CENTRAL UNIVERSITY OF JHARKHAND
DEPARTMENT OF MATHEMATICS

**Based on New Ph.D. ordinance 2016, a Ph.D. student has to complete minimum 12 credits of course work.**

**Syllabus for Papers in PhD. Course work in Department of Mathematics 2018 onwards.**
**L – Lecture, T- Tutorial, P – Practical (Lab), Cr – Credits.**

**Compulsory Paper**

| S. No. | Course Code | Course Title | | | | CR |
|---|---|---|---|---|---|---|
| | | | L | T | P | |
| 1 | PHDAM 018 | Research Methodology | | | | 4 |
| **Total Credits** | | | | | | |

**Based on the suggestions of Ph.D. Supervisor, the Ph.D. student has to take at least two papers from the following list of Papers.**

| S. No. | Course Code | Course Title | | | | CR |
|---|---|---|---|---|---|---|
| | | | L | T | P | |
| 1 | PHDAM 001 | Fundamentals of Computer & C Programming | 3 | 0 | 1 | 4 |
| 2 | PHDAM 002 | Basics of Number Theory and Discrete Mathematics | 3 | 1 | 0 | 4 |
| 3 | PHDAM 003 | Introduction to Numerical Analysis – I | 3 | 1 | 0 | 4 |
| 4 | PHDAM 004 | Field Theory | 3 | 1 | 0 | 4 |
| 5 | PHDAM 005 | Object Oriented Programming with C++ | 3 | 0 | 1 | 4 |
| 6 | PHDAM 006 | Functional Analysis | 3 | 1 | 0 | 4 |
| 7 | PHDAM 007 | Introduction to Numerical Analysis – II | 3 | 1 | 0 | 4 |
| 8 | PHDAM 008 | Algebraic Number Theory | 3 | 1 | 0 | 4 |
| 9 | PHDAM 009 | Advanced Number Theory | 3 | 1 | 0 | 4 |
| 10 | PHDAM 010 | Numerical Optimization Techniques | 3 | 1 | 0 | 4 |
| 11 | PHDAM 011 | Operator Theory | 3 | 1 | 0 | 4 |
| 12 | PHDAM 012 | Advanced Discrete Mathematics | 3 | 1 | 0 | 4 |
| 13 | PHDAM 013 | Theoretical Numerical Analysis | 3 | 1 | 0 | 4 |
| 14 | PHDAM 014 | Coding Theory | 3 | 1 | 0 | 4 |
| 15 | PHDAM 015 | Optimization by Vector Space Methods | 3 | 1 | 0 | 4 |
| 16 | PHDAM 016 | Analytic Number Theory | 3 | 1 | 0 | 4 |
| 17 | PHDAM 017 | Introduction to Integral Equations | 3 | 1 | 0 | 4 |
| 18 | PHDAM 019 | Advanced Linear Algebra | 3 | 0 | 1 | 4 |
| 19 | PHDAM 020 | Combinatorics | 3 | 0 | 1 | 4 |
| 20 | PHDAM 021 | Difference Equations and Discrete Dynamical Systems | 3 | 1 | 0 | 4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 21 | PHDAM 022 | Theory of Groups and Rings | 3 | 1 | 0 | 4 |
| 22 | PHDAM 023 | Theory of Modules and Commutative Rings | 3 | 1 | 0 | 4 |
| 23 | PHDAM 024 | Lie Group and Lie Algebra | 3 | 1 | 0 | 4 |
| 24 | PHDAM 025 | Representation Theory | 3 | 1 | 0 | 4 |
| 25 | PHDAM 026 | Theory of Relativity | 3 | 1 | 0 | 4 |
| 26 | PHDAM 027 | Theory and Applications of Fuzzy Sets | 3 | 1 | 0 | 4 |
| 27 | PHDAM 028 | Cryptography | 3 | 1 | 0 | 4 |
| 28 | PHDAM 029 | Theory of Differential Equations | 3 | 1 | 0 | 4 |
| **Total Credits** | | | | | | |

## Research Methodology

**A. The syllabus of Research Methodology (Mathematics) (4 credits) (Compulsory):**

(i) Latex and Beamer (10 hours).

(ii) At least one mathematical software out of the following: Scilab/KASH/Maxima/SAGE/Other software suggested by the research supervisor (10 hours).

(iii) Working knowledge of MathSciNet, JSTORE and other online journals, Review of a research paper (4 hours),

(iv) Rapid Reader: Mathematics and its History, by J. Stillwell, Springer International Edition, 4th Indian Reprint, 2005, Write Mathematics Right by L. Radhakrishnan (2013) (10 hours).

(v) Participating in seminar/lectures on different topics in Mathematics (6 hours).

**B. ATM School Participation (4 credits) (Optional):** Advanced Training in Mathematics (ATM) schools have been devised by NBHM to broaden the knowledge of a research student in Mathematics and also inculcating problem solving skills for better understanding of the subject and developing research orientation. These are now organised by National Centre for Mathematics (NCM). A student participating in an NCM-sponsored ATM school of 3-4 weeks duration such as Annual Foundation School I, II or III or an Advanced Instructional School on a specific topic will earn 5 credits provided the school is attended after getting provisional admission for Ph.D. The Research Guide will request the coordinator of the school to give a grade to the student based on the participation of the student in the ATM school.

Texts/References


1. R. Pratap: Getting Started with MATLAB: A Quick Introduction for Scientists and Engineers, Oxford, 2010.
2. M. L. Abell, J. P. Braselton: Mathematica by Example, 4th Edition, Academic Press, 2008.

3. Tobi Oetiker et al. The Not So Short Introduction to LaTeX, web: https://tobi.oetiker.ch/lshort/lshort.pdf

## Fundamentals of Computers and C Programming (3-0-1 4)

Introduction to computers, generations of computer, processors, memory hierarchy and I/O devices, System and application software, generation of languages, compiler, interpreter, assembler, Number systems, computer arithmetic.
Flow Charting, Sequential, Branching & Iterative.
Introduction to 'C' as Programming Language, An overview of a 'C' programme, 'C' character set, 'C' tokens, 'C' key words, Data Types (primary, derived & user defined), Storage classes, symbolic constants, operators (arithmetic, logical & relational), Flow of control (If- else, switch-case; while, do-while & for-loops).
Functions (UDF, String Functions, Mathematical functions)
Recursion, pointers, array (2-D & 3-D), Strings, pre-processor directives, structures, linked list file handling.
C-lab: Execution of a simple programme, Conditional & Un-conditional Branching, Loops, Functions (Interactive & Recursive), Arrays (2-D & 3-D), Structures, Linked Lists, File I/O.

Texts/References

1. B.W. Kernighan, D.M. Ritchie: *The C Programming Language*, Prentice Hall India, 1990.
2. Y.P. Kanetkar: Let us C, BPB Publications, 2002.
3. E. Balagurusamy: *Programming in ANSI C*, 4th edition, Tata McGraw Hill.

## Basics of Number Theory and Discrete Mathematics (3-1-0 4)

Linear congruences, Algebraic congruences of degree $\geq 2$. General Taylor Expansion Method for Prime Power Modulus. Theorems of Euler, Lagrange and Wilson. Primality Testing and Factoring, Primitive Roots, Quadratic Congruence, Euler's Criteria and Legendre's Symbol, two square theorem, quadratic reciprocity law. Simple continued fractions, Pell's Equation.
Pigeon Hole Principle, Inclusion Exclusion Principle, Techniques of Counting, Recurrence relations. Introduction to Lattice theory, Boolean algebra with application to switching circuits.

**Texts/References**

1. G.H. Hardy and E.M. Wright: *An Introduction to the Theory of Numbers*, 6th edition, Oxford University Press, 2008.
2. D.M. Burton: *Elementary Number Theory*, 6th edition, McGraw-Hill, 2005.

3. I. Niven, H.S. Zuckerman and H.L. Montgomery: *An Introduction to the Theory of Numbers*, 5th edition, Wiley, 1991.
4. *K. D. Joshi: Foundations* of Discrete Mathematics, New Age International, 1996.

## Introduction to Numerical Analysis - I (3-1-0- 4)

**Nature of numerical computations:** Errors and their propagation, convergence and stability of numerical algorithms; efficiency and arithmetic, complexity.
**Numerical solution of systems of linear equations:** Direct methods for solving linear systems, error analysis. The residual correction method. Iteration methods, Error prediction and Acceleration.
**Matrix Eigenvalue problem:** Eigenvalue location, error, and stability results, Power method. Orthogonal transformations using Householder matrices. The eigenvalues of a symmetric Tridiagonal matrix. QR method. The calculation of Eigenvectors and Inverse iteration.
**Numerical solutions of Non-linear equations**: Solution of non-linear equations by iterative methods, acceleration of convergence. Newton's methods for polynomials, quotient-difference algorithms. Numerical solution of system of Non-linear equations.
**Interpolation:** Interpolating polynomial and its construction using Lagrange methods and methods of differences, iterated interpolation, method of divided differences, inverse interpolation, Hermite Interpolation. The general Hermite interpolation problem. Spline function and their use.
**Lab Component:** Exposure to Matlab/Mathematica/Scilab and computational experiments based on the algorithms discussed in the course.

**Texts/References:**

1. K. Atkinson: *An Introduction to Numerical Analysis*, 2nd edition, Wiley, 1989.
2. R.L. Burden and J.D. Faires: *Numerical analysis*, 7th edition, Brooks Cole, 2001.
3. P.J. Davis: *Interpolation and Approximation*, Dover, 1975.
4. J.M. Ortega: *Numerical Analysis: A Second Course*, SIAM, 1987.
5. *S.S. Sastry: Introductory Methods of Numerical Analysis,* Phi Learning, 2009.

## Field Theory (3-1-0 4)

Fields- Field extensions, algebraic and transcendental field extensions, finite fields.
Galois extensions. Constructibility by ruler and compass, Fundamental Theorem of Galois Theory.
The impossibility of solving the general quintic by radicals.

Text/References

1. M. Artin: *Algebra*, Prentice Hall India, 2009.

2. S. Lang: *Algebra*, 3$^{rd}$ edition, Springer, 2002.
3. J. Rotman: *Galois Theory,* 2$^{nd}$ edition, Springer, 2006.
4. P. Morandi: *Field and Galois Theory,* Springer, 2010.
5. I. S. Luthar and I. B. S. Passi: Algebra 4 - *Field Theory*, Narosa, 2004.

## Object Oriented Programming through C++ (3-0-1 4)

Concepts of objects, class, inheritance, data encapsulation, polymorphism etc., Introduction to C++, Input and output in C++, C++ declaration, Control structure, Function in C++, Classes and objects in C++. Constructors and destructors, Operator overloading and type conversion, Inheritance, Pointers and arrays in C++, Binding, polymorphism, virtual functions and pure virtual functions. Applications with files, Generic programming with templates, Exception handling, Working with Streams.
Lab work.

**Texts/References**

A. N. Kamthane: *Object oriented programming with ANSI and turbo C++*, Pearson Education, 2011.

H. Schildt: *C++ The Complete Reference*, 4$^{th}$ edition, Tata McGraw Hill, 2003.

E. Balaguruswamy: *Object Oriented Programming with C++,* 4$^{th}$ edition, Tata McGraw Hill, 2008.

R. Lafore: *Object-Oriented Programming in C++,* Galgotia Publications, 2006.

## Functional Analysis (3-1-0 4)

Normed linear spaces: Finite dimensional normed spaces, Heine-Borel theorem, Riesz lemma, Continuity of linear maps, Hahn-Banach extension theorem, Banach spaces, Dual spaces and transposes, Uniform-boundedness principle and its applications; Spectrum of a bounded operator.

Inner product spaces: Hilbert spaces, Orthonormal basis, Total Orthonormal Sets and Sequences Projection theorem and Riesz representation theorem. Representation of Functionals on Hilbert Spaces, Hilbert-Adjoint Operator, Self-Adjoint, Unitary and Normal Operators, Open Mapping Theorem, Closed Graph Theorem.

**Texts/References**

E. Kreyszig: *Introduction to Functional Analysis with Applications*, Wiley, 1974.

J.B. Conway: *A course in Functional Analysis*, 2$^{nd}$ edition, Springer, Berlin, 1990.

A.N. Kolmogorov and S. Fomin: *Elements of the theory of functions and functional analysis*, Dover, 1999.

A. Taylor and D. Lay: *Introduction to Functional Analysis*, 2$^{nd}$ edition, Wiley, 1980.

## Introduction to Numerical Analysis - II (3-1-0 4)

**Approximation of functions:** The Minimax and Least squares approximation problem. Orthogonal polynomials, Recurrence relations. Least squares approximations using orthogonal polynomials. Minimax and Near-minimax approximations using orthogonal polynomials.

**Numerical Integration:** Newton-Cotes integration formulas. Gaussian Quadrature. Asymptotic error formulas and their applications. Romberg integration. Automatic numerical integration. Multiple Integrals, Singular integrals. Numerical Differentiations.

**Ordinary differential equations:** Numerical solutions of IVP – Difference equations, stability, error and convergence analysis. Single step methods - Taylor series method, Euler method, Picard's method of successive approximation, Runge-Kutta method. Multi step methods – Predictor-Corrector(PC) method, Euler PC method, Milne and Adams Moulton PC method. System of first order ODE, higher order IVPs. Numerical solutions of BVP – Linear BVP, finite difference methods, shooting methods, stability, error and convergence analysis, nonlinear BVP, higher order BVP.

**Lab Components:** Exposure to Matlab/Mathematica/SciLab and computational experiments based on the algorithms discussed in the course.

**Texts/References**


1. K. Atkinson: *An Introduction to Numerical Analysis*, 2nd edition, Wiley, 1989.
2. R.L. Burden and J.D. Faires: *Numerical Analysis*, 7th edition, Brooks Cole, 2001.
3. A. Iserles: *A First Course in the Numerical Analysis of Differential Equations*, Cambridge University Press, 1996.
4. P.J. Davis and P. Rabinowitz: *Methods of Numerical Integration*, 2nd edition, AP, 1984.
5. R. LeVeque: *Finite Difference Methods for Ordinary and Partial Differential Equations Steady-State and Time-Dependent Problems*, SIAM, 2007.
6. L. N. Trefethen and D. Bau III: *Numerical Linear Algebra,* SIAM, Philadelphia, 1997.
7. G. Sewell: *The Numerical Solution of Ordinary and Partial Differential Equations*, 2nd edition, Wiley, 2005.
8. E. Isaacson and H.B. Keller: *Analysis of Numerical Methods*, Dover, 1994.
9. P.J. Davis: *Interpolation and Approximation*, Dover, 1975.
10. J.M. Ortega: *Numerical Analysis: A Second Course*, SIAM, 1987.


## Algebraic Number Theory (3-1-0 4)

**Integral domain:** Basic Properties of Integral Domain, Units, Properties of Units, Associates, Divisibility in an Integral Domain, Prime and Irreducible Elements in an Integral Domain, GCD and HCF of two Elements in an Integral Domain, Prime Ideals and Maximal Ideals, Noetherian Domain, PID,UFD,ED, Field Extensions, Algebraic and Transcendental Extension, Algebraic and Transcendental Numbers, algebraic integers, Algebraic Number Field, Ring of Integers in Algebraic Number Field, Ring of Gaussian Integers.

**Bases:** Finite extensions and bases, Properties of finite extensions, Conjugates and discriminants, The cyclotomic field.

**Arithmetic in Algebraic Number Fields:** Units and primes, Units in a quadratic field, The uniqueness of factorization, Ideals in an algebraic number field.

**The Fundamental Theorem of Ideal Theory:** Basic properties of ideals, The classical proof of the unique factorization theorem.

**Consequences of the Fundamental Theorem:** The highest common factor of two ideals, Unique factorization of integers, The problem of ramification, Congruences and norms, Further properties of norms.

**Class-Numbers and Fermat's Problem:** Class numbers, The Fermat conjecture.

<u>**Texts/References**</u>


1. Harry Pollard, Harold G. Diamond: *The Theory of Algebraic Numbers*, Dover, 2010.
2. S. Alaca, K. S. Williams: *Introductory Algebraic Number Theory*, CUP, 2003.
3. E. Weiss: *Algebraic Number Theory*, Dover, 1998.
4. I. Stewart, D. Tall: *Algebraic Number Theory and Fermat's Last Theorem*, 3rd edition, A K Peters/CRC Press, 2001.
5. G.J. Janusz: *Algebraic Number Fields*, 2nd edition, 1996.


## Advanced Number Theory (3-1-0 4)

The partition function $P(n)$ and congruence relations of Ramanujan.

Application to Cryptography. Factoring Methods using continued fractions, Binary quadratic form, Diophantine approximations and some results from geometry of numbers.

Dirichlet series, Dirichlet's theorem on primes in AP. Riemann zeta Function, Prime Number Theorem.

<u>**Texts/References**</u>


1. R. Kumanduri and C. Romero: *Number Theory with Computer Applications*, Prentice Hall, 1997.
2. G. H. Hardy: *Introduction to the Theory of Numbers*, 6th edition, Oxford University Press, 2008.
3. G. E. Andrews: *Number Theory*, Dover, 1994.
4. J. W. S. Cassels: *An Introduction to Diophantine Approximation*, Cambridge University Press, 1957.

## Numerical Optimization Techniques (3-1-0 4)

Introduction: Optimization, Types of Problems and Algorithms. Convex Sets and Convex Functions, Unconstrained Optimization: Basic properties of solutions and algorithms, Global convergence, Basic Descent Methods: Line Search Methods, Steepest Descent and Newton Methods, Modified Newton methods, Globally convergent Newton Method. Nonlinear Least Squares Problem and Algorithms, Conjugate Direction Methods, Trust-Region Methods.
Lab Component: Exposure to Matlab/Mathematica and computational experiments based on the algorithms discussed in the course.

**Texts/References**


1. E.K.P. Chong and S.H. Zak: *An Introduction to Optimization,* 2nd edition, Wiley, 2001.
2. R. Fletcher: *Practical Methods of Optimization,* 2nd edition, Wiley, 2000.
3. S. S. Rao: *Engineering Optimization: Theory and Practice,* 4th edition, Wiley, 2009.
4. D. Luenberger and Y. Ye: *Linear and Nonlinear Programming,* 3rd edition, Springer, 2008.
5. M.S. Bazaraa et al.: Nonlinear Programming - Theory and Algorithms, 3rd edition, Wiley, 2006.


## Operator Theory (3-1-0 4)

Unit-I Linear Operators, self adjoint operators and compact operators.
Unit-II Eigenvalues, Eigenvectors, Spectrum, spectral theorem, Sturm-Liouville systems, and the Fredoholm alternative.
Unit-III Nonlinear operators, variational inequalities, complementarity problems.

**Texts/References**


1. B. Choudhary and S. Nanda: Functional Analysis with Applications, Wiley, 1989.
2. E. Kreyszig: Introductory Functional Analysis with Applications, Wiley, 1978.
3. N. Dunford and J. T. Schwartz: Linear Operators, Part I-III, Wiley, 2009.
4. G. Bachman and L. Narici: Functional analysis, AP, 1966.


## Advanced Discrete Mathematics (3-1-0 4)

**Polya's Enumeration formula:** Equivalence and Symmetry Groups; Burnside's Theorem; The Cycle Index; Polya's Formula.
Ramsey numbers and general existence theorem and simple calculations.
Erdős–De Bruijn sequence and its enumeration.
Balanced incomplete block designs, parametric relations and Bruck–Ryser–Chowla theorem.
Constructions via difference sets, association scheme, partially balanced designs and
Steiner triple systems.

Latin squares, orthogonality, orthogonal array and disproof of Euler's conjecture.
Hadamard matrix together with some important constructions and links with PBIBD, BIBD.

**Texts/References**


1. M. Hall: *Combinatorial Theory*, Blaisdel Publication, 1967.
2. A. Dey: *Theory of Block Designs*, Wiley, 1986.
3. R.A. Brualdi: *Introductory Combinatorics*, 5th edition, Pearson, 2010.
4. J. H. van Lint and R. M. Wilson: *A Course in Combinatorics*, 2nd edition, Cambridge University Press, 2001.
5. A. Tucker: *Applied Combinatorics*, 5th edition, Wiley, 2010.
6. A. Hedayet, N.J.A. Sloane and J. Stufken: *Orthogonal Arrays, Theory and Applications*, Springer, 1999.


## Theoretical Numerical Analysis (3-1-0 4)

Review of Functional Analysis: Linear Spaces, Norms,Banach and Hilbert Spaces, Mapping and Operators, Classification of Problems in Computational Mathematics.
Approximation Theory: The General Interpolation Problem, Polynomial Interpolation, Piecewise Polynomial Approximations and Splines, Best Approximations in Inner product Spaces, Best Approximations in the Maximum Norm, Approximations in Several Variables.
Nonlinear Equations and Their Solution by Iteration: The Banach fixed-point theorem, Applications to iterative methods, Differential calculus for nonlinear operators, Fréchet and Gâteaux derivatives, Newton's method in Banach spaces, Completely continuous vector fields, Conjugate gradient method for operator equations.
The Approximate Solution of Linear Operator Equations: Some Theorems on Linear Operators, Approximate Expansion Methods, Stability and Convergence, Error Estimates and Extrapolation, approximate Computation of Eigenvalues.
Numerical Solution of Fredholm Integral Equations of the Second Kind: Projection methods: General theory, Collocation methods, Galerkin methods, Iterated projection methods, The Nyström method, Product integration, Iteration methods, Projection methods for nonlinear equations, Linearization.

**Texts/References:**


1. K.E. Atkinson and W. Han: *Theoretical Numerical Analysis: A Functional Analysis Framework*, 3rd edition, Springer, 2009.
2. L.B. Rall: *Computational solutions of nonlinear operator equations*, Wiley, 1969.
3. L.V. Kantorovich, G.P. Akilov: *Functional Analysis*, Pergamon Press, Oxford, 1982.
4. P. Linz: *Theoretical Numerical Analysis: An Introduction to Advanced Techniques*, *Wiley, New York,* 1979.
5. P. Davis: *Interpolation and Approximation*, *Dover, New York,* 1975.

6. J. Stoer and R. Bulirsch: *Introduction to Numerical Analysis*, *Springer*-Verlag*, New York,* 2002.
7. E. Kreyszig: *Introductory Functional Analysis with Applications*, Wiley, 1978.
8. T.J. Rivlin: *An Introduction to the Approximation of Functions*, Dover, 2010.
9. V.S. Ryaben'kii and S.V. Tsynkov: *A Theoretical Introduction to Numerical Analysis*, CRC, 2006.
10. K.E. Atkinson: *The Numerical Solution of Integral Equations of the Second Kind*, Cambridge University Press, 2009.
11. E. Zeidler: *Applied Functional Analysis. Applications to Mathematical Physics*, Springer, 1995.
12. C. T. Kelley: *Solving Nonlinear Equations with Newton's Method*, SIAM, 2003.
13. I. Argyros: *Computational Theory of Iterative Methods*, Elsevier, 2007.
14. I. Argyros: *Convergence and Applications of Newton-type Iterations*, Springer, 2008.

## Coding Theory (3-1-0 4)

Introduction: The coding problem. Linear codes, generator matrix and parity check matrices, dual codes, weights and distances, new codes from old codes, Permutation equivalent codes, Hamming codes, Golay codes, Reed–Muller codes, Encoding, decoding and Shannon's theorem, sphere packing bound, covering radius and perfect codes.
Bounds on size of codes: $A_q(n,d)$ and $B_q(n,d)$, Johnson upper bounds, the singleton upper bound and MDS codes, Griesmer upper bound, Gilbert lower bound and Varshamov lower bound.
Finite fields: Introduction, Polynomials and Euclidean algorithm, primitive elements, constructing finite fields, subfields, Field automorphisms, cyclotomic cosets and minimal polynomials, Cyclic codes: factoring $x^n - 1$, basic theory of cyclic codes, idempotents and multipliers, zeros of a cyclic codes, minimum distance of cyclic codes.
Constructions of some specific codes: Propagation rules, BCH, Reed-Soloman codes, generalized Reed-Soloman codes, decoding BCH codes, Burst errors, concatenated codes and interleaving, coding for the compact disc.

**Texts/References**

1. W.C. Huffman and V. Pless: *Fundamentals of Error-correcting Codes*, Cambridge University Press, 2003.
2. S. Ling and C. Xing: *Coding Theory - A First Course*, Cambridge University Press, 2004.
3. E. R. Berlekamp: *Algebraic Coding Theory*, Aegean Park Press, 1984.
4. J. H. Van Lint: *Introduction to Coding Theory*, 3rd edition, Springer, 1999.
5. R. Roth: *Introduction to Coding Theory*, Cambridge University Press, 2006.
6. S. Roman: *Introduction to Coding and Information Theory*, Springer-Verlag, 1997.

## Optimization by Vector Space Methods (3-1-0 4)

Geometric form of Hahn-Banach theorem, convex sets and cones, convex functionals in normed linear spaces, optimization by convex functional, conjugate convex functionals, sub-differentiable convex functionals, monotone operator and its relation with convex functional, dual optimization problem, Fenchel duality theorem, minimax theorem of game theory, Lagrange's multiplier, sufficiency, sensitivity, Lagrange duality, Kuhn-Tucker theorem, complementarity problem.

Texts/References

1. J. M. Borwein, A.S. Lewis: Convex Analysis and Nonlinear Optimization Theory and Examples, Springer, 2005.
2. D. G. Luenberger, Y. Ye: Linear and Nonlinear Programming, $3^{rd}$ edition, Springer, 2008
3. R. T. Rockafellar: The Theory of Subgradients and Its Applications to Problems of Optimization: Convex and Nonconvex Functions, Heldermann, 1981.
4. D. P. Bertsekas, A. Nedic, A.E. Ozdaglar: Convex Analysis and Optimization, Athena Scientific, 2003.
5. Y. Nesterov: Introductory Lectures on Convex Optimization. A Basic Course, Kluwer, 2004.
6. S. Boyd: Convex Optimization, Cambridge University Press, 2004.
7. L. D. Berkovitz: Convexity and Optimization in $R^n$, Wiley, 2001.
8. S. K. Mishra, S.Y. Wang K. K. Lai: Generalized Convexity and Vector Optimization, Springer, 2009.
9. A. Cambini, L. Martein: Generalized Convexity and Optimization, Springer, 2009.

## Analytic Number Theory (3-1-0 4)

The Prime Number Theorem: Dirichlet's theorem for primes in an Arithmetic Progression. Zero free regions for the Riemann zeta function and other L-functions. Euler products and the functional equations for the Riemann zeta function and Dirichlet L-functions.

Modular forms for the full modular group: Eisenstein series, cusp forms, structure of the ring of modular forms. Hecke operators and Euler product for modular forms. The L-function of a modular form, functional equations. Modular forms and the sums of four squares.

Optional topics: Discussion of L-functions of number fields and the Chebotarev Density Theorem. Discussion of elliptic curves and the Shimura-Taniyama conjecture (Wiles' Theorem).

**Text/References**

T. Apostol: *Introduction to Analytic Number Theory*, Springer-Verlag, 1998.

J. P. Serre: *A Course in Arithmetic*, Springer-Verlag, 1996.

S. Lang: *Algebraic Number Theory*, Springer-Verlag, 2000.

G. J. O. Jameson: *The Prime Number Theorem*, Cambridge University Press, 2003.

## Introduction to Integral Equations (3-1-0 4)

Introduction and basic examples, Classification, Conversion of Volterra Equation to ODE, Conversion of IVP and BVP to Integral Equation, Decomposition, direct computation, Successive approximation, Successive substitution methods for Fredholm Integral Equations, A domain decomposition, series solution, successive approximation, successive substitution method for Volterra Integral Equations, Volterra Integral Equation of first kind, Integral Equations with separable Kernel, Fredholm's first, second and third theorem, Integral Equations with symmetric kernel, Eigenfunction expansion, Hilbert-Schmidt theorem, Fredholm and Volterra Integro-Differential equation, Singular and nonlinear Integral Equation.

**Texts/References**

1. W. V. Lovitt: Linear Integral Equations, Dover, 2005.
2. R. Courant and D. Hilbert: *Methods of Mathematical Physics*, Vol I. John Wiley & Sons, 1989.
3. D. Porter and D. S. G. Stirling: *Integral Equations - A Practical Treatment from Spectral Theory and Applications*, Cambridge University Press, 1990.
4. C. Corduneanu: *Integral Equations and Applications*, Cambridge University Press, 1991.
5. S. G. Mikhlin: *Integral Equations*, Hindustan Publishing Co., 1960.
6. E. G. Tricomi: *Integral Equations*, Interscience, 1957.
7. F. B. Hildebrand: *Methods of Applied Mathematics*, 2nd edition, Prentice Hall, 1965.
8. R. P. Kanwal: Linear Integral Equations - Theory & Technique, Springer, 2013.

## Advanced Linear Algebra (3-1-0 4)

Finite dimensional vector spaces over a field, linear combination, linear dependence and independence, basis, dimension, inner product spaces, linear transformations, matrix representation of linear transformations, linear functional, dual spaces, eigenvalues and eigenvectors, rank and nullity, inverse of a linear transformation, Cayley-Hamilton theorem, norms of vectors and matrices, transformation of matrices, Jordan's form, adjoint of an operator, normal, unitary, Hermitian and skew-Hermitian operators, bilinear forms. Application of Jordan form to discrete system of equation and system of linear differential equation. Singular value decomposition (SVD) and application of SVD to find least square solution and data compression. Cholesky decomposition and QR decomposition. Positive definite and negative definite matrices, Sylvester's criterion, orthogonal transformations, Householder and Jacobi transformations. Introduction to pseudo-inverse, Moore-Penrose generalized inverse.

**Texts/References**


1. P. D. Lax: *Linear Algebra and Its Applications*, 2nd edition, Wiley, 2007.
2. R. A. Horn and C.R. Johnson: *Matrix analysis*, Cambridge University Press, 1990.
3. K. Hoffman and R. Kunze: *Linear Algebra*, 2nd edition, Prentice Hall, 1971.
4. P. R. Halmos: *Finite-dimensional Vector Spaces*, Springer, 1974.
5. C. D. Meyer: *Matrix Analysis and Applied Linear Algebra*, SIAM, 2000.
6. S. L. Campbell and C.D. Meyer: *Generalized Inverses of Linear Transformations*, SIAM, 2008.
7. A. J. Laub: *Matrix Analysis for Scientists and Engineers*, SIAM, 2004.


## Combinatorics (3-1-0 4)

Unit-I

The Pigeonhole Principle:

Pigeonhole Principle: Simple Form, Pigeonhole Principle: Strong Form, A Theorem of Ramsey.

The Inclusion-Exclusion Principle and Applications:

The Principle of Inclusion and Exclusion and a variety of ways to apply it, notably combinations with repetition, Derangements, permutations with forbidden positions, circular permutations with forbidden relations, Möbius Inversion.

Polya's Enumeration formula: Equivalence and Symmetry Groups ; Burnside's Theorem ; The Cycle Index ; Polya's Formula .

Unit - II

Recurrence Relations and Generating Functions: Some Number Sequences, Generating Functions, Exponential Generating Functions, Recurrence relations, Catalan Numbers, Difference Sequences and Stirling Numbers, Partition Numbers.

Introduction to finite geometry: Finite Geometry, Projective and affine geometries, duality, Orthogonal sets of Latin squares, Modular arithmetic (with some finite field arithmetic) and applications to orthogonal Latin squares.

Unit - III

Combinatorial Structures: Hadamard Matrix; Different constructions of Hadamard Matrix, Orthogonal Array, constructions of Orthogonal Array, Association Scheme, Partially Balanced Design. The DeBruijn theorem, Steiner systems, balanced incomplete block designs, Hadamard designs, counting, (higher) incidence matrices, the Wilson-Petrenjuk theorem, symmetric designs, derived and residual designs, the Bruck-Ryser-Chowla theorem, constructions of Steiner triple Systems.

**Texts/References**

1. R.A. Brualdi: Introductory Combinatorics, 5th edition, Pearson, 2010.
2. J. H. van Lint and R. M. Wilson: A Course in Combinatorics, 2nd edition, Cambridge University Press, 2001.
3. A. Tucker: Applied Combinatorics, 5th edition, Wiley, 2010.
4. Marshal Hall: Combinatorial Theory, 2nd Edition, Wiley, 1998.
5. Aloke Dey :Theory of Block Designs, Wiley, 1987.
6. A.S. Hedayat, N.J.A. Sloane, John Stufken: Orthogonal Arrays: Theory and Applications, Springer, 1999.

## Difference Equations and Discrete Dynamical Systems (3-1-0 4)

**Difference Equations:** Introduction to Difference Equations, First order DEs, linear equations with constant coefficients, variable coefficients, stability in both hyperbolic and nonhyperbolic cases, bifurcations, symbolic dynamics and chaos, linear theory for two dimensional systems of difference equations, equilibria, stability, periodic solutions, period-doubling bifurcation, Lyapunov numbers, box dimension, stable and unstable manifolds, area preserving maps, systems with order higher than 2, numerical issues in difference equations.

**Discrete Dynamical Systems:** Discrete and continuous dynamical systems, One and two dimensional maps as discrete dynamical systems, Fixed points, periodic points and stability, Chaos, Lyapunov exponents and chaotic attractors, Differential equations as continuous dynamical systems, Periodic orbits and limit sets, Bifurcations.

Text/References

1. S. Goldberg: *Introduction to difference Equations*, Dover, 1986.
2. K.T. Alligood, T.D. Sauer and J.A. Yorke: *An Introduction to Dynamical Systems*, Springer, 1997.
3. E.Ott: *Chaos in Dynamical Systems*, Cambridge University Press, 2nd edition 2002.
4. S.H. Strogatz: *Nonlinear Dynamics and Chaos - With Applications to Physics, Biology, Chemistry and Engineering*, Westview Press, 2000.
5. S. Elaydi: *An Introduction to Difference Equations*, Springer, 1995.
6. W.G. Kelley and A.C. Peterson: Difference Equations - An Introduction with Applications, 2nd edition, AP, 2001.

## Theory of Groups and Rings (3-1-0 4)

Semigroups, Groups, Homomorphisms, Subgroups, Permutation Groups, Normal Subgroups, Isomorphism Theorem, Automorphisms, Conjugacy and G-sets.
Normal Series, Solvable groups, Nilpotent groups, Cyclic decomposition of permutations, Alternating group. Structure Theorem of Finite abelian groups. Sylows theorems, groups of orders $p^2, pq$.
Rings, Subrings, Ideals, Homomorphisms, Prime and Maximal Ideals, Nilpotent and Nil Ideals, UFD, PID and ED. Polynomial rings over UFD.

**Texts/References**

1. P.B. Bhattacharya, S. K. Jain and S. R. Nagpaul: *Basic Abstract Algebra*, 2nd edition, Cambridge University Press, 1995.
2. J. A. Gallian*: Contemporary Abstract Algebra*, 4th edition, Narosa, 1998.
3. D. S. Dummit and R. M. Foote: *Abstract Algebra*, 2nd edition, Wiley, 1999.
4. I. N. Herstein: *Topics in Algebra*, 2nd edition, Wiley, 1975.

## Theory of Modules and Commutative Rings (3-1-0-4)

Rings and Ideals: Introduction, Quotient rings, Zero divisors, Nilpotents, Units, Prime and Maximal Ideals, Nilradical, Jacobson radical, Extension and Contraction, factorization in Integral domains, UFD, PID and ED.
Modules: Introduction, Submodules and Quotient modules, Direct sum and Product, Finitely generated modules, Exact sequences, Tensor product of modules, Algebras.
Rings and Modules of Fractions: Local properties, Extended and Contracted ideals in rings of fractions. Noetherian and Artinian modules.

**Texts/References:**

M. Atiyah: *Introduction to Commutative Algebra*, Westview Press, 1994.
D.S. Dummit and R.M. Foote: *Abstract Algebra*, 3rd edition, Wiley, 2003.
O. Zariski and P. Samuel: Commutative Algebra I. Vol. 1, Springer, 1975.

## Lie Groups and Lie Algebras (3-1-0 4)

**Lie Algebras and Root Systems**: Introduction to Lie Algeras, Representations, Special kind of Lie Algebra, $sl_n(C)$, Simple Lie Algebras over $\mathbb{C}$, Killing form, Weyl group, Representations of simple Lie algebras, Simple groups of Lie type.
**Lie Groups:** Introduction, $SU_2$, $SO_3$ and $Sl_2(R)$, Homogeneous spaces, some theorems about matrices, Lie theory, Representation theory, Compact groups and integration,

Maximal compact subgroups, the Peter-Weyl theorem, Functions on $R^n$ and $S^{n-1}$, Induced representations.

**Texts/References**

1. R. Carter, G. Segal and I. Macdonald: *Lectures on Lie Groups and Lie Algebras,* London Mathematical Society, 1995.
2. J. E. Humphreys: *Introduction to Lie Algebras and Representation Theory,* Springer, 2010.
3. D. A. Bump: *Lie Groups*, Springer, 2011.

## Representation Theory (3-1-0 4)

Representations, Subrepresentations, Irreducible representations, Tensor products, Symmetric and Alternating Squares.

Characters: Schur's lemma, Orthogonality relations, Decomposition of regular representation, Number of irreducible representations, canonical decomposition and explicit decompositions.

Examples: Cyclic groups, alternating and symmetric groups.

Subgroups, Products, Induced Representations, The character of induced representation, Frobenius Reciprocity Theorem, Mackey's irreducibility criterion, Examples of induced representations.

**Texts/References**

1. J.P. Serre: Linear Representation of Groups, Springer-Verlag, 1977.
2. S. Lang: Algebra, 3rd edition, Springer, 2004.
3. N. Jacobson: Basic Algebra II, Hindustan Publishing Corporation, 1983.
4. M. Burrow: Representation Theory of Finite Groups, Academic Press, 1965.

## Theory of Relativity (3-1-0 4)

**Classical Theory of Relativity:** Inertial frame, Galilean transformations, Lorentz transformation.

**Tensor Analysis:** Transformation of coordinates, Tensors, Algebra of Tensor, Symmetric and skew-Symmetric tensors, Contraction of Tensor and Quotient law, Riemannian metric, Christoffel Symbol, Covariant derivatives, Intrinsic derivatives and geodesics, Riemann Christoffel Curvature Tensor and it’s symmetry properties, Binachi identities and Einstein tensor.

**General Theory of relativity:** Review of the special theory of relativity and the Newtonian theory of gravitation, Principle of equivalence and general covariance, geodesic principle, Newtonian approximation of relativistic equation of motion, Einstein’s Field equations and its Newtonian approximation. Schwarzchild's external solution and isotropic form, Planetary Orbits, Advance of perihelion of a planet, Bending of light rays in a gravitational field. Energy-Momentum tensor of a perfect fluid, Schwarzchild's internal solution, Boundary conditions, Energy-Momentum tensor of an electromagnetic field, Einstein-Maxwell equations, Reissner-Nordstrom solution.

**Texts/References**


1. C. E. Weatherburn: An Introduction to Riemannian Geometry and the Tensor Calculus, CUP, 2008.
2. H. Stephani et al.: General Relativity: An Introduction to the Theory of Gravitational Field, 2nd edition, CUP, 1990.
3. A. S. Eddington: The Mathematical Theory of Relativity, 2nd edition, CUP, 2010.
4. J. V. Narlikar: Lectures on General Relativity and Cosmology, Macmillan Press, 1979
5. R. Adler: Introduction to General Relativity, 2nd edition, McGraw-Hill, 1975.
6. B. Schutz: A First Course in General Relativity, 2nd edition, CUP, 2010.
7. J.K. Goyal and K.P. Gupta: Theory of Relativity, Krishna Prakashan, 1976.


## Theory and Applications of Fuzzy Sets (3-1-0 4)

Basic concepts of fuzzy sets, fuzzy logic, operations on fuzzy sets, fuzzy relations, equivalence and similarity relations, ordering, morphisms, fuzzy relation equations, fuzzy measures, probability measures, possibility and necessity measures, measures of uncertainty, dissonance, confusion and nonspecificity. Principles of uncertainty and information. Applications of fuzzy sets in management, decision making, computer science and systems science.

Texts/References:


1. T. J. Ross: *Fuzzy Logic with Engineering Applications*, 3rd edition, Wiley, 2010.
2. G.J. Klir and B. Yuan: *Fuzzy Sets and Fuzzy Logic Theory and Applications*, Prentice Hall, 1995.
3. G. Chen and T. Pham: *Introduction to Fuzzy Sets, Fuzzy Logic, and Fuzzy Control Systems*, CRC, 2000.
4. H.J. Zimmermann: *Fuzzy Set Theory - and Its Applications*, 2nd edition, Springer, 1991.


## Cryptography (3-1-0 4)

Introduction to basic terminologies associated with Cryptography, Definition and classification of Cryptosystem, Classical crypto systems, Description of rail fence cipher, Simple Columnar cipher, Caesar cipher, Linear cipher, Affine linear cipher, Distinction between Substitution cipher and Permutation cipher. Classical cipher as particular case of Affine linear cipher, Insecurity of Affine linear cipher, Block cipher and different modes of implementation of Block cipher, Stream cipher, Feistel cipher, DES (Data Encryption Standard) and AES (Advanced Encryption Standard).

Public Key cryptosystems, Need for Public Key cryptosystems, Description of RSA, Rabin cryptosystem, Diffie-Hellman key exchange, ElGamal cryptosystem, Cryptanalysis of Public Key cryptosystem, Digital signatures, Introduction to Elliptic curve cryptography, Perfect security and Shanon's Theorem. Mathematical problems related to cryptography, Division Algorithm and extended Division Algorithm, Calculation of Units in Z/nZ, Fast Exponentiation, Factoring problem, Different factorisation Algorithms, Discrete Log Problem, Discussion of different algorithms for finding discrete log.

**Lab Component:** Cryptography Lab in C (at least 10 Sessions), Use of Sage software.

**Texts/References**


1. J. A. Buchmann: Introduction to Cryptography, Springer, 2004.
2. N. Koblitz: A Course in Number Theory and Cryptography, Springer, 1994.
3. M. Welschenbach: Cryptography in C and C++, 2nd edition, Apress, 2002.


## Theory of Differential Equations (3-1-0 4)

**Unit-1**

System of Differential Equations: System of First Order Equations, Existence and uniqueness of solution, Gronwall's inequality, continuous dependence on initial conditions and parameters.

Linear systems: Autonomous systems, Transition matrix, Phase-Space of two dimensional systems, Time varying systems, Fundamental matrix and its properties, linear system with periodic coefficients.

Stability of differential systems: Stability of linear systems, almost linear systems, stability of periodic solutions, Lyapunov Stability theorems for nonlinear system, limit cycles Poincare-Bendixon Theorem, Lienard Systems, Constructions of Lyapunov function , Bifurcations (Transcritical, Saddle-node, Pitchfork, Hopf, Sotomayor Theorem).

**Unit-2**

Review of first order PDE: Classification, solution method for quasi-linear and nonlinear PDE, discontinuous solutions, conservation laws and shocks.

Four important linear PDEs (transport, Laplace, heat and wave equation): Fundamental solution, mean value formulae, properties of harmonic functions, Green's Function and energy method.

**Unit-3**

Elliptic Equations: Definition, Existence of weak solutions, Regularity, Maximum Principles, Eigenvalues and Eigenfunctions.

Linear Evolution Equations: Parabolic equations, Hyperbolic equations, Semi-group theory.

**Texts/References**

1. G. F. Simmons, Differential equations with applications and historical notes, 2nd Ed., McGraw-Hill., 1991.
2. R. P. Agarwal, D. O'Regan, An introduction to ordinary differential equations, Springer, 2008.
3. K. S. Bhamra, Ordinary differential equations, Narosa Publications., 2015.
4. I. N. Sneddon, Elements of Partial Differential Equations, McGraw-Hill., 1957.
5. L. C. Evan, Partial differential Equations, 2nd Ed., AMS, 2015.
6. M. Renardy, R. C. Rogers, An introduction to partial differential equations, 2nd Ed., Springer, 2010.

CENTRAL UNIVERSITY OF JHARKHAND
DEPARTMENT OF MATHEMATICS
2017 ONWARDS

**Programme structure for Two years MSc degree programme in Mathematics**
**L – Lecture, T- Tutorial, P – Practical (Lab), Cr – Credits.**

**FIRST SEMESTER**

| Sl. No. | Course Code | Course Title | L | T | P | CR |
|---|---|---|---|---|---|---|
| 1 | MMA 111010 | Complex Analysis | 3 | 1 | 0 | 4 |
| 2 | MMA 111020 | Differential Equations | 3 | 1 | 0 | 4 |
| 3 | MMA 111030 | Mathematical Analysis | 3 | 1 | 0 | 4 |
| 4 | MMA 111040 | Abstract Algebra | 3 | 1 | 0 | 4 |
| 5 | MMA 111050 | Fundamentals of Computers and C Programming | 2 | 0 | 2 | 4 |
| Total Credits | | | | | | 20 |

**SECOND SEMESTER**

| Sl. No. | Course Code | Course Title | L | T | P | CR |
|---|---|---|---|---|---|---|
| 1 | MMA 121010 | Metric Spaces and Topology | 3 | 1 | 0 | 4 |
| 2 | MMA 121020 | Linear Algebra | 3 | 1 | 0 | 4 |
| 3 | MMA 121030 | Numerical Analysis | 3 | 1 | 0 | 4 |
| 4 | MMA 121040 | Number Theory | 3 | 1 | 0 | 4 |
| 5 | MMA 121050 | Statistics – I | 3 | 1 | 0 | 4 |
| **Total Credits** | | | | | | **20** |

**THIRD SEMESTER**

| Sl. No. | Course Code | Course Title | L | T | P | CR |
|---|---|---|---|---|---|---|
| | MMA 211010 | Functional Analysis | 3 | 1 | 0 | 4 |
| | MMA 211020 | Classical Mechanics | 3 | 0 | 1 | 4 |
| | MMA 211030 | Calculus of Variations and Integral Equations | 3 | 1 | 0 | 4 |
| | | Elective – I | 3 | 1 | 0 | 4 |
| | | Elective – II | 3 | 1 | 0 | 4 |
| | MMA 213060 | Seminar | | | | 2 |
| | **Total Credits** | | | | | **22** |

| FOURTH SEMESTER | | | | | | |
|---|---|---|---|---|---|---|
| Sl. No. | Course Code | Course Title | L | T | P | CR |
| 1 | MMA 221010 | Partial Differential Equations | 3 | 0 | 1 | 4 |
| 2 | MMA 221020 | Differential Geometry | 3 | 1 | 0 | 4 |
| 3 | | Elective – III | 3 | 1 | 0 | 4 |
| 4 | MMA 223030 | Project | | | | 6 |
| Total Credits | | | | | | 18 |

| List of Electives for 3rd Semester | | | | | | |
|---|---|---|---|---|---|---|
| Sl. No. | Course Code | Course Title | L | T | P | CR |
| 1 | MMA 215040 | Theory of Computations | 3 | 1 | 0 | 4 |
| 2 | MMA 215050 | Numerical Linear Algebra | 3 | 1 | 0 | 4 |
| 3 | MMA 215060 | Field Theory | 3 | 1 | 0 | 4 |
| 4 | MMA 215070 | Statistics-II | 3 | 1 | 0 | 4 |
| 5 | MMA 215080 | Discrete Mathematics | 3 | 1 | 0 | 4 |
| 6 | MMA 215090 | Fluid Dynamics | 3 | 1 | 0 | 4 |
| 7 | MMA 215100 | Theory and Applications of Fuzzy sets. | 3 | 1 | 0 | 4 |
| 8 | MMA 215110 | Data Structures and Algorithm Analysis | 3 | 0 | 1 | 4 |
| 9 | MMA 215120 | Cryptography | 3 | 1 | 0 | 4 |
| 10 | MMA 215130 | Java Programming | 3 | 0 | 1 | 4 |
| 11 | MMA 215140 | Graph Theory | 3 | 1 | 0 | 4 |
| 12 | MMA 215150 | Advanced Numerical Analysis | 3 | 1 | 0 | 4 |

| List of electives for 4th Semester | | | | | | |
|---|---|---|---|---|---|---|
| Sl. No. | Course Code | Course Title | L | T | P | CR |
| 1 | MMA 226040 | Optimization Techniques | 3 | 1 | 0 | 4 |
| 2 | MMA 226050 | Artificial Intelligence and Hybrid Systems | 3 | 1 | 0 | 4 |
| 3 | MMA 226060 | Algebraic Number Theory | 3 | 1 | 0 | 4 |
| 4 | MMA 226070 | Statistics III | 3 | 1 | 0 | 4 |
| 5 | MMA 226080 | Difference Equations and Discrete Dynamic Systems | 3 | 1 | 0 | 4 |
| 6 | MMA 226090 | Coding Theory | 3 | 1 | 0 | 4 |
| 7 | MMA 226100 | Operator Theory | 3 | 1 | 0 | 4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 8 | MMA 226110 | Operating Systems | 3 | 1 | 0 | 4 |
| 9 | MMA 226120 | Relational Database Management Systems | 3 | 0 | 1 | 4 |

## FIRST SEMESTER

### Complex Analysis (3-1-0 4)

Basic algebraic properties of complex numbers, Exponential form, Roots of complex numbers. Functions of a complex variable, mappings, Cauchy-Riemann equations, sufficient conditions for differentiability, Analytic functions, Harmonic functions. Elementary functions: The exponential, logarithm functions, branches and derivatives of logarithms. Complex exponents, trigonometric, hyperbolic functions and their inverses.

Integrals: Complex integrals, Upper bounds for moduli of contour integrals, Cauchy's theorem, Cauchy's integral formula, Liouvilles' theorem and fundamental theorem of algebra, maximum modulus principle. Series: Classification of singularities. Representations of holomorphic functions in terms of power series, Meromorphic functions, zeros and poles, Laurent expansions. Residues and Poles: poles and zeroes, Cauchy's residue theorem, Residue at infinity, Residue at poles. Evaluation of improper integrals and definite integrals using contour integration. Argument principle and Rouche's theorem. Mapping by Elementary functions: Linear transformations, linear fractional transformations, other mappings by elementary functions. Conformal mapping: Preservation of angles, transformations of harmonic functions and boundary conditions. Applications of conformal mappings.

Texts/References


1. R. V. Churchill and J. W. Brown: Complex Variables and Applications, 8th edition, McGraw Hill, 2009.
2. L. Ahlfors: Complex Analysis: an Introduction to the Theory of Analytic Functions of One Complex Variable, 3rd edition, Tata McGraw Hill, 1979.
3. E.T. Copson: Theory of Functions of a Complex Variable, Oxford University Press, 1970.
4. J.B. Conway: Functions of One Complex Variable, 2nd edition, Narosa, 1973.
5. D. Sarason: Complex Function Theory, 2nd edition, Hindustan Publishing Company, 2008.
6. M.J. Ablowitz: Complex Variables Introduction and Applications, 2nd edition, Cambridge University Press, 2003.
7. S. Ponnusamy and H. Silverman: Complex Variables with Applications, Birkh¨auser, 2006.


### Differential Equations (3-1-0 4)

Existence and uniqueness of solution to first order ordinary differential equation, Picard's iteration. Systems of first order differential equations, Trial solution method for a linear system with constant coefficients and Eigen value technique.
Simultaneous differential equations. Total (or Pfaffian) differential equations.
Orthogonal functions. Equations with regular singular points, power series solutions, Frobenius method. Bessel's Equation, Legendre equation, Hermite equation, Laguerre equation, Hypergeometric equation.
Sturm–Liouville problems and eigenfunction expansions: The Sturm–Liouville problem, Inner product spaces and orthonormal systems, basic properties of Sturm–Liouville eigenfunctions and eigenvalues, Nonhomogeneous equations, Nonhomogeneous boundary conditions, Green's functions.
Elements of Fourier analysis: The Fourier series of a function, convergence of Fourier series, Fourier Integral, Fourier transform and their convergence.

**Texts/References**


1. M. Braun: Differential Equations and Their Applications, 3rd edition, Springer, 1983.
2. S. Padhy and J. Sinha Roy: A Course in Ordinary and Partial Differential Equations, 3rd edition, Kalyani, 2003.
3. W. E. Boyce and R. C. DiPrima: Elementary Differential Equation, 8th edition, Wiley, 2005.
4. C. H. Edwards and D. E. Penney: Elementary Differential Equations, 6th edition, Pearson, 2008.
5. J.R. Hanna and J.H. Rowland: Fourier series, Transforms, and Boundary Value Problems, Wiley, 1990.
6. J.W. Brown and R.V. Churchill: Fourier Series and Boundary Value Problems, 7th edition, McGraw Hill, 2008.
7. A. Vretblad: Fourier Analysis and its Applications, Springer, 2003.
8. E.A. Coddington and R. Carlson: Linear Ordinary Differential Equations, SIAM, 1997.


## Mathematical Analysis (3-1-0 4)

Unit I Uniform Converengence
Sequence of functions- point wise versus uniform convergence for a function defined on an interval of $\mathbb{R}$, Integration of a limit of a sequence of functions. The Weierstrass' approximation theorem. Periodic functions.
UNIT II – Functions of Several Variables
Derivative of a function from an open subset of $R^n$ into $R^m$ as a linear transformation. Chain rule. Partial derivatives. Taylor's theorem. Inverse function theorem. Implicit function theorem, Jacobians.
Unit III Measure Theory

Measure and outer measure Measure induced by an outer measure. Extension of a measure. Uniqueness of extension, Completion of a measure, Lebesgue outer mearure, Measurable sets, non-Lebesgue measures.
Measure theory on $\mathbb{R}$, measurable functions, Borel sets, Lebesgue integration and convergence theorems.

**Texts/References**

1. N.L. Carothers: Real Analysis, Cambridge University Press, 2000.
2. G. F. Simmons: Introduction to Topology and Modern Analysis, Tata McGraw-Hill, 2004.
3. P. K. Jain and V. P. Gupta: Lebesgue Measure and Integration, New Age International (P) Ltd., 2000.
4. G. De. Barra: Introduction to Measure Theory, New Age International (P) Ltd., 2000.
5. H. L. Royden and P. Fitzpatrick: Real Analysis, 4th edition, PHI, 2010.

## Abstract Algebra (3-1-0 4)

Unit I

Groups: Quick review of basic ideas of Group Theory, Sylow's theorems and their applications, Finitely generated abelian groups.

Unit II

Rings and ideals: Quick review in Commutative rings, Nilradical, Jacobson radical, Extension and Contraction, UFD, PID and ED, Rings of Fractions, Noetherian rings, Primary decomposition.

Unit III

Modules: Introduction, Submodules and Quotient modules, Direct sum and Product, Finitely generated modules, Exact sequences, Tensor product of modules, Noetherian and Artinian modules, Modules of Fractions.

**Texts/References:**

1. M. Atiyah: Introduction to Commutative Algebra, Westview Press, 1994.
2. D.S. Dummit and R.M. Foote: Abstract Algebra, 3rd edition, Wiley, 2003.
3. O. Zariski and P. Samuel: Commutative Algebra I. Vol. 1, Springer, 1975.
4. P. B. Bhattacharya, S. K. Jain, S. R. Nagpaul: Basic Abstract Algebra, 2nd edition, Cambridge, 1995.

## Fundamentals of Computer and C Programming (3-0-1 4)

Introduction to computers, generations of computer, processors, memory hierarchy and I/O devices, System and application software, generation of languages, compiler, interpreter, assembler, Number systems, computer arithmetic.
Flow Charting, Sequential, Branching & Iterative.

Introduction to 'C' as Programming Language, An overview of a 'C' programme, 'C' character set, 'C' tokens, 'C' key words, Data Types (Primary, derived & user defined), Storage classes, symbolic constants, operators (arithmetic, logical & relational), Flow of control (if- else, switch-case; while, do-while & for-loops).
Functions (UDF, String Functions, Mathematical functions)
Recursion, pointers, array (2-D & 3-D), Strings, pre-processor directives, structures, linked list file handling.
C-lab: Execution of a simple programme, Conditional & Un-conditional Branching, Loops, Functions (Interactive & Recursive), Arrays (2-D & 3-D), Structures, Linked Lists, File I/O.

**Texts/References**

1. B.W. Kernighan, D.M. Ritchie: The C Programming Language, Prentice Hall India, 1990.
2. Y.P. Kanetkar: Let us C, BPB Publications, 2002.
3. E. Balagurusamy: Programming in ANSI C, 4th edition, Tata McGraw Hill.

## Semester II

### Metric Spaces and Topology (3-1-0 4)

**Unit I Metric Spaces**

Review of compact metric spaces, Banach's contraction principle and its use in the proofs of Picard's theorem, inverse & implicit function theorems.
Baire category theorem and some of its applications in analysis of $C(X)$as a complete metric space when X is a compact metric space. Stone- Weierstrass theorem and Arzela-Ascoli theorem for $C(X)$.

**Unit II Topology.**

**Topological Spaces:** Introduction, open set topology, Basis, Subbasis, closed sets and closure, Order Topology, Product Topology, Subspace Topology, Quotient Topology, Metric Topology, Continous functions, Homeomorphisms, Open and Closed Maps.
**Connectedness and Compactness:** Connected and Path Connected Spaces, Components and Path Components, Local Connectedness, Compact Spaces, Local compact spaces, Heine Borel Theorem, Tychonoff Theorem.
**Countability and Seperation Axioms:** Countability Axioms, Separation Axioms, Urysohn Lemma, Urysohn Metrization Theorem, Tietze extension Theorem.

**Texts/References**

1. J. R. Munkres: Topology, Prentice Hall of India, 2001.

2. J. Dugundji: Topology, Universal Book Stall, New Delhi, 1990.
3. G. F. Simmons: Introduction to Topology and Modern Analysis, Tata McGraw-Hill edition, 2004.
4. M. D. Crossley: Essential Topology, Springer International Edition, 2008.

## Linear Algebra (3-1-0, 4)

A Quick review of matrices: Algebra of matrices, determinants, rank and nullity of matrices, system of linear equations, Symmetric, orthogonal and other special types of matrices, eigenvalues and eigen vectors of matrices, minimal and char. polynomial of a matrix, similar matrices, diagonalizable matrices.

Finite dimensional vector spaces over a field: Linear span, linear dependence and independence, basis and dimension. Linear transformation and rank-nullity theorem . Matrix representation of a Linear transformation. Matrix of Change of basis, algebra of linear operators, eigenvalues and eigenvectors, minimal and char. polynomial of a linear operator, Cayley-Hamilton theorem, transformation of linear operators to canonical forms: diagonal, triangular and Jordan forms.

Inner product spaces, Orthogonality, Gram-Schmidt ortogonalisation process, norms of vectors and matrices, linear functional, dual spaces, adjoint of an operator, normal, unitary, Hermitian and skew-Hermitian operators, Quadratic forms, reduction and classification of quadratic forms, Positive definite and negative definite matrices,

**Texts/References**

1. P. D. Lax: Linear Algebra and Its Applications, 2nd edition, Wiley, 2007.
2. R. A. Horn and C.R. Johnson: Matrix Analysis, Cambridge University Press, 1990.
3. K. Hoffman and R. Kunze: Linear Algebra, 2nd edition, Prentice Hall, 1971.
2. P. R. Halmos: Finite-dimensional Vector Spaces, Springer, 1974.
3. C.D. Meyer: Matrix Analysis and Applied Linear Algebra, SIAM, 2000.
4. S.L. Campbell and C.D. Meyer: Generalized Inverses of Linear Transformations, SIAM, 2008.
5. A. J. Laub: Matrix Analysis for Scientists and Engineers, SIAM, 2004.
6. H. Anton and C.Rorres: Elementary Linear Algebra, Wiley India Edition 2009.
7. V. Krishnamurthy, V.P Mainra and J.L Arora: An Introduction to Linear Algebra, East-West Press, New Delhi 2011.

## Numerical Analysis (3-1-0- 4)

**Nature of numerical computations:** errors and their propagation, convergence and stability of numerical algorithms; efficiency and arithmetic, complexity.

**Numerical solution of systems of linear equations:** Direct methods for solving linear systems, error analysis. The residual correction method. Iteration methods, Error prediction and Acceleration.

**Matrix Eigenvalue problem:** Eigenvalue location, error, and stability results, Power method. Orthogonal transformations using Householder matrices. The eigenvalues of a symmetric Tridiagonal matrix. QR method. The calculation of Eigenvectors and Inverse iteration.

**Numerical solutions of Non-linear equations**: Solution of non-linear equations by iterative methods, acceleration of convergence. Newton's methods for polynomials, quotient-difference algorithms. Numerical solution of system of Non-linear equations.

**Interpolation:** Interpolating polynomial and its construction using Lagrange methods and methods of differences, iterated interpolation, method of divided differences, inverse interpolation, Hermite Interpolation. The general Hermite interpolation problem. Spline function and their use.

**Solutions of ordinary differential equations**: Euler's method, Trapezoidal method, Runge-Kutta method.

**Lab Component:** Exposure to Matlab/Mathematica and computational experiments based on the algorithms discussed in the course.

**Texts/References:**


1. K. Atkinson: An Introduction to Numerical Analysis, 2nd edition, Wiley, 1989.
2. R.L. Burden and J.D. Faires: Numerical analysis, 7th edition, Brooks Cole, 2001.
3. P.J. Davis: Interpolation and Approximation, Dover, 1975.
4. J.M. Ortega: Numerical Analysis: A Second Course, SIAM, 1987.
5. S.S. Sastry: Introductory Methods of Numerical Analysis, Phi Learning, 2009.
6. S.D. Conte and C. de Boor: Elementary Numerical Analysis, 3rd edition, Tata McGraw Hill, 1980.


## Number Theory (3-1-0 4)

Unit I: Fundamental theorem of arithmetic, divisibility in Z, congruences, Chinese Remainder Theorem, Euler's Ø- function, primitive roots, Fermat's Little, Euler and Wilsons Theorem.

Unit II: Linear Conguence, Algebraic congruences of degree $\geq 2$. Theorems on Prime Power, Modulus, Lagrange Theorem, Quadratic Congruences, Quadratic reciprocity law, two square theorem, Primality Testing and Factoring.

Unit III: Simple continued fractions, Pell's Equation, Diophantine Approximation. Arithmetical functions. Sum and number of Divisors, Dirichlet Product, Mobius inversion formula, Totally multiplicative functions.

**Texts/References**

1. G.H. Hardy and E.M. Wright: An Introduction to The Theory of Numbers, 6th edition, Oxford University Press, 2008.
2. D.M. Burton: Elementary Number Theory, 6th edition, McGraw-Hill, 2005.
3. I. Niven, H.S. Zuckerman and H.L. Montgomery: An Introduction to The Theory of Numbers, 5th edition, Wiley, 1991.
5. T. M. Apostol: Introduction to Analytic Number Theory, Springer- Verlag, 1976.

## Statistics- I (3-1-0 4)

**UNIT- I**

**Introduction to Probability:** Concept of Random Experiment, Sample Space, Event, Definitions of Probability, Conditional Probability, Independent events and Mutually exclusive events. Addition and Multiplication Theorems, Bayes' Theorem.

**Random Variables and Probability Distributions:** Concept of a random variable, Discrete and Continuous Random Variables, Distribution Function, Probability Mass and Density Functions, Mathematical Expectation, Moment Generating Function, Characteristic Function, Probability Generating Function, Discrete and Continuous Probability Distributions such as Bernoulli, Binomial, Negative Binomial, Geometric, Hyper-Geometric, Poisson, Multinomial, Uniform, Exponential, Beta, Gamma and Normal.

**UNIT- II**

**Joint Probability Distributions:** Introduction, Joint Distribution for Two Dimensional Random Variables, Marginal Distributions, Conditional Distributions, Covariance, Conditional Expectation, Independence of Random Variables, Distribution of Sum of Two Independent Random Variables.

**Sampling Distributions:** Sampling Distribution based on Normal Random Variables, t-Distribution, Chi-Square Distribution, F- Distribution, Order Statistics and their Distributions, Bivariate Normal Distribution, Multivariate Normal Distribution.

**UNIT- III**

**Correlation and Regression Analysis:** Introduction, Types of Correlation, Karl Pearson's Coefficient of Correlation, Spearman's Rank Correlation, Multiple and Partial Correlation, Linear Regression Model, Regression Coefficient and its Properties, Computation of Regression Equation, Multiple Regression Analysis.

**Stochastic Process:** Introduction, Poisson Process, Birth and Death Process, Markov Chain, Transition Probabilities, Classification of States, Stationary Process.

**Texts/ References**

1. S.M. Ross: Introduction to Probability and Statistics for Engineers and Scientists, Academic Press, 4th Edition, 2010.
2. W.W. Hines, D.C. Montgomery, D.M. Goldsman, and C.M. Borror: Probability and Statistics in Engineering, John Wiley and Sons, 4th Edition, 2007.
3. S.C. Gupta and V.K. Kapoor: Fundamentals of Mathematical Statistics, Sultan Chand and Sons, 2007.
4. A.M. Goon, M.K. Gupta, B. Dasgupta: Fundamental of Statistics, Vol. I, II, World Press, 2001.
5. V.K. Rohatgi and A.K. Ehsanes Saleh: An Introduction to Probability and Statistics, John Wiley and Sons, Inc. 2003.
6. G. Casella and R.L. Berger: Statistical Inference, Cengage Learning, 3rd Edition, 2008.
7. J. Medhi: Stochastic Processes, New Age Publication, 2nd Edition, 2002.

## SEMESTER III

### Functional Analysis (3-1-0 4)

Normed linear spaces: Finite dimensional normed spaces, Heine-Borel theorem, Riesz lemma, Continuity of linear maps, Hahn-Banach extension theorem, Banach spaces, Dual spaces and transposes, Uniform-boundedness principle and its applications; Spectrum of a bounded operator.

Inner product spaces: Hilbert spaces, Orthonormal basis, Total Orthonormal Sets and Sequences Projection theorem and Riesz representation theorem. Representation of Functionals on Hilbert Spaces, Hilbert-Adjoint Operator, Self-Adjoint, Unitary and Normal Operators, Open Mapping Theorem, Closed Graph Theorem.

**Texts/References**

1. E. Kreyszig: Introduction to Functional Analysis with Applications, Wiley, 1974.
2. J.B. Conway: A course in Functional Analysis, 2nd edition, Springer, Berlin, 1990.
3. A.N. Kolmogorov and S. Fomin: Elements of the theory of functions and functional analysis, Dover, 1999.
4. A. Taylor and D. Lay: Introduction to Functional Analysis, 2nd edition, Wiley, 1980.

### Classical Mechanics (3-1-0- 4)

Integrals of Motion : Ignorable Coordinates, Routhian function. Generalized coordinates, Lagrange’s equations, Hamilton’s canonical equations, Hamilton’s

principle and principle of least action, Hamilton Jacobi equation, Possain and Lagrange's Brackets, Canonical transformation'. Two-dimensional motion of rigid bodies, Euler's dynamical
equations for the motion of a rigid body about a fixed point, theory of small oscillations.

**Text/References:**


1. T. Greenwood: Classical Dynamics, Dover, 1997.
2. H. Goldstein, C.R. Poole and J. Safko: Classical Mechanics, 3rd Edition, Pearson India, 2002.
3. E. T. Whittaker: A Treatise on the Analytical Dynamics of Particles and Rigid Bodies: With an Introduction to the Problem of Three Bodies, 4th edition, CUP, 1989.
4. L. D. Landau and E.M. Lifshitz: Mechanics, 3rd edition, Butterworth-Heinemann, 1976.
5. H. C. Corben and P. Stehle: Classical Mechanics, 2nd edition, Dover Publications, 1994.
6. J. B. Marion and S.T. Thornton: Classical Dynamics of Particles and Systems, 5th edition, Cengage Learning, 2003.
7. V. I. Arnold and A. Weinstein: Mathematical Methods of Classical Mechanics, 2nd edition, Springer, 1989.


## Calculus of Variations and Integral Equations (3-1-0 4)

**Calculus of Variations:** Introduction, problem of brachistochrone, problem of geodesics, isoperimetric problem,Variation and its properties, functions and functionals, Comparison between the notion of extrema of a function and a functional. Variational problems with the fixed boundaries, Euler's equation, special cases containing only some of the variables, Invariance of the Euler-Lagrange Equation, Functionals Containing Higher-Order Derivatives, Euler- Poisson equation, Functionals Containing Several Dependent Variables, System of Euler's equation, Functionals containing several independent variables, Ostrogradsky equation. Variational problems in parametric form, applications to differential equations. The Isoperimetric Problem and some of their generalizations. Applications to Eigenvalue Problems. Holonomic and Nonholonomic Constraints. Variational problems with moving boundaries, pencil of extremals, Transversality condition. Extremals with corners, refraction of extremals, examples, One-sided variations, conditions for one sided variations, Field of extremals, central field of extremals, The Hamiltonian Formulation, Jacobi's condition. The Weierstrass function, a weak extremum, a strong extremum. The Legendre condition, Conjugate Points, Variational methods for boundary value problems in ordinary and partial differential equations.

**Integral Equations:** Introduction and basic examples, Classification, Conversion of Volterra Equation to ODE, Conversion of IVP and BVP to Integral Equation, Successive approximation, Successive substitution methods for Fredholm Integral Equations, series solution, successive approximation, successive substitution method for Volterra Integral Equations, Volterra Integral Equation of first kind, Integral Equations with separable Kernel, Fredholm's first, second and third theorem, Integral Equations with symmetric kernel, Eigen functions expansion, Hilbert-Schmidt theorem, Fredholm and Volterra Integro-Differential equation, Singular Integral Equation.

**Texts/References**


1. B. Brunt: The Calculus of Variations, Springer-Verlag, New York, 2004.
2. F. Y. M. Wan: Introduction to the Calculus of Variations and its Applications, 2nd edition, Chapman & Hall, 1995.
3. M. Gelfand and S. V. Fomin: Calculus of Variations, Prentice Hall, 1963.
4. R. Weinstock: Calculus of Variations with Applications to Physics and Engineering, Dover, 1974.
5. R. Courant and D. Hilbert: Methods of Mathematical Physics, Vol I. John Wiley & Sons, 1989.
6. L.E. Elsgolc: Calculus of Variations, Pergamon Press Ltd., 1962.
2. D. Porter and D. S. G. Stirling: Integral Equations - A Practical Treatment from Spectral Theory and Applications, Cambridge University Press, 1990.
3. C. Cordumeanu: Integral Equations and Applications, Cambridge University Press, 1991.
4. S. G. Mikhlin: Integral Equations, Hindustan Publishing Co., 1960.
5. E. G. Tricomi: Integral Equations, Interscience, 1957.
6. 11. F. B. Hildebrand: Methods of Applied Mathematics, 2nd edition, Prentice Hall, 1965.


**Electives of Semester III**

**Field Theory** **(3-1-0 4)**

Unit I: Fields, finite fields, Polynomial rings and irreducibility criteria. Field extensions, Algebraic field extensions.

Unit II: Normal and Separable Extensions, Galois extensions, Fundamental Theorem of Galois Theory.

Unit III: Constructibility by ruler and compass, Solvability by radicals, Insolvability of the general quintic by radicals.

Text/References

1. P. B. Bhattacharya, S. K. Jain, S. R. Nagpaul: Basic Abstract Algebra, 2nd edition, Cambridge, 1995.
2. M. Artin: Algebra, Prentice Hall India, 2009.
3. S. Lang: Algebra, 3rd edition, Springer, 2002.
4. J. Rotman: Galois Theory, 2nd edition, Springer, 2006.
5. P. Morandi: Field and Galois Theory, Springer, 2010.
6. I. S. Luthar and I. B. S. Passi: Algebra 4 - Field Theory, Narosa, 2004.

## Statistics- II (3-1-0 4)

**UNIT- I**

**Inequalities and Limit Theorems:** Introduction, Markov's Inequality, Chebyshev's Inequality, One-sided Chebyshev Inequality, Jensen's Inequality, Random Sample, Modes of Convergence of a sequence of random variables: Convergence in Distribution, Convergence in Probability, Convergence Almost Sure; Weak Law of Large Numbers (WLLN), Strong Law of Large Numbers (SLLN) and Central Limit Theorems (CLT).

**UNIT- II**

**Theory of Estimation:** Introduction, Point Estimation and Interval Estimation, Methods of Estimation: Method of Maximum Likelihood, Method of Moments; Properties of Estimators: Unbiasedness, Consistency, Efficiency, Sufficiency; Minimum Variance Unbiased Estimator (MVUE), Cramer-Rao Inequality, Minimum Variance Bound (MVB) Estimator, Bayes Estimators.

**Confidence Interval (CI) Estimation:** Introduction, CI on Mean and Variance of a Normal Distribution, CI on a Proportion, CI on the difference between Means for Paired Observations, CI on the ratio of Variances of Two Normal Distributions, CI on the difference between Two Proportions.

**UNIT- III**

**Tests of Hypotheses:** Introduction, Statistical Hypotheses, Type-I and Type-II Errors, One-Sided and Two-Sided Hypotheses, Tests of Hypotheses on the Mean of a Normal Distribution; Variance Known as well as Unknown Cases, Tests of Hypotheses on the Variance of a Normal Distribution, Tests of Hypotheses on a Proportion, Tests of Hypotheses on the Means of Two Normal Distributions; Variances Known as well as Unknown Cases, The Paired t-Test, Tests for Equality of two Variances, Tests of Hypotheses on two Proportions, Testing for Goodness of Fit, Contingency Table Tests, Neyman-Pearson Theory of Testing of Hypotheses, Uniformly Most Powerful Tests, Likelihood Ratio Tests, Unbiased Tests.

<u>**Texts/ References**</u>

1. S.M. Ross: Introduction to Probability and Statistics for Engineers and Scientists, Academic Press, 4th Edition, 2010.

2. W.W. Hines, D.C. Montgomery, D.M. Goldsman, and C.M. Borror: Probability and Statistics in Engineering, John Wiley and Sons, 4th Edition, 2007.
3. S.C. Gupta and V.K. Kapoor: Fundamentals of Mathematical Statistics, Sultan Chand and Sons, 2007.
4. A.M. Goon, M.K. Gupta, B. Dasgupta: Fundamental of Statistics, Vol. I, II, World Press, 2001.
5. V.K. Rohatgi and A.K. Ehsanes Saleh: An Introduction to Probability and Statistics, John Wiley and Sons, Inc. 2003.
6. G. Casella and R.L. Berger: Statistical Inference, Cengage Learning, 3rd Edition, 2008.
2. S. Ross: A First Course in Probability, 8th Edition, Pearson Education, 2010.

## Discrete Mathematics (3-1-0 4)

Unit I

Pigeon Hole Principle, Inclusion Exclusion Principle, Techniques of Counting, Recurrence relations.

Unit II

Mathematical Logic, Truth Table, Introduction to Lattice theory, Boolean algebra with application to switching circuits.

Unit III

Introduction to Graph Theory, Basic terms of graph theory, handshaking theorem, Eulerian Graph, Hamiltonian Graph, Planar Graph, Colouring of Graphs, Colouring problem, Five colour Theorem.

**Texts/References**

1. K. D. Joshi: Foundations of Discrete Mathematics, New Age International Pb., 1996.
2. R. A. Brualdi, Introductory Combinatorics, Fifth Edition, Pearson Education, 2009.
3. R. J. Wilson, Introduction to Graph Theory, Fifth edition, Printice Hall, 2010.
4. A. Bondy, U. S. R. Murty, Graph Theory, Springer Verlag, 2008.
5. J. P. Tremblay and R. Manohar, Discrete Mathematical Structures with Application to Computer Science, Tata McGraw-Hill, 2008.

## Numerical Linear Algebra (3-1-0 4)

Introduction. Summary/recap of basic concepts from linear algebra and numerical analysis: matrices, operation counts. Introduction to MATLAB. Matrix norms. Linear system sensitivity. Matrix factorizations. Cholesky factorization. QR factorization by Householder matrices and by Givens rotations. LU factorization and Gaussian elimination; partial pivoting. Error analysis. Block algorithms and their suitability for modern machine architectures. The BLAS and LAPACK. Linear systems. Solving triangular systems by substitution. Solving full systems by factorization. Approximation of inverse of matrices. Moore-Penrose inverses.

Application: Newton's, Secant, Steffensen, Kurchatov methods etc. for nonlinear systems. Sparse and banded linear systems and iterative methods. LU factorization for banded and sparse matrices. Storage schemes. Iterative methods: Jacobi, Gauss-Seidel and SOR iterations. Krylov subspace methods, conjugate gradient method. Preconditioning. Application: differential equations. Linear least squares problem. Basic theory using singular value decomposition (SVD) and pseudoinverse. Perturbation theory. Numerical solution: normal equations. SVD and rank deficiency. Application: image deblurring. Eigenvalue problem. Basic theory, including perturbation results. Power method, inverse iteration. Similarity reduction. QR algorithm. Application: Google PageRank.

**Texts/References:**


1. K. Atkinson: An Introduction to Numerical Analysis, 2$^{nd}$ edition, Wiley, 1989.
2. R.L. Burden, J.D. Faires: Numerical analysis, 7$^{th}$ edition, Brooks Cole, 2001.
3. A. Iserles: A first course in the numerical analysis of differential equations, Cambridge University Press, 1996.
4. R. LeVeque: Finite Difference Methods for Ordinary and Partial Differential Equations Steady-State and Time-Dependent Problems, SIAM, 2007.
5. L. N. Trefethen and D. Bau, III:Numerical Linear Algebra. Philadelphia, SIAM, 1997.
6. G. Sewell: The Numerical Solution of Ordinary and Partial Differential Equations, 2$^{nd}$ ed., Wiley, 2005.
7. J.M. Ortega: Numerical Analysis: A Second Course, SIAM, 1987.
8. E. Isaacson, H.B. Keller: Analysis of numerical methods, Dover, 1994.
9. Timothy A. Davis, Direct Methods for Sparse Linear Systems, Society for Industrial and Applied Mathematics, Philadelphia, PA, USA, 2006, ISBN 0-89871-613-6, xii+217pp.
10. James W. Demmel, Applied Numerical Linear Algebra, Society for Industrial and Applied Mathematics, Philadelphia, PA, USA, 1997, ISBN 0-89871-389-7, xi+419pp.
11. Gene H. Golub and Charles F. Van~Loan, Matrix Computations Johns Hopkins University Press, Baltimore, MD, USA, third edition, 1996, ISBN 0-8018-5413-X (hardback), 0-8018-5414-8 (paperback), xxvii+694pp.
12. Desmond J. Higham and Nicholas J. Higham, MATLAB Guide, Society for Industrial and Applied Mathematics, Philadelphia, PA, USA, second edition, 2005, ISBN 0-89871-578-4, xxiii+382pp.
13. Nicholas J. Higham, Accuracy and Stability of Numerical Algorithms, Society for Industrial and Applied Mathematics, Philadelphia, PA, USA, second edition, 2002, ISBN 0-89871-521-0, xxx+680pp.
14. G. W. Stewart, Introduction to Matrix Computations, Academic Press, New York, 1973, ISBN 0-12-670350-7, xiii+441pp.
15. G. W. Stewart, Matrix Algorithms, Volume I: Basic Decompositions, Society for Industrial and Applied Mathematics, Philadelphia, PA, USA, 1998, ISBN 0-89871-414-1, xx+458pp.

16. G. W. Stewart, Matrix Algorithms, Volume II: Eigensystems, Society for Industrial and Applied Mathematics, Philadelphia, PA, USA, 2001, ISBN 0-89871-503-2, xix+469pp.
17. Lloyd N. Trefethen and David Bau III, Numerical Linear Algebra, Society for Industrial and Applied Mathematics, Philadelphia, PA, USA, 1997, ISBN 0-89871-361-7, xii+361pp.
18. David S. Watkins, Fundamentals of Matrix Computations, Wiley, New York, second edition, 2002, ISBN 0-471-21394-2, xiii+618pp.
19. Per Christian Hansen, James G. Nagy, and Dianne P. O'Leary, Deblurring Images: Matrices, Spectra, and Filtering, Society for Industrial and Applied Mathematics, Philadelphia, PA, USA, 2006, ISBN 0-89871-618-7, xiv+130pp.
20. C. T. Kelley, Iterative Methods for Linear and Nonlinear Equations, Society for Industrial and Applied Mathematics, Philadelphia, PA, USA, 1995, ISBN 0-89871-352-8, xiii+165pp.
21. Amy N. Langville and Carl D. Meyer, Google's PageRank and Beyond: The Science of Search Engine Rankings, Princeton University Press, Princeton, NJ, USA, 2006, ISBN 0-691-12202-4, x+224 pp.

## Fluid Dynamics (3-1-0 4)

Lagrangian and Eularian description, stream lines, path lines, streak lines, vortex lines, vorticity vector, equation of continuity, circulation, rotational and irrotational flows, boundary surface. General equations of motion, Bernoulli's theorem ( Compressible , incompressible flows) Kelvin's theorem (constancy of circulation). Stream function, complex potential, sources, sinks and dublets, Circle theorem, Method of images. Theorem of Blasius. Viscuss flows- stress analysis in fluid motion, relations between stress and rate of strain. Stoke's stream function, Spherical Harmonics and motion of a Sphere. Helmholtz's vorticity equation (permanence of vorticity) Vortx filaments, vortex pair. Navier-Stoke's equations. Dissipation of energy. Diffusion of vorticity, Steady flow between two infinite parallel plates, through a circular pipe (Hagen Poiseuille flow).

**Text/References**

1. R.W. Fox et.al. Introduction to Fluid Mechanics, 7th edition, Wiley, 2009.
2. B.R. Munson et.al. Fundamentals of Fluid Mechanics, 6th edition, Wiley, 2009.
3. A.K. Mohanty: Fluid Mechanics, 2nd edition, PHI, 2009.
4. M.D. Raisinghania: Fluid Dynamics, 9th edition, S. Chand, 2010.
5. F. Durst, Fluid Mechanics: An introduction to the Theory of Fluid Flows, Springer, 2008.

## Theory and Applications of Fuzzy Sets (3-1-0 4)

Basic concepts of fuzzy sets, fuzzy logic, operations on fuzzy sets, fuzzy relations, equivalence and similarity relations, ordering, morphisms, fuzzy relation equations, fuzzy measures, probability measures, possibility and necessity measures, measures of uncertainty, dissonance, confusion and nonspecificity. Principles of uncertainty and information. Applications of fuzzy sets in management, decision making, computer science and systems science.

Texts/References:


1. T. J. Ross: Fuzzy Logic with Engineering Applications, 3rd edition, Wiley, 2010.
2. G. J. Klir and B. Yuan: Fuzzy Sets and Fuzzy Logic Theory and Applications, Prentice Hall, 1995.
3. G. Chen and T. Pham: Introduction to Fuzzy Sets, Fuzzy Logic, and Fuzzy Control Systems, CRC, 2000.
4. H. J. Zimmermann: Fuzzy Set Theory - and Its Applications, 2nd edition, Springer, 1991.


## Data Structures and Algorithm Analysis (2-1-1 4 )

Unit I: Data and Algorithms

Introduction to Data, Information and structures of Data, Algorithms (Quick Review with algorithm design techniques). Introducing uses of data structures in algorithms ( fundamental examples).

Types of Data Structure: Linear and Non-Linear.

Array, Linked List. Stack, Queue (s), Graph (s) (Quick review to type and its properties) and Trees (Binary and others), Priority Queue, Heaps (Binary). Stack and Queue using Array and Linked List.

Unit II: Asymptotic analysis

Introduction to Algorithms' analysis, cost of algorithms in terms of steps (time) and space (memory).

Asymptotic Notations and analysing algorithms. growth of functions (Graph representation). Recurrance and asymptotic notations, solving recurrances (Master theorem), Problems practices.

Unit III: Algorithms and analysis

**Searching**: Linear, Binary, B-Tree, DFS, BFS, Binary Search Tree, AVL Search Tree, Hashing.

**Sorting**: Finding max, min and sorting, Insertion Sort, Bubble Sort, Selection Sort, Heap sort, Quick sort, Merge sort, String sort.

Strassen's matrix multiplication, Sum of subsets, Minimum spanning trees, Shortest Path algorithm.

**Computer Experiments using C Programming Language**

Texts/References:

1. Expert Data Structures with C by R.B. Patel; Khanna Publishers, New Delhi.
2. Algorithms + Data Structures = Programs by Niklaus Wirth; Prentice Hall, 1976.
3. Horowitz and Sahani: Fundamentals of Computer Algorithms.
2. T.H. Coremen, C.E. Leiserson, R.L. Rivest and C. Stein: Introduction to Algorithms, 20th edition,
3. Prentice Hall India, 2010.
4. Shaum's Outline Series by Lipschutz; McGraw Hill Education P Ltd , New Delhi.

## Cryptography (3-1-0 4)

Introduction to basic terminologies associated with Cryptography, Definition and classification of Cryptosystem, Classical crypto systems, Description of rail fence cipher, Simple Columnar cipher, Caesar cipher, Linear cipher, Affine linear cipher, Distinction between Substitution cipher and Permutation cipher. Classical cipher as particular case of Affine linear cipher, Insecurity of Affine linear cipher, Block cipher and different modes of implementation of Block cipher, Stream cipher, Feistel cipher, DES (Data Encryption Standard) and AES (Advanced Encryption Standard).
Public Key cryptosystems, Need for Public Key cryptosystems, Description of RSA, Rabin cryptosystem, Diffie-Hellman key exchange, ElGamal cryptosystem, Cryptanalysis of Public Key cryptosystem, Digital signatures, Introduction to Elliptic curve cryptography, Perfect security and Shanon's Theorem. Mathematical problems related to cryptography, Division Algorithm and extended Division Algorithm, Calculation of Units in Z/nZ, Fast Exponentiation, Factoring problem, Different factorisation Algorithms, Discrete Log Problem, Discussion of different algorithms for finding discrete log.
**Lab Component:** Cryptography Lab in C (at least 10 Sessions), Use of Sage software.

**Texts/References**

1. J. A. Buchmann: Introduction to Cryptography, Springer, 2004.
2. N. Koblitz: A Course in Number Theory and Cryptography, Springer, 1994.
3. M. Welschenbach: Cryptography in C and C++, 2nd edition, Apress, 2002.

## JAVA Programming (3-0-1-4)

History of java, Features of java, JVM Architecture, Data Types, Operators, Arrays, Command Line Arguments, OOPS in java, Abstract Classes, Interfaces, Packages, Access modifiers, Access Specifiers, Exception Handling, Applet, Multithreading, Streams(File I/O), Introduction to AWT, Introduction to Collection Framework (java.util.*), String Handling.

Lab: JAVA lab.

**Text/References**

1. H. Schildt: The complete Reference, 8th Edition, Tata McGraw Hill, 2011.
2. K. Sierra, B. Bates; SCJP Sun certified Programmer for java 6 study Guide, Tata McGraw Hill, 2008.
3. E. Balagurusamy: Programming with java, 4th Edition Tata McGraw Hill 2009.

## Theory of Computation (3-1-0 4)

**Unit 1:** Chomsky Hierarchy: regular grammars, unrestricted grammars, context sensitive languages, relations between classes of languages. Finite Automata and Regular Expressions: Deterministic and non-deterministic finite automata, regular expressions, Two way finite automata, finite automata with output**:** Mealy and Moore machines; Properties of Regular Sets**:** Pumping lemma, closure properties, decision algorithm, MyHill-Nerode theorem and minimization of finite automata.

**Unit 2:** Context-Free Grammars (CFG): CFGs, derivation trees, simplification, Chomsky normal forms, Greibach normal forms; Pushdown Automata (PDA): Definitions, relationship between PDA and context free languages, Properties of Context-Free Languages**,** Pumping lemma, closure properties, decision algorithm; Turing Machines: The turing machine model, computable languages and functions, techniques for turing machine construction, modification of turing machines, Church's hypothesis, Turing machines as enumerators;

**Unit 3:** Decidability: Decidable Languages, The Halting problem, Reducibility. Undecidability: properties of recursive and recursively enumerable languages, universal Turing machines, rice's theorem, post correspondence problem, Greibach's theorem, Introduction to recursive function theory; Complexity Theory: Measuring complexity, The P, NP, NP-Hard and NP completeness.

Texts/References

1. K.L.P. Mishra and N. Chandrasekharan: Theory of Computer Science: Automata Language and Computation, Prentice Hall of India, 3rd edition, 2007.
2. P. Linz: Introduction to Formal Language and Computation, Narosa, 2nd edition, 2006.
3. M. Sipser: Introduction to the Theory of Computation, Thomson Learning, 2001.
4. J. Martin: Introduction to Languages and the Theory of Computation, 3rd edition, McGraw Hill, 2002.
5. J. E. Hopcroft, R. Motwani and J.D. Ullman: Introduction to Automata Theory, Languages and Computation, 2nd Edition, Pearson Education, 2001.

## Graph Theory (3-1-0 4)

Graphs and Sub graphs:- Graphs and simple graphs, Graph isomorphism, The incidence and adjacency matrices, sub graphs, connected and bipartite graphs, walk, trail, path and cycles. Application:- The Shortest path problem, Dijkstra algorithm, Warshall Algorithm.
Trees:- Trees, Cut Edge and Bond, Cut vertex, spanning trees and Cayley's formula. The Connector Problem: Prim's Algorithm, Kruskal's Algorithm.
Euler tour and Hamilton's Cycles, characterization of Eulerian graphs, a necessary and some sufficient characterizations of Hamiltonian graph. Closure and degree majorization and related results, Chinese Postman Problem.
Matchings: Theorem of Berge, Matchings and coverings in Bipartite graphs, Application: Hall's marriage theorem, Some Assignment Problems.
Connectivity: m-connectivity and blocks, Construction of Reliable Communication Networks.
Vertex Coloring: Planar graph, Euler's formula, Chromatic Number, Brook's Theorem, 5-color theorem.
**Lab Component:** Implementation in C: Dijkstra Algorithm, Warshall Algorithm, BFS, DFS, Prims Algorithm, Kruskal Algorithm, Connectivity Algorithm, Flurey Algorithm.

Text/References

1. J.A. Bondy and U.S.R Murty: Graph Theory, Springer, 2008.
2. F. Harary: Graph Theory, Westview Press, 1994.
3. R.J. Wilson: Introduction to Graph Theory, 4th edition, Pearson, 2002.
4. J. Clark and D. A. Holton: A First Look at Graph Theory, World Scientific, 1991.
5. D.B. West: Introduction to Graph Theory, 2nd edition, PHI Learning, 2009.
6. N. Deo: Graph Theory with Applications to Engineering and Computer Science, Prentice-Hall of India, 2004.

## SEMESTER IV

### Partial Differential Equations (3-1-0 4)

Introduction to partial differential equations. Solution of linear and nonlinear partial differential equations of order one. Introduction to Cauchy's problem. Homogeneous and non-homogeneous linear partial differential equations.

Classification of partial differential equations, reduction to canonical or normal form. Monge's method, second order Cauchy Problem.
**Wave equation:** d'Alembert solution of the Cauchy problem, the characteristic triangle, Fourier series solution. A Wave equation in two space dimensions, The Kirchhoff-Poisson solution, Hadamard's method of Descent.

**Heat Equation:** The Cauchy problem and initial conditions, Solution of homogenous and non-homogenous problem, heat kernel. the heat equation in two space variables.
**Laplace's equation: Dirichlet and Neumann Problems** Harmonics functions, Dirichlet problems, Poisson's integral representation, The Neumann problem, Green's function, conformal techniques, existence theorems, solutions by Eigen function expansions.
**Elliptic equations:** Existence of weak solutions, The maximum principle, Green's identities.

**Texts/References**


1. P.V. O'Neil: Beginning Partial Differential Equations, 2nd edition, Wiley, 2008.
2. Y. Pinchover and J. Rubinstein: An Introduction to Partial Differential Equations, Cambridge University Press, 2005.
3. R. Haberman: Applied Partial Differential Equations with Fourier Series and Boundary Value Problems, 4th edition, Pearson, 2004.
4. M. D. Raisinghania: Ordinary and Partial Differential Equations, 12th edition, S. Chand, 2010.
5. R. Agarwal and D. O'Regan: Ordinary and Partial Differential Equations. With Special Functions, Fourier Series, Boundary Value Problems, Springer 2009.
2. L.C. Evans: Partial Differential Equations, AMS, 1998.
3. E. A. Coddington and N. Levinson: Theory of Ordinary Differential Equations, Tata McGraw Hill, 1987.


## Differential Geometry (3-1-0 4)

Quick review to Curves and Surfaces (at most 5 classes).
Manifolds, Smooth maps and diffeomorphisms, Tangent Spaces to a manifold, Derivatives of smooths maps, Immersions and submersions, submanifolds, Vector fields, Flows and exponential map, Frobenius theorem, Lie groups and Lie algebras, Homogeneous spaces, Multilinear algebra, Exterior algebra, Tensor fields, Exterior derivative, Lie derivatives. Orientable manifolds, Integration on manifolds, Stokes' theorem, Tangent Bundles and Vector Bundles.

Texts/References


1. S. Kumaresan: A Course in Differential Geometry and Lie Groups, Hindustan Book Agency, 2002.
2. J. R. Munkres: Analysis on Manifolds, Westview Press, 1997.
3. S. Lang: Introduction to Differentiable Manifold, 2nd edition, Springer, 1927.
4. L. Auslander and R. E. Mackenzie: Introduction to Differentiable Manifolds, Dover, 2009.


## Advanced Numerical Analysis (3-1-0 4)

**Interpolation Theory:** Review of basic polynomial interpolation. Hermite Interpolation. The general Hermite interpolation problem.
**Approximation of functions:** The Minimax and Least squares approximation problem. Orthogonal polynomials, The Least squares approximation problem using orthogonal polynomials. Minimax and Near-minimax approximations.
**Numerical Integration:** Review of Newton-Cotes integration formulas. Gaussian Quadrature. Asymptotic error formulas and their applications. Automatic numerical integration. Multiple Integrals, Singular integrals.
**Ordinary differential equations:** Numerical solutions of IVP – Difference equations, stability, error and convergence analysis. Single step methods - Taylor series method, Euler method, Picard's method of successive approximation, Runge-Kutta method. Multi step methods – Predictor-Corrector(PC) method, Euler PC method, Milne and Adams Moulton PC method. System of first order ODE, higher order IVPs. Numerical solutions of BVP – Linear BVP, finite difference methods, shooting methods, stability, error and convergence analysis, nonlinear BVP, higher order BVP.
**Numerical solution of systems of linear equations:** Review of Direct methods for solving linear systems, error analysis. The residual correction method. Iteration methods, Error prediction and Acceleration.
**The Matrix Eigenvalue problem:** Review of Eigenvalue location, error, and stability results, Power method. Orthogonal transformations using Householder matrices. The eigenvalues of a symmetric Tridiagonal matrix. QR method. The calculation of Eigenvectors and Inverse iteration.

**Lab Components:** Exposure to Matlab/Mathematica and computational experiments based on the algorithms discussed in the course.

**Texts/References**


1. K. Atkinson: An Introduction to Numerical Analysis, 2nd edition, Wiley, 1989.
2. R.L. Burden and J.D. Faires: Numerical Analysis, 7th edition, Brooks Cole, 2001.
3. S.D. Conte and C. de Boor: Elementary Numerical Analysis, 3rd edition, Tata McGraw Hill, 1980.
4. A. Iserles: A First Course in the Numerical Analysis of Differential Equations, Cambridge University Press, 1996.
5. P.J. Davis and P. Rabinowitz: Methods of Numerical Integration, 2nd edition, AP, 1984.
6. R. LeVeque: Finite Difference Methods for Ordinary and Partial Differential Equations Steady-State and Time-Dependent Problems, SIAM, 2007.
7. L. N. Trefethen and D. Bau III: Numerical Linear Algebra, SIAM, Philadelphia, 1997.
8. G. Sewell: The Numerical Solution of Ordinary and Partial Differential Equations, 2nd edition, Wiley, 2005.
9. E. Isaacson and H.B. Keller: Analysis of Numerical Methods, Dover, 1994.
10. P.J. Davis: Interpolation and Approximation, Dover, 1975.

11. J.M. Ortega: Numerical Analysis: A Second Course, SIAM, 1987.

## Electives of Semester IV

### Algebraic Number Theory (3-1-0 4)

Unit I

Algebraic Numbers and Algebraic Integers, Algebraic Number Fields, Integral Basis and Discriminant, Ring of Integers in an Algebraic Number Field (with explicit calculations for Quadratic & Cyclotomic fields).

Unit II

Divisibility in Algebraic Number Fields, Euclidean Fields, Group of Units in an Algebraic Number Field, Divisibility in Quadratic Fields.

Unit III

Ideals, Divisors and Factors, Fundamental Theorem of Ideal Theory, Fractional Ideals, Inverse of an Ideal, Congruences, Norm of an Ideal , The problem of ramification, Class numbers, The Fermat conjecture.

**Texts/References**

1. Harry Pollard, Harold G. Diamond: The Theory of Algebraic Numbers, 3rd edition, Dover, 2010.
2. S. Alaca, K. S. Williams: Introductory Algebraic Number Theory, CUP, 2003.
3. E. Weiss: Algebraic Number Theory, Dover, 1998.
4. Stewart, D. Tall: Algebraic Number Theory and Fermat's Last Theorem, 3rd edition, A K Peters/CRC Press, 2001.
5. G. J. Janusz: Algebraic Number Fields, 2nd edition, 1996.

### Statistics III (3-1-0 4)

**Sampling Theory:** Introduction, Concept of Population and Sample, Primary and Secondary data, Methods of Collecting Primary data, Sampling frame, Sampling design, Determination of sample size, Census and Sample Surveys, Sampling and Non-sampling errors, Simple Random Sampling, Stratified Sampling, Systematic Sampling, Probability Proportional to Size (PPS) Sampling, Ratio and Regression Methods of Estimation.

**Design and Analysis of Experiments:** Introduction, Analysis of Variance (ANOVA) and Analysis of Covariance (ANCOVA), Fixed, Random and Mixed effects Models, ANOVA for one-way and two-way Classified Data, Basic principles of Design of Experiments, Completely Randomized Design (CRD), Randomized Block Design (RBD) and Latin Square Design (LSD), Factorial Experiments, Confounding in symmetrical factorial experiments ($2^n$ series), Connectedness and Orthogonality of Block Designs, Balanced Incomplete Block Design (BIBD).

**Texts/ References**

1. W. G. Cochran: Sampling Techniques, John Wiley and Sons, 3rd Edition, 1977.

2. P. V. Sukhatme, B. V. Sukhatme, S Sukhatme & C. Ashok : Sampling Theory of Surveys with Applications, Iowa State University Press and Indian Society of Agricultural Statistics, New Delhi, 1984.
3. W. G. Cochran & D. R. Cox : Experimental Designs, John Wiley, 1957.
4. D. C. Montgomery: Design and Analysis of Experiments, John Wiley and Sons, 8th Edition, 2013.
5. S.C. Gupta and V.K. Kapoor: Fundamentals of Applied Statistics, Sultan Chand and Sons, 1994.
6. M.N. Das and N.C. Giri: Design and Analysis of Experiments, New Age Publication, 2nd Edition, 1986.

## Optimization Techniques (3-1-0 4)

**UNIT- I**

**Linear Programming:** Introduction, Linear Programming Problem (LPP) and its formulation, Graphical method for solving LPP, Basic Feasible Solution, Simplex Method, Big-M and Two-phase methods, Degeneracy, Alternative Optimal Solution, Unbounded Solution, Infeasible Solution, Dual Problem and Duality Theorems, Dual Simplex Method and its application in post-optimality analysis.

**UNIT- II**

**Transportation and Assignment Problems:** Introduction, Transportation algorithm, Mathematical formulation, Balanced and Unbalanced Transportation Problems, Vogel's approximation method for solving Transportation Problems, Hungarian method for solving Assignment Problems.

**UNIT- III**

**Queueing and Inventory Theory:** Introduction, Queueing System, Elements of a Queueing System, Operating Characteristics, Probability distributions in Queueing Systems, Elementary Queueing and Inventory Models, Steady-state solutions of Markovian Queueing Models: M/M/1, M/M/1 with limited waiting space, M/M/C, M/M/C with limited waiting space, M/G/1.

**Texts/ References**

1. E.K.P. Chong and S.H. Zak: An Introduction to Optimization, 2nd edition, Wiley, 2001.
2. D.G. Luenberger, Y. Ye: Linear and Nonlinear Programming, 3rd edition, Springer, 2008.
3. A.Ravindran, K.M. Ragsdell, G.V. Reklaitis: Engineering Optimization, 2nd edition, Wiley, 2006.
4. H.A. Taha: Operations Research: An Introduction, 8th edition, Prentice Hall, 2007.

5. K. Swarup, P. K. Gupta and M. Mohan: Operations Research, Sultan Chand and Sons, 2004.

## Difference Equations and Discrete Dynamical Systems (3-1-0 4)

**Difference Equations:** Introduction to Difference Equations, First order DEs, linear equations with constant coefficients, variable coefficients, stability in both hyperbolic and nonhyperbolic cases, bifurcations, symbolic dynamics and chaos, linear theory for two dimensional systems of difference equations, equilibria, stability, periodic solutions, period-doubling bifurcation, Lyapunov numbers, box dimension, stable and unstable manifolds, area preserving maps, systems with order higher than 2, numerical issues in difference equations.

**Discrete Dynamical Systems:** Discrete and continuous dynamical systems, One and two dimensional maps as discrete dynamical systems, Fixed points, periodic points and stability, Chaos, Lyapunov exponents and chaotic attractors, Differential equations as continuous dynamical systems, Periodic orbits and limit sets, Bifurcations.

Text/References

1. S. Goldberg: Introduction to difference Equations, Dover, 1986.
2. K.T. Alligood, T.D. Sauer and J.A. Yorke: An Introduction to Dynamical Systems, Springer, 1997.
3. E. Ott: Chaos in Dynamical Systems, Cambridge University Press, 2nd edition 2002.
4. S.H. Strogatz: Nonlinear Dynamics and Chaos - With Applications to Physics, Biology, Chemistry and Engineering, Westview Press, 2000.
5. S. Elaydi: An Introduction to Difference Equations, Springer, 1995.
6. W.G. Kelley and A.C. Peterson: Difference Equations - An Introduction with Applications, 2nd edition, AP, 2001.

## Coding Theory (3-1-0 4)

Unit I

The Communication Channel, The coding problem, Block codes, Hamming metric, Nearest neighbour decoding, Linear codes, Generator and parity check matrices, dual codes, Standard array decoding, Syndrome decoding, Permutation equivalent codes.

Unit II

Hamming codes, Golay codes, Reed–Muller codes, Codes derived from hadamard matrices. Bounds on codes: $A_q(n,d)$ and $B_q(n,d)$, sphere packing bound, covering radius and perfect codes. Singleton bound and MDS codes, Gilbert lower bound and Varshamov lower bound, Plotkin bound.

Unit III

Finite fields, cyclotomic cosets and minimal polynomials. Cyclic codes: factoring $x^n - 1$, basic theory of cyclic codes, Generator polynomial and check polynomial, minimum distance of cyclic codes.
BCH bound, Encoding decoding of cyclic codes, Hamming and Golay codes as cyclic codes, BCH codes, Reed-Soloman codes, Quadratic residue codes, Graphical codes, Convolutional codes.

**Texts/References**


1. W.C. Huffman and V. Pless: Fundamentals of Error-correcting Codes, Cambridge University Press, 2003.
2. S. Ling and C. Xing: Coding Theory - A First Course, Cambridge University Press, 2004.
3. E. R. Berlekamp: Algebraic Coding Theory, Aegean Park Press, 1984.
4. J. H. Van Lint: Introduction to Coding Theory, 3rd edition, Springer, 1999.
5. R. Roth: Introduction to Coding Theory, Cambridge University Press, 2006.
6. S. Roman: Introduction to Coding and Information Theory, Springer-Verlag, 1997.


## Operator Theory (3-1-0 4)

Unit I-Linear Operators, self adjoint operators and compact operators.
Unit II- Eigenvalues, Eigenvectors, Spectrum, spectral theorem, Sturm-Liouville systems, and the Fredoholm alternative.
Unit III- Nonlinear operators, variational inequalitites, complimentarity problems.

**Texts/References**


1. B. Choudhary and S. Nanda: Functional Analysis with Applications, Wiley, 1989.
2. E. Kreyszig: Introductory Functional Analysis with Applications, Wiley, 1978.
3. N. Dunford and J. T. Schwartz: Linear Operators, Part I-III, Wiley, 2009.
4. G. Bachman and L. Narici: Functional analysis, AP, 1966.


## Artificial Intelligence and Hybrid Systems (3-1-0 4 )

Unit I : Artificial Intelligence
Overview of AI, Knowledge representation, Mappings, Approaches and issues, Predicate logic, Propositional logic, Procedural and declarative knowledge.
**Fuzzy Logic**: Fuzzy Sets, Fuzzy Relations, Fuzzy operations (on fuzzy sets), Fuzzy numbers and arithmetics, Fuzzy Logic and Possibility Theory.
**Problem space and searching techniques** (Algorithms and Problem Practices): Heuristic search technique (s), State Space Search, Graph Search, Search Based on Recursion, Pattern-directed Search.

Unit II : Machine Learning
Introduction, training data, function approximation, Learning Input-Output Functions, Performance Evaluation.
**Learning** (Algorithms and Problem Practices): Dicision Tree based, Error correction learning, Supervised, Unsupervised, Hebbian learning, Clustering, K-Means Clustering, Credit assignment problem, Bayes Theorem and Classification.

Unit III: Intelligent Systems
Introduction, Cognitive Science, Expert Systems, Stages in the Development, Probability-based Expert Systems, Example of Chess game (Practice with 8-Queens problem)

Unit IV : Artificial Neural Networks
Neural network, human brain, model of an artificial neuron, mathematical preliminaries, taxonomy of NN, classical artificial intelligence and neural network.
**Artificial Neural Network**: Feed-forward network, Feed-backward network, Recurrent Network, Single Layer and Multi-layer Networks, Perceptron (example of Rosenblatt perceptron)
**Single layer Perceptrons** (Algorithms and Problem Practices): Adaptive Filtering Problem, unconstrained optimization techniques, linear least square algorithm, perceptron convergence theorem.
**Multilayer Perceptrons:** Back propagation algorithm, XOR problem, output representation and decision rule, back propagation and differentiation.
**Geometry of Binary Threshold Neurons:** Pattern recognition and data classification, convex sets, convex hulls and linear separability, space of Boolean functions, binary neurons are pattern dichotomizers, non-linear separable problems, capacity of a simple threshold logic neurons, Re-visiting the XOR problem.

Unit V : Hybrid systems, Decision Making Systems, Neuro- fuzzy systems

**Texts/References:**


1. Artificial Intelligence: Elaine Rich, Kevin Knight, Mc-Graw Hill.
2. Introduction to AI & Expert Systems: Dan W. Patterson, PHI.
3. G. J. Klir & B. Yuan, Fuzzy sets & Fuzzy logic by PHI.
4. Introduction To Machine Learning, Nils J. Nilsson.
5. C. M. Bishop: Pattern Recognition and Machine Learning, Springer, 2006.
6. S. Kumar: Neural Networks – A Classroom Approach, Tata McGraw-Hill, 2003.
7. Da Ruan: Intelligent hybrid systems: Fuzzy logic, neural networks, and genetic algorithms, Kluwer academic Publishers 1997.

## Operating systems (3-1-0 4)

**Unit1:** Introduction to Operating Systems, Evolution, Types of OS. Processes: Concept of processes, process scheduling, operations on processes, co-operating processes, interprocess communication. Overview of Threads, benefits of threads, CPU scheduling Criteria, Scheduling Algorithms (FCFS, SRTN, RR), Algorithm evaluation. Process Synchronization, critical section problem, critical region, classical problems of synchronization, semaphores. Deadlocks: Deadlock characterization, Methods to handle deadlocks, deadlock (prevention, avoidance, detection, recovery).
**Unit 2:** Memory Management, logical vs. physical address space, swapping, contiguous memory allocation, paging, segmentation, segmentation with paging. Virtual Memory, demand paging, performance, page replacement, page replacement algorithms (FCFS, LRU), allocation of frames, thrashing, Concept of Cache Memory.
**Unit 3:** File System concepts, access methods, directory structure, file system structure, allocation methods (contiguous, linked and indexed) and free-space management. Disk Management: disk structure, disk scheduling (FCFS, SSTF, SCAN, C-SCAN). Protection and Security.

**Laboratory:** Basic Unix command, Simple shell scripts theory and lab.

<u>Text/References</u>


1. A. S. Tanenbaum: Operating System Design and Implementation, 3rd edition, Phi Learning, 2009.
2. A. Silberschatz, G. Gagne and P.B. Galvin: Operating System Concepts, Wiley, 2009.
3. D. M. Dhamdhere: Operating Systems - A Concept Based Approach, 3rd edition, 2012.
4. W. Stallings: Operating Systems: Internals and Design Principles, 6th edition, Pearson Education, 2009.
5. S. Das: Unix Concept and Application, Tata McGraw-Hill, 2006.


## Relational Database Management Systems (RDBMS) (3-0-1 4)

**Unit 1:** Data and Database Management System, the Database Life Cycle, the Relational Model. ER Model: Entities, Relationship, Attributes, Degree of Relationship connectivity, attributes of a relationship. Concepts of Generalization, Specialization & Aggregation. Concepts of FD. Normalisation: 1NF, 2NF, 3NF & BCNF, lossless join, dependency preservation. Denormalization.
**Unit 2:** Relational Algebra & Calculus. Transforming the Conceptual Data Model to SQL Storage using RAID architecture. B-tree and $B^+$-tree Index Files. Measures of Query Cost & overview of query evaluation.
**Unit 3:** Transaction concept, Concurrency Control, Database Recovery.

**Laboratory:** Types of SQL commands: DDL, DML, DQL & DCL. Tables: create, alter, drop. View: creating view, Data query and manipulation with view. Testing for NULL and when not to use NULL. Aggregate Functions: Count(), SUM(), AVG(), MAX(), MIN(). Select Statement, Subquaries, INSERT, UPDATE and DELETE operation. Joins: Natural join, Self join, outer join and Cartesian product. Data security: GRANT and REVOKE.

**<u>Texts/References</u>**


1. T. J. Teorey et al.: Database Modelling and Design: Logical Design, 4th Edition, Morgan Kaufmann, 2005.
2. A. Silberschatz, H. F. Korth and S. Sudarshan: – Database System Concepts, 6$^{th}$ edition, McGraw Hill, 2010.
3. A. Leon, M. Leon: SQL A Complete Reference, McGraw Hill, 1999.