SRI SATHYA SAI INSTITUTE OF HIGHER LEARNING
(Deemed to be University)

DEPARTMENT OF MATHEMATICS
AND
COMPUTER SCIENCE

Syllabus for

M.Sc. (Mathematics)

with specialization in

(a) ACTUARIAL SCIENCE

(b) COMPUTER SCIENCE

(Effective from the batch 2018-19 onwards)

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ELECTIVES

SRI SATHYA SAI INSTITUTE OF HIGHER LEARNING

(Deemed to be University)

DEPARTMENT OF MATHEMATICS AND COMPUTER SCIENCE

Syllabus for Two Year M.Sc. in Mathematics

(Effective from the batch 2018-2019 onwards)

M.Sc. (Mathematics)

with specialization in (a) Actuarial Science / (b) Computer Science

INTRODUCTION

M.Sc. Mathematics is a four semester course. The students with B.Sc.(Honours) degree in Mathematics are admitted for this programme. The students after completing the programme either join research work or some professional courses like M.Tech. in Computer Science or take up jobs in various fields including software development. The syllabus of M.Sc.(Mathematics) has been prepared by taking into consideration the GATE and CSIR-UGC syllabi of mathematics.

Programme Objectives

The proposed syllabus aims to achieve the following objectives:

1. To provide broad based knowledge of mathematics. This is achieved by giving the basic Mathematics courses. The areas covered include: Analysis, Algebra, Geometry, Differential equations, Statistics, Operations research etc.

2. To provide scope for choice based electives for the students this programme offers 4 elective courses out of total 18 courses in the programme. Electives are offered from various areas of specialization in mathematics, actuarial science and computer science and listed as different streams. These electives are grouped under different streams from I to VI. Students can take the electives depending on their interest, inclination and guidance, counselling from faculty.

3. Specialization: Keeping in view of the trend in the academic and industrial scenario and also the composition of the faculty in the Department, it is offered that students of M.Sc.(Mathematics) programme may specialize in Computer Science or Actuarial Science. For doing so the student is required to take the four subjects listed as STREAM CORE for a given specialization.

Stream Core	Specialization in Computer Science (CS)	Specialization in Actuarial Science (AS)
Stream Core-I	Computer Organization and Design	Actuarial Mathematics
Stream Core-II	Computer Networks	Applied Statistical Methods
Stream Core-III	Systems Programming	Actuarial Models
Stream Core-IV	Database Systems	Financial Economics

4. Term paper: Students are expected to choose a topic of their interest and take up an expository and comprehensive study based on research and analytical work done under the guidance of a faculty member. The topic should be related to the courses that they have already completed. This is included in the third semester of the programme. At the end of the semester the student will submit a written report and make a seminar presentation.

5. In order to facilitate development of skill in problem solving and to provide exposure to applications of the concepts learnt in a given Theory subject a facility for Tutorial/Practical is also provided within the curriculum. One or two periods per week is provided for Tutorial/Practical for every subject based on the requirement.

6. To provide training in use of Software packages and Computer Programming the syllabus provides scope for one Software laboratory course in the first two semesters for 4 credits each. In these courses the students learn software packages and programming languages by working in different platforms.

Programme Outcomes

At the end of the course, students will have enough theoretical and problem solving knowledge in the area of their specialization. A student will be able to

- Solve problems in the areas of Analysis, Algebra, Geometry, Differential equations, Statistics etc.
- Read, analyze, and write logical arguments to prove mathematical concepts.
- Communicate mathematical ideas with clarity and coherence, both written and verbally.
- Join for Research or M.Tech course depending on his specialization.
- Attempt practical problems in a suitable Industry for real world solutions.
- Understand the core values and philosophy of Sri Sathya Sai Institute of Higher Learning.
- Appreciate Core values in life and living as depicted by Bhagawan Baba.

In order to add value to the specialization chosen by the student, he is permitted to choose one of the labs of his interest. The availability of facility and faculty to run the lab would finally ascertain the approval of the choice. List of lab courses are given below.

<u>LAB Courses pertaining to Computer Science</u>

(i) C++ Programming
(ii) Advanced C++ Programming
(iii) Programming in Python
(iv) Numerical Methods and Simulation Lab
(v) Introduction to SageMath Programming
(vi) Symbolic Computing in SageMath
(vii) Introduction to MATLAB Programming
(viii) Advanced MATLAB Programming
(ix) Introduction to OCTAVE Programming
(x) Advanced OCTAVE Programming
(xi) Data Analysis and Visualization using Python
(xii) Mathematical Methods in Data Mining using Python
(xiii) SQL Programming
(xiv) Core Java Programming
(xv) Operating Systems Lab

<u>LAB Courses pertaining to Actuarial Science</u>

(xvi) Actuarial Mathematics using R
(xvii) Actuarial Mathematics using SAS

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DEPARTMENT OF MATHEMATICS & COMPUTER SCIENCE

SCHEME OF INSTRUCTION AND EVALUATION

M.Sc. (Mathematics)
with specialization in (a) Actuarial Science / (b) Computer Science

(Effective 2018-19 batch onwards)

Paper Code	Title of the Paper	Credits	Hours	Modes of Evaluation	Types of Papers	Maximum Marks
Semester I						
PMAT-101	Advanced Real Analysis	**4**	4	IE2	T	100
PMAT-102	Advanced Linear Algebra	**4**	4	IE2	T	100
PMAT-103	Commutative Algebra	**4**	4	IE2	T	100
PMAT-104(NT)/ “” (CS-COD)/ “” (AS-AM)	Number Theory/ Stream Core-I	**4**	4	IE2	T	100
PMAT-105	Software Lab I ##	**4**	8	I	P	100
PAWR-100	Awareness Course – I: Education for Life	**1**	2	I	T	50
		21 credits	**26 Hours**			**550 Marks**

Semester II						
PMAT-201	Functional Analysis	**4**	4	IE2	T	100
PMAT-202	Probability and Statistics	**4**	4	IE2	T	100
PMAT-203(MT)/ “” (CS-CN)/ “” (AS-ASM)	Measure Theory/ Stream Core-II	**4**	4	IE2	T	100
PMAT-204(TODE)/ “” (CS-SP)/ “” (AS-AMOD)	Theory of Ordinary Differential Equations / Stream Core-III	**4**	4	IE2	T	100
PMAT-205	Software Lab II ##	**4**	8	I	P	100
PMAT-206	Seminar	**1**	1	I	-	50
PAWR-200	Awareness Course – II: God, Society and Man	**1**	2	I	T	50
		22 credits	**27 hours**			**600 marks**

Paper Code	Title of the Paper	Credits	Hours	Modes of Evaluation	Types of Papers	Maximum Marks
Semester III						
PMAT-301	Differential Geometry	**4**	4	IE2	T	100
PMAT-302	Optimization Techniques	**4**	4	IE2	T	100
PMAT-303(TPDE)/ "" (CS-DS)/ "" (AS-FE)	Theory of Partial Differential Equations/Stream Core-IV	**4**	4	IE2	T	100
PMAT-304	Elective - I	**4**	4	IE2	T	100
PMAT-305/ PMAT-405	Term Paper / Dissertation Interim Review*	**2 / --**	--	I	-	50
PAWR-300	Awareness Course – III: Guidelines for Morality	**1**	2	I	T	50
		19/17* credits	**18 Hours**			**500/450 ** marks**
Semester IV						
PMAT-401	Mathematical Modelling	**4**	4	I	P	100
PMAT-402	Elective - II	**4**	4	IE2	T	100
PMAT-403	Elective - III	**4**	4	IE2	T	100
PMAT-404	Elective - IV	**4**	4	IE2	T	100
PMAT-405	Dissertation*	**6**	--	E2	D	200
PMAT-406	Comprehensive Viva voce	**1**	--	E1	COV	50
PAWR-400	Awareness Course –IV: Wisdom for Life	**1**	2	I	T	50
		18/20* credits	**18 hours**			**500/ 600** marks**
	GRAND TOTAL	**80 credits**	**89 hours**			**2150 / 2200** marks**

Specialization: The Department offers specialization in Computer Science or Actuarial Science. For doing so the student is required to take the four subjects listed as STREAM CORE for a given specialization.

Stream Core	Specialization in Computer Science (CS)	Specialization in Actuarial Science (AS)
Stream Core-I	Computer Organization and Design	Actuarial Mathematics
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Stream Core-IV	Database Systems	Financial Economics

Notes:

1. (*) Dissertation PMAT-405 will commence in 3rd semester and continue to 4th semester with the allocation of 6 credits in the fourth semester towards the dissertation work. Dissertation is optional and the students who are desirous of taking dissertation are permitted to commence the work in the third semester in lieu of PMAT-305. Similarly, in the fourth semester a student will continue with the dissertation in lieu of any one course specified under PMAT-402, PMAT-403, and PMAT-404.

2. (**) For students undertaking dissertation (PMAT-405), the evaluation will be based on three components, viz.
    a. A preliminary review of an interim report in respect of the dissertation work (PMAT-405) at the end of 3rd semester will be conducted for 50 marks and the marks allocated will be carried forward to 4th semester PMAT-405 for overall grading. The interim review committee will be constituted by the Head of the Department.
    b. A dissertation Viva voce by a committee constituted by the Head of the Department as per regulations will be conducted for 50 marks in the 4th semester.
    c. An internal and external double evaluation of the Dissertation (written report) at the end of 4th semester will be for 100 marks.

3. Total marks for dissertation will be 200 marks against a total credit of 6 accounted in 4th semester.

4. M.Sc. (Mathematics) programme is offered with specialization in Actuarial Science and Computer Science. For doing so the student is required to do the four Courses defined as the STREAM CORE for the particular stream. Such students are also advised to do at least 2 electives from the designated stream, such as Stream V: Computer Science or Stream VI: Actuarial Science. Otherwise, Candidates will be given a general degree M.Sc. in Mathematics without any specialization.

5. A number of electives have been identified as suitable for consideration in specialization streams. These courses are identified with a special code.

6. Term paper: Students are expected to choose a topic of their interest and take up an expository and comprehensive study based on research and analytical work done under the guidance of a faculty member. The topic should be related to the courses that they have already completed. This is included in the third semester of the programme. At the end of the semester the student will submit a written report and make a seminar presentation. This will be evaluated for 50 marks only.

7. The choice of electives being offered in each semester is at the discretion of the Head of the Department.

To provide training in use of Software packages and Computer Programming the syllabus provides scope for one Software laboratory course in the first two semesters for 4 credits. In these courses the students learn software packages and/or programming languages by working in different platforms.

In order to add value to the specialization chosen by the student, he is permitted to choose one of the labs of his interest. List of labs are given below. The availability of facility and faculty to run the lab would finally ascertain the approval of the choice.

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(xii) Mathematical Methods in Data Mining using Python
(xiii) SQL Programming
(xiv) Core Java Programming
(xv) Operating Systems Lab
(xvi) Actuarial Mathematics using R
(xvii) Actuarial Mathematics using SAS

Indicator	Legend
IE1	CIE and ESE ; ESE single evaluation
IE2	CIE and ESE ; ESE double evaluation
I	Continuous Internal Evaluation **(CIE)** only Note: 'I' does not connote 'Internal Examiner'
E	End Semester Examination **(ESE)** only Note: 'E' does not connote 'External Examiner'
E1	ESE single evaluation
E2	ESE double evaluation

Indicator	Legend
T	Theory
P	Practical
V	Viva voce
PW	Project Work
D	Dissertation

Continuous Internal Evaluation (CIE) & End Semester Examination (ESE)

PS: Please refer to guidelines for 'Modes of Evaluation for various types of papers', and 'Viva voce nomenclature & scope and constitution of the Viva voce Boards'.

M.Sc. MATHEMATICS

LIST OF ELECTIVE COURSES

STREAM-I: Algebra, Geometry & Number Theory (AGN)

AGN-AT	Algebraic Topology
AGN-AG	Algebraic Geometry
AGN-SG	Symplectic Geometry
AGN-FANT	Foundations on Algebraic Number Theory
AGN-ANT	Analytic Number Theory
AGN-RM	Riemannian Manifolds
AGN-DM	Differentiable Manifolds
AGN-CRYPTO	Mathematical Cryptography

STREAM-II: Analysis and Applications (AA)

AA-SSSF	Sobolev Spaces and Sobolev Functions
AA-DT	Distribution Theory
AA-ACA	Advanced Complex Analysis
AA-FAMPDE	Functional Analytic Methods for Partial Differential Equations
AA-STLO	Spectral Theory of Linear Operators
AA-HA	Harmonic Analysis

STREAM-III: Differential Equations and Dynamical Systems (DEDS)

DEDS-DS	Dynamical Systems
DEDS-ANLDS	Advanced Non-Linear Dynamical Systems
DEDS-TS	Time scale
DEDS-IE	Integral Equations
DEDS-CT	Control Theory
DEDS-NSPDE	Numerical Solutions of Partial Differential Equations

STREAM-IV: Applied Mathematics (AM)

AM-CV	Calculus of Variations
AM-FEM	Finite Element Methods
AM-WA	Wavelet Analysis
AM-ME	Mathematical Ecology
AM-MMIP	Mathematical Methods in Image Processing
AM-NMIP	Numerical Methods in Image Processing
AM-IT	Integral Transforms
AM-TAM	Techniques in Applied Mathematics
AM-CS	Computational Statistics
AM-CO	Convex Optimization
AM-GT	Game Theory

STREAM-V : Computer Science (CS)

CS-AI	Artificial Intelligence
CS-CG	Computer Graphics
CS-FLA	Formal Languages and Automata
CS-PR	Pattern Recognition
CS-C	Cryptography
CS-NN	Neural Networks
CS-MMDM	Mathematical Methods for Data Mining
CS-DA	Design of Algorithms
CS-OS	Operating Systems

STREAM-VI: Actuarial Science (AS)

AS-GILH	General Insurance, Life and Health Contingencies
AS-ARMF	Actuarial Risk Management 1 – Foundation
AS-ARMA	Actuarial Risk Management 2 – Advanced
AS-ERM	Enterprise Risk Management

PMAT-101 Advanced Real Analysis **4 Credits**

Course Objectives: This course is an extension to the Basic Undergraduate Real Analysis. This course aims to achieve the following objectives:

- Learning in detail the concepts of pointwise and uniform convergence of continuous functions leading to some very important approximation results.
- Extending the concepts of basic real analysis in R to higher dimensions on R^n and study the mapping theorems.
- Extending the basic Riemann Integration to Riemann Stieltges Integral and further to Lebesgue Integral, thus getting a comprehensive idea of Integration on R.

Course Outcomes: Upon the completion of the course, the student should be

- Able to relate concepts of Finite dimensional vector spaces and Linear Transformations while working with Derivative and use mapping theorems to know the local behaviour of functions.
- Able to approximate continuous functions according to the scenario using the concepts of convergence of functions.
- Able to apply Riemann-Stieltjes Integral to relevant applications
- Able to use the basics of Lebesgue Integration to understand the theory of measure and probability leading to Mathematical Finance and other relevant topics.

Course Syllabus:

Unit 1: **6 periods**
Sequences of Continuous Functions-Limits of Functions

Unit 2: **12 periods**
The Stone And Stone-Weierstrass, Approximation Theorem, Polynomial Approximation Theorem,Tietze's Extention Theorem, Arzela – Ascoli Theorem

Unit3: **3 periods**
The Riemann -Stieltjes Integration – Definition, Examples, criterions, properties.

Unit4: **13 periods**
Lebesgue Measure: Introduction, Outer Measure, Measurable sets, Lebesgue measure, Measurable functions.

The Lebesgue Integral**:** The Lebesgue integral of a bounded function over a set of finite measure, The integral of a nonnegative function, The general Lebesgue integral.

Unit5: **10 periods**
The Derivative In R(P), The Chain Rule, Mean Value Theorem

Unit6: **8 periods**
Mapping Theorems
Total **52 periods**

KEY TEXT BOOK

1. R.G. Bartle, The Elements of Real Analysis, IInd edn, John Wiley 1964.
   [Sections 24, 25, 26, 29.1 – 29.4, 39 To 41(Implicit Function, Rank and Parameterization Theorems are excluded)].

2. Royden, H. L., Real Analysis, Third Edition, (1988), Macmillan Publishing Company. **Chapters:** Ch 3 (sections: 3.1, 3.2, 3.3, 3.5), 4 (sections: 4.2, 4.3, 4.4)

REFERENCES

1. W. Flemming, Functions of Several Variables, Springer Verlag, 1977.
2. Serge Lang, Analysis, Addision - Wesley, 1978.
3. I. Rana, An Introduction to Measure and Integration, Volume. 25, Graduate studies in Mathematics, 2002.

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PMAT-102 Advanced Linear Algebra **4 Credits**

Course Objectives: This is a sequel course to a couple of basic courses students have already completed in linear algebra. This course will meet the following objectives:

- Give both theoretical and practical flavour to advanced concepts in linear algebra.
- Detailed introduction to various factorization methods including QR factorization, LU factorization, SVD decomposition, Cholesky factorization, Hessenberg reduction etc. as tools for solving system of linear equations, least squares problem and eigen value problems
- Present some insights into differences in implementation of algorithms under infinite precision and finite precision arithmetic
- Elucidate on some theoretical development for the case of defective matrices viz Jordan form and functions of non-diagonalizable matrices
- Introduction to modern iterative methods like Krylov subspace methods for solving linear algebra problems when the order of matrices is very large.

Course Outcomes: Upon the completion of the course, the student will be

- Able to differentiate small scale and large scale linear algebra problems
- Choose appropriate tool depending on the structure of the matrix, size of the matrix etc. to solve the given linear algebra problem
- Analyze the linear algebra algorithms for their complexity in terms of space and time
- Able to appreciate the theory behind solutions/algorithms to linear algebra problems
- Ready for taking up courses like Data Science, Machine Learning etc that heavily depends on linear algebra

Course Syllabus:

Unit 1: System of linear Equations and Matrix Algebra
Gaussian Elimination – Making Gaussian Elimination work – Ill-conditioned matrices – Reduced Echelon form – consistency of linear systems – Homogenous and non-homogenous systems – Matrix addition, transposition, multiplication, inverses – sensitivity – Elementary matrices and equivalence – LU factorization **9 periods**

Unit 2: Vector Spaces
Spaces and Subspaces - Four Fundamental Subspaces - Linear Independence - Basis and Dimension - More about Rank - Classical Least Squares – Linear Transformations - Change of Basis and Similarity – Invariant Subspaces **10 periods**

Unit 3: Norms, Inner Products, and Orthogonality
Vector Norms – Matrix Norms – Inner-product Spaces – Orthogonal Vectors – Gram-Scmidt Procedure – Unitary and Orthogonal Matrices – Complementary Subspaces – Range – Null Space Decomposition – Orthogonal Decomposition – Singular Value Decomposition – Orthogonal Projection **–** Orthogonal Reduction **16 periods**

Unit 4: Eigen Values and Eigen Vectors
Elementary Properties of Eigensystems - Diagonalization by Similarity Transformations - Functions of Diagonalizable Matrices - Normal Matrices – Positive Definite Matrices - Nilpotent Matrices and Jordan Structure - Jordan Form– Functions of non-diagonalizable matrices - Minimal Polynomial and Krylov Subspace methods
17 periods

Total **52 periods**

KEY TEXT BOOK

1. Carl D. Meyer, Matrix analysis and Applied Linear Algebra SIAM Publications, ISBN: 978-0-898714-54-8, Year 2000. Chapter 1 (1.2, 1.5, 1.6), 2 (2.1-2.5), 3, 4, 5 (5.1-5.7, 5.9-5.13), 7 (7.1-7.3, 7.5-7.9, 7.11).

REFERENCES

1. Roger A. Horn and Charles R. Johnson, Matrix Analysis, 2nd edition, ISBN: 978-0521548236, Cambridge University Press, Year 2013.

2. James W. Demmel, Applied Numerical Linear algebra, SIAM publications, ISBN: 978-0-89871-389-3, Year 1997.

3. Lloyd Trefethen and David Bau III, Numerical Linear algebra, SIAM Publications, ISBN: 978-0-898713-61-9 (pbk), 1997.

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PMAT-103 Commutative Algebra **4 Credits**

Course Objectives: The aim of the course is to serve as a first level foundational course in commutative algebra. In this course, the students will be introduced to the algebra of rings and modules. The students will also be exposed to certain modules that possess some special properties and relationships between them.

Course Outcomes: Upon the completion of the course, the student will be

- Able to appreciate quotienting as a tool to solve algebraic problems.
- Able to understand vector spaces algebraically as free modules and appreciate the differences between modules defined over different rings.
- Exposed to different kinds of modules based on chain conditions.

Course Syllabus:

Unit 1: Rings, Ideals and Ring Homomorphism **17 periods**
Definition of rings and subrings, units, some examples, characteristic of a ring, definition of ideals, maximal ideals and prime ideals, generators of ideals, basic properties of ideals, algebra of ideals, quotient rings, ideals in quotient rings, local rings, definition of ring homomorphism and basic properties, fundamental theorems of homomorphism, endomorphism rings, fields of fractions, prime fields.

Unit 2: Modules **16 periods**
Definition of modules, examples, direct sums, free modules, vector spaces, quotient modules, homomorphism of modules, simple modules, modules over PIDs.

Unit 3: Modules with Chain Conditions **19 periods**
Artinian modules, Noetherian modules, modules of finite length, Artinian rings, Noetherian rings, radicals, nil radical, Jacobson radical, radical of an Artinian ring.

Total: **52 Periods**

KEY TEXT BOOK
1. C. Musili, Rings and Modules, 2nd revised edition, Narosa Publishing House, 1994. Chapter 1 (Sections 1.1, 1.2, 1.4, 1.7-1.10, 1.12), Chapter 2 (theorem proofs omitted), Chapter 3 (theorem proofs omitted), Chapter 5, Chapter 6.

REFERENCES

1. M. F. Atiyah and I. G. MacDonald, Introduction to Commutative Algebra, Addison-Wesley Publishing House, 1969.
2. Pete L. Clark, Commutative Algebra, 2015. URL: http://math.uga.edu/~pete/integral2015.pdf
3. James S. Milne, A Primer of Commutative Algebra, 2017. URL: http://www.jmilne.org/math/xnotes/CA.pdf

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PMAT-104(NT) Number Theory **4 Credits**

Course Objectives: Number theory is primarily the study of integers and their properties.

To present a rigorous development of Number Theory using axioms, definitions, examples, theorems and their proofs. The course provides students an opportunity to develop an appreciation of pure mathematics while engaged in the study of basic number theoretic results. The course is also designed to provide students an opportunity to work with conjectures, proofs, and analyzing mathematics.

Course Outcomes: After successfully completing this course the student is able to:
1. Define and interpret the concepts of divisibility, congruence, greatest common divisor, prime numbers and Arithmetical functions.

2. Prove statements and solve problems involving divisibility, prime numbers and quadratic residues.

3. Solve various types of congruence problems and use theory of congruences in applications.

4. Construct mathematical proofs of existence of primitive roots modulo m.

5. Apply techniques to solve linear Diophantine equations.

6. Apply properties of multiplicative functions such as Euler's Phi function and Mobius function.

Course Syllabus:

Unit 1: ARITHMETICAL FUNCTIONS AND DIRICHLET MULTIPLICATION:

Introduction- The Mobius function functionμ(n) – The Euler totient function ϕ (n)- A relation connecting ϕ and μ - A product formula for ϕ (n)- The Dirichlet product of arithmetical functions- Dirichlet inverses and the Mobius inversion formula- The Mangoldt function Λ (n)- multiplicative functions- multiplicative functions and Dirichletmultiplication- The inverse of a completely multiplicative function-Liouville's function λ (*n*) - The divisor functions, Generalized convolutions. **14 periods**

Unit 2: CONGRUENCES:

Definition and basic properties of congruences- Residue classes and complete residue systems- Linear congruences- Reduced residue systems and the Euler- Fermat theorem- Polynomial congruences modulo p. Lagrange's theorem- Applications of Lagrange's theorem- Simultaneous linear congruences. The Chinese remainder theorem- Applications of the Chinese remainder theorem- Polynomial congruences with prime power moduli. **11 periods**

Unit3: QUADRATIC RESIDUES AND THE QUADRATIC RECIPROCITY LAW:

Quadratic residues- Legendre's symbol and its properties- Evaluation of (-1/p) and (2/p)- Gauss Lemma-The quadratic reciprocity law-Applications of the reciprocity law-The Jacobi symbol-Applications to Diophantine equations. **11 periods**

Unit4: PRIMITIVE ROOTS:

The exponent of a number mod m. Primitive roots- Primitive roots and reduced residue systems-The nonexistence of primitive roots mod 2^a
for $a \geq 3$ – The existence of primitive roots and p for odd primes p. Primitive roots and quadratic residues- The existence of primitive roots mod p^a- The existence of primitive roots mod 2 p^a- The nonexistence of primitive roots in the remaining cases- The number of primitive roots mod m. **16 periods**

Total **52 periods**

KEY TEXT BOOK

1. Tom M. Apostol, **Introduction to Analytic Number Theory**, Springer International Student Edition, ISBN 3-540-78031-9.

[Chapter 2**:**Sections 2.1 to 2.14, Chapter 5: Sections 5.1 to 5.9,
Chapter 9: Sections 9.1 to 9.8 and Chapter 10 : Sections 10.1 to 10.9]

REFERENCES

1. G.H. Hardy and E.M. Wright, D.R. Heath-Brown, J.H. Silverman, "An Introduction to the Theory of Numbers", Oxford University Press, sixth edition.
2. Ivan Niven, Herbert S. Zuckerman, Hugh L. Montgomery, "An Introduction to the Theory of Numbers", Wiley student edition.

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PMAT-201 Functional Analysis **4 Credits**

Course Objectives: Modern Analysis is built over the ideas of Functional Analysis. Many problems of classical analysis pertaining to Real Analysis, Complex Analysis, Differential Equations, Integration Theory, Harmonic Analysis, and Probability Theory can be efficiently tackled with the language of Functional Analysis. The aim of the course is to learn basic notions and tools of Banach and Hilbert spaces, linear operators and the four pillars of Banach space theory namely Hahn-Banach Theorem, Uniform Bounded Principles, Open Mapping Theorem and Closed Graph Theorem.

Course Outcomes:

1. Student should know the basic notions of Banach space and linear operators defined on these spaces.

2. Student should have a working knowledge of two example sequences spaces and function spaces.

3. Student should know basic geometric and analytic properties of Hilbert spaces.

4. Student should appreciate the role of Riesz Representation Theorem and its application to Adjoint of a bounded operator on Hilbert spaces.

5. Student should be to able provide Baire's category argument to Banach spaces.

6. Student should know the four fundamental theorems of Functional Analysis (Hahn Banach Theorem, Uniform-Boundedness Theorem, Open Mapping Theorem and Closed Graph Theorem) and its application to Bounded Operators on Banach spaces and also to Classical Analysis.

Course Syllabus:

Unit 1: Metric Spaces, Examples, Convergence, Cauchy Sequences, Completeness **5 periods**

Unit 2: Normed Spaces, Properties, Finite Dimensional Normed Spaces, Compactness and Finite Dimensional normed space **5 periods**

Unit 3: Linear operators, Bounded linear operators, Linear Functionals**,** Linear operators and linear functionals on finite dimensional spaces, Normed spaces of operators, Dual spaces. **7 periods**

Unit 4: Inner product spaces, Hilbert spaces, Properties, Orthogonal Complements and Direct Sums, Orthogonal sets and sequences, Series, Total Orthonormal sets and sequences **6 Periods**

Unit 5: Representation of functional on a Hilbert space, Hilbert adjoint Operator, Self adjoint, Unitary, Normal operators **7 periods**

Unit 6: Hahn Banach Theorems, Apppications to C[a,b], Adjoint operators, Reflexive spaces **8 periods**

Unit 7: Category Theorem, Uniform Boundedness Principle, Strong Weak Convergence, Operators and functional convergence **6 periods**

Unit 8: Open mapping theorem, Closed linear operators, Closed graph theorem **8 periods**

Total **52 periods**

KEY TEXT BOOK

1. Kreyszig, Functional Analysis, John Wiley & Sons, 1978. [Chapters: 1 To 4]

REFERENCES

1. G. Bachmann & L. Narici, Functional Analysis, Academic Press Pub.1966.

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PMAT-202 Probability and Statistics **4 Credits**

Course Objectives
The main objective of this course is to provide students with the foundations of probabilistic and statistical analysis mostly used in varied applications in engineering and science disciplines like disease modeling, climate prediction and computer networks etc.

Course Outcomes
On completion of this course the student

1. Will be able to appreciate the importance of probability and statistics in computing and research
2. Will develop skills in presenting quantitative data using appropriate diagrams, tabulations and summaries
3. Will be able to use appropriate statistical methods in the analysis of simple datasets
4. Will be able to interpret and clearly present output from statistical analysis in a clear, concise and understandable manner.

Course Syllabus:

Unit 1: Introduction
Why study statistics? - Modern Statistics- Population and Sample. **2 periods**

Unit 2: Organization and Description of Data
Pareto and Dot diagrams – Frequency distributions – Stem and Leaf displays – Descriptive measures – Quartiles and percentiles – Calculation of $\bar{X}$ and S. **5 periods**

Unit 3: Probability
Sample spaces and events – Counting – Probability – Axioms of probability – Some elementary theorems – Conditional probability – Bayes theorem – Normal expansion **5 periods**

Unit 4: Probability distributions
Random Variables – Binomial distributions – mean and variance of a probability distribution – Chebyshev's theorem – Poisson distribution and rare events – Poisson processes. **5 periods**

Unit 5: Probability Densities
Continuous random variables – Normal distribution – Normal approximation to binomial distribution – Uniform Distribution – Log-Normal distribution – Joint distribution (Discrete and Continuous) - Checking if Data are normal **5 periods**

Unit 6: Sampling distributions
Population and samples – Sampling distribution of mean (Variance known and unknown) – Sampling distribution of the variance **4 periods**

Unit 7: Inference concerning a Mean
Point Estimation – Interval estimation – Maximum likelihood estimation – Test of hypotheses – Null hypotheses and test of hypotheses – Hypotheses concerning one mean **8 periods**

Unit 8: Comparing two treatments
Experimental designs for comparing two treatments – comparing two independent small samples – matched pairs comparisons **5 periods**

Unit 9: Inferences concerning populations
Estimation of proportions – Hypotheses concerning one proportion – Hypotheses concerning several proportions – Analysis of r x c tables **4 periods**

Unit 10: Regression Analysis
Least squares – Inference based on least squares estimators – curvilinear regression **5 periods**

Unit 11: Factorial experimentation
Two-factor experiments – Multifactor experiments **4 periods**

Total **52 periods**

KEY TEXT BOOK
1. Miller & Freund's Probability and statistics for engineers, Ninth edition, Global edition. Richard A. Johnson, Pearson Publications, 2017. ISBN 978-0-321-98624-5

Chapters: 1 (1.1, 1.2, 1.6), 2, 3, 4(4.1 – 4.7), 5(5.1-5.6, 5.10, 5.12), 6(6.1 - 6.4), 7(7.1-7.7), 8(8.1 - 8.4), 10(10.1-10.4), 11(11.1 – 11.3), 13(13.1 – 13.2)

REFERENCES
1. Prasanna Sahoo, Probability and Mathematical Statistics, 2008.

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PMAT-203(MT) Measure Theory **4 Credits**

Course Objectives: Measure Theory provides a rigorous foundation for several branches of Analysis, in particular, Integration Theory and Probability Theory. The course first builds the abstract theory of measures by discussing the algebra of sets, inner and outer measures. Then, a detailed introduction of Lebesgue integral by bringing out the distinctions with the Riemann Integral. The function space L^p is also introduced.

Course Outcomes:

1. Student will be comprehending an abstract view point of Probability and Integration Theories.
2. Student learns about the algebra of sets and their utility in defining a measure.
3. Student can relate to the notion of measurability (and non-measurability) of sets and understand the relevance of Axiom of Choice in this context.
4. Student can define the Lebsegue Integral and distinguish from that of the Riemann Integral.
5. Student is introduced to the L^p spaces.

Course Syllabus:

Unit 1: Semi Rings and Algebra of Sets	**6 periods**
Unit 2: Measures on Semi Ring	**4 periods**
Unit 3: Outer Measures and Measurable Sets	**6 periods**
Unit 4: The Outer Measure Generated by a Measure	**5 periods**
Unit 5: Measurable Functions	**4 periods**
Unit 6: Simple and Step Functions	**4 periods**
Unit 7: TheLebesgue Measure	**4 periods**
Unit 8: Upper Functions	**4 periods**
Unit 10: Integrable Functions	**6 periods**
Unit 11: The Reimann Integral as a Lebesgue Integral (Statements only)	**1 period**
Unit 12: L^p spaces	**8 periods**
Total	**52 periods**

KEY TEXT BOOK

1. Charalambos D. Aliprantis and Owen, Principles of Real Analysis, IInd Edition. Burkinshow] Academic Press Inc., [Sections.9 to 19 and 31].

REFERENCES

1. H.L. Royden, Real Analysis, Macmillan Pub.1968.
2. P.R. Halmos, Measure Theory, Dvan Pub.1968.

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PMAT-204(TODE) Theory of Ordinary Differential Equations

4 Credits

Course Objectives: This course aims at providing basics of rigorous theory of Ordinary Differential Equations. This course is about qualitatively analysing the ODE by first learning the Basic Existence and Uniqueness of solutions of ODE or system of ODEs and studying the asymptotic behaviour of solutions if they exist without actually computing them.

Course Outcomes: After going through the course the student will be able to:

- Apply Existence and Uniqueness theorem to ODEs or system of ODEs to know the existence/uniqueness of solution.
- Solve Linear systems of ODEs using appropriate matrix methods and Exponential of a matrix.
- Study the types of Non-Linear systems and solutions for a few specific systems.
- Apply stability tests to know the stability of the solution of systems of ODEs.

Course Syllabus:

Unit 0: Gronwall's Inequality **2 Periods**

Unit 1: Linear Systems with an Introduction to Phase Space Analysis 12 Periods
Existence and Uniqueness for Linear Systems - Homogeneous and Nonhomogeneous Systems - Systems with Constant Coefficients – Asymptotic Behaviour - Autonomous Systems - Phase Space - Two Dimensional Systems - Periodic Coefficients.

Unit 2: Existence Theory: 12 periods
Existence in Scarlar Case - Existence Theory for Systems of First Order Equations - Uniqueness and Continuation of Solutions – Dependence on Initial - Conditions and Parameters.

Unit 3: Stability of Linear and Almost Linear Systems : 12 periods
Definitions of Stability – Linear Systems – Almost Linear Systems.

Unit 4: Lyapunov's Second Method: 14 periods
Lyapunov's Theorems and Proofs

Total 52 periods

KEY TEXT BOOK

1. F. Brauer and J.A. Nohel, Benjamin, Qualitative Theory of Ordinary Differential Equations, 1967. [Chapters 1:Sec.1.7 Only; Chapter 2: Except Sec. 2.6; Chapter 3; Chapter 4 : Except Sec 4.6 ; Chapter. 5: Except Sec. 5.4 And 5.5]

REFERENCES

1. E.A. Coddington & N. Levinson, Theory Of Ordinary Differential Equations, Tata McGraw Hill pub,1972.
2. N.Rouche & M. Loloy, Stability Theory By Liapunov's Direct Method, Springer - Verlag Pub, 1977.

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PMAT-301 Differential Geometry **4 Credits**

Course Objectives: This course aims at the study of geometric objects using differential calculus as a tool. In this course, the students will be introduced to modelling geometric shapes as mathematical entities and study their properties. The students will also be exposed to calculation of some local and global properties of the surfaces.

Course Outcomes: Upon the completion of the course, the student will be

- Able to model an n-dimensional smooth geometric shape as a level set suspended in an (n+1)- dimensional space and study its properties.
- Able to appreciate the concept of shortest path from one point to another on a generic smooth surface.
- Exposed to modelling an n-dimensional surface as a parametrization.
- Exposed to calculation of curvature, surface area and volume of different surfaces.

Course Syllabus:

Unit 1: Graph and Level Sets	**2 periods**
Unit 2: Vector Fields, Tangent Spaces	**5 periods**
Unit 3: Surfaces, Vector Fields on Surfaces, Orientation	**4 periods**
Unit 4: The Gauss Map	**3 periods**
Unit 5: Geodesics	**4 periods**
Unit 6: Parallel Transport	**4 periods**
Unit 7: The Weingarten Map	**5 periods**
Unit 8: Curvatures of Plane Curves	**4 periods**
Unit 9: Arc length and Line Integrals	**4 periods**
Unit 10: Curvature of Surfaces	**5 periods**
Unit 11: Parameterized surfaces	**5 periods**
Unit 12: Surface Area and Volume	**7 periods**
Total:	**52 Periods**

KEY TEXT BOOK

1. J. A. Thrope, Elementary Topics in Differential Geometry, Sringer-Verlag, 1979.Chapters 1 to 12 (Chapter 6 theorem no proof, Chapter 11 theorem 1 no proof), 14 and 17.

REFERENCES

1. W. Klingenberg, A Course in Differential Geometry, Springer-Verlag, 1978.
2. A. N. Pressley, Elementary Differential Geometry, Second Edition, Springer, 2010.

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PMAT-302 Optimization Techniques **4 Credits**

Course Objectives: In this course, the students will be introduced to the mathematical formulation of optimization. The students will be exposed to a spectrum of optimization techniques and their applicability.

Course Outcomes: Upon the completion of the course, the student will be

- Able to apply mathematical skills to model optimization problems.
- Able to critically analyze theoretical principles and choose the relevant optimization techniques for a specific problem.
- Exposed to solutions for various types of optimization problems and will be enabled to adopt them for situation at hand.

Course Syllabus:

Unit 1: Mathematical Review – Lines – Hyperplanes and linear varities – convex sets – neighborhoods – polytopes and polyhedra – derivative matrix – level sets and gradients-Taylor's series (**3 periods**)

Unit 2: Unconstrained Optimization – conditions for local minimizers – one dimensional serach methods including golden section, Fibonacci, bisections and Newton's method – line search in multidimensional optimization - Gradient methods including steepest descent, Newtons method and its modifications – conjugate direction methods – Quasi-Newton methods including DFP and BFGS algorithm – Bacpropagation algorithm in neural networks **(16 periods)**

Unit 3: Linear Programming - standard form – basic solutions – properties of basic solutions – geometric view – simplex method, two-phase simplex method and revised simplex method - duality **(8 periods)**

Unit 4: Non-linear constrained optimization – problems with equality constraints – Lagrange condition – second-order condition – minimizing quadratics subject to equality constraints – problems with inequality constraints – Karush-Kuhn-Tucker conditions – second-order conditions (**10 periods)**

Unit 5: Convex Optimization Problems - Convex Functions - Convex Optimization Problems – semi-definite programming **(6 periods)**

Unit 6: Algorithms for constrained optimization – projected gradient methods with linear constraints – Lagrangian algorithms – penalty methods **(9 periods)**

Total **(52 periods)**

KEY TEXT BOOK

Edwin K. P. Chong and Stanislaw H. Zak, An Introduction to Optimization, Wiley Inter-science Publication, John Wiley and Sons Inc., ISBN 978-1-118-27901-4, 2013, 4^{th} edition.

Chapters: 4, 5(5.3-5.6), 6, 7(7.1-7.5, 7.8), 8, 9, 10, 11, 13, 15, 16, 17, 18, 20, 21, 22, 23.

REFERENCES

1. L.R. Foulds, Optimization Techniques, Springer, Utm, 1981
2. Boyd, Stephen, and Lieven Vanderberghe, Convex Optimization. Cambridge, UK: Cambridge University Press, 2004.
3. http://freevideolectures.com/Course/3072/Numerical-Optimization

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PMAT-303 (TPDE) Theory of Partial Differential Equations

4 Credits

Course Objectives: Using the tools of calculus, the course covers the basic methods of solving linear and non-linear partial differential equations. No assumptions on the knowledge of Analysis is made. Fundamental equations such as Laplace, Heat, Transport and Wave equation are discussed in detail. Fourier Transform in the higher dimensions is also introduced. For solving first order partial differential equations with real coefficients, the method of characteristics is employed.

Course Outcomes:

1. Student will be able the classify a given partial differential equation.
2. Student can discuss the role of fundamental solution and its utility for basic equations such as Laplace, Heat and Wave equations.
3. Student learns approach to solve partial differential equations through transforms techniques. In particular, the student learns higher dimensional Fourier Transform.
4. Student learns the method of characteristic and its geometric insights to solve a first order partial differential equation with real coefficients.
5. Students also appreciates the role of symmetry in solving partial differential equations.

Course Syllabus:

Unit 0: Review of Calculus Facts: Boundaries, Gauss-Green theorem, Polar coordinates, Coarea formula **2 Periods**

Unit 1: Convolution and Smoothing **4 Periods**

Unit 2: Singles and Systems of PDEs and Strategies for studying PDE **1 Period**

Unit 3: Transport equations: IVP, Nonhomogeneous **2 Periods**

Unit 4: Laplace's equation: fundamental solution, mean-value formulas, properties of harmonic functions, green's function, energy methods **10 Periods**

Unit 5: Heat equation: fundamental solution, mean-value formulas, properties of solution, energy method **9 Periods**

Unit 6: Wave equations: solution of wave equation, d'Alembert's formula and Spherical means **4 Periods**

Unit 7: Non-linear first-order PDE: complete integrals, envelops, characteristics **10 Periods**

Unit 8: Similarity methods and Transform methods: Fourier transform, Laplace transform, Converting nonlinear into linear PDE **10 Periods**

Total: **52 periods**

KEY TEXT BOOK

1. Lawrence C. Evans, Partial Differential Equations, Graduate Studies in Mathematics, Volume 19, 1997. Chapters: 1, 2 (sec 2.1 to 2.3 and 2.4.1), 3 (sec 3.1 to 3.2), 4 (sec 4.2, 4.3, 4.4), Appendix C.1, C.2, C.3, C.4, D.5

REFERENCES

1. Francois Treves, Basic Linear Partial Differential Equations, Dover Publications, Inc.

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PMAT-401 Mathematical Modelling **4 Credits**

Course Objectives: In this course, the students will be introduced to both deterministic and stochastic methods of mathematical modeling. The students will be introduced to working in a group and communicating mathematics to achieve a realistic model of a given scenario.

Course Outcomes: Upon the completion of the course, the student will be

- Able to understand the use of mathematics to solve a variety of problems across various disciplines.
- Able to appreciate the ideas and interconnections between various branches of mathematics when they become relevant in the contexts at hand.
- Able to apply core techniques of mathematical modeling to model, analyze and interpret real life scenarios.
- Able to formulate and communicate effectively the mathematical models of situations.

Course Syllabus:

Unit 1: Deterministic analysis of observations
Data transformations (linear models), model development (polynomial models), model evaluation (population modeling), the advantage of modeling (global warming modeling) **7 Periods**

Unit 2: Stochastic analysis of observations
Model errors, optimal linear models **7 Periods**

Unit 3: Deterministic states
Dimensionality analysis and similarity, applications of low complexity **8 Periods**

Unit 4: Stochastic states
Probability density functions, models for probability density functions, data analysis, real distributions **8 Periods**

Case studies **22 Periods**

Total **52 Periods**

Practical: Students (in groups) will develop models on their own, submit a report, make presentations.

KEY TEXT BOOK
1. Stefan Heinz, Mathematical Modeling, Springer-Verlag Berlin Heidelberg, First Edition, 2011.
[Chapters 1,2.1-2.3,3.1-3.3,5,7.1-7.4,9.1-9.3]

REFERENCES

1. Frank R. Giordano, William P. Fox and Steven B. Horton, A first course in Mathematical Modeling, Fifth Edition, Brooks/Cole CENGAGE Learning, 2014.
2. Mike Mesterton-Gibbons, A concrete approach to Mathematical Modeling, John Wiley & Sons, 1995.

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* Case studies will be selected by the instructor.

* Completely internal evaluation: CIEs

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STREAM CORE- I: Computer Science (CS)

PMAT 104(CS-COD) Computer Organization and Design

4 Credits

Course Objectives:
The aim of this course is to introduce students to the foundation of computer design, implementation, and the shift to modern architecture design principles. In particular, students will demonstrate an understanding of basic concepts of performance measures, computer arithmetic, instruction set design, computer micro architecture, and memory hierarchy.

Course Outcome: Student who has undergone the course will be able to:

- Differentiate two computers with respect to their performance with regard to speed, power consumption etc.
- Appreciate the design principles of instruction set and understand the rationale for different addressing modes, instruction formats etc.
- Understand computer arithmetic and computer data representation formats.
- Understand arithmetic and logical unit design and implementation.
- Demonstrate knowledge of computer micro architecture related concepts such as simple CPU design and its implementation, instruction fetch mechanisms, f branch prediction mechanisms, basic instruction execution pipeline etc.
- Demonstrate knowledge of memory hierarchy of register, cache, main, and virtual memories.
- Understand and differentiate between spatial and temporal localities as well as other memory access patterns.

Course Syllabus:

Unit 1: **2 Periods**
Introduction, Performance, the Power Wall, the Switch from Uniprocessors to Multiprocessors, Historical Perspective.

Unit 2: **8 Periods**
Instruction Set Design, Operations of the Computer Hardware, Operands of the Computer Hardware, Signed and Unsigned Numbers, Representing Instructions in the Computer, Logical Operations, Instructions for Making Decisions, Supporting Procedures in Computer Hardware, MIPS Addressing for 32-Bit Immediates and Addresses, Parallelism and Instructions.

Unit 3: **10 Periods**
Arithmetic for Computers, Addition and Subtraction, Multiplication, Division, Floating Point representation, Parallelism and Computer Arithmetic.

Unit 4: **16 Periods**
The Processor Logic Design Conventions, Building a Datapath, Pipelining, Pipelined Datapath and Control, Data Hazards: Forwarding vs. Stalling, Control Hazards, Exceptions, Parallelism and Advanced Instruction Level Parallelism.

Unit 5: **16 Periods**

Memory Hierarchy, The Basics of Caches, Measuring and Improving Cache Performance, Virtual Memory, A Common Framework for Memory Hierarchies, Parallelism and Memory Hierarchies: Cache Coherence

Total **52 Periods**

KEY TEXT BOOK

1. Patterson, David A. and Hennessy, John L, Computer Organization and Design: The Hardware/Software Interface, Fourth Edition. [From Chapters 1, 2, 3, 4, 5]

REFERENCES

1. Randal E. Bryant and David R. O'Hallaron, Computer Systems: A Programmer's Perspective, Prentice Hall, 2011 (Second Edition).
2. John P. Hayes, Computer Architecture and Organization, McGraw Hill Edition.

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STREAM CORE- II: Computer Science (CS)

PMAT 203(CS-CN) Computer Networks 4 Credits

Course Objectives: The aim of this course is to introduce students to various types of networks such as local, metropolitan, and wide area networks, standard OSI & TCP/IP reference models, important Internet protocols and design issues across different layers, discussion of various networking technologies.

Course Outcomes:

1. To master the terminology and concepts of the OSI and TCP/IP reference models
2. To master the concepts of protocols, network interfaces, and design/performance issues in local area networks and wide area networks
3. To have sufficient knowledge in reliable communication principles in Transport layer and also routing strategies in network layer
3. To be familiar with wireless networking concepts
4. To be familiar with contemporary issues in networking technologies such as network security, mobility in cellular networks, multicast routing, congestion in networks etc.

Course Syllabus:

Unit 1: 2 periods
Introduction -Network edge, Network core, ISPs and Internet, Protocol Layers and service models, OSI, TCP/IP reference models.

Unit 2: 10 periods
Application Layer: Principles, Web and HTTP, FTP, SMPT, DNS, Peer-to-Peer Applications

Unit 3: 10 periods
Transport Layer: Services, Multiplexing and demultiplexing, principles of reliable data transfer, connection oriented transport, TCP, Connectionless support, UDP, Congestion control.

Unit 4: 10 periods
Network Layer and Routing : Service models, datagram service virtual circuit service, routing principles, routing algorithms, IP protocol, routing in internet, IPV6, Multicast routing.

Unit 5: 10 periods
Link Layer and LAN: The Data Link Layer services, Error Detection and Correction, Multiple Access protocols, LAN addresses and ARP, Bridges, Routers. Wireless and Mobile Networks: Wireless links, characteristics, CDMA, IEEE 802.11 wireless LANs, Cellular Internet Access, addressing and routing to mobile users, Mobile IP, Handling mobility in cellular networks.

Unit 6: **10 periods**

Network Security: Principles of Cryptography, Authentication Protocols, Digital Signatures, Message Digests, Key distribution and certification, Packet Sniffing, Secure email, secure sockets, IPsec

Total **52 periods**

KEY TEXT BOOK

1. Jim Kurose, Keith Ross, Computer Networks: A Top down Approach Featuring the Internet, Fifth Edition, Pearson Education, 2010.
[Chapters 1, 2.1 - 2.6,3, 4.1 - 4.7,5.1 – 5.6, 6.1 – 6.7, 8]

REFERENCES

1. William Stallings, Data and Computer Communications, VIIth Edn, Pearson Education, 2005.

2. Andrew S. Tanenbaum, Computer Networks, IV Ed, Pearson Education, 2003.

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STREAM CORE- III: Computer Science (CS)

PMAT 204(CS-SP) Systems Programming 4 Credits

Course Objectives: This course objective is to make a student understand the basics of system programs such as compiler, assembler, linker, loader. It delivers various key concepts of system software and their principles of working.

Course Outcomes: At the completion of this course, a student should be able to

1. Understand and explain the basics of system programs like editors, compiler, assembler, linker, loader, interpreter etc.
2. Implement a two pass strategy algorithm for a simple assembler, macro processor.
3. Understand and explain the basics of various phases of compiler and compare its working with assembler.
4. Understand how linker and loader create an executable program from an object module created by Assembler and compiler.
5. Implement lexical analyser for simple statements and a recursive descent parser for syntactic analysis.

Course Syllabus:

Unit 1: **3 Periods**
Introduction

Unit 2: **6 Periods**
Simplified Instructional Computer

Unit 3: **12 Periods**
Assemblers

Unit 4: **10 Periods**
Loaders and Linkers,

Unit 5: **6 Periods**
Macro Processors

Unit 6: **15 Periods**
Compilers

Total **52 periods**

KEY TEXT BOOK

1. Leland Beck, Systems Programming, III Ed, Pearson Education, 1997.
[Ch 1(1.1 – 1.3), Ch 2(2.1 – 2.4), Ch 3(3.1 – 3.4), Ch 4(4.1 – 4.3), Ch 5(5.1 – 5.3), Ch 6(6.1 – 6.3)]

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STREAM CORE- IV: Computer Science (CS)

PMAT 303(CS-DS) Database systems 4 Credits

Course Objectives: This course is aimed to serve as a first level course to introduce relational database management systems (RDBMS). The students will be exposed to basics of RDBMS and its design. The students will also be exposed to transactions.

Course Outcomes: Upon the completion of the course, the student will be

- Able to appreciate the relational algebra aspects of database tables and various operations on them.
- Able to draw Entity-Relationship (ER) models from a given requirement specifications of a database system.
- Able to build a schema from an ER model.
- Able to analyse the normal form of the schema given the functional dependencies in the system.
- Exposed to ACID properties of transactions in RDBMS.

Course Syllabus:

Unit 1: **3 periods**
Introduction to Database Management Systems

Unit 2: **10 periods**
Relational Model

Unit 3: **12 periods**
SQL – Other Relational Languages

Unit 4: **8 periods**
Database Design and ER Model

Unit 5: **8 periods**
Relational Database Design

Unit 6: **6 periods**
Object Based Databases

Unit 7: **5 periods**
Transactions

Total **52 periods**

KEY TEXT BOOK

1. Abraham Silberschatz, Henry F. Korth, S. Sudarshan, Database System Concepts, Vth edn, Tata McGraw Hill, 2005, [Chapters 1,2,3,5,6,7,9,15].

REFERENCES

1. Raghu Ramakrishnan, Johannes Gehrke, Database Management Systems, IIIrd Edition, Tata McGraw Hill, 2002.
2. Micahael V. Mannino, Database Design, Applications and Administration with ER assistant, IInd edn, Tata McGraw Hill, 2002.
3. Connolly and Begg, Database Systems: A practical approach to design, implementation, and Management, IVth Edition, Pearson Education, 2005.

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STREAM CORE- I: Actuarial Science (AS)

PMAT 104(AS-AM) Actuarial Mathematics 4 Credits

Course objectives:
The aim of the Actuarial Mathematics subject is to provide a grounding in financial mathematics and its simple applications.

Course Outcomes:
On completion of the subject the trainee actuary will be able to:

(i) Describe how to use a generalised cashflow model to describe financial transactions.
(ii) Describe how to take into account the time value of money using the concepts of compound interest and discounting.
(iii) Show how interest rates or discount rates may be expressed in terms of different time periods.
(iv) Demonstrate a knowledge and understanding of real and money interest rates.
(v) Calculate the present value and the accumulated value of a stream of equal or unequal payments using specified rates of interest and the net present value at a real rate of interest, assuming a constant rate of inflation.
(vi) Define and use the more important compound interest functions including annuities certain.
(vii) Define an equation of value.
(viii) Describe how a loan may be repaid by regular instalments of interest and capital.
(ix) Show how discounted cashflow techniques can be used in investment project appraisal.
(x) Describe the investment and risk characteristics of the various types of asset available for investment purposes.
(xi) Analyse elementary compound interest problems.
(xii) Calculate the delivery price and the value of a forward contract using arbitrage free pricing methods.
(xiii) Show an understanding of the term structure of interest rates.
(xiv) Show an understanding of simple stochastic models for investment returns.

Course Syllabus:

Unit -1 (13 Periods)
Cashflow models, The time value of money, Interest rates, Real and money interest rates, Discounting and accumulating, Level annuities, Deferred and increasing annuities,

Unit -2 (14 Periods)
Equations of value, Loan schedules, Project appraisal

Unit -3 (13 Periods)
Investments, Elementary compound interest problems, Arbitrage and forward contracts

Unit -4 **(12 Periods)**

Term structure of interest rates, Stochastic interest rate models

Total **52 periods**

KEY TEXT BOOK

An introduction to the mathematics of finance. McCutcheon, J. J.; Scott, W. F.Heinemann, 1986. 463 pages. ISBN: 9780434912285. (Chapters 1 to 7 and Chapter 10)

REFERENCES

1. Bowers, N. L.; Gerber, H. U.; Hickman, J, C. et al., In Actuarial mathematics, 2nd ed. Society of Actuaries, 1997. 753 pages. ISBN: 9780938959465.
2. Butcher, M. V., Mathematics of compound interest, Nesbitt, C. J. Ulrich's Books, 1971. 324 pages. ISBN: 9780960300013.
3. Ingersoll, J. E. Rowman & Littlefield, 1987, Theory of financial decision making. 474 pages. ISBN: 9780847673599.
4. Kellison, S. G., The theory of interest. 3rd ed. Irwin, 2008. 463 pages. ISBN: 9780073382449.
5. Gerber, H. U., Life insurance mathematics, 3rd ed. Springer; Swiss Association of Actuaries, 1997. 217 pages. ISBN: 9783540622420.

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STREAM CORE-III: Actuarial Science (AS)

PMAT 203(AS-ASM) Applied Statistical Methods **4 Credits**

Course objectives:
The aim of the Statistical Methods subject is to provide a further grounding in mathematical and statistical techniques of particular relevance to financial work.

Course Outcome:
On completion of the subject the trainee actuary will be able to:

(i) Explain the concepts of decision theory and apply them.
(ii) Calculate probabilities and moments of loss distributions both with and without limits and risk-sharing arrangements.
(iii) Construct risk models involving frequency and severity distributions and calculate the moment generating function and the moments for the risk models both with and without simple reinsurance arrangements.
(iv) Explain the concept of ruin for a risk model. Calculate the adjustment coefficient and state Lundberg's inequality. Describe the effect on the probability of ruin of changing parameter values and of simple reinsurance arrangements.
(v) Explain the fundamental concepts of Bayesian statistics and use these concepts to calculate Bayesian estimators.
(vi) Describe and apply techniques for analysing a delay (or run-off) triangle and projecting the ultimate position.
(vii) Explain the fundamental concepts of a generalised linear model (GLM), and describe how a GLM may apply.
(viii) Define and apply the main concepts underlying the analysis of time series models.
(ix) Explain the concepts of "Monte Carlo" simulation using a series of pseudo-random numbers.

Course Syllabus:

Unit 1 **(13 Periods)**
Decision theory, Bayesian statistics, Loss distributions, Reinsurance

Unit 2 **(15 Periods)**
Credibility theory, Empirical Bayes credibility theory, Risk models - Collective Risk Model, Risk models - Individual Risk Model

Unit 3 **(14 Periods)**
Ruin theory, Generalised linear models, Run-off triangles.

Unit 4 **(10 Periods)**
Time series - Auto Regressive models, Time series - ARCH, GARCH models, Monte Carlo simulation

Total **52 periods**

KEY TEXT BOOK

Loss models: from data to decisions. - Klugman, Stuart A; Panjer, Harry H; Willmot, Gordon E; Venter, Gary G. - John Wiley & Sons, 1998. 644 pages. ISBN: 0 471 23884 8. (Chapters 5 and 6, Chapters 9 to 11, Chapters 15, Chapters 20 and 21)

Mathematical statistics. Freund, John E f - 6th ed. - Prentice Hall International, 1999. 624 pages. ISBN: 0 13 974155 0 (Chapter 9)

REFERNCES

1. Dobson, Annette J., An introduction to statistical modelling, - Chapman & Hall, 1983. 125 pages. ISBN: 0 412 24860 3.
2. Hossack, Ian B, Pollard, John H, Zehnwirth, Benjamin, Introductory statistics with applications in general insurance, - 2nd ed. - Cambridge University Press, 1999 - 282 pages. ISBN: 0 521 65534 X.
3. Daykin, Chris D; Pentikainen, Teivo; Pesonen, Martti, Practical risk theory for actuaries, Chapman & Hall, 1994. 545 pages. - ISBN: 0 412 42850 4.

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STREAM CORE- IV: Actuarial Science (AS)

PMAT 204(AS-AMOD) Actuarial Models 4 Credits

Course objectives:
The aim of the Models subject is to provide a grounding in stochastic processes and survival models and their application.

Course Outcomes:
On the successful completion of this subject, the candidate will be able to:

(i) Describe the principles of actuarial modelling.
(ii) Describe the general principles of stochastic processes, and their classification into different types.
(iii) Define and apply a Markov chain.
(iv) Define and apply a Markov process.
(v) Explain the concept of survival models.
(vi) Describe estimation procedures for lifetime distributions.
(vii) Derive maximum likelihood estimators for the transition intensities in models of transfers between states with piecewise constant transition intensities.
(viii) Describe the Binomial model of mortality, derive a maximum likelihood estimator for the probability of death and compare the Binomial model with the multiple state models.
(ix) Describe how to estimate transition intensities depending on age, exactly or using the census approximation.
(x) Describe how to test crude estimates for consistency with a standard table or a set of graduated estimates, and describe the process of graduation.

Course Syllabus:

Unit 1 **(15 Periods)**
Principles of actuarial modeling, stochastic processes, Markov chains, The two-state Markov model

Unit 2 **(11 Periods)**
Time-homogeneous Markov jump processes, Time-inhomogeneous Markov jump processes

Unit 3 **(10 Periods)**
Survival models, Estimating the lifetime distribution function, The Cox regression model

Unit 4 **(16 Periods)**
The Binomial and Poisson models, Exposed to risk, Graduation and statistical tests, Methods of graduation

Total **52 periods**

KEY TEXT BOOK
Kulkarni, Vidyadhar G, Modeling, analysis, design, and control of stochastic systems, Springer, 1999. 374 pages. – ISBN: 0 387 98725 8. (Chapters 1, 2, 4 and 5)

Elandt-Johnson, Regina C; Johnson, Norman L, Survival models and data analysis, John Wiley & Sons, 1999, 457 pages. – ISBN: 0 47134992 5. (Chapters 2 Sec 2.10, 3, 4 and 6)

REFERENCES

1. Macdonald A S, *An Actuarial Survey of Statistical Models for Decrement and Transition Data,* British Actuarial Journal 2 (1996).

2. Brzezniak, Zdzislaw; Zastawniak, Tomasz, Basic stochastic processes; A course through exercises – Springer, 1998. - 225 pages. – ISBN: 3 540 76175 6.

3. Hickman, James C., Introduction to actuarial modeling, North American Actuarial Journal (1997) 1(3) 1-5.

4. Grimmett, Geoffrey; Stirzaker, David, Probability and random processes, 3rd ed. –Oxford University Press, 2001. 596 pages. – ISBN: 0 19 857222 0.

5. Bowers, Newton L; Gerber, Hans U; Hickman, James C;Jones, Donald A; Nesbitt, Cecil J., Actuarial mathematics - 2nd ed., - Society of Actuaries, 1997. 753 pages. - ISBN: 0 938959 46 8.

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PMAT 303(AS-FE) Financial Economics 4 Credits

Course objectives:
The aim of the Financial Economics subject is to develop the necessary skills to construct asset liability models and to value financial derivatives. These skills are also required to communicate with other financial professionals and to critically evaluate modern financial theories.

Course Outcomes:
On completion of the subject the trainee actuary will be able to:

(i) Describe and discuss the application of utility theory to economic and financial problems.

(ii) Discuss the advantages and disadvantages of different measures of investment risk.

(iii) Describe and discuss the assumptions of mean-variance portfolio theory and its principal results.

(iv) Describe and discuss the properties of single and multifactor models of asset returns.

(v) Describe asset pricing models, discussing the principal results and assumptions and limitations of such models.

(vi) Discuss the various forms of the Efficient Markets Hypothesis and discuss the evidence for and against the hypothesis.

(vii) Demonstrate a knowledge and understanding of stochastic models of the behaviour of security prices.

(viii) Define and apply the main concepts of Brownian motion (or Wiener Processes).

(ix) Demonstrate a knowledge and understanding of the properties of option prices, valuation methods and hedging techniques.

(x) Demonstrate a knowledge and understanding of models of the term structure of interest rates.

(xi) Demonstrate a knowledge and understanding of simple models for credit risk.

Course Syllabus:

Unit I. Introduction – Efficient Market Hypothesis, Risk Assessment (13 Periods)

Introduction to financial economics, Efficient Market Hypothesis (EMH), Evidence for and against EMH, Utility theory, stochastic dominance and behavioral finance, Measures of investment risk, Portfolio theory, Models of asset returns

Unit II. Determination of Efficient Frontier using Statistical and Economic Pricing Models (9 Periods)

Asset pricing models, Brownian motion and martingales, stochastic calculus and Ito processes, stochastic models of security prices

Unit III. Introduction to Stochastic Models (15 Periods)

Introduction to the valuation of derivative securities, The Greeks, The binomial model, The Black-Scholes option pricing formula

Unit IV. Properties and Valuation of Derivatives (15 Periods)

The 5-Step method in discrete time, The 5-step method in continuous time, Term Structure of interest Rates, Credit Risk Models: JLT Model, Two State Model.
Tutorials: 1 period per week

Total 52 periods

KEY TEXT BOOK

Elton, Edwin J, Martin J Gruber, Stephen J Brown, & William N Goetzmann, Modern portfolio theory and investment analysis (6^{th} edition), John Wiley, 2003 (Chapters: 1, 4, 5,6, 13, 17, 20)

Hull, John C, Options, Futures and other derivatives (5th edition), Prentice Hall, 2002. (Chapters: 1, 12, 13, 14, 18, 20, 23, 30)

REFERENCES

1. Baxter, Martin & Andrew Rennie, Financial calculus; An introduction to derivative pricing, Cambridge University Press, 1996.
2. Panjer, Harry H (ed), Financial economics: with applications to investments, insurance and pensions, The Actuarial Foundation, 1998.

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M.Sc. MATHEMATICS with

Specialization in Actuarial Science
Specialization in Computer Science

LIST OF ELECTIVE COURSES

STREAM-I: Algebra, Geometry & Number Theory (AGN)

AGN-AT	Algebraic Topology
AGN-AG	Algebraic Geometry
AGN-SG	Symplectic Geometry
AGN-FANT	Foundations on Algebraic Number Theory
AGN-ANT	Analytic Number Theory
AGN-RM	Riemannian Manifolds
AGN-DM	Differentiable Manifolds
AGN-CRYPTD	Mathematical Cryptography

STREAM-II: Analysis and Applications (AA)

AA-SSSF	Sobolev Spaces and Sobolev Functions
AA-DT	Distribution Theory
AA-ACA	Advanced Complex Analysis
AA-FAMPDE	Functional Analytic Methods for Partial Differential Equations
AA-STLO	Spectral Theory of Linear Operators
AA-HA	Harmonic Analysis

STREAM-III: Differential Equations and Dynamical Systems (DEDS)

DEDS-DS	Dynamical Systems
DEDS-ANLDS	Advanced Non-Linear Dynamical Systems
DEDS-TS	Time scale
DEDS-IE	Integral Equations
DEDS-CT	Control Theory
DEDS-NSPDE	Numerical Solutions of Partial Differential Equations

STREAM-IV: Applied Mathematics (AM)

AM-CV	Calculus of Variations
AM-FEM	Finite Element Methods
AM-WA	Wavelet Analysis
AM-ME	Mathematical Ecology
AM-MMIP	Mathematical Methods in Image Processing
AM-NMIP	Numerical Methods in Image Processing
AM-IT	Integral Transforms
AM-TAM	Techniques in Applied Mathematics
AM-CS	Computational Statistics
AM-CO	Convex Optimization
AM-GT	Game Theory

STREAM-V : Computer Science (CS)

CS-AI	Artificial Intelligence
CS-CG	Computer Graphics
CS-FLA	Formal Languages and Automata
CS-PR	Pattern Recognition
CS-C	Cryptography
CS-NN	Neural Networks
CS-MMDM	Mathematical Methods for Data Mining
CS-DA	Design of Algorithms
CS-OS	Operating Systems

STREAM-VI: Actuarial Science (AS)

AS-GILH	General Insurance, Life and Health Contingencies
AS-ARMA	Actuarial Risk Management 1 – Foundation
AS-ARMA	Actuarial Risk Management 2 – Advanced
AS-ERM	Enterprise Risk Management

STREAM-I: Algebra, Geometry & Number Theory (AGN)

AGN-AT	Algebraic Topology
AGN-AG	Algebraic Geometry
AGN-SG	Symplectic Geometry
AGN-FANT	Foundations on Algebraic Number Theory
AGN-ANT	Analytic Number Theory
AGN-RM	Riemannian Manifolds
AGN-DM	Differentiable Manifolds
AGN-CRYPTO	Mathematical Cryptography

AGN-AT Algebraic Topology **4 Credits**

Course Objectives: Algebraic Topology studies the properties of topological spaces and maps between them by associating algebraic invariants (fundamental groups, homological groups, cohomology groups) to each space. The course covers topics that are relevant from an application point of view to branches of physics and computer science.

Course Outcomes:

1. Student can explain the fundamental concepts of algebraic topology and their role in modern mathematics.
2. Student can comprehend the relevance of group theoretic approach to study of topological spaces.
3. Student will be able to reduce the space to a simple geometric structure and understand its homological properties.

Course Syllabus:

Unit 1:
Geometric Complexes and Polyhedra-Orientation of Geometric Complexes.
Simplicial Homolgy Groups-Chains-Cycles-Boundaries-Euler Poincare Theorem
-Simplicial Approximation. **15 periods**

Unit 2:
Homomorphism of Homolgy Groups-The Brouwer Fixed Point Theorem and Related Results. **15 periods**

Unit 3:
Fundamental Groups-Homototpic Paths-Covering Homotopy. Covering Spaces-Basic Properties of Covering Spaces-Classification of Covering Spaces-Universal Covering Spaces. **15 periods**

Unit 4:
Higher Homotopy Groups. **7 periods**

Total **52 Periods**

KEY TEXT BOOK

1. Fred. H. Croom, Basic concepts of Algebraic Topology, Springer-Verlag, 1978, [Chapters: 1 to 6].

REFERENCES

1. James R. Munkres, Elements of Algebraic Topology, Benjamin / Cummins, 1984.

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AGN-AG Algebraic Geometry 4 Credits

Course Objectives: Assuming a prerequisite of Commutative Algebra and Differential Geometry the course discusses the concepts of surface from an algebraic point of view called as Varieties. The course covers the material in a highly abstract view of sheaves and schemes. A brief introduction is also given.

Course Outcomes:

1. Student appreciates an algebraic approach to study of geometry.
2. Student learns the necessity of prime ideals and how to use them for defining a surface.
3. Student learns to work on both affine and projective coordinates.
4. Student is introduced to the definition of the schemes.
5. Student learns a bit of sheaf theory and cohomologies.

Course Syllabus:

Unit 1:
Varieties: Affine and Projective varieties, Morphisms, Regular functions and Maps, Non-singular curves, Non-singular varieties. Intersection of projective spaces.
20 Periods

Unit 2:
Sheaves: Sheaves, Schemes, Properties of schemes, Separated and proper morphisms, Sheaves of modules, Divisors. Projective morphisms, Differentials, Formal Scheme. **20 Periods**

Unit 3:
Cohomologies: Derived Functors, Cohomology of sheaves, Cohomology of Noetherian Affine Schemes. Cech Cohomolgy. **12 Periods**

Total **52 periods**

KEY TEXT BOOK

1. Robin Hartshorne, Algebraic geometry, Volume 52 of Graduate texts in mathematics, Ed. 8, Springer. Chapters: 1, 2, 3(3.1 to 3.4).

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AGN-SG Symplectic Geometry 4 Credits

Course Objectives: Symplectic Geometry has emerged a geometry of physics. In particular, the topics of classical mechanics, quantum mechanics and optics can be viewed from a theoretical viewpoint. It is interesting that this geometry finds fruitful applications in understanding the solvability of partial differential equations. In this course, a basic introduction is given to the subject and its applications to the cotangent bundle space are discussed.

Course Outcomes:

1. Student learns Symplectic Linear Algebra and its necessity in defining the symplectic manifolds.
2. Students can provide a few examples of symplectic spaces, especially those that have cotangent bundle structure.
3. Student learns different (isotropic, coisotropic and lagrangian) submanifolds of a symplectic manifold.
4. Student can construct product manifolds from given symplectic manifolds.

Course Syllabus:

Unit 1:	Symplectic Forms	**14 Periods**
Unit 2:	Symplectic Form on the Cotangent Bundle	**12 Periods**
Unit 3:	Lagrangian Sub manifold	**14 Periods**
Unit 4:	Generating Functions	**12 Periods**
Total:		**52 periods**

KEY TEXT BOOK

Ana Cannas da Silva, Lectures on Symplectic Geometry, Lecture Notes in Mathematics, 1764, Springer, 2001.

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AGN-FANT Foundations on Algebraic Number Theory

4 Credits

Course objectives: Assuming that a student has prerequisite foundations in commutative algebra and number theory, the course discusses the algebraic treatment of Number Theory.

Course outcomes: After having gone through the course, a student will be able to

- Appreciate the use of commutative algebra as a tool for solving number theoretic problems.
- Appreciate the different types of algebraic structures that appear in number theory.

Course Syllabus:

Unit 0: **6 periods**
Elementary Number Theory: Integers, Applications of Unique Factorization, The ABC Conjecture, Euclidean Rings: Preliminaries, Gaussian Integers, Eisenstein Integers.

Unit 1: **12 periods**
Algebraic Numbers and Integers: Basic concepts, Liouville's theorem, and generalizations, Localization, Integral closure, Prime Ideals, Chinese reminder theorem, Galois Extensions, Dedekind rings, discrete, valuation rings, Explicit factorization of a prime, projective modules over Dedekind rings.

Unit 2: **10 periods**
Completions: Definitions and completions, Polynomial in complete fields, some filtrations', unramified extensions, Tamely ramified extensions.

Unit 3: **12 periods**
Integral Bases: The Norm and the Trace, Integral Basis of an Algebraic Number Field and its existence, Minimal Integers, Some Integral Bases in Cubic Fields, Index and Minimal Index of an Algebraic Number Field, Integral Basis of a Cyclotomic Field.

Unit 4: **12 periods**
Dedekind Domains :Dedekind Domains, Ideals in a Dedekind Domain, Factorization into Prime Ideals, Order of an Ideal with respect to a Prime Ideal, Generators of Ideals in a Dedekind Domain, Integral Closure (recap), Characterizing Dedekind Domains, Fractional Ideals and Unique Factorization, Dedekind's Theorem.

Total **52 periods**

KEY TEXT BOOK

1. Saban Alaca and Kenneth S. Williams, Introductory Algebraic Number Theory, Cambridge University Press, 2004, (Chapters 7, 8).
2. M. Ram Murty and Jody Esmonde, Problems in Algebraic Number Theory, Springer, Second Edition, 2004, (Chapters 1- 5).
3. Serge Lang, Algebraic Number Theory, Springer, Second Edition, 1994, (Chapters 1, 2).

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AGN-ANT Analytic Number Theory 4 Credits

Course Objectives : To illustrate how general methods of analysis can be used to obtain results about integers and prime numbers and investigate the Distribution of prime numbers.

Course Outcomes: After successfully completion of this course student will be able to:

1. Prove elementary results on sums over primes and will be calculate averages of arithmetical functions.
2. Understand better the Distribution of prime numbers.
3. To understand the proof of Dirichlet's theorem.
4. Know the basic theory of Riemann zeta and L- functions.
5. Prove some analytic properties of Riemann zeta function including an analytic continuation, a zero-free region and estimates of growth of zeta function.

Course Syllabus:

Unit-I: AVERAGES OF ARITHMETICAL FUNCTIONS: Introduction - The big oh notation. Asymptotic equality of functions- Euler's summation formula- Some elementary asymptotic formulas - The average order of d(n)- The average order of the divisor functions - The average order of ϕ(n). The partial sums of a Dirichlet product- Applications to μ (n) and Λ(n)- Another identity for the partial sums of a Dirichlet product **-** The partial sums of a Dirichlet product- Applications to μ(n) and Λ(n)- Another identity for the partial sums of a Dirichlet product. **14 periods**

Unit-II: SOME ELEMENTARY THEOREMS ON THE DISTRIBUTION OF PRIME NUMBERS

Introduction- Chebyshev's functions ψ(x) and ϑ(x) - Relations connecting ϑ(x) and π(x) – Relations connecting ϑ(x) and π(x) - Some equivalent forms of the prime number theorem – Inequalities for μ(n) and P_n - Shapiro's Tauberian theorem – Applications of Shapiro's theorem – An asymptotic formula for the partial sums – The partial sums of the Mobius function. **12 periods**

Unit-III: FINITE ABELIAN GROUPS AND THEIR CHARACTERS

Characters of finite abelian groups. The Character group, The Orthogonality relations for characters, Dirichlet characters, Sums involving Dirichlet characters, The novanishing of L(1,χ) for real nonprincipal χ. **8 periods**

Unit-IV: DIRICHLET SERIES AND EULER PRODUCTS

The half- plane of absolute convergence of a Dirichlet series, The function defined by Dirichlet series, Multiplication of Dirichlet series, Euler Products, The half-plane of convergence of a Dirichlet series, Analytic properties of Dirichlet series, Dirichlet series with non-negative coefficients. **18 periods**

Total **52 periods**

TEXT BOOK

T.M. Apostol, Introduction to Analytic Number Theory - Springer Verlag-New York. Chapter -3:- Articles 3.1 to 3.7 and Articles 3.10, 3.11, Chapter-4:- Articles 4.1 to 4.9, Chapter-6 :- 6.5 to 6.10, Chapter- 11:- Articles 11.1 to11.7

REFERENCES

1. M. Ramamurthy: "Problems in Analytic Number Theory" Springer, 2007, Second Edition.
2. A. J. Hildebrand: "Introduction to Analytic Number Theory"

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AGN-RM Riemannian Manifolds **4 Credits**

Course Objectives:

- To introduce the idea of connection and covariant differentiation on a manifold
- To introduce curvature, exterior calculus and involutivity of distributions
- To introduce Jacobi fields on Riemannian manifolds and manifolds with constant curvature

Course Outcomes: At the end of this course, students will be able to

- compute the covariant derivatives of vector and tensor fields
- compute curvature, verify associated identities, compute exterior derivatives and check the involutivity of the standard distributions.
- relate the Jacobi fields with first and second variation, forms and be able to know the canonical forms and the criteria for constancy of curvature.

Course Syllabus:

Unit 1: Tensors and forms **5 Periods**

Unit 2: Connexions – Invariant viewpoint – Cartan viewpoint – coordinate viewpoint – difference tensor of two connexion **10 Periods**

Unit 3: Riemmanian Manifolds and submanifolds – Length and distance – Riemannian connexion and curvature – curves in Riemannian manifolds – submanifolds – canonical spaces of constant curvature –Existence **15 Periods**

Unit 4: Operators on Forms and Integration – Exterior derivative – contraction **8 Periods**

Unit 5: The Existence theory–Involutive distributions and the Frobenius theorem **6 Periods**

Unit 6: Topics in Riemannian geometry – Jacobi Fields and conjugate points – First and second variation formulae – Manifolds with constant Riemannian curvature **8 Periods**

Total **52 periods**

KEY TEXT BOOK

1. Noel J Hicks, Notes on Differential Geometry, Von no strand Riehold Company, Litton Educational Publishing Inc, 1965.
   Chapters: 4, 5.1, 5.2, 5.3, 5.4, 6.1, 6.2, 6.3, 6.4, 6.7, 6.8, 7.1, 7.2, 9.1, 10.1, 10.2, 10.6

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AGN-DM Differentiable Manifolds **4 Credits**

Course Objectives:

- To introduce the basic structure of a manifold and submanifold.
- To introduce the tangent space, vector fields, line integration and immersion.
- To introduce Lie groups and Lie algebras, exponential map and homogenous spaces.

Course Outcomes:

- The students will be able to comprehend the underlying structures of a manifold and verify them on standard examples of manifolds and submanifolds.
- The student will be able to formulate the tangent space to a manifold from that of other manifolds, and also how to integrate a form obtained by an induced map.
- The students will be able to understand Lie groups and their Lie algebras through matrix examples, later adjoint representation and finally understanding a homogenous space through Lie group actions (emphasizing on standard examples)

Course Syllabus:

Unit 1: Differentiable Manifolds – Topological Manifolds – charts, atlases, smooth structures - smooth maps and diffeomorphisms – cut-off functions and partition of unity – coverings and discrete groups – regular submanifolds – manifolds with boundary.
14 periods

Unit 2: The tangent structure – tangent space and maps – tangents of products – tangent and cotangent bundles – vector fields and 1-forms – line integrals and conservative fields – moving frames. **14 periods**

Unit 3: Immersion and Submersion – Immersions – Immersed and weakly embedded submanifolds – submersions. **12 periods**

Unit 4: Lie Groups – Linear Lie groups – Lie group homomorphisms – Lie algebras and exponential maps – adjoint representation – Maurer-Cartan form – Lie group actions – homogenous spaces – combining representations. **12 periods**
TOTAL **52 Periods**

KEY TEXT BOOK

1. Jeffrey M. Lee, Manifolds and Differential geometry, Graduate studies in Mathematics, Volume 107, American Mathematical Society, Indian Edition. [Chapters: 1, 2, 3 and 5].

REFERENCES

1. William. M. Boothby, An Introduction to Differentiable Manifolds, Academic Press, 1975.
2. Ralph Abraham, Jerrold. E. Marsden, Tudor Ratice, Manifolds, Tensor Analysis and Applications, Addison-Wesley, 1983.
3. Auslander, and Mackenzie, Introduction to Differentiable Manifolds, McGraw hill, 1963.

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AGN-CRYPTO Mathematical Cryptography 4 Credits

Total Periods: **52**

Course Objective:

1. To offer number theoretic preliminaries for widely used public-key cryptosystems.
2. To teach public-key cryptographic primitives and their role in communication.

Course Outcome:

The students will be able to

1. Appreciate the role of mathematics in cryptography.
2. Understand how secure communications happen over insecure channels.
3. Appreciate how computational complexities form the basis of public-key cryptography.
4. Understand the importance of data secrecy, data integrity, and data authentication and the ways to achieve them.
5. Understand key-agreement, public-key encryption and digital signatures.

PMAT : Mathematical Cryptography			
Unit No.	**Unit Title**	**Unit Contents**	**No. of Periods**
1	Introduction to Cryptography	Simple substitution ciphers-Divisibility and GCD(without proofs) – Modular arithmetic- Prime numbers, unique factorization and finite fields-Powers and primitive roots in finite fields.	6
2	Discrete Logarithms and Diffie – Hellman Key Exchange	The birth of public key cryptography- Discrete Logarithm Problem-Diffie-Hellman key exchange- ElGamal public key cryptosystem-The Chinese remainder theorem.	10
3	Integer Factorization and RSA	Euler’s formula and roots modulo pq – RSA public key cryptosystem-Implementations and security issues-Primality testing-Pollard’s p-1 factorization algorithm-Quadratic residues and Quadratic reciprocity-Probabilistic encryption	10
4	Elliptic Curves and Cryptography	Elliptic Curves(Theorems without proofs)- Elliptic Curves over finite fields-Elliptic Curve Discrete Logarithm Problem-Elliptic Curve Cryptography and Lenstra’s ECFM.	12
5	Digital Signatures	Digital Signatures – An Over View and Definitions-RSA Digital Signatures	2
KEY TEXT BOOK: An Introduction to Mathematical Cryptography, Authors : Jeffrey Hoffstein, Jill Pipher and Joseph H. Silverman, ISBN : 978-1-4419-2674-6, Springer, 2010.			
Chapters: 1.1-1.5, 2.1-2.4, 2.8, 3.1-3.5 (excluding 3.4.1 & 3.4.2), 3.9-3.10, 5.1-5.4,5.6, 7.1-7.2.			
REFERENCES: 1. Neal Koblitz, A Course in Number Theory and Cryptography, Springer, 1994. 2. Jonathan Katz and Yehuda Lindell, Introduction to Modern Cryptography, Second edition, CRC Press, 2015. 3. Douglas R.Stinson, Cryptography Theory and Practice, CRC Press, Third edition, 2005			

STREAM-II: Analysis and Applications (AA)

AA-SSSF	Sobolev Spaces and Sobolev Functions
AA-DT	Distribution Theory
AA-ACA	Advanced Complex Analysis
AA-FAMPDE	Functional Analytic Methods for Partial Differential Equations
AA-STLO	Spectral Theory of Linear Operators
AA-HA	Harmonic Analysis

AA-SSSF Sobolev Spaces and Sobolev Functions 4 Credits

Course Objectives: Assuming a prerequisite of Functional Analysis and Lp-spaces an introduction to Sobolev spaces is given. Various analytic properties, inequalities and embedding theorems on Sobolev functions are proved.

Course Outcomes:

1. Student can define and provide examples of Sobolev spaces.
2. Student can discuss the behaviour of the (generalized) derivative of Sobolev functions.
3. Student can provide an intuitive view of the indices associated with the Sobolev spaces and discuss the embedding theorems.
4. Student can prove several inequalities on the Sobolev functions, including the important Poincare inequality.

Course Syllabus:

Unit 1: Sobolev Spaces and their Basic Properties **20 periods**

Unit 2: Point-wise Behaviour of Sobolev Functions **20 periods**

Unit 3: Poincare Inequalities-A Unified Approach. **12 periods**

Total **52 periods**

KEY TEXT BOOK

1. William. P. Ziemer, Weakly Differentiable Functions, Springer-Verlag, 1989. New York, [Chapters.2 to 4].

REFERENCES

1. R.A. Adams, Sobolev Spaces, Academic Press,1975
2. C.W.Clark, Introduction To Sobolev Spaces, University Columbia Pub, 1968.

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AA-DT Distribution Theory 4 Credits

Course Objectives: Assuming a prerequisite of Functional Analysis this course discuss a generalized view of functions and the associated differential calculus. These generalized functions, also called as distributions, provide a natural framework for solutions of partial differential equations. The course also discusses in detail the Fourier Transform of these generalized functions.

Course Outcomes:

1. Student can provide a comprehensive view point to the concept of distribution or generalized function.
2. Student can perform algebraic operations and differential calculus on distributions.
3. Student can determine the fourier transform of the distributions and solve linear differential equations using fourier transform.
4. Student can associate the distributions with the classical functions such as continuous and differentiable functions through the Structure theorems.

Course Syllabus:

Unit 1: What are Distributions?	**8 periods**
Unit 2: The Calculus of Distributions	**8 periods**
Unit 3: Fourier Transforms	**10 periods**
Unit 4: Fourier Transforms of Tempered Distributions	**8 periods**
Unit 5: Solving Partial Differential Equations	**8 periods**
Unit 6: The Structure of Distributions	**10 periods**
Total	**52 periods**

KEY TEXT BOOK

1. Robert S. Strichartz, A guide to distribution theory and Fourier transforms, Edition2, illustrated, reprint Publisher World Scientific, 2003. Chapters: 1 to 6

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AA-ACA Advanced Complex Analysis **4 Credits**

Course Objectives: This is an advanced level course in Complex Analysis of one variable. The course dwells deeper into the analytic properties of holomorphic and harmonic functions. The course intends to focus on topics that were dealt in an elementary complex analysis course from a more deeper point of view.

Course Outcomes:

1. Student will be able to discuss the properties of holomorphic and harmonic functions.
2. Student can prove the Maximum Modulus Principle and prove its corollaries.
3. Student will get more acquainted with rational functions on single complex variables and, its zeroes and poles.
4. Student appreciates the role of analytic continuation.

Course Syllabus:

Unit 1: Elementary Properties of Holomorphic Functions	**7 periods**
Unit 2: Harmonic Functions	**7 periods**
Unit 3: The Maximum Modulus Principle	**7 periods**
Unit 4: Approximation by Rational Functions	**7 periods**
Unit 5: Conformal Mapping	**8 periods**
Unit 6: Zeros of Holomorphic Functions	**8 periods**
Unit 7: Analytic Continuation	**8 periods**
Total	**52 periods**

KEY TEXT BOOK

1. Walter Rudin, Real and complex analysis, McGraw-Hill International Editions, Ed. 3, revised, 1987.Chapters: 10 to 16.

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AA-FAMPDE Functional Analytic Methods for Partial Differential Equations

4 Credits

Course Objectives: Assuming the course Functional Analysis as a prerequisite this course covers essentials tools for the theory of partial differential equations pursued from a functional analytic viewpoint. The course covers the theory of generalized functions, also called as distributions, and the operations and fourier transform on these are also discussed. Sobolev spaces are introduced from fourier transform and several pointwise properties of these functions are proved. The notion of weak derivative is also introduced in the context of solving partial differential equations using the Galerkin method.

Course Outcomes:

1. Student becomes familiar with the notion of weak derivative and the differential calculus associated with the generalized functions , called distributions.
2. Student can compute the fourier transform of tempered distribution and also can discuss the properties of fourier transform.
3. Student can comprehend the use of Sobolev spaces in the theory of partial differential equations and work out some embedding theorems.
4. Student becomes familiar with the approximation method to solve partial differential equations using functional analytic approach called the Galerkin method.

Course Syllabus:

Unit 1: Distribution Theory
Test functions, Operations on distributions, Supports and singular supports of distributions, convolutions, fundamental solutions, The Fourier transform, Schwartz space, The Fourier Inversion formula, Tempered Distributions. **20 periods**

Unit 2: Sobolev Spaces
Definitions and basic properties, Approximation by smooth functions, Extension theorem, Imbedding theorems, Compactness theorem, Dual spaces, Fractional order spaces, Trace spaces, Trace theory. **20 periods**

Unit 3: Weak Solutions of Elliptic Boundary Value Problems
Abstract Variational problems, Regularity of weak solutions, Galerkin method, Maximum principles, Eigen values problems, Introductions to the Finite Element Methods.
12 periods

Total **52 periods**

KEY TEXT BOOK

1. S Kesavan, Topics in Functional Analysis and Applications, Wiley Eastern Limited, 1989, [Chapters: 1, 2, 3].

REFERENCES

1. J. Ian Richards, Heekyung Youn, Theory of Distributions- a non-technical introduction, Cambridge University Press, 1990.
2. J. T. Marti, Introduction to Sobolev Space and Finite Element Solution of Elliptic Boundary Value Problems in Computational Mathematics and Applications, Academic Press Inc. 1986.

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AA-STLO Spectral Theory of Linear Operators **4 Credits**

Course Objectives: In this advanced level course in Functional Analysis, a study of linear operators and their eigenvalue problem in the context of infinite dimension is given. As it turns out in the infinite dimensional context the eigenvalue set (called the spectrum) becomes richer. The special case of the spectrum of a bounded, self-adjoint operator is discussed in detail. The course also aims at addressing certain unbounded operators of Quantum mechanics.

Course Outcomes:
1. Student can define and classify the spectrum of certain bounded linear operators defined on a Banach space.
2. Student gets a feel of how the compact operators are the next best operators to that of finite dimensional operators.
3. Student gets a comprehensive view of the spectral theory of bounded self-adjoint operators.
4. Student is introduced to certain unbounded operators that appear in Quantum mechanics.

Course Syllabus:

Unit 1:
Spectral Theory of Linear Operators in Normal Spaces. **16 periods**

Unit 2:
Compact Linear Operators in Normed Spaces and Their Spectrum. **12 periods**

Unit 3:
Spectral Theory Of Bounded Self-Adjoint Linear Operators. **12 periods**

Unit 4:
Unbounded Operators in Hilbert Spaces. **12 periods**

Total **52 periods**

KEY TEXT BOOK
1. Erwin Kreyszig, Introductory Functional Analysis with Applications, John Wiley, New York 1978.

REFERENCES

1. Walter Rudin, Functional Analysis, McGraw Hill Pub, 1991.
2. E. Kreyszig, Introduction to Functional Analysis and Applications, John Wiley &Sons, 1978.

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AA-HA Harmonic Analysis **4Credits**

Course Objectives: The Fourier Transform is discussed on compact lie groups. Several consequences of the abstraction of the fourier transform are discussed. One of the main thrusts of the course is to relate to topic discussed in functional analysis.

Course Outcome:

1. Student will be able to comprehend the abstraction of fourier transform to compact lie group, especially to a torus.
2. Student can prove theorem associated with the properties of fourier series and convergence.
3. Student can perform an interpolation of bounded linear operators defined on Banach spaces.

Course Syllabus:

Unit 1: Fourier Series on T	**14 Periods**
Unit 2: The Convergence of Fourier Series	**12 Periods**
Unit 3: The Conjugate Function	**14 Periods**
Unit 4: Interpolation of Linear Operators	**12 Periods**
Total	**52 periods**

KEY TEXT BOOK

1. Yitzhak Katzelson, An Introduction to Harmonic Analysis, 3rd edition, Cambridge University Press, 2004. Chapters: 1 to 4.

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STREAM-III: Differential Equations and Dynamical Systems

DEDS-DS	Dynamical Systems
DEDS-ANLDS	Advanced Non-Linear Dynamical Systems
DEDS-TS	Time scale
DEDS-IE	Integral Equations
DEDS-CT	Control Theory
DEDS-NSPDE	Numerical Solutions of Partial Differential Equations

DEDS-DS Dynamical Systems **4 Credits**

Prerequisites are Theory of ODE and Linear Algebra.

Course Objectives: This course is an extension of PMAT – 203.
The objectives of this course are to:

- Understand the concept of a Dynamical System from the system of Ordinary Differential Equations and their applications
- Apply techniques from Linear algebra to obtain the solution of Linear Dynamical Systems and visualize the solution along with their stability.
- Use the Existence and Uniqueness theorem for Non-Linear systems of ODEs to study the Local theory of ODEs and their stability.
- Transform the Non-Linear system into local Linear System using the Differential and studying their properties using the Hartman-Grobman and Stable Manifold theorems.
- Give idea about Central and Normal form theory for Non-Linear Dynamical Systems.

Course Outcomes: After going through this course a student should be able to:

- Solve Linear Systems upto 4X4 systems
- Translate Non-Linear system to local Linear Systems and study the stability.
- Draw phase portraits for 2X2 Linear systems and 2 dimensional Non-Linear Systems.
- Use Picard’s Iteration to prove Existence and Uniqueness of solution for Non-Linear system

Course Syllabus:

Unit 1: Linear Systems – Part - I **14 periods**
Uncoupled Linear Systems, Diagonalization, Exponentials of Operators, The Fundamental Theorem for Linear Systems.

UNIT-2: Linear Systems – Part - II **14 periods**
Linear Systems in R^2, Complex Eigenvalues, Multiple Eigenvalues, Jordan Forms, Stability Theory, Nonhomogeneous Linear Systems.

UNIT-3: Nonlinear Dynamical Systems 24 periods

Some preliminary concepts and Definitions, The Fundamental Existence-Uniqueness Theorem, Dependence on Initial Conditions and Parameters, Maximal interval of existence, Flow defined by differential equations, Linearization, The stable Manifold Theorem, The Hartman-Grobman Theorem, Stability and Liyapunov Functions, Saddles, Nodes, Foci and Centers, Nonhyperbolic Critical points in R^2, Center Manifold Theory, Normal Form Theory, Gradient and Hamiltonian theory.

Total 52 periods

KEY TEXT BOOK

1. Lawrence Perko, Differential Equations and Dynamical Systems, Springer, 3rd Edition, 2001.

REFERENCES

1. R. Clark Robinson, An Introduction to Dynamical Systems, 2rd Edition, American Mathematical Society, 2012.

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DEDS-ANLDS   Advanced Non-Linear Dynamical Systems

(4 Credits)

Pre-Requisite: First level course in Dynamical Systems, Differential Equations and Linear Algebra

Course Objectives: This course is an extension of Dynamical Systems. The objectives of this course are to:

- Understand Global theory of Non-Linear Dynamical Systems
- Get introduction to Global Phase portraits
- Study about Periodic orbits, Limit cycles and Attractors
- Study Poincare` Bendixson Theory and Index Theory
- Introduce Bifurcation theory in 2-dimensional case
- Study Bifurcations at Non-Hyperbolic points and Global Bifurcations.

Course Outcomes: After going through this course a student should be able to:

- Arrive at the global dynamics given a 2-dimensional system
- Identify all possible bifurcations taking place and guess the phase portrait.

Course Syllabus:

UNIT 1: GLOBAL THEORY OF NON-LINEAR SYSTEMS (22 Periods)

Dynamical Systems and Global Existence Theorems; Limit Sets and Attractors; Periodic Orbits, Limit Cycles and Separatrix Cycles; The Poincare' Map; The Stable Manifold Theorem for Periodic Orbits; Hamiltonian Systems for Two Degrees of Freedom; The Poincare'-Bendixson Theory in $\mathbb{R}^2$; Lienard Systems; Bendixson's Criteria; The Poincare Sphere and Behavior at Infinity; Global Phase Portraits and Seoaratrix Configurations; Index Theory

UNIT 2: BIFURCATION THEORY OF NON-LINEAR SYSTEMS (30 Periods)

Structural Stability and Peixoto's Theorem; Bifurcations at Non-Hyperbolic Equilibrium Points; Higher Codimension Bifurcations at Non-Hyperbolic Equilibrium Points; Hopf Bifurcations and Bifurcations of Limit Cycles from Multiple Focus; Bifurcations at Non-Hyperbolic Periodic Orbits; One-Parameter Families of Periodic Orbits; Homoclinic Bifurcations; Melnikov's Method; Global Bifurcations of Systems in $\mathbb{R}^2$; Second and Higher Order Melnikov's Theory; Francoise's Algorithm for Higher Order Meliikov's Functions; The Takens-Bogdanov Bifurcation; Coppel's Problem for Bounded Quadratic Systems; Finite Codimension Bifurcations in the Class of Bounded Quadratic Systems.

TOTAL: (52 Periods)

KEY TEXT BOOK:

Lawrence Perko, Differential Equations and Dynamical Systems, Springer, 3rd Edition, 2001. Chapters 3 and 4.

REFERENCES

R. Clark Robinson, An Introduction to Dynamical Systems, 2nd Edition, American Mathematical Society, 2012.

DEDS-TS Time Scale 4 Credits

Course Objectives: The objectives of the course are to know what Time Scales are, to study basic analysis on Time scales, and solve dynamic equations of various types including Self Adjoint equations and Riccati equations on time scales

Course Outcomes: After going through the course, a student should be able to perform calculus-based study on Time Scales and Solve Dynamic Equations based on Green's function**.**

Course Syllabus:

Unit 1:
Time scale calculus – First order linear equations on time scale **12 periods**

Unit 2:
Hilger's complex plane – Initial value problems **6 periods**

Unit 3:
Second order linear equations on time scale – hyperbolic and trigonometric functions – Euler –Cauchy equations- Laplace transforms **6 periods**

Unit 4:
Self-Adjoint equations **6 periods**

Unit 5:
Riccati equation **5 periods**

Unit 6:
Boundary value problems and Green's function–Eigenvalue problems **17 periods**

Total **52 periods**

KEY TEXT BOOK

1. Martin Bohner and Allan Peterson, Dynamic Equations on Time Scales an introduction with applications, BIRKHAUSER BOSTON. BASEL. BERLIN, 2001, [Chapters: 1 to 4].

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DEDS-IE Integral Equations **4 Credits**

Course Objectives: The objectives of this course are:

- Introducing Integral Equations along with their relevance to the corresponding differential equations.
- Learning how to model phenomena using Integral Equations.
- Classifying Integral Equations based on Volterra and Fredholm and study standard methods of solving each of these.
- Knowing the theory behind the Integral Operator and proving the existence of solutions using Banach Fixed Point theorem.

Course Outcomes: After going through this course, a student will be able to:

- Convert an Initial Value problem to a Volterra integral Equation and Boundary Value Problem to a Fredholm Integral Equation.
- Solve Fredholm equations using Green's Function methods
- Solve Volterra Equations based on various Kernels or Successive approximation method.

Course Syllabus:

Unit 1:
Integral Equations, Their Origin and Classification **6 periods**

Unit 2:
Modeling of Problems as Integral Equations **4 periods**

Unit 3:
Volterra Integral Equations **11 periods**

Unit 4:
The Green's Function **8 periods**

Unit 5:
Fredholm's Integral Equations-Existence Of Solutions **17 periods**

Unit 6:
Basic Fixed Point Theorems. **6 periods**

Total **52 periods**

KEY TEXT BOOK

1. Abdul. J. Jerri, Introduction to Integral Equations with Applications, Marcel Dekkes Inc, New York, 1985, [Chapters: 1 to 6].

REFERENCES

1. L. G. Chambers, Integral Equations-A Short Course, International Text Book.

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DEDS-CT Control Theory 4 Credits

Course Objectives: The objectives of this course are to introduce theory of Optimal control as a dynamic extension of the Calculus of variations and to be able to give the perspectives of necessary conditions of Optimal control from the point of view of Maximum Principle and Hamilton- Jacobi Bellman Equation.

Course Outcomes: After going through this course, a student will be able to:

- Apply the theories of Control and Calculus of Variations based on the context of the modelled optimization problem.
- Use the approach either of Maximum Principle or HJB equation depending on the Optimization problem.
- Obtain the various control strategies for a given optimization problem.

Course Syllabus:

Unit 1: Introduction **7 Periods**
Introduction to Optimal Control

Unit 2: Calculus of Variation **10 Periods**
Examples – Weak and Strong Extrema—First order necessary conditions for weak Extrema – Hamiltonian formalism and mechanics – Variational problems with constraints – Second order conditions.

Unit 3: Calculus of Variation to Optimal Control **10 Periods**
Necessary conditions for strong Extrema – Calculus of variation VS optimal control – Optimal control problems formulations and assumptions – variational approach to the fixed time, free end point problem.

Unit 4: Maximum Principle **14 Periods**
Statement – Proof of Maximum Principle—Discussion – Time optimal control problem – Existence of optimal controls

Unit 5: Hamilton Jacobi Bellman equation **11 Periods**
Dynamic Programming and HJB equation – HJB equation VS the Maximum Principle.

Total **52 periods**

KEY TEXT BOOK

1. Daniel Liberzon, Calculus of Variation and Optimal Control Theory: A concise Introduction, Princeton University Press, Princeton and Oxford
Copyright 2012 by Princeton University Press, ISBN: 978-0-691-15187-8
e-Book: ISBN: 9780691151878, available. Chapters: 1 to 5.

REFERENCES

1. Lamberto and Cesari, Optimization Theory and Applications: Problems with ODE, Springer-Verlag, ISBN: 978-1-4613-8167-9 (Print) 978-1-4613-8165-5 (Online).

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DEDS-NSPDE   Numerical Solutions of Partial Differential Equations

4 Credits

Course Objectives: In this course, the students will be introduced to the mathematical formulation of Finite Difference schemes for various Types of Partial Differential Equations. Students will also be exposed to Error Analysis.

Course Outcomes: Upon the completion of the course, the student will be

- Able to derive a Finite Difference Equation for a PDE
- Analyze the types of Error involved in the Approximate solution derived out of the Finite Difference Equation.
- Again familiarity with number of finite difference schemes for all the three types of Equations

Course Syllabus:

Unit 0: Introduction to Finite Difference Formulae **3 periods**

Unit 1: Parabolic Equation
Explicit method – Implicit method – Crank Nicolson – Solution by Gaussian Elimination – Iterative point methods for solving the finite difference equations of implicit methods : Jacobi and Gauss Seidel methods – Derivative Boundary conditions – Two dimensional parabolic equations Alternating –direction implicit method. **15 periods**

Unit 2: Convergence, Stability, Systematic Iterative Methods
Descriptive treatment of Convergence and stability - Analytic treatment of Convergence and stability- Matrix method- Fourier method - General treatment of systematic iterative methods for linear equations - consistent ordering.
10 Periods

Unit 3: Hyperbolic Equations
Method of characteristics – propagation of discontinuities – regular nets and finite difference methods. **9 periods**

Unit 4: Elliptic Equations
The Torsion problem - Derivative boundary conditions in a heat conduction problem – Finite difference in polar coordinate – Formulae for derivative near a curved boundary when using a square mesh – Improvement of the accuracy of the solutions – systematic iterative method – Relaxation method. **15 periods**
Total **52 periods**

KEY TEXT BOOK

1. G. D. Smith, Numerical Solution of Partial Differential Equations, Oxford Publications, Chapters: 1, 2, 3, 4, 5 (Ch 5 till pg 276 of text book).

REFERENCES

1. Leon Lapidus and George F Pinder, Numerical Solution of Partial Differential Equations in science and engineering, John Willey and Sons., 1982.

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STREAM-IV: Applied Mathematics (AM)

AM-CV	Calculus of Variations
AM-FEM	Finite Element Methods
AM-WA	Wavelet Analysis
AM-ME	Mathematical Ecology
AM-MMIP	Mathematical Methods in Image Processing
AM-NMIP	Numerical Methods in Image Processing
AM-IT	Integral Transforms
AM-TAM	Techniques in Applied Mathematics
AM-CS	Computational Statistics
AM-CO	Convex Optimization
AM-GT	Game Theory

AM-CV Calculus of Variations 4 Credits

Course Objectives: In this course, the students will be introduced to some variational problems. The students will be exposed and gain familiarity with certain classical variational problems.

Course Outcomes: Upon the completion of the course, the student will be able to

- derive necessary conditions for an extremum value of a functional
- comprehend and use Fixed Point Theorem for n unknowns.
- use subsidiary conditions to variational problems
- use Principle of Least Action, Conservation Laws.

Course Syllabus:

Unit 1:
ELEMENTS OF THE THEORY : Functionals, Some Simple Variational Problems, Function Spaces, The Variation of a Functional, A Necessary Condition for an Extremum, The Simplest Variational Problem, Euler's Equation, The Case of Several Variables, A Simple Variable End Point Problem, The Variational Derivative, Invariance of Euler's Equation.

15 Periods

Unit 2:
FURTHER GENERALIZATIONS: The Fixed End Point Problem for n Unknown Functions, Variational Problems in Parametric Form, Functionals Depending on Higher-Order Derivatives, Variational Problems with Subsidiary Conditions.

10 periods

Unit 3:
THE GENERAL VARIATION OF A FUNCTIONAL : Derivation of the Basic Formula, End Points Lying on Two Given Curves or Surfaces, Broken Extremals, The Weierstrass-Erdmann Conditions. **12 periods**

Unit 4:
THE CANONICAL FORM OF THE EULER EQUATIONS AND RELATED TOPICS: The Canonical Form of the Euler Equations, First Integrals of the Euler Equations, The Legendre Transformation, Canonical Transformations, Noether's Theorem, The Principle of Least Action, Conservation Laws, The Hamilton-Jacobi Equation. Jacobi's Theorem. **15 periods**

Total **52 periods**

KEY TEXT BOOK

1. I. M. Gelfand and S. V. Fomin, Calculus of Variations, Prentice-Hall, Inc., Englewood Cliffs, N. J., (1963), Chapters: 1 to 4(Ch 4: Sec 16-19 only).

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AM-FEM Finite Element Methods 4 Credits

Course Objectives: In this course, the students will be introduced to the mathematical formulation Finite Element Methods. Students will be also exposed to solving Linear System of Equations.

Course Outcomes: Upon the completion of the course, the student will adapt in
- Formulation of FEM for an Elliptic Equation.
- Choice of Basis functions for a given problem.
- Direct and Iterative solution methods.

Course Syllabus:

Unit 1: Introduction to FEM for elliptic problems- Abstract formulation of the FEM for elliptic problem. **8 Periods**

Unit 2: Some Finite element spaces - Approximation theory for FEM – Applications to elliptic problem. **10 Periods**

Unit 3: Direct methods for solving Linear Systems of equations - Minimization Algorithms – Iterative methods. **10 Periods**

Unit 4: FEM for Parabolic problems. **12 Periods**

Unit 5: FEM for Hyperbolic problems. **12 Periods**

Total **52 Periods**

KEY TEXT BOOK

1. Claes Johnson, Numerical Solution of Partial Differential Equations using Finite Element Method, Cambridge University Press, 1988, **ISBN:** 9780521347587 [Chapters: 1 to 7, Ch 8: (excluding 8.4.4), Ch 9: 9.1 to 9.4].

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AM-WA Wavelet Analysis 4 Credits

Course Objectives: Assuming a prerequisite of the course Functional Analysis, the course discusses the concept of wavelet basis for representation of a square integrable function. The course relies on fourier transform techniques to derive the relevant functions. The concepts of Multiresolution Analysis (MRA) and Wavelet Transform are also discussed in detail.

Course Outcomes:

1. Student can understand the scaling and wavelet functions and learn to use them in function approximation.
2. Student can comprehend the idea of Multiresolution Analysis (MRA) in theoretical as well as applied context.
3. Student will be able to view the theoretical aspect and problem solving techniques in the modern technologies.

Course Syllabus:

Unit 1:
Wavelet Expansions : Orthogonal Series – Haar and Shannon System – Orthogonal Wavelet Theory – MRA - Mother Wavelets – Mallets decompositions and reconstruction algorithm - Convergence and Summability of Fourier Series - Gibbs Phenomenon – Wavelets and Tempered Distributions – Point wise Convergence of Wavelet expansion – Shannon sampling theorem in wavelet subspaces. **30 periods**

Unit 2:
Wavelet Transforms: Continuous Wavelet Transform and basic properties – Discrete Wavelet Transform – Orthonormal Wavelets. **22 periods**

Total 52 periods

KEY TEXT BOOK

1. Gilbert G. Walter, Wavelets and Other Orthogonal Systems, 2nd ed., Xiaoping Studies in advanced mathematics, [Chapters: 1, 3, 4, 5, 8, 9].
2. Lokenath Debnath, Birkhauser, Wavelet Transforms and their Applications, Boston 2002, [Chapters: 6].

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AM-ME Mathematical Ecology **4 Credits**

Course Objectives: The objectives of this course are:

- To Introduce Mathematical Modelling of population dynamics under various conditions.
- To analyse mathematical models using the theory of Linear and Non-Linear Dynamical Systems.

Course Outcomes: After going through this course a student will be able to:

- Apply theory of Non-Linear Dynamical Systems and theory of Bifurcations to analyse the dynamics of the model and determine the futuristic population of species in an ecosystem.
- Comprehensively understand Predator-Prey models, their analysis and dynamics for a 2-dimensional system.

Course Syllabus:

Unit 1: Single-species models **20 periods**

1. Exponential, Logistic and Gompertz Growth
2. Harvest Models: Bifurcation and Break Points

Unit 2: Interacting populations **32 periods**

1. A Classical Prey-Predator model
2. To cycle or not to cycle
3. Global Bifurcations in Prey-Predator Models
4. Competition Models
5. Mutualism Models

Total **52 periods**

KEY TEXT BOOK

1. Mark Kot, Elements of Mathematical Ecology, Cambridge University press, 2001. [Chapters: I. A: Sec 1, 2, I.B: 7, 8, 9, 12, 13]

REFERRENCES

1. J. D. Murray, Mathematical Biology: An Introduction, 3rdedition, Springer, 2001.

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AM-MMIP Mathematical Methods in Image Processing

4 Credits

Course Objectives:
The course familiarizes the students with the advanced mathematical tools necessary for the area called Image Processing. A special emphasis is given to the mathematical areas of functional analysis, partial differential equations and calculus of variations approach. Image Restoration is discussed as case study of the mathematical methods.

Course Outcomes: Upon completion of the course the student will
- Be given a deeper knowledge of Functional Analytic methods in Image Processing
- Be able to make a variational formulation (wherever possible) of a task in image processing
- Learn some of the modern algorithms for image restoration.
- Prepare for research skill associated with the domain of Image Processing
- Know how to make a basic implementation for solving the PDEs that emerge from the formulation

Course Syllabus:

Unit 1: Introduction
What is a Digital Image? Partial Differential Equations and Image Processing
3 Periods

Unit 2: Mathematical Preliminaries

Direct methods in the Calculus of Variations	**5 Periods**
Space of Bounded Variation functions	**5 Periods**
Viscosity solutions in PDEs	**5 Periods**
Curvature	**4 Periods**
Other classical results	**4 Periods**

Units 3: **Image restoration**

Image Degradation	**5 Periods**
The Energy Method	**5 Periods**
Regularization problem	**5 Periods**
PDE-Based methods: Nonlinear Diffusion, Smoothing-Enhancing PDEs	**6 Periods**
Scale space theory	**5 Periods**

Total **52 Periods**

KEY TEXT BOOK
1. Gilles Aubert, Pierre Kornprobst, Mathematical Problems in Image Processing, Springer, 1 edition (November 9, 2001), [Chapters: 1, 2, 3].

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AM-NMIP Numerical Methods in Image Processing

4 Credits

Course Objectives:

The course familiarizes the students with the advanced mathematical tools necessary for the area called Image Processing. A special emphasis is given to the mathematical areas of differential geometry and partial differential equations. Some of the recent advances in Image Processing such as Level Set Methods are discussed in detail.

Course Outcomes: Upon completion of the course the student will

- Be given a deeper knowledge of Geometric methods in Image Processing
- Be able to make a geometric formulation (wherever possible) of a task in image processing
- Learn some of the modern algorithms of image processing such as Level Set Methods.
- Prepare for research skill associated with the domain of Image Processing

Course Syllabus:

Unit 1: Short introduction to calculus of variations, Short introduction to differential geometry **15 Periods**

Unit 2: Curve evolution theory and invariant signatures **5 Periods**

Unit 3: The Osher-Sethian level-set method **10 Periods**

Unit 4: The level-set method: numerical considerations **7 Periods**

Unit 5: Mathematical morphology, Distance maps and skeletons **15 Periods**

Total **52 Periods**

KEY TEXT BOOK

Ron Kimmel, M. Bronstein, A. Bronstein, Numerical Geometry of Images, Springer, 2003, [Chapters: 1 to 6].

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AM-IT Integral Transforms **4 Credits**

Course Objectives: Transform techniques to solve some of the fundamental problems is well known in the scientific literature. This course deals with important four transforms, namely Fourier, Hankel, Mellin and Hilbert Transforms.

Course Outcomes:
1. Student can solve problems of algebraic, differential and integral equations using the transform techniques.
2. Student can comprehend the versatility of the Fourier Transform.
3. Student can appreciate the power of complex analytic techniques in applying transforms.

Course Syllabus:

Unit 1: Fourier Transforms and their Applications	**10 Periods**
Unit 2: Hankel Transforms and their Applications	**14 Periods**
Unit 3: Mellin Transforms and their Applications	**14 Periods**
Unit 4: Hilbert and StieltjesTranfroms	**14 Periods**
Total	**52 Periods**

KEY TEXT BOOK
1. Loknath Debnath, Dambaru Bhatta, Integral Transforms and Their Applications, 2^{nd} edition, Chapman and Hall/CRC, 2006. Chapters: 2, 7, 8, 9.

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AM-TAM Techniques in Applied Mathematics **4 Credits**

COURSE OBJECTIVES

The course is aimed to lay a broad foundation for an understanding of the problems of the calculus of variations and its many methods and techniques and to prepare students for the study of modern optimal control theory. To make the students familiar with the methods of solving Integral Equations.

COURSE OUTCOMES

On successful completion of the course students will be able to recognize difference between Volterra and Fredholm Integral Equations, First kind and Second kind, homogeneous and inhomogeneous etc. The students will also be able to appreciate variational formulations. They will be able to apply different methods to solve Integral Equations and variational problems.

Course Syllabus:

Unit 1: Calculus of Variation **18 Periods**
Necessary Condition for Extrema, The Simplest Problem, Generalizations, Isoperimetric Problems.

Unit 2: Integral Equations **14 periods**
Classification and Origin, Volterra Equations, Fredholm Equations, Symmetric Kernels.

Unit 3: Integral Transform **20 periods**
Fourier Transform, Fourier Cosine, Sine Transforms, Basic Properties, Solving ODEs, PDEs and Integral Equations, Laplace Transform, Existence condition, Basic Properties, Convolution Theorem, Differentiation and Integration of Laplace Transform.

Total **52 periods**

KEY TEXT BOOK

1) J. David Logan, Applied Mathematics, John Wiley, 3rd Edition (2006), Chapters: 3:3.1 to 3.6 (exclude 3.5); 4: 4.3 only.
2) Lokenath Debnath, Integral transforms and their applications, 2nd edition, CRC Press, Chapters: 2: 2.1 to 2.10; 3.1 to 3.6.

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AM-CS Computational Statistics 4 Credits

Course Objectives: This course will meet the following objectives:

- Introduction to need for computers in statistics
- Tools to sample from a simple low dimensional population distribution to very high dimensional complex population distribution
- Methods to reduce variance in estimation
- Monte carlo methods for estimation and inference in high dimensional scenarios

Course Outcomes: Upon the completion of the course, the student will be

- Able to differentiate small scale and large scale statistics problems
- Able to differentiate numerical solutions based on analysis and solutions based on monte carlo algorithms
- Able to implement the studied tools in a programming language like Python or R
- Ready for taking up advanced courses Bayesian machine learning, Probabilistic graphical models etc.

Course Syllabus:

Unit 1: Introduction – What is computational statistics – Review of probability and statistics **6 periods**

Unit 2: Methods for generating random variables – Inverse transform method – acceptance Rejection methods – Transformation methods – Sums and Mixtures - Multivariate Distributions – Stochastic Processes **7 periods**

Unit 3: Monte Carlo Integration and Variance reduction – Antithetic variables – control variables – Importance sampling – Stratified sampling – Stratified Importance sampling **7 Periods**

Unit 4: Monte Carlo methods in Inference – Monte Carlo methods for estimation and hypothesis tests **8 Periods**

Unit 5: Bootstrap and Jackknife – Jackknife after bootstrap – Bootstrap confidence intervals – Better bootstrap confidence intervals **8 Periods**

Unit 6: Permutation tests – Tests for equal distributions – Multivariate tests for equal distributions **8 Periods**

Unit 7: Markov chain Monte Carlo methods – Metropolis-Hastings algorithm – Gibb's Sampler – Monitoring convergence **8 Periods**

Total **52 Periods**

KEY TEXT BOOK

1) Maria L. Rizzo, Statistical Computing with R, ISBN-13: 978-1584885450, ISBN-10: 1584885459, 1st edition, Chapman & Hall/CRC. The R Series, Hardcover – November 15, 2007, Chapters: 2, 3, 5, 6, 7, 8, 9.

REFERENCES

1) Geof H. Givens and Jennifer A. Hoeting, Computational Statistics, ISBN-13: 978-0470533314, ISBN-10: 0470533315, 2nd Edition, Hardcover – November 6, 2012.

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AM-CO Convex Optimization 4 Credits

Course Objectives:

- Introduce convex sets, convex functions and convex optimization problems
- Elucidate on theory and implementation of iterative methods to solve unconstrained convex minimization problems
- Elucidate on theory and implementation of iterative methods to solve constrained convex minimization problems

Course Outcomes:

- Students will be able verify whether a given problem is convex minimization problem
- Students will be able to able to formulate the dual of the given convex minimization problem and analyse.
- Students will be able to demonstrate on paper stepwise methods like gradient descent, Newton's method etc they studied to solve convex minimization problems

Course Syllabus:

Unit 1: Introduction – Mathematical optimization - least squares and linear programming – convex optimization – nonlinear optimization. **5 periods**

Unit 2: Affine and convex sets – operations preserving convexity - separating and supporting hyperplanes. **5 periods**

Unit 3: Convex function - operations preserving convexity – conjugate function – quasiconvex functions – log concave and convex functions. **8 periods**

Unit 4: Convex optimization problems – convex, linear, quadratic optimization problems. **5 periods**

Unit 5: Duality – The Lagrange dual function and problem - Geometric and saddle point interpretation – optimality conditions – Theorem of Alternatives. **7 periods**

Unit 6: Unconstrained minimization - Gradient descent – steepest descent – Newton's method . **8 periods**

Unit 7: Equality constrained minimization – Newton's method and infeasible start Newton's method . **5 periods**

Unit 8: Interior point methods – inequality constrained minimization problems – Logarithmic barrier function and central path – barrier method – primal-dual interior point method. **9 periods**

Total **52 periods**

KEY TEXT BOOK

1. Boyd, Stephen, and Lieven Vanderberghe, Convex Optimization, Cambridge, UK: Cambridge University Press, 2004.

Chapters: 1, 2.1-2.3, 2.5, 3.1-3.5, 4.1-4.4, 5.1-5.5, 5.8, 9.1-9.5, 10.1-10.3, 11.1-11.3, 11.7 (Implementation section in all chapters are omitted for exams).

REFERENCES

1. Bertsekas, Dimitri. Convex Optimization Theory. Nashua, NH: Athena Scientific, 2009.

2. L. R. Foulds, Optimization Techniques, Springer, Utm, 1981.

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AM-GT Game Theory 4 Credits

Course Objectives: This course will meet the following objectives

- Provide a foundation in the basic concepts of Game Theory
- Understand Nash's equilibrium
- Understand Cooperative v/s Non-Cooperative games

Course Outcomes: Upon completion of this course, a student will be

- Clear of how to strategize in day to day situations
- Take decisions which benefit as many as possible
- Model all practical situations as a game and find its solution
- When to form coalitions and not.

Course Syllabus:

Unit 1 : Introduction (4 periods)
Games and Solutions, Game theory and the Theory of Competitive Equilibrium, Rational Behaviour, The Steady State and Deductive Interpretations, Bounded Rationality, Terminology and Notation.

Unit 2 : Nash Equilibrium (5 periods)
Strategic Games, Nash Equilibrium, Existence of a Nash Equilibrium, Strictly Competitive Games, Bayseian Games: Strategic Games with Imperfect Information.

Unit 3 : Mixed, Correlated, and Evolutionary Equilibrium (4 periods)
Mixed Strategy Nash Equilibrium, Interpretations of Mixed Strategy Nash Equilibrium, Correlated Equilibrium, Evolutionary Equilibrium.

Unit 4 : Rationalizability, Iterated Elimination of Dominated Actions (3 periods)
Rationalizability, Iterated Elimination of Strictly Dominated Actions, Iterated Elimination of Weakly Dominated Actions

Unit 5 : Knowledge and Equilibrium (3 periods)
A Model of Knowledge, Common Knowledge, Can People Agree to Disagree, Knowledge and Solution Concepts, The Electronic Mail Game

Unit 6 : Extensive Games with Perfect Information (5 periods)
Extensive Games With Perfect Information, Subgame Perfect Equilibrium, two Extensions of the Definition of Game, The Interpretation of a Strategy, Two Notable Finite Horizon Games, Iterated Elimination of Weakly Dominated Strategies.

Unit 7 : Bargaining Games (3 Periods)
Bargaining and Game Theory, A Bargaining Game of Alternating Offers, Subgame Perfect Equilibrium, Variations and Extensions

Unit 8 : Repeated Games **(10 periods)**
The Basic Idea, Infinitely Repeated Games vs Finitely Repeated Games, Strategies as Machines, Trigger Strategies: Nash Folk Theorems, Punishing for a Limited Length of Time, Punishing the Punisher, Rewarding Players who Punish, The Structure of Subgame Perfect Equilibria under the Discounting Criterion, Finitely Repeated Games

Unit 9 : Complexity Considerations in Repeated Games **(4 periods)**
Introduction, Complexity and the Machine Game, The Structure of The Equilibria of a Machine Game, The Case of Lexicographic Preferences.

Unit 10 : Coalitional Games : The Core **(4 periods)**
Coalitional Games with Transferrable Payoff, The Core, Nonemptiness of The Core, Markets with Transferrable Payoff, Coalitional Games without Transferrable Payoff, Exchange Economies

Unit 11: Stable Sets, The Bargaining Set, and The Shapely Value **(3 periods)**
Two Approaches, The Stable sets of von Neumann and Morgenstern, The Bargaining Set, Kernel and Nucleolus, The Shapely Value

Unit 12 : The Nash Solution **(4 periods)**
Bargaining problems, The Nash Solution: Definition and Characterization, An Axiomatic Definition, The Nash Solution and the Bargaining Game of Alternating Offers, An Exact Implementation of the Nash Solution.

Total Periods **(52 periods)**

KEY TEXT BOOK
Martin J Osborne and Ariel Rubinstein, A Course in Game Theory, The MIT Press, Cambridge Massachusetts, London.

REFERENCES
N.N. Vorobev, Game Theory, Springer Verlag Publications, 1977

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STREAM-V: Computer Science (CS)

CS-AI	Artificial Intelligence
CS-CG	Computer Graphics
CS-FLA	Formal Languages and Automata
CS-PR	Pattern Recognition
CS-C	Cryptography
CS-NN	Neural Networks
CS-MMDM	Mathematical Methods for Data Mining
CS-DA	Design of Algorithm
CS-OS	Operating System

CS-AI Artificial Intelligence 4 Credits

Course Objectives:

- The course introduces to students the concepts and principles behind mapping Human Intelligence onto Artificial Systems. It is Primarily the study of agents different types of Intelligent agents, Search Techniques, Heuristics based, State Space Search for Problem Solving. It is followed by Inferencing, Logical Reasoning Approaches and Knowledge representation applicable to real world problems and situations.
- Finally, the course provides students an insight into the basics of Machine Learning, the various types of learning with examples of learning
- The course is designed to provide students an opportunity to gain ground and skills in fundamentals of Artificial Intelligence that can take them to understand and work with Machine Intelligence.

Course Outcomes: After successfully completing this course the student is able to:

1. Understand the concepts of Artificial Intelligence State Space Search and Problem Solving
2. Work on Uninformed and Informed Search Techniques
3. Solve various types of real world problems and use theory in simulations.
4. Construct Logical Statements from Natural Language Sentences and create a Facts base and deduce new facts by the application of reasoning procedures
5. Apply techniques of Knowledge representation to solve real world problems
6. Acquire skills needed to work with Machine Learning

Course Syllabus:

Unit 1:

Introduction – what is AI? – Intelligent agents, environments – Solving problems by searching: problem solving agents –Example problems – Uninformed search strategies – Informed search and exploration: Informed search strategies –Heuristic functions– Local search algorithms – Optimization problems. **12 periods**

Unit 2:
Logical Agents: Knowledge Based Agents – Logic – Propositional logic – Reasoning patterns – Propositional Inference – Agents based on propositional logic – First Order Logic :Representation–Using FOL–Knowledge Engineering–Inference in FOL : Unification And Lifting – Forward Chaining – Backward Chaining – Resolution – Examples. **16 periods**

Unit 3:
Knowledge Representation: Ontological Engineering – Categories and objects – Actions situations and events – Mental events and mental objects – Reasoning Systems – Truth maintenance systems **12 periods**

Unit 4:
Learning from Observations: Forms of learning – Inductive learning – Learning Decision trees - Knowledge in Learning – Knowledge in Learning – Explanation based learning – Learning using relevance information **12 periods**

Total **52 periods**

KEY TEXT BOOK

1. Stuart J. Russel and Peter Norvig, Artificial Intelligence – A Modern Approach, Prentice Hall, Pearson Education, 2003.
[Chapters & Sections : 1: 1.1 ; 2: 2.1 to 2.4 ; 3:3.1 to 3.6; 4: 4.1 to 4.3 ; 7: 7.1 to 7.7; 8 : 8.1 to 8.4; 9: 9.1 to 9.5 ; 10: 10.1 to 10.8; 18: 18.1 to 18.3 ; 19: 19.1 to 19.4].

REFERENCES

1. George F. Luger and William A. Stubblefield, Artificial Intelligence, Structures and Strategies for Complex Problem Solving, The Benjamin / Cummings Publishing Co, 1993.

2. Amit Konar, Artificial Intelligence and Soft Computing, CRC Press, 2000.

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CS-CG Computer Graphics **4 Credits**

Course Objectives:

The course introduces students to the concepts, principles and mathematics of graphics and how it can be mapped onto computers. It is primarily the study of computational methods and techniques, algorithms to draw different types of graphics starting from the basic primitive points, lines, planes, regular shapes, polygons, conic sections, curves etc. The Matrix Transformations forms a part of mathematics of graphics to work with all types of graphics objects. Apart from treating different dimensions of graphic operations the students are exposed to viewing and clipping graphics

Finally, the course provides students an insight into the graphic object representations, splines, surfaces and color models. The course is designed to provide students an opportunity to gain ground and skills in fundamentals of Computer Graphics that can take them to understand and work with Visual Graphics, Animation etc.

Course Outcomes:

After successfully completing this course the student is able to:

1. Understand the concepts and basics of Computer Graphics

2. Work on lines, circles drawing algorithms, fill area functions

3. Know the different types of output primitives and their uses

4. Construct 2 dimensional geometric transformations (matrices) and find their applications

5. Learn and apply techniques and algorithms for 2 dimensional and 3 dimensional viewing of graphic shapes.

6. Learn and have a foundation on various types of object representations: surfaces, splines

7. Acquire knowledge to work with different types of Color Models

Course Syllabus:

Unit 0: Output Primitives **10 Periods**

Line drawing algorithms, Frame buffer, Circle-generating algorithms, Ellipse-generating algorithms, other curves, Pixel addressing and object geometry, Filled-Area primitives, scan-line polygon fill algorithm, Inside-outside tests, Boundary fill algorithm, Fill-Area functions, Character generation.

Unit 1: Attributes of Output Primitives **7 Periods**

Line attributes. Curve attributes. Color and grayscale levels, Area-Fill attributes. Character attributes.

Unit 2: Two-Dimensional Geometric Transformations **7 Periods**
Basic transformations, matrix representations and homogeneous coordinate. Composite transformations. Reflection and shear. Transformations between coordinate systems. Affine transformation. Transformation functions. Raster methods.

Unit 3: Two-Dimensional Viewing **9 Periods**
The viewing pipe line, window-viewport coordinate transformations, Line clipping-Cohen-Sutherland algorithm, Sutherland-Hodgeman polygon clipping, Structure concepts & editing structure.

Unit 4: Three-Dimensional Graphics **9 Periods**
3-d display methods. Three dimensional object representations: Polygon surfaces, curved lines and quadric surfaces, Spline representations, Natural cubic splines.

Unit 5: Colour models and colour applications **10 Periods**
RGB, YIQ, CMY, and HSV Colour models, conversion between HSV and RGB Models.Computer Animation, Fractals.

Total **52 Periods**

KEY TEXT BOOK

1. Donald Hearn, Computer Graphics – C Version, Pauline Baker, second edition, 2009, Pearson Education.

REFERENCES

1. Foley, Van Dam, Feiner, Hughes, Computer Graphics Principles & Practice, Second edition, 2003, Pearson Education.
2. Shalini, Govid-Pai, Principles of Computer Graphics, Springer.
3. Steven Harrington, Computer Graphics, TMH.

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CS-FLA Formal Languages and Automata 4 Credits

Prerequisite: Introduction to Theory of Sets and Functions - Mathematical Logic - Discrete Mathematics

Course Objectives: To expose the students of M.Sc.(Mathematics) programme, to the areas of Formal Languages and Automata. To impart the comprehension of deterministic versus non-determisnistic processes. Exposure to the idea of un-computability. Also introduce the idea of complexity classes.

Course Outcomes:

- Construction of Regular & Context free Grammar.
- Construction of FA, PDA and Turing machines to recognize a given language.
- Construction of Turing machine for a given problem.
- Use of polynomial time transformation to show a problem not computable.

Course Syllabus:

Unit 1:
Regular languages and finite automata **14 Periods**

Unit 2:
Context free languages and Push-down automata **14 Periods**

Unit 3:
Recursively enumerable sets and Turing machines, **12 Periods**

Unit 4:
Undecidability **7 Periods**

Unit 5:
Basic concepts of complexity classes P, NP, NP-complete. **5 Periods**

Total: **52 Periods**

KEY TEXT BOOK

1. Peter Linz, An Introduction to Formal Languages and Automata, Narosa, 4th Edition. Chapters & Sections: 1 to 4; 5: 5.1; 6 to 9; 11; 12: 12.1, 12.2; 14: 14.1, 14.2.

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CS-PR Pattern Recognition **4 Credits**

Course Objectives:

The objective of this course is to introduce the state-of-the-art various theories that are used in pattern recognition. They primarily depend upon feature space partitioning viz. Bayes theory, linear Classifiers and their limitations, non-linear classifiers, and feature point clustering in n-dimensional space

Course Outcomes:

At the end of the course students will be able to solve real-world pattern recognition and feature space clustering problems using

- Bayes decision theory, Bayes inference, Bayes classifier, and Bayes Networks.
- Linear discriminant functions, logistic discriminant functions, SVM for separable and non-linearly separable classes
- Non-linear classifiers and their combinations
- A host of Clustering algorithms for small and large data set
- In depth of understanding of theory to select the right approach to solve a given problem.

Course Syllabus:

Unit 1: Introduction **4 Periods**

Introduction, Features, Feature Vectors, Classifiers, Supervised, Unsupervised and Semi-Supervised Learning.

Unit 2: Classifiers based on Bayes Theory **8 Periods**

Introduction, Bayes Decision Theory, Discriminant Functions, Bayes Classification for Normal Distributions, Estimation of Unknown Probability Distributions: ML Parameter Estimation, MAP Estimation, Bayesian Inference, Maximum Entropy Estimation, Mixture Models, Non-Parametric Estimation, the Naïve-Bayes Classifier, the Nearest Neighbor Rule, Bayesian Networks.

Unit 3: Linear Classifiers **8 Periods**

Introduction, Linear Discriminant Functions and Decisions, Hyper-planes, The Perceptron algorithm, Least Square Methods, Mean Square Estimation Revisited, Logistic Discrimination, Support Vector Machines for Separable Classes, SVM for Non-Separable Classes, SVM for Multiclass Case, ϑ-SVM

Unit 4: Nonlinear Classifiers **12 Periods**

XOR Problem, Two Layer Perceptron, Three-Layer Perceptrons, Algorithms based on Exact Classification of Training Set, The Back-Propagation Algorithm, Variation of BP Theme, Choice of Cost Function, Choice of Network Size, Generalized Linear Classifiers, Capacity of d-dimensional space in linear Dichotomies, Polynomial Classifiers, Radial Basis Function Networks, Universal Approximators, Probabilistic Neural Networks, SVM-Nonlinear Case, Beyond SVM Paradigm, Decision Trees, Combining Classifiers, Boosting, Class Imbalance Problem

Unit 5: Clustering **20 Periods**

Introduction, Proximity Measures, Number of Possible Clusterings, Categories of Clustering Algorithms, Sequential Clustering Algorithms, Agglomerative Algorithms, Divisive Algorithms, Hierarchical Algorithms for Large Datasets., Choice of the Best Number of Clusters, Hard Clustering Algorithms, Vector Quantization. Algorithms based on Graph Theory, Competitive Learning algorithms

Total **52 Periods**

KEY TEXT BOOK

1. Sergios Theodoridis and Knostantinos Koutroumbas, Pattern Recognition, Fourth Edition, Elsevier Publications, 2009, Chapters: 1, 2, 3, 4, 11, 12.1-12.3, 13, 14.5, 15.1-15.3.

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CS-C Cryptography **4 Credits**

Course Objectives: This course is aimed to serve as a first level course to introduce modern cryptography. The students will be exposed to basics of encryption and authentication in the context of symmetric-key and asymmetric-key cryptography.

Course Outcomes: Upon the completion of the course, the student will be

- Able to understand the security aspects of a communication channel and the role of mathematics in it.
- Able to analyse and counter generic attacks on communication channels.
- Able to analyse how message secrecy and message authentication is achieved in communication channels using symmetric-key and asymmetric-key cryptography.

Course Syllabus:

Unit 1: Introduction to Classical Cryptography **8 Periods**
Cryptography and modern cryptography, Setting of private key encryption, Historical ciphers and their Cryptanalysis, Principles of modern cryptography, Perfectly secret encryption, One-Time Pad, Limitations of Perfect Secrecy

Unit 2: Private-Key Encryption **9 Periods**
Computational Security, Defining Computationally Secure Encryption, Constructing Secure Encryption Schemes, Stronger Security Notions, Constructing CPA-Secure Encryption Schemes, Modes of Operation, Chosen-Ciphertext Attacks

Unit 3: Message Authentication Codes and Hash Functions **9 Periods**
Message Integrity, Message Authentication Codes – Definitions, Hash Functions – Definitions, Merkle–Damgard Transform, Birthday Attacks on Hash Functions

Unit 4: Number Theory and Key Exchange **8 Periods**
Preliminaries and Basic Group Theory, Factoring and RSA, Cryptographic Assumptions in Cyclic Groups, Key Exchange and the Diffie–Hellman Protocol

Unit 5: Public-Key Encryption **9 Periods**
Public-Key Encryption – An Overview and Definitions, Hybrid Encryption and KEM/DEM paradigm, RSA Encryption – Plain RSA, Padded RSA and PKCS #1 v1.5

Unit 6: Digital Signature Schemes **9 Periods**
Digital Signatures – An Overview and Definitions, Hash-and-Sign Paradigm, RSA Signatures – Plain RSA, Schnorr Signature Scheme

Total **52 Periods**

KEY TEXT BOOK

1. J. Katz and Y. Lindell, Introduction to Modern Cryptography, Second edition, CRC Press, 2015, Chapters & Sections: 1.1-1.4, 2.1-2.3, 3.1-3.6, 3.7.1, 4.1-4.3, 5.1-5.2, 5.4.1-5.4.2, 8.1.1-8.1.4, 8.2.1, 8.2.3-8.2.4, 8.3.1-8.3.3, 10.3, 11.1-11.3, 11.5.1-11.5.2, 12.1-12.3, 12.4.1, 12.5.1, 12.8.

REFERENCES

1. S. Goldwasser and M. Bellare, Lecture Notes on Cryptography, July 2008. Available online: https://cseweb.ucsd.edu/~mihir/papers/gb.pdf
2. C. Paar and J. Pelzl, Understanding Cryptography, Springer, 2010.

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CS-NN Neural Networks **4 Credits**

Course Objectives:
The objective of this course is to introduce students to various neural network architectures and the associated learning paradigms such as perceptrons, multilayer perceptrons, radial-basis function networks, support vector machines. regularization networks, and self-organizing networks.

Students will realize that the connecting thread in all these learning structures is to map the adaptation of various parameters as a non-linear optimization.

Course Outcomes:
At the end of the course students will be able to solve real-world problems such as

- pattern classification as a non-linear feature space partitioning either by estimating the feature space density or by using the feature vectors that lie at the class boundaries.
- input-output functional mapping and then using these as universal approximators for computing outcomes for the inputs that are unseen.
- Topological mapping of input features to codebook vectors through self-organizing maps.

Course Syllabus:

Unit 1: Introduction **7 Periods**
What is Neural Networks? Human Brain, Models of a Neuron, Neural Networks viewed as Directed Graphs, Network Architectures, Learning Processes: Learning With a Teacher, Learning Without a Teacher: Reinforcement Learning and Unsupervised Learning, Learning Tasks.

Unit 2: Rosenblatt's Perceptrons **7 Periods**
Introduction, Perceptron, Perceptron Convergence Theorem, The Batch Perceptron Algorithm.

Unit 3: Multi-Layer Perceptrons **7 Periods**
Preliminaries, Batch Versus On-line Learning, Back-Propagation Algorithm, Summary of BP Algorithm, Heuristics for making BP Algorithm Perform better, Virtues and Limitations of BP Learning, Supervised Learning viewed as an Optimization Problem.

Unit 4: Radial-Basis Function Networks **7 Periods**
Introduction, Cover's Theorem, Interpolation Problem, Radial Basis Function Networks, K-Means Clustering, Recursive Least-Squares Estimation of the weight vector, Hybrid learning procedure for RBF Networks, Interpretations of Gaussian Hidden Units, Kernel regression and its relation to RBF Networks.

Unit 5: Support Vector Machines **7 Periods**
Introduction, Optimal Hyper-plane for Linearly Separable Patterns and Non-separable Patterns, SVM viewed as a Kernel Machine, Design of SVMs, XOR problem.

Unit 6: Regularization Networks **9 Periods**

Introduction, Hadamard's conditions for well-posedness, Tikhonov's Regularization Theory, Regularization Networks, Generalized Radial-Basis-Function networks.

Unit 7: Self-Organizing Maps **8 Periods**

Introduction, Two Basic Feature mapping Models, Self-Organizing Maps, Summary of Self-organizing Algorithm, Properties of Feature Map, Contextual Maps Hierarchical Vector Quantization, Kernel Self-Organizing Map. Relationship between Kernel SOM and Kullback-Leibler Divergence.

Total **52 Periods**

KEY TEXT BOOK

1. Neural Networks and Learning Machines: by Simon Haykin, Eastern Economy Edition, Third Edition, 2009. [Chapters: Introduction (1-6,8,9), Chapter 1(1.1-1.4, 1.6, 1.8), Chapter 4(4.1-4.4, 4.6, 4.15, 4.16), Chapter 5(5.1-5.11), Chapter 6(6.1-6.6), Chapter 7(7.1-7.5), Chapter 9(9.1-9.4, 9.6-9.8, 9.10).

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CS-MMDM Mathematical Methods for Data Mining

4 Credits

Course objectives: This course is concerned with data mining - that is, finding interesting and useful patterns in large data repositories. It aims to provide the student with conceptual and practical knowledge on important developments in data mining. Main objective of the course is to deliver the main concepts, principles and techniques of data mining so that the student will develop the confidence to analyse data of various forms, including transaction data, relational data and textual data.

Course outcomes:

- Demonstrate fundamental knowledge of data mining concepts and techniques.
- Apply the techniques of clustering, classification, association finding, feature selection and visualisation on real world data
- Apply data mining software and toolkits in a range of applications
- Set up a data mining process for an application, including data preparation, modelling and evaluation

Course Syllabus:

Unit 0: **5 Periods**

Introduction Motivating Challenges, The Origins of Data Mining, Data Mining Tasks, Data Attributes and Measurement, Types of Data Sets, Measurement and Data Collection Issues, Data Preprocessing: Aggregation, Sampling, Dimensionality Reduction

Unit 1: **10 Periods**

Basic techniques for Classification Decision Trees, Model Over fitting, Evaluating the Performance of a Classifier, Holdout Method, Random Subsampling, Cross-Validation, Bootstrap, Methods for Comparing Classifiers.

Unit 2: **14 Periods**

Advanced Techniques for Classification Rule-Based Classifier, Nearest-Neighbor classifiers, Bayesian Classifiers, Artificial Neural Network(ANN), Support Vector Machine (SVM), Ensemble Methods: Bias-Variance Decomposition, Bagging, Boosting, The Receiver Operating Characteristic Curve, Class Imbalance problem, Multiclass Problem

Unit 3: **14 Periods**

Association Analysis: Basic Concepts and Algorithms Frequent Item set Generation-The Apriori Principle, Rule Generation in Apriori Algorithm, Alternative Methods for Generating Frequent Item sets: FP-Growth Algorithm, Evaluation of Association Patterns, Objective Measures of Interestingness, Simpson's Paradox.

Unit 5: **9 Periods**

Cluster Analysis: Basic Concepts and Algorithms The Basic K-means Algorithm, Agglomerative Hierarchical Clustering, The DBSCAN Algorithm, Strengths and Weaknesses of DBSCAN, Cluster Evaluation techniques.

Total: **52 Periods**

KEY TEXTBOOK

1. Pang-Ning Tan, Introduction to Data Mining, Michael Steinbach, Vipin Kumar, Pearson Publishers, 2007, [Chap. 1 to 6, 8].

REFERENCES

1. Jiawei Han, Micheline Kamber, Data Mining: Concepts and Techniques, Morgan Kaufmann pub, 2001

2. Ian H. Witten, Eibe Frank, Mark A. Hall, Data Mining: Practical Machine Learning Tools and Techniques, Morgan Kaufmann pub, 2011, 3rd Ed.

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CS-DA Design of Algorithms **4 Credits**

Course Objectives: The course takes a mathematical problem solving approach to writing algorithms. The course deals with designing algorithms through the process of induction and simultaneously prove its correctness. A variety of domains such as sequences, sets, graphs and geometric are discussed.

Course Outcomes:

1. Student will be able to design and develop an algorithm using the induction processes.
2. Student can prove the correctness of an algorithm.
3. Student becomes a better problem solver.

Course Syllabus:

Unit 1: Design of Algorithms by Induction	**10 Periods**
Unit 2: Algorithms involving Sequences and Sets	**10 Periods**
Unit 3: Graph Algorithms	**12 Periods**
Unit 4: Geometric Algorithms	**10 Periods**
Unit 5: Algebraic and Numeric Algorithms	**10 Periods**
Total	**52 Periods**

KEY TEXT BOOK

1. Udi Manber, Introduction to Algorithms: A Creative Approach, Addison-Wesley, 1988, Chapters: 5 to 9.

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CS-OS Operating Systems 4 Credits

Course objectives: The objective of the course is to provide basic knowledge of computer operating system structure and functioning.

Course outcomes: Upon completing the course, the student is expected to

- Explain the basic structure and functioning of operating system.
- Identify the problems related to process management and synchronization as well as apply learned methods to solve basic problems.
- Understand the cause and effect related to deadlocks and analyse them related to common circumstances in operating systems.
- Explain basics of memory management, the use of virtual memory in modern operating systems as well as the structure of the most common file-systems.

Course Syllabus:

UNIT - I:

Introduction - Operating Systems Objectives and functions, Computer System Architecture, OS Structure, OS Operations, Evolution of Operating Systems - Simple Batch, Multi programmed, time shared, Personal Computer, Parallel, Distributed Systems, Real-Time Systems, Special - Purpose Systems, Operating System services, user OS Interface, System Calls, Types of System Calls, System Programs, Opening System Design and Implementation, OS Structure, Virtual machines.

(6 periods)

UNIT - II:

Process and CPU Scheduling - Process concepts - The Process, Process State, Process Control Block, Threads, Process Scheduling - Scheduling Queues, Schedulers, Context Switch, Preemptive Scheduling, Dispatcher, Scheduling Criteria, Scheduling algorithms, Multiple-Processor Scheduling, Real-Time Scheduling, Thread scheduling, Case studies: Linux, Windows. Process Coordination - Process Synchronization, The Critical section Problem, Peterson's solution, Synchronization Hardware, Semaphores, and Classic Problems of Synchronization, Monitors, Case Studies: Linux, Windows.

(12 periods)

UNIT - III:

Memory Management and Virtual Memory - Logical & physical Address Space, Swapping, Contiguous Allocation, Paging, Structure of Page Table. Segmentation, Segmentation with Paging, Virtual Memory, Demand Paging, Performance of Demanding Paging, Page Replacement Page Replacement Algorithms, Allocation of Frames, Thrashing. **(12 periods)**

UNIT - IV:

File System Interface - The Concept of a File, Access methods, Directory Structure, File System Mounting, File Sharing, Protection, File System Implementation - File System Structure, File System Implementation, Allocation methods, Free-space Management, Directory Implementation, Efficiency and Performance. Mass Storage Structure - Overview of Mass Storage Structure, Disk Structure, Disk Attachment, Disk Scheduling, Disk Management, Swap space Management. **(12 periods)**

UNIT - V:

Deadlocks - System Model, Deadlock Characterization, Methods for Handling Deadlocks, Deadlock Prevention, Deadlock Avoidance, Deadlock Detection and Recovery from Deadlock.

Protection - System Protection, Goals of Protection, Principles of Protection, Domain of Protection, Access Matrix, Implementation of Access Matrix, Access Control, Revocation of Access Rights, Capability-Based Systems, Language-Based Protection.
(10 periods)

Total **(52 periods)**

TEXT BOOKS:

1. Abraham Silberchatz, Peter B. Galvin, Greg Gagne, Operating System Principles, 8th Edition, Wiley Student Edition.

REFERENCES BOOKS:

1. Russ Cox, Frans Kaashoek, Robert Morris, "xv6: a simple, Unix-like teaching operating system", Revision 8.
2. Andrew S Tanenbaum, Modern Operating Systems, 3rd Edition PHI.
3. W. Stallings, Operating systems - Internals and Design Principles, 6th Edition, Pearson.
4. B. L. Stuart, Principles of Operating Systems, Cengage learning, India Edition.

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STREAM-VI: Actuarial Science (AS)

AS-GILH	General Insurance, Life and Health Contingencies
AS-ARMF	Actuarial Risk Management 1 – Foundation
AS-ARMA	Actuarial Risk Management 2 – Advanced
AS-ERM	Enterprise Risk Management

AS-GILH General Insurance, Life and Health Contingencies

4 Credits

Course Objectives:
The aim of the Contingencies subject is to provide a grounding in the mathematical techniques that can be used to model and value cash-flows dependent on death, survival, or other uncertain risks.

Course Outcomes:
On completion of this subject the candidate will be able to:

(i) Define simple assurance and annuity contracts, and develop formulae for the means and variances of the present values of the payments under these contracts, assuming constant deterministic interest.

(ii) Describe and use practical methods of evaluating expected values and variances of the simple contracts defined in objective (i).

(iii) Describe and calculate, using ultimate or select mortality, net premiums and net premium reserves of simple insurance contracts.

(iv) Describe and calculate, using ultimate or select mortality, net premiums and net premium reserves for increasing and decreasing benefits and annuities.

(v) Describe and calculate gross premiums and reserves of assurance and annuity contracts.

(vi) Define and use functions involving two lives.

(vii) Describe and illustrate methods of valuing cashflows that are contingent upon multiple transition events.

(viii) Describe and use methods of projecting and valuing expected cashflows that are contingent upon multiple decrement events.

(ix) Describe and use projected cashflow techniques, where and as appropriate for use in pricing, reserving, and assessing profitability.

(x) Describe the principal forms of heterogeneity within a population and the ways in which selection can occur.

Course Syllabus:

Unit 1 **(8 Periods)**
Life assurance contracts, Life annuity contracts, The life table, Evaluation of assurances and annuities

Unit 2 **(15 Periods)**
Net premiums and reserves, Variable benefits and with-profit policies, Gross premiums and reserves for fixed and variable benefit contracts

Unit 3 **(17 Periods)**
Simple annuities and assurances involving two lives, Contingent and reversionary benefits, Profit testing, Determining reserves using profit testing

Unit 4 **(12 Periods)**
Competing risks, Multiple decrement tables, Pension funds, Mortality, selection and standardisation

Total **(52 periods)**

KEY TEXT BOOK

Actuarial mathematics. Bowers, Newton L et al. – 2nd ed. – Society of Actuaries, 1997. 753 pages. ISBN: 0 938959 46 8. (Chapters: 3 to 8, Ch9-Sec 9.1 to 9.7, Ch 10 and Ch 20)

REFERENCES

1. Benjamin, Bernard; Pollard, The analysis of mortality and other actuarial statistics, John H. – 3rd ed. – Faculty and Institute of Actuaries, 1993. 519 pages. ISBN 0 90106626 5.
2. Neill, Alistair, Life contingencies – Heinemann, 1977. 452 pages. ISBN 0 434 91440 1.
3. Gerber, Hans U., Life insurance mathematics – 3rd ed. – Springer. Swiss Association of Actuaries, 1997. 217 pages. ISBN 3 540 62242 X.
4. Booth, Philip M et al., Modern actuarial theory and practice – Chapman & Hall, 1999. 716 pages. ISBN 0 8493 0388 5.

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AS-ARMF Actuarial Risk Management 1 - Foundation

4 Credits

Course objectives:
The aim of the Actuarial Risk Management subject is that upon successful completion, the candidate should understand strategic concepts in the management of the business activities of financial institutions and programmes, including the processes for management.

Course Outcomes:
On the successful completion of this subject the candidate will be able to understand
1. How to do a professional job?
2. Stakeholders and their needs
3. General environment for business
4. Specifying the problem for a given business
5. Data requirements
6. Risk management of financial business
7. Investment management of Insurance Firms

Course Syllabus:

Unit 1 – Introduction (12 Periods)
How to do a professional job, Stakeholders, External environment, Introduction to financial products, Cash-flows of simple products

Unit 2 – Project Management and Money Markets (14 Periods)
Contract Design, Project Management, capital project appraisal, Money Markets, Bond Markets, Equity Markets, Property Markets, Futures and Options, Collective Investment schemes, Overseas markets

Unit 3 – Economic Influences on Investment Markets and Asset Valuation (18 Periods)
Economic influences on investment markets, Other influences on investment markets, Relationship between returns on asset classes, Valuation of individual investments, Valuation of asset classes and portfolios

Unit 4 – Investment Strategy (8 Periods)
Investment strategy – institutions, individuals, Developing an investment strategy
Total (52 periods)

KEY TEXT BOOK
Paul Sweeting, Financial Enterprise Risk Management – Cambridge University Press, 2011. ISBN: 9780521111645. (Chapters: 2, 3, 5, 11)

REFERENCES

1. Gemmell, J. R.; McAusland, G. S.; Shah, H. M. et al. (2000). Demystifying Capital Management in the Life Assurance Industry. SIAS, London.

2. Goford, J. (1985). The Control Cycle: Financial Control of a Life Assurance Company. JSS, 28, 99–114.

AS-ARMA Actuarial Risk Management 2 - Advanced **4 Credits**

Course objectives:
The aim of the Actuarial Risk Management subject is that upon successful completion, the candidate should understand strategic concepts in the management of the business activities of financial institutions and programmes, including the processes for management of the various types of risk faced, and be able to analyse the issues and formulate, justify and present plausible and appropriate solutions to business problems.

Prerequisite: AS-ARM - Actuarial Risk Management –Foundation

Course Outcomes: On the successful completion of this subject the candidate will be able to understand

1. Producing the solution
    - 1.1 Modelling
    - 1.2 Assumption setting
    - 1.3 Expenses
    - 1.4 Developing the cost and the price
    - 1.5 Investment management
    - 1.6 Provisioning
    - 1.7 Relationship between assets and liabilities
2. Living with the solution
3. Monitoring
4. Have an understanding of the principal terms used in financial services and risk management.

Course Syllabus:

Unit 1 – Modelling and Monitoring (12 Periods)
Modelling, Data, Setting assumptions, Expenses, Pricing and financing strategies.

Unit 2 – Liabilities (14 Periods)
Discontinuance, Valuing liabilities - Foundation, Valuing liabilities - Advanced, Accounting and Disclosure, Surplus and surplus management.

Unit 3 – Risks and Risk Management Process (18 Periods)
Sources of risk, Risks in benefit Schemes, Pricing and insuring risks, Risk Management Process – Foundation, Risk Management Process – Advanced

Unit 4 – Risk Management Tools and Capital Management (8 Periods)
Risk Management Tools – Foundation, Risk Management Tools – Advanced, Capital Management – Foundation, Capital Management – Advanced, Monitoring
Total (52 periods)

KEY TEXT BOOK
Financial Enterprise Risk Management – Paul Sweeting, Cambridge University Press, 2011. ISBN: 9780521111645. (Chapters: 7, 11, 16, 17, 18, 19)

REFERENCES

1. Gemmell, J. R.; McAusland, G. S.; Shah, H. M. et al. (2000). Demystifying Capital Management in the Life Assurance Industry. SIAS, London.
2. Goford, J. (1985). The Control Cycle: Financial Control of a Life Assurance Company. JSS, 28, 99–114.

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AS-ERM Enterprise Risk Management 4 Credits

Course objectives:
The aim of the Enterprise Risk Management (ERM) is to instill in successful candidates the key principles underlying the implementation and application of ERM within an organisation, including governance and process as well as quantitative methods of risk measurement and modelling. The student should gain the ability to apply the knowledge and understanding of ERM practices to any type of organisation.

Course Outcomes:
On completion of this subject the candidate will be able to understand:
1. ERM Concept and Framework
2. ERM Process
3. Risk Categories and Classification
4. Risk Modelling and Aggregation of Risks
5. Risk Measurement and Assessment
6. Risk Management Tools and Techniques

Course Syllabus:

Unit 1 - COMPONENTS OF ERM (12 Periods)
Introduction to ERM, ERM processes and structures, Risk policy, Monitoring and communication of risk, Stakeholders, Governance /assurance functions and the role of the CRO

Unit 2 - RISK AWARENESS (9 Periods)
Business analysis, risk identification and initial assessment, Introduction to risk measurement

Unit 3 - RISK MODELLING (18 Periods)
Introduction to risk modeling, Statistical distributions, Time series analysis, Copulas, Fitting models, Extreme value theory, Use of models in ERM

Unit 4 - RISK ASSESSMENT (13 Periods)
Assessment of market risks, Assessment of credit risks, Assessment of operational risks, Assessment of other risks
Total (52 periods)

KEY TEXT BOOK
James Lam, Enterprise Risk Management from Incentives to Controls (Second edition), Wiley, 2015. ISBN: 9781118413616. (Chapters: 1, 3, 5, 9, 15, 20, 23)

Paul Sweeting, Financial Enterprise Risk Management – Cambridge University Press, 2011. ISBN: 9780521111645. (Chapters: 3, 10, 11, 12, 13, 14, 17, 21)

REFERENCES

1. Robert J Chapman, Simple Tools and Techniques for Enterprise Risk Management – Wiley, 2006. ISBN: 0-470-014666-0
2. McNeil, Frey & Embrechts, Quantitative Risk Management: Concepts, Techniques and Tools – Princeton University Press, 2005. ISBN: 0-691-12255-5

Computer Lab Courses

1. C++ Programming 4 credits

Course objectives: Following are the objectives of the course

1. To understand the various Control Structures, Functions, Arrays, Pointers.
2. To learn the basic principles of object-oriented programming such as creating classes and objects, constructors and destructors
3. To enhance problem solving and programming skills in C++ with extensive programming exercises.
4. To become familiar with the LINUX software development environment.

Course Outcome: Upon completion of this course, students should be able to:

- Write a psudo code for a given problem and covert the same to a C++ program that works
- Discover errors in a C++ program and to fix them using proper tools and methodology
- Critique a C++ program and describe ways to improve it
- Choose and apply the required Linux commands to develop C++ programs in a command-line environment

Course Syllabus:

Unit 1: (20 periods)
Evolution of Programming methodologies, Introduction to OOP and its basic features, Basic components of a C++, Program and program structure, Compiling and Executing C++ Program. Selection control statements in C++.

Unit 2: (22 periods)
Data types, Expression and control statements Iteration statements in C++, Introduction to Arrays, Multidimensional Arrays, Strings and String related Library Functions.

Unit 3: (22 periods)
Functions, Passing Data to Functions, Scope and Visibility of variables in Functions, Structures in C++.

Unit 4: (24periods)
Creating classes and Abstraction: Classes objects, data members, member functions, this Pointer, Friends, Friend Functions, Friend Classes, Friend Scope, and Static Functions.

Unit 5: **(16 periods)**
Constructors and Destructors, Static variables and Functions in class.

Total **(104 periods)**

Reference Texts:

1. C++ Primer Fifth Edition, Stanley B.Lippman, Josee Lajoie, Barbara E.Moo, Pearson Education(Low priced Edition)
2. Programming with C++ Third Edition, John R.Hubbard, Schaum's outlines, McGraw Hill
3. C++ How To Program Tenth Edition, Paul Dietel , Harvey Deitel, Introduction to New C++14 standards

Suggested Readings:

1. The C++ Programming Language, 4th Editionby Bjarne Stroustrup
2. C++: The Complete Reference, 4th Edition by Herbert Schildt
3. Problem Solving with C++ by Pearson by Savitch Walter

2. Advanced C++ Programming 4 Credits

Prerequisite: Basic introduction to C++

Course objectives: Following are the objectives of the course

1. To impart advanced features of object oriented programming such as data abstraction and information hiding, Polymorphism, Inheritance, and dynamic binding of the messages to the methods.
2. To learn the principles of object-oriented design and software engineering in terms of software reuse and managing complexity.
3. To enhance problem solving and programming skills in OOD with extensive programming exercises.

Course Outcome: Upon completion of this course, students should be able to:

- Explain about OOPS concepts that were used in a program and their relevance
- Write a pseudocode for a given problem and covert the same to a C++ program that works
- Discover errors in a C++ program and to fix them using proper tools and methodology
- Critique a C++ program and describe ways to improve it
- Choose and apply the required Linux commands to develop C++ programs in a command-line environment

Course Syllabus:

Unit 1: **(16 periods)**
Operator Overloading in C++, Overloading Unary Operators, Overloading binary operators.

Unit 2: **(16 periods)**
Inheritance in C++, Types of Inheritance, Pointers, Objects and Pointers, Multiple Inheritance.

Unit 3: **(16 periods)**
Virtual Functions, Polymorphism, Abstract classes.

Unit 4: **(12 periods)**
Files and streams in C++: Character and String input and output to files, Command Line Arguments and Printer Output.

Unit 5: (10 periods)

Standard input and output operations: C++ iostream hierarchy, Standard Input/output Stream Library, Organization Elements of the iostream Library, Programming using Streams, Basic Stream Concepts.

Unit 6: (12 periods)

Class templates: Implementing a class template, Using a class template, Function templates, , Template instantiation, Template parameters, Static members and variables, Templates and friends, Templates and multiple-file projects.

Unit 7: (10 periods)

Standard Template library: Containers, iterators and application of container classes.

Unit 8: (12 periods)

Exception handling: Throwing an exception, catching an exception: The try block, Exception handlers, Exception specification, rethrowing an exception, uncaught exceptions, Standard exceptions, Programming with exceptions.

Total (104 periods)

Reference Texts:

1. C++ Primer Fifth Edition, Stanley B.Lippman, Josee Lajoie, Barbara E.Moo, Pearson Education(Low priced Edition)
2. Programming with C++ Third Edition, John R.Hubbard, Schaum's outlines, McGraw Hill
3. C++ How To Program Tenth Edition, Paul Dietel , Harvey Deitel, Introduction to New C++14 standards

Suggested Readings:

1.The C++ Programming Language, 4th Editionby Bjarne Stroustrup

2. C++: The Complete Reference, 4th Edition by Herbert Schildt

3. Problem Solving with C++ by Pearson by Savitch Walter

4. Data Structures and Algorithm Analysis in C++ 3rd Edition, Mark Allen Weiss, Pearson

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3. Programming in Python 4 Credits

Course Objectives:

- Basics of programming computers using Python 3
- To prepare students for advanced programming courses
- To impress upon students why Python is popular among programming languages by describing its features like dynamic typing, easy Object oriented programming interface, open source, availability of plethora of packages for plethora of domains written in python, powerful regular expressions package etc

Course Outcomes: At the end of the course, students should be able to

- program computers using python
- appreciate and appropriately use the powerful data structures like lists, sets, tuples and dictionaries provided by python
- Use exception handling to write good programs that can gracefully exit on exceptions
- Use python debugger to trace python program
- Evince deep interest and enthusiasm to attempt projects by preferring python.

Course Syllabus:

Unit 1 - Introduction To Python (6 periods)
Installation and Working with Python, Understanding Python variables, Python basic Operators, Understanding python blocks

Unit 2 - Python Data Types (7 periods)
Declaring and using Numeric data types - int, float, complex Using string data type and string operations, Defining list and list slicing, Use of Tuple data type

Unit 3 - Python Program Flow Control (10 periods)
Conditional blocks using if, else and elif, Simple for loops in python, For loop using ranges, string, list and dictionaries, Use of while loops in python, Loop manipulation using pass, continue, break and else, Programming using Python conditional and loops block

Unit 4 - Python Functions, Modules And Packages (9 periods)
Organizing python codes using functions, Organizing python projects into modules, Importing own module as well as external modules, Understanding Packages, Powerful Lamda function in python, Programming using functions, modules and external packages

Unit 5 - Python String, List And Dictionary Manipulations (12 periods)
Building blocks of python programs, Understanding string in build methods, List manipulation in build methods, Dictionary manipulation, Programming using string, list and dictionary in build functions

Unit 6 - Python File Operation (8 periods)
Reading config files in python, Writing log files in python, Understanding read functions, read(), readline() and readlines(), Understanding write functions, write() and writelines(), Manipulating file pointer using seek, Programming using file operations

Unit 7 - Python Object Oriented Programming – Oops (10 periods)
Concept of class, object and instances, Constructor, class attributes and destructors, Real time

use of class in live projects, Inheritance, overlapping and overloading operators, Adding and retrieving dynamic attributes of classes, Programming using Oops support

Unit 8 - Python Regular Expression (12 periods)
Powerful pattern matching and searching, Power of pattern searching using regex in python, Real time parsing of networking or system data using regex, Password, email, url validation using regular expression, Pattern finding programs using regular expression

Unit 9 - Python Exception Handling (10 Periods)
Avoiding code break using exception handling, Safe guarding file operation using exception handling, Handling and helping developer with error code, Programming using Exception handling

Unit 10 – Introduction to Python Debugger (4 periods)

Unit 11 – Project (16 Periods)

Total 104 periods

Reference Texts:

None (It is better to follow the course using online materials as listed under 'Suggested Reading heading.)

Suggested Reading:

1.https://realpython.com/learning-paths/python3-introduction/
2.https://www.python-course.eu/python3_course.php
3.http://do1.dr-chuck.com/pythonlearn/EN_us/pythonlearn.pdf

4. Numerical Methods and Simulation Lab 4 credits

Course Objectives: The diversity of the real world problem requires one to master several computational methods. Several methods based on sound mathematical principles have to be learnt and mastered in order to handle, simulate and experiment with a particular mathematical model. Such methods include optimisation, interpolation, prediction, linear algebra, differential equations and stochastic methods. This course covers some of these topics and provides a platform for the student to learn the aspects of modelling, simulations and obtaining approximate solutions to real world problems.

Course Outcomes:

1. Student can demonstrate an understanding of common numerical methods and how to obtain approximate solutions of certain mathematical problems.
2. Student can derive numerical methods to solve basic operations such as interpolation, integration and differentiation.
3. Student will be able to construct linear and non-linear models, obtain and interpret their solutions.
4. Student can perform monte carlo simulations.

Course Syllabus:

Topics:

Basic approach to numerical approximation of solutions to scientific problems.	**10 Periods**
Optimization: Linear and Quadratic Programming	**20 Periods**
Interpolation: Polynomial and spline interpolation	**20 Periods**
Numerical Integration and differentiation	**10 Periods**
Linear and Nonlinear algebraic systems	**20 Periods**
Modelling and solution of sparse equations	**14 Periods**
Randomized algorithms: Monte carlo Simulations	**10 Periods**
Total	**(104 periods)**

Reference Texts:

1. A. Greenbaum & T. P. Chartier, Numerical methods, Princeton University Press, 2012.

2. W. Cheney & D. Kincaid, Numerical mathematics and computing, Thomson, 2004.

3. D. P. O'Leary, Scientific Computing with case studies, SIAM, 2008.

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5. Introduction to SageMath Programming 4 credits

Course Objective: This lab introduces students to SageMath programming. This lab does not assume that the students are familiar with any programming language.

Course Outcome: Students will be able to appreciate the assistance of computers and programming in understanding mathematical concepts.

Course Syllabus:

Basic Python: Syntax, programming constructs, function calls, Collection data types such as list, set, dictionary, tuple. **(12 periods)**

Basics of Sage: Installation, Using Sage as a sophisticated scientific calculator. **(5 periods)**

Function plots: 2D-Plotting and 3D-Plotting. **(7 periods)**

Basic Rings and Fields: Integers and Rational Numbers, Real and Complex Numbers, Finite Rings and Fields, Polynomials. **(20 periods)**

Linear Algebra: Vectors, Matrices, Vector Spaces. **(20 periods)**

Mathematical Structures: Groups, Rings. **(20 periods)**

Symbolic Computation: Symbolic Expressions, Symbolic Equations, Symbolic Calculus, Symbolic integration. **(10 periods)**

Miscellaneous: Graph Theory, Galois Fields, Elliptic Curves. **(10 periods)**

Total: **104 periods**

Reference Texts:

- Sage Tutorial by The Sage Development Team. http://doc.sagemath.org/pdf/en/tutorial/SageTutorial.pdf
- Sage for Linear Algebra by Robert Beezer. http://linear.ups.edu/download/fcla-2.22-sage-4.7.1-preview.pdf
- Sage for Abstract Algebra by Robert Beezer. http://abstract.ups.edu/download/aata-20111223-sage-4.8.pdf

6. Symbolic Computing in SageMath 4 credits

Course Objective: This lab course deals with symbolic computations of various algebraic structures such as polynomials, power series, groups, rings, fields and modules. Many insights on these structures are obtained through experimentation. The course has a special emphasis on the 'big' theorems of Modern Algebra. SAGE (Software for Algebra and Geometry Experimentation), an open source software is used in the lab.

Course Outcome:

1. Student learns how to use the libraries of SAGE to create and work with several algebraic structures.
2. Student can experiment with some of the theorems in their Algebra textbook.
3. Student will cultivate the art of conjecturing through their observations based on their experiments.

Course Syllabus:

Polynomials and Formal Power Series: Symbolic operations on polynomials and power series of one or more variables **20 Periods**

Group Theory: Normal Subgroups, Homomorphism, fundamental theorem of isomorphism, Sylow's Theorem, Conjugacy classes of the symmetric group, Examples of named groups such as Sn, An, Dn, Dih(G), KleinFourGroup, Rubik's Cube group. **30 Periods**

Ring Theory: Prime and Maximal Ideals, Ring homomorphism, fundamental theorem of isomorphism, fraction field of integral domains, Galois field, 'algebraic' derivative, Number Fields, Field extensions, Galois theory **30 Periods**

Commutative Algebra: Noetherian Rings and Modules, Function Fields, Grobner Basis **24 Periods**

Total: **104 Periods**

Reference Texts:

1) SAGE Reference Manual, https://doc.sagemath.org/pdf/en/reference/

2) Beezer, R., Sage for Abstract Algebra, http://abstract.ups.edu/download/aata-20111223-sage-4.8.pdf

7. Introduction to MATLAB Programming 4 credits

Course Objectives: The objectives of this software lab course are to introduce coding on MATLAB software to students who have chosen Mathematics as their Stream Core. The main aim is to make them use MATLAB not just as a computing software bust also as a programming and visualizing platform. This is mainly to make students visually see the theory that they have already studied.

Course Outcomes: After going through this software lab, a student will be able to:

- Use MATLAB as a basic arithmetic, computing and plotting platform.
- Write functions on MATLAB and run them
- Use Symbolic methods to perform calculus and solve differential equations.

Course Syllabus:

Unit 1 - First Steps in MATLAB 10 periods
Starting MATLAB, Matrices,Variables,Plotting Vectors,
Command Line Editing, Smart Recall

Unit 2 – Matrices 10 periods
Typing Matrices, Concatenating Matrices, Useful Matrix Generators
Subscripting, End as a subscript, Deleting Rows or Columns
Matrix Arithmetic, Transpose

Unit 4 - Basic Graphics 10 periods
Plotting Many Lines, Adding Plots, Plotting Matrices
Clearing the Figure Window, Subplots,Three-Dimensional Plots

Unit 5 - Graphics of Functions of Two Variables 10 periods

Basic Plots, Colour Maps, Colour Bar, Good and Bad Colour Maps
Extracting Logical Domains, Nonrectangular Surface Domains

Unit 6 - M-Files 15 periods
Scripts, Functions, Flow Control, Comparing Strings

Unit 7 – Polynomials, Curve Fitting and Interpolation 10 periods

Unit 8– Three Dimensional Plots 15 periods
Line Plots, Mesh and Surface Plots, Plots with Special Graphics
The View Command

Unit 9 – Symbolic Math 25 periods
Symbolic Objects and Symbolic Expressions
Changing the form of An Existing Symbolic Expression
Solving Algebraic Expression, Differentiation, Integration
Solving ODE's, Plotting Symbolic Expressions, Numerical Calculations with Symbolic Expressions

Total **105 periods**

Reference Texts:

1. Andrew Kinght, Basics of MATLAB and Beyond, Chapman & Hall/CRC, 2000.
2. Amos Gilat, MATLAB: An Introduction with Applications, Fifth Edition, Wiley, 2015.

Suggested Reading:

Standard Online Courses dealing with the Basics of MATLAB.

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8. Advanced MATLAB Programming 4 Credits

Prerequisites: Introduction to MATLAB programming

Course Objectives: This course takes off from the introductory MATLAB course and aims to impart certain advanced concepts of MATLAB programming to equip the student better for realistic programming challenges.

Course Outcomes: By the end of the course, the student should be able to handle a MATLAB programming task of medium difficulty like creating an app in the field of his choice. The student will also appreciate the nuances of MATLAB, the advanced features it offers and certain pitfalls associated with this unique platform which make him a more knowledged programmer.

Course Syllabus:

Toolboxes and area specific exploration	16 periods
Advanced data structures, advanced functions	16 periods
Advanced plotting	8 periods
External interfacing and data import/export	8 periods
Profiling and debugging	8 periods
GUI and App creation	16 periods
Mini project	32 periods
Total	**(104 periods)**

Reference Texts:

1. Stormy Attaway, "MATLAB - A practical introduction to programming and problem solving", Fourth edition, 2017, Butterworth-Heinemann Publications
2. Online material from www

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9. Introduction to OCTAVE Programming 4 credits

Course Objective:

This course provides an introduction to computing using Octave. It teaches how to use Octave to perform calculations, plot graphs, and write simple programs. The close compatibility of the open-source Octave1 package with MATLAB2, which is heavily used in industry and academia, gives the user the opportunity to learn the syntax and power of both packages where funding and licence restrictions prevent the use of commercial packages.

Course Outcomes:
After going through this software lab, a student will be able to:

1. Solve linear and nonlinear problems numerically, and use this software for performing other numerical experiments .

2. It teaches one to perform calculations, plot graphs, and write simple programs.

3. Octave makes it easy to solve a wide range of numerical problems, allowing you to spend more time experimenting and thinking about the wider problem.

Course Syllabus:

Unit 1:Introduction to Octave Programming 10 periods

1.1 What is octave ?
1.2 Who uses Octave?
1.3 Why not use a 'normal' high-level language, e.g. C++

Unit 2: Simple calculations 10 periods

2.1 Starting Octave
2.2 Octave as a calculator
2.3 Built-in functions .

Unit 3: The Octave environment 10 periods

3.1 Named variables
3.2 Numbers and formatting
3.3 Number representation and accuracy
3.4 Loading and saving data
3.5 Repeating previous commands
3.6 Getting help
3.7 Cancelling a command
3.8 Semicolons and hiding answers

Unit 4: Arrays and vectors 10 periods

4.1 Building vectors
4.2 The colon notation
4.3 Displaying large vectors and matrices
4.4 Vector creation functions
4.5 Extracting elements from a vector
4.6 Vector maths

Unit 5:Plotting Graphs 10 periods

5.1 Improving the presentation
5.2 Multiple graphs
5.3 Multiple figures
5.4 Manual scaling
5.5 Saving and printing figures

Unit 6: Matrices 8 periods

6.1 Matrix multiplication
6.2 The transpose operator
6.3 Matrix creation functions
6.4 Building composite matrices
6.5 Matrices as tables
6.6 Extracting bits of matrices .

Unit 7:Octave programming : Script files 8 periods

7.1 Creating and editing a script
7.2 Running and debugging scripts
7.3 Remembering previous scripts

Unit 8: Control Statements 8 periods

8.1 if...else selection
8.2 switch selection
8.3 for loops
8.4 while loops .

Unit 9: Solving Ax = b 10 periods

9.1 Solution when A is invertible
9.2 Gaussian elimination and LU factorisation
9.3 Matrix division and the slash operator
9.4 Singular matrices and rank
9.5 Ill-conditioning
9.6 Over-determined systems: Least squares
9.7 Example: Triangulation

Unit 10 : More graphs 10 periods

10.1 Putting several graphs in one window
10.2 3D plots
10.3 Changing the viewpoint
10.4 Plotting surfaces
10.5 Images and Movies .

Unit 11: Eigenvectors and the S.V.D 10 periods

11.1 The eigen function
11.2 The Singular Value Decomposition
11.3 Approximating matrices: Changing rank
11.4 The svd function
11.5 Economy SVD

Total 104 periods

Reference Texts:

1. Dr. P.J.G. Long, Introduction to Octave, Department of Engineering University of Cambridge.

2. Mike James, A Programmers Guide to Octave.

Suggested Reading:

Standard Online Courses dealing with the Basics of Octave Programming.

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10. Advanced OCTAVE Programming **4 credits**

Prerequisites: Introduction to OCTAVE programming

Course Objectives: This course aims to impart certain advanced concepts of OCTAVE programming to equip the student better for practical programming challenges.

Course Outcomes: By the end of the course, the student should be able to handle an OCTAVE programming task in the field of his choice. The student will also appreciate the nuances of OCTAVE, the ease of programming it offers, its compatibility with MATLAB and practice using this platform to solve a problem at hand.

Course Syllabus:

OCTAVE packages and area specific exploration	16 periods
Advanced data containers, advanced functions and scripts	16 periods
Advanced plotting	8 periods
External code interfacing, data import/export, MATLAB compatibility	8 periods
Errors, warnings and debugging	8 periods
GUI development	16 periods
Mini project	32 periods
Total	**(104 periods)**

Reference Texts:

1. Online material from www
2. GNU Octave Docs

11. Data Analysis and Visualization using Python 4 Credits

Course Objectives:

- Understanding the following tools in Python
  - NumPy
  - SciPy
  - Pandas
  - matplotlib
- Using Python for data visualization

Course Outcomes:

- Understanding structured and unstructured data
- Develop Data analytic skills

Course Syllabus:

Unit 1: NumPy Basics 20 periods
The NumPy ndarray, Universal Functions: Fast Element-wise Array Functions, Data Processing Using Arrays, File Input and Output with Arrays, Linear Algebra, Random Number Generation, Random Walks

Unit 2: Getting Started with Pandas 20 periods
Introduction to pandas Data Structures, Essential Functionality, Summarizing and Computing Descriptive Statistics, Handling Missing Data, Hierarchical Indexing, Integer Indexing, Panel Data

Unit 3: Data Loading, Storage and File formats 16 periods
Reading and Writing Data in Text Format, Binary Data Formats, Interacting with HTML and Web APIs, Interacting with Databases

Unit 4: Data Wrangling: Clean, Transform, Merge, Reshape 10 periods
Combining and Merging Data Sets, Reshaping and Pivoting, Data Transformation, String Manipulation

Unit 5: Plotting and Visualization 10 periods
A Brief matplotlib API Primer, Plotting functions in Pandas, Plotting Maps, Python Visualization Tool Ecosystem

Unit 6: Data Aggregation and Group Operations 10 periods
GroupBy Machanics, Data Aggregation, Group-wise Operations and Transformations, Pivot Tables and Cross-Tabulation,

Unit 7: Time Series 18 periods
Date and Time Data Types and Tools, Time Series Basics, Date Ranges, Frequencies and Shifting, Time Zone Handling, Periods and Period Arithmetic, Resampling and Frequency Conversion, Time Series Plotting, Moving Window Functions

Total **104 periods**

Reference Texts: Python for Data Analysis by Wes McKinney, October 2012, First Edition

12. Mathematical Methods in Data Mining using Python 4 Credits

Course Objective: The course objective is to introduce practical experience of coding some simple datamining tasks/algorithms.

Course Outcome:
By the end of this course, students will be able to:
- Implement basic daprograms for linear regression, classification.
- Implement clustering algorithms such as K-means, density based etc.
- Implement association rule mining algorithm.

Course Syllabus:

Unit 1: Installing Python and loading sample datasets	(4 periods)
Unit 2: Basic Linear regression examples	(6 periods)
Unit 3: Logistic and polynomial regression	(8 periods)
Unit 4: Classification examples	(6 periods)
Unit 5: Some standard techniques for classification	(24 periods)
Unit 6: Clustering techniques	(16 periods)
Unit 7: A mini project	(40 periods)
Total	**(104 periods)**

Reference Texts:
1. Online material
2. Learning Data Mining with Python: Use Python to manipulate data and build predictive models, 2nd Edition by Robert Layton

13. SQL Programming 4 Credits

Course Objectives:

- Data and Databases are everywhere in the industry today. Relational database is the most popular form of storing data. Understanding relational databases is important.
- SQL programming is an essential skill for a computer science student

Course Outcomes:

- Create, manipulate and understand a relational database
- Apart from popular programming languages used for problem solving and software design etc., SQL a specific skill that is acquired for understanding most popular databases like Oracle.
- Every assignment in the lab is performed on the Oracle database.

Course Syllabus:

Unit 1 - Introduction to SQL. 4 periods

What is SQL? What is ANSI SQL? Basics of the RDBMS,Types of SQL commands: DDL, DML.

Unit 2 - Data Definition Language 18 periods

What is Data? What are database objects? What is a schema?, The SQL statement CREATE TABLE. List the data types that are available for columns: character, numeric, date, large objects (LOBs). Creating CONSTRAINTS in the CREATE TABLE statement, types of CONSTRAINTS. ALTER TABLE and DROP TABLE commands. Creating a table from an existing table.

Unit 3 - Data Manipulation Language 15 periods

Overview of data manipulation: INSERT/UPDATE/DELETE rows in a table, default column list, enumerated column list, Control transactions: COMMIT, ROLLBACK, SAVEPOINT. Inserting data from another table.

Unit 4 - Data Retrieval, restricting and sorting 15 periods

The SELECT statement—an example. The WHERE clause, boolean logic, additional WHERE clause features (IN, BETWEEN, IS NULL/IS NOT NULL). Order by clause.

Unit 5 - Specialized Functions 6 periods

Character functions, number functions, date functions, conversion functions.

Unit 6 - Aggregate Functions 10 periods

COUNT, SUM, MIN/MAX, AVG. Group data by using the GROUP BY clause: multiple columns, ORDER BY revisited, nesting functions. HAVING clause.

Unit 7 - Joins 8 periods

Types of joins: inner joins, outer joins, natural joins.

Unit 8 - Sub-queries and set operators 14 periods

Define subqueries. Types of subqueries: single-row subqueries, multiple-row subqueries, multiple-column subquery. Correlated subqueries. Set operators: UNION, UNION ALL, INTERSECT, EXCEPT (MINUS).

Unit 9 - Views and Normalization 14 periods

Create and use simple and complex views. Normalization: before the first normal form, the first normal form, the second normal form, the third normal form, higher normal forms. Integrity rules: general integrity rules, database-specific integrity rules.

Total **104 periods**

Reference Texts:

Abraham Silberschatz, Henry F. Korth, S. Sudarshan, Database System Concepts, Vth edn, Tata McGraw Hill, 2005.

Suggested Reading:

Connolly and Begg, Database Systems: A practical approach to design, implementation, and Management, IVth Edition, Pearson Education, 2005.

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14. Core Java Programming 4 Credits

Course Objectives:

This Course will introduce the students to Java Programming environment. This will enable students the exposure to code, execute and configure core java programs on a standalone system. All the Object Oriented Programming concepts are deeply covered and implemented in various lab sessions. Few of the programming design patterns are also covered.

Course Outcomes:

At the completion of this course, the student will be able to:

- Good understanding of Java environment
- Good programming skills in Java on various topics like networking, streams, multi-threading, IOs, Collections, etc.
- Hands on labs and assignments on all the advanced topics of Core Java like developing TCP Server and Client programs, multi-threading, etc.
- Mini Project on TCP Server and Client with various services provisioning.

Course Syllabus:

Unit 1: (4 periods)
Introduction to Java environment

Unit 2: (8 periods)
Access Modifiers, Control statements, Java Classes, Enums

Unit 3: (12 periods)
Introduction to OOPs and Java API

Unit 4: (10 periods)
Implementing Inheritance, Arrays

Unit 5: (12 periods)
Introducing Interfaces

Unit 6: (10 periods)
Java Packages and Modules

Unit 7: (10 periods)
Java Exceptions

Unit 8: (10 periods)
Java Generics and Collections Framework

Unit 9: (8 periods)
Inner Classes

Unit 10: (8 periods)

IO streams and Networking

Unit 11: (12 periods)

Threads, Lambdas

Total (104 Periods)

Reference Texts:

Thinking in Java, Fourth Edition by Bruce Eckel, Prentice Hall

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15. Operating Systems Lab 4 Credits

Course Objectives:
This course will introduce students to the basic and advanced features of the Unix Operating System. Features like, OS File system, Events generation and handling, Processes and their environment, Inter-process communication mechanisms, etc. Students with C background will code/program and familiarize with programmatic perspective of Unix Operating system.

They will perform some basic to advanced coding to customize and interact with underlying OS. Students are introduced to Unix OS library and utilize them to accomplish certain tasks with system level calls and features.

Course Outcomes: At the completion of the course the student will be able to

- Utilize Unix OS system Library and the C Standard Library to access/manipulate the file system, internal data structures, etc.
- Understand and apply Multithreading concepts, Inter-process communication mechanisms like, Pipe, FIFO, Shared Memory, Semaphores.
- Understand and implement concepts to create processes, child processes, data structures used and invoke system libraries to manipulate process.
- Code to generate the Signals, and handle the Signals, different types of Signals generated by Kernel etc.

Course Syllabus:

Unit 1 : Introduction (16 Periods)
UNIX System Overview, UNIX Architecture Files and Directories, Input and Output, Error Handling, Signals, Time Values, System Calls and Library Functions

Unit 2 : File I/O (20 Periods)
File Descriptors, open and open at Functions, creat Function, close Function, lseek Function, read Function, write Function, I/O Efficiency, File Sharing, dup and dup2 Functions sync, fsync, and fdatasync Functions, fcntl Function

Unit 3: Files and Directories (20 Periods)
stat, fstat, fstatat, and lstat Functions, File Types, File Access Permissions, Ownership of New Files and Directories, chmod, fchmod, and fchmodat Functions, chown, fchown, fchownat, and lchown Functions, link, linkat, unlink, unlinkat, and remove Functions, Creating and Reading Symbolic Links, Reading Directories, chdir, fchdir, and getcwd Functions, Device Special Files

Unit 4: Process Control (26 Periods)
fork Function, vfork Function, exit Functions, wait and waitpid Functions, waitid Function, wait3 and wait4 Functions, Race Conditions, exec Functions, Interpreter Files, system Function

Unit 5: Inter Process Communication (12 Periods)
PIPES, FIFOs, Semaphores, shared Memory

Unit 6: Signals (10 Periods)

signal Function, Unreliable Signals, Interrupted System Calls, Reentrant Functions, SIGCLD Semantics, kill and raise Functions, alarm and pause Functions, sigprocmask Function, sigpending Function, sigaction Function, sigsetjmp and siglongjmp Functions, sigsuspend Function, sleep, nanosleep, and clock_nanosleep, sigqueue Function

Total **(104 periods)**

Reference Texts: Advanced Programming in the UNIX Environment Third Edition by W. Richard Stevens Stephen A. Rago

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16. Actuarial Mathematics using R **Credits 4**

Course Objectives: Following are the objectives of the course
1. Describe and use statistical distribution for risk modelling
2. To enhance problem solving and programming skills in R with extensive programming exercises.

Course Outcome:
1. Explain about the various statistical concepts that were used in a program and their relevance
2. Create an algorithm for a given problem and implement the same in R.
3. Discover errors in a R program and to fix them using proper tools and methodology
4. Critique a R program and describe ways to improve it.
5. Predict or describe the patterns in data using machine learning techniques in R.

Course Syllabus:

Unit 1 (16 Periods)
Evolution of programming methodologies, Introduction to R and its basic features, Basic components of R, Program and program structure, Compiling and executing R program,Data Science Overview, Introduction To Business Analytics, Business Decisions And Analytics, Types Of Business Analytics, Applications Of Business Analytics

Unit 2: (10 Periods)
Importance Of R, Data Types And Variables In R, Operators In R, Conditional Statements In R,Loops In R, R Script, Functions In R

Unit 3: (10 Periods)
Overview of Data Structures, Identifying Data Structures, Demo Identifying Data Structures, Assigning Values To Data Structures, Data Manipulation, Demo Assigning Values And Applying Functions

Unit 4: (10 Periods)
Introduction To Data Visualization, Data Visualization Using Graphics In R, Ggplot2, File Formats Of Graphic Outputs

Unit 5: (10 Periods)
Introduction To Hypothesis, Types Of Hypothesis, Data Sampling, Confidence And Significance Levels

Unit6: (10 Periods)
Hypothesis Test, Parametric Test, Non-Parametric Test, Hypothesis Tests About Population Means, Hypothesis Tests About Population Variance, Hypothesis Tests About Population Proportions

Unit 7: (10 Periods)
Introduction To Regression Analysis, Types Of Regression Analysis Models, Linear Regression, Demo Simple Linear Regression, Non-Linear Regression, Demo Regression Analysis With Multiple Variables, Cross Validation, Non-Linear To Linear Models, Principal Component Analysis, Factor Analysis

Unit 8: (10 Periods)

Classification And Its Types, Logistic Regression, Support Vector Machines, Demo Support Vector Machines, K-Nearest Neighbours, Naive Bayes Classifier, Demo Naive Bayes Classifier, Decision Tree Classification, Demo Decision Tree Classification, Random Forest Classification, Evaluating Classifier Models, Demo K-Fold Cross Validation

Unit 9: (10 Periods)

Introduction To Clustering, Clustering Methods, Demo K-Means Clustering, Demo Hierarchical Clustering

Unit 10: (8 Periods)

Association Rule,Apriori Algorithm, Demo Apriori Algorithm

Total (104 Periods)

Reference Texts:

Book1: Computational Actuarial Science with R, Author(s): Arthur Charpentier, Series: Chapman & Hall/CRC The R Series, Publisher: Chapman and Hall/CRC, Year: 2014. ISBN: 1466592591,9781466592599

Book2: R for Data Science, G. Grolemund, H. Wickham, O’Reilly Media, 2017

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17. Actuarial Mathematics using SAS **Credits 4**

Course Objectives: Following are the objectives of the course
1.Describe and use statistical distribution for risk modelling
2.To enhance problem solving and programming skills in SAS with extensive programming exercises.

Course Outcomes:
1.Explains about the various statistical concepts that were used in a program and their
2.Create an algorithm for a given problem and implement the same in a SAS environment.
3.Debug a SAS program and to fix them using proper tools and methodology
4.Critically analyse a SAS program and describe ways to improve it.
5.Predict and/or identify the patterns from the given data using Machine Learning Techniques in SAS

Course Syllabus:

Unit 1: (10 Periods)
Evolution of programming methodologies, Introduction to SAS and its basic features, Basic components of SAS, Program and program structure, Compiling and executing SAS program,Data Science Overview, Introduction To Business Analytics, Business Decisions And Analytics, Types Of Business Analytics, Applications Of Business Analytics

Unit 2: (6 Periods)
What Is SAS, Navigating In The SAS Console, SAS Language Input Files, DATA Step, PROC Step And DATA Step – Example, DATA Step Processing, SAS Libraries, Demo - Importing Data, Demo - Exporting Data

Unit 3: (8 Periods)
Why Combine Or Modify, Concatenating, Interleaving, One - To – One, One - To - One Merging, Data Manipulation, Modifying Variable Attributes

Unit 4: (10 Periods)
Introduction to PROC SQL, Retrieving Data From A Table, Demo - Retrieve Data From A Table,Selecting Columns In A Table, Retrieving Data From Multiple Tables, Selecting Data From Multiple Tables, Concatenating Query Results

Unit 5: (10 Periods)
Introduction to SAS Macros, Need For SAS Macros, Macro Functions, Macro Functions Examples, SQL Clauses For Macros, The % Macro Statement, The Conditional Statement

Unit6: (10 Periods)
Introduction to Statistics, Procedures In SAS For Descriptive Statistics, Demo - Descriptive Statistics, Hypothesis Testing, Variable Types, Hypothesis Testing – Process, Demo - Hypothesis Testing, Parametric And Non - Parametric Tests,

Parametric Tests, Non - Parametric Tests, Parametric Tests - Advantages And Disadvantages

Unit 7: (10 Periods)
Introduction to Statistical, PROC, PROC Means – Examples, PROC FREQ, Demo - PROC FREQ, PROC UNIVARIATE, Demo - PROC UNIVARIATE, PROC CORR, PROC CORR Options, Demo - PROC CORR, PROC REG, PROC REG Options, Demo - PROC REG, PROC ANOVA, Demo - PROC ANOVA

Unit 8: (10 Periods)
Introduction to Data Preparation, General Comments And Observations On Data Cleaning, Data Type Conversion, Character Functions, SCAN Function, Date/Time Functions, Missing Value Treatment, Various Functions To Handle Missing Value, Data Summarization

Unit 9: (10 Periods)
Introduction ToAdvanced Statistics, Introduction To Cluster, Clustering Methodologies, Demo - Clustering Method, K Means Clustering, Decision Tree, Regression, Logistic Regression

Unit 10: (10 Periods)
Need For Time Series Analysis, Time Series Analysis — Options, Reading Date And Date time Values, White Noise Process, Stationarity Of A Time Series, Demo — Stages Of ARIMA Modelling, Plot Transform Transpose And Interpolating Time Series Data

Unit 11: (10 Periods)
Introduction to Designing Optimization Models, Need For Optimization, Optimization Problems, PROC OPTMODEL, Optimization - Example 1, Optimization - Example 2

Total (104 Periods)

Reference Texts:

Lora D. Delwiche, The Little SAS Book, A Primer -- Fifth Edition

Ron Cody, Learning SAS by Example: A Programmer's Guide, Second Edition

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