CAPITAL UNIVERSITY OF SCIENCE & TECHNOLOGY
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PhD Comprehensive Examination
(Faculty of Computing)

PhD Computer Science

General

S. No.	Subject	Duration of Written Paper	Max Marks
1	Design & Analysis of Algorithms	40 Minutes	50
2	Operating Systems	40 Minutes	50
3	Theory of Computation	40 Minutes	50
4	Computer Architecture	40 Minutes	50
5	Programming (DS+OOP+DB)	80 Minutes	100
Total: -		240 Minutes (04 Hours)	300

Minimum pass percentage is 60 % in written part.

Syllabus for Computer Science

Subject Name: Design & Analysis of Algorithms	
Relevant Book: Introduction to Design & Analysis of Algorithms By Anany Levitin (Third Edition)	
Objectives: **1** Analyze the time and space complexity of different algorithms by using standard analysis techniques **2** Understand different algorithm design techniques and their relative advantages in order to select a better algorithm to solve a problem	
List of Topics:	
Sr No	**Topic**
1	Introduction
2	Analysis of Algorithm Efficiency
3	Brute Force and Exhaustive Search

4	Decrease-and-Conquer
5	Divide-and-Conquer
6	Transform-and-Conquer
7	Space and Time Trade-Offs
8	Dynamic Programming
9	Greedy Technique
10	Limitations of Algorithm Power
11	Coping with the Limitations of Algorithm Power
12	Useful Formulas for the Analysis of Algorithms

Subject Name: Operating Systems

Relevant Book: Operating System Concepts By Abraham Silberschatz, Peter Baer Galvin, and Greg Gagne (Ninth Edition)

Objectives:

1 Understand fundamental operating system abstractions such as processes, threads, files, semaphores, IPC abstractions, shared memory regions, etc.

2 Analyze important algorithms e.g. process synchronization, CPU scheduling, deadlock management and memory management.

List of Topics:

Sr No	Topic
1	Introduction
2	Operating System structures
3	Processes
4	Threads
5	Process synchronization
6	CPU scheduling
7	Deadlocks
8	Main Memory
9	Virtual memory
10	Virtual machines
11	Distributed systems

Subject Name: Theory of Computation

Relevant Book: Introduction to Languages and the Theory of Computation (4^{th} Edition) By: John C. Martin

Objectives:

1 Build different types of automata to define formal languages

2 Prove decidability and reducibility of computational problems

3 Analyze time complexity of a Turing Machine

List of Topics:

Sr No	Topic
1	Finite state automata
2	Regular expressions
3	Context-free grammars

4	Push-down automata
5	Turing machines;
6	Recursively enumerable languages; Chomsky's hierarchy
7	Turing decidability and reductions
8	Turing computability;
9	Time complexity of a TM; Complexity classes

Subject Name: Computer Architecture

Relevant Book: Computer Organization & Architecture, Designing for Performance By William Stalling (11th Edition 2019)

Objectives:

1 Understand the functionality of major components of a computer system.

2 Understand principles of instruction set design

3 Understand pipelining and parallelism features applied in modern systems.

List of Topics:

Sr No	Topic
1	Introduction and Basic Concept
2	The Memory Hierarchy: Locality and Performance
3	Cache Memory
4	Internal Memory
5	External Memory
6	Input/Output
7	Parallel Processing
8	Multicore Computers

Subject Name: Programming (DS+OOP+DB)

Sub Domain: Data Structures

Relevant Book: "Data structures and algorithm analysis." 3rd Edition By Shaffer, Clifford A.

Objectives:

1 Understand the design of fundamental data structures

2 Implementing different data structures in a programming language

3 Analyze data structures according to their typical uses, strengths, and weaknesses

Sr No	Topic
1	Data Structures and Algorithms
2	Linked Lists: Singly Linked Lists, Doubly Linked Lists, Circular List
3	Stacks
4	Queues
5	Trees: Binary Trees, Binary Heap, Binary Search, Tree Traversal, Insertion, Deletion, and Balancing a Tree; Heap; B-Tree; Spanning Tree, Splay Trees, Searching Revisited: Red-Black trees, AVL trees, General n-ary trees
6	Sorting Algorithms: Insertion Sort, Selection Sort, Bubble Sort, Shell Sort, Heap Sort, Quick Sort, Merge Sort, Radix Sort, Bucket Sort
7	Hashing

8	Indexing
9	Graphs: Representation, Traversal, Graph Traversal Algorithms Depth-First Search, Breadth-First Search, Topological Sort Shortest Path, and Cycle Detection; Isomorphic Graphs;
10	List and Arrays
Sub Domain: Object Oriented Programming **Relevant Book:** Lafore, Robert. Object-oriented programming in C++. Pearson Education, Fourth Edition	
Objectives: **1** Describe key concepts of object-oriented programming paradigm **2** Interpret real world problems in terms of objects rather than procedure **3** Apply object-oriented programming principles to implement programs	
Sr No	**Topic**
12	Loops and Decisions: For Loop, While Loop, Do While Loop, Precedence: Arithmetic and Relational Operators, Switch Statement, Conditional Operator, Control Statements
13	Structures and Enumerations
14	Functions, Reference Arguments, Overloaded Functions, Recursion, Inline Functions, Scope and Storage Class, Returning by Reference
15	Class and Objects, Overloaded Constructors, Static Class, const and Classes
16	Encapsulation
17	Arrays and Strings, Arrays as Class Member Data, The Standard C++ string Class
18	Operator Overloading
19	Association
20	Inheritance and Generalization: Derived Class and Base Class, Overriding Member Functions, Public and Private Inheritance, Multiple Inheritance
21	Aggregation: Classes Within Classes
21	Composition
23	Pointer
24	Virtual Functions
25	Polymorphism
26	Abstract Class
27	Friend Class
28	Dynamic Binding
29	Templates and Exception
30	OOP Software Development
Sub Domain: Database Systems **Relevant Book**: Database Systems, A Practical Approach to Design Implementation and Management, Pearson Education ,6th Edition	
Objectives: **1** Acquire the basic concepts and uses of databases with different applications **2** Describe and apply different stages of database development **3** Identify function dependencies and resolve database anomalies	
Sr No	**Topic**
31	Logical Database Design
32	Conceptual Database design
33	Normalization
34	Relational Algebra
35	Transaction Processing

PhD Mathematics

General

Following is the list of the subjects from which the comprehensive examination question papers will be prepared after approval. All Mathematics students are required to select **six** subjects from the following list of **eight** subjects.

List of papers

Papers	Subjects
1	Ordinary Differential Equations
2	Linear Algebra and Vector Calculus
3	Fourier Analysis and Partial Differential Equations
4	Complex Analysis
5	Numerical Analysis
6	Optimization Theory
7	Probability and Statistics
8	Functional Analysis

The contents and recommended books for each subject are detailed in the next sections.

Paper 1: Ordinary Differential Equations

1. First-Order ODEs

1.1. Basic Concepts, Modeling

1.2. Geometric Meaning of Direction Fields, Euler's Method

1.3. Separable ODEs, Modeling

1.4. Exact ODEs, Integrating Factors

1.5. Linear ODEs, Bernoulli Equation, Population Dynamics

1.6. Orthogonal Trajectories

1.7. Existence and Uniqueness of Solutions for Initial Value Problems

2. Second-Order Linear ODEs

2.1. Homogeneous Linear ODEs of Second Order

2.2. Homogeneous Linear ODEs with Constant Coefficients

2.3. Differential Operators

2.4. Modeling of Free Oscillations of a Mass–Spring System

2.5. Euler–Cauchy Equations

2.6. Existence and Uniqueness of Solutions, Wronskian

2.7. Nonhomogeneous ODEs

2.8. Modeling: Forced Oscillations, Resonance

2.9. Modeling: Electric Circuits

2.10. Solution by Variation of Parameters

3. Higher Order Linear ODEs

3.1. Homogeneous Linear ODEs

3.2. Homogeneous Linear ODEs with Constant Coefficients

3.3. Nonhomogeneous Linear ODEs

4. Systems of ODEs, Phase Plane, Qualitative Methods

4.1. For Reference: Basics of Matrices and Vectors

4.2. Systems of ODEs as Models in Engineering Applications

4.3. Basic Theory of Systems of ODEs, Wronskian

4.4. Constant-Coefficient Systems, Phase Plane Method

4.5. Criteria for Critical Points, Stability

4.6. Qualitative Methods for Nonlinear Systems

4.7. Nonhomogeneous Linear Systems of ODEs

5. Series Solutions of ODEs, Special Functions

5.1. Power Series Method

5.2. Legendre's Equation, Legendre Polynomials

5.3. Extended Power Series Method: Frobenius Method

5.4. Bessel's Equation, Bessel Functions

5.5. Bessel Functions and General Solution

6. Laplace Transforms

6.1. Laplace Transform, Linearity, First Shifting Theorem (*s*-Shifting)

6.2. Transforms of Derivatives and Integrals, ODEs

6.3. Unit Step Function (Heaviside Function),

6.4. Second Shifting Theorem (*t*-Shifting)

6.5. Short Impulses, Dirac's Delta Function, Partial Fractions

6.6. Convolution, Integral Equations

6.7. Differentiation and Integration of Transforms

6.8. ODEs with Variable Coefficients

6.9. Systems of ODEs

6.10. Laplace Transform: General Formulas

6.11. Table of Laplace Transforms

Relevant Books:

1. *Advanced Engineering Mathematics*, 10th Edition by Erwin Kreyszig
2. *A First Course in Differential Equations with Modeling Applications*, 10th Edition by Dennis G. Zill
3. *Elementary Differential Equations and Boundary Value Problems*, 10th Edition by William E. Boyce, Richard C. DiPrima
4. *Introduction to Partial Differential Equations,* 2nd by Rao K. Sankara

Paper 2: Linear Algebra and Vector Calculus

1. Linear Algebra: Matrices, Vectors, Determinants

1.1. Linear Systems

1.2. Matrices, Vectors: Addition and Scalar Multiplication

1.3. Matrix Multiplication

1.4. Linear Systems of Equations, Gauss Elimination
1.5. Linear Independence, Rank of a Matrix, Vector Space
1.6. Solutions of Linear Systems: Existence, Uniqueness
1.7. For Reference: Second- and Third-Order Determinants
1.8. Determinants, Cramer's Rule

1.9. Inverse of a Matrix, Gauss–Jordan Elimination
1.10. Vector Spaces, Inner Product Spaces, Linear Transformations

2. Linear Algebra: Matrix Eigenvalue Problems

2.1. The Matrix Eigenvalue Problem

2.2. Determining Eigenvalues and Eigenvectors

2.3. Some Applications of Eigenvalue Problems

2.4. Symmetric, Skew-Symmetric, and Orthogonal Matrices

2.5. Eigenbases, Diagonalization, Quadratic Forms

2.6. Complex Matrices and Forms

3. Vector Differential Calculus, Grad, Div, Curl

3.1. Vectors in 2-Space and 3-Space

3.2. Inner Product (Dot Product)

3.3. Vector Product (Cross Product)

3.4. Vector and Scalar Functions and Their Fields, Vector Calculus: Derivatives

3.5. Curves, Arc Length, Curvature, Torsion

3.6. Calculus Review: Functions of Several Variables

3.7. Gradient of a Scalar Field, Directional Derivative

3.8. Divergence of a Vector Field

3.9. Curl of a Vector Field

4. Vector Integral Calculus, Integral Theorems

4.1. Line Integrals

4.2. Path Independence of Line Integrals

4.3. Calculus Review: Double Integrals

4.4. Green's Theorem in the Plane

4.5. Surfaces for Surface Integrals

4.6. Surface Integrals

4.7. Triple Integrals, Divergence Theorem of Gauss

4.8. Further Applications of the Divergence Theorem

4.9. Stokes's Theorem

Relevant Books:

1. *Advanced Engineering Mathematics*, 10th Edition by Erwin Kreyszig
2. *Linear Algebra and Its Applications,* 5th Edition by David C. Lay
3. *Thomas Calculus*, 11th Edition, by George B. Thomas
4. *Calculus: Early Transcendentals,* 10th Edition by Howard Anton, Irl C. Bivens, Stephen Davis

Paper 3: Fourier Analysis and Partial Differential Equations

1. Fourier Analysis

1.1. Fourier Series

1.2. Arbitrary Period, Even and Odd Functions, Half-Range Expansions

1.3. Forced Oscillations

1.4. Approximation by Trigonometric Polynomials

1.5. Sturm–Liouville Problems, Orthogonal Functions

1.6. Orthogonal Series, Generalized Fourier Series

1.7. Fourier Integral

1.8. Fourier Cosine and Sine Transforms

1.9. Fourier Transform, Discrete and Fast Fourier Transforms

1.10. Tables of Transforms

2. Partial Differential Equations

2.1. Basic Concepts of PDEs

2.2. Modeling: Vibrating String, Wave Equation

2.3. Solution by Separating Variables, Use of Fourier Series

2.4. D'Alembert's Solution of the Wave Equation, Characteristics

2.5. Modeling: Heat Flow from a Body in Space, Heat Equation

2.6. Heat Equation: Solution by Fourier Series

2.7. Steady Two-Dimensional Heat Problems, Dirichlet Problem

2.8. Heat Equation: Modeling Very Long Bars

2.9. Solution by Fourier Integrals and Transforms
2.10. Modeling: Membrane, Two-Dimensional Wave Equation
2.11. Rectangular Membrane, Double Fourier Series
2.12. Laplacian in Polar Coordinates, Circular Membrane, Fourier–Bessel Series
2.13. Laplace's Equation in Cylindrical and Spherical Coordinates, Potential

2.14. Solution of PDEs by Laplace Transforms

Relevant Books:

1. *Advanced Engineering Mathematics,* 10th Edition by Erwin Kreyszig
2. *Applied Partial Differential Equations: With Fourier Series and Boundary Value Problems,* 4th Edition by Richard Haberman
3. *Linear Partial Differential Equations for Scientists and Engineers,* 4th Edition by Tyn Myint-U
4. *Introduction to Partial Differential Equations,* 2nd by Rao K. Sankara

Paper 4: Complex Analysis

1. Complex Numbers and Functions

1.1. Complex Numbers and Their Geometric Representation

1.2. Polar Form of Complex Numbers, Powers and Roots

1.3. Derivative, Analytic Function

1.4. Cauchy–Riemann Equations, Laplace's Equation

1.5. Exponential Function

1.6. Trigonometric and Hyperbolic Functions, Euler's Formula

1.7. Logarithm, General Power, Principal Value

2. Complex Integration

2.1. Line Integral in the Complex Plane

2.2. Cauchy's Integral Theorem

2.3. Cauchy's Integral Formula

2.4. Derivatives of Analytic Functions

3. Power Series, Taylor Series

3.1. Sequences, Series, Convergence Tests

3.2. Power Series

3.3. Functions Given by Power Series

Paper 5: Numeric Analysis

1. Numerics in General

1.1. Introduction

1.2. Solution of Equations by Iteration

1.3. Interpolation

1.4. Spline Interpolation

1.5. Numeric Integration and Differentiation

2. Numeric Linear Algebra

2.1. Linear Systems: Gauss Elimination

2.2. Linear Systems: LU-Factorization, Matrix Inversion

2.3. Linear Systems: Solution by Iteration

2.4. Linear Systems: Ill-Conditioning, Norms

2.5. Least Squares Method

2.6. Matrix Eigenvalue Problems: Introduction

2.7. Inclusion of Matrix Eigenvalues

2.8. Power Method for Eigenvalues

2.9. Tridiagonalization and QR-Factorization

3. Numerics for ODEs and PDEs

3.1. Methods for First-Order ODEs

3.2. Multistep Methods

3.3. Methods for Systems and Higher Order ODEs

3.4. Methods for Elliptic PDEs

3.5. Neumann and Mixed Problems, Irregular Boundary

3.6. Methods for Parabolic PDEs

3.7. Method for Hyperbolic PDEs

Relevant Books:

1. *Advanced Engineering Mathematics*, 10th Edition by Erwin Kreyszig
2. *Numerical Analysis,* 10th Edition by Richard L. Burden, J. Douglas Faires
3. *Applied Numerical Analysis, 7*th Edition by Gerald
4. *Introduction to Numerical Analysis:* 2nd Edition by F. B. Hildebrand

Paper 6: Optimization Theory

1. **Unconstrained Optimization, Linear Programming**
   - 1.1. Basic Concepts, Unconstrained Optimization: Method of Steepest Descent
   - 1.2. Linear Programming
   - 1.3. Simplex Method
   - 1.4. Simplex Method: Difficulties

2. **Graphs, Combinatorial Optimization**
   - 2.1. Graphs and Digraphs
   - 2.2. Shortest Path Problems, Complexity
   - 2.3. Bellman's Principle, Dijkstra's Algorithm
   - 2.4. Shortest Spanning Trees: Greedy Algorithm
   - 2.5. Shortest Spanning Trees: Prim's Algorithm
   - 2.6. Flows in Networks
   - 2.7. Maximum Flow: Ford–Fulkerson Algorithm
   - 2.8. Bipartite Graphs, Assignment Problems

Relevant Books:

1. *Advanced Engineering Mathematics*, 10th Edition by Erwin Kreyszig
2. *A First Course in Optimization Theory*, 1st Edition by Rangarajan K. Sundaram
3. *An Introduction to Optimization* 4th Edition by Edwin K. P. Chong, Stanislaw H. Zak
4. *Operations Research: An Introduction*, 10th Edition by Hamdy A. Taha

Paper 7: Probability and Statistics

1. **Data Analysis, Probability Theory**
   - 1.1. Data Representation, Average, Spread
   - 1.2. Experiments, Outcomes, Events 1.3. Probability
   - 1.4. Permutations and Combinations
   - 1.5. Random Variables, Probability Distributions
   - 1.6. Mean and Variance of a Distribution
   - 1.7. Binomial, Poisson, and Hypergeometric Distributions
   - 1.8. Normal Distribution
   - 1.9. Distributions of Several Random Variables

Relevant Books:

1. *Advanced Engineering Mathematics*, 10th Edition by Erwin Kreyszig
2. *Probability and Statistics for Engineering and the Sciences*, 9th Edition by Jay L. Devore
3. *A Modern Introduction to Probability and Statistics: Understanding Why and How*, by

F.M. Dekking, C. Kraaikamp, H.P. Lopuhaä, L.E. Meester

4. *Introductory Statistics,* 5th Edition by Thomas H. Wonnacott, Ronald J. Wonnacott
5. *Fundamentals of Probability and Statistics for Engineers,* 1st Edition by T. T. Soong

Paper 8: Functional Analysis

1. Metric Space

1.1. Metric Space

1.2. Further Examples of Metric Spaces

1.3. Open Set, Closed Set, Neighborhood

1.4. Convergence, Cauchy Sequence, Completeness

2. Normed Spaces, Banach Spaces

2.1. Vector Space

2.2. Normed Space, Banach Space

2.3. Further Properties of Normed Spaces

2.4. Finite Dimensional Normed Spaces and Subspaces

2.5. Compactness and Finite Dimension

2.6. Linear Operators

2.7. Bounded and Continuous Linear Operators

2.8. Linear Functionals

3. Inner Product Spaces, Hilbert Spaces

2.1. Inner Product Space, Hilbert Space

2.2. Further Properties of Inner Product Spaces

2.3. Orthogonal Complements and Direct Sums

Relevant Books:

1. *Introductory Functional Analysis with Applications,* 1st Edition by Erwin Kreyszig
2. *Elements of Functional Analysis,* 2nd Edition by I. J. Maddox
3. *Functional Analysis: An Introduction to Metric Spaces, Hilbert Spaces, and Banach Algebras, 2*014th Edition by Joseph Muscat
4. *An Introduction to Metric Spaces and Fixed Point Theory, 1st Edition* by Mohamed A. Khamsi, William A. Kirk