and dynamical systems.
- understand the concepts, models and techniques to realize the real-world problems and stability of the systems along with the chaotic dynamic behaviour of models by understanding bifurcations.

Learning Outcomes

This course will enable the students to learn:

- formulation of mathematical models with the stability analysis near the equilibrium points.
- how the concept of phase portraits helps to analyse mathematical model graphically.
- the qualitative behaviour of the solution set of a given system of differential equations including the invariant sets and limiting behaviour of the dynamical system or flow defined by the system of differential equations.
- how different bifurcations explain the chaotic behaviour of the system.

Syllabus

Unit – 1 **(13 hours)**

Linear systems: Jordan forms, Stability theory; Nonlinear systems: Fundamental existence-uniqueness theorem, Dependence on initial conditions and parameters, Flow of a differential equation, Linearization, Stable manifold theorem, Hartman–Grobman theorem.

Unit – 2 **(10 hours)**

Stability and Lyapunov functions, Saddle points, Nodes, Foci, Centers and nonhyperbolic critical points, Center manifold theorem.

Unit – 3 **(12 hours)**

Limit sets and attractors, Periodic orbits and limit cycles, Poincaré map, Stable manifold theorem for periodic orbits, Poincare-Bendixson theorem.

Unit – 4 **(10 hours)**

Bifurcations at nonhyperbolic equilibrium points, Saddle node, Transcritical and Pitchfork bifurcations, Hopf bifurcation.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. W. Hirsch, S. Smale and R. L. Devaney, *Differential Equations, Dynamical Systems, and an Introduction to Chaos*, Third Edition, Academic Press, 2013.
[2] L. Perko, *Differential Equations and Dynamical Systems*, Third Edition, Springer Verlag, 2001.

Suggested Readings

(i) R. L. Devaney, *A First Course in Chaotic Dynamical Systems: Theory and Experiment*, CRC Press, Taylor & Francis, 2018.
(ii) S. H. Strogatz, *Nonlinear Dynamics and Chaos*, Second Edition, CRC Press, Taylor & Francis, 2018.
(iii) S. Wiggins, *Introduction to Applied Nonlinear Dynamical Systems and Chaos*, TAM Volume 2, Springer-Verlag, NY, 1990.

GENERIC ELECTIVE – 1 (ii): NUMERICAL METHODS FOR ORDINARY DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
GE-1 (ii): Numerical Methods for Ordinary Differential Equations	4	3	1	0	Class XII pass with Mathematics	Basics of Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- develop the basic theory underlying the numerical solution of differential equations.
- introduce the concepts of consistency, stability and convergence of finite difference methods.
- execute the numerical schemes for the solution of differential equations.

Learning Outcomes

This course will enable the students to:

- gain a thorough understanding of the fundamental concepts involved in the construction and analysis of finite difference schemes for solving ordinary differential equations (ODEs).
- apply various numerical methods based on finite difference approaches to obtain approximate solutions for both initial value problems (IVPs) and boundary value problems (BVPs).
- develop the ability to select appropriate finite difference methods for specific types of problems and effectively apply them to real world applications.

Syllabus

Unit – 1 **(11 hours)**

Initial value problems: Existence and uniqueness of solution, Finite difference equation, Truncation error, Single step methods for first order IVPs and system of IVPs- Family of explicit and implicit Runge–Kutta methods, Taylor series methods, Derivation, Truncation error, Consistency, Stability and convergence analysis.

Unit – 2 **(12 hours)**

IVPs for the system of ODEs, Consistency, Zero stability and convergence of linear multistep methods, Routh–Hurwitz criterion, Order and error constant, First Dahlquist Barrier, Local truncation error and global truncation error, Error bounds, Local error, Linear stability theory, Higher order differential equations.

Unit – 3 **(12 hours)**

Derivation of explicit and implicit multistep methods for IVPs and system of IVPs, Truncation error, Stability and convergence analysis of family of Nystrom method, Adams–Bashforth method,

Adams–Moulton method, Milne–Simpson method, Predictor corrector method, and Modified predictor corrector method, Hybrid method, Multistep methods for second order IVPs.

Unit – 4 **(10 hours)**

Linear BVPs for second order ordinary differential equations, Shooting method, Finite difference method, Collocation method, Derivative boundary conditions, Nonlinear two-point BVPs, Higher order finite difference methods, Stability, Truncation error and convergence analysis.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. K. Jain, S. R. K. Iyenger and R. K. Jain, *Numerical Methods for Scientific and Engineering Computations*, Seventh Edition, New Age International Publisher, 2019.
[2] J. D. Lambert, *Numerical Methods for Ordinary Differential Systems: The Initial Value Problem*, John Wiley & Sons, 1991.

Suggested Readings

(i) K. E. Atkinson, W. Han and D. E. Stewart, *Numerical Solution of Ordinary Differential Equations*, John Wiley & Sons, 2009.
(ii) J. C. Butcher, *The Numerical Analysis of Ordinary Differential Equations*, Second Edition, Wiley, New York, 2008.
(iii) L. Collatz, *The Numerical Treatment of Differential Equations*, Springer-Verlag, 1966.

Syllabi of Courses in Semester-II of One-year M.Sc. Mathematics under Structure-2 (Course work + Research)

Discipline Specific Core (DSC) Courses

DISCIPLINE SPECIFIC CORE – 3: PARTIAL DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC-3: Partial Differential Equations	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Multivariate Calculus and Differential Equations

Learning Objectives

The main objective of this course is to introduce:

- well-posedness, fundamental solutions, existence and uniqueness of solutions for Laplace equation, Poisson equation and heat equation.
- solution for wave equation by spherical means.
- characteristics, complete integrals, envelopes and conservation laws for first-order nonlinear partial differential equations.
- classical solution techniques such as Green's function, similarity solutions and transform methods.

Learning Outcomes

This course will enable the students to:

- understand Laplace equation, Poisson equation, and Heat equation, their fundamental solutions, uniqueness principles, mean value properties, and Green's function.
- apply the method of spherical means to solve homogeneous and nonhomogeneous wave equations.
- use characteristics to solve nonlinear partial differential equations, construct complete integrals and envelopes, and understand conservation laws.
- implement various techniques such as similarity solutions and transform methods to derive solutions of different types of partial differential equations.

Syllabus

Unit – 1 **(12 hours)**

Well-posed problems, Classical solution, Laplace equation, Poisson equation, Fundamental solution, Strong maximum principle and uniqueness of solution, Mean value formulas, Representation formula, Green's function, Poisson's formula.

Unit – 2 **(10 hours)**

Heat equation, Fundamental solution for homogeneous and nonhomogeneous initial-value problems, Mean value formula, Strong maximum principle and uniqueness of solution, Local estimates for the solution.

Unit – 3 **(13 hours)**

Wave equation: Solution of homogeneous and nonhomogeneous problems by spherical means,

Nonlinear first order partial differential equations: Complete integrals and envelopes, Characteristics, Introduction to conservation laws.

Unit – 4 **(10 hours)**

Other solution methods: Similarity solutions, Fourier transform and Laplace transform, Cole–Hopf transformation, Potential function, Hodograph and Legendre transform.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] L. C. Evans, *Partial Differential Equations*, American Mathematical Society, Providence, RI, 1998.
[2] F. John, *Partial Differential Equations*, Fourth Edition, Springer-Verlag, New York, 1982.

Suggested Readings

(i) P. R. Garabedian, *Partial Differential Equations*, John Wiley & Sons, Inc., New York- London-Sydney, 1964.
(ii) A. K. Nandakumaran and P. S. Datti, *Partial Differential Equations: Classical Theory with a Modern Touch*, Cambridge University Press, 2020.

DISCIPLINE SPECIFIC CORE – 4: ANALYSIS OF SEVERAL VARIABLES

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC-4: Analysis of Several Variables	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Calculus, Real Analysis including Riemann Integration

Learning Objectives

The primary objective of this course is to:

- introduce differentiation of vector valued functions on $\mathbb{R}^n$ and their properties.
- familiarize students with integration of functions over rectangles and bounded sets in $\mathbb{R}^n$.
- extend integration of functions to unbounded sets in $\mathbb{R}^n$.
- study change of variables and its applications.

Learning Outcomes

This course will enable the students to:

- check differentiability of vector valued functions on $\mathbb{R}^n$, understand the relation between directional derivative and differentiability, apply chain rule, mean value theorems, inverse and implicit function theorems.
- understand higher order derivatives and be able to apply Taylor's formulas with integral remainder, Lagrange's remainder and Peano's remainder.
- master the concepts of integration over rectangles and bounded sets in $\mathbb{R}^n$.
- generalize the integration theory to unbounded sets in $\mathbb{R}^n$.
- grasp the effect of change of variables in integration.

Syllabus

Unit– 1 **(12 hours)**

The differentiability of functions from $\mathbb{R}^n$ to $\mathbb{R}^m$, Partial derivatives and differentiability, Directional derivatives and differentiability, Chain rule, Mean value theorems, Inverse function theorem and Implicit function theorem.

Unit– 2 **(11 hours)**

Derivatives of higher order, Taylor's formulas with integral remainder, Lagrange's remainder and Peano's remainder, Integral over a rectangle, Existence of the integral.

Unit– 3 **(10 hours)**

Evaluation of the integral, Fubini's theorem, Integral over a bounded set.

Unit– 4 **(12 hours)**

Rectifiable sets, Improper integrals**,** Change of variable theorem, Applications of change of variables.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. Giaquinta and G. Modica, *Mathematical Analysis: An Introduction to Functions of Several Variables*, Birkhäuser, 2009.
[2] J. R. Munkres, *Analysis on Manifolds*, CRC Press, Taylor & Francis, 2018.

Suggested Readings

(i) W. Rudin, *Principles of Mathematical Analysis*, Third Edition, Mc Graw Hill, 1986.
(ii) M. Spivak, *Calculus on Manifolds: A Modern Approach to Classical Theorems of Advanced Calculus*, Taylor & Francis, 2018.

Discipline Specific Elective (DSE) Courses

DSE-3 and DSE-4

Group-1

DISCIPLINE SPECIFIC ELECTIVE: ADVANCED FLUID DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Advanced Fluid Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Calculus and Partial Differential Equations

Learning Objectives

The primary objective of this course is to:

- prepare a foundation for advanced studies in compressible flow, boundary layer theory and magnetohydrodynamics.
- develop concepts, models, and techniques that enable problem-solving in compressible flow, boundary layer theory and magnetohydrodynamics.
- equip students with concepts and techniques to conduct research in the above mentioned domains.

Learning Outcomes

This course will enable the students to:

- learn conservation laws, first and second laws of thermodynamics, internal energy and entropy, different forms of energy equations and dimensional analysis.
- know about compressibility in real fluids, wave motion, sound waves, hyperbolic and dispersive waves, shock waves, their formation, properties and elementary analysis.
- know the concepts of boundary layer, boundary layer equations and their solutions, measurements of boundary layer thickness.
- understand the interaction between hydrodynamic processes and electromagnetic phenomena.
- formulate the basic equations of motion in inviscid and viscous conducting fluid flow and explain Alfven's theorem and magnetohydrodynamic (MHD) waves and MHD shocks.

Syllabus

Unit – 1 **(11 hours)**

Flow characteristics, Conservation laws, Equation of state of a substance, First and second law of thermodynamics, Internal energy and entropy, Energy equation, Nondimensionalizing the basic

equations of incompressible viscous fluid flow, Nondimensional numbers.

Unit – 2 **(12 hours)**

Compressibility effects in real fluids, Equations of motion, Sound wave, Hyperbolic and dispersive waves, Isentropic gas flow, Flow through a nozzle, Method of characteristics, Shock jump conditions, Non-linear plane waves, Shock waves and their elementary analysis, Similarity solutions.

Unit – 3 **(11 hours)**

Boundary layer concept, Estimation of boundary layer thickness and friction forces, Prandtl's boundary layer equations, Boundary layer along a flat plate, Boundary layer thickness, General properties of the boundary layer equations, Similar solutions, Momentum and energy integral equations for the boundary layer.

Unit – 4 **(11 hours)**

Maxwell's electromagnetic field equations, Magnetohydrodynamic (MHD) approximations, Magnetic field equation, Magnetic Reynolds number, Magnetic body force, Equations of Motions of conducting fluid, Alfven's theorem, MHD waves, MHD shock waves.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] F. Chorlton, *Text Book of Fluid Dynamics*, CBS Publisher, 2005.
[2] H. Schlichting and K. Gersten, *Boundary Layer Theory*, Ninth Edition, Springer, 2017.
[3] G. B. Witham, *Linear and Nonlinear Waves*, John Wiley & Sons, 1999.

Suggested Readings

(i) K. R. Cramer and S. I. Pai, *Magnetofluid Dynamics for Engineers and Applied Physics*, McGraw Hill Book Co., New York, 1973.
(ii) Y. Shao-Wen, *Foundations of Fluid Mechanics*, PHI, New Delhi, 1960.

DISCIPLINE SPECIFIC ELECTIVE: MODULE THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Module Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Groups and Rings

Learning Objectives

The primary objective of this course is to:

- introduce a new algebraic structure, namely, module which is a generalization of a vector space when the underlying field is replaced by an arbitrary ring. The study of modules over a ring also provides an insight into the structure of the ring.
- study free modules, finitely generated modules, projective and injective modules.
- classify the finitely generated modules over a principal ideal domain (PID).

Learning Outcomes

This course will enable the students to:

- identify and construct examples of modules, and apply homomorphism theorems on the same.
- define and characterize Noetherian, Artinian module, and apply the structure theorem of finitely generated modules over PID.
- distinguish between projective, injective, free, and semi simple modules.
- prove universal property of tensor product of modules, and Hilbert basis theorem.

Syllabus

Unit – 1 **(13 hours)**

Basic concepts of module theory, Fundamental theorems of homomorphism, Direct product and direct sum of modules, Exact sequences, Split exact sequences.

Unit – 2 **(10 hours)**

Free modules, Projective and injective modules, Dual basis lemma, Baer's criterion, Divisible modules.

Unit – 3 **(12 hours)**

Tensor product of modules, Chain conditions, Hilbert basis theorem.

Unit – 4 **(10 hours)**

Modules over PID's, Semi simple modules.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. F. Athiyah and I. G. Macdonald, *Introduction to Commutative Algebra*, Addison Wesley, 1969.
[2] P. M. Cohn, *Basic Algebra*, Springer International Edition, 2003.
[3] P. M. Cohn, *Classic Algebra*, John Wiley & Sons Ltd., 2000.

Suggested Readings

(i) D. S. Dummit and R. M. Foote, *Abstract Algebra*, Wiley India Pvt. Ltd., 2011.
(ii) N. Jacobson, *Basic Algebra*, Volume II, Dover Publications Inc., 2009.
(iii) T. W. Hungerford, *Algebra*, Springer-Verlag, 1981.

DISCIPLINE SPECIFIC ELECTIVE: PROBABILITY THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Probability Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Measure Theory

Learning Objectives

The primary objective of this course is to introduce:

- probability space as a measure space and random variables as measurable functions.
- expectation and moments of random variables.
- notion of convergence in probability.
- conditioning on sub-σ-algebra.

Learning Outcomes

This course will enable the students to learn:

- about probability or uncertainty in abstract setting.
- moments and expectation of random variables which help to understand applications of probability in industry.
- how to apply the idea of convergence in probability.
- weak law and strong law of large numbers and their applications.

Syllabus

Unit – 1 **(11 hours)**

Probability: σ-algebra, Constructing probability triples, The extension theorem, Random variables, Independence of events, Continuity of probabilities, Limit events, The Borel–Cantelli Lemma.

Unit – 2 **(10 hours)**

Expected values: Simple, general non-negative and arbitrary random variables, Moment generating functions, Markov's inequality, Chebyshev's inequality.

Unit – 3 **(12 hours)**

Convergence of random variables: Convergence almost surely, Convergence in probability, Weak law of large numbers, Strong law of large numbers.

Unit – 4 **(12 hours)**

Distributions of random variables: Examples of distributions, Characteristic functions, The central limit theorem, Conditional probability, Conditioning on random variable, Conditioning on a sub-σ-algebra, Conditional variance.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. S. Rosenthal, *A First Look at Rigorous Probability Theory*, Second Edition, World Scientific, Singapore, 2006.

Suggested Readings

(i) W. Feller, *An Introduction to Probability Theory and its Applications*, Volume 1, Third Edition, Wiley, 2008.
(ii) J. E. Michael and J. S. Rosenthal, *Probability and Statistics: The Science of Uncertainty*, Second Edition, W. H. Freeman & Co Ltd., 2009.
(iii) S. Ross, *A First Course in Probability*, Tenth Edition, Pearson Education, 2022.
(iv) D. W. Stroock, *Probability Theory, An Analytic View*, Cambridge University Press, 2024.

DISCIPLINE SPECIFIC ELECTIVE: THEORY OF UNBOUNDED OPERATORS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Theory of Unbounded Operators	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis and Bounded Operators

Learning Objectives

The primary objective of this course is to:

- introduce the notion of unbounded operators.
- develop the theory of operator semigroups and understand their role in applications, particularly for solving differential equations.

Learning Outcomes

This course will enable the students to:

- identify closed and closable linear operators on Banach spaces.
- compute adjoints of unbounded linear operators.
- understand spectral properties of some unbounded operators.
- comprehend the role unbounded operators and semigroups play in applications, particularly in studying solutions of differential equations.

Syllabus

Unit – 1 **(10 hours)**

Unbounded linear operators, Hilbert adjoints, Hellinger–Toeplitz theorem, Hermitian, symmetric and self-adjoint linear operators, Closed linear operators, Closable operators and their closures on Banach spaces.

Unit – 2 **(12 hours)**

Cayley transform, Deficiency indices, Spectral properties of self-adjoint operators, Multiplication and differentiation operators and their spectra.

Unit – 3 **(11 hours)**

Analytic properties of exponential functions, Matrix Semigroups, Uniformly continuous semigroups, Semigroups on Hilbert spaces, Strongly continuous semigroups.

Unit – 4 **(12 hours)**

Generators of semigroups and their resolvents, Hille–Yosida theorem (for contraction semigroup), Dissipative operators and their properties, Lumer–Phillips theorem, Generators of Group, Stone's theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] K. J. Engle and R. Nagel, *One-parameter Semigroups for Linear Evolution Equations*, Springer-Verlag, New York, 2000.
[2] E. Kreyszig*, Introductory Functional Analysis with Applications*, John Wiley & Sons, 2006.

Suggested Readings

(i) S. Goldberg, *Unbounded Linear Operators: Theory and Applications*, Dover Publications, 2006.
(ii) E. Hille and R. S. Phillips, *Functional Analysis and Semi-groups*. American Mathematical Society, Providence, RI, 1957.
(iii) A. Pazy*, Semigroups of Linear Operators and Applications to Partial Differential Equations*, Springer, 1983.
(iv) M. Schechter, *Principles of Functional Analysis*, Second Edition, American Mathematical Society, 2001.
(v) J. Weidmann, *Linear Operators in Hilbert Spaces, Graduate Texts in Mathematics*, Springer, New York, 1980.

Group-2

DISCIPLINE SPECIFIC ELECTIVE: BANACH AND C*-ALGEBRAS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Banach and C*-Algebras	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis and Topology

Learning Objectives

The primary objective of this course is to introduce:

- Banach algebras and C*-algebras.
- various ways to construct new operator algebras using given ones.
- spectrum of elements in Banach algebras and to study its properties.
- Gelfand representations of commutative Banach algebras and of C*-algebras.

Learning Outcomes

This course will enable the students to:

- familiarize with the representations of operator algebras.
- realize commutative Banach algebras and abelian C*-algebras as space of continuous functions on locally compact groups.
- understand the powerful tool of functional calculus.
- identify any C*-algebra as closed *-subalgebra of space of bounded linear operators on a Hilbert space.

Syllabus

Unit – 1 **(11 hours)**

Elementary properties and examples of Banach algebras, Ideals and quotients, Invertible elements, Spectrum and spectral radius, Spectral radius formula, Spectral mapping theorem (for polynomials), Gelfand–Mazur theorem.

Unit – 2 **(11 hours)**

Multiplicative linear functionals, Commutative Banach algebra, w*-topology, Gelfand transform of an element, Structure space, Gelfand representation.

Unit – 3 **(12 hours)**

Elementary properties and examples of C*-algebras, Unitization, Gelfand–Naimark representation of commutative C*-algebras, Continuous functional calculus, Spectral mapping theorem for normal elements, Positive elements of C*-algebras.

Unit – 4 **(11 hours)**

Ideals in C*-algebras, Approximate units, Quotients, Positive linear functionals, Gelfand–Naimark–Segal representation of C*-algebras.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.
[2] G. J. Murphy, *C*-algebras and Operator Theory*, Academic Press Inc., 1990.

Suggested Readings

(i) J. B. Conway, *A Course in Operator Theory, Graduate Texts in Mathematics*, Springer, 2007.
(ii) J. Dixmier, *C*-algebras*, North-Holland Publishing Company, 1977.
(iii) R. G. Douglas, *Banach Algebra Techniques in Operator Theory, Graduate Texts in Mathematics*, Springer, 1998.
(iv) E. Kaniuth, *A Course on Commutative Banach Algebras*, Graduate Texts in Mathematics, Springer, 2009.
(v) S. Kantorovitz, *Introduction to Modern Analysis*, Oxford Graduate Texts in Mathematics, Oxford University Press, 2006.
(vi) M. Takesaki, *Theory of Operator Algebras I*, Springer, 2002.

DISCIPLINE SPECIFIC ELECTIVE: CHAOS THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Chaos Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- introduce some useful and interesting notions like Topological Transitivity and Sensitive dependence on initial conditions.
- study different types of chaos including Devaney's chaos and finding their interrelationships.
- know classical result that period three implies chaos on intervals.
- relate chaos and decomposition theorems.
- study Topological entropy through open covers and also Bowen's definition of entropy, equivalence of these two definitions on compact metric spaces.
- study various interesting results related to topological entropy.

Learning Outcomes

This course will enable the students to:

- construct interesting examples of Topological transitive maps, Topological mixing maps etc.
- know classical examples of Devaney's chaotic maps like tent map, shift maps, logistic maps.
- study and compare different types of chaos.
- find relation between transitivity and chaos on intervals.
- relate chaos theory and classical decomposition theorems.
- study very useful notion of Topological entropy including its properties.
- calculate entropy of any homeomorphism of closed unit interval and of unit circle.

Syllabus

Unit – 1 **(12 hours)**

Topological Transitivity, Locally eventually onto maps, Topological mixing, Sensitive dependence on initial conditions, Devaney's definition of chaos, Transitivity and limit sets for continuous interval maps.

Unit – 2 **(11 hours)**

Characterizing topological mixing in terms of topological transitivity for continuous interval maps, Topological Weakly Mixing, Totally Transitive maps, Relation between transitivity and chaos on intervals, Logistic maps and shift maps as chaotic maps.

Unit – 3 **(12 hours)**

Various other definitions of chaos and their interrelationships. Period three implies chaos, Chaos and decomposition theorems including Bowen's decomposition theorem, Topological Entropy: Definition using open covers, Examples and properties, Bowen's definition of topological entropy,

Equivalence of two definitions, Topological version of Kolmogorov–Sinai theorem.

Unit – 4 **(10 hours)**

Topological Entropy of maps on a compact metric space, Topological Entropy of product maps, of iterations of a map, Topological entropy of an expansive homeomorphism on a compact metric space, of the two-sided shift, of any homeomorphism of the unit interval and of the unit circle.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] N. Aoki and K. Hiraide, *Topological Theory of Dynamical Systems: Recent Advances*, North Holland Publications, 1994.
[2] R. L. Devaney, *A First Course in Chaotic Dynamical Systems*, CRC Press, 2018.
[3] S. Ruette, *Chaos for Continuous Interval Maps: A Survey of Relationship Between Various Kinds of Chaos*, 2018.
[4] Peter Walters, *An Introduction to Ergodic Theory*, Springer, 2000.

Suggested Readings

(i) L. Alsedà, J. Llibre and M. Misiurewicz, *Combinatorial Dynamics and Entropy in Dimension One*, Advanced Series in Nonlinear Dynamics, World Scientific, 2000.
(ii) L. S. Block and W. A. Coppel, *Dynamics in One Dimension*, Springer, 2014.
(iii) M. Brin and G. Stuck, *Introduction to Dynamical Systems*, Cambridge University Press, 2015.

DISCIPLINE SPECIFIC ELECTIVE: COMPLEX ANALYSIS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Complex Analysis	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Real Analysis and Metric Spaces

Learning Objectives

The primary objective of this course is to:

- gain insights of well-known classical results in the field of complex analysis.
- investigate various properties of analytic functions, conformal mappings and Möbius transformations.
- derive various forms of Cauchy's theorem, integral formulas and maximum principles.
- represent complex-valued functions as Taylor and Laurent series.

Learning Outcomes

This course will enable the students to:

- construct Möbius transformations using Symmetry and Orientation principles.
- foresee the usage of simply connected regions in the complex plane for the existence of primitives and branch of logarithm.
- understand the behavior of zeros of analytic functions and meromorphic functions through Argument principle and Rouche's theorem.
- evaluate the real integrals involving rational and trigonometric functions by contour integration using Residue theorem.
- apply Schwarz's lemma to characterize the conformal maps of the open unit disk onto itself.

Syllabus

Unit – 1 **(10 hours)**

Extended plane and its spherical representation, Analytic functions, Branch of logarithm, Conformal mappings, Möbius transformations.

Unit – 2 **(10 hours)**

Line integrals, Fundamental theorem of Calculus for line integrals, Power series representation of analytic functions, Zeros of analytic functions, Liouville's theorem.

Unit – 3 **(12 hours)**

Index of a closed curve, Cauchy's theorem and integral formula, Morera's Theorem, Homotopic version of Cauchy's theorem and simple connectivity, Counting Zeros, Open mapping theorem, Goursat's theorem.

Unit – 4 **(13 hours)**

Classification of singularities, Laurent series, Casorati-Weierstrass theorem, Residue theorem with applications, Argument principle, Rouche's theorem, Maximum principles, Schwarz lemma.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. B. Conway, *Functions of One Complex Variable*, Second Edition, Narosa Publishing House, New Delhi, 2002.

Suggested Readings

(i) L. V. Ahlfors, *Complex Analysis*, Mc Graw Hill Co., Indian Edition, 2017.
(ii) T. W. Gamelin, *Complex Analysis*, Springer New York, NY, 2001.
(iii) L. Hahn and B. Epstein, *Classical Complex Analysis*, Jones and Bartlett, 1996.
(iv) E. M. Stein and R. Shakarchi, *Complex Analysis*, Princeton University Press, 2003.

DISCIPLINE SPECIFIC ELECTIVE: NONSMOOTH OPTIMIZATION

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Nonsmooth Optimization	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Nonlinear Optimization

Learning Objectives

The primary objective of this course is to:

- understand the tools to deal with nonsmooth convex functions.
- study conjugate duality in terms of conjugate functions for constrained nonlinear optimization problems.
- introduce numerical techniques to solve constrained nonlinear optimization problems.

Learning Outcomes

This course will enable the students to learn:

- the notions of subgradients and subdifferentials for nonsmooth convex functions.
- the use of conjugate functions to develop the theory of conjugate duality.
- about numerical methods like gradient descent method, gradient projection method, Newton's method and conjugate gradient method.
- penalty approach technique to solve constrained nonlinear optimization problems.

Syllabus

Unit – 1 **(11 hours)**

Extended real valued functions, Proper convex functions, Closure of convex functions, Differential derivatives, Subgradients and subdifferentials.

Unit – 2 **(12 hours)**

Conjugate functions, Biconjugate functions, Perturbation functions, Closure of convex functions, Directional derivatives, Subgradients and subdifferentials.

Unit – 3 **(12 hours)**

Gradient descent method, Gradient projection method, Newton's method, Conjugate gradient method.

Unit – 4 **(10 hours)**

Penalty function methods, Exterior penalty function, Interior penalty functions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. Avriel, *Nonlinear Programming: Analysis and Methods*, Dover Publications, 2003.

[2] O. Güler, *Foundations of Optimization*, Springer, 2010.

Suggested Readings

(i) A. Bagirov, N. Karitsa and M. M. Makela, *Introduction to Nonsmooth Optimization: Theory, Practice and Software*, Springer, 2014.
(ii) M. S. Bazaraa, H. D. Sherali and C. M. Shetty, *Nonlinear Programming: Theory and Algorithms,* Third Edition, John Wiley & Sons, 2013.
(iii) D. G. Luenberger and Y. Ye, *Linear and Nonlinear Programming*, Springer, 2008.

Group-3

DISCIPLINE SPECIFIC ELECTIVE: COMPUTATIONAL FLUID DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Computational Fluid Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Partial Differential Equation (Undergraduate level)

Learning Objectives

The primary objective of this course is to teach:

- various numerical schemes on finite difference and finite volume methods for solving PDEs.
- discretization errors and grid dependence.
- some real-world applications of PDEs and fluid dynamics.
- discretization of governing equations of diffusion, convection-diffusion, fluid flow and thereby computing the numerical solutions using the flow variables using algorithms.

Learning Outcomes

This course will enable the students to learn:

- techniques for solving the PDEs along with some initial and boundary conditions by using the finite difference and finite volume methods.
- the basic conservation principles of mass, momentum, energy, discretization of governing equations.
- discretization techniques.
- some popular algorithms like SIMPLE and SIMPLER used to obtain the solutions of steady and unsteady flow problems by finite volume methods.

Syllabus

Unit – 1 **(12 hours)**

Basics of discretization using finite differences, Various single and multi-step explicit and implicit finite difference schemes for 1-D and 2-D parabolic and hyperbolic initial boundary value problems, Alternating Direction Implicit schemes (ADI) for 2-D parabolic and hyperbolic equations, Order of accuracy, Consistency, Stability and convergence of a finite difference scheme, Courant Friedrich Lewy condition.

Unit – 2 **(12 hours)**

Finite difference schemes for second and fourth order 2-D elliptic boundary value problem and applications, Finite volume method for diffusion and convection-diffusion equations, Discretization of one and two-dimensional steady state diffusion and convection-diffusion equations, Central difference, Upwind, Exponential, Hybrid, Power-law and QUICK schemes and their properties.

Unit – 3 **(11 hours)**

Flow field calculation, Pressure-velocity coupling, Vorticity-stream function approach, Primitive variables, Staggered grid, Pressure and velocity corrections, Pressure correction equation, SIMPLE and SIMPLER algorithms.

Unit – 4 **(10 hours)**

Finite volume methods for unsteady flows, Discretization of one-dimensional transient heat conduction, Explicit, fully implicit and Crank–Nicolson schemes, Implementation of boundary conditions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. C. Strikweda, *Finite Difference Schemes and Partial Differential Equations*, Second Edition, SIAM, 2004.

[2] H. K. Versteeg and W. Malalasekera, *An Introduction to Computational Fluid Dynamics: The Finite Volume Method*, Second Edition, Pearson, 2008.

Suggested Readings

(i) J. D. Anderson, *Computational Fluid Dynamics*, McGraw-Hill, 1995.

(ii) S. V. Patankar, *Numerical Heat Transfer and Fluid Flow*, CRC Press, Taylor and Francis, Indian Edition, 2017.

(iii) R. H. Pletcher, J. C. Tannehill and D. A. Anderson, *Computational Fluid Mechanics and Heat Transfer*, CRC Press, Taylor and Francis, 2013.

(iv) J. W. Thomas, *Numerical Partial Differential Equations: Finite Difference Methods*, Springer, 2013.

DISCIPLINE SPECIFIC ELECTIVE: DIFFERENTIAL TOPOLOGY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Differential Topology	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- introduce the concepts of topological manifolds, smooth structures, smooth manifolds, and manifolds with boundary.
- develop an understanding of smooth functions, smooth maps, diffeomorphisms, and tangent spaces.
- explain the Inverse function theorem, immersions and submersions.
- develop the fundamental concepts of 2-manifolds and distinguish between orientable and non-orientable surfaces.
- explore the properties of compact and connected surfaces.

Learning Outcomes

This course will enable the students to:

- identify and construct examples of topological manifolds, smooth structures and manifolds with and without boundary.
- demonstrate understanding of diffeomorphisms and tangent spaces.
- apply the Inverse function theorem, immersions and submersions.
- define key concepts such as 2-manifolds, orientability, compactness, connectedness and boundary of a surface.
- differentiate between orientable and non-orientable surfaces using examples such as the sphere, torus, Möbius strip and Klein bottle.

Syllabus

Unit – 1 **(12 hours)**

Topological manifolds, Topological properties of manifolds, Smooth structures, Examples of smooth manifolds, Manifolds with boundary.

Unit – 2 **(11 hours)**

Smooth functions and smooth maps, Lie groups, Diffeomorphisms.

Unit – 3 **(10 hours)**

Derivatives and tangents, Inverse function theorem, Immersions and submersions.

Unit – 4 **(12 hours)**

Complexes, Connected sum of two surfaces, Non-orientable surfaces (2- Manifolds), Compact and connected surfaces, Classification of compact and connected surfaces with and without boundary.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] V. Guillemin and Alan Pollack, *Differential Topology*, Prentice-Hall, 1974.
[2] L. C. Kinsey, *Topology of Surfaces*, Springer Verlag, 1997.
[3] J. M. Lee, *Introduction to Smooth Manifolds*, Second Edition, Springer, 2013.

Suggested Readings

(i) L. Conlon, *Differentiable Manifolds*, Second Edition, Birkhäuser Advanced Texts, 2001.
(ii) M. Spivak, *A Comprehensive Introduction to Differential Geometry*, Volume 1, Third Edition, Publish or Perish, Huston, Texas, 1999.
(iii) L. W. Tu, *Introduction to Manifolds*, Second Edition, Springer, 2011.
(iv) F. W. Warner, *Foundations of Differentiable Manifolds and Lie Group*, Springer-Verlag, 1983.

DISCIPLINE SPECIFIC ELECTIVE: GENERAL MEASURE THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: General Measure Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Measure Theory and Topology

Learning Objectives

The primary objective of this course is to introduce:

- real valued and complex valued measures.
- decomposition of measure spaces and of measures.
- extension of a premeasure to a measure, Lebesgue measure on Euclidean spaces.
- representation of measures and functionals in terms of integrals.
- product measures.

Learning Outcomes

This course will enable the students to:

- appreciate signed measures and complex measures, mutual singularity of measures, Hahn and Jordan decompositions, Lebesgue decomposition, Radon–Nikodym theorem.
- verify conditions under which a set function defined on a collection of subsets of a set has an extension to a measure on a sigma-algebra.
- apply Riesz representation theorem for bounded linear functionals on L^p-spaces.
- understand product measure and the results of Fubini and Tonelli, and express the Lebesgue measure on Euclidean spaces as a product measure.
- apply Riesz–Markov representation theorem for the bounded linear functionals on the space of continuous functions.

Syllabus

Unit – 1 **(13 hours)**

Signed measures, Hahn and Jordan decompositions, Mutually singular measures, Radon–Nikodym theorem, Lebesgue decomposition, Complex measure.

Unit – 2 **(10 hours)**

The Carathéodory extension theorem, Lebesgue measure on $\mathbb{R}^n$, Regularity and translation invariance of Lebesgue measure on $\mathbb{R}^n$.

Unit – 3 **(10 hours)**

Riesz representation theorem for the dual of L^p-spaces, Product measures, Fubini's theorem, Tonelli's theorem.

Unit – 4 **(12 hours)**

Locally compact Hausdorff spaces and construction of Radon measure, Riesz–Markov representation theorem for positive linear functionals on $C_c(X)$, Riesz representation theorem for the dual of $C(X)$.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] H. L. Royden and P. M. Fitzpatrick, *Real Analysis*, Fourth Edition, Pearson, 2015.
[2] M. E. Taylor, *Measure Theory and Integration*, American Mathematical Society, 2006.

Suggested Readings

(i) G. B. Folland, *Real Analysis: Modern Techniques and Their Applications*, Second Edition, Wiley, New York, 1999.
(ii) P. R. Halmos, *Measure Theory*, Springer Science + Business Media, LLC, 2014.
(iii) E. M. Stein and R. Shakarchi, *Real Analysis: Measure Theory, Integration and Hilbert Spaces*, New Age International Publishers, New Delhi, 2010.

DISCIPLINE SPECIFIC ELECTIVE: THEORY OF NON-COMMUTATIVE RINGS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Theory of Non-commutative Rings	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Groups and Rings

Learning Objectives

The primary objective of this course is to:

- give students an understanding of Wedderburn–Artin theory of semisimple rings.
- develop Jacobson's general theory of radicals, prime and semiprime rings, and primitive and semiprimitive rings.
- introduce the structure of primitive rings as a generalisation of the Wedderburn–Artin theorem on Artinian simple rings.

Learning Outcomes

This course will enable the students to:

- know about an extensive variety of rings, including free rings, Weyl algebra, Hilbert twist and triangular ring.
- understand the module theoretic definition of semisimple rings and how it leads to the Wedderburn–Artin structure theorem on their complete classification.
- know Jacobson's general theory of radicals, semiprime rings, prime, primitive and semiprimitive rings and their structures.
- understand the significance of the fundamental result 'Density Theorem' and its consequences on the structure of primitive rings.

Syllabus

Unit – 1 **(11 hours)**

Simple rings, Reduced rings, Dedekind-finite rings, Algebra, Quaternions, Free k-rings, Rings with generators and relations, Weyl algebra, Formal power series ring, Hilbert's twist ring, Differential polynomial rings, Derivation and inner derivation on a ring, Triangular rings, Characterization of one-sided and two-sided ideals in such rings.

Unit – 2 **(11 hours)**

Noetherian and Artinian rings, Examples of one-sided Noetherian and Artinian triangular rings, Twisted polynomial ring and Quotient of free $\mathbb{Z}$-ring, Semisimple rings, Structure of semisimple rings: Wedderburn–Artin's theorem.

Unit – 3 **(10 hours)**

Structure theorem of simple left Artinian rings, Jacobson radical, J-semisimple rings, Nil and nilpotent ideals, Connection between semisimple and J-semisimple rings, Hopkins–Levitzki theorem, Nakayama's lemma.

Unit – 4 **(13 hours)**

Prime radical, Characterisation of prime and semiprime ideals, Prime and semiprime rings, Structure theorem of primitive rings, Density theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] T.-Y. Lam, *A First Course in Noncommutative Rings*, Springer, 2001.

Suggested Readings

(i) I. N. Herstein, *Noncommutative Rings*, The Mathematical Association of America, 2005.
(ii) T. W. Hungerford, *Algebra*, Springer-Verlag, New York, 1981.
(iii) L. H. Rowen, *Ring Theory*, Student Edition, Academic Press, 1991.

Generic Elective (GE) Courses

GENERIC ELECTIVE – 2 (i): NONSMOOTH OPTIMIZATION

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
GE-2 (i): Nonsmooth Optimization	4	3	1	0	Class XII pass with Mathematics	Basics of Nonlinear Optimization

Learning Objectives

The primary objective of this course is to:

- understand the tools to deal with nonsmooth convex functions.
- study conjugate duality in terms of conjugate functions for constrained nonlinear optimization problems.
- introduce numerical techniques to solve constrained nonlinear optimization problems.

Learning Outcomes

This course will enable the students to learn:

- the notions of subgradients and subdifferentials for nonsmooth convex functions.
- the use of conjugate functions to develop the theory of conjugate duality.
- about numerical methods like gradient descent method, gradient projection method, Newton's method and conjugate gradient method.
- penalty approach technique to solve constrained nonlinear optimization problems.

Syllabus

Unit – 1 **(11 hours)**

Extended real valued functions, Proper convex functions, Closure of convex functions, Differential derivatives, Subgradients and subdifferentials.

Unit – 2 **(12 hours)**

Conjugate functions, Biconjugate functions, Perturbation functions, Closure of convex functions, Directional derivatives, Subgradients and subdifferentials.

Unit – 3 **(12 hours)**

Gradient descent method, Gradient projection method, Newton's method, Conjugate gradient method.

Unit – 4 **(10 hours)**

Penalty function methods, Exterior penalty function, Interior penalty functions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. Avriel, *Nonlinear Programming: Analysis and Methods*, Dover Publications, 2003.
[2] O. Güler, *Foundations of Optimization*, Springer, 2010.

Suggested Readings

(i) A. Bagirov, N. Karitsa and M. M. Makela, *Introduction to Nonsmooth Optimization: Theory, Practice and Software*, Springer, 2014.
(ii) M. S. Bazaraa, H. D. Sherali and C. M. Shetty, *Nonlinear Programming: Theory and Algorithms,* Third Edition, John Wiley & Sons, 2013.
(iii) D. G. Luenberger and Y. Ye, *Linear and Nonlinear Programming*, Springer, 2008.

GENERIC ELECTIVE – 2 (ii): PROBABILITY THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
GE-2 (ii): Probability Theory	4	3	1	0	Class XII pass with Mathematics	Basics of Integration

Learning Objectives

The primary objective of this course is to introduce:

- probability space as a measure space and random variables as measurable functions.
- expectation and moments of random variables.
- notion of convergence in probability.
- conditioning on sub-σ-algebra.

Learning Outcomes

This course will enable the students to learn:

- about probability or uncertainty in abstract setting.
- moments and expectation of random variables which help to understand applications of probability in industry.
- how to apply the idea of convergence in probability.
- weak law and strong law of large numbers and their applications.

Syllabus

Unit – 1 **(11 hours)**

Probability: σ-algebra, Constructing probability triples, The extension theorem, Random variables, Independence of events, Continuity of probabilities, Limit events, The Borel–Cantelli Lemma.

Unit – 2 **(10 hours)**

Expected values: Simple, general non-negative and arbitrary random variables, Moment generating functions, Markov's inequality, Chebyshev's inequality.

Unit – 3 **(12 hours)**

Convergence of random variables: Convergence almost surely, Convergence in probability, Weak law of large numbers, Strong law of large numbers.

Unit – 4 **(12 hours)**

Distributions of random variables: Examples of distributions, Characteristic functions, The central limit theorem, Conditional probability, Conditioning on random variable, Conditioning on a sub-σ-algebra, Conditional variance.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. S. Rosenthal, *A First Look at Rigorous Probability Theory*, Second Edition, World Scientific, Singapore, 2006.

Suggested Readings

(i) W. Feller, *An Introduction to Probability Theory and its Applications*, Volume 1, Third Edition, Wiley, 2008.
(ii) J. E. Michael and J. S. Rosenthal, *Probability and Statistics: The Science of Uncertainty*, Second Edition, W. H. Freeman & Co Ltd., 2009.
(iii) S. Ross, *A First Course in Probability*, Tenth Edition, Pearson Education, 2022.
(iv) D. W. Stroock, *Probability Theory, An Analytic View*, Cambridge University Press, 2024.

Syllabi of Courses in Semester-I of One-year M.Sc. Mathematics under Structure-3 (Research)

Discipline Specific Core (DSC) Course

DISCIPLINE SPECIFIC CORE: MATRIX GROUPS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC: Matrix Groups	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Calculus and Linear Algebra

Learning Objectives

The primary objective of this course is to:

- introduce the notion of matrix groups which serves as a bridge between algebra, geometry and analysis.
- use exponential and logarithm maps to connect one-parameter subgroups with Lie algebras.
- connect Clifford algebra constructions to orthogonal groups, spin groups and isomorphism questions.

Learning Outcomes

This course will enable the students to:

- distinguish between general linear, orthogonal and special orthogonal groups with explicit examples.
- construct and compute reflection and rotation matrices in $\mathbb{R}^n$and analyze their properties.
- comprehend maximal tori, their coverings and conjugacy results in compact matrix groups.
- appreciate the applications of matrix groups in algebraic geometry, complex analysis, group and ring theory, number theory, quantum physics, Einstein's special relativity, Heisenberg's uncertainty principle, quark theory, Fourier series, combinatorics and many more areas.

Syllabus

Unit – 1 **(10 hours)**

The general linear groups, The orthogonal groups, The isomorphism question, Reflection in $\mathbb{R}^n$, Curves in a vector space, Smooth homeomorphisms, The special orthogonal groups.

Unit – 2 **(11 hours)**

Orthogonal matrices and isometries, Exponential and Logarithm of a matrix, One-parameter subgroups, Lie Algebras, $SO(3)$ and $Sp(1)$.

Unit – 3 **(12 hours)**

Maximal tori, Covering by maximal tori, Reflections in $\mathbb{R}^n$, Monogenic groups.

Unit – 4 **(12 hours)**

Conjugacy of maximal tori, Clifford algebras, $Pin(k)$, $Spin(k)$ and isomorphisms.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. L. Curtis, *Matrix Groups*, Springer, 1984.

Suggested Readings

(i) A. Baker, *Matrix Groups: An Introduction to Lie Group Theory*, Springer Undergraduate Mathematics Series, 2001.

(ii) K. Tapp, *Matrix Groups for Undergraduates*, American Mathematical Society, 2016.

Discipline Specific Elective (DSE) Courses

DISCIPLINE SPECIFIC ELECTIVE: ADVANCED FUNCTIONAL ANALYSIS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Advanced Functional Analysis	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis and Topology

Learning Objectives

The primary objective of this course is to:

- define and explain the structure of a topological vector space and its fundamental properties.
- differentiate between normed, metrizable, locally convex and Hausdorff topological vector spaces.
- introduce the foundational theorems of functional analysis, including the Hahn–Banach, Banach–Steinhaus, Open mapping, and Closed graph theorems in the context of locally convex spaces.
- explain some applications of Banach–Alaoglu theorem and Krein–Milman theorem.

Learning Outcomes

This course will enable the students to:

- appreciate types of topological vector spaces and their separation properties.
- understand quotient spaces, weak topology and weak*-topology.
- analyze concepts of continuity, boundedness, and convergence for linear operators and functionals on topological vector spaces.
- understand the notion of local convexity and the role of seminorms in defining locally convex topologies.

Syllabus

Unit – 1 **(12 hours)**

Topological vector spaces, Types of Topological vector spaces, Separation properties, Linear mappings, Finite dimensional spaces, Metrization, Boundedness and continuity, Seminorms and local convexity, Normability.

Unit – 2 **(11 hours)**

Quotient spaces, Seminorms and quotient spaces, Examples, Baire category theorem, Banach–Steinhaus theorem, The open mapping theorem and the closed graph theorem on topological vector spaces.

Unit – 3 **(11 hours)**

Hahn–Banach separation theorem on topological vector spaces, Continuous extension theorem, Weak topologies, Weak topology and convexity, Weak topology and metrizability, Weak*-

topology of a dual space, Compact convex sets, Banach–Alaoglu theorem and applications, Goldstine theorem.

Unit – 4 **(11 hours)**

Extreme points, Krein–Milman theorem, Convex hull of compact sets, Applications of Krein–Milman theorem: Stone–Weierstrass theorem, Markov–Kakutani fixed point theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.
[2] W. Rudin, *Functional Analysis*, Second Edition, Tata Mc Graw-Hill, 2011.

Suggested Readings

(i) V. I. Bogachev and O. G. Smolyanov, *Topological Vector Spaces and Their Applications*, Springer, 2017.
(ii) S. Kantorovitz, *Introduction to Modern Analysis*, Oxford Graduate Texts in Mathematics, Oxford University Press, 2006.
(iii) J. Voigt, *A Course on Topological Vector Spaces*, Birkhäuser, 2020.

DISCIPLINE SPECIFIC ELECTIVE: ALGEBRAIC CODING THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Algebraic Coding Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra, Groups and Rings

Learning Objectives

The primary objective of this course is to:

- provide an introduction to algebraic coding theory, particularly linear codes.
- discuss bounds on the parameters along with cyclic codes.
- describe some well-known codes, such as Reed–Muller and Golay codes.
- explore the algebraic structure of Cyclic and Quadratic residue codes over fields and rings.

Learning Outcomes

This course will enable the students to:

- get an insight into the matrix representation of a code, as well as encoding and decoding.
- understand Hamming, MDS and Reed–Muller codes.
- describe cyclic codes and their generator polynomial.
- learn about special cyclic codes, such as Quadratic residue codes, and their properties over the ring $\mathbb{Z}_4$.

Syllabus

Unit – 1 **(10 hours)**

Error detecting and error correcting codes, Maximum likelihood decoding, Hamming distance, Linear codes, Hamming weight, Generator matrix, Parity check matrix, Equivalence of linear codes, Encoding and decoding of linear codes, Syndrome decoding.

Unit – 2 **(11 hours)**

Bounds on codes, Sphere covering bound, Hamming bound, Perfect codes, Binary Hamming codes, Binary Golay codes, Singleton bound and MDS codes. Propagation rules, Reed–Muller codes.

Unit – 3 **(12 hours)**

Cyclic codes, Cyclic codes as ideals, Generator polynomial of cyclic codes, Generator and parity-check matrices of cyclic codes**,** Decoding of cyclic codes, Burst error correcting codes.

Unit – 4 **(12 hours)**

Quadratic residue codes: QR codes over fields of characteristic 2 and 3, Cyclic codes and their generating polynomial over $\mathbb{Z}_4$, QR codes over $\mathbb{Z}_4$.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] S. Ling and C. Xing, *Coding Theory: A First Course*, Cambridge University Press, 2004.
[2] W. C. Huffman and V. Pless, *Fundamentals of Error Correcting Codes*, Cambridge University Press, 2010.

Suggested Readings

(i) R. Hill, *A First Course in Coding Theory*, Oxford University Press, 1986.
(ii) F. J. Mac William and N. J. A. Sloane, *Theory of Error Correcting Codes, Part I & II,* Elsevier/North-Holland, Amsterdam, 1977.

DISCIPLINE SPECIFIC ELECTIVE: COMMUTATIVE ALGEBRA

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Commutative Algebra	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra and Field Theory

Learning Objectives

The objective of this course is to:

- develop a solid understanding of the structure of commutative rings, ideals, their radicals, extension, contraction etc.
- study important constructions such as total quotient rings, localizations.
- develop basic foundation in other areas of mathematics such as algebraic geometry, algebraic number theory.

Learning Outcomes

This course will enable the students to:

- know the localization of rings at a prime ideal that is an algebraic analogue of the geometric notion concentrating attention near a point.
- know more closely the polynomial rings, power series rings in one or more variables over a commutative ring and their prime spectrum.
- define, identify, and elaborate integral closure of rings, valuations rings, discrete valuation rings, structure theorem of Artin rings.

Syllabus

Unit – 1 **(12 hours)**

Radical of an ideal, Prime avoidance lemma, Chinese remainder theorem, Extension and contraction of ideals, Jacobson radical of a ring, Nakayama lemma, Tensor product of modules.

Unit – 2 **(13 hours)**

Rings and modules of fractions, Localization, Local properties, Primary decomposition, First and second uniqueness theorem of primary decomposition, Associated prime ideals of decomposable ideals.

Unit – 3 **(10 hours)**

Integral ring extensions, Going up theorem, Going down theorem, Integrally closed domains, Valuation rings, Hilbert's Nullstellensatz theorem.

Unit – 4 **(10 hours)**

Noetherian rings, Primary decomposition in Noetherian rings, Artin rings, Structure theorem for Artin rings, Discrete valuation rings.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. F. Atiyah and I. G. MacDonald, *Introduction to Commutative Algebra*, CRC Press, Taylor & Francis, 2018.

Suggested Readings

(i) D. Eisenbud, *Commutative Algebra with a View Towards Algebraic Geometry*, Springer, 2004.
(ii) R. Y. Sharp, *Steps in Commutative Algebra*, Cambridge University Press, 2000.
(iii) B. Singh, *Basic Commutative Algebra*, World Scientific, 2011.
(iv) O. Zariski and P. Samuel, *Commutative Algebra*, Volume I & II, Springer, 1975.

DISCIPLINE SPECIFIC ELECTIVE: DIFFERENTIAL GEOMETRY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Differential Geometry	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra, Multivariate Calculus and Differential Equations

Learning Objectives

The primary objective of this course is to introduce:

- surfaces and parametrized surfaces.
- orientation on connected surfaces.
- geodesics on surfaces.
- Weingarten maps on oriented surfaces.
- arc length and curvature of oriented plane curves.
- curvatures of oriented surfaces.

Learning Outcomes

This course will enable the students to:

- understand the concepts of level sets and graphs of functions, smooth vector fields, tangent spaces of level sets.
- appreciate surfaces and parametrized surfaces, Gauss map, geodesics and parallel transport on oriented surfaces.
- know what the Weingarten map of an oriented surface is, realize it as shape operator and use it to compute curvature of oriented plane curves.
- find global parametrization and hence arc length of an oriented plane curve.
- compute various types of curvatures of surfaces.

Syllabus

Unit – 1 **(10 hours)**

Level sets in $\mathbb{R}^{n+1}$ and graphs of functions, Smooth vector fields and existence and uniqueness of their integral curves, Tangent spaces of level sets at regular points, Surfaces in $\mathbb{R}^{n+1}$ as inverse images of regular values of smooth functions, Necessary condition for extrema of functions on surfaces-Lagrange multipliers, Existence of a normal vector field on a connected surface, Orientation, Gauss map.

Unit – 2 **(13 hours)**

The notion of a geodesic on a surface, Existence and uniqueness of a geodesic on a surface through a given point with a given velocity vector thereof, Covariant derivative of a smooth vector field, Parallel vector field along a curve, Existence and uniqueness of a parallel vector field along a curve with a given initial vector, Weingarten map of a surface at a point, Local parametrization and curvature of a plane curve.

Unit – 3 **(10 hours)**

Global parametrization and arc length of an oriented plane curve, Differential 1-forms, Line integral of 1-forms over parametrized curves.

Unit – 4 **(12 hours)**

Parametrized surfaces with examples, Curvature of surfaces, Normal curvature of a surface at a point in a given direction, Principal curvatures, First and second fundamental forms, Gauss-Kronecker curvature and mean curvature.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] A. Pressley, *Elementary Differential Geometry*, Springer-Verlag London Limited, 2012.
[2] J. A. Thorpe, *Elementary Topics in Differential Geometry*, Springer (India) Pvt. Limited, 2004.

Suggested Readings

(i) W. Kuhnel, *Differential Geometry: Curves-Surfaces-Manifolds*, Third Edition, American Mathematical Society, 2015.
(ii) B. O' Neill, *Elementary Differential Geometry*, Second Edition, Academic Press INC., Academic Press, New York, 2006.

DISCIPLINE SPECIFIC ELECTIVE: DYNAMICAL SYSTEMS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Dynamical Systems	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology and Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- understand discrete and continuous systems with case studies to study nonlinear systems of ordinary differential equations and dynamical systems.
- understand the concepts, models and techniques to realize the real-world problems and stability of the systems along with the chaotic dynamic behaviour of models by understanding bifurcations.

Learning Outcomes

This course will enable the students to learn:

- formulation of mathematical models with the stability analysis near the equilibrium points.
- how the concept of phase portraits helps to analyse mathematical model graphically.
- the qualitative behaviour of the solution set of a given system of differential equations including the invariant sets and limiting behaviour of the dynamical system or flow defined by the system of differential equations.
- how different bifurcations explain the chaotic behaviour of the system.

Syllabus

Unit – 1 **(13 hours)**

Linear systems: Jordan forms, Stability theory; Nonlinear systems: Fundamental existence-uniqueness theorem, Dependence on initial conditions and parameters, Flow of a differential equation, Linearization, Stable manifold theorem, Hartman–Grobman theorem.

Unit – 2 **(10 hours)**

Stability and Lyapunov functions, Saddle points, Nodes, Foci, Centers and nonhyperbolic critical points, Center manifold theorem.

Unit – 3 **(12 hours)**

Limit sets and attractors, Periodic orbits and limit cycles, Poincaré map, Stable manifold theorem for periodic orbits, Poincare-Bendixson theorem.

Unit – 4 **(10 hours)**

Bifurcations at nonhyperbolic equilibrium points, Saddle node, Transcritical and Pitchfork bifurcations, Hopf bifurcation.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials

along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. W. Hirsch, S. Smale and R. L. Devaney, *Differential Equations, Dynamical Systems, and an Introduction to Chaos*, Third Edition, Academic Press, 2013.
[2] L. Perko, *Differential Equations and Dynamical Systems*, Third Edition, Springer Verlag, 2001.

Suggested Readings

(i) R. L. Devaney, *A First Course in Chaotic Dynamical Systems: Theory and Experiment*, CRC Press, Taylor & Francis, 2018.
(ii) S. H. Strogatz, *Nonlinear Dynamics and Chaos*, Second Edition, CRC Press, Taylor & Francis, 2018.
(iii) S. Wiggins, *Introduction to Applied Nonlinear Dynamical Systems and Chaos*, TAM Volume 2, Springer-Verlag, NY, 1990.

DISCIPLINE SPECIFIC ELECTIVE: FINITE ELEMENT METHODS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Finite Element Methods	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Differential Equations

Learning Objectives

The primary objective of this course is to:

- introduce basic aspects of finite element methods (FEM) including domain discretization, polynomial interpolation, application of boundary conditions, assembly of global arrays, and solution of the resulting algebraic systems.
- discuss the use of finite element methods in solving engineering problems in the domain of solid mechanics, fluid mechanics, heat transfer and electromagnetism.

Learning Outcomes

This course will enable the students to:

- use integral statement to deduce finite element approximations for the underlying linear partial differential equations.
- write special-purpose finite element programs within a procedural programming environment.
- use finite element methods to solve engineering problems in solids mechanics, fluid mechanics, heat transfer, and electromagnetism.
- assess the accuracy and reliability of finite element solutions and troubleshoot problems arising from errors in a given finite element analysis.

Syllabus

Unit – 1 **(12 hours)**

Basic concepts of weak formulation, Variational formulation of a one dimensional model equation, Basis function and finite element solutions, Collocation method, Ritz method, Least square method, Standard Galerkin method, FEM for model problem, Error estimate for FEM for model equation, Convergence analysis.

Unit – 2 **(11 hours)**

Various shapes of finite element, Higher order basis functions, Finite element methods for elliptic problems: Variational methods, Standard Galerkin method, Error estimate for FEM for elliptic problem, FEM for Poisson equation.

Unit – 3 **(12 hours)**

Finite element methods for parabolic problems: One dimensional model problems, Semi-discretization in space, Error estimates, Discretization in space and time, Galerkin method, Finite element methods for hyperbolic problems: Standard Galerkin method, Standard Galerkin method with strongly and weakly imposed boundary conditions.

Unit – 4 **(10 hours)**

Applications of the FEM to second order BVPs in one dimension, Applications of the FEM to linear elliptic, parabolic and hyperbolic equations.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. Evans, J. Blackledge and P. Yardley, *Numerical Methods for Partial Differential Equations*, Springer-Verlag, London, 2000.

[2] C. Johnson, *Numerical Solutions of Partial Differential Equations by Finite Element Methods*, *Cambridge University Press*, Cambridge, 1987.

[3] J. Whiteley, *Finite Element Methods - A Practical Guide*, Springer, 2016.

DISCIPLINE SPECIFIC ELECTIVE: NUMERICAL METHODS FOR ORDINARY DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Numerical Methods for Ordinary Differential Equations	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Ordinary Differential Equations

Learning Objectives

The primary objective of this course is to:

- develop the basic theory underlying the numerical solution of differential equations.
- introduce the concepts of consistency, stability and convergence of finite difference methods.
- execute the numerical schemes for the solution of differential equations.

Learning Outcomes

This course will enable the students to:

- gain a thorough understanding of the fundamental concepts involved in the construction and analysis of finite difference schemes for solving ordinary differential equations (ODEs).
- apply various numerical methods based on finite difference approaches to obtain approximate solutions for both initial value problems (IVPs) and boundary value problems (BVPs).
- develop the ability to select appropriate finite difference methods for specific types of problems and effectively apply them to real world applications.

Syllabus

Unit – 1 **(11 hours)**

Initial value problems: Existence and uniqueness of solution, Finite difference equation, Truncation error, Single step methods for first order IVPs and system of IVPs- Family of explicit and implicit Runge–Kutta methods, Taylor series methods, Derivation, Truncation error, Consistency, Stability and convergence analysis.

Unit – 2 **(12 hours)**

IVPs for the system of ODEs, Consistency, Zero stability and convergence of linear multistep methods, Routh–Hurwitz criterion, Order and error constant, First Dahlquist Barrier, Local truncation error and global truncation error, Error bounds, Local error, Linear stability theory, Higher order differential equations.

Unit – 3 **(12 hours)**

Derivation of explicit and implicit multistep methods for IVPs and system of IVPs, Truncation error, Stability and convergence analysis of family of Nystrom method, Adams–Bashforth method,

Adams–Moulton method, Milne–Simpson method, Predictor corrector method, and Modified predictor corrector method, Hybrid method, Multistep methods for second order IVPs.

Unit – 4 **(10 hours)**

Linear BVPs for second order ordinary differential equations, Shooting method, Finite difference method, Collocation method, Derivative boundary conditions, Nonlinear two-point BVPs, Higher order finite difference methods, Stability, Truncation error and convergence analysis.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. K. Jain, S. R. K. Iyenger and R. K. Jain, *Numerical Methods for Scientific and Engineering Computations*, Seventh Edition, New Age International Publisher, 2019.

[2] J. D. Lambert, *Numerical Methods for Ordinary Differential Systems: The Initial Value Problem*, John Wiley & Sons, 1991.

Suggested Readings

(i) K. E. Atkinson, W. Han and D. E. Stewart, *Numerical Solution of Ordinary Differential Equations*, John Wiley & Sons, 2009.

(ii) J. C. Butcher, *The Numerical Analysis of Ordinary Differential Equations*, Second Edition, Wiley, New York, 2008.

(iii) L. Collatz, *The Numerical Treatment of Differential Equations*, Springer-Verlag, 1966.

DISCIPLINE SPECIFIC ELECTIVE: REPRESENTATION OF FINITE GROUPS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Representation of Finite Groups	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Linear Algebra and Group Theory

Learning Objectives

The primary objective of this course is to:

- represent finite groups as groups of matrices (via homomorphisms) and apply the tools of linear algebra to study the group structure.
- introduce the notion of Group algebra, which plays an essential role in classifying representations of groups.
- to discuss some applications of representations of finite groups, such as the Burnside's theorem.

Learning Outcomes

This course will enable the students to:

- define and construct examples of group representations, FG-modules, group algebras.
- grasp key concepts and tools of representation theory and establish a link between FG-modules and group representations.
- prove and apply Maschke's theorem and Schur's lemma to describe all irreducible representations of finite groups over the field of complex numbers.
- apply the theory of characters and group representations to gain insight into group structure, such as normal subgroups, and the solubility of groups.

Syllabus

Unit – 1 **(11 hours)**

Representation of groups, FG-modules and FG-submodules, and reducibility, Permutation modules, FG-modules and equivalent representations, Reducible and irreducible FG-modules, Group algebra of G, Regular FG-module and regular representations, FG-homomorphisms, Direct sum of FG-modules.

Unit – 2 **(11 hours)**

Maschke's theorem for FG-modules and consequences. Schur's lemma and its converse, Application of Schur's lemma, Irreducible modules and group algebra, Structure of group algebra and space of CG-homomorphisms.

Unit – 3 **(10 hours)**

Characters and their properties, Permutation and regular characters, Inner product, Number of irreducible characters, Orthogonality relations and finding normal subgroups.

Unit – 4 **(13 hours)**

Algebraic numbers, Algebraic integers and their properties, Character values, The Burnside's *(p,q)*-theorem and solubility of some particular groups.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] G. James and M. Liebeck, *Representations and Characters of Groups*, Second Edition, Cambridge University Press, 2005.

Suggested Readings

(i) C. W. Curtis and I. Reiner, *Representation Theory of Finite Groups and Associative Algebras*, American Mathematical Society, 2006.
(ii) W. Fulton and J. Harris, *Representation Theory - A First Course*, Springer-Verlag, 2004.
(iii) I. M. Issacs, *Character Theory of Finite Groups*, American Mathematical Society reprint, 2006.

DISCIPLINE SPECIFIC ELECTIVE: THEORY OF BOUNDED OPERATORS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Theory of Bounded Operators	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis

Learning Objectives

The primary objective of this course is to:

- introduce some classes of bounded linear operators which play a central role in both pure and applied mathematics.
- study the properties and spectral theory of these operators.

Learning Outcomes

This course will enable the students to understand:

- the spectrum and sub-divisions of spectrum of standard operators like shifts and multiplication.
- the spectral theorem for some classes of bounded linear operators.
- the concepts of compactness, self-adjointness and positivity of bounded linear operators.
- trace class and Hilbert–Schmidt operators.

Syllabus

Unit – 1 **(11 hours)**

Properties of spectrum and resolvent of bounded operators, Subdivision of the spectrum including point, approximate and compression spectrum.

Unit – 2 **(10 hours)**

Operators on Hilbert spaces, Adjoint operator, Projections and idempotents, Operations with projections, Invariant and reducing subspaces.

Unit – 3 **(14 hours)**

Compact operators on Hilbert spaces, Diagonalisation of compact self-adjoint operators, Spectral theorem and functional calculus for Compact normal operators, Positive operators, Compact operators on Banach spaces, Spectral theory of compact operators.

Unit – 4 **(10 hours)**

Polar decomposition, Singular values, Trace class operators, Trace norm and Hilbert Schmidt operators.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] R. Bhatia, *Notes on Functional Analysis*, Hindustan Book Agency, 2009.
[2] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.

Suggested Readings

(i) E. Kreyszig, *Introductory Functional Analysis with Applications*, John Wiley & Sons, 2006.
(ii) B. Simon, *Operator Theory: A Comprehensive Course in Analysis*, Part 4, American Mathematical Society, 2015.
(iii) S. R. Garcia, J. Mashregi and W. T. Ross, *Operator Theory by Example*, Oxford University Press, 2023.

DISCIPLINE SPECIFIC ELECTIVE: TOPOLOGICAL DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Topological Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- provide a strong background of topological dynamical systems including their applications.
- develop some useful and interesting dynamical properties like expansivity, shadowing and topological stability with supporting examples and results from symbolic and topological dynamics.
- introduce the celebrated Sarkovskii's theorem.

Learning Outcomes

This course will enable the students to:

- construct interesting examples of dynamical systems and topological conjugacy.
- visualize stable sets, omega sets and alpha limit sets.
- understand the applications of Sarkovskii's theorem.
- use subshifts of finite type to characterize irreducible matrices.
- prove key results on expansivity and shadowing regarding existence/non-existence, product, subspace and their different characterizations etc.
- find the class of topologically stable homeomorphisms.

Syllabus

Unit – 1 **(10 hours)**

Definition and examples (including real life examples) of dynamical systems, Orbits, Types of orbits, Topological conjugacy and orbits, Phase portrait-graphical analysis of orbit, Periodic points and stable sets, Omega and alpha limit sets and their properties.

Unit – 2 **(10 hours)**

Sarkovskii's theorem, Shift spaces and subshift, Subshift of finite type, Subshift represented by a matrix, Characterizations of irreducible matrices.

Unit – 3 **(13 hours)**

Definition and examples of expansive homeomorphisms, Properties of expansive homeomorphisms, Non-existence of expansive homeomorphism on the unit interval and unit circle, Generators and weak generators, Generators and expansive homeomorphisms.

Unit – 4 **(12 hours)**

Converging semi-orbits for expansive homeomorphisms, Definition, examples and properties of maps having shadowing property, Topological Anosov homeomorphisms and topological stability.

Essential Readings

[1] G. G. Joseph, *Indian Mathematics: Engaging with the World from Ancient to Modern Times*, World Scientific Publishing Europe Ltd., 2016.
[2] Committee on Publication Ethics- COPE (https://publicationethics.org/)
[3] University Grants Commission (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulations 2018 (The Gazette of India: Extraordinary, Part-iii-Sec.4)

Syllabi of Courses in Semester-II of One-year M.Sc. Mathematics under Structure-3 (Research)

Discipline Specific Elective (DSE) Courses

DISCIPLINE SPECIFIC ELECTIVE: ADVANCED FLUID DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Advanced Fluid Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Calculus and Partial Differential Equations

Learning Objectives

The primary objective of this course is to:

- prepare a foundation for advanced studies in compressible flow, boundary layer theory and magnetohydrodynamics.
- develop concepts, models, and techniques that enable problem-solving in compressible flow, boundary layer theory and magnetohydrodynamics.
- equip students with concepts and techniques to conduct research in the above mentioned domains.

Learning Outcomes

This course will enable the students to:

- learn conservation laws, first and second laws of thermodynamics, internal energy and entropy, different forms of energy equations and dimensional analysis.
- know about compressibility in real fluids, wave motion, sound waves, hyperbolic and dispersive waves, shock waves, their formation, properties and elementary analysis.
- know the concepts of boundary layer, boundary layer equations and their solutions, measurements of boundary layer thickness.
- understand the interaction between hydrodynamic processes and electromagnetic phenomena.
- formulate the basic equations of motion in inviscid and viscous conducting fluid flow and explain Alfven's theorem and magnetohydrodynamic (MHD) waves and MHD shocks.

Syllabus

Unit – 1 **(11 hours)**

Flow characteristics, Conservation laws, Equation of state of a substance, First and second law of thermodynamics, Internal energy and entropy, Energy equation, Nondimensionalizing the basic equations of incompressible viscous fluid flow, Nondimensional numbers.

Unit – 2 **(12 hours)**

Compressibility effects in real fluids, Equations of motion, Sound wave, Hyperbolic and dispersive waves, Isentropic gas flow, Flow through a nozzle, Method of characteristics, Shock jump conditions, Non-linear plane waves, Shock waves and their elementary analysis, Similarity solutions.

Unit – 3 **(11 hours)**

Boundary layer concept, Estimation of boundary layer thickness and friction forces, Prandtl's boundary layer equations, Boundary layer along a flat plate, Boundary layer thickness, General properties of the boundary layer equations, Similar solutions, Momentum and energy integral equations for the boundary layer.

Unit – 4 **(11 hours)**

Maxwell's electromagnetic field equations, Magnetohydrodynamic (MHD) approximations, Magnetic field equation, Magnetic Reynolds number, Magnetic body force, Equations of Motions of conducting fluid, Alfven's theorem, MHD waves, MHD shock waves.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] F. Chorlton, *Text Book of Fluid Dynamics*, CBS Publisher, 2005.
[2] H. Schlichting and K. Gersten, *Boundary Layer Theory*, Ninth Edition, Springer, 2017.
[3] G. B. Witham, *Linear and Nonlinear Waves*, John Wiley & Sons, 1999.

Suggested Readings

(i) K. R. Cramer and S. I. Pai, *Magnetofluid Dynamics for Engineers and Applied Physics*, McGraw Hill Book Co., New York, 1973.
(ii) Y. Shao-Wen, *Foundations of Fluid Mechanics*, PHI, New Delhi, 1960.

DISCIPLINE SPECIFIC ELECTIVE: BANACH AND C*-ALGEBRAS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Banach and C*-Algebras	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis and Topology

Learning Objectives

The primary objective of this course is to introduce:

- Banach algebras and C*-algebras.
- various ways to construct new operator algebras using given ones.
- spectrum of elements in Banach algebras and to study its properties.
- Gelfand representations of commutative Banach algebras and of C*-algebras.

Learning Outcomes

This course will enable the students to:

- familiarize with the representations of operator algebras.
- realize commutative Banach algebras and abelian C*-algebras as space of continuous functions on locally compact groups.
- understand the powerful tool of functional calculus.
- identify any C*-algebra as closed *-subalgebra of space of bounded linear operators on a Hilbert space.

Syllabus

Unit – 1 **(11 hours)**

Elementary properties and examples of Banach algebras, Ideals and quotients, Invertible elements, Spectrum and spectral radius, Spectral radius formula, Spectral mapping theorem (for polynomials), Gelfand–Mazur theorem.

Unit – 2 **(11 hours)**

Multiplicative linear functionals, Commutative Banach algebra, w*-topology, Gelfand transform of an element, Structure space, Gelfand representation.

Unit – 3 **(12 hours)**

Elementary properties and examples of C*-algebras, Unitization, Gelfand–Naimark representation of commutative C*-algebras, Continuous functional calculus, Spectral mapping theorem for normal elements, Positive elements of C*-algebras.

Unit – 4 **(11 hours)**

Ideals in C*-algebras, Approximate units, Quotients, Positive linear functionals, Gelfand–Naimark–Segal representation of C*-algebras.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. B. Conway, *A Course in Functional Analysis*, Second Edition, Springer, 2007.
[2] G. J. Murphy, *C*-algebras and Operator Theory*, Academic Press Inc., 1990.

Suggested Readings

(i) J. B. Conway, *A Course in Operator Theory, Graduate Texts in Mathematics*, Springer, 2007.
(ii) J. Dixmier, *C*-algebras*, North-Holland Publishing Company, 1977.
(iii) R. G. Douglas, *Banach Algebra Techniques in Operator Theory, Graduate Texts in Mathematics*, Springer, 1998.
(iv) E. Kaniuth, *A Course on Commutative Banach Algebras*, Graduate Texts in Mathematics, Springer, 2009.
(v) S. Kantorovitz, *Introduction to Modern Analysis*, Oxford Graduate Texts in Mathematics, Oxford University Press, 2006.
(vi) M. Takesaki, *Theory of Operator Algebras I*, Springer, 2002.

DISCIPLINE SPECIFIC ELECTIVE: CHAOS THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Chaos Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- introduce some useful and interesting notions like Topological Transitivity and Sensitive dependence on initial conditions.
- study different types of chaos including Devaney's chaos and finding their interrelationships.
- know classical result that period three implies chaos on intervals.
- relate chaos and decomposition theorems.
- study Topological entropy through open covers and also Bowen's definition of entropy, equivalence of these two definitions on compact metric spaces.
- study various interesting results related to topological entropy.

Learning Outcomes

This course will enable the students to:

- construct interesting examples of Topological transitive maps, Topological mixing maps etc.
- know classical examples of Devaney's chaotic maps like tent map, shift maps, logistic maps.
- study and compare different types of chaos.
- find relation between transitivity and chaos on intervals.
- relate chaos theory and classical decomposition theorems.
- study very useful notion of Topological entropy including its properties.
- calculate entropy of any homeomorphism of closed unit interval and of unit circle.

Syllabus

Unit – 1 **(12 hours)**

Topological Transitivity, Locally eventually onto maps, Topological mixing, Sensitive dependence on initial conditions, Devaney's definition of chaos, Transitivity and limit sets for continuous interval maps.

Unit – 2 **(11 hours)**

Characterizing topological mixing in terms of topological transitivity for continuous interval maps, Topological Weakly Mixing, Totally Transitive maps, Relation between transitivity and chaos on intervals, Logistic maps and shift maps as chaotic maps.

Unit – 3 **(12 hours)**

Various other definitions of chaos and their interrelationships. Period three implies chaos, Chaos and decomposition theorems including Bowen's decomposition theorem, Topological Entropy: Definition using open covers, Examples and properties, Bowen's definition of topological entropy,

Equivalence of two definitions, Topological version of Kolmogorov–Sinai theorem.

Unit – 4 **(10 hours)**

Topological Entropy of maps on a compact metric space, Topological Entropy of product maps, of iterations of a map, Topological entropy of an expansive homeomorphism on a compact metric space, of the two-sided shift, of any homeomorphism of the unit interval and of the unit circle.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] N. Aoki and K. Hiraide, *Topological Theory of Dynamical Systems: Recent Advances*, North Holland Publications, 1994.
[2] R. L. Devaney, *A First Course in Chaotic Dynamical Systems*, CRC Press, 2018.
[3] S. Ruette, *Chaos for Continuous Interval Maps: A Survey of Relationship Between Various Kinds of Chaos*, 2018.
[4] Peter Walters, *An Introduction to Ergodic Theory*, Springer, 2000.

Suggested Readings

(i) L. Alsedà, J. Llibre and M. Misiurewicz, *Combinatorial Dynamics and Entropy in Dimension One*, Advanced Series in Nonlinear Dynamics, World Scientific, 2000.
(ii) L. S. Block and W. A. Coppel, *Dynamics in One Dimension*, Springer, 2014.
(iii) M. Brin and G. Stuck, *Introduction to Dynamical Systems*, Cambridge University Press, 2015.

DISCIPLINE SPECIFIC ELECTIVE: COMPUTATIONAL FLUID DYNAMICS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Computational Fluid Dynamics	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Partial Differential Equation (Undergraduate level)

Learning Objectives

The primary objective of this course is to teach:

- various numerical schemes on finite difference and finite volume methods for solving PDEs.
- discretization errors and grid dependence.
- some real-world applications of PDEs and fluid dynamics.
- discretization of governing equations of diffusion, convection-diffusion, fluid flow and thereby computing the numerical solutions using the flow variables using algorithms.

Learning Outcomes

This course will enable the students to learn:

- techniques for solving the PDEs along with some initial and boundary conditions by using the finite difference and finite volume methods.
- the basic conservation principles of mass, momentum, energy, discretization of governing equations.
- discretization techniques.
- some popular algorithms like SIMPLE and SIMPLER used to obtain the solutions of steady and unsteady flow problems by finite volume methods.

Syllabus

Unit – 1 **(12 hours)**

Basics of discretization using finite differences, Various single and multi-step explicit and implicit finite difference schemes for 1-D and 2-D parabolic and hyperbolic initial boundary value problems, Alternating Direction Implicit schemes (ADI) for 2-D parabolic and hyperbolic equations, Order of accuracy, Consistency, Stability and convergence of a finite difference scheme, Courant Friedrich Lewy condition.

Unit – 2 **(12 hours)**

Finite difference schemes for second and fourth order 2-D elliptic boundary value problem and applications, Finite volume method for diffusion and convection-diffusion equations, Discretization of one and two-dimensional steady state diffusion and convection-diffusion equations, Central difference, Upwind, Exponential, Hybrid, Power-law and QUICK schemes and their properties.

Unit – 3 **(11 hours)**

Flow field calculation, Pressure-velocity coupling, Vorticity-stream function approach, Primitive

variables, Staggered grid, Pressure and velocity corrections, Pressure correction equation, SIMPLE and SIMPLER algorithms.

Unit – 4 **(10 hours)**

Finite volume methods for unsteady flows, Discretization of one-dimensional transient heat conduction, Explicit, fully implicit and Crank–Nicolson schemes, Implementation of boundary conditions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. C. Strikweda, *Finite Difference Schemes and Partial Differential Equations*, Second Edition, SIAM, 2004.

[2] H. K. Versteeg and W. Malalasekera, *An Introduction to Computational Fluid Dynamics: The Finite Volume Method*, Second Edition, Pearson, 2008.

Suggested Readings

(i) J. D. Anderson, *Computational Fluid Dynamics*, McGraw-Hill, 1995.

(ii) S. V. Patankar, *Numerical Heat Transfer and Fluid Flow*, CRC Press, Taylor and Francis, Indian Edition, 2017.

(iii) R. H. Pletcher, J. C. Tannehill and D. A. Anderson, *Computational Fluid Mechanics and Heat Transfer*, CRC Press, Taylor and Francis, 2013.

(iv) J. W. Thomas, *Numerical Partial Differential Equations: Finite Difference Methods*, Springer, 2013.

DISCIPLINE SPECIFIC ELECTIVE: DIFFERENTIAL TOPOLOGY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Differential Topology	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Topology

Learning Objectives

The primary objective of this course is to:

- introduce the concepts of topological manifolds, smooth structures, smooth manifolds, and manifolds with boundary.
- develop an understanding of smooth functions, smooth maps, diffeomorphisms, and tangent spaces.
- explain the Inverse function theorem, immersions and submersions.
- develop the fundamental concepts of 2-manifolds and distinguish between orientable and non-orientable surfaces.
- explore the properties of compact and connected surfaces.

Learning Outcomes

This course will enable the students to:

- identify and construct examples of topological manifolds, smooth structures and manifolds with and without boundary.
- demonstrate understanding of diffeomorphisms and tangent spaces.
- apply the Inverse function theorem, immersions and submersions.
- define key concepts such as 2-manifolds, orientability, compactness, connectedness and boundary of a surface.
- differentiate between orientable and non-orientable surfaces using examples such as the sphere, torus, Möbius strip and Klein bottle.

Syllabus

Unit – 1 **(12 hours)**

Topological manifolds, Topological properties of manifolds, Smooth structures, Examples of smooth manifolds, Manifolds with boundary.

Unit – 2 **(11 hours)**

Smooth functions and smooth maps, Lie groups, Diffeomorphisms.

Unit – 3 **(10 hours)**

Derivatives and tangents, Inverse function theorem, Immersions and submersions.

Unit – 4 **(12 hours)**

Complexes, Connected sum of two surfaces, Non-orientable surfaces (2- Manifolds), Compact and connected surfaces, Classification of compact and connected surfaces with and without boundary.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] V. Guillemin and Alan Pollack, *Differential Topology*, Prentice-Hall, 1974.
[2] L. C. Kinsey, *Topology of Surfaces*, Springer Verlag, 1997.
[3] J. M. Lee, *Introduction to Smooth Manifolds*, Second Edition, Springer, 2013.

Suggested Readings

(i) L. Conlon, *Differentiable Manifolds*, Second Edition, Birkhäuser Advanced Texts, 2001.
(ii) M. Spivak, *A Comprehensive Introduction to Differential Geometry*, Volume 1, Third Edition, Publish or Perish, Huston, Texas, 1999.
(iii) L. W. Tu, *Introduction to Manifolds*, Second Edition, Springer, 2011.
(iv) F. W. Warner, *Foundations of Differentiable Manifolds and Lie Group*, Springer-Verlag, 1983.

DISCIPLINE SPECIFIC ELECTIVE: GENERAL MEASURE THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: General Measure Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Measure Theory and Topology

Learning Objectives

The primary objective of this course is to introduce:

- real valued and complex valued measures.
- decomposition of measure spaces and of measures.
- extension of a premeasure to a measure, Lebesgue measure on Euclidean spaces.
- representation of measures and functionals in terms of integrals.
- product measures.

Learning Outcomes

This course will enable the students to:

- appreciate signed measures and complex measures, mutual singularity of measures, Hahn and Jordan decompositions, Lebesgue decomposition, Radon–Nikodym theorem.
- verify conditions under which a set function defined on a collection of subsets of a set has an extension to a measure on a sigma-algebra.
- apply Riesz representation theorem for bounded linear functionals on L^p-spaces.
- understand product measure and the results of Fubini and Tonelli, and express the Lebesgue measure on Euclidean spaces as a product measure.
- apply Riesz–Markov representation theorem for the bounded linear functionals on the space of continuous functions.

Syllabus

Unit – 1 **(13 hours)**

Signed measures, Hahn and Jordan decompositions, Mutually singular measures, Radon–Nikodym theorem, Lebesgue decomposition, Complex measure.

Unit – 2 **(10 hours)**

The Carathéodory extension theorem, Lebesgue measure on $\mathbb{R}^n$, Regularity and translation invariance of Lebesgue measure on $\mathbb{R}^n$.

Unit – 3 **(10 hours)**

Riesz representation theorem for the dual of L^p-spaces, Product measures, Fubini's theorem, Tonelli's theorem.

Unit – 4 **(12 hours)**

Locally compact Hausdorff spaces and construction of Radon measure, Riesz–Markov representation theorem for positive linear functionals on $C_c(X)$, Riesz representation theorem for the dual of $C(X)$.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] H. L. Royden and P. M. Fitzpatrick, *Real Analysis*, Fourth Edition, Pearson, 2015.
[2] M. E. Taylor, *Measure Theory and Integration*, American Mathematical Society, 2006.

Suggested Readings

(i) G. B. Folland, *Real Analysis: Modern Techniques and Their Applications*, Second Edition, Wiley, New York, 1999.
(ii) P. R. Halmos, *Measure Theory*, Springer Science + Business Media, LLC, 2014.
(iii) E. M. Stein and R. Shakarchi, *Real Analysis: Measure Theory, Integration and Hilbert Spaces*, New Age International Publishers, New Delhi, 2010.

DISCIPLINE SPECIFIC ELECTIVE: NONSMOOTH OPTIMIZATION

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Nonsmooth Optimization	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Nonlinear Optimization

Learning Objectives

The primary objective of this course is to:

- understand the tools to deal with nonsmooth convex functions.
- study conjugate duality in terms of conjugate functions for constrained nonlinear optimization problems.
- introduce numerical techniques to solve constrained nonlinear optimization problems.

Learning Outcomes

This course will enable the students to learn:

- the notions of subgradients and subdifferentials for nonsmooth convex functions.
- the use of conjugate functions to develop the theory of conjugate duality.
- about numerical methods like gradient descent method, gradient projection method, Newton's method and conjugate gradient method.
- penalty approach technique to solve constrained nonlinear optimization problems.

Syllabus

Unit – 1 **(11 hours)**

Extended real valued functions, Proper convex functions, Closure of convex functions, Differential derivatives, Subgradients and subdifferentials.

Unit – 2 **(12 hours)**

Conjugate functions, Biconjugate functions, Perturbation functions, Closure of convex functions, Directional derivatives, Subgradients and subdifferentials.

Unit – 3 **(12 hours)**

Gradient descent method, Gradient projection method, Newton's method, Conjugate gradient method.

Unit – 4 **(10 hours)**

Penalty function methods, Exterior penalty function, Interior penalty functions.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] M. Avriel, *Nonlinear Programming: Analysis and Methods*, Dover Publications, 2003.

[2] O. Güler, *Foundations of Optimization*, Springer, 2010.

Suggested Readings

(i) A. Bagirov, N. Karitsa and M. M. Makela, *Introduction to Nonsmooth Optimization: Theory, Practice and Software*, Springer, 2014.
(ii) M. S. Bazaraa, H. D. Sherali and C. M. Shetty, *Nonlinear Programming: Theory and Algorithms,* Third Edition, John Wiley & Sons, 2013.
(iii) D. G. Luenberger and Y. Ye, *Linear and Nonlinear Programming*, Springer, 2008.

DISCIPLINE SPECIFIC ELECTIVE: PROBABILITY THEORY

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Probability Theory	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Measure Theory

Learning Objectives

The primary objective of this course is to introduce:

- probability space as a measure space and random variables as measurable functions.
- expectation and moments of random variables.
- notion of convergence in probability.
- conditioning on sub-σ-algebra.

Learning Outcomes

This course will enable the students to learn:

- about probability or uncertainty in abstract setting.
- moments and expectation of random variables which help to understand applications of probability in industry.
- how to apply the idea of convergence in probability.
- weak law and strong law of large numbers and their applications.

Syllabus

Unit – 1 **(11 hours)**

Probability: σ-algebra, Constructing probability triples, The extension theorem, Random variables, Independence of events, Continuity of probabilities, Limit events, The Borel–Cantelli Lemma.

Unit – 2 **(10 hours)**

Expected values: Simple, general non-negative and arbitrary random variables, Moment generating functions, Markov's inequality, Chebyshev's inequality.

Unit – 3 **(12 hours)**

Convergence of random variables: Convergence almost surely, Convergence in probability, Weak law of large numbers, Strong law of large numbers.

Unit – 4 **(12 hours)**

Distributions of random variables: Examples of distributions, Characteristic functions, The central limit theorem, Conditional probability, Conditioning on random variable, Conditioning on a sub-σ-algebra, Conditional variance.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] J. S. Rosenthal, *A First Look at Rigorous Probability Theory*, Second Edition, World Scientific, Singapore, 2006.

Suggested Readings

(i) W. Feller, *An Introduction to Probability Theory and its Applications*, Volume 1, Third Edition, Wiley, 2008.
(ii) J. E. Michael and J. S. Rosenthal, *Probability and Statistics: The Science of Uncertainty*, Second Edition, W. H. Freeman & Co Ltd., 2009.
(iii) S. Ross, *A First Course in Probability*, Tenth Edition, Pearson Education, 2022.
(iv) D. W. Stroock, *Probability Theory, An Analytic View*, Cambridge University Press, 2024.

DISCIPLINE SPECIFIC ELECTIVE: THEORY OF NON-COMMUTATIVE RINGS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Theory of Non-commutative Rings	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Groups and Rings

Learning Objectives

The primary objective of this course is to:

- give students an understanding of Wedderburn–Artin theory of semisimple rings.
- develop Jacobson's general theory of radicals, prime and semiprime rings, and primitive and semiprimitive rings.
- introduce the structure of primitive rings as a generalisation of the Wedderburn–Artin theorem on Artinian simple rings.

Learning Outcomes

This course will enable the students to:

- know about an extensive variety of rings, including free rings, Weyl algebra, Hilbert twist and triangular ring.
- understand the module theoretic definition of semisimple rings and how it leads to the Wedderburn–Artin structure theorem on their complete classification.
- know Jacobson's general theory of radicals, semiprime rings, prime, primitive and semiprimitive rings and their structures.
- understand the significance of the fundamental result 'Density Theorem' and its consequences on the structure of primitive rings.

Syllabus

Unit – 1 **(11 hours)**

Simple rings, Reduced rings, Dedekind-finite rings, Algebra, Quaternions, Free k-rings, Rings with generators and relations, Weyl algebra, Formal power series ring, Hilbert's twist ring, Differential polynomial rings, Derivation and inner derivation on a ring, Triangular rings, Characterization of one-sided and two-sided ideals in such rings.

Unit – 2 **(11 hours)**

Noetherian and Artinian rings, Examples of one-sided Noetherian and Artinian triangular rings, Twisted polynomial ring and Quotient of free $\mathbb{Z}$-ring, Semisimple rings, Structure of semisimple rings: Wedderburn–Artin's theorem.

Unit – 3 **(10 hours)**

Structure theorem of simple left Artinian rings, Jacobson radical, J-semisimple rings, Nil and nilpotent ideals, Connection between semisimple and J-semisimple rings, Hopkins–Levitzki theorem, Nakayama's lemma.

Unit – 4 **(13 hours)**

Prime radical, Characterisation of prime and semiprime ideals, Prime and semiprime rings, Structure theorem of primitive rings, Density theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

Essential Readings

[1] T.-Y. Lam, *A First Course in Noncommutative Rings*, Springer, 2001.

Suggested Readings

(i) I. N. Herstein, *Noncommutative Rings*, The Mathematical Association of America, 2005.
(ii) T. W. Hungerford, *Algebra*, Springer-Verlag, New York, 1981.
(iii) L. H. Rowen, *Ring Theory*, Student Edition, Academic Press, 1991.

DISCIPLINE SPECIFIC ELECTIVE: THEORY OF UNBOUNDED OPERATORS

CREDIT DISTRIBUTION OF THE COURSE

Course Title & Code	Credits	Credit Distribution of the Course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE: Theory of Unbounded Operators	4	3	1	0	Same as for entry to M.Sc. Mathematics	Basics of Functional Analysis and Bounded Operators

Learning Objectives

The primary objective of this course is to:

- introduce the notion of unbounded operators.
- develop the theory of operator semigroups and understand their role in applications, particularly for solving differential equations.

Learning Outcomes

This course will enable the students to:

- identify closed and closable linear operators on Banach spaces.
- compute adjoints of unbounded linear operators.
- understand spectral properties of some unbounded operators.
- comprehend the role unbounded operators and semigroups play in applications, particularly in studying solutions of differential equations.

Syllabus

Unit – 1 **(10 hours)**

Unbounded linear operators, Hilbert adjoints, Hellinger–Toeplitz theorem, Hermitian, symmetric and self-adjoint linear operators, Closed linear operators, Closable operators and their closures on Banach spaces.

Unit – 2 **(12 hours)**

Cayley transform, Deficiency indices, Spectral properties of self-adjoint operators, Multiplication and differentiation operators and their spectra.

Unit – 3 **(11 hours)**

Analytic properties of exponential functions, Matrix Semigroups, Uniformly continuous semigroups, Semigroups on Hilbert spaces, Strongly continuous semigroups.

Unit – 4 **(12 hours)**

Generators of semigroups and their resolvents, Hille–Yosida theorem (for contraction semigroup), Dissipative operators and their properties, Lumer–Phillips theorem, Generators of Group, Stone's theorem.

Tutorial

Problem-solving sessions based on material covered in the lectures will be taken up in the tutorials along with scholastic work related to conceptual understanding of the subject.

2nd Year of 2-Year
MASTER OF COMPUTER APPLICATIONS (MCA)
PROGRAMME
Postgraduate Curriculum Framework
under NEP 2020
(w.e.f. 2025)

DEPARTMENT OF COMPUTER SCIENCE
FACULTY OF MATHEMATICAL SCIENCES
UNIVERSITY OF DELHI
DELHI
110007

Master of Computer Application (MCA) Program Details

Affiliation

The proposed programme shall be governed by the Department of Computer Science, Faculty of Mathematical Sciences, University of Delhi, Delhi-110007.

Programme Structure and Objectives

The MCA is a four-semester program spanning two years. It has two structures – Structure 1 **MCA with coursework and Structure 4 - MCA with** Academic/Industry Project**.**

First three semesters comprise of course - work common to both the structures. In structure 4, students are required to do an industry project with at least one supervisor from the department in the fourth semester,.

The Programme objectives of MCA with Coursework are to

- **E**quip the students with the **foundations of** computer science.
- **Enable the students to follow the career path of their choice by choosing** courses from a wide list of specialised **c**ourses with progression**.**
- **Prepare the students to take up a career in the highly competitive IT industry with Applications of Computer Science.**

The Programme objectives of MCA with Academic/Industry Project are to

- **E**quip the students with the **foundations of** computer science.
- **Enable the students to follow the career path of their choice by choosing** courses from a wide list of specialised **c**ourses with progression**.**
- Provide students **with hands-on experience on live projects**, fostering practical skills and enabling them to prepare technical reports.
- **Prepare the students to take up a career in the highly competitive IT industry with applications of computer science.**

Project: In Structure 4, each student shall carry out a project in the fourth semester of MCA with internship. The project may be carried out in an external organisation (academic institution/industry). In such a case, a supervisor shall be appointed from the external organisation. The project will be carried out under the overall supervision of one or more (jointly) teachers of the department. The project work will be evaluated jointly by the internal supervisor and an examiner to be appointed by the department in consultation with the internal supervisor

The project evaluation shall be as follows:

- Mid-semester evaluation: 25% weight
- End-semester evaluation
    - Dissertation: 35% weight
    - Viva-voce: 40% weight

Justification for Structure IV : Since the inception of the MCA program in 1984, it has

had one full semester devoted to hands-on projects primarily in the industry. The format has led to a strong alumni base enjoying high positions and packages in the IT industry. Our alumni are currently placed in prestigious global companies like Apple, Facebook, Microsoft, Adobe, Paytm, Amazon to name a few. **The main attraction of our programs for the recruiters is its full time fourth semester Industry Internship.** During this period, students learn by doing and get acquainted with the environment of their work place while still earning their degree. Companies get a trained workforce when the students finally join the job.

With the emphasis of skill development and experiential learning being one of the emphasis of NEP, we have introduced Structure 4 which is different from Structure 1 only in Semester IV which allows the students to earn their 22 credits from an academic project/industry internship.

Semester III

Semester III (Common to both structures)					
	Number of core courses				**2**
Course Code	**Course Title**	**Credits in each core course**			
		Theory	**Tutorial**	**Practical**	**Total**
DSC301	Data Communication and Computer Networks	3	0	1	**4**
DSC302	Information Security	3	0	1	**4**
SBC301	Prompt Engineering	0	0	2	**2**
	Total credits in core course				10
	Number of DSE/GE courses				3**
	DSE 5	3	0	1	**4**
	DSE 6	3	0	1	**4**
	DSE 7 / GE 3	3	0	1	**4**
	Total credits in GE/DSE				**12**
	Total credits in Semester III				**22**

****Select three DSEs or two DSEs and one GE**
Note: All DSEs are offered as GE, subject to the fulfilment of the prerequisites and availability of seats.

List of DSE for Semester III (common to both structures)		
Course Code	**Course Title**	**L-T-P**
DSE301	Link Prediction	3-0-1
DSE302	Recommender Systems	3-0-1
DSE303	Time Series Data Analysis	3-0-1
DSE304	Quantum Computing and Applications	3-0-1
DSE305	Digital Forensics	3-0-1
DSE306	Human-Computer Interaction	3-0-1
DSE307	Influence Maximization	3-0-1
DSE308	Deep Learning (only for structure 4)	3-0-1

Semester IV

Semester IV (Structure 1 Coursework)					
	Number of core courses				**2**
Course Code	**Course Title**	**Credits in each core course**			
		Theory	**Tutorial**	**Practical**	**Total**
DSC401	Software Engineering	3	0	1	**4**
DSC402	Deep Learning	3	0	1	**4**
SBC401	Communication Skills	0	0	2	**2**
	Total credits in core course				10
	Number of DSE /GE courses				3**
	DSE 8	3	0	1	**4**
	DSE 9	3	0	1	**4**
	DSE 10 / GE 4	3	0	1	**4**
	Total credits in GE/DSE				12
	Total credits in Semester IV				**22**

****Select three DSEs or two DSEs and one GE**
Note: All DSEs are offered as GE, subject to the fulfilment of the prerequisites and availability of seats.

List of DSE for Semester IV (Structure 1 - Coursework)		
Course Code	**Course Title**	**L-T-P**
DSE401	Computer Graphics	3-0-1
DSE402	Compiler Design	3-0-1
DSE403	Cloud Computing	3-0-1
DSE404	Theory of Computation	3-0-1
DSE405	Wireless and Mobile Communication	3-0-1
DSE406	Advance Classification Methods	3-0-1
DSE407	Incident Response and Threat Hunting	3-0-1

Semester IV (Structure 4 - Academic/Industry Project)					
	Number of core courses				**0**
Course Code	**Course Title**	**Credits in each core course**			
		Theory	**Tutorial**	**Practical**	**Total**
	Academic Project/Industry Internship	0	0	22	**22**
	Total credits in Semester IV				**22**

In **Structure 4 - MCA with** Academic/Industry Project, the following outcomes must be achieved by the end of the fourth semester in addition to the outcomes mentioned for Structure 1:

i) Completion of experimentation/fieldwork or similar tasks.

ii) Submission of the project report.

SEMESTER – III

DSC301: DATA COMMUNICATION AND COMPUTER NETWORKS [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC301	4	3	0	1	Graduation	NIL

Course Objectives:

The course introduces the basic concepts of data communication techniques, computer networks, various protocols, and their applications. It also aims to develop skills for interworking between computer networks and switching components in telecommunication systems.

Course Learning Outcomes:

On completing this course, the student will be able to:

1. Understand the basics of computer networks, such as network types, topologies, layered architectures, and the specific functions of each layer in the OSI and TCP/IP models.
2. Analyze the flow and structure of network packets to understand data transmission across a communication channel.
3. Design/implement various protocols in a simulated networking environment.
4. Simulate error detection and correction techniques in a noisy communication channel to ensure reliable data transmission.
5. Develop foundational skills to avail network services efficiently and design new networking applications.

Syllabus:

Unit-I **(15 hours)**

Introduction: Data communications systems and their components, Computer networks, Types of connections, Local Area Networks, Wide Area Networks, History, standards, and applications of the Internet; Network Models and Principles of protocol layering, TCP/IP protocol suite, OSI model; Layers and their functions.

Physical Layer: Data and signals, periodic analog signals, Digital signals, Bit rate, Bit length, Transmission impairment, Noisy and noiseless channels; Digital Transmission – Digital to digital conversion, Line coding, Block coding, Scrambling; Analog Transmission – Digital to analog conversion, Amplitude shift keying, Frequency shift keying, Phase shift keying, Analog to analog conversion, Amplitude modulation, Frequency modulation, Phase modulation; Bandwidth Utilization – Multiplexing and Spectrum Spreading, Guided and Unguided Transmission Media, Circuit-switched, datagram and virtual-circuit networks.

Unit-II **(12 hours)**

Data Link Layer: Nodes and links, Sublayers of data link layer and their functions, Link layer addressing and Address Resolution Protocol (ARP); Error detection and correction, Block coding, Cyclic codes, Checksum; Data Link Control – connectionless and connection-oriented services, stop-and-wait protocol, piggybacking, point-to-point protocol; Media Access Control - Random access (ALOHA, CSMA/CD, CSMA/CA), controlled access (polling, token passing) and channelization protocols (FDMA, TDMA, CDMA); Wireless LAN, hubs, switches and routers; Virtual LAN.

Unit-III **(10 hours)**

Network Layer: Packetizing, Routing and forwarding, Circuit switching, Packet switching, Delay and throughput; IPv4 addresses, Forwarding of IP packets, Internet Protocol (IPv4), Classful and classless addressing, Datagram format, fragmentation, IPv6 address space, IPv6 packet format, Extension header, Transition from IPv4 to IPv6.

Unit-IV **(8 hours)**

Transport Layer: Connectionless and connection-oriented protocols; Stop-and-Wait, Go-back-N, and Selective-Repeat protocols; Port numbers, User Datagram Protocol (UDP), User Datagram format, UDP applications; Transmission Control Protocol (TCP), TCP segment format, connection establishment, data transfer, and termination; Data flow and flow control.

Application Layer: World Wide Web (WWW), File transfer protocol, Electronic mail, Domain Name System (DNS).

Readings:

1. Tanenbaum, A. S. *Computer networks* (5th ed.). Pearson Education India, 2013.
2. Forouzan, B. A. *Data communications and networking* (5th ed.). McGraw-Hill Education, 2017.
3. Kurose, J. F. *Computer networking: A top-down approach* (9th ed.). Pearson, 2024.

List of Practicals:

1. Explore the network by capturing the packets using network packet analyzer, apply a filter for HTTP packets and report the observed findings, such as version, IP address of client and server, status code, size of packet, protocols, in a PDF. **(2 hours)**
2. Explore the ARP packets (request and reply) using a network packet analyzer and retrieve their corresponding fields. ARP Request: payload, opcode, query. Response: Payload, opcode, response, source and destination address. **(2 hours)**
3. Simulate ARP and RARP networking protocols using a Python script. **(4 hours)**
4. Simulate Cyclic Redundancy Check (CRC) error detection algorithm for the noisy channel**. (4 hours)**
5. Write a python program to implement Checksum and Hamming (7, 4) coding for error detection and error correction in data transmission. Simulate single-bit errors, verify data integrity and display corrected output. **(4 Hours)**
6. Simulate and implement the Stop and Wait protocol for the noisy channel. **(2 hours)**
7. Simulate and implement the Go Back N and Selective Repeat sliding window protocols. **(4 hours)**
8. Write a python script to demonstrate the transmission of an IP Packet between two nodes in a network**. (2 hours)**
9. Write a Python script to demonstrate a 3-way handshake synchronization process of the TCP protocol between two nodes. Set the Urgent Flag to '1' and Destination Port to '5394' in the packet. Also, verify the details of the packet received on the receiver end. **(4 hours)**
10. Write a python program to simulate the DNS protocol to resolve domain name to the corresponding IP address. **(2 hours)**

DSC302: INFORMATION SECURITY [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSC201	**4**	**3**	**0**	**1**	Graduation	**NIL**

Course Objectives:

This course aims to provide a comprehensive understanding of security principles, threats, and cryptographic techniques used in modern computing systems. It covers security models, authentication mechanisms, and key management protocols to safeguard data and

communication. The course also emphasizes real-world applications of security frameworks, to enhance secure communication and data protection.

Course Learning Outcomes:

Upon successful completion of this course, students will be able to:

1. analyze the distinction between system protection and security, emphasizing their role in safeguarding digital assets
2. implement symmetric and asymmetric encryption algorithms
3. describe the role and implementation of digital signatures.
4. understand how cryptographic methods and security models are applied in practical systems like secure communication and e-commerce

Syllabus:

Unit-I (4 hours)

Overview of Security: Protection versus security; aspects of security– confidentiality, data integrity, availability, privacy; user authentication, access controls. Security Threats and Models: Program threats – worms, viruses, Trojan horse, trap door, stack and buffer overflow; system threats – intruders; communication threats- tapping and piracy.

Unit-II (20 hours)

Cryptography: Substitution, transposition ciphers, symmetric-key algorithms: Data Encryption Standard, Advanced Encryption Standard, IDEA, block cipher operation, stream ciphers: RC-4. Public key encryption: knapsack, RSA, El Gamal, Elliptic curve cryptography.

Unit-III (15 hours)

Integrity and authentication: Message Integrity - MDC, MAC, cryptographic hash function - iterated hash functions, compression functions, SHA-512, Digital signatures -RSA digital signature scheme, ElGamal digital signature scheme, digital signature standard (DSS), elliptic curve digital signature scheme, entity authentication.

Unit-IV (6 hours)

Key Management and Intrusion Detection & Prevention: Symmetric key distribution, Kerberos, Diffie-Hellman key agreement, public key distribution, public key infrastructures, and Intrusion Detection and Prevention Systems.

Readings:

1. Stalling, William. *Cryptography and Network Security Principles and Practices*. 8th edition, Pearson education, 2023
2. Forouzan, Behrouz A., and Debdeep Mukhopadhyay. *Cryptography and Network Security.* 3rd edition. McGraw-Hill Education, 2015.
3. Elbirt, Adam. J. *Understanding and Applying Cryptography and Data Security*. CRC Press, Taylor Francis Group, 2015.
4. Pfleeger, Charles P. SL Pfleeger, Jonathan Margulies. *Security in Computing*. 5th edition. Prentice-Hall of India, 2018.

List of practical's:

Students may choose a suitable programming language to do the following lab exercises.

1. Implement the extended Euclidean algorithm **(2 hours)**
2. Implement Encryption and decryption using the Additive Cipher **(2 hours)**
3. Cryptanalysis of the Additive Cipher **(2 hours)**
4. Implement Encryption and decryption using the Multiplicative Cipher **(2 hours)**
5. Cryptanalysis of the Multiplicative Cipher **(2 hours)**
6. Implementation of columnar transposition cipher for encryption and decryption of messages. **(2 hours)**
7. Encryption and decryption of files using python's cryptography library to demonstrate symmetric encryption and asymmetric encryption algorithms discussed in the class **(10 hours)**
8. Computation of SHA-512 Hash and HMAC for file integrity verification using a Shared Secret Key. **(4 hours)**
9. Verification of file integrity and displaying "Integrity Verified" or "Integrity Compromised" Based on various hashing algorithms. **(4 hours)**

SBC301: Prompt Engineering [0-0-2]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
SBC301	2	0	0	2	Graduation	NIL

Course Objective:

The objective of this course is to provide hands-on experience in understanding, designing, and optimizing prompts for large language models (LLMs), covering foundational and advanced prompting techniques.

Course Learning Outcomes:

Upon successful completion of this course, students will

1. understand the foundational concepts of prompting and LLM behaviour.
2. design structured, effective prompts using templates, constraints, roles, and examples.
3. apply advanced prompting methods such as chain-of-thought, few-shot prompting, ReAct, and self-consistency.
4. debug, evaluate, and optimize prompts for accuracy, clarity, and reliability.
5. design task-specific prompt workflows for reasoning, transformation, and creative tasks.

Syllabus:

Unit I: Foundations of Prompting

Introduction to LLMs and text generation; tokens and context windows; deterministic vs.

stochastic decoding; Basic prompt structures—role prompting, instruction prompting, format constraints, delimiting techniques; Prompt templates, input–output structuring, controlling style and tone; Evaluating prompts—hallucinations, ambiguity, and prompt robustness; Prompt debugging essentials.

Unit II: Advanced Prompt Patterns

Few-shot prompting, example ordering and construction; Chain-of-Thought (CoT) prompting, self-consistency, multi-step reasoning; ReAct Prompting (Reason + Act); Prompt compression, prompt optimization strategies; Hallucination mitigation and safety prompting.

Readings:

1. Phoenix, J., & Taylor, M. (2024). *Prompt Engineering for Generative AI: Future-Proof Inputs for Reliable AI Outputs*. O'Reilly Media.
2. DAIR.AI. (2024). *Prompt Engineering Guide*. https://www.promptingguide.ai
3. *Prompt engineering (OpenAI Documentation)*. https://platform.openai.com/docs/guides/prompting
4. Kojima, T., Gu, S., Reid, M., Matsuo, Y., & Iwasawa, Y. (2022). *Large language models are zero-shot reasoners*. In *Advances in Neural Information Processing Systems (NeurIPS 2022)*. https://arxiv.org/abs/2205.11916
5. Wei, J., Wang, X., Schuurmans, D., Le, Q. V., Chi, E. H., Narang, S., Chowdhery, A., & Zhou, D. (2022). *Self-Consistency improves chain of thought reasoning in language models*. In *International Conference on Learning Representations (ICLR 2023)*. https://arxiv.org/abs/2203.11171
6. Yao, S., Zhao, J., Yu, D., Du, N., & Shafran, I. (2022). *ReAct: Synergizing reasoning and acting in language models*. https://arxiv.org/abs/2210.03629

List of Practicals

1. Accessing LLM playground/API and experimenting with temperature, top-p, max tokens; Observe behavior changes with different parameters. **(4 hours)**
2. Write prompts for summarization, rephrasing, extraction; Refine prompts using delimiters and explicit constraints. **(4 hours)**
3. Design prompts with roles (teacher, analyst, developer, critic); Test how role affects style, depth, and tone. **(4 hours)**
4. Generate structured outputs (tables, bullet lists, JSON-like format); Enforce formatting rules using clear instructions and delimiters. **(4 hours)**
5. Create task-specific prompt templates; Experiment with placeholders and reusable modules. **(4 hours)**
6. Study cases of ambiguous or misleading prompts; Debug hallucinations and refine instructions. **(4 hours)**
7. Apply criteria like clarity, consistency, correctness; Score outputs against evaluation rubrics. **(4 hours)**
8. Design 1-shot, 2-shot, and 5-shot examples; Experiment with example selection and ordering. **(4 hours)**
9. Apply few-shot prompts to classification, reasoning, summarization; Compare

performance against zero-shot. **(4 hours)**

10. Add intermediate reasoning steps; Use CoT for math problems, logic puzzles, and complex decision tasks. **(4 hours)**
11. Generate multiple reasoning paths; Compare and reconcile different answers. **(4 hours)**
12. Implement ReAct-style prompts for stepwise reasoning; Use reasoning traces followed by actions. **(4 hours)**
13. Shorten prompts while preserving performance; Experiment with paraphrasing, constraint tightening, and anchor examples. **(4 hours)**
14. Identify unsafe outputs; Apply safety prompting patterns and refusal formats. **(4 hours)**
15. Students build a small prompt-based system, such as: **(4 hours)**
    - a reasoning assistant
    - a structured information extractor
    - a creative writing pipeline
    - a domain-specific Q&A prompt workflow

    Includes demonstration and evaluation.

List of DSEs for Semester III

DSE301: Link Prediction [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE301	**4**	**3**	**0**	**1**	Graduation	**Basic knowledge of Graph Theory and social network analysis**

Course Objectives:

The student learns the theoretical foundations and important properties of link prediction in networks. The students learn and explore similarity-based, probabilistic, and learning-based methods for link prediction. They can apply link prediction techniques in real-world domains such as social networks, biological networks, and recommendation systems.

Course Learning Outcomes:

At the end of the course, the students will be able to:

1. Understand basic concept and importance of link prediction.
2. Simulate link prediction approaches in network datasets.
3. Design and implement link prediction experiments on real-world datasets.
4. Evaluate link prediction models using standard performance measures.

Syllabus:

Unit-I **(9 hours)**

Introduction: Definition and motivation for link prediction; Applications of link prediction: social networks, biological networks, recommendation systems, citation networks; Problem formulation and evaluation framework, dimensionality reduction, and community detection.

Unit-II **(15 hours)**

Similarity-based methods: Local similarity: Common Neighbors, Jaccard Coefficient, Adamic-Adar, Resource Allocation Index; Global similarity: Katz Index, Hitting Time, Rooted PageRank, SimRank, Path-based and walk-based similarity measures; Structural and topological features for link prediction.

Unit-III **(15 hours)**

Probabilistic and statistical methods: Local probabilistic model, Probabilistic relational model (PRM), Hierarchical structure model (HSM), Stochastic block model (SBM), Exponential random graph model (ERGM).

Other methods: Dimensionality reduction-based link prediction, Information Diffusion-based Link Prediction, Learning-based frameworks, Information theory-based, Clustering-based, Structural perturbation method (SPM)

Unit-IV **(6 hours)**

Evaluation metrics: Recall, Area under the precision–recall curve (AUPR), Area under the receiver operating characteristics curve AUROC), and Average precision

Readings:

1. Newman, M. E. J. *Networks: An introduction*. Oxford University Press, 2010.
2. Easley, D., & Kleinberg, J. *Networks, crowds, and markets*. Cambridge University Press, 2010.
3. Barabási, A.-L. *Network science*. Cambridge University Press, 2016.
4. Golbeck, J. *Analyzing the social web*. Morgan Kaufmann, 2013.
5. Wasserman, S., & Faust, K. *Social network analysis: Methods and applications*. Cambridge University Press, 2012.
6. Kolaczyk, E. D. *Statistical analysis of network data: Methods and models*. Springer, 2009.
7. Estrada, E. *The structure of complex networks: Theory and applications*. Oxford University Press, 2011.
8. Srinivas, V., & Mitra, P. *Link prediction in social networks: Role of power law distribution*. Springer International Publishing, 2016.

List of Practicals:

1. Extract structural features (degree, clustering coefficient, centrality) and apply the dimensionality reduction method PCA to visualise nodes in a reduced feature space. (**4 hours**)
2. Implement Common Neighbours, Jaccard Coefficient, Adamic–Adar, and Resource Allocation Index manually and validate with NetworkX built-in functions. (**4 hours**)
3. Write a Python function to compute the Katz Index using matrix operations (numpy.linalg.inv), with damping factor β. (**2 hours**)
4. Compute Rooted PageRank (Personalized PageRank) from a given root node using the random walk with restart method. (**2 hours**)
5. Compute Hitting Time between all pairs of nodes using BFS-based random walks. (**2 hours**)
6. Implement SimRank recursively and analyze how similarity scores evolve over iterations. (**4 hours**)
7. Generate all paths between node pairs up to length 3 and calculate similarity based on path counts. (**2 hours**)
8. Simulate Independent Cascade (IC) or Linear Threshold (LT) models and estimate missing links based on influence overlap. (**4 hours**)
9. Implement Recall, Precision, AUPR, AUROC, and Average Precision. (**4 hours**)
10. Compare accuracy (AUC, precision) between attribute-based PRM and structure-based probabilistic models. (**2 hours**)

DSE302: RECOMMENDER SYSTEMS [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE302	**4**	**3**	**0**	**1**	Graduation	**NIL**

Course Objectives:
The student learns the fundamental and advanced concepts of recommender systems, including collaborative filtering, content-based, hybrid, and context-aware techniques. The student develops analytical and technical skills to design, implement, and evaluate recommender algorithms using real-world datasets and modern machine learning frameworks.

Course Learning Outcomes:
On completing this course, students will be able to:

1. explain the theoretical foundations, types, and working principles of recommender systems.
2. apply collaborative filtering, content-based, and hybrid methods to build personalised recommendation models.
3. analyze user–item interactions and contextual factors influencing recommendation quality.
4. evaluate recommender system performance using standard metrics, validation methods, and benchmark datasets.
5. design and create advanced recommender systems integrating deep learning, graph-based, and sequential modeling techniques for real-world applications.

Syllabus:

Unit-I **(11 hours)**

Introduction to Recommender Systems: Purpose, significance, and real-world applications; types of recommender systems. Data sources including user profiles, item attributes, and implicit and explicit feedback. Data preprocessing techniques for effective recommendation. Evaluating Recommender Systems: Online and offline evaluation methodologies; performance metrics such as RMSE, MAE, Precision, Recall, F1-score, NDCG, Average Reciprocal Rank, and Top-K measures. Beyond-accuracy evaluation covering fairness, coverage, diversity, novelty, and serendipity to ensure a comprehensive assessment of recommender systems.

Unit-II **(14 hours)**

Collaborative Filtering – Neighbourhood-Based Approaches: Introduction, user-based and item-based models, similarity measures, and prediction functions; efficiency analysis and comparative evaluation; clustering and dimensionality reduction techniques; regression-based and graph-based extensions. Latent Factor Models and Matrix Factorization: Singular Value Decomposition (SVD), Non-negative Matrix Factorization (NMF), Stochastic Gradient Descent (SGD), and Alternating Least Squares (ALS) with regularization.

Unit-III **(10 hours)**

Content-Based Recommender Systems: Introduction and Basic Components, Preprocessing and Feature Engineering, Collecting User Preferences, Supervised Feature Selection and Weighting Techniques, Learning User Profiles and Filtering Approaches. Content-Based vs. Collaborative Recommendations. Hybrid recommender systems combining collaborative and content-based filtering.

Unit-IV **(10 hours)**

Advanced Topics – Deep Learning-Based Recommender Systems: Neural Approaches, Autoencoders, Sequence-Aware Models (RNN, LSTM, Transformer), Graph Neural Network-Based Recommenders, Explainable Recommendations, Fairness and Bias Mitigation, Multi-Modal and Context-Aware Recommendation, Emerging Trends and Research Directions.

Readings:

1. Aggarwal, Charu C., *Recommender Systems: The Textbook*, Springer International Publishing, 2016.
2. Ricci, Francesco, Lior Rokach, and Bracha Shapira (Ed.), *Recommender Systems Handbook*, Third Edition, Springer, 2022.
3. Advances in recommender systems using recent research papers.

List of Practicals:

1. Implement a user-based collaborative filtering recommender system using a given dataset (e.g., MovieLens). **(4 hours)**
2. Implement an item-based collaborative filtering recommender and compare its performance with the user-based model. **(2 hours)**
3. Perform matrix factorisation using Singular Value Decomposition (SVD) on a user-item rating matrix and predict missing ratings. **(4 hours)**
4. Implement non-negative matrix factorisation (NMF) on a dataset and analyse the latent factors for top-N recommendation. **(2 hours)**
5. Build a content-based recommender system using item features (e.g., genres, tags, descriptions) and evaluate using cosine similarity. **(2 hours)**
6. Implement a hybrid recommender system combining collaborative and content-based approaches and evaluate improvements over individual models. **(4 hours)**
7. Build a sequence-aware recommendation model using RNN or LSTM and evaluate next-item prediction performance. **(6 hours)**
8. Implement a graph-based recommender system using a Graph Neural Network (GNN) and analyse user-item interaction patterns. **(6 hours)**

DSE303: Time Series Data Analysis [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE303	**4**	**3**	**0**	**1**	Graduation	**Basic knowledge of programming and statistics**

Course Objectives:

This course provides a comprehensive understanding of time series analysis, covering fundamental principles, statistical modeling techniques, and forecasting methods. The course balances theoretical concepts with hands-on applications using real-world datasets in R and Python.

Course Learning Objectives:

By the end of this course, students will be able to:

1. Understand the basic properties and components of time series data.
2. Perform stationarity tests and data transformations.
3. Apply statistical and machine learning models for time series forecasting.
4. Analyse multivariate time series data and apply feature engineering techniques.
5. Implement real-world forecasting applications across different domains.

Syllabus:

Unit-I **(10 Hours)**

Fundamentals of Time Series Analysis: Introduction to Time Series Data, Time Series Components, Trend, Seasonality, Cyclicality, and Noise, Time Series Data Visualization and Preprocessing, Stationarity and Unit Root Tests (ADF, KPSS).

Unit-II **(12 Hours)**

Time Series Models and Forecasting: Moving Average and Exponential Smoothing Models, Autoregressive (AR), Moving Average (MA), and ARMA Models, ARIMA and Seasonal ARIMA (SARIMA), Model Selection and Diagnostics (AIC, BIC, Residual Analysis), Performance Metrics.

Unit-III **(11 Hours)**

Advanced Time Series Methods: State-Space Models and Kalman Filters, Spectral Analysis and Fourier Transforms, Long Memory Processes and Fractional Differencing, and Nonlinear Time Series Models.

Unit-IV **(12 Hours)**

Multivariate Time Series and Machine Learning Approaches: Vector Autoregression (VAR) and Cointegration, Dynamic Factor Models and PCA, Machine Learning for Time Series (LSTMs, XGBoost, Prophet), Feature Engineering and Dimensionality Reduction.

Readings:

1. Brockwell, Peter J., and Richard A. Davis, eds. *Introduction to time series and forecasting*. New York, NY: Springer New York, 2002.
2. Montgomery, Douglas C., Cheryl L. Jennings, and Murat Kulahci. *Introduction to time series analysis and forecasting*. John Wiley & Sons, 2015.
3. Beran, Jan., *Mathematical Foundations of Time Series Analysis*. Switzerland: Springer, 2017.
4. Wei, William W. S., *Multivariate Time Series Analysis and Applications*. United Kingdom: Wiley, 2019.
5. Hyndman, Rob J., Athanasopoulos, George. *Forecasting: Principles and Practice*. United Kingdom: OTexts, 2021. [https://otexts.com/fpp3/index.html]

List of Practicals:

1. Write a program that reads a time series with missing timestamps, fills or interpolates missing values, resamples the data at a different frequency (e.g., converting daily data

into monthly averages), and removes outliers using z-score or IQR. Plot the data before–after pre-processing **(2 Hours).**

2. Write a program that loads a time series dataset (such as AirPassengers or daily stock prices) and then plots the raw data along with a rolling mean and rolling standard deviation. The program should also generate autocorrelation (ACF) and partial autocorrelation (PACF) plots. **(2 Hours)**
3. Write a program to perform additive and multiplicative decomposition on a given time series using STL or classical decomposition. The program should extract and plot the trend, seasonal, and residual components separately, and print a short interpretation describing the nature of seasonality and trend. **(2 Hours)**
4. Write a program that visually checks stationarity using rolling mean/variance plots and then performs ADF and KPSS tests on the original series. The program should apply first-order differencing or log transformation until the series becomes stationary and then re-run the tests, printing the p-values and conclusions. **(2 Hours)**
5. Write a program to apply simple moving average, weighted moving average, and exponential smoothing to a time series. The program should compare smoothed curves on a single plot and show how different window sizes or smoothing factors affect the trend. It should also print summary statistics comparing original and smoothed series. **(2 Hours)**
6. Write a program that analyzes the ACF and PACF plots to choose tentative orders for AR, MA, and ARMA models. Then fit AR(p), MA(q), and ARMA(p,q) models, print model parameters, and perform residual analysis using the Ljung–Box test. Evaluate the performance of the model using MAE, RMSE, MAPE, and sMAPE. **(6 Hours)**
7. Write a program that identifies the required differencing order using ADF/KPSS and then fits an ARIMA model with manually selected or auto-selected orders. The program should also fit a SARIMA model if seasonality exists, compare AIC/BIC values, and display forecast plots along with residual diagnostics **(2 Hours).**
8. Write a program that builds a state-space representation of a time series (e.g., a local linear trend model), applies the Kalman filter to estimate hidden states, and plots filtered and smoothed estimates. The program should compare the Kalman-based trend with the trend obtained using classical smoothing **(2 Hours).**
9. Write a program that computes the periodogram of a time series, applies the Fast Fourier Transform (FFT), and identifies the dominant frequencies contributing to seasonality. The program should print the main repeating cycle (e.g., weekly, yearly) based on the spectral peaks**. (2 Hours)**
10. Write a program that loads two or more related time series (such as GDP, inflation, and interest rates), checks their stationarity, and fits a VAR model. The program should compute impulse response functions and plot how one variable responds over time to a shock in another variable. **(2 Hours)**
11. Write a program that applies PCA to a multivariate time series dataset, extracts major components, and reconstructs the series using those components. Then fit a dynamic factor model and compare the variance explained by PCA factors versus dynamic factors. **(2 Hours)**
12. Write a program that converts a time series into a supervised learning dataset by

generating lag features, rolling statistics, and date-time features. Train XGBoost or Prophet models on the processed data, generate forecasts, and compare their performance with ARIMA using common error metrics. **(2 Hours)**

13. Write a program that converts the time series into sliding windows, normalizes the data, and trains an LSTM or GRU neural network for next-step prediction. The program should plot predicted vs actual values and compare LSTM accuracy with traditional models such as ARIMA or exponential smoothing**. (2 Hours)**

DSE304: QUANTUM COMPUTING AND ITS APPLICATIONS [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSC304	**4**	**3**	**0**	**1**	Graduation	**Basic knowledge of Number theory or information security**

Course Objectives:

This course provides a foundation for quantum computing, post-quantum cryptography and quantum machine learning. It covers the fundamental concepts of quantum mechanics, quantum algorithms, and their applications in various areas, including cryptography, cybersecurity, machine learning, finance, the energy sector, etc. Students will gain a theoretical understanding of quantum computing and practical skills in implementing quantum algorithms for various tasks.

Course Learning Outcomes:

On completing this course, the student will be able to:

1. Understand the basic principles of quantum mechanics and their relevance to quantum computing.
2. Comprehend quantum algorithms and their applications.
3. Apply quantum optimisation techniques in problem-solving.
4. Demonstrate practical skills in quantum computing in various areas, including cryptography and machine learning.

Syllabus:

Unit-I **(10 hours)**

Fundamentals of Quantum Computing: Mathematical foundations: Vectors, Vector space, Inner product, Tensor Product; Qubits, Introduction to quantum mechanics and its relevance to Quantum gates, superposition principle, and entanglement Quantum parallelism and interference, No cloning theorem, quantum teleportation, Introduction to quantum error

Correction.

Unit-II **(15 hours)**

Quantum Algorithms and Post-Quantum Security: Phase Kick-Back Algorithm, Deutsch-Jozsa algorithm, Simon's algorithm, Bernstein-Vazirani, RSA algorithm and factorization attack on RSA, Shor's algorithm for integer factorization, Grover's algorithm for unstructured search, Hash preimage attack with Grover's algorithm, Quantum Fourier transform and its applications, Harrow–Hassidim–Lloyd (HHL) algorithm, Kyber Algorithm, Quantum attack resistant Digital Signature.

Unit-III **(10 hours)**

Quantum Machine Learning and Optimization: Quantum machine learning (QML) models – QSVM, QNN, QCNN, Quantum Linear Regression, Variational Quantum Classifier (VQC), Quantum k-means clustering; kernel methods, Quantum Boltzmann Machines; Quantum optimization techniques: QAOA, quantum annealing.

Unit-IV: **(10 hours)**

Introduction to quantum simulation tools and platforms: Google CIRQ, Amazon Braket, IBM Qiskit, Pennylane, Q#, Tensorflow quantum, Tket/pyket, XACC, Project Q, Quantum Development Kit (QDK).

Readings:

1. Noson S. Yanofsky and Mirco A. *Mannucci. Quantum computing for computer scientists*. Cambridge University Press, 2008.
2. Michael A Nielsen, Isaac L. Chuang, *Quantum computation and quantum Information*, Cambridge University Press.
3. Elias F. Combarro, Samuel González-Castillo, and Alberto Di Meglio. *A Practical Guide to Quantum Machine Learning and Quantum Optimization: Hands-on Approach to Modern Quantum Algorithms*. Packt Publishing Ltd, 2023.

References:

1. Santanu Ganguly. Quantum Machine Learning: An Applied Approach. Apress, 2021.
2. https://docs.quantum.ibm.com/
3. https://quantumai.google/cirq/experiments/textbook_algorithms

List of practical:

1. Install and configure a quantum computing framework such as IBM Qiskit or Google Cirq, and create basic quantum circuits using single-qubit gates to perform measurements. **(3 Hours)**

2. Write a program to visualise qubit states and their rotations on the Bloch Sphere using suitable simulation tools. **(2 Hours)**

3. Implement a program to demonstrate the concepts of superposition and entanglement

using multi-qubit circuits. **(3 Hours)**

4. Write a program to simulate the process of quantum teleportation using an entangled qubit pair. **(3 Hours)**
5. Implement the Deutsch–Jozsa algorithm to identify whether a given function is constant or balanced. **(3 Hours)**
6. Write a program to implement Grover's search algorithm for an unstructured search problem and analyze its efficiency**. (4 Hours)**
7. Implement a simplified version of the Quantum Fourier Transform (QFT) for a small number of qubits and observe the results. **(3 Hours)**
8. Write a program to demonstrate the Quantum Approximate Optimisation Algorithm (QAOA) for solving simple optimisation problems. **(3 Hours)**
9. Write a program to generate and analyze quantum random numbers using measurement of superposition states. **(4 Hours)**
10. Write and execute quantum circuits on different quantum-computing platforms and compare their performance and features**. (2 Hours)**

DSE305: Digital Forensics [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE305	**4**	**3**	**0**	**1**	Graduation	**Basic knowledge of Computer Networks and operating systems**

Course Objective:

This course provides a comprehensive introduction to the principles, practices, and legal frameworks of digital forensics. Students will gain hands-on experience in the complete investigation lifecycle—from evidence acquisition and validation to in-depth analysis of computer, mobile, and network data. The course prepares students to conduct rigorous digital investigations and effectively report on findings in accordance with modern Indian legal standards.

Course Learning Outcomes:

Upon successful completion of this course, students will be able to:

1. apply the forensic investigation process in compliance with Indian legal acts and ethical guidelines.
2. acquire and validate data from live and dead systems, including hard drives (disk imaging) and volatile memory (RAM).
3. analyse and reconstruct digital evidence from various file systems (FAT, NTFS, ext4), memory dumps, and core operating system artefacts (e.g., Windows Registry, browser history).
4. analyse evidence from specialised sources, including mobile devices (Android) and network packet captures (PCAPs).
5. Evaluate the challenges and methodologies associated with emerging threats, such as deepfake media, AI-generated evidence, and dark web artefacts.

Syllabus

Unit I: (8 hours)

Introduction: Definition, distinction between cyber forensics and Digital forensics, Evolution of computers and digital forensics, modern challenges in the AI and cloud era. Digital Footprints and Attack Vectors, Case Studies (Indian and Global), Digital forensics Investigation process: Identification, Preservation, Collection and Acquisition, Analysis, Documentation & Presentation, Numbering Systems, Data structure – endianness, character encoding, Data nature and state, Reporting: Best practices for making Forensic reports

Unit II: (10 hours)

Legal and Ethical Frameworks: IT Act, 2000 (amendments of 2008) and IT (Intermediary Guidelines and Digital Media Ethics Code) Rules, 2021 (and subsequent amendments), BNS 2023, BNSS 2023, BSA 2023, DPDP Act, 2023, Budapest Convention, ISO/IEC Standards in Forensics, Chain of custody, 65A/65B Certificates, Ethical dilemmas in Forensics, CERT-in Procedures and Coordination

Unit III: (15 hours)

Acquisition and Analysis: Acquisition: Live vs Dead Acquisition, Methods for Data Acquisition, Hashing (MD5, SHA) and Data Validation. File System Analysis: FAT, NTFS, ext4, methods for recovering data from deleted files, File carving, Memory forensics: Volatile data collection and analysis, analysing memory dumps for processes, network connections, OS Artifacts analysis: Time reconstruction, Email Header analysis and tracing, Windows registry analysis, browser history, anti-forensics technique and detection

Unit IV: (12 hours)

Advanced and Emerging Forensics: Mobile Forensics: Overview of acquisition and analysis of Android, unique challenges: diverse OS, encryption, complex appdata, Legal and ethical considerations, Network Forensics: analysing network traffic (PCAP files); Emerging Threats: Dark Web Forensics, Synthetic Media and Deepfake Detection; AI-generated Evidence:

Admissibility Challenges.

References:

1. Dejey, M. *Cyber forensics*. Oxford University Press India, 2018.
2. Moustafa, N. *Digital forensics in the era of artificial intelligence* (1st ed.). CRC Press, 2023.
3. Gogolin, G. *Digital forensics explained* (2nd ed.). CRC Press, 2021.
4. Kävrestad, J. *Fundamentals of digital forensics: Theory, methods, and real-life applications*. Springer International Publishing AG, 2020

List of Practicals

1. Consider a scenario in which you are a junior forensic analyst. You received a sealed 16GB USB drive (Evidence #001). Create a new case in Autopsy, fill out a chain of custody form to document its receipt, and then draft a sample 65B certificate for a hypothetical file (e.g., secret_ledger.xlsx) found on the drive to understand legal documentation. **(4 hours)**

2. Explore WinHex and Hex Workshop to analyse and examine various file headers. **(4 hours)**

3. Install FTK Imager and acquire the volatile memory (RAM) of your system. **(2 hours)**

4. Acquire non-volatile memory (hard disc) using FTK Imager **(2 hours)**

5. Analyse the disk image created in the previous lab by loading it into Autopsy. Examine the NTFS structure, with a focus on the Master File Table (MFT). Analyse MFT entries for deleted files, looking specifically at how the FILE_NAME attribute (flagged as ;in-use and/or deleted) and timestamp attributes change. Using this analysis, identify and recover five specific deleted files, documenting their original file paths. **(4 hours)**

6. In Gmail, select a SPAM email and analyse its header. Detect possible spoofing or malicious activity using a mail header analyser. https://mxtoolbox.com/EmailHeaders.aspx. Identify key header fields such as From, To, Subject, Date, Return-Path, Received, Message-ID, and SPF / DKIM / DMARC. Use tools like WHOIS or online IP lookup services to identify the geographical location and ownership of IP addresses found in the Received lines. Verify if any IPs are suspicious or if the hostname doesn't match the expected sending server. **(2 hours)**

7. Visit the website https://testphp.vulnweb.com/ and start capturing packets using Wireshark. Some HTTP packets will be captured. Look for form data that the user submitted to the website. Find the user credentials sent in the HTTP request. **(2 hours)**

8. Analyse a provided Windows memory dump using the Volatility framework. You will identify the correct OS profile, then run commands to extract the list of running

processes (pslist), identify active network connections (netscan), and dump command history (cmdscan) **(6 hours)**

9. Analyse a provided logical Android backup (android_backup.ab) using Autopsy. You will extract and query key databases to document recent calls (calllog.db), find specific text messages (mmssms.db), and locate the WhatsApp message database (msgstore.db). **(2 Hours)**

10. Using Registry Explorer and the RegRipper tool, analyse the SAM registry Hive and identify your own user SID. **(2 hours)**

DSE306: Human Computer Interaction [3-0-1]

Course Code	**Credits**	**Credit distribution of the course**			Eligibility Criteria	**Pre-requisite of the course (if any)**
		Lecture	**Tutorial**	**Practical/Practice**		
DSE306	4	3	0	1	Graduation	Programming language and prototypes of computer interfaces

Course Objectives:

The course aims to introduce students to the fundamental concepts of human-computer interaction and their application in society.

Course Learning Outcomes:

Upon successful completion of this course, the student will-

1. understand basic theories, tools and techniques in HCI.
2. empathize with the fundamental aspects of designing and evaluating interfaces.
3. apply appropriate HCI techniques to design systems that people use.

Syllabus:

UNIT I: **(12 Hours)**

HCI Foundations- Input–output channels, human memory, thinking: reasoning and problem solving, emotion, individual differences, psychology and the design of interactive systems; text entry devices, positioning, pointing and drawing, display devices, devices for virtual reality and 3D interaction, physical controls, sensors and special devices, paper: printing and scanning; models of interaction, frameworks and HCI, industrial interfaces, interaction styles, navigation in 3D and 2D, elements of the WIMP interface, learning toolbars, interactivity, the context of

the interaction; paradigms.

UNIT II: (14 Hours)

Design Process- Process of design, scenarios, navigation design, beware the big button trap, modes, screen design and layout, alignment and layout matter, checking screen colors, iteration and prototyping; HCI in the software process- the software life cycle, usability engineering, iterative design and prototyping, design rationale; design rules- principles to support usability, standards, golden rules and heuristics, HCI patterns; elements of windowing systems, programming the application, user interface management systems; evaluation through expert analysis, evaluation through user participation, choosing an evaluation method; universal design principles, multi-modal interaction, designing for diversity; requirements of user support, approaches to user support, designing user support systems.

UNIT III: (9 Hours)

Models and Theories- cognitive models- introduction, goal and task hierarchies, linguistic models, physical and device models, cognitive architectures; organizational issues, capturing requirements; communication and collaboration models- introduction, face-to-face communication, conversation, text-based communication; task analysis- introduction, task decomposition, knowledge-based analysis, entity–relationship-based techniques.

UNIT IV: (10 Hours)

Dialog design notations, diagrammatic notations, dialog semantics, dialog analysis and design; interaction models; rich contexts, low intention and sensor-based interaction; groupware-introduction and systems, meeting and decision support systems, shared applications and artifacts, frameworks for groupware, implementing synchronous groupware; virtual and augmented reality, information and data visualization.

Readings:

1. Dix, A., Finlay, J., Abowd, G. D., & Beale, R. *Human–computer interaction* (3rd ed.). Pearson, 2008.
2. Shneiderman, B., Plaisant, C., Cohen, M., & Jacobs, S. *Designing the user interface: Strategies for effective human–computer interaction* (6th ed.). Pearson, 2021.
3. Bhattacharya, S. *Human–computer interaction* (1st ed.). McGraw-Hill, 2019.

References:

1. Galitz, Wilbert O., *The Essential Guide to User Interface Design: An Introduction to GUI Design Principles and Techniques*, 3rd edition, Wiley Publishing, 2007.

List of practical:

You may choose a suitable programming language and define all necessary/relevant inputs/ problems.

1. Implement a program for short-term memory and long-term memory. **(2 Hours)**

2. Implement a program to perform natural language interfaces. **(2 Hours)**

3. Write a program for a full-page word-processor that is or is not a direct manipulation interface for editing a document using Shneiderman's criteria. **(4 Hours)**

4. Write a program to find a book on guidelines. List the guidelines that are provided and classify them in terms of the activity in the software life cycle to which they would most likely apply. **(2 Hours)**

5. Implement a program for a keystroke level analysis for opening up an application in a visual desktop interface using a mouse as the pointing device, comparing at least two different methods for performing the task. Repeat the exercise using a trackball. **(4 Hours)**

6. Write a program to test whether adding colour coding to an interface will improve accuracy. **(2 Hours)**

7. You have been asked to compare user performance and preferences with two different learning systems, one using hypermedia and the other sequential lessons. Write a program to design a questionnaire to find out what the users think of the system. **(4 Hours)**

8. Implement a program for online support systems. **(2 Hours)**

9. Write a program for the operations in a standard drawing package (for example, draw, move, copy, delete, rotate). **(4 Hours)**

10. Write a program for Icon Design and VCR Remote Control. **(4 Hours)**

DSE307: Influence Maximization [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE307	**4**	**3**	**0**	**1**	Graduation	**Basic knowledge of Graph Theory and social network analysis**

Course Objectives:

This course provides a comprehensive introduction to the principles of information diffusion and influence propagation in networks. To learn classical and advanced influence maximization algorithms. To analyze efficient and effective algorithms for influence maximization under various constraints. To study evaluation metrics and performance analysis for influence maximization. To apply influence maximization techniques in real-world applications such as viral marketing, epidemic control, and opinion formation.

Course Learning Outcomes

At the end of the course, the students will be able to:

1. Understand the basic concept of influence maximization in networked datasets.
2. Model and simulate the spread of influence using classical propagation models.
3. Identify influential nodes using various influence maximization algorithms.
4. Analyze and compare algorithmic efficiency and approximation guarantees of influence maximization algorithms.

Syllabus:

Unit-I **(8 hours)**

Introduction: Overview of social networks and types of social networks, Network structure and properties (degree, clustering, centrality), social network analysis concepts, viral marketing, rumor spreading, and epidemic diffusion; real-world applications, NP-hardness, monotone and sub-modularity properties.

Unit-II **(12 hours)**

Information Diffusion Models: Basics of information diffusion and influence propagation, Independent Cascade (IC) model, Linear Threshold (LT) model, SIR: variants and extensions (weighted, time-aware, competitive, signed), Influence spread and expected diffusion, Analytical and simulation-based evaluations.

Unit-III **(13 hours)**

Classical Influence Maximization Algorithms: Simulation-based Algorithms: Greedy algorithms and approximation guarantees, CELF, and CELF++ optimization; Heuristic-based Algorithms: Degree, PageRank, Centrality-based and Community-based; Sampling-based Algorithms; Path-based Algorithms. Performance evaluation metrics.

Unit-IV **(12 hours)**

Advanced Influence Maximization Algorithms: Budgeted Influence Maximization, Influence maximization in Dynamic and Temporal Networks, Competitive Influence Maximization, Location-aware Influence Maximization, Topic-aware Influence Maximization, Conformity and Semantic-based Influence Maximization.

Readings:

1. Newman, M.E.J. *Networks: An introduction*. Oxford University Press, 2010.
2. Easley D. and Kleinberg J. *Networks, Crowds, and Markets.* Cambridge University Press, 2010.
3. Barabási A.L. *Network Science.* Cambridge University Press, 2016.
4. Kolaczyk, E. D. *Statistical Analysis of Network Data: Methods and Models.* Springer, 2009.
5. Estrada, E. *The Structure of Complex Networks: Theory and Applications.* Oxford University Press, 2011
6. Chen, W. Castillo, C and Lakshmanan, L.V.S. *Information and influence propagation in social networks*, Springer Nature, 2014

List of Practicals:

1. Create a graph from different types of input files and display the nodes and edges properties. **(4 hours)**
2. Implement the Independent Cascade Model (ICM) to observe the spread of influence from a given set of seed nodes. **(2 hours)**
3. Implement the Linear Threshold Model (LTM) to observe the spread of influence from a given set of seed nodes. **(2 hours)**
4. Select top-k nodes based on degree centrality and evaluate influence spread under the IC model. **(2 hours)**
5. Compare influence spread using degree, closeness, betweenness, and eigenvector centrality as seed criteria. **(4 hours)**
6. Implement the Greedy and CELF algorithms to efficiently select the top-k influential nodes for maximizing the influence spread. **(4 hours)**
7. Detect communities using the Louvain or Girvan–Newman algorithm. Select seed nodes evenly from the identified communities and compare the influence spread. **(2 hours)**
8. Implement Greedy algorithm for Budgeted Influence Maximization and Fairness Influence Maximization. **(2 hours)**
9. Implement algorithms of Multiple Influence Maximization (MIM) to find the seed set. **(4 hours)**
10. Determine the potential fairness issues that may exist in advanced influence maximisation algorithms. **(4 hours)**

DSE308/DSC 402: Deep Learning [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSC308	**4**	**3**	**0**	**1**	Graduation	**Basic Knowledge of Machine Learning Algorithms**

Course Objectives:
This course introduces students to modern deep learning architectures and training methodologies used to solve real-world problems. Students will learn to design neural network models, understand optimization and regularization strategies, and work with major deep learning frameworks such as TensorFlow and PyTorch. Emphasis is placed on applying deep learning techniques to computer vision, natural language processing, and generative modeling.

Course Learning Outcomes:
On completing this course, students will be able to:

1. Describe feedforward neural networks, deep architectures, and their learning procedures.
2. Design and train single-layer and multi-layer deep neural networks while tuning hyperparameters effectively.
3. Analyze and evaluate the performance of deep learning models across vision, NLP, and generative tasks.

Syllabus:

Unit-I **(14 hours)**

Introduction: Historical context and motivation for deep learning; deep feedforward neural networks, regularizing a deep network, model exploration, and hyperparameter tuning. Convolution Neural Networks: Introduction to convolution neural networks: stacking, striding, and pooling, applications like image and text classification.

Unit-II **(17 hours)**

Introduction to Natural Language Processing (NLP), Traditional NLP Techniques, Sequence Modeling: Recurrent Nets: Unfolding computational graphs, recurrent neural networks (RNNs), bidirectional RNNs, encoder-decoder sequence to sequence architectures, deep recurrent networks. Large Language Models: Transformer Architecture, Pre-training and Fine-tuning Language Models, Ethical Considerations and Bias in Language Models, Applications of Large Language Models (Text Generation, Sentiment Analysis, Question Answering)

Unit-III **(10 hours)**

Autoencoders: Undercomplete autoencoders, regularized autoencoders, sparse autoencoders, denoising autoencoders, representational power, layer, size, and depth of autoencoders, stochastic encoders and decoders. Generative Adversarial Networks (GANs): Introduction to Generative Adversarial Networks, GAN Architectures (DCGAN, CycleGAN), Applications of GANs (Image Generation, Style Transfer)

Unit-IV **(4 hours)**

Structuring Machine Learning Projects: Orthogonalization, evaluation metrics, train/dev/test distributions, size of the dev and test sets, cleaning up incorrectly labelled data, bias and variance with mismatched data distributions, transfer learning, multi-task learning.

Readings:

1. Goodfellow, I., Bengio, Y., & Courville, A. (2016). Deep Learning. MIT Press.
2. Heaton, J. (2015). Deep Learning and Neural Networks. Heaton Research Inc.
3. Hall, M. L. (2011). Deep Learning. VDM Verlag.
4. Deng, L., & Yu, D. (2009). Deep Learning: Methods and Applications. Now Publishers Inc.

List of Practicals:

1. Implement a deep neural network using PyTorch or TensorFlow on a simple dataset. Apply techniques for regularization, such as dropout and early stopping. Tune hyperparameters like learning rate, number of layers, and batch size. **(4 hours)**
2. Design and train a convolutional neural network on an image dataset. Apply stacking, striding, pooling, and normalization techniques. Evaluate model performance using accuracy and confusion matrix. **(4 hours)**
3. Preprocess text data, tokenize and vectorize inputs, and implement a CNN-based model for sentiment classification. **(2 hours)**
4. Implement a basic RNN to model sequences, such as character-level language modeling. Visualize unfolding of the computational graph and train the model on a small text corpus. **(4 hours)**
5. Build a sequence-to-sequence model using an encoder-decoder architecture with bidirectional RNNs for tasks like machine translation. Evaluate output quality using BLEU score or accuracy. **(2 hours)**
6. Use Transformers to load a pre-trained BERT or GPT model. Fine-tune it on a downstream task such as sentiment analysis or question answering datasets. **(4 hours)**
7. Analyze generated outputs from a large language model for biased or unethical responses. **(2 hours)**
8. Implement different types of autoencoders (undercomplete, sparse, denoising) on the MNIST dataset. Visualize reconstructed images and evaluate reconstruction error. (**4 hours)**
9. Build and train a simple GAN on MNIST or CelebA dataset. Generate synthetic images and compare visual quality with real images. Track generator and discriminator loss over time. (**2 hours)**
10. Use transfer learning with a pre-trained CNN (e.g., ResNet) to classify a small custom dataset. Discuss best practices for train/dev/test splits, evaluation metrics, and handling label noise. Experiment with multi-task learning if time permits. (**2 hours)**

SEMESTER – IV

DSC401: SOFTWARE ENGINEERING [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSC401	**4**	**3**	**0**	**1**	Graduation	**NIL**

Course Objectives:

This course aims to develop professional competence in software engineering by introducing engineering principles, process models, software design approaches, quality assurance techniques, and project management practices. Students will gain the ability to analyze, design, develop, test, and maintain reliable and high-quality software systems.

Course Learning Outcomes:

On completing this course, the student will be able to:

1. Understand and apply software process models, including agile development approaches.
2. Use modeling techniques and design principles to develop structured and component-based software solutions.
3. Apply quality assurance methods, reviews, metrics, and testing techniques to ensure software quality.
4. Demonstrate the ability to plan, manage, and monitor software projects using industry-standard practices.

Syllabus

Unit-I: Software Process & Agile Development (9 Hours)

Software process models; generic process model; prescriptive and specialized process models; process assessment and improvement, Agile development: concepts and principles of agility, cost of change, agile process models, Extreme Programming (XP), Scrum, feature-driven

development, and other agile approaches.

Unit-II: Requirements Engineering & Software Design (12 Hours)

Principles governing software engineering practice; core design and modeling principles, Requirements engineering: elicitation, analysis, negotiation, validation; building requirements models; use case modeling; UML diagrams; class-based modeling; flow-oriented modeling; behavioral modeling; patterns in requirements modeling, Design concepts: design process, abstraction, modularity, coupling and cohesion, design patterns, Component-level design: structure and behavior of components, class-based design, component-based development, traditional and object-oriented design approaches.

Unit-III: Software Quality Management & Testing (13 Hours)

Quality concepts: definition, software quality, quality dilemmas, achieving quality, Review techniques: review spectrum, informal reviews, formal technical reviews, defect amplification, review metrics, Software Quality Assurance (SQA): objectives, tasks, metrics, statistical quality assurance, software reliability, Testing strategies: validation, system testing, black-box and white-box testing, debugging practices, testing for conventional and object-oriented software, Software Configuration Management: SCM repository and process, Product metrics: metrics for requirements, design, testing, maintenance, and overall product quality.

Unit-IV: Software Project Management (11 Hours)

Project management concepts: management spectrum, people, product, process, and project dimensions, Process and project metrics: software measurement, metrics for quality, productivity, and estimation; metrics for small organizations, Project scheduling: task sets, task networks, scheduling techniques, Gantt charts, critical path method, earned value analysis, Risk management: reactive and proactive strategies; risk identification, analysis, projection, refinement, mitigation, monitoring, and planning; RMMM plan.

Readings:

1. Pressman, R. S. (2010). Software Engineering: A Practitioner's Approach (7th Ed.). McGraw-Hill.
2. Sommerville, I. (2015). Software Engineering (10th Ed.). Pearson Education.
3. Mall, R. (2014). Fundamentals of Software Engineering (4th Ed.). PHI.
4. Jalote, P. (2005). An Integrated Approach to Software Engineering (3rd Ed.). Narosa Publishing House.

Additional References:

1. Aggarwal, K. K., & Singh, Y. (2008). *Software Engineering* (4th Ed.). New Age International Publishers.

2. Godbole, N. S. (2007). *Software Quality Assurance: Principles and Practice*. Alpha Science.

List of practicals:

You may choose a suitable programming language and define all necessary/relevant inputs/ problems.

1. Defining a software problem and establishing project scope. **(2 Hours)**
2. Preparing documentation for the selected project, including SRS, design documents, testing plan, configuration management plan, and risk management plan. **(8 Hours)**
3. Implementing the design or coding phase for the chosen software project. **(8 Hours)**
4. Conducting a structured software review (peer review / technical review). **(4 Hours)**
5. Applying software quality checks and relevant product metrics. **(2 Hours)**
6. Performing software testing using appropriate test strategies and documenting results. **(4 Hours)**
7. Executing software verification activities according to standards. **(2 Hours)**
8. Performing software estimation and proposing improvements based on metrics and testing outcomes. **(4 Hours)**

SBC 401:COMMUNICATION SKILLS [1-1-0]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
SBC401	2	1	1	0	Graduation	NIL

Course Objective:

This course aims to build essential communication competencies required in academic and professional settings. It focuses on strengthening verbal, non-verbal, written, and digital communication; enhancing listening, reading, and analytical skills; and developing clarity, coherence, and professionalism in both interpersonal and workplace communication. The course prepares students to confidently handle presentations, interviews, team communication, and the creation of structured technical documents while fostering ethical and culturally sensitive communication practices.

Course Learning Outcomes:

Upon successful completion of this course, students will:

1. Explain key principles of verbal, non-verbal, written, and digital communication and their role in academic and workplace contexts.
2. Apply effective communication techniques to produce clear, structured, and professional documents such as emails, reports, summaries, proposals, and résumés.
3. Analyze interpersonal and workplace communication situations, including interviews, presentations, group discussions, and team interactions, for clarity, intent, and effectiveness.
4. Evaluate communication practices—such as media texts, presentations, and written

documents—using criteria of coherence, accuracy, tone, ethics, and audience appropriateness.

5. Create persuasive and professional oral and written communication outputs, including presentations, structured arguments, and workplace documents that demonstrate confidence, clarity, and ethical awareness.

Syllabus:

Unit I: Foundations & Interpersonal Communication (8 hours)

Nature, scope, and process of communication; verbal, non-verbal, digital, and intercultural communication; major communication barriers and strategies to overcome them; essential listening and reading skills including comprehension, summarizing, inference, and note-making; fundamentals of oral presentations with focus on structure, tone, clarity, and audience awareness; storytelling for impact; professional spoken communication including interviews (technical and HR), group discussions, debates, conflict resolution, and teamwork in diverse workplaces.

Unit II: Written & Professional Communication (7 hours)

Principles of technical and academic writing; professional emails, notices, memos, minutes, and digital communication etiquette; summaries, analytical writing, and structured document development; informational and analytical reports, proposals, and basic project documentation; survey and questionnaire design; preparation of CVs, résumés, and Statements of Purpose; writing for media such as feature articles and press releases; ethical and leadership-oriented communication including bias, representation, and responsible messaging.

Readings:

1. Adler, R. B. & Proctor, R. F. (2013). Interplay: The process of interpersonal communication (16th ed.). Oxford University Press.
2. Bovee, C. L., & Thill, J. V. (2017). Business communication today (14th ed.). Pearson.
3. Raman, M., & Sharma, S. (2015). Technical communication: Principles and practice (3rd ed.). Oxford University Press.
4. McCarthy, P., & Hatcher, C. (2020). Presentation skills for students (4th ed.). Sage.

Tutorials

Case Study 1 (2 Hours) – Communication Breakdown in a Technical Interview

- Students analyse excerpts from technical and HR interview transcripts to identify unclear responses, weak articulation, and gaps in technical explanation. They rewrite improved responses and conduct a short mock interview.

Case Study 2 (2 Hours) – Miscommunication in a Multicultural Software Team

- A scenario involving an international development team shows misinterpreted emails, tone issues, and unclear task delegation. Students diagnose communication barriers and propose culturally sensitive revisions to improve clarity.

Case Study 3 (2 Hours) – Non-Verbal and Digital Cues in Remote Meetings

- Learners study a recorded or scripted virtual meeting with poor camera presence, weak tone, poor turn-taking, and digital distractions. They identify ineffective non-verbal cues and redesign the meeting communication plan.

Case Study 4 (2 Hours) – Analytical Summary from Technical Content

- Using a short technical document (e.g., system logs, analytics data, research abstract), students prepare a concise summary and inference-based note-making sheet demonstrating clarity and coherence.

Case Study 5 (2 Hours) – Workplace Document Reconstruction

- Students examine flawed workplace documents, such as emails, memos, notices, and meeting minutes, and correct issues related to tone, structure, coherence, ambiguity, and professionalism. Tasks include rewriting documents using standard templates.

Case Study 6 (2 Hours) – Report and Proposal Writing for a Mini Project

- A scenario on a small technical project (e.g., improving app usability) is provided. Students prepare a short informational or analytical report, including problem definition, findings, and a proposal section with recommendations.

Case Study 7 (2 Hours) – Résumé, SOP, and Job Role Alignment

- Students are given a job description and three sample résumés/SOPs. They analyse alignment, coherence, and tone; then rewrite a résumé/SOP tailored for the role while maintaining ethical communication practices.

Case Study 8 (1 Hour) – Media Bias and Ethical Communication

- Students examine two short news/tech-media snippets on the same topic (AI, cybersecurity, data privacy). They identify bias, tone shifts, and misrepresentation and suggest an ethically balanced rewrite.

List of DSEs for Semester IV

DSE401: Computer Graphics [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE401	**4**	**3**	**0**	**1**	Graduation	**NIL**

Course Objectives:

The course is designed to introduce students to the basic concepts and theory of computer graphics. The aim is to introduce students regarding various object rendering algorithms, projections, and latest concepts related to virtual reality.

Course Learning Outcomes:

On completing this course, the student will be able to:

1. acquire familiarity with the concepts and relevant mathematics of computer graphics.
2. ability to implement various algorithms to scan, convert the basic geometrical primitives, transformations, area filling, clipping.
3. describe the importance of viewing and projections.
4. ability to design basic graphics application programs.
5. familiarize with fundamentals of animation and virtual reality technologies.
6. be able to design applications that display graphic images to given specifications.

Syllabus:

UNIT I **(10 hours)**

Application Areas of Computer Graphics: Overview of graphics systems and devices; points and lines, line drawing algorithms, mid-point circle and ellipse algorithms; filled area primitives, polygon filling algorithms; curve generation: Bezier and B-Spline Curves.

UNIT II **(11 hours)**

2-D Geometrical Transforms: Translation, scaling, rotation, reflection and shear transformations composite transforms, transformations between coordinate systems; 2-D Viewing: viewing pipeline, viewing coordinate reference frame, window to viewport coordinate transformation, viewing functions, Homogeneous coordinates and matrix representation; Line Clipping Algorithms: Cohen-Sutherland and Cyrus Beck Line Clipping Algorithms, Sutherland–Hodgeman polygon clipping algorithm; 3-D object representation: polygon surfaces, quadric surfaces, spline representation.

UNIT III **(13 hours)**

3-D Geometric Transformations: Translation, rotation, scaling, reflection and shear transformations, composite transformations, 3-D viewing: viewing pipeline, viewing coordinates, view volume, general projection transforms and clipping; Visible Surface; Detection Methods: Classification, back-face detection, depth-buffer; scanline, depth sorting, BSP-tree methods, area sub-division and octree methods illumination models and surface rendering methods: basic illumination models, polygon rendering methods computer animation: design of animation sequence, general computer animation functions key frame animation, animation sequence, motion control methods, morphing, mesh warping.

UNIT IV **(11 hours)**

Virtual Reality: Basic concepts, classical components of VR system, types of VR systems, three-dimensional position trackers, navigation and manipulation interfaces, gesture interfaces. input devices, graphical rendering pipeline, haptic rendering pipeline, OpenGI rendering pipeline; applications of virtual reality.

Readings:

1. Donald Hearn, Pauline Baker, Warren Carithers, Computer Graphics with Open GL, Pearson, 4th Edition, 2011.
2. R. K Maurya, Computer Graphics with Virtual Reality Systems, Wiley, 3rd Edition, 2018
3. P. Shirley, M. Ashikhmin and S. Marschner, Fundamentals of Computer Graphics, 3rd Edition, CRC Press, 2009.

List of practical:

You may choose a suitable programming language and define all necessary/relevant inputs/ problems.

1. Write a program to draw basic geometric shapes: lines, circles, rectangles, and ellipses. (**2 hours**)

2. Write a program to generate ellipses using the Midpoint method. (**2 hours**)

3. Write a program to implement the polygon filling using Flood-fill, Boundary-fill and Scan-line algorithms. (**4 hours**)

4. Write a program for the Polygon Clipping using the Sutherland-Hodgeman algorithm. (**2 hours**)

5. Write a program to implement Curve generation using B-spline and Bezier curves. (**2 hours**)

6. Write a menu-driven program of 2D transformation: Translation, Scaling, Rotation, Mirror Reflection, Shearing, and Window-Viewport. (**4 hours**)

7. Write a program to implement Line Clipping using the Cohen-Sutherland algorithm and the Bisection Method. (**2 hours**)

8. Write a program to implement the 3D geometric transformations: Translation, Scaling and rotation. (**2 hours**)

9. Write a program to create 3D Scenes and 3D Projections. (**2 hours**)

10. Write a program to implement texture mapping on a 3D model, and observe the changes in the rendered output. (**4 hours**)

11. Write a program to animate a fish, or write a program to create an interactive animation using any authoring tool. (**2 hours**)

12. Write a program to implement the Back face removal algorithms using the Depth-Buffer algorithm and the Scan-line algorithm. (**2 hours**)

DSE402: Compiler Design [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE402	**4**	**3**	**0**	**1**	Graduation	**NIL**

Course Learning Objectives

The basic objective of this course is to understand the basic principles of compiler design, its various constituent parts, algorithms, and data structures required to be used in the compiler. It also aims to understand the use of basic compiler-building tools.

Course Learning Outcomes

On successful completion of the course, the students will be able to:

1. Describe the concepts and different phases of compilation.
2. Represent language tokens using regular expressions and context free grammars.
3. Describe the working of lexical analyzers.
4. Understand the working of different types of parsers and parse a particular string.
5. Describe intermediate code representations using syntax trees and DAG's as well as use this knowledge to generate intermediate code in the form of three address code representations.
6. Apply optimization techniques to intermediate code and generate machine code for high level language program.
7. Use Lex and Yacc automated compiler generation tools.

Syllabus

Unit I: (10 Hours)

Introduction to Compilation and Lexical Analysis: Phases of a compiler, Role of a lexical analyzer, Specification and recognition of tokens, Symbol table management, Error reporting and recovery in lexical analysis, Regular expressions and regular definitions, Lexical Analyzer Generator – *Lex*

Unit II: (15 Hours)

Syntax Analysis (Parsing Techniques) Context-Free Grammars (CFGs), Elimination of left recursion and left factoring, Top-down parsing techniques – Recursive Descent and LL Parsers, Bottom-up parsing techniques –, Shift-Reduce, LR Parsers (SLR, Canonical LR, LALR), Yet Another Compiler Compiler (YACC)

Unit III: (12 Hours)

Syntax-Directed Translation and Intermediate Code Generation: Syntax Directed Definitions (SDDs), Evaluation orders for SDDs (S-attributed, L-attributed definitions),

Intermediate representations – Syntax Trees and Three-Address Code (TAC), Types and declarations, Translation of expressions, control flow statements (loops, conditionals), Type checking

Unit IV: (8 Hours)

Runtime Environment, Code Generation, and Optimization: Storage organization and runtime environment, Activation records and stack allocation, Issues in code generation, Design of a simple code generator, Principal sources of optimization, peephole optimisation techniques

Readings

1. Alfred, V. A., Monica, S. L., & Jeffrey, D. U. *Compilers principles, techniques & tools*. Pearson Education, 2007
2. Chattopadhyay, S.. Compiler design. PHI Learning Pvt. Ltd, 2022

List of Practicals:

1. Write a Lex program to count the number of tabs, spaces and punctuation characters in an input file. **(2 hours)**
2. Write a Lex program to count the number of uppercase, lowercase and numeric characters separately. **(2 hours)**
3. Write a Lex program that implements a Vigenère cipher (given a short key); encrypt the input text and print the cipher text. **(2 hours)**
4. Write a Lex program to find and print the top 5 longest identifiers in a source file (identifiers = letters followed by letters/digits/underscores). **(2 hours)**
5. Write a Lex program that extracts all string literals (delimited by double quotes) from a source file and prints them with their line numbers. **(2 hours)**
6. Write a Lex program to count all multi-line comments (`/* ... */`) and single-line comments starting with `//` in a C file. **(2 hours)**
7. Write a YACC program to parse arithmetic expressions with `+ - * / ^` and parentheses. **(2 hours)**
8. Write a YACC program to accept conditional statements of the form `if (E) S else S` and translate them into simple three-address code (TAC) with labels and gotos. **(4 hours)**
9. Write a YACC program that recognises strings of the form `a^n b^n c^n (n≥1)` and accepts/rejects them. **(4 hours)**
10. Write a YACC program that parses simple `for` loops `for (init; cond; incr) stmt` and produces TAC for loop entry, body and exit. **(4 hours)**
11. Write a program (C++/Python) that constructs a DFA for identifiers and tests a list of input strings, printing accept/reject. **(4 hours)**

DSE403: Cloud Computing [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE403	**4**	**3**	**0**	**1**	Graduation	**NIL**

Course Objectives:

This course aims to equip the students with parallel and distributed computing and cloud computing concepts. Students will learn about cloud computing's characteristics, benefits, and historical developments. They will learn cloud computing architecture, service models (IaaS, PaaS, SaaS), deployment models, and emerging paradigms like edge computing and mobile cloud computing.

Course Learning Outcomes :

Upon successful completion of this course, a student will be able to:

1. describe cloud computing's characteristics, benefits, and historical developments, including distributed systems and virtualisation.
2. compare and contrast cloud computing architectures, service models, and deployment models.
3. analyze cloud economics, address open challenges.
4. discuss emerging paradigms like edge computing and mobile cloud computing
5. develop a cloud comping application.

Syllabus:

Unit-I **(11 hours)**

Introduction: Introduction to parallel and distributed computing; cloud computing: characteristics and benefits; historical developments and evolution of cloud computing: distributed systems, virtualization, Web 2.0, service-oriented computing, utility computing.

Unit-II **(11 hours)**

Virtualization: Cloud computing reference model, characteristics of virtualized environments, taxonomy of virtualization techniques, virtualization and cloud computing, pros and cons of virtualization; technology examples: Xen: paravirtualization; VMware: full virtualization, Microsoft Hyper-V.

Unit-III **(12 hours)**

Cloud Computing Architecture and Service models: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), Software as a Service (SaaS); Deployment models: Public, Private, Hybrid, Community; IaaS: Introduction to IaaS, Resource Virtualization i.e. Server, Storage and Network virtualization; PaaS: Introduction to PaaS, Cloud platform & Management of Computation and Storage; SaaS: Introduction to SaaS, Cloud Services, Web services, Web 2.0, Web OS; Case studies related to IaaS, PaaS and SaaS, Economics of the cloud.

Unit-IV **(11 hours)**

Current Topics: Open Challenges in Cloud Computing; Introduction to emerging computing paradigms and research challenges: edge computing, mobile cloud computing, fog computing,

etc.; Introduction to IoT cloud; study on simulators related to cloud computing and emerging computing paradigms.

Readings:

1. Buyya, R., Vecchiola, C., & Thamarai Selvi, S. *Mastering cloud computing*. McGraw Hill, 2013.
2. Sosinsky, B. *Cloud computing bible*. Wiley, 2010.
3. Hwang, K., Fox, G. C., & Dongarra, J. *Distributed and cloud computing: From parallel processing to the Internet of Things*. Morgan Kaufmann, 2011.

List of Practicals:

1. Exploring Distributed Systems : Install and run a simple distributed framework (e.g., Hadoop single-node) to understand parallelism. **(2 hours)**
2. Cloud Characteristics Demo : Use AWS/GCP free tier to demonstrate elasticity, scalability, and pay-per-use features. **(2 hours)**
3. Web 2.0 & Service-Oriented Computing : Build a basic REST API and consume it with a web client to show service orientation. **(2 hours)**
4. Utility Computing Case Study : Analyze Google Workspace or Microsoft 365 as examples of utility computing and document benefits. **(2 hours)**
5. Virtual Machine Setup : Install VMware/VirtualBox and configure a Linux VM to demonstrate virtualization basics. **(2 hours)**
6. Paravirtualization with Xen : Install Xen and run a guest OS to explore paravirtualization concepts. **(2 hours)**
7. Hyper-V Demo : Configure Microsoft Hyper-V on Windows and create a virtual machine. **(2 hours)**
8. Virtualization Comparison : Benchmark performance differences between VMware, Xen, and Hyper-V using sample workloads. **(2 hours)**
9. IaaS Hands-On : Launch and manage a virtual server instance on AWS EC2 or Azure VM. **(2 hours)**
10. Storage Virtualization : Configure cloud storage (AWS S3, Google Cloud Storage) and test access control. **(2 hours)**
11. PaaS Deployment : Deploy a sample web app using Heroku or Google App Engine. **(2 hours)**
12. SaaS Exploration : Evaluate SaaS applications (Salesforce, Google Docs) and document features. **(2 hours)**
13. Deployment Models Case Study : Compare public, private, and hybrid cloud setups using OpenStack vs AWS. **(2 hours)**
14. Edge/Fog Computing Simulation : Use iFogSim/CloudSim to simulate fog computing scenarios. **(2 hours)**
15. IoT Cloud Integration : Connect an IoT device (Raspberry Pi/Arduino sensor) to AWS IoT Core or Google IoT Cloud and visualize data. **(2 hours)**

DSE404: Theory of Computation [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE404	**4**	**3**	**0**	**1**	Graduation	**NIL**

Course Learning Objectives

The course introduces the theoretical models of computation and their limitations. The students will develop skills to analyze automata and their computational power to recognize languages. The students will learn to apply the knowledge of Automata Theory, Grammar, and Turing machines to solving problems in language translation.

Course Learning Outcomes

On completion of this course, the student will be able to:

1. describe the mathematical models of machines and discuss their limitations.
2. prove equivalence of different computation models equivalent to Turing machines.
3. reason out why the computers cannot solve some apparently simple tasks, for example the Halting problem.
4. design and implement a parser for a context-free grammar. .

Syllabus

Unit I: Foundations of Formal Languages and Automata (10 Hours)

Introduction to formal languages, Alphabets, strings, and languages, Operations on strings and languages, Deterministic and Non-deterministic Finite Automata (DFA, NFA), Regular expressions and equivalence with finite automata

Unit-II Regular Languages and Their Properties (10 Hours)

Regular languages and their properties, Closure properties of regular languages, Pumping Lemma for regular languages, Decision properties of regular languages, Applications of finite automata

Unit-III Context-Free Grammars and Pushdown Automata (13 Hours)

Context-Free Grammars (CFG), Parse trees and derivations, Ambiguity in grammars and languages, Pushdown Automata (PDA): deterministic and non-deterministic, Equivalence of CFGs and PDAs, Properties of Context-Free Languages (CFLs): normal forms, pumping lemma, closure, and decision properties

Unit-IV Turing Machines and Undecidability (12 Hours)

Turing Machines: definition, construction, and programming, Variants of Turing Machines and their equivalence, Recursive and recursively enumerable languages, Undecidable problem: Halting Problem

Readings:

1. J. E. Hopcroft, R. Motwani, and J. D. Ullman, **Introduction to Automata Theory,**

languages, and computation, 2016.
2. H.R. Lewis, C.H. Papadimitriou, C. Papadimitriou, **Elements of the Theory of Computation** (2nd ed.), Pearson Education, 2015
3. P. Linz, **Introduction to Automata Theory, Languages, and Computation**, Jones & Bartlett, 2016.

List of Practicals:

1. Write a program to simulate operations on strings and languages (concatenation, reversal, substring, prefix, suffix). **(2 Hours)**
2. Construct a DFA for a given regular language and test string acceptance using simulation (e.g., JFLAP or Python). **(2 Hours)**
3. Construct an NFA for a given regular language and convert it into an equivalent DFA.
4. Design a regular expression for a given language and verify its equivalence with a finite automaton using a simulator. **(2 Hours)**
5. Implement a program to minimize a DFA using the state equivalence method. **(2 Hours)**
6. Demonstrate closure properties of regular languages (union, concatenation, Kleene star) using examples and simulation. **(2 Hours)**
7. Apply the Pumping Lemma to prove that a given language is not regular (manual exercise + verification). **(2 Hours)**
8. Design and simulate a lexical analyzer using regular expressions (Lex/PLY/Python regex). **(2 Hours)**
9. Construct a Context-Free Grammar (CFG) for a given language and generate its parse tree. **(2 Hours)**
10. Show ambiguity in a grammar by deriving multiple parse trees for the same string. **(2 Hours)**
11. Design a Pushdown Automaton (PDA) to accept strings belonging to a simple context-free language (e.g., balanced parentheses). **(2 Hours)**
12. Convert a CFG to an equivalent PDA and verify acceptance using simulation (e.g., JFLAP). **(2 Hours)**
13. Construct a Turing Machine (TM) to perform a simple computation (e.g., binary increment, palindrome checking). **(2 Hours)**
14. Design and simulate a two-tape or multi-track Turing Machine and verify its equivalence to a single-tape TM. **(4 Hours)**

DSE405: Wireless and Mobile Communications [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE405	**4**	**3**	**0**	**1**	Graduation	**NIL**

Course Objectives:

This course aims to provide a comprehensive understanding of wireless communication principles, including propagation mechanisms, fading effects, and multiple access techniques. It explores IEEE 802.11 WLANs and cellular communication concepts such as frequency reuse, handoff strategies, and interference management. It provides insights into ad-hoc and sensor networks, regulatory aspects, and network design challenges, preparing students to apply these concepts in real-world scenarios and emerging wireless technologies.

Course Learning Outcomes:

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

1. analyze and simulate wireless communication scenarios to observe propagation effects, fading impacts, and the performance of multiple access techniques.
2. understand and evaluate cellular network design by analyzing frequency reuse, handoff strategies, interference management, and capacity enhancement techniques
3. compare GSM, CDMA, LTE, WiFi, and WiMAX while understanding regulatory and spectrum management
4. analyze the architecture and key factors influencing the deployment of wireless sensor networks (WSNs) and vehicular ad-hoc networks (VANETs)

Syllabus:

Unit-I **(10 hours)**

Introduction: Wireless communication systems, history and evolution (1G to 5G and beyond), Radio wave propagation mechanisms (reflection, diffraction, scattering), large-scale path loss models, small-scale fading and multipath propagation, doppler effect and delay spread, spread spectrum techniques, multiple access and duplexing techniques

Unit-II **(10 hours)**

Cellular mobile communication: frequency re-use and channel assignment strategies, handoff strategies, types, priorities, practical considerations, interference and system capacity, co-channel and adjacent channel interference, power control measures, grade of service, definition, standards, coverage and capacity enhancement in cellular network, cell splitting, sectoring, microcells

Unit-III **(10 hours)**

Wireless systems and standards: Global System for Mobile (GSM) - services and features, system architecture, radio sub-system, channel types (traffic and control), frame structure, signal processing, CDMA standards-frequency and channel specifications, Forward and Reverse CDMA channels, WiFi, WiMAX, UMB, UMTS, LTE, and recent trends, Regulatory issues (spectrum allocation, spectrum pricing, licensing, tariff regulation and interconnection issues)

Unit-IV **(15 hours)**

IEEE 802.11(Wireless LAN) Standards: IEEE 802.11 standards overview (802.11a/b/g/n), physical layer, medium access control layer-CSMA/CA mechanism, RTS/CTS mechanism for collision avoidance, hidden node and exposed node problems, QoS enhancements in IEEE 802.11, future trends in IEEE 802.11, IEEE 802.11 and IEEE 802.3 (Ethernet) interoperability, IEEE 802.11 in cellular networks (5G and Wi-Fi Offloading); Ad-hoc networks and sensor networks: introduction, challenges and issues, AODV, DSR, DSDV routing protocols; architecture and factors influencing the sensor network design; concept of MANET and VANET

Readings:

1. Rappaport, Theodore S. *Wireless communications: principles and practice*. Cambridge University Press, 2024.
2. Murthy, C. Siva Ram, and B. S. Manoj. *Ad hoc wireless networks: Architectures and protocols*. Pearson education, 2008.
3. Stallings, William. *Wireless communications & networks*. Pearson Education India, 2009.
4. Goldsmith, Andrea. *Wireless communications*. Cambridge university press, 2013.
5. Garg, Vijay. *Wireless communications & networking*. Elsevier, 2010.
6. Carlos,M.d. and Agrawal, D P. *Ad Hoc and Sensor Networks: Theory and Applications*, World scientific publishing company, 2011.

List of Practical's

1. Write a program to: **(4 hours)**
   a) determine the free-space path loss and the power received.
   b) endorse the statement: "Free Space Attenuation increases by 6 dB whenever the length of the path is doubled. Similarly, as frequency is doubled, free space attenuation also increases by 6 dB".
   c) plot a chart between PL (dB) and distance (Km) with varying frequencies.

2. Write a program to: **(4 hours)**
   (a) determine the two-ray path loss and the power received.
   (b) Endorse the statement: "The total attenuation increases by 12 dB when the separation distance is doubled" in the two-ray model.
   (c) plot a chart between PL(dB) and distance (Km) with varying frequencies for the two ray path loss model.
   (d) Further, plot a chart between PL(dB) and distance (Km) comparing the free space path loss model and two-ray model with varying frequencies.

3. Write a program to generate a PN (Pseudo-Noise) sequence using a Linear Feedback Shift Register (LFSR). **(2 hours)**

4. Write a program to: **(4 hours)**

a) Calculate the received power at a distance d using a log-normal shadowing model for both indoor and outdoor environments.
b) plot a graph for Log normal shadowing model between distance and path loss/received power
    i. varying path loss exponent
    ii. varying standard deviation of shadowing parameters.
c) Compare friss-space path loss model and log normal shadowing model

5. Implement a function to create a hexagonal grid with a specified cluster size and cell size. Visualise the hexagonal grid using matplotlib. **(2 hours)**

6. Simulate a cellular network with a given number of base stations (BS) and mobile users randomly distributed in the hexagonal cells. Assign frequencies to each base station. Implement a function to calculate the signal strength at each mobile user's location based on the distance from the serving base station. Consider the free space path loss model for signal propagation. **(4 hours)**

(a)Plot a heatmap or contour plot of signal strength across the cellular network.

(b) Observe how signal strength varies within and between cells.

7. Capture WiFiTraffic on your device using the tool Wireshark. Analyse the interframe gaps for DIFS, SIFS and EIFS. Further, for each data frame, identify the corresponding ACK frame. Check whether the ACK frame is immediately following the data frame and has the SIFS timing gap. If not, determine if there is any delay and discuss possible reasons. **(2 hours)**

8. Write a Python script to simulate cell splitting. Divide some existing cells into smaller cells to demonstrate how this process increases system capacity. **(2 hours)**

9. Simulate a wireless network with three nodes (A, B, C) where A and C are hidden terminals. Implement the RTS/CTS protocol to prevent collisions at B when both A and C attempt to send data simultaneously. **(4 hours)**

10. Capture Wi-Fi frames using Wireshark on your machine's Wi-Fi interface and observe basic WLAN information. Filter for beacon frames and identify the BSSID and SSID, then find and analyze at least one Data frame and one ACK frame. Note the packet's source and destination MAC addresses. **(2 hours)**

DSE406: Advance Classification Methods [3-0-1]

Course Code	Credits	Credit distribution of the course		Pre-requisite of the course (if any)

		Lecture	Tutorial	Practical/Practice	Eligibility Criteria	
DSE406	**4**	**3**	**0**	**1**	Graduation	**Basic understanding of machine learning concepts, and familiarity with Python programming.**

Course Objectives

By the end of this course, students will be able to apply various classification techniques and evaluate model performance using appropriate metrics. They will also gain expertise in advanced topics such as ensemble learning, semi-supervised and self-supervised methods, zero-shot and few-shot learning, and improving model robustness against adversarial attacks.

Course Outcomes

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

1. explain the fundamental and advanced classification techniques.
2. apply various binary, multi-class, and multi-label classification methods.
3. analyze and compare classification models using appropriate evaluation metrics.
4. design and optimize classification models for real-world applications.

Syllabus

Unit-I **(16 Hours)**

Review of classification problems and algorithms, Evaluation metrics, Handling imbalanced data, Cross-validation, and Model selection. Ensemble learning for classification: Weak learners and Strong learners, Model creation, Model combination; Bagging and Boosting; Random Forest; Combination Strategies, Meta-learning; Diversity in ensemble; Ensemble pruning.

Unit-II **(12 hours)**

Multi-class classification problem; Aggregation-based approach: One-versus-all, One-versus-one, Directed Acyclic Graph approach, Tree-based approach, Error-correcting output codes; multi-class SVMs; Class Imbalance in Multi-class Settings.

Unit-III **(12 hours)**

Multi-label Classification, Problem Transformation approach: Binary Relevance, Classifier Chains, Label Powerset, Algorithm Adaptation Methods; Neural Network Approaches for Multi-label Classification, Evaluation metrics for multi-label classification.

Unit-IV **(5 hours)**

Semi-supervised and Self-supervised Classification Methods, Zero-shot and Few-shot Learning, Adversarial Attacks and Robustness in Classification,

Readings

1. Zhou, Zhi-Hua. *Machine learning*. Springer nature, 2021.

2. Mohri, Mehryar, A. Rostamizadeh, and A. Talwalkar. Foundations of machine learning. The MIT Press. 2012
3. Charte, Francisco, Antonio J. Rivera, and María J. Del Jesus. *Multilabel classification: problem analysis, metrics and techniques*. Springer International Publishing, 2016.
4. Ian Goodfellow, Bengio, Yoshua, and Aaron Courville. *Deep learning*. MIT press, 2017.
5. Research papers on emerging classification techniques.

List of Practical's:

1. Implement basic classification models such as Logistic Regression, Decision Trees and SVM on benchmark datasets. Evaluate the performance of these classifiers using metrics such as accuracy, precision, recall, F1-score, ROC-AUC, and confusion matrix. Perform k-fold cross-validation and interpret the results. **(2 hours)**
2. Use a dataset with imbalanced classes and then apply techniques like SMOTE, random oversampling/under sampling, and evaluate their impact on model performance using appropriate metrics like precision-recall and balanced accuracy. **(4 hours)**
3. Implement ensemble models, including Random Forest (bagging) and AdaBoost/Gradient Boosting (boosting), using scikit-learn or XGBoost. Compare performance, analyse feature importance, and visualise ensemble effects**. (4 hours)**
4. Create a diverse ensemble of traditional machine learning classifiers such as Logistic Regression, SVM and Decision Tree using stacking or voting. Analyze diversity among models and perform ensemble pruning based on accuracy or diversity criteria. **(4 hours)**
5. Use multi-class datasets and implement one-vs-all and one-vs-one strategies. Train binary classifiers accordingly and compare both strategies in terms of performance and scalability. **(2 hours)**
6. Implement multi-class classification using tree-based methods and error-correcting output codes (ECOC). Evaluate performance and interpret how each approach handles class boundaries. **(4 hours)**
7. Train and evaluate multi-class SVMs using one-vs-all or one-vs-one schemes. Use imbalanced versions of multi-class datasets to analyze the effect of class imbalance and apply weighted loss or resampling. (**2 hours)**
8. Implement multi-label classification approaches such as Binary Relevance, Classifier Chains, and Label Powerset using scikit-multilearn or similar libraries. Compare performance using hamming loss, precision, recall, and subset accuracy**. (4 hours)**
9. Build a neural network using PyTorch or similarly libraries for multi-label classification with appropriate activation function. Train the model on a multi-label dataset and evaluate using multi-label metrics. (**2 hours)**
10. Explore few-shot classification using pre-trained models and implement semi-supervised learning on a partially labelled dataset to improve performance with limited annotations. **(2 hours)**

DSE407: Incident Response and Threat Hunting [3-0-1]

Course In Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical /Practice		
DSE407	**4**	**3**	**0**	**1**	**Graduation**	**NIL**

Course Objectives:

This course enables students to understand the modern cyber threat landscape and the principles of risk management. Students will learn to apply industry-standard frameworks, such as MITRE ATT&CK and NIST, to execute proactive, hypothesis-driven threat hunts.Students will also master the complete incident response lifecycle, from initial triage and containment to final eradication and recovery.

Course Learning Outcome

Upon successful completion of this course, students will be able to:

1. Analyse cyber threats, assess organisational risk, and apply conceptual frameworks (e.g., Cyber Kill Chain, MITRE ATT&CK, Pyramid of Pain) to deconstruct adversary TTPs.
2. Formulate and execute proactive, hypothesis-driven threat hunts by analysing endpoint (EDR), network (traffic), and authentication (Event Log) data.
3. Apply the complete NIST Incident Response lifecycle, including the triage of security events, selection of containment strategies, and execution of eradication and recovery plans.
4. Conduct post-incident reviews to identify lessons learned and integrate findings into a continuous monitoring strategy aligned with the NIST Cybersecurity Framework (CSF).

Syllabus:

Unit I: (8 hours)

Introduction to Threat Hunting and Risk Management: Threat landscape, attacker motivation, common attack methods, anatomy of an attack, indicators of compromise (IoC) and indicators of attack (IoA), understanding Advanced Persistent Threats (APT) and Tactics, Techniques and Procedures (TTP), relationship between vulnerabilities, threats and risk, measuring risk severity and risk assessment

Unit II: (10 hours)

Frameworks for analysis: The pyramid of pain, Cyber Kill Chain, diamond model of intrusion detection, MITRE ATT&CK for Mapping TTP, selection of the right model

Unit III (14 hours)

Proactive threat hunting: Shifting from reactive to proactive hunting, Alert-driven vs Hypothesis-driven analysis, Threat Hunting methodologies: Investigation based on known indicators of compromise or Indicators of Attack (IoA), Hypothesis-driven hunting, Anomaly-based/Statistical hunting, Reference models for Hunting: Sqrrl, TaHiti, PEAK, F3EAD, Data-driven hunting: Endpoint Detection and Response(EDR), Event log analysis: understanding event logs, account-related logs, auditing system configuration changes, Lateral Movement Analysis: Server message block, Kerberos attack, scheduled tasks, identification of security events

Unit IV **(13 hours)**

Incident Response and Recovery:introduction to NIST Incident Response Frameworks (NIST 800-61), building an incident response plan, SOC workflows, Triage fundamentals, event identification, escalation, Containment Fundamentals, Strategy Selection of Containment Eradication, Recovery and post-incident review: Removing the attacker's artefacts, vulnerability scanning, restoring systems via backup, Continuous monitoring strategy, incorporating continuous monitoring into the NIST CSF environment

References:

1. Anson, Steve,, *Applied Incident Response*, 2020 John Wiley & Sons, Inc.
2. Eric C. Thompson, *Cybersecurity Incident Response: How to contain, eradicate and recover from incidents*, 2018, Apress
3. Scott J. Roberts ; Rebekah Brown, *Intelligence Driven Incident Response: Outwitting the adversary*, O'Reilly Media Inc., 2017
4. The MITRE Corporation, MITRE ATT&CK framework, https://attack.mitre.org/

List of Practicals:

1. Choose one of the following APT groups: APT28 (often referred to as "Fancy Bear") and APT41 ("Wicked Panda" or "Double Dragon"). Compare these two prominent threat actors and make a document containing the details, such as group name, suspected country of origin, primary motivation, common targets, common TTPs and notable examples of their activities **(2 hours)**
2. Download Process Explorer and open Notepad through the command prompt. Take a screenshot of your Process Explorer. What does it show? How this technique is used to find malicious child processes **(2 hours)**
3. Install the SIEM (e.g. Splunk or Wazuh), Windows VM(Victim) and Kali Linux VM (Attacker). Run a simple command on the Windows VM and find the corresponding process creation event in the installed SIEM. Explore the SIEM interface. **(4 hours)**
4. Read any incident report. Identify the stages of the Cyber Kill Chain present in the report. Similarly, use the MITRE ATT&CK website to find the TTPs described in the report. Identify IoC from the report and place them on a diagram of the pyramid of pain. **(8 hours)**
5. A lab exercise based on the identification of lateral movement **(8 hours)**
6. A lab exercise based on the containment and eradication phase of the NIST IR lifecycle **(2 hours)**
7. A lab exercise based on restoring the system and improving defence. **(2 hours)**

Techniques of Report Writing [1-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
Skill	**2**	**1**	**0**	**1**	Graduation	**NIL**

Course Objectives:

The student learns professional-level report writing skills. Students will learn the structure, format, and style of various types of reports. They can also get proficiency in data interpretation, visual presentation, and documentation.

Course Learning Outcomes:

At the end of the course, the students will be able to:

1. Understand the principles of effective technical and professional writing.
2. Prepare different types of reports (informational, analytical, technical, project, research).
3. Use visual aids (charts, tables, figures) appropriately.
4. Edit and proofread for clarity and professionalism.
5. Prepare digital reports using modern tools (MS Word, LaTeX, Google Docs).

Syllabus:

Unit-I **(7 hours)**

Foundations: Purpose of reports, Types of reports, Structure of reports: Title page, abstract, TOC, introduction, body, conclusion, recommendations, references; Difference between essays, articles, and reports.

Writing Techniques and Style: Paragraph structure and flow, Writing effective introductions and conclusions, Use of numbered sections, headings, and subheadings, integrating quotes, paraphrasing, and citing sources, and avoiding plagiarism.

Unit-II **(8 hours)**

Data, and Visual Representation: Data interpretation and summarisation, Use of tables, graphs, charts, diagrams, incorporating figures and captions, Formatting tools: MS Word styles, templates, referencing tools; Basics of LaTeX for structured reports.

Editing and Proofreading: Editing techniques: macro-editing, micro-editing, Common writing errors (grammar, punctuation, redundancy, logical gaps), Readability improvement techniques, Peer review and collaborative editing, Use of digital tools: Grammarly, Google Docs comments.

Readings:

1. Pal, Rajendra & Korlahalli, J.S., *Essentials of Business Communication.*
2. Raman, Meenakshi & Sharma, Sangeeta, *Technical Communication.*
3. Lesikar, R.V. *Report Writing for Business*.
4. Pfeiffer, William S. *Technical Communication: A Practical Approach*.
5. Bailey, Stephen. *Academic Writing: A Handbook for International Students*.

List of practicals:

1. Prepare an outline for a technical or business report. **(2 hours)**
2. Draft a field visit / industrial visit report. **(2 hours)**
3. Write an analytical report using the provided data. **(2 hours)**

4. Design at least five charts using the data from lab exercise 3 and integrate them into a report. **(2 hours)**
5. Edit and proofread a report. **(2 hours)**
6. A lab exercise related to preparing a research/problem-solving report. **(2 hours)**
7. Create a report in LaTeX with sections, figures, and references. **(3 hours)**

MASTER OF COMPUTER SCIENCE PROGRAMME

2nd Year of 2 year M.Sc. (Computer Science) /1 year M.Sc. (Computer Science)

Postgraduate Curriculum Framework

under

NEP 2020

(w.e.f Academic Year 2026)

Department of Computer Science
Faculty of Mathematical Sciences
University of Delhi
Delhi-110007

MSc Computer Science Programme Details:

- **Affiliation**

  The proposed programme shall be governed by the Department of Computer Science, Faculty of Mathematical Sciences, University of Delhi, Delhi-110007.

- **Programme Structure and Objectives**

  The M.Sc. Computer Science programme is a four-semester program spanning two years. It has four structures - **MSc Computer Science with Coursework, MSc Computer Science with Coursework and Research, MSc Computer Science with Research and MSc Computer Science with Academic/Industry Project.** The first year (Semesters I and II) are common to all four structures. In the second year, the student can choose the structure he/she wishes to follow.

  To be eligible for the "Research" track, students must have studied **research methodology either in** the first year or in a UG program.

  The Programme objectives of the M. Sc Computer Science with coursework are to
  - Equip the students with comprehensive knowledge of the current trends in computer science.
  - Enable the students to follow the career path of their choice by choosing courses from a wide list of specialised courses with progression.
  - Prepare the students to take up a career in the highly competitive **IT industry with development skills.**

  The Programme objectives of M. Sc Computer Science with Coursework and Research are to
  - Equip the students with comprehensive knowledge of the current trends in computer science and **introduce them to computer science research.**
  - Enable the students to follow the career path of their choice by choosing courses from a wide list of specialised courses with progression.
  - Prepare the students to take up a career
    - in the highly competitive IT industry **with research/development skills**.
    - computer science research.

  The Programme objectives of M.Sc. Computer Science with Research are to
  - Equip the students with comprehensive knowledge of the current trends in **computer science research**.
  - Enable the students to follow the research path of their choice by choosing courses from a wide list of specialised courses with progression.
  - Prepare the students to take up a career in
    - the highly competitive IT industry **with research**
    - computer science research.

  The Programme objectives of M.Sc. Computer Science with Academic/Industry Project are to
  - Equip the students with comprehensive knowledge of the current trends in

computer science.
- Enable the students to follow the career path of their choice by choosing courses from a wide list of specialised courses with progression.
- Prepare the students to take up a career in the highly competitive **IT industry with development skills.**
- Provide students **with hands-on experience on large/live projects**, fostering practical skills and enabling them to prepare technical reports.

Project: In Structure 4, each student shall carry out a minor project in the third semester and a major project in the fourth semester of M.Sc. Computer Science program. The major project may be carried out in an external organisation (academic institution/industry). In such a case, a supervisor shall be appointed from the external organisation. The project will be carried out under the overall supervision of one or more (jointly) teachers of the department. The project work will be evaluated jointly by the internal supervisor and an examiner to be appointed by the department in consultation with the internal supervisor.

The project evaluation (minor/major) shall be as follows:

- Mid-semester evaluation: 25% weight
- End-semester evaluation
  - Dissertation: 35% weight
  - Viva-voce: 40% weight

Justification for Structure IV : Since the inception of the MSc program in 2004, it has had minor projects in Semester III and one full semester (Semester IV) devoted to hands-on projects (research/industry/academic). The format has led to a strong alumni base enjoying high positions and packages in the IT industry along with some opting for research careers in top schools of the country and abroad.. Our alumni in industry are currently placed in prestigious global companies like Apple, Facebook, Microsoft, Adobe, Paytm, Amazon to name a few. **The main attraction of our programs for the recruiters is its provision for full time fourth semester Industry Internship.** During this period, students learn by doing and get acquainted with the environment of their work place while still earning their degree. Companies get a trained workforce when the students finally join the job.

With the emphasis of skill development and experiential learning being one of the emphasis of NEP, we have introduced Structure 4 which is similar to Structure 3 except that the research component has been replaced with industry-relevant content in Semesters III and IV.

Semester III of 2year MSc/ Semester I of 1year MSc

Structure 1 Coursework

Semester III/I (Structure 1 Coursework)		
	Number of core courses	2

Course Code	Course Title	Credits in each core course			
		Theory	Tutorial	Practical	**Total**
DSC301	Optimization Methods	3	0	1	**4**
DSC302	Natural Language Processing	3	0	1	**4**
SBC 301	Prompt Engineering	0	0	2	**2**
	Total credits in core course				10
	Number of DSE/GE courses				3**
	DSE5	3	0	1	**4**
	DSE6	3	0	1	**4**
	DSE7/GE3	3	0	1	**4**
	Total credits in DSE/GE				12
	Total credits in Semester III				**22**

**** Select three DSEs or two DSEs and one GE**

Note: All DSEs are offered as GE, subject to the fulfilment of the prerequisites and the number of seats.

List of DSE for Semester III/I (Structure 1 Coursework)		
Course Code	**Course Title**	**L-T-P**
DSE301	Link Prediction	3-0-1
DSE302	Recommender System	3-0-1
DSE303	Time Series Data Analysis	3-0-1
DSE304	Quantum Computing and Applications	3-0-1
DSE305	Digital Forensics	3-0-1
DSE306	Human-Computer Interaction	3-0-1
DSE307	Influence Maximization	3-0-1
DSE308	Data Engineering	3-0-1

Semester IV of 2year MSc/Semester II of 1year MSc

Semester IV/II (Structure 1 Coursework)					
	Number of core courses				2
Course Code	**Course Title**	**Credits in each core course**			
		Theory	Tutorial	Practical	**Total**
DSC401	Reinforcement learning	3	0	1	**4**
DSC402	Computer Vision	3	0	1	**4**
SBC 401	Communication Skills	0	0	2	**2**
	Total credits in core course				10
	Number of DSE/GE courses				3**
	DSE8	3	0	1	**4**
	DSE9	3	0	1	**4**

	DSE10/GE4	3	0	1	**4**
	Total credits in DSE/GE				12
	Total credits in Semester IV				**22**

**** Select three DSEs or two DSEs and one GE**
Note: All DSEs are offered as GE, subject to the fulfilment of the prerequisites and the number of seats.

List of DSE for Semester IV/II (Structure 1 Coursework)		
Course Code	**Course Title**	**L-T-P**
DSE401	Edge Computing	3-0-1
DSE402	Mobile Application Development Technology	3-0-1
DSE403	Compiler Design	3-0-1
DSE404	Incident Response and Threat Hunting	3-0-1
DSE405	Systems Modeling and Simulation	3-0-1
DSE406	Graph Neural Networks	3-0-1
DSE407	Cryptography	3-0-1
DSE408	Computational Linguistics	3-0-1

Structure 2 Course Work and Research

Semester III/I (Structure 2 Coursework and Research)					
	Number of core courses				2
Course Code	**Course Title**	**Credits in each core course**			
		Theory	Tutorial	Practical	**Total**
DSC301	Optimization Methods	3	0	1	**4**
DSC302	Natural Language Processing	3	0	1	**4**
	Research-1	0	0	6	**6**
	Total credits in core course				14
	Number of DSE/GE courses				2*
	DSE5	3	0	1	**4**
	DSE6/GE3	3	0	1	**4**
	Total credits in DSE/GE				8
	Total credits in Semester III				**22**

**** Select two DSEs or one DSE and one GE**
Note: All DSEs are offered as GE, subject to the fulfilment of the prerequisites and the number of seats.

List of DSE for Semester III/I (Structure 2 Coursework and Research)

Course Code	Course Title	L-T-P
DSE301	Link Prediction	3-0-1
DSE302	Recommender Systems	3-0-1
DSE303	Time Series Data Analysis	3-0-1
DSE304	Quantum Computing and Applications	3-0-1
DSE305	Digital Forensics	3-0-1
DSE306	Human-Computer Interaction	3-0-1
DSE307	Influence Maximization	3-0-1
DSE308	Data Engineering	3-0-1

Semester IV/II (Structure 2 Coursework and Research)					
	Number of core courses	2			
Course Code	**Course Title**	**Credits in each core course**			
		Theory	Tutorial	Practical	**Total**
DSC401	Reinforcement learning	3	0	1	**4**
DSC402	Computer Vision	3	0	1	**4**
	Research-2	0	0	6	**6**
	Total credits in core course				14
	Number of DSE/GE courses				2*
	DSE7	3	0	1	**4**
	DSE8/GE4	3	0	1	**4**
	Total credits in DSE/GE				8
	Total credits in Semester IV				**22**

*** Select two DSEs or one DSE and one GE**
Note: All DSEs are offered as GE, subject to the fulfilment of the prerequisites and the number of seats.

List of DSEs for Semester IV/II (Structure 2 Coursework and Research)		
Course Code	**Course Title**	**L-T-P**
DSE401	Edge Computing	3-0-1
DSE402	Mobile Application Development Technology	3-0-1
DSE403	Compiler Design	3-0-1
DSE404	Incident Response and Threat Hunting	3-0-1
DSE405	Systems Modelling and Simulation	3-0-1
DSE406	Graph Neural Networks	3-0-1
DSE407	Cryptography	3-0-1
DSE408	Computational Linguistics	3-0-1

Structure 3 Research

Semester III/I (Structure 3 Research)					
	Number of core courses				1
Course Code	**Course Title**	**Credits in each core course**			
		Theory	Tutorial	Practical	**Total**
DSC301	Optimization Methods	3	0	1	**4**
	Advanced Research Methodology	1	0	1	**2**
SBC301	Tools for Research	2	0	0	**2**
	Research-1	0	0	10	**10**
	Total credits in core course				18
	Number of DSE courses				1
	DSE5	3	0	1	**4**
	Total credits in DSE				4
	Total credits in Semester III				**22**

List of DSE for Semester III/I (Structure 3 Research)		
Course Code	**Course Title**	**L-T-P**
DSE301	Link Prediction	3-0-1
DSE302	Recommender Systems	3-0-1
DSE303	Time Series Data Analysis	3-0-1
DSE304	Quantum Computing and Applications	3-0-1
DSE305	Digital Forensics	3-0-1
DSE306	Human-Computer Interaction	3-0-1
DSE307	Influence Maximization	3-0-1
DSE308	Data Engineering	3-0-1
DSE309	Natural Language Processing	3-0-1

Semester IV/II (Structure 3 Research)					
	Number of core courses				0
Course Code	**Course Title**	**Credits in each core course**			
		Theory	Tutorial	Practical	**Total**
	Techniques for Research Writing	1	0	1	**2**
	Research-2	0	0	16	**16**
	Total credits in core course				18
	Number of DSE courses				1

		Theory	Tutorial	Practical	**Total**
	DSE6	3	0	1	**4**
	Total credits in DSE				4
	Total credits in Semester IV				**22**

List of DSE for Semester IV/II (Structure 3 Research)		
Course Code	**Course Title**	**L-T-P**
DSE401	Edge Computing	3-0-1
DSE402	Mobile Application Development Technology	3-0-1
DSE403	Compiler Design	3-0-1
DSE404	Incident Response and Threat Hunting	3-0-1
DSE405	Systems Modelling and Simulation	3-0-1
DSE406	Graph Neural Networks	3-0-1
DSE407	Cryptography	3-0-1
DSE408	Computational Linguistics	3-0-1

Structure 4 - Academic/Industry Project

Semester III/I (Structure 4 Academic/Industry Project)					
	Number of core courses				1
Course Code	**Course Title**	**Credits in each core course**			
		Theory	Tutorial	Practical	**Total**
DSC301	Optimization Methods	3	0	1	**4**
	Web Development	0	0	2	**2**
SBC 301	Prompt Engineering	0	0	2	**2**
	Minor Project	0	0	10	**10**
	Total credits in core course				18
	Number of DSE courses				1
	DSE5	3	0	1	**4**
	Total credits in DSE				4
	Total credits in Semester III				**22**

Semester IV/II (Structure 4 Academic/Industry Project)					
	Number of core courses				0
Course Code	**Course Title**	**Credits in each core course**			
		Theory	Tutorial	Practical	**Total**

	Major Project	0	0	16	**16**
	Techniques of Report Writing*	0	0	2	**2**
	Total credits in core course				18
	Number of DSE courses				1
		Theory	Tutorial	Practical	**Total**
	DSE 6*	3	0	1	**4**
	Total credits in DSE				4
	Total credits in Semester IV				**22**

List of DSE for Semester IV/II (Structure 4 Academic/Industry Project)		
Course Code	**Course Title**	**L-T-P**
DSE401	Edge Computing	3-0-1
DSE402	Mobile Application Development Technology	3-0-1
DSE403	Compiler Design	3-0-1
DSE404	Incident Response and Threat Hunting	3-0-1
DSE405	Systems Modelling and Simulation	3-0-1
DSE406	Graph Neural Networks	3-0-1
DSE407	Cryptography	3-0-1
DSE408	Computational Linguistics	3-0-1

* Credits for the course may be earned by the students in Semester II/III

For **Structure 4 (**Academic/Industry Project**),** the following outcomes must be achieved by the end of the fourth semester in addition to the outcomes mentioned for Structure 1

i) Completion of experimentation/fieldwork or similar tasks.

ii) Submission of the project report.

SEMESTER - III

DSC301: Optimization Methods [3-0-1]

		Credit distribution of the course		

Course title & Code	Credits	Lecture	Tutorial	Practical/Practice	Eligibility Criteria	Pre-requisite of the course (if any)
DSC 301	**4**	**3**	**0**	**1**	**Graduation**	**NIL**

Course Objectives:

The course aims to impart comprehensive knowledge about operations research and optimization techniques. Its objectives are to help students understand the fundamental concepts of operations research, to discuss and analyze the need for various optimization techniques, to design and develop appropriate mathematical models, and to formulate and optimize real-world problems using these models.

Course Learning Outcomes:

On completing this course, the student will be able to:

1. Understand the operation research concepts
2. Analyse the need of optimisation techniques
3. Able to design and develop mathematical models for realm applications
4. Inculcate modeling skills necessary to describe and formulate optimization problems

UNIT-I: (10 Hours)

Introduction to the modelling approach of operation research, introduction to linear programming, formulating and solving linear programming models, graphical method, simplex methods. Transportation problems: mathematical formulation, balanced transportation problem, unbalanced transportation problem. assignment problem – mathematical formulation, Hungarian assignment method, travelling salesman problem.

Unit II (10 Hours)

Game theory: Formulation of two-person, zero-sum games and games with mixed strategies. Sequencing problems: processing of n jobs through 2 machines, processing of 2 jobs through m machines. Integer Programming: Gomory's method, branch and bound method. Network Scheduling: Basic terms, critical path methods (CPM), program evaluation and review technique (PERT).

Unit III (15 Hours)

Queuing Theory: Characteristics of queuing systems, Poisson process and exponential distribution, steady state M/M/1, M/M/C (Models I, II, IV, V), applications of queuing theory.

Inventory Control: Inventory Costs, economic order quantity, deterministic inventory problems, EOQ problems with no shortage, with shortage, production problem with no shortage, with shortage.

Unit IV **(10 Hours)**

Search methods: one dimensional minimisation methods, fibonacci and golden section methods. Non-linear programming: One dimensional minimization method: unconstrained optimization techniques, constrained optimization techniques, graphical solution, Kuhn-Tucker conditions, quadratic programming problems.

Readings:

1. Frederick S. Hillier, and Gerald J. Lieberman, *Introduction to Operations Research. McGraw-Hill, 2015.*
2. Hamdy A Taha, *Operations research: An introduction*. Pearson Education India, 2013.
3. S.S. Rao, *Engineering optimization: Theory and Practice*, New Age International, 3rd edition, 2013.
4. K. Deb, *Optimization for Engineering Design: Algorithms and Examples*, PHI, 2nd Edition, 2012.
5. J. S. Arora, *Introduction to Optimum Design,* Academic Press, 4th Edition, 2017.

List of Practicals:

1. Formulation and graphical solution of linear programming problems **(2 hours)**
2. Solving linear programming problems using simplex method **(2 hours)**
3. Transportation problems: balanced/unbalanced cases **(2 hours)**
4. Assignment problem: Hungarian method and travelling salesman problem **(2 hours)**
5. Game theory: solving two-person zero-sum games with pure and mixed strategies **(2 hours)**
6. Sequencing problems: n jobs through 2 machines, 2 jobs through m machines **(2 hours)**
7. Branch and bound method for integer programming **(2 hours)**
8. Network scheduling: CPM and PERT analysis **(2 hours)**
9. Queuing theory: simulation of M/M/1 queue with Poisson arrivals and exponential service **(2 hours)**
10. Analysis of M/M/C queues (Models I, II, IV, V) **(2 hours)**
11. Inventory control: EOQ problems with and without shortages **(2 hours)**
12. Replacement problems: deteriorating items, group vs individual replacement **(2 hours)**
13. Information theory: entropy, mutual information, uncertainty measures **(2 hours)**
14. Search methods: one-dimensional minimization using Fibonacci and golden section methods **(2 hours)**
15. Non-linear programming: unconstrained optimization techniques and graphical solutions **(2 hours)**

DSC302, DSE309: NATURAL LANGUAGE PROCESSING [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSC302 DSE309	**4**	**3**	**0**	**1**	**Graduation**	**Basic understanding of probability and statistics and familiarity with Python programming**

Course Objectives:

The course provides a rigorous introduction to the essential components of a Natural Language Processing (NLP) system. The students will learn various statistical, machine learning, and deep learning techniques in NLP and apply them to solve diverse language-related tasks.

Course Learning Outcomes:

On completing this course, the student will be able to:

1. Understand natural language basics, its structure, history, and levels of NLP analysis.
2. Convert raw text into numerical representations using preprocessing and vectorization techniques.
3. Build and apply language models, including n-gram, neural, and transformer-based models.
4. Use vector semantics and embeddings to represent and analyze word meaning.

Syllabus:

UNIT I **(10 Hours)**

Introduction: Definition and features of natural language, NLP needs and major applications areas, History of NLP, Turing test, Chinese room test, Chomsky grammar, IBM Georgetown experiment, ELIZA, Types of analysis involved: lexical, syntactic, semantic, discourse, and pragmatic.

Unit II **(10 Hours)**

Text-to-Vector: Need and role, Text preprocessing, Stemming, Lemmatization, Spelling variation, Edit distance, Character-level encoding, Word-level one-hot vectors, Bag-of-Words (BoW), Term Frequency (TF), Inverse Document Frequency (IDF), TF-IDF vectors, Application: Text-vector similarity, classification, clustering, retrieval, topic modelling.

Unit III: **(10 Hours)**

Language Modeling: Introduction to Language Models (LM), Predictive probability of word sequences, Types of LMs: statistical vs neural vs transformer-based, N-gram Language Models: Unigram, bigram, trigram models, Markov assumption, Maximum likelihood

estimation for n-grams, Language Model Evaluation, Perplexity, Smoothing, BackOff, Interpolation Techniques.

Unit IV: **(15 Hours)**

Vector Semantics: Introduction and motivation, Distributional hypothesis, Sparse vs dense vectors, Word-embeddings, Count-Based Models, TF-IDF, Pointwise Mutual Information (PMI), Positive PMI, Word Embeddings, word2vec, Continuous BoW, Skip-gram, Negative sampling, Global vector approach (GloVe), fastText, Vector arithmetic, Neural network based embeddings, Limitations of static embeddings, Contextual representations, Encoder-based LM vectors (BERT, RoBERTa), Decoder-based LM vectors (GPT), Sentence-level and token-level contextual embeddings.

Readings:

1. Jurafsky, D., & Martin, J. H. *Speech and language processing*. Pearson, 2000.
2. Eisenstein, J. *Introduction to natural language processing*. MIT Press, 2019.
3. Goldberg, Y. *Neural network methods in natural language processing*. Morgan & Claypool Publishers, 2017.
4. Brownlee, J. *Deep learning for natural language processing*. Machine Learning Mastery, 2017.

List of Practicals:

1. Use standard Python NLP libraries (such as NLTK and SpaCy) to perform fundamental text preprocessing operations, including tokenization, stemming, lemmatization, and stop-word removal.(**2 hours)**

2. Apply advanced text preprocessing techniques using regular expressions to handle tasks such as pattern matching, text removal, and substitution in practical real-world scenarios. (**2 hours)**

3. Transform textual data into Bag-of-Words (BoW) and other frequency-based vector representations, and implement classification algorithms such as logistic regression and Naïve Bayes to evaluate model performance. (**2 hours)**

4. Explore the principles of information retrieval by designing a query-based document retrieval system using vector representations of text. (**4 hours)**

5. Perform document clustering using text-vector representations and apply unsupervised learning methods such as K-means clustering and hierarchical clustering. (**4 hours)**

6. Implement and analyze basic statistical language models, including bigram and trigram models, for text generation and processing. (**4 hours)**

7. Enhance bigram, trigram, and 4-gram models by applying techniques such as smoothing, back-off, and interpolation to improve model accuracy and generalisation. (**4 hours)**

8. Develop a text classification system using vector semantics by training Word2Vec embeddings and evaluating their effectiveness in downstream classification tasks. (**4 hours)**

9. Design and develop an end-to-end natural language processing system using a real-life textual dataset. (**4 hours)**

Advanced Research Methodology (1-0-1)

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
	2	**1**	**0**	**1**	**Graduation**	**A course in Research Methodology**

Course Learning Objectives:

This second-level course in research methodology aims to advance the research skills of the students. The course aims to develop analytical skills for computer science research and the skills for technical writing and communicating the research for publication, while maintaining ethical practices.

Course Learning outcomes:

Upon completion of this course, students will be able to:

1. Conceptualize research problems in terms of research questions, hypotheses, and conceptual models.
2. Select and apply appropriate research designs for answering research questions that address the research questions.
3. Critically analyse research from the literature in terms of the appropriateness of the study design, data analysis, results, and interpretation.

Syllabus:

Unit I **(6 Hours)**

Research Design and Philosophy: Deeper understanding of research philosophies (positivism, interpretivism, etc.); Advanced research designs, Advanced searching tools and referencing tools, Publication ethics (plagiarism, copyright, patents), conceptualising research questions and hypotheses.

Unit II **(9 Hours)**

Advanced Data Analysis and Research Writing: Advanced quantitative and qualitative data analysis (grounded theory, case studies), Multivariate data analysis techniques, Testing of hypothesis, Levels of significance, confidence limits and intervals, Type I and Type II error, Technical writing, Code of Ethics in Research (COPE guidelines).

References:

1. Creswell, J. W., & Creswell, J. D. *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage Publications, 2017.
2. Kothari, C. R., & Garg, G. *Research methodology: Methods and techniques*. New Age International Publishers, 2019.
3. Oshima, A., & Hogue, A. *Introduction to academic writing* (3rd ed.). Pearson Education, Inc., 2007.
4. Relevant study material from ACM, IEEE, Elsevier, and Springer digital libraries.

List of Practicals

Identify three research papers in consultation with the project supervisor, ensuring that the code for the paper is available. Read the papers carefully and perform the following exercises for each paper. (10 x 3 = 30 hours)

1. Prepare a well structured summary of the paper, clearly stating the research gaps identified by the author, strengths and weaknesses of the research in your opinion.
2. Execute the available code for the problem on the datasets mentioned in the paper and reproduce the results.
3. Create the plots and result tables shown in the papers, and write your detailed interpretation. This is expected to be same as authors', but if there is something that you have observed and which was not stated by the authors, please highlight it.
4. Identify the research gaps in the work, and add as future work in the summary

WEB DEVELOPMENT [0-0-2]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
	2	0	0	2	Graduation	NIL

Course Objective:

The objective of this course is to provide hands-on experience in building interactive, structured, and dynamic webpages using HTML, CSS, JavaScript, jQuery, and JSON. Students will gain practical abilities in web content creation, styling, scripting, and event-driven programming.

Course Learning Outcomes:

Upon successful completion of this course, students will

1. understand the foundations of web development and webpage structure.

2. create well-designed webpages using HTML elements, semantic tags, tables, links, lists, images, and forms.
3. style webpages using CSS selectors, layout techniques, and class/id attributes.
4. apply JavaScript for DOM manipulation, event handling, and form validation.
5. implement jQuery functions for simplified scripting, UI behaviour, and event-driven actions.
6. use JSON for structured data representation in browser-based applications.

Syllabus:

Unit I: Foundations of Web Development (HTML + CSS)

Introduction to Web Development: Internet basics, websites, planning webpages, HTML Basics: Elements, attributes, headings, paragraphs, text formatting, Images, links, lists, tables, div elements, semantic tags, HTML Forms: input controls, buttons, text area, dropdown, radio, checkboxes, CSS Basics: inline/internal/external CSS, CSS Selectors: id, class, element selectors, structural elements, Page layout, backgrounds, borders, padding, margins, Styling tables, lists, images, and form components

Unit II: Web Scripting (JavaScript + jQuery + JSON)

JavaScript Fundamentals: variables, data types, operators, Conditional statements, functions, DOM access, Form validation using JavaScript, Event Handling, jQuery Basics: selectors, functions, document ready, jQuery events: blur, change, focus, click, dblClick, hover, submit, jQuery DOM manipulation & effects, JSON Basics: syntax, arrays, objects, parsing, stringifying

Readings:

1. Minnick, J. (2017). *Responsible web design with HTML5 and CSS* (9th ed.). Cengage Learning.
2. Nixon, R. (2021). *Learning PHP, MySQL & JavaScript with jQuery, CSS and HTML5* (6th ed.). O'Reilly Media.
3. Bayross, I. (2010; Reprint 2022). *Web-enabled commercial application development using HTML, DHTML, JavaScript, Perl CGI* (4th rev. ed.). BPB Publications.
4. Duckett, J. (2014). *JavaScript and jQuery: Interactive front-end web development*. Wiley.

List of Practicals

HTML + CSS Practicals

(Use CSS to style the webpage components, wherever possible)

1. Design a product showcase page containing product cards (image, name, description, price) arranged in a table or grid using HTML only. **(2 hours)**
2. Create a webpage with internal sections (About, Gallery, Achievements) and implement internal jumping links using anchor tags. **(2 hours)**
3. Create a homepage for the Department with a header, navigation bar, and footer using semantic tags. Include a short introduction paragraph and two images placed side-by-side. Use lists to display the faculty details (including the date of joining the department). Design a navigation menu with dropdown submenus that utilize a CSS hover effect. **(6**

hours)

4. Create an Alumni registration form with relevant fields such as name, batch, and current designation. Style a registration form with CSS to format labels, inputs, spacing, and button styles. **(4 hours)**
5. Design a webpage using HTML to display your course timetable. **(2 hours)**
6. Apply CSS to an existing HTML page to style headings, lists, paragraphs, backgrounds, margins, padding, and borders. **(2 hours)**
7. Create a 3-column layout using CSS (float/flexbox) for "News", "Events", and "Notices". **(2 hours)**
8. Design a navigation menu with dropdown submenus using CSS hover effects. **(2 hours)**

JavaScript Practicals

9. Write a JavaScript code to display a random image from a pool of event images whenever the Department page is refreshed. **(2 hours)**
10. Write a JavaScript code to display the years of experience (computed based on their date of joining) for each faculty in the Department webpage designed in exercise #3. **(2 hours)**
11. Add another field in the Alumni registration form designed in exercise#4 to collect the feedback (not more than 300 characters) from Alumni. Develop a character-count tool that displays a live count of characters typed into a text area. Also, implement JavaScript validation for this form (minimum length, no empty fields, valid date of birth).**(4 hours)**
12. Write JavaScript to change the background color of a text box on focus. **(2 hours)**
13. Create a light/dark theme toggle using JavaScript to switch CSS classes. **(2 hours)**
14. Detect and display the key pressed by the user using the keypress event. **(2 hours)**
15. Write a script to hide/show an image when a button is clicked. **(2 hours)**
16. Create a basic digital clock using JavaScript and update it every second. **(2 hours)**

jQuery + JSON Practicals

17. Write a script to dynamically add items to a list when a user enters text and clicks "Add Item". **(2 hours)**
18. Create a jQuery script to fade in and fade out images on button click. **(2 hours)**
19. Use jQuery to validate the Alumni registration form designed in exercise #4.**(2 hours)**
20. Filter list items using jQuery: user types text, matching items remain visible while others hide. **(2 hours)**

21. Demonstrate jQuery event handling (focus, blur, change, click, dblclick, submit) using a mini interactive form. **(2 hours)**
22. Use jQuery hover events to display additional information about an image. **(2 hours)**
23. Implement a JSON-based student data viewer: **(2 hours)**
    a. Store student data in JSON
    b. Display name, roll number, and department dynamically on the webpage
24. Parse a JSON array of faculty members and generate an HTML list of names and their qualifications. **(2 hours)**
25. Create a jQuery animation that moves a box from left to right across the webpage. **(2 hours)**
26. Create a jQuery-based color palette: clicking a color button changes the background color of a div.

SBC301: Prompt Engineering [0-0-2]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
SBC301	2	0	0	2	Graduation	NIL

Course Objective:

The objective of this course is to provide hands-on experience in understanding, designing, and optimizing prompts for large language models (LLMs), covering foundational and advanced prompting techniques.

Course Learning Outcomes:

Upon successful completion of this course, students will

1. understand the foundational concepts of prompting and LLM behaviour.
2. design structured, effective prompts using templates, constraints, roles, and examples.
3. apply advanced prompting methods such as chain-of-thought, few-shot prompting, ReAct, and self-consistency.
4. debug, evaluate, and optimize prompts for accuracy, clarity, and reliability.
5. design task-specific prompt workflows for reasoning, transformation, and creative tasks.

Syllabus:

Unit I: Foundations of Prompting

Introduction to LLMs and text generation; tokens and context windows; deterministic vs. stochastic decoding; Basic prompt structures—role prompting, instruction prompting, format constraints, delimiting techniques; Prompt templates, input–output structuring, controlling style and tone; Evaluating prompts—hallucinations, ambiguity, and prompt robustness; Prompt

debugging essentials.

Unit II: Advanced Prompt Patterns

Few-shot prompting, example ordering and construction; Chain-of-Thought (CoT) prompting, self-consistency, multi-step reasoning; ReAct Prompting (Reason + Act); Prompt compression, prompt optimization strategies; Hallucination mitigation and safety prompting.

Readings:

1. Phoenix, J., & Taylor, M. (2024). *Prompt Engineering for Generative AI: Future-Proof Inputs for Reliable AI Outputs*. O'Reilly Media.
2. DAIR.AI. (2024). *Prompt Engineering Guide*. https://www.promptingguide.ai
3. *Prompt engineering (OpenAI Documentation)*. https://platform.openai.com/docs/guides/prompting
4. Kojima, T., Gu, S., Reid, M., Matsuo, Y., & Iwasawa, Y. (2022). *Large language models are zero-shot reasoners*. In *Advances in Neural Information Processing Systems (NeurIPS 2022)*. https://arxiv.org/abs/2205.11916
5. Wei, J., Wang, X., Schuurmans, D., Le, Q. V., Chi, E. H., Narang, S., Chowdhery, A., & Zhou, D. (2022). *Self-Consistency improves chain of thought reasoning in language models*. In *International Conference on Learning Representations (ICLR 2023)*. https://arxiv.org/abs/2203.11171
6. Yao, S., Zhao, J., Yu, D., Du, N., & Shafran, I. (2022). *ReAct: Synergizing reasoning and acting in language models*. https://arxiv.org/abs/2210.03629

List of Practicals

1. Accessing LLM playground/API, experimenting with temperature, top-p, max tokens; Observe behavior changes with different parameters. **(4 hours)**
2. Write prompts for summarization, rephrasing, extraction; Refine prompts using delimiters and explicit constraints. **(4 hours)**
3. Design prompts with roles (teacher, analyst, developer, critic); Test how role affects style, depth, and tone. **(4 hours)**
4. Generate structured outputs (tables, bullet lists, JSON-like format); Enforce formatting rules using clear instructions and delimiters. **(4 hours)**
5. Create task-specific prompt templates; Experiment with placeholders and reusable modules. **(4 hours)**
6. Study cases of ambiguous or misleading prompts; Debug hallucinations and refine instructions. **(4 hours)**
7. Apply criteria like clarity, consistency, correctness; Score outputs against evaluation rubrics. **(4 hours)**
8. Design 1-shot, 2-shot, and 5-shot examples; Experiment with example selection and ordering. **(4 hours)**
9. Apply few-shot prompts to classification, reasoning, summarization; Compare performance against zero-shot. **(4 hours)**

10. Add intermediate reasoning steps; Use CoT for math problems, logic puzzles, and complex decision tasks. **(4 hours)**

11. Generate multiple reasoning paths; Compare and reconcile different answers. **(4 hours)**

12. Implement ReAct-style prompts for stepwise reasoning; Use reasoning traces followed by actions. **(4 hours)**

13. Shorten prompts while preserving performance; Experiment with paraphrasing, constraint tightening, and anchor examples. **(4 hours)**

14. Identify unsafe outputs; Apply safety prompting patterns and refusal formats. **(4 hours)**

15. Students build a small prompt-based system, such as: **(4 hours)**

- a reasoning assistant
- a structured information extractor
- a creative writing pipeline
- a domain-specific Q&A prompt workflow

Includes demonstration and evaluation.

SBC301: Tools for Research [2-0-0]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
SBC301	**2**	**2**	**0**	**0**	**Graduation**	NIL

Course Objectives:

The course aims to familiarize students with a comprehensive set of digital tools and platforms essential for conducting high-quality academic research. It focuses on equipping learners with the ability to efficiently search, organize, and manage scholarly literature using professional discovery and reference management tools. Students will also gain proficiency in using software for data handling, analysis, visualization, and document preparation, enabling them to produce well-structured and ethically sound research outputs. Additionally, the course emphasizes research integrity, collaborative workflows, and effective dissemination techniques to help students navigate the complete research lifecycle with confidence and competence.

Course Learning Outcomes

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

1. identify and use major tools for discovering scholarly literature.

2. manage references using professional citation management tools.
3. use document preparation and research organization software.
4. apply tools for data cleaning, visualization, and analysis.
5. understand plagiarism, research ethics, and publication workflows.

Syllabus

1. Create an effective research problem statement based on a given topic. (3 hours)
2. Perform a structured literature search using Boolean operators across three academic databases. (2 hours)
3. Build a reference library in Mendeley/Zotero and generate citations in two different styles. (3 hours)
4. Prepare a LaTeX document on Overleaf containing tables, figures, equations, and a BibTeX bibliography. (3 hours)
5. Use a PDF annotation tool and a digital note-taking app to organize insights from three research papers. (3 hours)
6. Design an online survey using Google Forms with proper question types and logic. (3 hours)
7. Clean a given dataset and handle missing or inconsistent data. (2 hours)
8. Perform descriptive and inferential statistical analysis using a data analysis tool. (2 hours)
9. Create visual analytics using Power BI/ Matplotlib based on a provided dataset. (3 hours)
10. Use Jupyter Notebook and GitHub to create a reproducible research workflow. (3 hours)
11. Create a research presentation and poster integrating results, tables, and visualizations. (3 hours)

Readings

1. Booth, Wayne C., et al. The Craft of Research. University of Chicago Press, 2016.
2. Walliman, Nicholas. Your Research Project: Designing and Planning Your Work. Sage, 2011.
3. Creswell, John W., and J. David Creswell. Research Design: Qualitative, Quantitative, and Mixed Methods Approaches. Sage, 2018.
4. Kumar, Ranjit. Research Methodology: A Step-by-Step Guide for Beginners. Sage, 2019.

List of DSEs for Semester III

DSE301: Link Prediction [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE301	**4**	**3**	**0**	**1**	**Graduation**	**Basic knowledge of Graph Theory and social network analysis**

Course Objectives:

The student learns the theoretical foundations and important properties of link prediction in networks. The students learn and explore similarity-based, probabilistic, and learning-based methods for link prediction. They can apply link prediction techniques in real-world domains such as social networks, biological networks, and recommendation systems.

Course Learning Outcomes:

At the end of the course, the students will be able to:

1. Understand basic concept and importance of link prediction.
2. Simulate link prediction approaches in network datasets.
3. Design and implement link prediction experiments on real-world datasets.
4. Evaluate link prediction models using standard performance measures.

Syllabus:

Unit-I **(9 hours)**

Introduction: Definition and motivation for link prediction; Applications of link prediction: social networks, biological networks, recommendation systems, citation networks; Problem formulation and evaluation framework; dimensionality reduction, and Community detection.

Unit-II **(15 hours)**

Similarity-based methods: Local similarity: Common Neighbors, Jaccard Coefficient, Adamic-Adar, Resource Allocation Index; Global similarity: Katz Index, Hitting Time, Rooted

PageRank, SimRank; Path-based and walk-based similarity measures; Structural and topological features for link prediction.

Unit-III **(15 hours)**

Probabilistic and statistical methods: Local probabilistic model, Probabilistic relational model (PRM), Hierarchical structure model (HSM), Stochastic block model (SBM), Exponential random graph model (ERGM).

Other methods: Dimensionality reduction-based link prediction, Information Diffusion-based Link Prediction, Learning-based frameworks, Information theory-based, Clustering-based, Structural perturbation method (SPM)

Unit-IV **(6 hours)**

Evaluation metrics: Recall, Area under the precision–recall curve (AUPR), Area under the receiver operating characteristics curve AUROC), and Average precision

Readings:

1. Newman, M. E. J. *Networks: An introduction*. Oxford University Press, 2010.
2. Easley, D., & Kleinberg, J. *Networks, crowds, and markets*. Cambridge University Press, 2010.
3. Barabási, A.-L. *Network science*. Cambridge University Press, 2016.
4. Golbeck, J. *Analyzing the social web*. Morgan Kaufmann, 2013.
5. Wasserman, S., & Faust, K. *Social network analysis: Methods and applications*. Cambridge University Press, 2012.
6. Kolaczyk, E. D. *Statistical analysis of network data: Methods and models*. Springer, 2009.
7. Estrada, E. *The structure of complex networks: Theory and applications*. Oxford University Press, 2011.
8. Srinivas, V., & Mitra, P. *Link prediction in social networks: Role of power law distribution*. Springer International Publishing, 2016.

List of Practicals:

1. Extract structural features (degree, clustering coefficient, centrality) and apply the Dimensionality reduction method PCA to visualize nodes in a reduced feature space. (**4 hours**)
2. Implement Common Neighbors, Jaccard Coefficient, Adamic–Adar, and Resource Allocation Index manually and validate with NetworkX built-in functions. (**4 hours**)
3. Write a Python function to compute the Katz Index using matrix operations (numpy.linalg.inv), with damping factor β. (**2 hours**)
4. Compute Rooted PageRank (Personalized PageRank) from a given root node using the random walk with restart method. (**2 hours**)
5. Compute Hitting Time between all pairs of nodes using BFS-based random walks. (**2 hours**)
6. Implement SimRank recursively and analyze how similarity scores evolve over

iterations. (**4 hours**)

7. Generate all paths between node pairs up to length 3 and calculate similarity based on path counts. (**2 hours**)
8. Simulate Independent Cascade (IC) or Linear Threshold (LT) models and estimate missing links based on influence overlap. (**4 hours**)
9. Implement Recall, Precision, AUPR, AUROC, and Average Precision. (**4 hours**)
10. Compare accuracy (AUC, precision) between attribute-based PRM and structure-based probabilistic models. (**2 hours**)

DSE302:Recommender Systems [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE302	**4**	**3**	**0**	**1**	**Graduation**	**NIL**

Course Objectives:

The student learns the fundamental and advanced concepts of recommender systems, including collaborative filtering, content-based, hybrid, and context-aware techniques. The student develops analytical and technical skills to design, implement, and evaluate recommender algorithms using real-world datasets and modern machine learning frameworks.

Course Learning Outcomes:

On completing this course, students will be able to:

1. explain the theoretical foundations, types, and working principles of recommender systems.
2. apply collaborative filtering, content-based, and hybrid methods to build personalized recommendation models.
3. analyze user–item interactions and contextual factors influencing recommendation quality.
4. evaluate recommender system performance using standard metrics, validation methods, and benchmark datasets.
5. design and create advanced recommender systems integrating deep learning, graph-based, and sequential modeling techniques for real-world applications.

Syllabus:

Unit-I **(11 hours)**

Introduction to Recommender Systems: Purpose, significance, and real-world applications; types of recommender systems. Data sources including user profiles, item attributes, and implicit and explicit feedback. Data preprocessing techniques for effective recommendation. Evaluating Recommender Systems: Online and offline evaluation methodologies; performance metrics such as RMSE, MAE, Precision, Recall, F1-score, NDCG, Average Reciprocal Rank, and Top-K measures. Beyond-accuracy evaluation covering fairness, coverage, diversity, novelty, and serendipity to ensure a comprehensive assessment of recommender systems.

Unit-II **(14 hours)**

Collaborative Filtering – Neighborhood-Based Approaches: Introduction, user-based and item-based models, similarity measures, and prediction functions; efficiency analysis and comparative evaluation; clustering and dimensionality reduction techniques; regression-based and graph-based extensions. Latent Factor Models and Matrix Factorization: Singular Value Decomposition (SVD), Non-negative Matrix Factorization (NMF), Stochastic Gradient Descent (SGD), and Alternating Least Squares (ALS) with regularization.

Unit-III **(10 hours)**

Content-Based Recommender Systems: Introduction and Basic Components, Preprocessing and Feature Engineering, Collecting User Preferences, Supervised Feature Selection and Weighting Techniques, Learning User Profiles and Filtering Approaches. Content-Based vs. Collaborative Recommendations. Hybrid recommender systems combining collaborative and content-based filtering.

Unit-IV **(10 hours)**

Advanced Topics – Deep Learning-Based Recommender Systems: Neural Approaches, Autoencoders, Sequence-Aware Models (RNN, LSTM, Transformer), Graph Neural Network-Based Recommenders, Explainable Recommendations, Fairness and Bias Mitigation, Multi-Modal and Context-Aware Recommendation, Emerging Trends and Research Directions.

Readings:

1. Aggarwal, Charu C., *Recommender Systems: The Textbook*, Springer International Publishing, 2016.
2. Ricci, Francesco, Lior Rokach, and Bracha Shapira (Ed.), *Recommender Systems Handbook*, Third Edition, Springer, 2022.
3. Advances in recommender systems using recent research papers.

List of Practicals:

1. Implement a user-based collaborative filtering recommender system using a given dataset (e.g., MovieLens). **(4 hours)**
2. Implement an item-based collaborative filtering recommender and compare its performance with the user-based model. **(2 hours)**

3. Perform matrix factorisation using Singular Value Decomposition (SVD) on a user-item rating matrix and predict missing ratings. **(4 hours)**
4. Implement non-negative matrix factorisation (NMF) on a dataset and analyse the latent factors for top-N recommendation. **(2 hours)**
5. Build a content-based recommender system using item features (e.g., genres, tags, descriptions) and evaluate using cosine similarity. **(2 hours)**
6. Implement a hybrid recommender system combining collaborative and content-based approaches and evaluate improvements over individual models. **(4 hours)**
7. Build a sequence-aware recommendation model using RNN or LSTM and evaluate next-item prediction performance. **(6 hours)**
8. Implement a graph-based recommender system using a Graph Neural Network (GNN) and analyse user-item interaction patterns. **(6 hours)**

DSE303: Time Series Data Analysis [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE303	**4**	**3**	**0**	**1**	**Graduation**	**Basic knowledge of programming and statistics**

Course Objectives:

This course provides a comprehensive understanding of time series analysis, covering fundamental principles, statistical modeling techniques, and forecasting methods. The course balances theoretical concepts with hands-on applications using real-world datasets in R and Python.

Course Learning Objectives: By the end of this course, students will be able to:

1. Understand the basic properties and components of time series data.
2. Perform stationarity tests and data transformations.
3. Apply statistical and machine learning models for time series forecasting.
4. Analyse multivariate time series data and apply feature engineering techniques.
5. Implement real-world forecasting applications across different domains.

Syllabus:

Unit-I **(10 Hours)**

Fundamentals of Time Series Analysis: Introduction to Time Series Data, Time Series Components, Trend, Seasonality, Cyclicality, and Noise, Time Series Data Visualization and Preprocessing, Stationarity and Unit Root Tests (ADF, KPSS).

Unit-II **(12 Hours)**

Time Series Models and Forecasting: Moving Average and Exponential Smoothing Models, Autoregressive (AR), Moving Average (MA), and ARMA Models, ARIMA and Seasonal ARIMA (SARIMA), Model Selection and Diagnostics (AIC, BIC, Residual Analysis), Performance metric.

Unit-III **(11 Hours)**

Advanced Time Series Methods: State-Space Models and Kalman Filters, Spectral Analysis and Fourier Transforms, Long Memory Processes and Fractional Differencing, Nonlinear Time Series Models.

Unit-IV **(12 Hours)**

Multivariate Time Series and Machine Learning Approaches: Vector Autoregression (VAR) and Cointegration, Dynamic Factor Models and PCA, Machine Learning for Time Series (LSTMs, XGBoost, Prophet), Feature Engineering and Dimensionality Reduction.

Readings:

1. Brockwell, Peter J., and Richard A. Davis, eds. Introduction to time series and forecasting. New York, NY: Springer New York, 2002.
2. Montgomery, Douglas C., Cheryl L. Jennings, and Murat Kulahci. Introduction to time series analysis and forecasting. John Wiley & Sons, 2015.
3. Beran, Jan. Mathematical Foundations of Time Series Analysis. Switzerland: Springer, 2017.
4. Wei, William W. S.. Multivariate Time Series Analysis and Applications. United Kingdom: Wiley, 2019.
5. Hyndman, Rob J.., Athanasopoulos, George. Forecasting: Principles and Practice. United Kingdom: OTexts, 2021. [https://otexts.com/fpp3/index.html]

List of Practicals:

1. Write a program that reads a time series with missing timestamps, fills or interpolates missing values, resamples the data at a different frequency (e.g., converting daily data into monthly averages), and removes outliers using z-score or IQR. Plot the data before–after pre-processing **(2 Hours).**
2. Write a program that loads a time series dataset (such as AirPassengers or daily stock prices) and then plots the raw data along with a rolling mean and rolling standard deviation. The program should also generate autocorrelation (ACF) and partial autocorrelation (PACF) plots. **(2 Hours)**
3. Write a program to perform additive and multiplicative decomposition on a given time series using STL or classical decomposition. The program should extract and plot the trend, seasonal, and residual components separately, and print a short interpretation describing the nature of seasonality and trend. **(2 Hours)**
4. Write a program that visually checks stationarity using rolling mean/variance plots and then performs ADF and KPSS tests on the original series. The program should apply first-order differencing or log transformation until the series becomes stationary and then re-run the tests, printing the p-values and conclusions. **(2 Hours)**

5. Write a program to apply simple moving average, weighted moving average, and exponential smoothing to a time series. The program should compare smoothed curves on a single plot and show how different window sizes or smoothing factors affect the trend. It should also print summary statistics comparing original and smoothed series. **(2 Hours)**
6. Write a program that analyzes the ACF and PACF plots to choose tentative orders for AR, MA, and ARMA models. Then fit AR(p), MA(q), and ARMA(p,q) models, print model parameters, and perform residual analysis using the Ljung–Box test. Evaluate the performance of the model using MAE, RMSE, MAPE, and sMAPE. **(6 Hours)**
7. Write a program that identifies the required differencing order using ADF/KPSS and then fits an ARIMA model with manually selected or auto-selected orders. The program should also fit a SARIMA model if seasonality exists, compare AIC/BIC values, and display forecast plots along with residual diagnostics **(2 Hours).**
8. Write a program that builds a state-space representation of a time series (e.g., a local linear trend model), applies the Kalman filter to estimate hidden states, and plots filtered and smoothed estimates. The program should compare the Kalman-based trend with the trend obtained using classical smoothing **(2 Hours).**
9. Write a program that computes the periodogram of a time series, applies the Fast Fourier Transform (FFT), and identifies the dominant frequencies contributing to seasonality. The program should print the main repeating cycle (e.g., weekly, yearly) based on the spectral peaks**. (2 Hours)**
10. Write a program that loads two or more related time series (such as GDP, inflation, and interest rates), checks their stationarity, and fits a VAR model. The program should compute impulse response functions and plot how one variable responds over time to a shock in another variable. **(2 Hours)**
11. Write a program that applies PCA to a multivariate time series dataset, extracts major components, and reconstructs the series using those components. Then fit a dynamic factor model and compare the variance explained by PCA factors versus dynamic factors. **(2 Hours)**
12. Write a program that converts a time series into a supervised learning dataset by generating lag features, rolling statistics, and date-time features. Train XGBoost or Prophet models on the processed data, generate forecasts, and compare their performance with ARIMA using common error metrics. **(2 Hours)**
13. Write a program that converts the time series into sliding windows, normalizes the data, and trains an LSTM or GRU neural network for next-step prediction. The program should plot predicted vs actual values and compare LSTM accuracy with traditional models such as ARIMA or exponential smoothing**. (2 Hours)**

DSE304: QUANTUM COMPUTING AND ITS APPLICATIONS [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical /Practice		
DSE304	**4**	**3**	**0**	**1**	**Graduation**	**Basic knowledge of Number theory or information security**

Course Objectives:

This course provides a foundation for quantum computing, Post-Quantum Cryptography and quantum machine learning. It covers the fundamental concepts of quantum mechanics, quantum algorithms, and their applications in various areas, including cryptography, cybersecurity, machine learning, finance, the energy sector, etc. Students will gain a theoretical understanding of quantum computing and practical skills in implementing quantum algorithms for various tasks.

Course Learning Outcomes:

On completing this course, the student will be able to:

1. Understand the basic principles of quantum mechanics and their relevance to quantum computing.
2. Comprehend quantum algorithms and their applications.
3. Apply quantum optimisation techniques in problem-solving.
4. Demonstrate practical skills in quantum computing in various areas, including cryptography and machine learning.

Syllabus:

Unit-I **(10 hours)**

Fundamentals of Quantum Computing: Mathematical foundations: Vectors, Vector space, Inner product, Tensor Product; Qubits, Introduction to quantum mechanics and its relevance to Quantum gates, superposition principle, and entanglement Quantum parallelism and interference, No cloning theorem, quantum teleportation, Introduction to quantum error Correction.

Unit-II **(15 hours)**

Quantum Algorithms and Post-Quantum Security: Phase Kick-Back Algorithm, Deutsch-Jozsa algorithm, Simon's algorithm, Bernstein-Vazirani, RSA algorithm and factorization attack on RSA, Shor's algorithm for integer factorization, Grover's algorithm for unstructured search, Hash preimage attack with Grover’s algorithm, Quantum Fourier transform and its applications, Harrow–Hassidim–Lloyd (HHL) algorithm, Kyber Algorithm, Quantum attack resistant Digital Signature.

Unit-III **(10 hours)**

Quantum Machine Learning and Optimization: Quantum machine learning (QML) models – QSVM, QNN, QCNN, Quantum Linear Regression, Variational Quantum Classifier (VQC), Quantum k-means clustering; kernel methods, Quantum Boltzmann Machines; Quantum optimization techniques: QAOA, quantum annealing.

Unit-IV: (10 hours)

Introduction to quantum simulation tools and platforms: Google CIRQ, Amazon Braket, IBM Qiskit, Pennylane, Q#, Tensorflow quantum, Tket/pyket, XACC, Project Q, Quantum Development Kit (QDK).

Readings:

1. Noson S. Yanofsky and Mirco A. *Mannucci. Quantum computing for computer scientists*. Cambridge University Press, 2008.
2. Michael A Nielsen, Isaac L. Chuang, *Quantum computation and quantum Information*, Cambridge University Press.
3. Elias F. Combarro, Samuel González-Castillo, and Alberto Di Meglio. *A Practical Guide to Quantum Machine Learning and Quantum Optimization: Hands-on Approach to Modern Quantum Algorithms*. Packt Publishing Ltd, 2023.

References:

1. Santanu Ganguly. Quantum Machine Learning: An Applied Approach. Apress, 2021.
2. https://docs.quantum.ibm.com/
3. https://quantumai.google/cirq/experiments/textbook_algorithms

List of practical:

1. Install and configure a quantum computing framework such as IBM Qiskit or Google Cirq, and create basic quantum circuits using single-qubit gates to perform measurements. **(3 Hours)**

2. Write a program to visualise qubit states and their rotations on the Bloch Sphere using suitable simulation tools. **(2 Hours)**

3. Implement a program to demonstrate the concepts of superposition and entanglement using multi-qubit circuits. **(3 Hours)**

4. Write a program to simulate the process of quantum teleportation using an entangled qubit pair. **(3 Hours)**

5. Implement the Deutsch–Jozsa algorithm to identify whether a given function is constant or balanced. **(3 Hours)**

6. Write a program to implement Grover's search algorithm for an unstructured search problem and analyze its efficiency**. (4 Hours)**

7. Implement a simplified version of the Quantum Fourier Transform (QFT) for a small

number of qubits and observe the results. **(3 Hours)**

8. Write a program to demonstrate the Quantum Approximate Optimisation Algorithm (QAOA) for solving simple optimisation problems. **(3 Hours)**

9. Write a program to generate and analyze quantum random numbers using measurement of superposition states. **(4 Hours)**

10. Write and execute quantum circuits on different quantum-computing platforms and compare their performance and features**. (2 Hours)**

DSE305: Digital Forensics [3-0-1]

Course title & Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE305	**4**	**3**	**0**	**1**	**Graduation**	**Basic knowledge of Computer Networks and Operating System**

Course Objective:

This course provides a comprehensive introduction to the principles, practices, and legal frameworks of digital forensics. Students will gain hands-on experience in the complete investigation lifecycle—from evidence acquisition and validation to in-depth analysis of computer, mobile, and network data. The course prepares students to conduct rigorous digital investigations and effectively report on findings in accordance with modern Indian legal standards.

Course Learning Outcomes:

Upon successful completion of this course, students will be able to:

1. Apply the forensic investigation process in compliance with Indian legal acts and ethical guidelines.
2. Acquire and validate data from live and dead systems, including hard drives (disk imaging) and volatile memory (RAM).
3. Analyse and reconstruct digital evidence from various file systems (FAT, NTFS, ext4), memory dumps, and core operating system artefacts (e.g., Windows Registry, browser history).
4. analyse evidence from specialised sources, including mobile devices (Android) and network packet captures (PCAPs).

5. Evaluate the challenges and methodologies associated with emerging threats, such as deepfake media, AI-generated evidence, and dark web artefacts.

Syllabus

Unit I: (8 hours)

Introduction: Definition, distinction between cyber forensics and Digital forensics, Evolution of computers and digital forensics, modern challenges in the AI and cloud era. Digital Footprints and Attack Vectors, Case Studies (Indian and Global), Digital forensics Investigation process: Identification, Preservation, Collection and Acquisition, Analysis, Documentation & Presentation, Numbering Systems, Data structure- endianness, character encoding, Data nature and state, Reporting: Best practices for making Forensic reports

Unit II: (10 hours)

Legal and Ethical Frameworks: IT Act, 2000 (amendments of 2008) and IT (Intermediary Guidelines and Digital Media Ethics Code) Rules, 2021 (and subsequent amendments), BNS 2023, BNSS 2023, BSA 2023, DPDP Act, 2023, Budapest Convention, ISO/IEC Standards in Forensics, Chain of custody, 65A/65B Certificates, Ethical dilemmas in Forensics, CERT-in Procedures and Coordination

Unit III: (15 hours)

Acquisition and Analysis: Acquisition: Live vs Dead Acquisition, Methods for Data Acquisition, Hashing (MD5, SHA) and Data Validation. File System Analysis: FAT, NTFS, ext4, methods for recovering data from deleted files, File carving, Memory forensics: Volatile data collection and analysis, analysing memory dumps for processes, network connections, OS Artifacts analysis: Time reconstruction, Email Header analysis and tracing, Windows registry analysis, browser history, anti-forensics technique and detection

Unit IV: (12 hours)

Advanced and Emerging Forensics: Mobile Forensics: Overview of acquisition and analysis of Android, unique challenges: diverse OS, encryption, complex appdata, Legal and ethical considerations, Network Forensics: analysing network traffic (PCAP files); Emerging Threats: Dark Web Forensics, Synthetic Media and Deepfake Detection; AI-generated Evidence: Admissibility Challenges.

References:

1. Dejey, M. *Cyber forensics*. Oxford University Press India, 2018.
2. Moustafa, N. *Digital forensics in the era of artificial intelligence* (1st ed.). CRC Press, 2023.
3. Gogolin, G. *Digital forensics explained* (2nd ed.). CRC Press, 2021.
4. Kävrestad, J. *Fundamentals of digital forensics: Theory, methods, and real-life applications*. Springer International Publishing AG, 2020

List of Practicals

1. Consider a scenario in which you are a junior forensic analyst. You received a sealed 16GB USB drive (Evidence #001). Create a new case in Autopsy, fill out a chain of custody form to document its receipt and then draft a sample 65B certificate for a hypothetical file (e.g. secret_ledger.xlsx) found on the drive to understand legal documentation. **(4 hours)**

2. Explore WinHex and Hex Workshop to analyse and examine various file headers. **(4 hours)**

3. Install FTK Imager and acquire the volatile memory (RAM) of your system. **(2 hours)**

4. Acquire non-volatile memory (Hard Disk) using FTK Imager **(2 hours)**

5. Analyse the disk image created in the previous lab by loading it into Autopsy. Examine the NTFS structure, with a focus on the Master File Table (MFT). Analyse MFT entries for deleted files, looking specifically at how the FILE_NAME attribute (flagged as ;in-use and/or deleted) and timestamp attributes change. Using this analysis, identify and recover five specific deleted files, documenting their original file paths. **(4 hours)**

6. In Gmail, select a SPAM email and analyse its header. Detect possible spoofing or malicious activity using a mail header analyser. https://mxtoolbox.com/EmailHeaders.aspx. Identify key header fields such as From, To, Subject, Date, Return-Path, Received, Message-ID, SPF / DKIM / DMARC. Use tools like WHOIS or online IP lookup services to identify the geographical location and ownership of IP addresses found in the Received lines. Verify if any IPs are suspicious or if the hostname doesn't match the expected sending server. **(2 hours)**

7. Visit the website https://testphp.vulnweb.com/ and start capturing packets using Wireshark. Some HTTP packets will be captured. Look for form data that the user submitted to the website. Find the user credentials sent in the HTTP request. **(2 hours)**

8. Analyse a provided Windows memory dump using the Volatility framework. You will identify the correct OS profile, then run commands to extract the list of running processes (pslist), identify active network connections (netscan), and dump command history (cmdscan) **(6 hours)**

9. Analyse a provided logical Android backup (android_backup.ab) using Autopsy. You will extract and query key databases to document recent calls (calllog.db), find specific text messages (mmssms.db), and locate the WhatsApp message database (msgstore.db). **(2 Hours)**

10. Using Registry Explorer and the RegRipper tool, analyse the SAM registry Hive and identify your own user SID. **(2 hours)**

DSE306: Human Computer Interaction [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE306	4	3	0	1	Graduation	Basic knowledge of Programming language

Course Objectives:

The course aims to introduce students to the fundamental concepts of human-computer interaction and their application in society.

Course Learning Outcomes:

Upon successful completion of this course, the student will-

1. understand basic theories, tools and techniques in HCI.

2. empathize with the fundamental aspects of designing and evaluating interfaces.

3. apply appropriate HCI techniques to design systems that people use.

Syllabus:

UNIT I: **(12 Hours)**

HCI Foundations- Input–output channels, human memory, thinking: reasoning and problem solving, emotion, individual differences, psychology and the design of interactive systems; text entry devices, positioning, pointing and drawing, display devices, devices for virtual reality and 3D interaction, physical controls, sensors and special devices, paper: printing and scanning; models of interaction, frameworks and HCI, industrial interfaces, interaction styles, navigation in 3D and 2D, elements of the WIMP interface, learning toolbars, interactivity, the context of the interaction; paradigms.

UNIT II: **(14 Hours)**

Design Process- Process of design, scenarios, navigation design, beware the big button trap, modes, screen design and layout, alignment and layout matter, checking screen colors, iteration and prototyping; HCI in the software process- the software life cycle, usability engineering, iterative design and prototyping, design rationale; design rules- principles to support usability, standards, golden rules and heuristics, HCI patterns; elements of windowing systems, programming the application, user interface management systems; evaluation through expert analysis, evaluation through user participation, choosing an evaluation method; universal

design principles, multi-modal interaction, designing for diversity; requirements of user support, approaches to user support, designing user support systems.

UNIT III: **(9 Hours)**

Models and Theories- cognitive models- introduction, goal and task hierarchies, linguistic models, physical and device models, cognitive architectures; organizational issues, capturing requirements; communication and collaboration models- introduction, face-to-face communication, conversation, text-based communication; task analysis- introduction, task decomposition, knowledge-based analysis, entity–relationship-based techniques.

UNIT IV: **(10 Hours)**

Dialog design notations, diagrammatic notations, dialog semantics, dialog analysis and design; interaction models; rich contexts, low intention and sensor-based interaction; groupware-introduction and systems, meeting and decision support systems, shared applications and artifacts, frameworks for groupware, implementing synchronous groupware; virtual and augmented reality, information and data visualization.

Readings:

1. Dix, A., Finlay, J., Abowd, G. D., & Beale, R. *Human–computer interaction* (3rd ed.). Pearson, 2008.
2. Shneiderman, B., Plaisant, C., Cohen, M., & Jacobs, S. *Designing the user interface: Strategies for effective human–computer interaction* (6th ed.). Pearson, 2021.
3. Bhattacharya, S. *Human–computer interaction* (1st ed.). McGraw-Hill, 2019.

References:

1. Galitz, Wilbert O., *The Essential Guide to User Interface Design: An Introduction to GUI Design Principles and Techniques*, 3rd edition, Wiley Publishing, 2007.

List of practical:

You may choose a suitable programming language and define all necessary/relevant inputs/ problems.

1. Implement a program for short-term memory and long-term memory. **(2 Hours)**

2. Implement a program to perform natural language interfaces. **(2 Hours)**

3. Write a program for a full-page word-processor that is or is not a direct manipulation interface for editing a document using Shneiderman's criteria. **(4 Hours)**

4. Write a program to find a book on guidelines. List the guidelines that are provided and classify them in terms of the activity in the software life cycle to which they would most likely apply. **(2 Hours)**

5. Implement a program for a keystroke level analysis for opening up an application in a visual desktop interface using a mouse as the pointing device, comparing at least two different

methods for performing the task. Repeat the exercise using a trackball. **(4 Hours)**

6. Write a program to test whether adding colour coding to an interface will improve accuracy. **(2 Hours)**

7. You have been asked to compare user performance and preferences with two different learning systems, one using hypermedia and the other sequential lessons. Write a program to design a questionnaire to find out what the users think of the system. **(4 Hours)**

8. Implement a program for online support systems. **(2 Hours)**

9. Write a program for the operations in a standard drawing package (for example, draw, move, copy, delete, rotate). **(4 Hours)**

10. Write a program for Icon Design and VCR Remote Control. **(4 Hours)**

DSE307: Influence Maximization [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE 307	**4**	**3**	**0**	**1**	**Graduation**	**Basic knowledge of Graph Theory and social network analysis**

Course Objectives:

This course provides a comprehensive introduction to the principles of information diffusion and influence propagation in networks. To learn classical and advanced influence maximization algorithms. To analyze efficient and effective algorithms for influence maximization under various constraints. To study evaluation metrics and performance analysis for influence maximization. To apply influence maximization techniques in real-world applications such as viral marketing, epidemic control, and opinion formation.

Course Learning Outcomes

At the end of the course, the students will be able to:

1. Understand the basic concept of influence maximization in networked datasets.
2. Model and simulate the spread of influence using classical propagation models.
3. Identify influential nodes using various influence maximization algorithms.
4. Analyze and compare algorithmic efficiency and approximation guarantees of influence maximization algorithms.

Syllabus:

Unit-I **(8 hours)**

Introduction: Overview of social networks and types of social networks, Network structure and properties (degree, clustering, centrality), social network analysis concepts, viral marketing, rumor spreading, and epidemic diffusion; real-world applications, NP-hardness, monotone and sub-modularity properties.

Unit-II (12 hours)

Information Diffusion Models: Basics of information diffusion and influence propagation, Independent Cascade (IC) model, Linear Threshold (LT) model, SIR: variants and extensions (weighted, time-aware, competitive, signed), Influence spread and expected diffusion, Analytical and simulation-based evaluations.

Unit-III (13 hours)

Classical Influence Maximization Algorithms: Simulation-based Algorithms: Greedy algorithms and approximation guarantees, CELF, and CELF++ optimization; Heuristic-based Algorithms: Degree, PageRank, Centrality-based and Community-based; Sampling-based Algorithms; Path-based Algorithms. Performance evaluation metrics.

Unit-IV (12 hours)

Advanced Influence Maximization Algorithms: Budgeted Influence Maximization, Influence maximization in Dynamic and Temporal Networks, Competitive Influence Maximization, Location-aware Influence Maximization, Topic-aware Influence Maximization, Conformity and Semantic-based Influence Maximization.

Readings:

1. Newman, M.E.J. *Networks: An introduction*. Oxford University Press, 2010.
2. Easley D. and Kleinberg J. *Networks, Crowds, and Markets.* Cambridge University Press, 2010.
3. Barabási A.L. *Network Science.* Cambridge University Press, 2016.
4. Kolaczyk, E. D. *Statistical Analysis of Network Data: Methods and Models.* Springer, 2009.
5. Estrada, E. *The Structure of Complex Networks: Theory and Applications.* Oxford University Press, 2011
6. Chen, W. Castillo, C and Lakshmanan, L.V.S. *Information and influence propagation in social networks,* Springer Nature, 2014

List of Practicals:

1. Create a graph from different types of input files and display the nodes and edges properties. **(4 hours)**
2. Implement the Independent Cascade Model (ICM) to observe the spread of influence from a given set of seed nodes. **(2 hours)**
3. Implement the Linear Threshold Model (LTM) to observe the spread of influence from a given set of seed nodes. **(2 hours)**
4. Select top-k nodes based on degree centrality and evaluate influence spread under the IC model. **(2 hours)**

5. Compare influence spread using degree, closeness, betweenness, and eigenvector centrality as seed criteria. **(4 hours)**
6. Implement the Greedy and CELF algorithms to efficiently select the top-k influential nodes for maximizing the influence spread. **(4 hours)**
7. Detect communities using the Louvain or Girvan–Newman algorithm. Select seed nodes evenly from the identified communities and compare the influence spread. **(2 hours)**
8. Implement Greedy algorithm for Budgeted Influence Maximization and Fairness Influence Maximization. **(2 hours)**
9. Implement algorithms of Multiple Influence Maximization (MIM) to find the seed set. **(4 hours)**
10. Determine the potential fairness issues that may exist in advanced influence maximisation algorithms. **(4 hours)**

DSE308: Data Engineering [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE 308	**4**	**3**	**0**	**1**	**Graduation**	**NIL**

Course Objectives:

This course provides a comprehensive introduction to data engineering, focusing on the design, implementation, and management of data pipelines for analytics and decision-making. Students will gain hands-on experience with ETL processes, orchestration frameworks, and cloud-based data engineering services. Emphasis is placed on scalable data processing and real-world applications.

Course Learning Outcomes

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

1. Understand fundamental concepts of data engineering, data lifecycle, and the role of ETL/ELT in modern data systems.
2. Design and implement ETL pipelines for batch and streaming data using industry-standard tools.
3. Develop, schedule, and monitor workflows using orchestration tools such as Apache Airflow.
4. Apply cloud-native data engineering solutions (AWS Glue, GCP Dataflow, Azure Data Factory) for scalable and reliable data pipelines.

Syllabus

Unit-I **(10 hours)**

Foundations of Data Engineering: Introduction to Data Engineering and its role in modern analytics, Data lifecycle and architecture: OLTP vs OLAP, Data Lakes vs Data Warehouses, Types of data: structured, semi-structured, unstructured, ETL vs ELT processes, Data quality, governance, and lineage.

Unit-II **(10 hours)**

ETL and Data Transformation: Fundamentals of ETL pipelines, Data ingestion methods: batch and streaming, Data cleaning, preprocessing, and validation techniques, Tools for ETL: Apache Spark, Talend, AWS Glue basics, Performance optimization and error handling

Unit-III **(12 hours)**

Data Pipeline and Orchestration: Introduction to workflow orchestration, Orchestration vs scheduling, Apache Airflow: DAGs, operators, sensors, XComs, Building and deploying ETL pipelines with Airflow, Monitoring, logging, and troubleshooting pipelines, Case study: End-to-end automated pipeline

Unit-IV **(13 hours)**

Cloud Data Engineering: Overview of cloud data services, AWS Glue: architecture, job scripts, crawlers, integration with S3 and Redshift, GCP Dataflow: batch and streaming pipelines with Apache Beam, Azure Data Factory: pipelines, triggers, monitoring, Comparative analysis of AWS, GCP, and Azure services, Scalability, reliability, and cost optimization in cloud data engineering

Readings

1. Kleppmann, Martin. *Designing Data-Intensive Applications*. O'Reilly Media, 2017.
2. Karau, Holden, et al. *Learning Spark: Lightning-Fast Data Analytics*. O'Reilly Media, 2020.
3. Bilgin, Bas P. *Data Engineering with Python*. Packt Publishing, 2021.
4. Housley, Marc Lamberti. *Data Pipelines with Apache Airflow*. Manning Publications, 2021.
5. Zaharia, Matei. *Learning Apache Spark 2*. Packt Publishing, 2017.

List of Practicals:

1. Implement a basic ETL pipeline to extract data from CSV, transform it, and load it into a SQL database. **(2 hours)**
2. Perform batch and streaming data ingestion using Apache Spark. **(2 hours)**
3. Clean and preprocess a real-world dataset (missing values, outliers, normalization). **(2 hours)**
4. Build an Airflow DAG to automate a multi-step ETL pipeline. **(4 hours)**
5. Configure Airflow connections to an external database (PostgreSQL/MySQL) and schedule periodic ingestion tasks. **(2 hours)**
6. Implement an AWS Glue job to move and transform data from S3 to Redshift. **(4 hours)**
7. Design a GCP Dataflow pipeline for real-time streaming sensor/log data. **(4 hours)**
8. Create an Azure Data Factory pipeline to integrate on-premises SQL Server with Azure

Blob Storage. **(4 hours)**

9. Compare the performance and scalability of ETL pipelines across AWS Glue, GCP Dataflow, and Azure Data Factory. **(2 hours)**

10. Mini-project: Design, implement, and present a scalable end-to-end cloud-based data pipeline. **(4 hours)**

SEMESTER - IV

DSC401: Reinforcement Learning [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSC401	**4**	**3**	**0**	**1**	**Graduation**	**NIL**

Course Objectives:

This course develops foundational and practical skills in reinforcement learning. It covers Markov Decision Processes (MDPs), dynamic programming, Monte Carlo methods, temporal-difference learning, function approximation, and policy gradient approaches. Students will also gain hands-on experience implementing RL algorithms using standard Python libraries.

Course Learning Outcomes:

Upon successful completion of this course, students will be able to:

1. Understand reinforcement learning task formulations, principles, and key components.
2. Apply dynamic programming, Monte Carlo, and temporal difference methods to solve RL problems.
3. Implement common RL algorithms using Python and established RL libraries.
4. Analyze and develop policy gradient methods ranging from basic to advanced variants.

Unit I: **(10 hours)**

Foundations of Reinforcement Learning Historical background of RL; basics and definitions; how learning happens through interaction; key terminology and assumptions; core elements of RL: policy, reward, value functions, action-value functions, Bellman equations; exploration–exploitation; categories of RL methods. Introduction to Python RL ecosystems:

NumPy, OpenAI Gym, Keras/TensorFlow, and PyTorch; code standards and reproducibility practices.

Unit II: (11 hours)

Markov Decision Processes & Dynamic Programming: Markov property; Markov Reward Processes (MRP); definition and formulation of Markov Decision Processes (MDPs); states, actions, transitions, rewards; episodes and returns; value functions and optimality; Bellman optimality equations, Dynamic Programming for RL: iterative policy evaluation, policy improvement, policy iteration, value iteration, generalized policy iteration; asynchronous DP; limitations and efficiency considerations.

Unit III: (11 hours)

Monte Carlo & Temporal-Difference Learning Monte Carlo (MC) prediction: first-visit and every-visit methods; MC control; exploring starts; on-policy and off-policy MC; importance sampling (ordinary and weighted), Temporal Difference (TD) learning: TD(0), SARSA, Q-learning; on-policy vs off-policy TD; convergence aspects; overview of TD(1) and TD(λ); comparison of MC, TD, and DP.

Unit IV: (13 hours)

Function Approximation, Policy Gradients & Deep RL Function approximation: gradient MC, semi-gradient TD(0), TD with eligibility traces, after-states, least-squares TD, Policy gradient methods: policy parameterization, REINFORCE algorithm, variance reduction techniques, baselines, advantage function; actor–critic frameworks, Introduction to Deep Reinforcement Learning: neural network-based value and policy functions; overview of DRL applications and modern algorithms.

Readings

1. Sutton, R. S., & Barto, A. G. (2018). *Reinforcement Learning: An Introduction* (2nd ed.). MIT Press.
2. Bilgin, E. (2020). *Mastering reinforcement learning with python* (pp. 1-544). Packt Publishing.
3. Winder, P. (2020). *Reinforcement Learning: Industrial Applications of Intelligent Agents*. O'Reilly Media.
4. Zai, A., & Brown, B. (2020). *Deep Reinforcement Learning in Action*. Manning Publications.

List of Practicals:

1. Implementing Dynamic Programming Policy Evaluation. **(2 hours)**
2. Dynamic Programming Policy Iteration method. **(2 hours)**
3. Dynamic Programming Value Iteration method. **(2 hours)**
4. Monte Carlo Prediction implementation. **(4 hours)**
5. Off-Policy Monte Carlo Control using Importance Sampling. **(4 hours)**

6. Implementing SARSA (On-policy TD learning). **(4 hours)**
7. Implementing Q-learning (Off-policy TD learning). **(4 hours)**
8. Policy Gradient: REINFORCE algorithm implementation. **(4 hours)**
9. Actor–Critic method implementation. **(4 hours)**

DSE207, DSC402: Computer Vision [3-0-1]

Course title & Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE 207 DSC 402	**4**	**3**	**0**	**1**	**Graduation**	**foundation in mathematics, basic machine learning concepts, and programming**

Course Objectives:

The primary objective of this course is to introduce the fundamental principles, scope, and applications of computer vision and image processing, including image acquisition, representation, enhancement, and color processing. In addition, the course will help students to develop an understanding of early, mid, and high-level vision techniques. The students will be exposed to modern deep learning–based computer vision methods, particularly convolutional neural networks, and major architectures used in contemporary vision applications.

Course Learning Outcomes:

Upon successful completion of this course, the student will be able to

1. recognize and describe both the theoretical and practical aspects of computing with images.
2. understand image transformations, segmentation, feature detection, motion, matching, recognition, extraction, and categorization from images.
3. understand the geometric relationships between 2D images and the 3D world.
4. analyze the performance of deep networks within an image.

Syllabus:

Unit I: **(11 Hours)**

Overview of Computer Vision and Image Processing: Introduction of computer vision, definition, applications, and importance; historical context and evolution; image acquisition, image formats and representations, image enhancement, image filtering and convolution, RGB, HSV, and other color spaces, color manipulation in images.

Unit II: **(12 Hours)**

Early and Mid-level Vision: translation, rotation, scaling; affine and perspective transformations, thresholding, region-based segmentation, segmentation by clustering, segmentation by fitting a model, segmentation and fitting using probabilistic methods, feature detection and matching: points and patches, edges, lines, edge detection, corner detection, histogram equalization, adaptive histogram equalization, template matching, scale-invariant feature transform (SIFT).

Unit III: **(10 Hours)**

High Level Vision: Geometric methods: model-based vision, smooth surfaces and their outlines, aspect graphs, range data; probabilistic and inferential methods: recognition by relations between templates, geometric templates from spatial relations, application, image-based rendering.

Unit IV: **(12 Hours)**

Dense Motion Estimation: Translational alignment, parametric motion, spline-based motion, optical flow, layered motion.

Deep learning-based Computer Vision Techniques: Deep learning for computer vision, basics of neural networks, convolutional neural networks (CNNs), architecture of CNNs, training and fine-tuning CNNs, LeNet, AlexNet, GooleNet, VGG-Net, ResNet, comparative analysis of different architecture.

Readings:

1. Gonzalez, Rafael C. and Woods, Richard E., *Digital Image Processing*, 4th edition, Pearson Education, 2018.
2. Forsyth and Ponce, *Computer Vision: A Modern Approach*, 2nd edition, Pearson, 2015.
3. Szeliski, Richard, *Computer Vision: Algorithms and Applications*, Springer-Verlag, 2010.
4. Prince, Simon J. D., *Computer Vision: Models, Learning, and Inference*, 1st edition, Cambridge University Press, 2012.
5. Goodfellow, Ian, *Deep Learning (Adaptive Computation and Machine Learning series)*, The MIT Press, 2016

References:

1. Hartley, Richard and Zisserman, Andrew, *Multiple View Geometry in Computer Vision*, 2nd edition, Cambridge University Press, 2004.

List of practical:

You may choose a suitable programming language and the necessary/relevant inputs/ problems.

1. Implement a program for filtering and convolution techniques on the image. **(2 Hours)**

2. Implement a program to perform all colour space conversion and colour manipulation techniques in images. **(2 Hours)**

3. Write a program for all image translation, rotation, and scaling techniques. **(3 Hours)**

4. Write a program for all image segmentation techniques. **(4 Hours)**

5. Implement a program to perform all feature detection and matching techniques in images. **(3 Hours)**

6. Implement a program to apply histogram equalization to a colour image, and apply contrast stretching to the colour example image. Experiment with different parameter values to find an optimum for the visualization of this image. **(2 Hours)**

7. Write a program for the scale-invariant feature transform of an image. **(3 Hours)**

8. Implement a program for geometric methods of the image. **(3 Hours)**

9. Implement a program for dense motion estimation techniques on the image. **(2 Hours)**

10. Implement a program to apply different architectures of CNN to images to find the result of the image and investigate the usefulness of different architectures of CNN. **(6 Hours)**

SBC 401:COMMUNICATION SKILLS [1-1-0]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
SBC401	2	1	1	0	Graduation	NIL

Course Objective:

This course aims to build essential communication competencies required in academic and professional settings. It focuses on strengthening verbal, non-verbal, written, and digital communication; enhancing listening, reading, and analytical skills; and developing clarity, coherence, and professionalism in both interpersonal and workplace communication. The course prepares students to confidently handle presentations, interviews, team communication, and the creation of structured technical documents while fostering ethical and culturally sensitive communication practices.

Course Learning Outcomes:

Upon successful completion of this course, students will:

1. Explain key principles of verbal, non-verbal, written, and digital communication and their role in academic and workplace contexts.
2. Apply effective communication techniques to produce clear, structured, and professional documents such as emails, reports, summaries, proposals, and résumés.
3. Analyze interpersonal and workplace communication situations, including interviews, presentations, group discussions, and team interactions, for clarity, intent, and effectiveness.
4. Evaluate communication practices—such as media texts, presentations, and written documents—using criteria of coherence, accuracy, tone, ethics, and audience appropriateness.
5. Create persuasive and professional oral and written communication outputs, including presentations, structured arguments, and workplace documents that demonstrate confidence, clarity, and ethical awareness.

Syllabus:

Unit I: Foundations & Interpersonal Communication (8 hours)

Nature, scope, and process of communication; verbal, non-verbal, digital, and intercultural communication; major communication barriers and strategies to overcome them; essential listening and reading skills including comprehension, summarizing, inference, and note-making; fundamentals of oral presentations with focus on structure, tone, clarity, and audience awareness; storytelling for impact; professional spoken communication including interviews (technical and HR), group discussions, debates, conflict resolution, and teamwork in diverse workplaces.

Unit II: Written & Professional Communication (7 hours)

Principles of technical and academic writing; professional emails, notices, memos, minutes, and digital communication etiquette; summaries, analytical writing, and structured document development; informational and analytical reports, proposals, and basic project documentation; survey and questionnaire design; preparation of CVs, résumés, and Statements of Purpose; writing for media such as feature articles and press releases; ethical and leadership-oriented communication including bias, representation, and responsible messaging.

Readings:

1. Adler, R. B. & Proctor, R. F. (2013). Interplay: The process of interpersonal communication (16th ed.). Oxford University Press.
2. Bovee, C. L., & Thill, J. V. (2017). Business communication today (14th ed.). Pearson.
3. Raman, M., & Sharma, S. (2015). Technical communication: Principles and practice (3rd ed.). Oxford University Press.
4. McCarthy, P., & Hatcher, C. (2020). Presentation skills for students (4th ed.). Sage.

Tutorials

Case Study 1 (2 Hours) – Communication Breakdown in a Technical Interview

- Students analyse excerpts from technical and HR interview transcripts to identify unclear responses, weak articulation, and gaps in technical explanation. They rewrite improved responses and conduct a short mock interview.

Case Study 2 (2 Hours) – Miscommunication in a Multicultural Software Team

- A scenario involving an international development team shows misinterpreted emails, tone issues, and unclear task delegation. Students diagnose communication barriers and propose culturally sensitive revisions to improve clarity.

Case Study 3 (2 Hours) – Non-Verbal and Digital Cues in Remote Meetings

- Learners study a recorded or scripted virtual meeting with poor camera presence, weak tone, poor turn-taking, and digital distractions. They identify ineffective non-verbal cues and redesign the meeting communication plan.

Case Study 4 (2 Hours) – Analytical Summary from Technical Content

- Using a short technical document (e.g., system logs, analytics data, research abstract), students prepare a concise summary and inference-based note-making sheet demonstrating clarity and coherence.

Case Study 5 (2 Hours) – Workplace Document Reconstruction

- Students examine flawed workplace documents, such as emails, memos, notices, and meeting minutes, and correct issues related to tone, structure, coherence, ambiguity, and professionalism. Tasks include rewriting documents using standard templates.

Case Study 6 (2 Hours) – Report and Proposal Writing for a Mini Project

- A scenario on a small technical project (e.g., improving app usability) is provided. Students prepare a short informational or analytical report, including problem definition, findings, and a proposal section with recommendations.

Case Study 7 (2 Hours) – Résumé, SOP, and Job Role Alignment

- Students are given a job description and three sample résumés/SOPs. They analyse alignment, coherence, and tone; then rewrite a résumé/SOP tailored for the role while maintaining ethical communication practices.

Case Study 8 (1 Hour) – Media Bias and Ethical Communication

- Students examine two short news/tech-media snippets on the same topic (AI, cybersecurity, data privacy). They identify bias, tone shifts, and misrepresentation and suggest an ethically balanced rewrite.

Techniques for Research Writing [1-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
	2	**1**	**0**	**1**	**Graduation**	**NIL**

Course Objective:

This course aims to equip students with techniques for effective research writing, including structuring academic documents, presenting ideas clearly. The course also develops students' abilities to produce high-quality scholarly manuscripts using modern tools for drafting, editing, and citation management, while maintaining academic integrity.

Course Learning Outcomes

After completing this course, students will be able to:

- Employ effective writing techniques, citation styles, and scholarly communication practices for structuring research content.
- Utilize and evaluate digital tools for reference management, plagiarism detection, and manuscript preparation, following ethical standards of academic and scientific research writing.
- Create well-structured research documents, such as proposals, literature reviews, and research papers, following academic and publication guidelines.

Syllabus

Unit I **(8 Hours)**

Foundations of Research Writing: Introduction to academic writing; structure of research papers; types of academic documents (proposal, thesis, review article); components of literature review; critical reading and note-making; paraphrasing, summarization, and avoiding plagiarism; citation styles; research ethics and integrity; tools for literature search; reference management tools grammar and readability tools; manuscript templates and formatting guidelines; writing research documents using LaTex.

Unit II **(7 Hours)**

Advanced Techniques & Publication Process: Designing an argument and flow in research writing; coherence, cohesion, and academic tone; presenting results; writing methods, results, and discussion sections; crafting abstracts and titles; responding to peer reviewers; journal selection and indexing; publication ethics (COPE guidelines); plagiarism checking tools; tools

for research visualization; writing using AI responsibly; preparing final manuscript and submission process.

References

1. C.R. Kothari, and G.Garg. Research Methodology: Methods and Techniques. New Age International Publishers, 2019.
2. R. Panneerselvam. Research methodology. PHI Learning Pvt. Ltd., 2014

Reading List

1. Rowe, (2011). Towards a greater diversity in writing styles, argumentative strategies and genre of manuscripts. European Journal of Information Systems, 20, pp. 491–495.
2. Peterson, T.C., Kleppner, S.R., and Botham, C.M. (2018). Ten simple rules for scientists: Improving your writing productivity. PLoS Computational Biology, 14, 10, e1006379.
3. Roig, M. (2010). Plagiarism and paraphrasing criteria of College and University professors. Ethics & Behavior, 11, 3, pp. 307-323.
4. Akin, F., Koray, O. and Tavukçu, K. (2015). How effective is critical reading in the understanding of Scientific Texts? Procedia – Social and Behavioral Sciences, 174, pp. 2444-2451.

List of Practicals (30 Hours)

1. Practice searching literature using Google Scholar, Scopus, and Web of Science. (2 Hours)
2. Create a reference library and cite sources in a sample document using tools introduced in the class. (2 Hours)
3. Prepare a structured mini-literature review based on selected research papers using LaTex, with a suitable title, abstract, and keywords. (6 Hours)
4. Write a research proposal in Latex, including suitable illustrations (tables, figures, with captions) and references, following academic conventions. (10 Hours)
5. Perform paraphrasing and summarization exercises and check originality using plagiarism-checking tools. (6 Hours)
6. Use the available grammar and readability tools to refine the research proposal. (4 Hours)

Techniques of Report Writing [1-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		

Skill	**2**	**1**	**0**	**1**	**Graduation**	**NIL**

Course Objectives:
The student learns professional-level report writing skills. Students will learn the structure, format, and style of various types of reports. They can also get proficiency in data interpretation, visual presentation, and documentation.

Course Learning Outcomes:
At the end of the course, the students will be able to:

1. Understand the principles of effective technical and professional writing.
2. Prepare different types of reports (informational, analytical, technical, project, research).
3. Use visual aids (charts, tables, figures) appropriately.
4. Edit and proofread for clarity and professionalism.
5. Prepare digital reports using modern tools (MS Word, LaTeX, Google Docs).

Syllabus:

Unit-I **(7 hours)**

Foundations: Purpose of reports, Types of reports, Structure of reports: Title page, abstract, TOC, introduction, body, conclusion, recommendations, references; Difference between essays, articles, and reports.
Writing Techniques and Style: Paragraph structure and flow, Writing effective introductions and conclusions, Use of numbered sections, headings, and subheadings, integrating quotes, paraphrasing, and citing sources, and avoiding plagiarism.

Unit-II **(8 hours)**

Data, and Visual Representation: Data interpretation and summarisation, Use of tables, graphs, charts, diagrams, incorporating figures and captions, Formatting tools: MS Word styles, templates, referencing tools; Basics of LaTeX for structured reports.

Editing and Proofreading: Editing techniques: macro-editing, micro-editing, Common writing errors (grammar, punctuation, redundancy, logical gaps), Readability improvement techniques, Peer review and collaborative editing, Use of digital tools: Grammarly, Google Docs comments.

Readings:

1. Pal, Rajendra & Korlahalli, J.S., *Essentials of Business Communication*.
2. Raman, Meenakshi & Sharma, Sangeeta, *Technical Communication.*
3. Lesikar, R.V. *Report Writing for Business*.
4. Pfeiffer, William S. *Technical Communication: A Practical Approach*.
5. Bailey, Stephen. *Academic Writing: A Handbook for International Students*.

List of practicals:

1. Prepare an outline for a technical or business report. **(2 hours)**
2. Draft a field visit / industrial visit report. **(2 hours)**
3. Write an analytical report using the provided data. **(2 hours)**
4. Design at least five charts using the data from lab exercise 3 and integrate them into a report. **(2 hours)**
5. Edit and proofread a report. **(2 hours)**
6. A lab exercise related to preparing a research/problem-solving report. **(2 hours)**
7. Create a report in LaTeX with sections, figures, and references. **(3 hours)**

List of DSEs for Semester IV

DSE 401: Edge Computing [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE 401	**4**	**3**	**0**	**1**	**Graduation**	**NIL**

Course Learning Objectives:

The course enables students to describe key edge-computing concepts and technologies, including infrastructure components, deployment models, services, and real-world applications. Students will explain IoT service structures and devices used in edge-computing environments across various industries and Industrial IoT (IIoT) contexts. They will be able to analyse the differences, relationships, and interoperability between edge computing and other computing strategies.

Course Learning Outcomes:

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

1. describe fundamental concepts, architectures, and technologies of edge computing, including infrastructure components, service models, and real-world applications.
2. analyze an edge ecosystem to identify performance gaps and propose improvements, demonstrating understanding of edge-computing architectures and their major constituents.
3. explain IoT and Industrial IoT (IIoT) service structures, devices, and integration within edge computing environments across diverse industry contexts.
4. compare edge computing with other computing paradigms—such as cloud and fog computing—and evaluate their differences, complementarities, and interoperability.

Syllabus:

Unit I: **(10 Hours)**

Fundamentals of Edge Computing: Concepts of distributed systems and edge computing, edge computing architectures, IoT devices and edge computing in IoT gateways, edge computing interfaces, Edge computing vs. cloud computing vs. fog computing, and Key components of edge computing: Edge devices and sensors, and edge gateways and nodes.

Unit II: **(10 Hours)**

Edge Computing Networks: Network topologies and connectivity, edge servers and other devices, Sealing, Tiered network architecture, data transmissions in edge networks, Edge networks vs cloud networks vs fog networks, edge analytics: data types and types of data analytics, Core tenets of edge analytics, AI, ML, and Deep learning at the edge, Performance evaluations using queuing theory concepts.

Unit III: **(10 Hours)**

Network Advancements and Edge Computing: 5G technologies, mobile edge computing, network slicing, software-defined clouds, edge computing case studies: edge computing in Industry 4.0, IoT service architectures and devices, intelligent IoT applications, privacy and data security in edge computing: data confidentiality, security and privacy, identity management in edge computing, and security practice in edge computing.

Unit IV: **(15 Hours)**

Federating Edge Computing, Future Trends: Service-centric model, Multiple administrative domains, Deployment of services and applications in an edge environment, Edge as a service, Cloud as a service, Edge computing, and interoperability with cloud, Future trends and challenges of edge computing: Blockchain-enabled edge-supported Internet of Vehicles (IoV), Automation and robotics, Computer vision, Supply chain and Edge Computing, Roadmap for Edge Computing, Challenges of Edge Computing.

Readings:

1. Kumari, A., Sadasivam, G. S., Dharani, D., & Niranjanamurthy, M., *Edge computing fundamentals, advances and applications*. CRC Press, 2022.
2. Buyya, R., & Srirama, S. N. (2019). *Fog and edge computing: Principles and paradigms*. Wiley, 2019

List of Practicals:

1. Set up the Arduino IDE for the ESP8266-12 module and program it to configure sensors at the IoT edge setup. **(4 hours)**
2. Set up the communication parameters at the edge layer. **(4 hours)**
3. Implement any two communication protocols. **(2 hours)**
4. Deploy modules to a Windows IoT Edge device. **(2 hours)**
5. Create an IoT hub. **(4 hours)**
6. Register an IoT Edge device to your IoT hub. **(2 hours)**

7. Install and start the IoT Edge for Linux on Windows runtime on your device. **(4 hours)**
8. Remotely deploy a module to an IoT Edge device and send telemetry. **(4 hours)**
9. Deploy a module Manage your Azure IoT Edge device from the cloud to deploy a module that sends telemetry data to IoT Hub. **(4 hours)**

DSE402: Mobile App Development Technologies [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE 402	**4**	**3**	**0**	**1**	**Graduation**	**NIL**

Course Objectives:

This course introduces the students to modern mobile application development frameworks, tools, and best practices. It focuses on designing, building, testing, and deploying mobile apps for Android and iOS platforms using cross-platform technologies. Students will gain hands-on experience with UI design, state management, API integration, mobile databases, and performance optimisation. Emphasis is placed on real-world mobile development workflows, scalability, and user-centric design.

Course Learning Outcomes

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

1. understand the architecture and components of mobile applications across Android, iOS, and cross-platform ecosystems.
2. design intuitive and responsive user interfaces using modern UI frameworks.
3. develop mobile applications using cross-platform technologies such as Flutter or React Native.
4. integrate REST APIs, authentication, and mobile databases into mobile apps.
5. apply state management, debugging, testing, and performance optimization techniques.
6. deploy mobile applications to the Google Play Store and Apple App Store.

Syllabus

Unit-I **(10 hours)**

Foundations of Mobile Application Development: Introduction to mobile ecosystems: Android, iOS, cross-platform; Native vs hybrid vs cross-platform apps; Mobile app architecture: MVC, MVVM, Clean Architecture; Development environments: Android Studio, Xcode, VS Code; Introduction to Flutter/React Native; UI/UX principles for mobile design; navigation paradigms; material design & human interface guidelines.

Unit-II **(10 hours)**

User Interface Development & State Management: Widgets/components, layouts, and styling; Forms, inputs; Building responsive UIs for multiple screen sizes; State management techniques:

Provider/Bloc/Redux/Stateful Widgets for Flutter; Hooks/Context/Redux for React Native; Handling user interactions; Localization & accessibility.

Unit-III **(12 hours)**

Backend Integration, Data Handling & Device Features: REST APIs, JSON parsing, and API-driven apps; Authentication: token-based, OAuth; Local databases: SQLite, Room, Hive, Shared Preferences; Offline-first applications; Using device sensors: camera, GPS, accelerometer; notifications, background services, permissions; error handling, logging, and security considerations.

Unit-IV **(13 hours)**

Advanced Topics, Testing & Deployment: Performance optimization, memory management, and debugging tools; Automated testing: unit testing, widget testing, integration testing; Continuous Integration/Continuous Deployment (CI/CD) for mobile; Packaging and signing apps; Publishing to Google Play Store and Apple App Store; Comparison of Flutter, React Native, Kotlin Multiplatform, SwiftUI; Industry trends: cross-platform evolution, foldable devices, wearable apps.

Readings

1. Bailey, T., & Biessek, A. *Flutter for beginners: An introductory guide to building cross-platform mobile applications with Flutter 2.5 and Dart*. Packt Publishing Ltd., 2021.
2. Napoli, M. L. *Beginning Flutter: A hands-on guide to app development*. John Wiley & Sons, 2019.
3. Eisenman, B. *Learning React Native: Building native mobile apps with JavaScript*. O'Reilly Media, 2015.
4. Hardy, B., & Phillips, B. *Android programming: The Big Nerd Ranch guide*. Addison-Wesley Professional, 2013.
5. Mathias, M., Gallagher, J., & Ward, M. *Swift programming: The Big Nerd Ranch guide*. Pearson Technology Group, 2020

List of Practicals:

1. Set up the development environment (Android Studio/Xcode/Flutter/React Native). **(2 hours)**
2. Build a basic UI with screens, layouts, and navigation. **(4 hours)**
3. Implement forms, validation, and user input handling. **(2 hours)**
4. Create an app integrating a public REST API with JSON data. **(4 hours)**
5. Implement state management using Provider/Bloc or Context/Redux. **(4 hours)**
6. Implement the Add local storage using SQLite, Room, and Hive. **(4 hours)**
7. Implement the camera, location, and notifications using device features. **(4 hours)**

8. Develop the Mini-project: Develop and demonstrate a fully functional cross-platform mobile app with backend integration. **(6 hours)**

DSE 403: Compiler Design [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE403	**4**	**3**	**0**	**1**	**Graduation**	**NIL**

Course Learning Objectives

The basic objective of this course is to understand the basic principles of compiler design, its various constituent parts, algorithms, and data structures required to be used in the compiler. It also aims to understand the use of basic compiler-building tools.

Course Learning Outcomes

On successful completion of the course, the students will be able to:

1. Describe the concepts and different phases of compilation.
2. Represent language tokens using regular expressions and context free grammars.
3. Describe the working of lexical analyzers.
4. Understand the working of different types of parsers and parse a particular string.
5. Describe intermediate code representations using syntax trees and DAG's as well as use this knowledge to generate intermediate code in the form of three address code representations.
6. Apply optimization techniques to intermediate code and generate machine code for high level language program.
7. Use Lex and Yacc automated compiler generation tools.

Syllabus

Unit I: **(10 Hours)**

Introduction to Compilation and Lexical Analysis: Phases of a compiler, Role of a lexical analyzer, Specification and recognition of tokens, Symbol table management, Error reporting and recovery in lexical analysis, Regular expressions and regular definitions, Lexical Analyzer Generator – *Lex*

Unit II: **(15 Hours)**

Syntax Analysis (Parsing Techniques) Context-Free Grammars (CFGs), Elimination of left recursion and left factoring, Top-down parsing techniques – Recursive Descent and LL Parsers, Bottom-up parsing techniques –, Shift-Reduce, LR Parsers (SLR, Canonical LR, LALR), Yet Another Compiler Compiler (YACC)

Unit III: **(12 Hours)**

Syntax-Directed Translation and Intermediate Code Generation: Syntax Directed

Definitions (SDDs), Evaluation orders for SDDs (S-attributed, L-attributed definitions), Intermediate representations – Syntax Trees and Three-Address Code (TAC), Types and declarations, Translation of expressions, control flow statements (loops, conditionals), Type checking

Unit IV: (8 Hours)

Runtime Environment, Code Generation, and Optimization: Storage organization and runtime environment, Activation records and stack allocation, Issues in code generation, Design of a simple code generator, Principal sources of optimization, peephole optimisation techniques

Readings

1. Alfred, V. A., Monica, S. L., & Jeffrey, D. U. *Compilers principles, techniques & tools*. Pearson Education, 2007
2. Chattopadhyay, S.. Compiler design. PHI Learning Pvt. Ltd, 2022

List of Practicals:

1. Write a Lex program to count the number of tabs, spaces and punctuation characters in an input file. **(2 hours)**
2. Write a Lex program to count the number of uppercase, lowercase and numeric characters separately. **(2 hours)**
3. Write a Lex program that implements a Vigenère cipher (given a short key); encrypt the input text and print the cipher text. **(2 hours)**
4. Write a Lex program to find and print the top 5 longest identifiers in a source file (identifiers = letters followed by letters/digits/underscores). **(2 hours)**
5. Write a Lex program that extracts all string literals (delimited by double quotes) from a source file and prints them with their line numbers. **(2 hours)**
6. Write a Lex program to count all multi-line comments (`/* ... */`) and single-line comments starting with `//` in a C file. **(2 hours)**
7. Write a YACC program to parse arithmetic expressions with `+ - * / ^` and parentheses. **(2 hours)**
8. Write a YACC program to accept conditional statements of the form `if (E) S else S` and translate them into simple three-address code (TAC) with labels and gotos. **(4 hours)**
9. Write a YACC program that recognises strings of the form `a^n b^n c^n (n≥1)` and accepts/rejects them. **(4 hours)**
10. Write a YACC program that parses simple `for` loops `for (init; cond; incr) stmt` and produces TAC for loop entry, body and exit. **(4 hours)**
11. Write a program (C++/Python) that constructs a DFA for identifiers and tests a list of input strings, printing accept/reject. **(4 hours)**

DSE404: Incident Response and Threat Hunting [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE404	**4**	**3**	**0**	**1**	**Graduation**	**Knowledge of computer networks and cyber security**

Course Objectives:

This course enables students to understand the modern cyber threat landscape and the principles of risk management. Students will learn to apply industry-standard frameworks, such as MITRE ATT&CK and NIST, to execute proactive, hypothesis-driven threat hunts.Students will also master the complete incident response lifecycle, from initial triage and containment to final eradication and recovery.

Course Learning Outcome

Upon successful completion of this course, students will be able to:

1. Analyse cyber threats, assess organisational risk, and apply conceptual frameworks (e.g., Cyber Kill Chain, MITRE ATT&CK, Pyramid of Pain) to deconstruct adversary TTPs.
2. Formulate and execute proactive, hypothesis-driven threat hunts by analysing endpoint (EDR), network (traffic), and authentication (Event Log) data.
3. Apply the complete NIST Incident Response lifecycle, including the triage of security events, selection of containment strategies, and execution of eradication and recovery plans.
4. Conduct post-incident reviews to identify lessons learned and integrate findings into a continuous monitoring strategy aligned with the NIST Cybersecurity Framework (CSF).

Syllabus:

Unit I: (8 hours)

Introduction to Threat Hunting and Risk Management: Threat landscape, attacker motivation, common attack methods, anatomy of an attack, indicators of compromise (IoC) and indicators of attack (IoA), understanding Advanced Persistent Threats (APT) and Tactics, Techniques and Procedures (TTP), relationship between vulnerabilities, threats and risk, measuring risk severity and risk assessment

Unit II: (10 hours)

Frameworks for analysis: The pyramid of pain, Cyber Kill Chain, diamond model of intrusion detection, MITRE ATT&CK for Mapping TTP, selection of the right model

Unit III (14 hours)

Proactive threat hunting: Shifting from reactive to proactive hunting, Alert-driven vs Hypothesis-driven analysis, Threat Hunting methodologies: Investigation based on known indicators of compromise or Indicators of Attack (IoA), Hypothesis-driven hunting, Anomaly-based/Statistical hunting, Reference models for Hunting: Sqrrl, TaHiti, PEAK, F3EAD, Data-driven hunting: Endpoint Detection and Response(EDR), Event log analysis: understanding event logs, account-related logs, auditing system configuration changes, Lateral Movement

Analysis: Server message block, Kerberos attack, scheduled tasks, identification of security events

Unit IV **(13 hours)**

Incident Response and Recovery: introduction to NIST Incident Response Frameworks (NIST 800-61), building an incident response plan, SOC workflows, Triage fundamentals, event identification, escalation, containment fundamentals, strategy selection of containment eradication, recovery and post-incident review: Removing the attacker's artefacts, vulnerability scanning, restoring systems via backup, Continuous monitoring strategy, incorporating continuous monitoring into the NIST CSF environment

References:

1. Anson, Steve,, *Applied Incident Response*, 2020 John Wiley & Sons, Inc.
2. Eric C. Thompson, *Cybersecurity Incident Response: How to contain, eradicate and recover from incidents*, 2018, Apress
3. Scott J. Roberts ; Rebekah Brown, *Intelligence Driven Incident Response: Outwitting the adversary*, O'Reilly Media Inc., 2017
4. The MITRE Corporation, MITRE ATT&CK framework, https://attack.mitre.org/

List of Practicals:

1. Choose one of the following APT groups: APT28 (often referred to as "Fancy Bear") and APT41 ("Wicked Panda" or "Double Dragon"). Compare these two prominent threat actors and make a document containing the details, such as group name, suspected country of origin, primary motivation, common targets, common TTPs and notable examples of their activities **(2 hours)**
2. Download Process Explorer and open Notepad through the command prompt. Take a screenshot of your Process Explorer. What does it show? How this technique is used to find malicious child processes **(2 hours)**
3. Install the SIEM (e.g. Splunk or Wazuh), Windows VM(Victim) and Kali Linux VM (Attacker). Run a simple command on the Windows VM and find the corresponding process creation event in the installed SIEM. Explore the SIEM interface. **(4 hours)**
4. Read any incident report. Identify the stages of the Cyber Kill Chain present in the report. Similarly, use the MITRE ATT&CK website to find the TTPs described in the report. Identify IoC from the report and place them on a diagram of the pyramid of pain. **(8 hours)**
5. A lab exercise based on the identification of lateral movement **(8 hours)**
6. A lab exercise based on the containment and eradication phase of the NIST IR lifecycle **(2 hours)**
7. A lab exercise based on restoring the system and improving defence. **(2 hours)**

DSE 405: Systems Modeling and Simulation

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE 405	**4**	**3**	**0**	**1**	**Graduation**	**NIL**

Course Learning Objectives:

The objective of this course is to provide detailed understanding of Simulation concepts and their applications. This course will also help students to design and analyse simulation models with its application on real world problems to design and analyse simulation models with its application on real world problems.

Course Learning Outcomes:

Students completing this course will be able to:

1. Understand the Fundamentals of Simulation and Model Building.
2. Apply different methods of random number generation to generate discrete and continuous random variables.
3. Conduct analysis of simulation models.
4. Understand and apply principles of Monte Carlo simulation.
5. Decode case studies to discover various simulation applications.

Syllabus:

Unit I: (12 hours)

Fundamentals of Simulation and Modeling: Introduction to Simulation: Concept of model and model building, Concept and Terminologies of Simulation, Process of Simulation, Advantages and Limitations of Simulation, Classification of Simulation Models: physical and mathematical models, static and dynamic model, discrete and continuous models, deterministic and stochastic models. Application areas of Simulation.

Unit I1: (11 hours)

Random Number Generation: Properties of random numbers, generation of pseudo random numbers, techniques of generating discrete and continuous random variables: inverse transformation, direct transformation, rejection method, hazard rate method. Test for random numbers.

Unit III: (12 hours)

Design and Analysis of Simulation Models Data collection, identifying distributions with data, Parameter estimation, goodness-of-fit tests, selecting input models without data, Steady-

state simulation, terminating simulation, confidence interval estimation, and output analysis for steady-state simulation. Simulation run statistics, Replication of runs, elimination of initial bias.

Unit IV: **(10 Hours)**

Monte Carlo Methods, Simulation Tools, and Applications: Monte Carlo Simulation. Simulation Tools: General-Purpose Simulation Tools, Case Studies of different types of Simulation, General Sampling Methods, Generating Sample paths: Brownian and Geometric Brownian motions; Gaussian start rate methods; Square root diffusions; process with jumps.

Readings:

1. Ross, S., *Simulation,* Academic Press, 5th Edition 2012.
2. A.M. Law and W.D. Kelton, *Simulation and Modeling and analysis*, 5th Edition, 2015.
3. Evans, J. R., & Olson, D. L. *Introduction to simulation and risk analysis*. Prentice-Hall, Inc. 2nd Edition, 2001.
4. Geoffrey Gordon: *System Simulation*, 2nd Edition, 2002.
5. Frank L. Severance, *System Modeling And Simulation: An Introduction*, Wiley, 1st Edition, 2001.
6. J Banks, J. S. Carson II, B. L. Nelson, D. M. Nicol, 2010, Discrete Events System Simulation, 5th Edition, Prentice Hall.

List of Practicals:

1. Discrete vs continuous models (queue vs population growth) **(2 hours)**
2. Deterministic vs stochastic modeling comparison **(2 hours)**
3. Discrete-event single-server queue simulation (M/M/1) **(2 hours)**
4. Continuous simulation with logistic growth ODEs **(2 hours)**
5. Linear Congruential Generator pseudo-random number generation **(2 hours)**
6. Inverse transform sampling for exponential variables **(2 hours)**
7. Acceptance–rejection sampling for complex distributions **(2 hours)**
8. Hazard rate method for survival-time simulation **(2 hours)**
9. Randomness and distribution fit tests (Chi-square, KS) **(2 hours)**
10. Data collection and distribution fitting from real process **(2 hours)**
11. Parameter estimation and confidence interval analysis **(2 hours)**
12. Terminating vs steady-state simulation comparison **(2 hours)**
13. Replications and elimination of initial bias **(2 hours)**
14. Monte Carlo estimation of π and integrals **(2 hours)**
15. Sample paths of Brownian motion, Geometric Brownian motion, square-root diffusion and jump processes **(2 hours)**

DSE406: Graph Neural Networks [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE406	**4**	**3**	**0**	**1**	**Graduation**	Deep Learning

Course Objectives:

This course aims to introduce students to graph-structured data and the principles of graph representation learning. It familiarises students with foundational and advanced Graph Neural Network (GNN) architectures, their training procedures, scalability complexities, interpretability techniques, and real-world applications across domains. Students will explore recent trends and challenges in graph-based deep learning.

Course Learning Outcomes

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

1. Understand graph structures and their mathematical representations.
2. Explain the theoretical foundations of graph neural networks.
3. Apply advanced GNN models to real-world applications.
4. Develop and evaluate GNNs on small- and large-scale graph datasets.
5. Apply and explain interpretability techniques to analyse GNN predictions.

Syllabus

Unit-I **(10 hours)**

Introduction to graph-structured data, graph terminology, types of graphs, adjacency matrices, graph features, real-world graph datasets; Classical graph algorithms, BFS, DFS, PageRank, centrality measures, similarity measures; Introduction to graph representation learning, motivation for graph embeddings, limitations of Euclidean assumptions; Shallow graph embedding methods including DeepWalk, Node2Vec, LINE; Inductive vs transductive learning, challenges in graph-based machine learning.

Unit-II **(12 hours)**

Introduction to Graph Neural Networks, message passing framework, spatial and spectral perspectives; Spectral GNNs, graph Fourier transform, spectral convolution, ChebNet, limitations of spectral methods; Spatial GNNs, Graph Convolutional Networks, GraphSAGE, Graph Attention Networks, propagation and aggregation mechanisms; Training GNNs, loss functions for node classification, link prediction and graph classification, over-smoothing and over-squashing, regularization approaches including DropEdge and normalization techniques.

Unit-III **(12 hours)**

Advanced GNN architectures including Graph Isomorphism Networks, relational GNNs, heterogeneous GNNs, recurrent and temporal GNNs; Graph pooling and readout methods, hierarchical pooling techniques, global pooling strategies; GNN applications in recommender systems, natural language processing, knowledge graphs, computer vision tasks such as scene graph modeling, bioinformatics and molecular graph learning; Graph-level prediction, graph classification, molecular property prediction, graph regression tasks.

Unit-IV **(11 hours)**

Scalable GNN training, neighbour sampling, layer sampling, mini-batch GNNs, distributed GNN frameworks; Explainable Graph Neural Networks, GNNExplainer, PGExplainer, subgraph-based interpretability; Evaluation protocols for node and graph tasks, metrics, ablation analysis, robustness and fairness considerations; Recent trends including Graph Transformers, self-supervised GNNs, graph foundation models, domain-specific GNN applications; Limitations of GNNs, oversmoothing, expressivity bottlenecks, reproducibility challenges, emerging research directions.

Readings

1. Hamilton, W. L. *Graph representation learning*. Morgan & Claypool Publishers, 2020.
2. Wu, L., Cui, P., & Pei, J. (Eds.). *Graph neural networks: Foundations, frontiers, and applications*. Springer, 2022.
3. Stamile, C., De Simone, V., & Bustreo, A. *Hands-on graph neural networks using Python*. Packt Publishing, 2021.

List of practicals:

1. Implement graph data structures using adjacency lists and adjacency matrices, and analyze basic graph properties using NetworkX **(3 hours)**
2. Load and explore real-world graph datasets, perform preprocessing, and prepare data for graph-based learning tasks **(3 hours)**
3. Implement shallow graph embedding methods such as DeepWalk or Node2Vec and visualize learned embeddings **(3 hours)**
4. Set up a GNN framework (PyTorch Geometric or DGL) and build a basic graph neural network model **(3 hours)**
5. Implement a Graph Convolutional Network (GCN) for semi-supervised node classification using citation network datasets **(3 hours)**
6. Build an inductive learning model using GraphSAGE with different aggregation functions and evaluate performance **(3 hours)**
7. Implement a Graph Attention Network (GAT) and analyze attention mechanisms in node classification tasks **(3 hours)**

8. Perform graph-level classification using graph pooling techniques such as TopKPool or SAGPool **(3 hours)**

9. Implement a link prediction model using GNNs with edge splitting and negative sampling **(3 hours)**

10. Apply GNN explainability techniques (GNNExplainer or similar) to interpret node and graph predictions **(3 hours)**

DSE 407: CRYPTOGRAPHY [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE 407	**4**	**3**	**0**	**1**	**Graduation**	**NIL**

Course Objectives:

This course aims to provide a comprehensive understanding of number theory, cryptographic primitives, algorithms and cryptographic techniques used in modern security systems. It covers the foundation of number theory, block ciphers, confidentiality and modular arithmetic, public key cryptography and authentication requirements, integrity checks and authentication algorithms.

Course Learning Outcomes:

Upon successful completion of this course, students will be able to:

1. implement symmetric and asymmetric encryption algorithms
2. describe the role and implementation of digital signatures.
3. provide security of the data over the network.
4. do research in the emerging areas of cryptography

Syllabus:

Unit-I **(10 hours)**

Introduction to Cryptography and Block Ciphers Introduction to cryptography - Conventional Encryption: Conventional encryption model - classical encryption techniques - substitution ciphers and transposition ciphers – cryptanalysis – steganography - stream and blockciphers - Modern Block Ciphers: Block ciphers principals - Shannon's theory of confusion and diffusion - fiestal structure - data encryption standard(DES) - strength of DES - differential and linear cryptanalysis of DES - block cipher modes of operations - triple DES – AES.

Unit-II **(10 hours)**

Confidentiality and Modular Arithmetic Confidentiality using conventional encryption - traffic confidentiality - key distribution - random number generation - Introduction to graph - ring and field - prime and relative prime numbers - modular arithmetic - Fermat's and Euler's theorem - primality testing - Euclid's Algorithm - Chinese Remainder theorem - discrete algorithms.

Unit-III **(13 hours)**

Public key cryptography and Authentication requirements: Principles of public key crypto systems - RSA algorithm - security of RSA - key management – Diffle-Hellman key exchange algorithm - Elliptic curve cryptography – Elgamel encryption - Message Authentication and Hash Function: Authentication requirements - authentication functions - message authentication code - hash functions - birthday attacks – security of hash functions and MACS.

Unit-IV **(12 hours)**

Integrity checks and Authentication algorithms: MD5 message digest algorithm - Secure hash algorithm (SHA) Digital Signatures: Digital Signatures - authentication protocols - digital signature standards (DSS) - proof of digital signature algorithm - Authentication Applications: Kerberos and X.509 - directory authentication service - electronic mail security-pretty good privacy (PGP) - S/MIME.

Readings:

1. Stallings, W. *Cryptography and network security: Principles and practice*. Pearson/PHI.
2. Trappe, W., & Washington, L. C. *Introduction to cryptography with coding theory*. Pearson.
3. Forouzan, B. A., & Mukhopadhyay, D. *Cryptography and network security* (3rd ed.). McGraw-Hill Education, 2015.
4. Elbirt, A. J. *Understanding and applying cryptography and data security*. CRC Press, Taylor & Francis Group, 2015.

List of Practicals:

Students may choose a suitable programming language to do the following lab exercises.

1. Implement the substitution ciphers and transposition ciphers **(2 hours)**
2. Implement stream and blockciphers **(2 hours)**
3. Implement DES and do cryptanalysis of DES **(2 hours)**
4. Implement Chinese Remainder Theorem (CRT) and demonstrate its applications **(2 hours)**
5. Encryption and decryption of files using python's cryptography library to demonstrate symmetric encryption and asymmetric encryption algorithms discussed in the class **(8 hours)**
6. Computation of SHA-512 Hash and HMAC for file integrity verification using a Shared Secret Key. **(4 hours)**
7. Verification of file integrity and displaying "Integrity Verified" or "Integrity Compromised" Based on various hashing algorithms. **(4 hours)**
8. Implementation RSA based Digital Signature algorithms **(2 hours)**
9. Implementation Elliptic curve cryptography based Digital Signature algorithms **(4 hours)**

DSE 408: Computational Linguistics [3-0-1]

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/Practice		
DSE 408	**4**	**3**	**0**	**1**	**Graduation**	**Basic understanding of probability and statistics and familiarity with Python programming**

Course Objectives:

The course builds foundational and practical understanding of linguistic structures, formal grammars, parsing, corpus analysis, and semantic–pragmatic interpretation. It prepares students to design computational models that can effectively analyze, process, and generate natural language.

Course Learning Outcomes:

On completing this course, the student will be able to:

1. Understand major linguistic structures and their role in computational language processing.
2. Apply formal grammar models and parsing techniques to analyze sentence structure.
3. Apply corpus-based analysis to derive linguistic patterns and support data-driven NLP.
4. Evaluate semantic and pragmatic principles to interpret meaning and context in text.
5. Develop and assess basic computational models for effective language analysis and generation.

Syllabus:

UNIT I **(10 Hours)**

Introduction to Computational Linguistics: Nature and structure of natural language; goals of computational analysis; human–computer communication. Historical foundations: Turing Test, ELIZA, early MT systems, smart vs. solid solutions, verification of linguistic theories. Components of linguistic analysis: morphology, syntax, semantics, pragmatics, and their computational roles. Cognitive foundations of language: perception, recognition, context, reference, signs (symbols, indexicals, icons). Overview of SLIM theory: surface compositionality, time-linear processing, internal matching.

Unit II **(10 Hours)**

Formal Grammar: Introduction and role of parsing in CL, Categorial Grammar, Phrase Structure Grammar, adequacy and empirical motivation. Language hierarchies: generative

capacity, complexity classes, Phrase Structure (PS) vs Link-based Analysis (LA) grammar comparison. Parsing concepts: declarative vs procedural parsing, parser-grammar transparency, bottom-up/top-down parsing, convergence, robust parsing. Left-Associative Grammar (LAG): rule types, derivation order, time-linear analysis, LA hierarchy (A/B/C classes), ambiguity handling, linear-time parsing of natural language. Practical aspects: parser implementation, grammar testing on corpora, machine translation basics.

Unit III: (10 Hours)

Morphology: words, morphemes, word forms, segmentation, derivation, inflection, allomorphy. Automatic word-form recognition: rules, left-associative segmentation. Syntax: valency, agreement, word order; fixed vs free word orders; syntactic analysis of English with LA grammar; complex noun phrases, verb forms, interrogatives, subordinate clauses. Corpus analysis: building corpora, word frequency distributions, annotation, statistical tagging - Parts of Speech (PoS), Grammar implementation: testing grammatical rules against corpora, empirical evaluation, parser output analysis.

Unit IV: (15 Hours)

Semantics: types of semantics-logical, procedural, natural language semantics; meaning, truth, intension/extension, propositional attitudes, ontologies, vagueness. Semantic interpretation in computational systems: homomorphic semantics, time-linear interpretation, complexity of semantic processing. Database semantics: meaning as pattern matching, storing propositions in a word bank, semantic relations of structure, content coding (elementary, phrasal, clausal). Pragmatics: reference, context selection, speech acts, interpretation and production modes, conceptualization, inference, autonomous control in communication models. Integration of morphology-syntax-semantics-pragmatics for natural language understanding and generation.

Readings:

1. Hausser, R. (2001). *Foundations of computational linguistics*. Springer-Verlag Telos.
2. Bolshakov, I. A., & Gelbukh, A. (2006). *Computational linguistics: Models, resources, applications*. Computational Linguistics.
3. Grishman, R. (1986). *Computational linguistics: An introduction*. Cambridge University Press.
4. Mitkov, R. (Ed.). (2022). *The Oxford handbook of computational linguistics*. Oxford University Press.
5. Jurafsky, D. (2000). *Speech and language processing*. Pearson Education

List of Practicals:

1. Use standard Python NLP libraries (NLTK and spaCy) to perform basic text preprocessing operations, including tokenisation, stemming, lemmatisation, and stop-word removal. (**2 hours)**
2. Apply advanced text preprocessing techniques using regular expressions to handle pattern matching, text cleaning, removal, and substitution tasks. (**2 hours)**
3. Construct a phrase-structure grammar in NLTK and generate parse trees for basic English sentences using top-down and bottom-up parsers. (**2 hours)**
4. Perform part-of-speech tagging using NLTK and spaCy, compare outputs, and evaluate differences in tagging accuracy across tools.(**2 hours)**

5. Build a mini text corpus, compute word-frequency distributions, and visualize the results using Python. (**2 hours)**
6. Extract semantic relationships such as synonyms, hypernyms, and hyponyms using WordNet, and compute semantic similarity scores. (**4 hours)**
7. Transform text into Bag-of-Words (BoW) and TF-IDF vector representations, and train classifiers such as Logistic Regression and Naïve Bayes.(**4 hours)**
8. Train a Word2Vec model using Python (Gensim) and evaluate its effectiveness by performing vector-semantics tasks and a text-classification experiment. (**4 hours)**
9. Perform K-means clustering on textual data using BoW or TF-IDF vectors and interpret the resulting document clusters. (**4 hours)**
10. Design an end-to-end pipeline that includes preprocessing, vectorization, model training, and evaluation using a real-world text dataset.(**4 hours)**

Annexure-4

Minor Revision in 1st Year of M.Sc. (Computer Science)

1. **Minor Changes in Syllabus of DSC103: Mathematical Foundations of Computer Science**
2. **Addition of DSE 208: Research Methodology**

DSC103: Mathematical Foundations of Computer Science

Existing	Proposed
Course Objectives: This course will discuss fundamental concepts and tools in discrete mathematics with emphasis on their applications to computer science. The objectives of this course comprise providing students with knowledge of logic and Boolean circuits, sets, functions, relations, deterministic and randomised algorithms. Furthermore, the students will learn analysis techniques based on counting methods, recurrence relations, trees and graphs.	**Course Objective:** The objective of this course is to equip students with the selected fundamental concepts in mathematics and statistics that are commonly applied to solve computational problems. The students will learn exploratory data analysis techniques, visualization and basic data science techniques. NLP and Computer Vision applications of basic linear algebra concepts will be covered.
Course Learning Outcomes	**No Change**
Unit-I (8 Hours) **Vectors:** Definition of Vectors, Vector Addition, Dot and Cross Products, Span, Norm of vectors, Orthogonality, geometry of vectors, Application of vectors in document analysis.	**Unit-I (8 Hours)Vectors and Vector Spaces:** Definition of Vectors, Vector Addition, Dot and Cross Products, Span, Norm of vectors, Orthogonality, geometry of vectors; Projection of vector; Vector space, Subspace, Linear Combination, Linear Independence and Dependence, Basis and Dimensions, Convex set
Unit-II (12 Hours) **Matrix Algebra:** Matrix Algebra: Matrices as vectors; Matrix-vector, vector-matrix and matrix-matrix multiplications; Inner and outer products, triangular matrix, diagonal matrix, systems of linear equations, linear independence, determinant, rank of matrix, Eigen values and Eigen vectors, matrix transformations, geometry of transformations, Applications of matrix algebra in image representation and	**Unit-II (15 Hours)** **Matrix Algebra:** Matrices as vectors; Matrix-vector, vector-matrix and matrix-matrix multiplications; Inner and outer products, triangular matrix, diagonal matrix, determinant, rank of matrix, systems of linear equations, LU decomposition, Eigen values and Eigen vectors, matrix transformations, geometry of transformations, PCA, SVD, Applications of

transformations.	matrix algebra in Data Reduction, NLP, Face recognition, .
Unit-III (11 Hours) Probability Theory and Basic Statistics: Sample Space and Events, Probability axioms, Conditional Probability, Bayes' law, Introduction to Descriptive and Inferential Statistics, Describing Data Sets as Frequency tables, Relative frequency tables and graphs, Scatter diagram, Grouped data, Histograms, Ogives; Percentiles, Box Plot, Coefficient of variation, Skewness, Kurtosis.	**Unit-III (8 Hours)** Probability Theory and Basic Statistics: Sample Space and Events, Probability axioms, Conditional Probability, Bayes' Theorem, Joint and Marginal probability, Introduction to Descriptive and Inferential Statistics, Describing Data Sets as Frequency tables, Relative frequency tables and graphs, Scatter diagram, Grouped data, Histograms, Ogives; Percentiles, Box Plot, Coefficient of variation, Skewness, Kurtosis.
Unit-IV (14 Hours) Distributions: Continuous and Discrete random variables, probability density function, probability mass function, distribution function and their properties, mathematical expectation, conditional expectation, Uniform (continuous and discrete), Binomial, Poisson, Exponential, Normal, $\chi 2$ distributions, weak Law of Large Numbers, Central Limit Theorem, Chebyshev's inequality. Stochastic Processes Introduction to stochastic process, Markov Chain, Transition probabilities, Birth-Death process	**Unit-IV (14 Hours) Random Variables and Distributions:** Introduction to random variable, Discrete and Continuous random variables, probability density function, probability mass function, distribution function and their properties, Expectation, Variance, Conditional expectation, Moments, Discrete distributions (Bernoulli, Binomial, Multinomial, Poisson, Geometric), Continuous distributions(Uniform, Exponential, Normal, , $\chi 2$), Markov and Chebyshev's inequality, weak Law of Large Numbers, Central Limit Theorem, Stochastic Processes: Introduction to stochastic process, Markov Chain, Transition probabilities, Birth-Death process
Readings and Practicals	No Change

DSE208: Research Methodology

Course Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE208	4	3	0	1	Graduation	NIL

Course Objective

This course aims to impart the necessary skills to conduct research in computer science, enabling students to understand the research process, from problem identification to publication. The course also introduces students to research ethics.

Course Learning Outcomes

On the successful completion of the course, the student would be able to:

- identify the problem after conducting a literature survey using AI-supported tools.
- define goals, approach, and scope of the research and design the research methodology.
- effectively record and present study findings in a research paper format and prepare for publication.

Syllabus

Unit I **(13 Hours)**

Research Fundamentals: Meaning and significance of research, Characteristics of research, Types of research and research methods, Research process, Qualities of a good researcher, Choosing an appropriate problem area, Identifying sources of research articles, Research repositories and AI-based tools for literature survey, Metrics for research papers, Identifying research gaps, Formulating research questions, Research design.

Unit II **(15 Hours)**

Analysing Data and Experimental Results: Exploring and organising data sets, pre-processing data, and performing Exploratory data analysis, Descriptive statistics, analysing experimental results, Statistical inference, Testing of hypotheses, Interpretation of results, Presentation of experimental results as plots and tables, identification of possible weaknesses of the study.

Unit III **(12 Hours)**

Research Writing and Publication: Structure of the research paper/research proposal, Venues for publication and Funding agencies, Conference and Journal rankings, Process of journal/conference submission and review, Peer review process - single, blind and double blind, Preparing reply to editor and revising manuscript, scientometric analysis - citation index and analysis, plagiarism, plagiarism checker.

Unit IV **(5 Hours)**

Research Ethics: Ethical issues in research, protection from harm, right to privacy, conflict of interest, honesty with professional colleagues, professional code of ethics, intellectual property rights, fraud and misconduct in science, COPE guidelines, Asilomar AI Principles, research for societal good.

Essential/recommended readings

1. Thomas, C. G. (2021). Research Methodology and Scientific Writing, 2nd Ed. Springer.
2. Leedy, P. D., & Ormrod, J. E. (2016). Practical Research: Planning and Design, 11th Ed. Pearson.

Additional References:

1. Ghezzi. C. *Being a Researcher: An Informatics Perspective.* Springer
2. Locharoenrat, K. (2018). *Research Methodologies for Beginners*. PAN Stanford Publication, 2018
3. https://www.unesco.org/en/articles/what-you-need-know-about-unescos-new-ai-competency-frameworks-students-and-teachers?hub=32618

Suggested Practical List

Capstone Project: Students must choose an area of interest for research, based on the curriculum (but not limited by it) covered in the program. They should identify a research problem to solve. During the semester the students must document the research journey in the form of a report, which will be evaluated at the end of the semester. The students are encouraged to write a research paper based on the report, under the guidance of the teacher. The practical class for research methodology course should be utilized to perform the following tasks in the research process.

1. Search the research papers related to the chosen problem using academic search engines like Google Scholar, Scopus search, Web of Science database, etc.
    1. Evaluate the venue of the source of research paper - Journals using citation metrics like CiteScore, SCImago Journal Rank (SJR)), Source Normalized Impact per Paper (SNIP) etc., Conference venues are evaluated using indexing information, Core Ranking etc.
    2. Summarize the reviewed papers in a tabular format with columns: Paper Title, Author(s), Year, Key Findings, and Citation Count.
    3. Explore reference management tools like Mendley / Zotero / EndNote to organize, store, and manage references. (6 hours)

2. Identify a research problem after identifying the research gaps in the literature surveyed in your area of interest. Formulate the research questions that you aim to address. Design methodology to solve the problem, evaluate the performance of the proposed method using appropriate data analysis techniques / statistical tests. Check if the research questions have been answered. If not, note the possible reasons for failure. (15 hours)

3. Write the research report and convert it to the research paper format, as per the chosen venue of publication. (9 hours)

    a) Choose a document writing software and prepare the report as per the format given by the teacher.
    b) Use the plagiarism check tool to assess the similarity index of the report and ensure that it is less than 10%.
    c) Explore the journal finder tools available for the publishers and select a suitable journal to submit the manuscript