Four year Degree Program of

Computational Mathematics

BS

(Computational Mathematics)

DEPARTMENT OF MATHEMATICS
UNIVERSITY OF KARACHI

DEPARTMENT OF MATHEMATICS
UNIVERSITY OF KARACHI
BS Computational Mathematics

Total Credit Hours: 140

		Course No.	Course Title	Credit Hours	Course Type
YEAR - 1	SEMESTER - I	300.1 (E)	English – I	2+0	Gen Ed
		300.1 (I. S)	Islamic Studies OR Ethics (Non-Muslim)	2+0	Gen Ed
		300.1 (Civ/Com)	Civics and Community Engagement	2+0	Gen Ed
		300.1 (N. Sc)	Everyday Science, Astronomy, Physics, Chemistry, Earth Science or Biology	3+0	Gen Ed
		301STA	Stats-I	2+1	Int Disc
		301PHY	Phy-I	2+1	Int Disc
		CM301	Calculus	3+0	Major
			Total Credit Hours	**18**	
	SEMESTER - II	300.2	Ideology & Constitution of Pakistan/Pakistan Studies	2+0/2+0	Gen Ed
		300.2	Functional English	3+0	Gen Ed
		300.2 (Entr)	Entrepreneurship	2+0	Gen Ed
		300.2 (Soc. Sc)	Intro to Soc. Sc., Urdu, Economics, History, Geography or Psychology.	2+0	Gen Ed
		302STA	Stats-II	2+1	Int Disc
		302PHY	Phy-II	2+1	Int Disc
		CM302	Multivariable Calculus and Geometry	3+0	Major
			Total Credit Hours	**20**	

		Course No.	Course Title	Credit Hours	Course Type
YEAR - 2	SEMESTER-III	400.1 (Q. Reas)	Quantitative Reasoning-I	3+0	Gen Ed
		400.1 (E. Writ)	Expository Writing	3+0	Gen Ed
		401STA	Stats-III	2+1	Int Disc
		CM401	Data Structure & Algorithms	2+1	Int Disc
		CM403	Linear Algebra	3+0	Major
		CM405	Number Theory	3+0	Major
			Total Credit Hours	**18**	
	SEMESTER-IV	400.2 (Q. Reas)	Quantitative Reasoning-II	3+0	Gen Ed
		400.2 (ICT)	Application of Inf. & Comm. Technologies	3+0	Gen Ed
		402STA	Stats-IV	2+1	Sub
		CM402	Introduction to Database	2+1	Sub
		CM404	Mechanics	3+0	Major
		CM406	Discrete Mathematics	3+0	Major
			Total Credit Hours	**18**	

		Course No.	Course Title	Credit Hours	Course Type
YEAR - 3	SEMESTER-V	CM501	Real Analysis	3+0	Major
		CM503	Algorithm Design	2+1	Major
		CM505	Ordinary Differential Equations	3+0	Major
		CM507	Fluid Dynamics-I	3+0	Major
		CM509	Object Oriented Programming in Python	2+1	Major
			Total Credit Hours	**15**	
	SEMESTER-VI	CM502	Complex Analysis	3+0	Major
		CM504	Essential Software	2+1	Major
		CM506	Numerical Analysis-I	3+0	Major
		CM508	Fluid Dynamics-II	2+1	Major
		CM510	Object Oriented Programming in C/C++	3+0	Major
			Total Credit Hours	**15**	

		Course No.	Course Title	Credit Hours	Course Type
YEAR - 4	SEMESTER - VII	CM601	Numerical Analysis-II	3+0	Major / (Opt)
		CM603	Abstract Algebra	3+0	Major / (Opt)
			Optional-I	3+0	Major / (Opt)
			Optional-II	3+0	Major / (Opt)
			Optional-III	3+0	Major / (Opt)
		CM600.1	Field Experience / Internship	0+3	Major / (Opt)
			Total Credit Hours	18	
	SEMESTER - VIII	CM602	Partial Differential Equations	3+0	Major / (Opt)
		CM604	Stochastic Processes	3+0	Major / (Opt)
			Optional-I	3+0	Major / (Opt)
			Optional-II	3+0	Major / (Opt)
			Optional-III	3+0	Major / (Opt)
		CM600.2	Capstone Project	0+3	Major / (Opt)
			Total Credit Hours	18	

List of Elective Courses

Semester-VII	Semester-VIII
CM641 Modeling & Simulation (3+0)	CM642 Cryptography (3+0)
CM643 Perturbation Methods (3+0)	CM644 Fuzzy Mathematics (3+0)
CM645 Operations Research – I (3+0)	CM646 Operations Research – II (3+0)
CM647 Computational Fluid Dynamics – I (2+1)	CM648 Computational Fluid Dynamics– II (2+1)
CM649 Big Data Analytics- I (3+0)	CM650 Big Data Analytics-II (3+0)
CM651 Machine Learning (3+0)	CM652 Artificial Intelligence (3+0)
CM653 Optimization Theory (3+0)	CM654 Scientific Computing (2+1)
CM655 Numerical Linear Algebra (2+1)	CM606 Wavelets (3+0)

(Computational Mathematics)

First Year

		Course No.	Course Title	Credit Hours	Course Type
YEAR - 1	SEMESTER - I	300.1 (E)	English – I	2+0	Gen Ed
		300.1 (I. S)	Islamic Studies OR Ethics (Non-Muslim)	2+0	Gen Ed
		300.1 (Civ/Com)	Civics and Community Engagement	2+0	Gen Ed
		300.1 (N. Sc)	Everyday Science, Astronomy, Physics, Chemistry, Earth Science or Biology	3+0	Gen Ed
		301STA	Stats-I	2+1	Int Disc
		301PHY	Phy-I	2+1	Int Disc
		CM301	Calculus	3+0	Major
			Total Credit Hours	**18**	
	SEMESTER - II	300.2	Ideology & Constitution of Pakistan/Pakistan Studies	2+0/2+0	Gen Ed
		300.2	Functional English	3+0	Gen Ed
		300.2 (Entr)	Entrepreneurship	2+0	Gen Ed
		300.2 (Soc. Sc)	Intro to Soc. Sc., Urdu, Economics, History, Geography or Psychology.	2+0	Gen Ed
		302STA	Stats-II	2+1	Int Disc
		302PHY	Phy-II	2+1	Int Disc
		CM302	Multivariable Calculus and Geometry	3+0	Major
			Total Credit Hours	**20**	

First Semester

CM-301 Calculus (3 + 0)

Limits & Continuity: Limits, Continuity, Tangent lines & Rate of Change, Sequence and Series: Sequence and Their Divergence and Convergence Test, Introduction to Infinite Series, Taylor and Maclaurin Series, Convergence and Divergence Test for Series: Limit comparison test, Ratio test, Root test, Derivatives: Techniques of differentiation, Chain rule and implicit differentiation, derivatives of Inverse functions, hyperbolic functions, inverse trigonometric & hyperbolic functions, Applications of differentiation, Maxima and Minima of a function of single variable, Marginal analysis and approximations using increments, Indeterminate forms and L' Hospital Rule, The Integral: Riemann integral, Integration techniques, Integration by substitution, differentiation & integration of logarithmic & exponential function, Integrals of inverse trigonometric & hyperbolic function, Integration of Power of sine, cosine, secant and tangent, by parts, trigonometric substitution, Improper integrals, Beta and gamma integrals, Differential Equations: Differential equations, formation and solution, equations of first order, initial and boundary value problems, various methods of solving first order differential equations: Separable, Exact & Homogeneous equation, integration factor and orthogonal trajectories. Non-Linear First Order Equations, Envelopes and Singular solutions

Recommended Books:

1. Anton, H. and C. Rorres,. (2001), Calculus, 7th Edition, Wiley.
2. Hoffmann K, (2007), Calculus for Business, Economics and the social and the life sciences, 10th Edition, McGraw Hill.
3. Kreyszig, E., (2005), Advanced Engineering Mathematics, 9th Edition, John Wiley.
4. Morris T., & Harry.P., (2012), Ordinary Differential Equations, Dover Publications, Incorporated.
5. Thomas, G. B., & R. L. Finney, (2005), Calculus and Analytic Geometry, Addision Wesley Publishing Company.

Second Semester

CM-302 Multivariable Calculus and Geometry (3 + 0)

Polar Coordinates: Polar Coordinate & Sketching the graph of polar coordinates, Slope of tangent line and arc length for parametric and polar curve, Area in polar Coordinates, Introduction to Vectors, Line and Plane: Product of vectors, Projection of vectors, Parametric equation of line, Plane in three spaces, Quadratic surfaces, Cylindrical & Spherical coordinate, Derivatives of function of two variables: Partial derivative, Tangent plane, Euler's theorem with applications, Total differential for function of two variables, Directional derivatives and gradient for function of two variables, Maxima and minima for the function of two variables and Jacobians, The Integral: Introduction of double and triple integrals and their application.

Recommended Books:

1. Dineen S,(2001), Multivariate calculus and geometry, Springer.
2. Larson, R. & Edwards.B.H., (2013), Multivariable calculus, Cengage Learning.
3. Lax, P. D., & M. S. Terrell., (2017), Multivariable calculus with applications, Springer.
4. Marsden, J. E., (1993), Basic multivariable calculus, Springer.
5. Walschap, G., (2015), Multivariable calculus and differential geometry, Walter de Gruyter GmbH & Co.

Second Year

		Course No.	Course Title	Credit Hours	Course Type
YEAR - 2	SEMESTER-III	400.1 (Q. Reas)	Quantitative Reasoning-I	3+0	Gen Ed
		400.1 (E. Writ)	Expository Writing	3+0	Gen Ed
		401STA	Stats-III	2+1	Int Disc
		CM401	Data Structure & Algorithms	2+1	Int Disc
		CM403	Linear Algebra	3+0	Major
		CM405	Number Theory	3+0	Major
			Total Credit Hours	18	
	SEMESTER-IV	400.2 (Q. Reas)	Quantitative Reasoning-II	3+0	Gen Ed
		400.2 (ICT)	Application of Inf. & Comm. Technologies	3+0	Gen Ed
		402STA	Stats-IV	2+1	Sub
		CM402	Introduction to Database	2+1	Sub
		CM404	Mechanics	3+0	Major
		CM406	Discrete Mathematics	3+0	Major
			Total Credit Hours	18	

Third Semester

400.1 (Q.Reas) Quantitative Reasoning-I (3+0)

Numeric Reasoning: Number system, basic arithmetic equations, units and conversions, dimensions, rates, ratios, percentage, scientific notation, computation with real number, operations of integers, exponent, square root, measurement scales.

Algebraic and Geometric Reasoning: Basics of geometry, line, angle, circle, polygon, area, perimeter, volume, surface etc., introduction of set, properties and operation, functions, types of functions, graphical representation of functions, relations, types of relations, simplifying algebraic expressions exponents, factorization, algebraic solutions of linear and quadratic equations.

Logical and critical reasoning: Logic, proposition, propositional equivalence, truth table, Conjunction, disjunction, negation, propositions, logical fallacies, tautologies and contradictions, logical equivalence, Venn diagram, components of critical thinking, observation, analysis, interpretation, reflection, evaluation, inference, scientific reasoning.

Mathematical Modelling and Analysis: Introduction to deterministic models, linear and non-linear functions, system of linear equations, application of derivatives, linear and exponential growth decay model.

Recommended Books:

1. Alan F. Beardon. (2005). Algebra and Geometry, 1st edition, Cambridge University Press.
2. Eric Zaslow. (2020). Quantitative Reasoning, 1st edition, Cambridge University Press.
3. Forest Jim. (2020). Introduction to Statistics: An Intuitive Guide for Analyzing Data and Unlocking Discoveries, Jim Publishing.
4. Rosen, K. H. (2018). Discrete Mathematics and its Applications, 7th edition, McGraw Hill.
5. Sevilla. A & Somers K. (2008). Quantitative Reasoning: Tools for Today's Informed Citizen, 1st edition, Wiley.
6. Bennett.J & Briggs.W. (2018). Using & Understanding Mathematics: A Quantitative Reasoning Approach, 7th edition, Pearson.
7. Frank S Budnick. (1993). Applied Mathematics for Business, Economics, and the Social Sciences, 4th edition, McGraw Hill.
8. William Fox. (2017). Mathematical Modeling for Business Analytics, 1st edition, CRC Press.

CM-401 Data Structure & Algorithms (2+1)

Elementary Data Structures: Simple array-based data structures: arrays, matrices, stacks, queues, Linked lists, Introduction to Trees, Logical construction and traversing of Binary Trees, Implementation of Binary Trees (Insertion and Traversing), Searching and deletion in Binary Trees, Binary Search Tree, Introduction to Balanced and AVL Trees., Algorithm Specification: The Role of Algorithms in Computing, Properties of Algorithm, examples, performance, complexity analysis, measurement, and Big Oh notation, Abstract data types (ADTs): Array and Polynomial as an ADT, Sparse Matrices, and Representation of Arrays., Stack ADT, Linked lists and array implementations, Expressions, Postfix Notation, and Infix to postfix conversion.

Recursion and Queue: Recursive Definition and Processes, Writing Recursive Programs, analyzing recursive algorithms, Queue ADT, Linked and array implementations of queues, circular and double ended queue, dequeuer, priority queues, Self Referencing Classes: Dynamic Memory Allocation, garbage collection. Linked List: Singly Linked Lists, Circular Lists, Linked Stacks and Queues (Double Ended List), Doubly Linked Lists, *Sorting and Order Statistics*: Heaps and Heaps as Priority Queues, Double Ended Priority Queue. Searching: Linear Search, Binary Search, and Types of Indexing. Hash Functions, Division, Overflow Handling, Chaining. B-Trees, Generalized List, etc. Divide and conquer algorithms, Sorting, selection, insertion, merge, quick, bubble, heap, shell, radix, bucket.

Labs:

Implement basic operations on arrays and matrices.
Perform insertion, deletion, and traversal of array elements.
Implement stacks and queues using arrays and linked lists.
Perform stack operations: push, pop, and peek.
Implement singly linked lists, circular linked lists, and doubly linked lists.
Perform insertion, deletion, and traversal of linked list elements.
Implement binary trees and binary search trees.
Perform insertion, deletion, and traversal (in-order, pre-order, post-order) of binary trees.
Analyze the performance of recursive algorithms.
Implement and compare different sorting algorithms: selection sort, insertion sort, merge sort, quicksort, bubble sort, heap sort, shell sort, radix sort, and bucket sort.
Analyze the time and space complexity of each sorting algorithm.
Implement linear and binary search algorithms.
Analyze the performance of different hash functions.
Implement classic divide and conquer algorithms: merge sort, quicksort.
Analyze the performance and efficiency of divide and conquer algorithms.

Recommended Books

1. Adam B. Drozdek, (2012), Data Structure and Algorithm in C++, 4th Edition, Cengage Learning.
2. Conger S. (2021), Hands-on Database: An Introduction to Database Design and Development, 2nd Edition, Springer.
3. Horowitz.E, Sahni.S, & Mehta.D, (1995), Fundamentals of Data Structures in C++, 2nd Edition, Computer Science Press.
4. Rocca.M.L.,(2021), Advanced Algorithms and Data Structures, Manning Publication.
5. Wengrow.J, (2020), A Common-Sense Guide to Data Structures and Algorithms, 2nd Edition, Pragmatic Bookshelf.

CM-403 Linear Algebra (3 + 0)

Linear systems, Vector equations, Row reduction and echelon forms, The matrix equation Ax = b, Solution sets of linear systems, Applications of linear systems, Linear independence, Linear transformations, Matrix of a linear transformation, Linear models in business, science, and engineering, Matrix operations, Inverse of a matrix, Characterization of invertible matrices, Matrix factorization, Introduction to determinants, Properties of determinants, Cramer's rule, volume and linear transformations, Vector spaces and subspaces, Null spaces, column spaces, and linear transformations, Linearly independent sets; bases, Coordinate system, The dimension of a vector space, Rank, Change of basis, Eigenvectors and eigenvalues, The characteristic equation, Diagonalization, Diagonalization of symmetric matrices, Eigenvectors and linear transformations, Review of complex numbers, Complex eigenvalues, Applications to Markov chains, Applications to differential equations, Inner product, length and orthogonality, Orthogonal sets, Orthogonal projections, The Gram–Schmidt process, Least-squares problems, Application to linear models in Finance, Inner product spaces, The singular value decomposition.

Recommended Books:

1. Anton, H., & C. Rorres, (2010), Elementary Linear algebra: applications version, 7th Edition, John
2. Wiley & Sons.
3. David C. L, Steven R. L, & Judi J. M, (2014), Linear Algebra and Its Applications, 7th Edition, Pearson Education.
4. Cheney.E.W, & Kincaid.D.R, (2009), Linear Algebra, Theory and Applications, Jones & Bartlett Publishers.
5. Johnson.L.W, Riess.R.D, & Arnold.J.T, (2015), Introduction to Linear Algebra, 6th Edition, Pearson Education.

CM-405 Number Theory (3+0)

Introduction to Set theory operations with fundamental concepts, Divisibility, Linear Diophantine Equations, Unique Factorization, Applications of Unique Factorization, Congruences, Fermat, Euler, Wilson, Cryptographic Applications, Order and Primitive Roots, More Cryptographic Applications, Quadratic Reciprocity, Primality and Factorization, Sums of Squares, Arithmetic Functions, Continued Fractions, Recent Developments, Prime Factorization, The Sequence of Prime Numbers, The Ring of Integers Modulo n, Congruences Modulo n, The Chinese Remainder theorem, Primality testing, Public key cryptosystem, The RSA cryptosystem, Continued fraction system, Finite continued fractions, The continued fractions of exponent (e).

Recommended Books:

1. Boulagouaz M., & Tignol J.P, (1999), Algebra and Number Theory, 1st Edition, Chapman and Hall/CRC.
2. Hardy .G.H, & Wright.E.M, (2008), An Introduction to the Theory of Numbers Oxford University Press.
3. Kraft JS, & Washington LC, (2014), Elementary Number Theory, 1st Edition, Chapman and Hall/CRC.
4. Stein William, (2008), Elementary Number Theory: Primes, congruence and Secrets, Springer.
5. Vazzana.A, Erickson.M, & Garth.D, (2007), Introduction to Number Theory, 1st Edition, Chapman and Hall/CRC

Fourth Semester

400.2 (Q.Reas) Quantitative Reasoning-II (3+0)

Fundamental Statistical Concepts: Population and sample Interpretation of Tabular and Graphical form of data (Grouped and ungrouped). Summarizing data; Measures of central tendency, dispersion and Quantiles.
Combinatorial Analysis: Rules of counting (multiplicative, permutation and combination); Venn diagram
Basic concept of probability: Axioms of Probability. Introduction to probability models for continuous and discrete variables; Normal and Binomial distribution with simple applications.
Bivariate Data analysis: Scatter plots; Pearson correlation; Simple linear regression with simple application
Fundamental Concepts of Inference: Basic ideas of test of significance and testing of hypothesis. Concepts of level of significance and degree of freedom.
Quantitative reasoning exercises using fundamental statistical concepts

Recommended Books:

Bennett, J., & Briggs, W. (2019). Using & understanding mathematics: a quantitative reasoning approach. Pearson.
Mann, P. S. (2010). Introductory statistics. John Wiley & Sons.
Chatfield, C. (2018). Statistics for technology: a course in applied statistics. Routledge.
Lock, R. H., Lock, P. F., Morgan, K. L., Lock, E. F., & Lock, D. F. (2020). Statistics: Unlocking the power of data. John Wiley & Sons.
Peck, R., Short, T., & Olsen, C. (2020). Introduction to statistics and data analysis. Cengage Learning.

CM-402 Introduction to Database (2+1)

Introduction to Database Systems, Why databases, File systems versus DBMS, Roles of the database management system (DBMS),Types of database management systems, Description, data requirements and transaction requirements, Introduction to Database Design, DBMS architecture and data independence, The process for designing a database in industry, Database Languages, Data Definition Language (DDL), Data Manipulation Language (DML), Relational Model, Historical perspective: hierarchical and network models, Relational data structure, Relational algebra, Logical design of the application, Conceptual design of the application, Modeling relationships in the data, Entity Relationship (ER) and Extended Entity Relationship (EER) modeling concepts, Conceptual design with ER and EER modeling, Logical database design: ER to Relational Mapping, Database Application Development, Normalization of database, Integrity constraints, Tuning the database design

Labs: Generate a database application (DA) from an existing database, based on a real-world scenario, Write detailed specifications for the DA, Write data requirements for the DA Write transaction requirements for the DA, Design a conceptual model of the database application using ER and EER models, Complete logical design of the database application--ER to relational schema mapping, Tune the model using normalization, Implement the database application that includes, Fabricating substantial amount of data for the DA, Build a user interface for the A, Design an advanced application using cursors, triggers, stored procedures.

Recommended books

1. C.J. Date, (2003), an Introduction to Database Systems, 8th Edition, Pearson.
2. Conger S. (2021). Hands-on Database: An Introduction to Database Design and Development, 2nd Edition, Springer.
3. Peter Lake, Paul Crowther (auth.), (2013), Concise Guide to Databases: A Practical Introduction, 2nd Edition,
4. SatinderBal Gupta, Aditya Mittal, (2017), Introduction to DatabaseManagement System, 2nd Edition, Laxmi Publications Pvt Ltd
5. Wengrow.J, (2020), A Common-Sense Guide to Data Structures and Algorithms, 2nd Edition, Pragmatic Bookshelf.

CM-404 Mechanics (3 + 0)

Vectors: Differentiation of vectors and vector fields, Gradient, divergence and curl of a vector field, Vector integration, Applications of Green's, Stoke's and divergence theorems.

Statics: Composition of forces, equilibrium problems, moments and couples, centre of mass and gravity, friction, virtual work, flexible cables, Catenaries.

Dynamics: Galilean-Newtonian principle, inertial frames, Galilean transformations, kinematics, rectilinear motion with variable accelerations, simple harmonic motion, methods of dynamics, principles of energy and momentum, Motion of a projectile, orbital motion, moment of inertia, motion of a rigid body, plane impulsive motion Compound pendulum.

Recommended Books:

1. Chorlton, F., (1970), Mechanics, Van Nostrand, Reinhold.
2. Ghori, Q. K., (1971), Introduction to Mechanics, West Pakistan Publishing Co.
3. Kleppner D., (2013), An Introduction to Mechanics, 2nd Edition, McGraw-Hill.
4. Meirovitch L., (2007), Methods of Analytical Dynamics, 1st Edition, McGraw Hill, New York.
5. Meriam, J. L., & Kraige.L.G, (2012), Engineering mechanics: dynamics, John Wiley & Sons.

CM-406 Discrete Mathematics (3+0)

Logic: Propositions and Truth Values, Logical Connectives and Truth Tables, Tautologies and Contradictions, Logical Equivalence and Logical Implication, The Algebra of Propositions, Arguments, Formal Proof of the Validity of Arguments, Predicate Logic, Arguments in Predicate Logic

Mathematical Proof: The Nature of Proof, Axioms and Axiom Systems, Methods of Proof, Mathematical Induction

Sets: Sets and Membership, Subsets, Operations on Sets, Counting Techniques, The Algebra of Sets, Families of Sets, The Cartesian Product, Types and Typed Set Theory

Relations: Relations and Their Representations, Properties of Relations, Intersections and Unions of Relations, Equivalence Relations and Partitions, Order Relations, Hasse Diagrams, Relational Databases

Functions: Functions, Composite Functions, Injections and Surjections, Bijections and Inverse Functions, More on Cardinality, Functional Dependence and Normal Forms

Boolean Algebra: Introduction, Properties of Boolean Algebras, Boolean Functions, Switching Circuits, Logic Networks, Minimization of Boolean Expressions

Graph Theory: Introductions and types, Paths and Cycles, Isomorphism of Graphs, Planar Graphs, Directed Graphs, Trees and applications of trees

Applications of Graph Theory: Rooted Trees, Sorting, Searching Strategies, Weighted Graphs, The Shortest Path and Traveling Salesman Problems, graph colouring, Networks and Flows

Recommended Books:

1. J. Gallier, Discrete Mathematics, Springer, 2011
2. K. H. Rosen, Handbook of Discrete and Combinatorial Mathematics, 1999 Chapman and Hall/CRC
3. R. Garnier, J. Taylor, Discrete Mathematics: Proofs, Structures and Applications, CRC Press (3rd Edition), 2009
4. S. Govindarajan, A. Maheshwari, Algorithms and Discrete Applied Mathematics, Springer, 2016
5. W. Conradie, V. Goranko, Logic and Discrete Mathematics: A Concise Introduction, Wiley, 2015

Third Year

		Course No.	Course Title	Credit Hours	Course Type
YEAR - 3	SEMESTER-V	CM501	Real Analysis	3+0	Major
		CM503	Algorithm Design	2+1	Major
		CM505	Ordinary Differential Equations	3+0	Major
		CM507	Fluid Dynamics-I	3+0	Major
		CM509	Object Oriented Programming in Python	2+1	Major
			Total Credit Hours	15	
	SEMESTER-VI	CM502	Complex Analysis	3+0	Major
		CM504	Essential Software	2+1	Major
		CM506	Numerical Analysis-I	3+0	Major
		CM508	Fluid Dynamics-II	2+1	Major
		CM510	Object Oriented Programming in C/C++	3+0	Major
			Total Credit Hours	15	

Fifth Semester

CM-501 Real Analysis (3+0)

Algebra of sets; partition and equivalent classes; partially ordered sets and Axiom of Choice, Canonical decomposition of functions, Rn, n >= 1; Euclidean metric space, Completeness, Functions Convergence of sequences and completeness, Functions of several real variables; their continuity and differentiability Implicit and Inverse Function Theorems, Jacobians and emotional dependence, Taylor's Theorems, Jacobians and Minima: Language's method of undetermined multipliers, Riemann and Riemann-Stieltjes integrals, Differentiation under integral sign.

Uniform and absolute convergence of sequences and series of functions, Uniform convergence and continuity: Term by term differentiation and integration, Improper integrals and their convergence; their absolute and uniform convergence.

Recommended Books

1. Browder, A. (2012). Mathematical analysis: an introduction, 2nd Edition, Springer Science & Business Media.
2. Canuto, C., &Tabacco, A. (2015). Mathematical Analysis II (Vol. 85). Springer.
3. Johnsonbaugh, R., & Pfaffenberger, W. E. (2012). Foundations of mathematical analysis. Courier Corporation.
4. Robdera, M. A. (2011). A concise approach to mathematical analysis, 3rd Edition, Springer Science & Business Media.
5. Schröder, B. S. (2007). Mathematical analysis: a concise introduction, 2nd Edition, John Wiley & Sons.

CM-503 Algorithm Design (2+1)

Algorithm design paradigms - motivation; concepts of algorithmic efficiency; run-time analysis of algorithms, the Landau notation, Divide-and-Conquer: Structure of divide-and-conquer algorithms; example applications from Binary Search, Integer Multiplication, Nearest Neighbors. Analysis of divide-and-conquer run-time recurrence relations, Dynamic Programming, Form of dynamic programming algorithms; differences between dynamic programming and Divide-and-Conquer; example applications from: shortest path in graphs; ordering of matrix multiplications; longest common subsequence, Greedy Methods: Overall view of greedy paradigm. Example of exact optimization solution (Minimum spanning tree) and approximation solution (Integer Knapsack), Graph Searching and traversal: Pervasiveness of graph models in applications and notion of search, combinatorial search (e.g. Knight's Tour); graph traversal methods: depth-first and breadth-first search, s: does an algorithmic solution exist? does an efficient algorithmic solution exist? Models of algorithmic process and their universality: Church-Turing hypothesis, Introduction to Computability: The existence of problems with no algorithmic solution; an example and proof that a specific computational problem has no algorithmic solution, Computational Complexity: Quantification of resources used by algorithms: Time and Space; Complexity measures and Classes; Polynomial versus Non-Polynomial time complexity; the class *P* and motivation for viewing this as the set of tractable computational problems, NP-completeness, Combinatorial search and optimisation problems, informal view of the case *NP* as problems with efficient checking algorithms; approaches to tackling the question of *P = NP* - informal review of *NP*-completeness, Cook's Theorem (without proof).

Labs:

- Write programs to perform Binary Search, Integer Multiplication, and Nearest Neighbors. Analyze their run-time recurrence relations and compare the efficiencies.
- Implement algorithms to find the shortest path in graphs (e.g., Dijkstra's or Floyd-Warshall), optimize the ordering of matrix multiplications, and find the longest common subsequence. Compare these with corresponding divide-and-conquer approaches.
- Implement the Minimum Spanning Tree (using Prim's or Kruskal's algorithm) and solve the Integer Knapsack problem using a greedy approximation approach. Analyze the exactness and efficiency of these algorithms.
- Implement depth-first search (DFS) and breadth-first search (BFS) algorithms. Apply these methods to solve problems like the Knight's Tour and explore their efficiencies in different scenarios.
- Implement algorithms for combinatorial search and optimization problems. Conduct experiments to classify problems into P and NP, and perform an informal review of NP-completeness with examples such as the Cook's Theorem.

Recommended Books

1. Thomas H C, Charles E L, Ronald L R, & Clifford S., (2009), Introduction to Algorithms, 3rd Edition, MIT Press
2. Jon K., & Eva T., (2005), Algorithm Design, 1st Edition, Pearson.
3. M.A. Weiss., (1993), Data Structures and Algorithm Analysis in ADAl, Benjamin Cummings Publishing.
4. Michael T. G., & Roberto,. (2016). Algorithm Design and Applications, 1st Edition, Wiley.
5. P.E. Dunne., (1991) Computability Theory - concepts and applications, 3rd Edition, Ellis Horwood Ltd.

CM-505 Ordinary Differential Equations (3+0)

The course must cover linear equations of the first order; linear equations with constant coefficients; the general linear equation; Modeling with higher-order, variation of parameters; undetermined coefficients; linear independence; the Wronskian; Solving Higher order Differential equations by using Reduction of Order, With one known solution. Higher order differential equation which do not contain x directly, higher order equations which do not contain y directly, solution of higher order differential equations by changing independent variable, Laplace transforms; existence and uniqueness of solutions; solution by power series; Modelling of Electrical Circuits. Systems of Differential Equations, oscillation and comparison theorems, Laplace transform, and systems of linear first-order differential equations, transform methods.

Recommended Books

1. Brannan, J. R., & Boyce, W. E. (2015). Differential equations: An introduction to modern methods and applications, 3rd Edition, John Wiley & Sons.
2. Hassani, S. (2013). Mathematical physics: a modern introduction to its foundations,2nd Edition, Springer Science & Business Media.
3. Kreyszig, E. (2019). Advanced Engineering Mathematics, 10th Edition, John Wiley & Sons.
4. O'neil, P. V. (2017). Advanced engineering mathematics, 8th Edition, Cengage learning.
5. Zill, D. G. (2016). Differential equations with boundary-value problems, 9th Edition, Cengage Learning.

CM-507 Fluid Dynamics-I (3+0)

Introduction to fluid mechanics, real and ideal fluids, steady, unsteady, uniform, non-uniform, one, two, three dimensional, compressible, incompressible, rotational, irrotational flows etc., Differentiation following the motion of fluid particles, Langrangian and Eulerian methods, Equations of motion and continuity for incompressible inviscid fluids, Velocity potentials and stokes stream functions Properties of stream function, Bernoulli's equation with application to flow along curve paths, Kinetic energy: kinetic induced by a moving body, induced mass, Sources, sinks, doubles in 2- and 3- dimensions, limiting stream lines, Images and rigid planes.

Recommended Books

1. Bernard, P. S. (2015). Fluid Dynamics, 5th Edition, Cambridge University Press.
2. Frank, M. (2017). Fluid Mechanics, 4th Edition, McGraw-Hill.
3. Kambe, T. (2007). Elementary fluid mechanics, World Scientific.
4. Rieutord, M. (2014). Fluid dynamics: an introduction, Springer.
5. Young, D. F., Munson, B. R., Okiishi, T. H., &Huebsch, W. W. (2010). A brief introduction to fluid mechanics. 5th Edition, John Wiley & Sons.

CM-509 Object Oriented Programming in Python (2+1)

Intro and Overview, Principle of Software Engineering and Reusing and Extending Code, Review of Fundamentals of Procedural Programming, Objects, Data Abstraction, Information Hiding & Encapsulation, Constructors, destructors, and object creation, Name space and references, Class Methods, Methods Overloading, Inheritance, Polymorphism, Abstract Classes, Exceptions, Exception Handling, Templates, Example translations of concepts in Python to Java, Practical Example: Data Science Classes, Student final project presentations.

Labs: Relevant problem on each topic of Python Programming using Python

Recommended books

1. Ayeva, K., & Kasampalis, S. (2018). Mastering Python Design Patterns: A guide to creating smart, efficient, and reusable software, 2nd Edition, Packt Publishing.
2. Charles R. Severance. (2016). Python for Everybody: Exploring Data in Python 3, University of Michigan
3. Goldwasser, M. H., &Letscher, D. (2008). Object-oriented Programming in Python, Pearson Prentice Hall.
4. Lott, S. F. (2019). Mastering Object-Oriented Python: Build powerful applications with reusable code using OOP design patterns and Python 3.7, 2nd Edition: Packt Publishing.
5. Lott, S. F., & Phillips, D. (2021). Python Object-Oriented Programming: Build robust and maintainable object-oriented Python applications and libraries, 4th Edition: Packt Publishing.

Sixth Semester

CM-502 Complex Analysis (3+0)

Complex numbers and functions, complex limits and differentiability, elementary examples, analytic functions and power series, complex line integral, Cauchy's theorem and the Cauchy integral formula, Taylor's theorem, zeros of homomorphic functions, Schwarz Lemma, automorphisms of the ball, the plane and Riemann sphere, isolated singularities and their classifications, Laurent series, the Residue theorem, calculation of definite integrals and evaluation of infinite series using residues, Riemann Mapping Theorem.

Recommended Books

1. Alpay, D. (2015). An Advanced Complex Analysis Problem Book, 1st Edition, Springer.
2. Boas, R. P. (2020). Invitation to complex analysis (Vol. 20). American Mathematical Soc.
3. Marsden, J. E., Hoffman, M. J., & Marsden, T. (1999). Basic complex analysis, 3rd Edition, Macmillan.
4. Mathews, J., & Howell, R. (2012). Complex analysis for mathematics and engineering, 3rd Edition, Jones & Bartlett Publishers.
5. Zill, D. G., & Shanahan, P. D. (2013). Complex analysis: A first course with applications. 3rd Edition, Jones & Bartlett Publishers.

CM504 Essential Software (2+1)

Working with the MATLAB user interface, entering commands and creating variables, analyzing vectors and matrices, visualizing vector and matrix data, working with data files, working with data types, automating commands with scripts, writing programs with branching and loops, writing functions
Labs: Relevant problems on each topic of theory using MATLAB software

Recommended Books

1. Attaway, S. (2013). Matlab: a practical introduction to programming and problem solving, 3rd Edition. Butterworth-Heinemann.
2. Gilat, A. (2004). MATLAB: an introduction with applications, John Wiley & Sons.
3. Kattan, P. I. (2008). Matlab for Beginners: A gentle approach, 3rd Edition, Petra books.
4. Valentine, D. T., & Hahn, B. (2016). Essential MATLAB for engineers and scientists, Academic Press.

CM-506 NUMERICAL ANALYSIS-I (3+0)

Preliminaries of Computing, Error analysis, Numerical Solution of Nonlinear Equation: Bisection method, fixed-point iteration, Newton's method, Secant Method, Interpolation and polynomial Approximation: Newton's Method, Lagrange Polynomial, Divided differences, Hermite Interpolation, Spline Interpolation., Direct Method for Solving System of Linear Equations: LU decomposition method, numerical factorizations, Eigen value problems, Approximating Eigen values, Power method, House holder's method, Indirect Method for Solving System of Linear Equations: Gauss Siedel Method, Jacobi's Method, Relaxation Method, Numerical Integration: Trapezoidal Rule, Simpsons Rules, Gaussian quadrature method, Numerical solution of Ordinary Differential Equation: Euler Method, Modified Euler, Taylor's series, Runge-Kutta method, Software/ Language: Relevant problem on each topic of Numerical Analysis using software.

Recommended Books

1. Burden, R. L., Faires, J. D., & Burden, A. M. (2015). Numerical Analysis, Cengage Learning.
2. Epperson, J. F. (2013). An Introduction to Numerical Methods and Analysis, 3rd Edition, Wiley.
3. Gerald, C. F. (2004). Applied numerical analysis, 5th Edition, Pearson Education India.
4. Mathews, J. H., & Fink, K. D. (2004). Numerical methods using MATLAB (Vol. 4), Pearson prentice hall Upper Saddle River, NJ.
5. Süli, E., &Mayers, D. F. (2003). An introduction to numerical analysis, Cambridge university press.

CM-508 FLUID DYNAMICS-II (3+0)

Introduction of incompressible viscous fluid, Navier-Stokes and energy equations for viscous incompressible fluids, Dynamical similarity and Reynolds number, Steady one-dimensional flow of viscous fluid, Two-dimensional flow and small disturbance theory, Radial flow between plane walls, Open channel flow, axi-symmetric jets, Inviscid compressible flow, energy equation and compressibility effect, Unsteady one-dimensional flow, Equations of motion for some specific types of flow and ensuring solutions, gas dynamics.

Recommended Books

1. Cengel, Y., & Cimbala, J. (2013). EBOOK: Fluid Mechanics Fundamentals and Applications (SI units). 3rd Edition, McGraw Hill.
2. E. George (2015), Analytical Fluid Dynamics. 3rd Edition, CRC Press.
3. Kundu, P. K., Cohen, I. M., & Dowling, D. R. (2015). Fluid mechanics. 4th Edition, Academic press.
4. Spurk, J., &Aksel, N. (2008). Fluid mechanics. 2nd Edition, Springer Science & Business Media.
5. White, F. M., &Majdalani, J. (2006). Viscous fluid flow (Vol. 3, pp. 433-434). 2nd Edition, McGraw-Hill. New York.

CM-510 OBJECT ORIENTED PROGRAMMING C/C++ (2+1)

Introduction to basic C++ Programming (variables, data types, conditions, operators, loops, functions etc.), What is an Object, Benefits of OOP; Object Oriented Environment; Class Object; Object Oriented Programming (from C to C++); Constructor; Destructor; Program Style; Functions; Inheritance, I/O streams, Overloading operations, Programming Examples.

Labs: Relevant problem on each topic of theory using C++ language.

Recommended Books

1. Das, A. Object Oriented Programming With C++: Vikas Publishing House.
2. Deitel, P. J., &Deitel, H. M. (2017*).* C++ how to Program, 4th Edition, Pearson.
3. Doyle, B. (2013). C# Programming: From Problem Analysis to Program Design, Cengage Learning.
4. Malik, D. S. (2017). C++ Programming: From Problem Analysis to Program Design, 8th Edition, Cengage Learning.
5. Weisfeld, M. (2019*).* The Object-Oriented Thought Process, 5th Edition, Addison Wesley Professional.

Fourth Year

		Course No.	Course Title	Credit Hours	Course Type
YEAR - 4	**SEMESTER - VII**	CM601	Numerical Analysis-II	3+0	Major / (Opt)
		CM603	Abstract Algebra	3+0	Major / (Opt)
			Optional-I	3+0	Major / (Opt)
			Optional-II	3+0	Major / (Opt)
			Optional-III	3+0	Major / (Opt)
		CM600.1	Field Experience / Internship	0+3	Major / (Opt)
			Total Credit Hours	18	
	SEMESTER - VIII	CM602	Partial Differential Equations	3+0	Major / (Opt)
		CM604	Stochastic Processes	3+0	Major / (Opt)
			Optional-I	3+0	Major / (Opt)
			Optional-II	3+0	Major / (Opt)
			Optional-III	3+0	Major / (Opt)
		CM600.2	Capstone Project	0+3	Major / (Opt)
			Total Credit Hours	18	

Seventh Semester

CM-601 Numerical Analysis II (3+0)

Difference Equations, formation, Solutions and applications, Initial Value Problems (ODE-IVPs): Analytic Solutions of Linear ODE-IVP, Taylor series based and Runge-Kutta methods, Multi-step (predictor-corrector) approaches; Milnes Method, Adams Method, stability of ODE-IVP solvers, choice of step size and stability envelops, stiffness and variable step, size implementation, Introduction to the solutions of differential algebraic equations (DAEs), Boundary Value Problems (ODE-BVPs): Single shooting method, Finite difference Method for solving ODE-BVPs. Orthogonal Collocations method for solving ODE-BVPs, least square approximation, Gauss Newton Method, Method of least squares for solving ODE-BVP, Gelarkin's method and generic equation forms arising in problem discretization, Errors in Discretization, Solving Partial Differential Equation: Problem Discretization Using Approximation Theory, Weierstrass theorem and polynomial approximations, Taylor series approximation, Newton's Method for solving non-linear algebraic equation as an application of multivariable Taylor series, Introduction to polynomial interpolation, polynomial and function interpolations, Boundary Value Problems (PDE-BVPs): Finite difference Method for solving PDE-BVPs; Heat Equation, wave Equation, Laplace Equation.
Software/ Language: Relevant problem on each topic of Numerical Analysis using software.

Recommended Books

1. Ackleh, A. S., Allen, E. J., Kearfott, R. B., &Seshaiyer, P. (2009). Classical and modern numerical analysis: theory, methods and practice, Crc Press.
2. Argyros, I. K., Cho, Y. J., &Hilout, S. (2012). Numerical methods for equations and its applications, CRC Press.
3. Butcher, J. C. (2004). Numerical Methods for Ordinary Differential Equations 4th Edition, Wiley.
4. Isaacson, E., & Keller, H. B. (2012). Analysis of numerical methods, Courier Corporation.
5. Linz, P. (2019). Theoretical Numerical Analysis, 3rd Edition, Dover Publications.

CM-603 Abstract Algebra (3+0)

Group Theory: Groups, Subgroups, cyclic groups, normal subgroups, quotient groups, examples. Homomorphism of groups, the fundamental theorem of homorphism, Isomorphism of groups, the isomorphism theorems, Direct product of groups, Internal and external direct products, Finitely generated Abelian groups, Generators and torsion, The fundamental theorem of F.G. Abelian groups, Applications, Group action on a fixed sets and isotropy subgroups, orbits, Sylow theorems, p-groups, First, second and third Sylow theorems, Application of the Sylow theory,
RING THEORY: Rings, Integral domain, The characteristic of a ring, Fermat's and group algebra, Quotient rings, ideals, maximal and prime ideals, Ring homomorphism: Definition, properties, prime fields, Fundamental theorems of homorphism and isomorphism, Polynomial rings, the evaluation modules, ideals, Isomorphism theorem, Near rings, subnear rings, near ring modules, isomorphism theorem.

Recommended Books

1. Fraleigh, J. B., & Katz, V. J. (2003). A First Course in Abstract Algebra, 7th Edition, Pearson.
2. Landin, J. (2012). An Introduction to Algebraic Structures, Dover Publications.
3. Nicholson, W. K. (2012). Introduction to Abstract Algebra, 6thEdition, Wiley.
4. Pinter, C. C. (2010). A Book of Abstract Algebra: Second Edition, Dover Publications.
5. Rauf Querashi M.A., Foundation of Abstract Algebra, 1st Edition, 2018.
6. Warner, S. (2019). Abstract Algebra for Beginners: A Rigorous Introduction to Groups, Rings, Fields, Vector Spaces, Modules, Substructures, Homomorphisms, Quotients, Permutations, Group Actions, Polynomials, and Galois Theory, Get 800.

CM-600.1 Field Experience / Internship (0+3)

Students are required to complete a supervised field experience or internship at an appropriate organization. This practical component provides students with the opportunity to apply their computational mathematics knowledge to real-world challenges, develop professional competencies, and gain valuable industry exposure.

Eight Semester

CM-602 Partial Differential Equations (3+0)

Ordinary differential equation in more than one variable, partial differential equation (PDEs) of first order, Nonlinear PDEs of first order and its application, partial differential equation with variable coefficients reducible to constant coefficients, Second order Partial differential equation with variable coefficients, mathematical modeling of heat, Laplace and wave equation and classification of second order PDEs, boundary and initial conditions, reduction to canonical form and is solutions, Techniques of separation of variable for the solution of PDEs with special emphasis on Heat, Laplace and wave equation and Laplace transform, Difference equations, Elliptic equations. Dirichlet's problem, harmonic functions, the maximum principle, Poisson's formula, Green functions and integral representations, The heat kernel, Partial differential equations in higher dimensions.

Recommended Books

1. Haberman, R. (2018). Applied Partial Differential Equations with Fourier series and Boundary Value Problems (Classic Version), Pearson.
2. Jang, C. L. (2011). Partial Differential Equations: Theory, Analysis and Applications, 6th Edition, Nova Science Publishers.
3. Picard, R., & McGhee, D. (2011). Partial Differential Equations: A unified Hilbert Space Approach, De Gruyter.
4. Pinchover, Y., & Rubinstein, J. (2005). An Introduction to Partial Differential Equations, 1st Edition, Cambridge University Press.
5. Pinsky, M. A. (2011). Partial Differential Equations and Boundary-Value Problems with Applications, American Mathematical Society.
6. Strauss, W. A. (2007). Partial differential equations: An introduction, John Wiley & Sons.

CM-604 Stochastic Processes (3+0)

Stochastic Modeling, Probability Review, The Major Discrete and Continuous Distributions, Conditional Probability and Conditional Expectation, Conditioning on a Continuous Random Variable, Martingales, Stochastic Processes, Markov Chains: Chapman-Kolmogorov Equations, Classification of States of a Markov Chain, Long-Run, Properties of Markov Chains, First Passage Times, Absorbing States, Markov Decision Processes, Optimal Policies, Policy Improvement Algorithm for Finding Optimal Policies, Discounted Cost Criterion, Poisson Processes, The Poisson Distribution and the Poisson Process, The Law of Rare Events, Distributions Associated with the Poisson Process, The Uniform Distribution and Poisson Processes, Spatial Poisson Processes, Compound and Marked Poisson Processes., Continuous Time Markov Chains: Pure Birth Processes, Pure Death Processes, Birth and Death Processes, The Limiting Behavior of Birth and Death Processes, Birth and Death Processes with Absorbing States, Finite State Continuous Time Markov Chains.

Recommended Books

1. Taylor H.M., Karlin S. (1998), An Introduction to Stochastic Modeling, 3rd Edition, Academic Press.
2. Karlin S., Pinsky M. (2010). An Introduction to Stochastic Modeling, 4th Edition, Academic Press.
3. Cinlar, E. (2013). Introduction to Stochastic Processes, Dover Publications, IncorporatEdition
4. Kao, E. P. (2019). An introduction to stochastic processes, Courier Dover Publications.
5. Lindgren G. (2012). Stationary Stochastic Processes Theory and Applications, CRC Press.
6. Jones P.W., Smith P. (2017) Stochastic Processes, An Introduction, 3rdEdition, Chapman and Hall/CRC.

CM-600.2 Capstone Project (0+3)

Students will undertake an in-depth capstone project to apply their computational mathematics expertise to a complex problem or innovative solution. This culminating experience involves rigorous research, development, and documentation, culminating in a comprehensive report and presentation. The project is designed to foster critical thinking, problem-solving, and the ability to translate theoretical knowledge into practical applications.

Elective Courses

CM-641 Modelling & Simulation (3+0)

Introduction to modelling: Introduction, model: approximation of real world events, history of modelling and simulation, properties of useful model, model development process, static and dynamic models, model selection, model validation, ethics in modeling, Introduction to systems: System boundary, classification of systems, linear systems, mathematical point of view of linear systems, time varying vs time-interval systems, continuous time and discrete time systems, deterministic vs stochastic systems, System modelling: Need of system modelling, classification od models: mathematical vs descriptive models, static vs dynamic models, deterministic vs stochastic models, continuous discrete models, Mathematical modelling of physical systems, model order reduction, Introduction to simulation: Advantages of simulations, applications of simulation, Numerical methods for simulation, Nonlinear and Chaotic systems: Linear vs nonlinear systems, types of nonlinearities, Introduction to chaotic systems, first order continuous-time systems, bifurcations, second order systems, Discrete Event Modelling and Simulation: Introduction, some important definitions, discrete event system simulation, input data modelling, random number generation, chi-square test, Training on Lab View software etc.

Recommended Books

1. Birta, L. G., & Arbez, G. (2013). Modelling and simulation. London: Springer.
2. Chaturvedi, D. K. (2017). Modeling and simulation of systems using MATLAB® and Simulink®. 1st Edition, CRC press.
3. Giordano, F. R., Fox, W. P., & Horton, S. B. (2013). A first course in mathematical modeling. 5th Edition, Cengage Learning.
4. Mooney, D. D., & Swift, R. J. (2021). A course in mathematical modeling (Vol. 13). American Mathematical Society.
5. Velten, K. (2009). Mathematical modeling and simulation: introduction for scientists and engineers. John Wiley & Sons.

CM-642 Cryptography (3+0)

Background and overview: One-time encryption using stream ciphers, Semantic security, block Cipher and its principles, pseudorandom functions, Chosen plaintext and cipher text security and modes of operation, DES and AES block cipher, Message integrity, Hash function, CBC-MAC, HMAC, PMAC and CW-MAC, Collision resistant hashing., Classical Encryption Techniques: Symmetric and asymmetric cipher models, Substitution and Transposition techniques, Authenticated encryption: CCM, GCM, TLS and IPSec, Key derivation function, Deterministic encryption, non-expanding encryption and format preserving encryption, fully homomorphic encryption, Basic Key exchange: Diffie-Hellman, RSA and Merkle puzzles, Computational number theory, Number theoretic hardness assumptions, Authenticated and TLS key exchange, Public Key Cryptography: Principles of Public Key Cryptosystem, Public key encryption, Trapdoor permutation and RSA, The ElGamal system and variants, Digital Signatures and certificate, Identification Protocols, Authentication Protocols, Zero Knowledge Protocols and proof of knowledge, Privacy Mechanism: Group signatures and credential systems, Private information retrieval and oblivious transfer, Two Party Computations: Yao's protocol and its applications, Elliptic curve cryptography (ECC), Quantum computing, Pairing-based cryptography, Lattice based cryptography, Software/ Language: Usage of different Encryption and Decryption cipher, Symmetric and asymmetric cipher models, Different private and public key cryptosystem algorithms, RSA algorithms, Different protocols, Digital signature, Yao's protocol, Elliptic curve cryptography (ECC).

Recommended Books

1. Katz, J., &Lindell, Y. (2014). Introduction to Modern Cryptography, Second Edition, Taylor & Francis.
2. Lee, D. T., Shieh, S. P., &Tygar, D. (2005). Computer Security in the 21st Century, Springer US.
3. Paar, C., &Pelzl, J. (2009). Understanding cryptography: a textbook for students and practitioners, Springer Science & Business Media.
4. Stallings, W. (2016). Cryptography and Network Security: Principles and Practice, 2ndEdition, Pearson Education.
5. Stanoyevitch, A. (2010). Introduction to Cryptography with Mathematical Foundations and Computer Implementations, 2nd Edition, Taylor & Francis.

CM-643 Perturbation Methods (3+0)

Dimensional analysis, Gauge functions, asymptotic series, asymptotic expansions and sequences. Quadratic equations, cubic equations, higher order equations, transcendental equations. Expansion of integral, Integration by parts, Laplace's method, the method of stationary phase and the method of steepest descent, Straightforward expansion, exact solution, the Lindstedt- Poincare technique, method of renormalization, method of multiple scales, variation of parameters and method of averaging. Linear Damped Oscillator, Self-Excited Oscillator, System with Quadratic and Cubic Nonlinearities, Duffing Equation, The Mathieu Equations.

Recommended Books

1. Bender, C. M., &Orszag, S. A. (2013). Advanced Mathematical Methods for Scientists and Engineers I: Asymptotic Methods and Perturbation Theory, Springer Science & Business Media.
2. Kevorkian, J., & Cole, J. D. (2013). Perturbation Methods in Applied Mathematics, Springer New York.
3. Nayfeh, A. H. (2008). Perturbation methods, 2nd Edition, John Wiley & Sons.
4. Nayfeh, A. H. (2011). Introduction to Perturbation Techniques, 3rd Edition, Wiley.
5. Sanders, J. A., &Verhulst, F. (2013). Averaging Methods in Nonlinear Dynamical Systems: Springer New York.
6. Shivamoggi, B. (2002*).* Perturbation Methods for Differential Equations, Birkhäuser Boston.

CM-644 Fuzzy Mathematics (3+0)

Set Theory: Crisp set theory, Relation between sets, concept of a fuzzy set, relation between fuzzy sets, operations on fuzzy sets, properties of standard operations, Crisp vs Fuzzy types of fuzzy sets, membership functions, Fuzzy Relations: Relations, operation on fuzzy relations, α-cuts of a fuzzy relation, composition of fuzzy relations, projections of fuzzy relations, Propositional Logic: Introduction, syntax, semantics, semantic properties and properties satisfied by the connectives, inference rules and derivation.
Predicate Logic: Introduction, syntax, semantics, semantic properties and properties satisfied by the connectives, inference rules and derivation, Boolean Algebra: Introduction, Boolean algebra, identification, complete disjunctive normal form (CDNF), Fuzzy Mathematics: Addition, Subtraction, Multiplication and Division, Derivatives and Integration in Fuzzy Sense, Switching Functions and switching circuits: Introduction, switching functions, disjunctive normal form, switching circuits, relation between switching functions and switching circuits, equivalence of circuits, simplification of circuits, Fuzzy Methods in Decision Making: Introduction to decision making, Measures of Dissonance, Measures of confusion, Measures of Non-specificity, Uncertainty and information, Fuzzy methods in decision making, Fuzzy numerical analysis and other applications.

Recommended Books

1. Buckley, J. J., &Eslami, E. (2013). An Introduction to Fuzzy Logic and Fuzzy Sets, 2nd Edition, Physica.
2. Dubois, D., &Prade, H. (2012). Fundamentals of Fuzzy Sets, Springer US.
3. Klir, G. J., & Yuan, B. (2015). Fuzzy Sets and Fuzzy Logic: Theory and Applications, Pearson.
4. Lawry, J., Miranda, E., Bugarin, A., Li, S., Gil, M. A., Grzegorzewski, P., &Hryniewicz, O. (2007). *Soft* Methods for Integrated Uncertainty Modelling, Springer Berlin Heidelberg.
5. Zimmermann, H. J. (2013). Fuzzy Set Theory and Its Applications, Springer Netherlands.

CM-645 Operations Research-I (3+0)

Introduction to operations research, the Origins and applications of Operations Research, System Modeling Principles, Linear programming, the Linear Programming Model, The Art of Problem Formulation, Graphical Solution of Linear Programming Problems, Preparation for the Simplex Method, The Simplex Method, Initial Solutions for General Constraints, Two-phase simplex method and Big-M technique, Duality and Sensitivity Analysis, Primal-Dual Relationship, The Dual Simplex Method, Parametric Linear Programming, The Upper Bound Technique, Revised Simplex method and Computational Efficiency, Guide to Software Tools. The Transportation Problem, a Streamlined Simplex Method for the Transportation Problem, The Assignment Problem, Hungarian method. Network optimization models, The Shortest-Path Problem, The Minimum Spanning, Tree Problem, The Maximum Flow Problem, The Minimum Cost Flow Problem, The Network Simplex Method.

Recommended Books

1. Ficken, F. A. (2015). The simplex method of linear programming, 2nd Edition, Courier Dover Publications.
2. Hillier, F., & Lieberman, G. (2010). Introduction to Operations Research with Student Access Card, 9thEdition, McGraw-Hill Science
3. Maros, I. (2012). Computational Techniques of the Simplex Method (Vol. 61), Springer Science & Business Media.
4. Murthy, P. R. (2005). Operations research (linear programming). bohem press.
5. Taha, H. A. (2011). Operations research: an introduction (Vol. 790), Pearson/Prentice Hall.

CM-646 Operations Research-II (3+0)

Multiple Objective LP Problems Goal Programming (Pre-emptive, Non pre-emptive), Integer Programming, Binary Integer Programming (BIP) Applications, Use of Binary Auxiliary Variables, Branch and Bound Technique for BIP, Mixed Integer Programming (MIP) Branch and Bound Technique for MIP, Introduction to Meta Heuristics, Tabu Search, Simulated Annealing, Genetic Algorithm, Game Theory Two Person Zero Sum games, Two Person Constant Sum games, Using LP for Solving Games with Mix Strategies, Dual LP for Column Player Strategies, Prisoners Dilemma Problems, Decision Analysis, Decision Making under Uncertainty, Expected Monetary Value Criterion Value of Perfect Information, Decision Making with Experimentation, Value of Information, Posterior Probabilities Utility Theory in Decision Analysis, Developing Risk Profiles, Simulation Applications of Monte Carlo Simulation Models, Queuing Theory Queuing Models with multiple servers, Simulation Models for Queuing, Data Envelopment Analysis (DEA), Inventory Management Economic Order Quantity (EOQ) Inventory Model, Deterministic Periodic-Review Inventory Model, Deterministic Continuous-Review Inventory Model, Stochastic Continuous-Review Inventory Model, Aggregation Inventory Models, Forecasting Models, Time Series Models, Exponential Smoothing, Trend Models, Seasonal Models, Forecasting Errors, Tracking Signals in Forecast.

Recommended Books

1. Antunes, C. H., Alves, M. J., &Clímaco, J. (2016). Multi-objective linear and integer programming. Berlin, Springer.
2. DinhThe Luc. (2016). Multi- objective linear programming: an introduction, Springer International Publishing.
3. Nag, B., Hillier, F. S., Lieberman, G. J., &Basu, P. (2017). Introduction to Operations Research, 10th Edition, McGraw Hill.
4. Eiselt, H. A., Sandblom, C. L., &Sandblom, C. L. (2007). Linear programming and its applications. Berlin, Springer.
5. Tadelis, S. (2013). Game theory: an introduction, 3rd Edition, Princeton university press.

CM-647 Computational Fluid Dynamics – I (2+1)

Introduction: Typical partial differential equations in fluid dynamics, types of second order equations, well posed problems, properties of linear and Quasilinear equations, physical characters of subsonic and supersonic flows, second order wave equations, system of first order equations, weak solutions, Finite Difference and Finite Volume Discretization: Finite difference discretization, discretization of derivatives, consistency, convergence and stability, finite volume discretization, face area and cell volume, Equation of Parabolic Type: Finite difference scheme for heat conduction equation, Crank-Nicholson implicit scheme, analogy with schemes for ordinary differential equations, a note on implicit methods, Leap-frog and DuFrot-Frankel schemes, operator notation, the Alternating Direction Implicit (ADI) method, Equation of Hyperbolic Type: Explicit scheme, Lax-Wendroff scheme and variants, implicit schemes, more on upwind schemes, scalar conservation law: Lax-Wenderoff and related schemes, hyperbolic system of conservation laws, second-order wave equation, method of characteristics for second-order hyperbolic equations, model convection-diffusion equation, Equation of Elliptic Type: The Laplace equation in two dimension, iterative methods for solution of linear algebraic systems, solution of the Penta diagonal system, approximate factorization schemes, grid generation example, body-fitted grid generation using elliptic-type equations some observations of AF schemes, multi-grid method, Equation of Mixed Elliptic-Hyperbolic Type: Tricomi equation, transonic computations based on TSP model,

Labs: Usage of partial differential equations in fluid dynamics, solution of Quasilinear equations, Discretization of face area and cell volume, Lax-Wendroff scheme and its variants, Method of characteristics for second-order hyperbolic equations, The Laplace equation, TSP model.

Recommended Books

1. Emanuel, G. (2000). Analytical fluid dynamics. 2nd Edition, CRC press.
2. Tu, J., Yeoh, G. H., & Liu, C. (2018). Computational fluid dynamics: a practical approach. Butterworth-Heinemann.
3. Wendt, J. F. (Edition). (2008). Computational fluid dynamics: an introduction, 3rd Edition, Springer Science & Business Media.
4. White, F. M., &Majdalani, J. (2006). Viscous fluid flow, 2nd Edition, New York: McGraw-Hill.
5. Zikanov, O. (2019). Essential computational fluid dynamics, John Wiley & Sons.

CM-648 Computational Fluid Dynamics-II (2+1)

Introduction: Basic conservation principle, unsteady Navier-stokes equations in integral form, Navier-stokes equations in differential form, Euler equations for inviscid flows, full potential equation, inviscid incompressible irrotational flow, Grid Generation: Introduction, co-ordinate transformation, differential equation methods, algebraic methods, transfinite interpolation methods, unstructured grid generation, mesh adaptation, Inviscid Incompressible flow: Introduction, potential flow problem, panel methods, panel methods for subsonic and supersonic flows, Inviscid Compressible flow: Introduction, small-perturbation flow, numerical solution of the full potential equation, full potential solution in generalized coordinates, Euler model, computed examples based on Euler model, supersonic flow field computation, Viscous Incompressible Flow: Introduction, Incompressible flow computation, stream-function vorticity approach, primitive variable approach, The MAC method, solution scheme, Case study: separated flow in a constructed channel.

Viscous Compressible Flow: Introduction, dynamic similarity, Reynolds Averaged Compressible Navier-stokes) RANS equations, Turbulence modelling, basic computational methods for compressible flow, finite volume computation in 2D, solution procedure, computational results.

Labs: Solving unsteady Navier-stokes equations, Inviscid incompressible irrotational flow, Numerical solution of the full potential equation, Euler model, Incompressible flow algorithms, Reynolds Averaged Compressible Navier-stokes) RANS equations, Finite volume computation in 2D, Turbulence modelling.

Recommended Books

1. Emanuel, G. (2000). Analytical fluid dynamics, 2nd Edition, CRC press.
2. Tu, J., Yeoh, G. H., & Liu, C. (2018). Computational fluid dynamics: a practical approach. Butterworth-Heinemann.
3. Wendt, J. F. (Edition). (2008). Computational fluid dynamics: an introduction, 3rd Edition, Springer Science & Business Media.
4. White, F. M., &Majdalani, J. (2006). Viscous fluid flow, 2ndEdition, New York: McGraw-Hill.
5. Zikanov, O. (2019). Essential computational fluid dynamics, John Wiley & Sons.

CM-649 Big Data Analytics-I (3+0)

Overview of MATLAB interface and environment, Basic operations and syntax, Variables, data types, and arrays, Importing and exporting data, Summarize the central tendency, dispersion, and shape of the dataset.
Visualize data distributions and relationships among variables, Introduction to plotting functions (plot, scatter, bar, etc.), Functions: scatter, histogram, boxplot, heatmap, scatter3
Customizing plots (titles, labels, legends), Data cleaning techniques (handling missing values), Data Normalization, Test assumptions about populations and compare groups, Functions, t-test, anova1, chi2, Hypothesis testing (t-tests, chi-square tests) for inference of multidimensional data, Trend Analysis Test (MK test, MMK).
Satellite Data, Ground-Based Observations, Remote sensing gridded Data, Temporal and Spatial Resolution, Understanding time series data, Time series plotting and visualization.
Moving averages and smoothing techniques, Pearson's correlation coefficient, Partial correlation, Linear regression (LR), generalized linear models (glm).

Recommended Books

1. EMC Education Services. (2015). Data science and big data analytics: discovering, analyzing, visualizing and presenting data, Wiley.
2. Ghavami, P. (2019). Big data analytics methods. In Big Data Analytics Methods, 1st Edition,DeGruyter.
3. Hair, J. F. (2011). Multivariate data analysis: An overview. International encyclopedia of statistical science, 7th Edition, Pearson.,
4. Wilks, D. S. (2011). Statistical methods in the atmospheric sciences (Vol. 100),Academic press.
5. Zhang, Y. (2010). New advances in machine learning. Pearson.

CM-650 Big Data Analytics II (3+0)

Logistic regression, Model relationships between variables and make predictions, Autocorrelation and seasonality analysis, Group similar data points to identify patterns and structures, Advanced visualization techniques (heatmaps, 3D plots) Arc GIS,
Multivariate Analysis: Identifies underlying relationships between observed variables by modeling them as linear combinations of potential latent variables, Cluster Analysis, Factor Analysis, Principal Component Analysis, Canonical Correlation Analysis (CCA), Analyzes the relationships between two multivariate datasets.
Generalized Additive Models (GAM), Time Series Forecasting, ARIMA Models, Fits autoregressive integrated moving average models to time series data, Neural Networks
Approaches to Analyzing Big Data, The Two Domains of Big, Data Analytics, Introduction to Apache Hadoop and MapReduce, Apache Spark, Spark programming, (Python and PySpark), Spark - Resilient Distributed Dataset (RDDs), Spark - RDDs, Data Frames, Spark SQL, PySpark, NumPy, SciPy, Code Optimization, Cluster Configurations.

Recommended Books

1. EMC Education Services. (2015). Data science and big data analytics: discovering, analyzing, visualizing and presenting data, 2nd Edition, Wiley.
2. Ghavami, P. (2019). Big data analytics methods. In Big Data Analytics Methods, De Gruyter.
3. Hair, J. F. (2011). Multivariate data analysis: An overview. International encyclopedia of statistical science, Pearson.
4. Wilks, D. S. (2011). Statistical methods in the atmospheric sciences (Vol. 100), Academic press.
5. Zhang, Y. (2010). New advances in machine learning. Pearson.

CM-651 Machine Learning (3+0)

Machine learning basics, Logistic regression, perceptron, ANN, other ML models (e.g. decision tree and Random Forest), Deep learning, applications in computer vision, NLP, robotics. Logistic regression, Naive Bayes, Model selection, Support vector Machine, Tree Models, Model Selection (Practical Consideration, Boosting, Unsupervised Learning: Clustering, Unsupervised Learning: Principal Component Analysis, Supervised Learning and Linear Regression, Algorithms and Complexity, Intelligent Robotics, Machine Learning and Intelligent Data Analysis, Robot vision, Reinforcement Learning.

Recommended Books

1. Barber, D. (2012). Bayesian reasoning and machine learning, Cambridge University Press.
2. Bishop, C. M., & Nasrabadi, N. M. (2006). Pattern recognition and machine learning, Springer.
3. Duda, R. O., & Hart, P. E. (2006).Pattern classification, 1st Edition, John Wiley & Sons.
4. Flach, P. (2012). Machine learning: the art and science of algorithms that make sense of data, Cambridge university press.
5. Rogers, S., & Girolami, M. (2016). A first course in machine learning. 2nd Edition, Chapman and Hall/CRC.

CM-652 Artificial Intelligence (3+0)

Review of Algorithms & Data Structures, An introduction to the basic principles, techniques, and applications of Artificial Intelligence, Perception and intelligence, Coverage includes knowledge representation, logic, inference, problem solving, search algorithms, game theory, perception, learning, planning, and agent design. neural networks, fuzzy logic, robotics, natural language processing (NLP), and computer vision, Algorithms in AI, Humans and AI, Ethical AI and Biases, Concept of an agent, Structure of an agent, Rationality of an agent, Perfect agents, Task environments, Designing agents, Simple reflex agent, Model-based reflex agents, What are expert systems? Representing knowledge, Reasoning with logic, Backward chaining, Advantages and disadvantages of expert systems.

Recommended Books:

1. Akerkar, R. (2014). Introduction to artificial intelligence, PHI Learning Pvt. Ltd.
2. Ertel, W. (2018). Introduction to artificial intelligence, Springer.
3. Finlay, J., & Dix, A. (2020). An introduction to artificial intelligence, 1st Edition, CRC Press.
4. Flasiński, M. (2016). Introduction to artificial intelligence. Switzerland, Springer International Publishing.
5. Stuart, R., & Peter, N. (2016). Artificial intelligence-a modern approach. 3rd Edition, Wiley.

CM653 Optimization Theory (3+0)

Statement of the problem, condition for optimality, concept of direction of search, alternating direction and steepest descent methods, conjugate direction method, conjugate gradient method, Newton's method, Quasi-Newton equation, derivation of updating formulae for Quasi-Newton's equation, The Gauss-Newton method, The Levenberg-Marquardt method, The corrected Gauss-Newton method, Methods for large scale problems. Theory of constrained optimization, methods for minimizing a general function subject to linear equality constraints, active set strategies for linear inequality constraints, special forms of the objectives functions, Lagrange multiplier estimates, Changes in working set, Barries function methods, Penalty functions methods, Methods based on Lagrangian functions reduced gradient and gradient projection methods.

Recommended Books:

1. Gill P.E., Murray E. (1981). Wright, H.H., Practical Optimization, Academic Press
2. Luenberger D.G., (1986) Optimization by Vector Space Methods, John Wiley & Sons, 1986.
3. JoshiM.C. &K.M. Moudgalya. (2004). Optimization: Theory and Practice, 1st Edition, Alpha Science International
4. Ding-Zhu Du, Panos M. Pardalos & Weili Wu. (2001). Mathematical Theory of Optimization, Springer.
5. Gotfreid B.S., Weisan J., 1973). Introduction to Optimization Theory, Prentice Hall, Englewood Cliffs, NJ, USA.

CM-654 Scientific Computing (2+1)

C-Programming Primer with MEX-C interface in MATLAB, Structure and semantics of C language, definition of code blocks using { }, The main function, and important library headers and their declaration, the include statement, the define statement, Writing a simple Hello World program, The main function, and passing parameters to it, C language syntax for if, switch case, for, while, loops, The goto statement and how / why to avoid it, Mex-C program signature, Memory handing in C, and in Mex-C files, Testing and debugging Mex-C codes, Checking stand-alone C-code for memory leaks using valgrind, Errors in Scientific Computing, Discretization using Finite Difference Methods, Continuous and discrete boundary value problems, Stencil Notation, Types of PDEs, Grids and Discretization approaches, Poisson's equation, Matrix Terminology, Eigenvalues of continuous Laplace Operator, Exercises, Direct Methods The Gaussian Elimination Method, Norms, and Floating point numbers, Error Analysis of Gaussian Elimination, Pivoting, and iterative improvement, Cholesky decomposition for SPD matrices, Band Matrices, General Sparse Matrices, Iterative Methods – Basic, Iterative Solvers, Splitting's Preconditions, Jacobi and Gauss-Seidel iterative solution methods, Starting vector and termination criteria, convergence of Jacobi and Gauss-Seidel, Iterative Methods - Krylov-subspace Methods, Method for Systems with an SPD matrix, the Chebyshev method, the Conjugate Gradient (CG) method, the convergence behaviour of the CG method. Preconditioning of Krylov Subspace Methods, the Preconditioned Conjugate Gradients (PCG) method. Methods for General Matrices. Indefinite Symmetric matrices, iterative methods for General matrices, CG applied to the normal equations, BiCG type methods. GMRES type methods, Choice of iterative method, preconditioning for General matrices

Labs: Usage of MATLAB environment, Functions, Operators, Pseudo-code, flowcharts, and documentation, Designing an algorithm to find roots, Eigenvalues and solving algebraic equations, Mathematical models for problem solving, GUI Interface, basic function of MATLAB and its usage to solving ODE, PDE, Direct and Iterative Methods.

Recommended Books:

1. Attaway, S. (2013). MATLAB: A Practical Introduction to Programming and Problem Solving, 3rd Edition, Butterworth-Heinemann.
2. Quarteroni**,** Alfio, Saleri**,** Fausto.(2004).Scientific Computing with MATLAB, Springer.
3. Palm, W. (2010). Introduction to MATLAB for Engineers, 3rdEdition, McGraw-Hill.
4. Xue D., Chen Y.Q.. (2016). Scientific Computing with MATLAB, 2ndEdition, CRC Press.
5. Gustafsson**,** Bertil. (2011).Fundamentals of Scientific Computing, Springer.

CM-655 Numerical Linear Algebra (2 + 1)

Stability of Algorithms and Conditioning of Problems: Introduction, Efficiency of an algorithm, definition and concept of stability, conditioning of the problem and perturbation analysis, perturbation analysis of the linear system problem, effect of perturbation on RHS vector b, Effect of perturbation in the Matrix A, effect of perturbation in both Matrix A and vector B, some well-known ill-conditioned matrices, The condition number and nearness to singularity, example of ill-conditioned Eigenvalue problems. A computational template in numerical linear algebra, creating zeros in a vector matrix using elementary matrix, triangularization usingGaussian elimination, Gauss elimination with partial pivoting, Gaussian stability, Gauss elimination with complete pivoting, of Gaussian elimination, Basic results to existence and uniqueness, some applications giving rise to linear system problems, solution of Ax=b using LU factorization, solution Ax=b using factorization MA=U, solution of Ax=b without explicit factorization, solution of linear system with multiple right hand sides.

Effects of Condition Number on Accuracy of the Computed Solution: Computing and estimating condition number, component-wise perturbations and the errors, iterative refinement, special systems: positive definite; diagonally dominant; Hessenberg and tridiagonal, symmetric positive definite systems.

QR Factorization, Singular Value Decomposition, and Projection: Introduction, Householder's method for QR factorization, complex QR factorization, classical and Gram –Schmid algorithms for QR factorization, solution of Ax=b using QR factorization, projections using QR factorization, singular value decomposition and its projection, SVD of a complex matrix, some practical applications of SVD, geometric mean and generalized triangular decompositions.

Labs: Efficiency of an algorithm, Perturbation analysis of the linear system problem, Component-wise perturbations, Numerical solution of Gaussian elimination, Complex QR factorization, Classical and Gram – Schmid algorithms, Decomposition methods.

Recommended Books:

1.Datta.B.N, .(2010).Numerical Linear Algebra and Applications, SIAM publisher ,2nd Edition, 2010.

2. Gregoire.A, Kaber.M,.(2008). Numerical Linear Algebra, Springer.

3. Sundarapandian.V.(2008). Numerical Linear Algebra, PHI Learning.

4. William Ford. (2014). Numerical Linear Algebra with Applications: Using MATLAB,1st Edition, Academic Press.

5. William Layton.(2014). Myron.S, Numerical Linear Algebra, Lulu publishers.

CM-606 Wavelets (3 + 0)

Introduction to Wavelets: The Essence of Wavelet Analysis, Beyond the CWT: the Discrete Wavelet Transform, Review of Fourier Theory and Filters, Fourier Transform of Finite Sequences, Periodized Filters, Orthonormal Transforms of Time Series, The Projection Theorem, Complex-Valued Transforms, The Orthonormal Discrete Fourier Transform, The Discrete Wavelet Transform, Qualitative Description of the DWT, The Wavelet Filter, The Scaling Filter, First Stage of the Pyramid Algorithm, Second Stage of the Pyramid Algorithm, General Stage of the Pyramid Algorithm, The Partial Discrete Wavelet Transform, Daubechies Wavelet and Scaling Filters: Form and Phase, Coiflet Wavelet and Scaling Filters: Form and Phase, The Maximal Overlap Discrete Wavelet Transform, Effect of Circular Shifts on the DWT, MODWT Wavelet and Scaling Filters, The Discrete Wavelet Packet Transform, Time Shifts for Wavelet Packet Filters.

Haar Wavelet: Haar wavelet and their integrals, Haar matrices, Expanding functions into the Haar wavelet series, Non-uniform Haar wavelet, Solutions of Differential and Integral, Haar wavelet of Scale two and three.

Recommended Books:

1. Albert Boggess, Francis J. Narcowich, A First Course in Wavelets with Fourier Analysis, Prentice Hall, 2001.

2. Charles K. Chui, An Introduction to Wavelets, Elsevier Science, 2014.

3. Donald B. Percival, Andrew T. Walden, Wavelet Methods for Time Series Analysis Cambridge University Press, 2006.

4. Stephane M, A Wavelet Tour of Signal Processing, Third Edition, The Sparse Way', Academic Press, 2008.

5. Ülo Lepik, Helle Hein, Haar Wavelets, With Applications, Springer, 2014