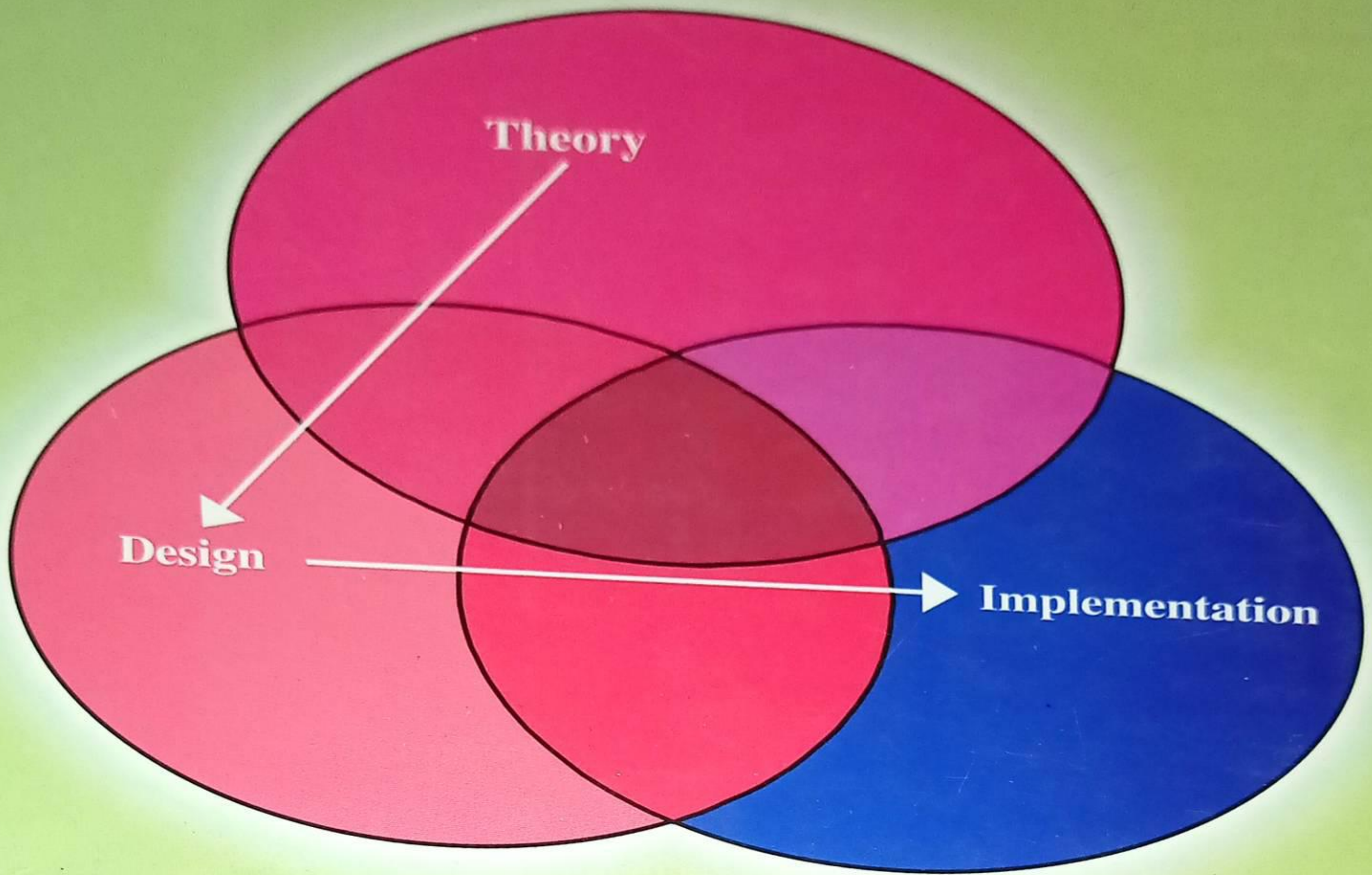


A Simplified Text-cum-Workbook on

# Data Structures & Algorithms

*Theory, Design and Implementation Using C*



R. S. Salaria

# Table of Contents

---

---

*Preface*  
*Acknowledgments*

<b>Chapter 1 : Overview of Data Structures</b> .....	<b>1-18</b>
1.1 INTRODUCTION.....	2
1.2 BASIC TERMINOLOGY OF DATA ORGANIZATION.....	2
1.3 CONCEPT OF A DATA TYPE.....	4
1.3.1 Primitive Data Type.....	4
1.3.2 Abstract Data Type.....	5
1.3.3 Polymorphic Data Type.....	5
1.4 DATA STRUCTURE DEFINED.....	6
1.5 DESCRIPTION OF VARIOUS DATA STRUCTURES.....	6
1.5.1 Arrays.....	7
1.5.1.1 Linear Arrays.....	7
1.5.1.2 Two-dimensional Arrays.....	8
1.5.2 Linked Lists.....	9
1.5.2.1 Linear Linked List.....	9
1.5.2.2 Doubly Linked List.....	10
1.5.2.3 Circular Linked List.....	11
1.5.3 Stacks.....	11
1.5.4 Queues.....	12
1.5.5 Trees.....	13
1.5.6 Heaps.....	13
1.5.7 Graphs.....	14
1.5.8 Hash Tables.....	15
1.6 COMMON OPERATIONS ON DATA STRUCTURES.....	16
1.7 A QUICK REVIEW.....	16
1.8 REVIEW EXERCISES.....	17

<b>Chapter 2 : Introduction to Program Design</b> .....	<b>19-60</b>
2.1 INTRODUCTION.....	20
2.2 PROGRAM DEVELOPMENT LIFE CYCLE.....	20
2.2.1 Defining the Problem.....	21
2.2.2 Designing the Program.....	21
2.2.2.1 Program Design Tools.....	22
2.2.3 Coding the Program.....	23
2.2.4 Testing and Debugging the Program.....	23
2.2.5 Documenting the Program.....	24
2.2.1 Implementing and Maintaining the Program.....	24
2.3 INTRODUCTION TO ALGORITHMS.....	25
2.3.1 A Typical Example.....	25
2.3.2 Algorithm Description.....	26
2.3.3 Sub-Algorithms.....	28
2.4 STRUCTURED PROGRAMMING CONSTRUCTS.....	29
2.4.1 Sequential Programming Construct.....	30
2.4.2 Selection Programming Construct.....	30
2.4.2.1 Single Alternative.....	31
2.4.2.2 Double Alternatives.....	31
2.4.2.3 Multiple Alternative.....	32
2.4.3 Iterative Programming Construct.....	33
2.4.3.1 For Construct.....	33
2.4.3.2 While Construct.....	34
2.4.3.3 Do – while Construct.....	35
2.5 ALGORITHM COMPLEXITY.....	36
2.5.1 Space Complexity.....	38
2.5.2 Time Complexity.....	38
2.5.3 Time-space Trade-off.....	39
2.5.4 Expressing Space and Time Complexity.....	39
2.6 Big Oh Notation.....	41
2.6.1 Categories of Algorithms.....	42
2.6.2 Limitations of Big Oh Notation.....	42
2.7 CONCEPT OF RECURSION.....	42
2.7.1 Recursion Defined.....	43
2.7.2 Depth of Recursion.....	43
2.7.3 Examples of Some Recursive Functions.....	43
2.7.3.1 Factorial Function.....	47
2.7.3.1.1 Recursive Function and Run Time Stack.....	50
2.7.3.2 Positive Exponential Power Function.....	52
2.7.3.3 Fibonacci Numbers.....	54
2.7.3.4 Counting Problem.....	54
2.7.3.5 Minmax Problem.....	55

2.7.4 Recursion, Iteration or ...?	57
2.8 A QUICK REVIEW	58
2.9 REVIEW EXERCISES	59
2.10 PROGRAMMING EXERCISES	60
<b>Chapter 3 : Arrays &amp; Matrices</b>	<b>61-92</b>
3.1 INTRODUCTION	62
3.2 LINEAR ARRAYS	62
3.2.1 Representing Linear Arrays in Memory	63
3.2.2 Operations on Linear Arrays	64
3.2.2.1 Traversal Operation	64
3.2.2.1.1 Analysis of Traversal Operation	65
3.2.2.2 Search Operation	66
3.2.2.2.1 Linear Search	66
3.2.2.2.1.1 Analysis of Linear Search	67
3.2.2.2.2 Binary Search	67
3.2.2.2.2.1 Analysis of Binary Search	69
3.2.2.3 Insert Operation	69
3.2.2.3.1 Inserting at Given Position	70
3.2.2.3.2 Inserting in a Sorted Array	70
3.2.2.3.3 Analysis of Insert Operation	71
3.2.2.4 Delete Operation	71
3.2.2.4.1 Deleting from Given Position	71
3.2.2.4.2 Deleting from a Sorted Array	72
3.2.2.4.3 Analysis of Delete Operation	72
3.2.2.5 Sort Operation	72
3.2.2.5.1 Bubble Sort Method	73
3.2.2.5.1.1 Analysis of Bubble Sort Method	74
3.2.2.6 Merge Operation	76
3.2.2.6.1 Analysis of Merge Operation	77
3.2.3 Applications of Linear Arrays	78
3.2.4 Limitations of Linear Arrays	78
3.3 TWO-DIMENSIONAL ARRAYS	78
3.3.1 Representing Two-dimensional Array in Memory	79
3.4 MATRICES	81
3.4.1 Special Matrices	82
3.4.1.1 Representing Special Matrices in Memory	83
3.4.2 Sparse Matrices	87
3.4.2.1 Representing Sparse Matrices	88
3.4.2.1.1 Array Representation	88
3.4.2.1.2 Linked Representation	89

3.5 A QUICK REVIEW.....	89
3.6 REVIEW EXERCISES.....	90
3.7 PROGRAMMING EXERCISES.....	90
<b>Chapter 4 : Linked Lists.....</b>	<b>93-138</b>
4.1 INTRODUCTION.....	94
4.2 IMPLEMENTING LISTS.....	94
4.2.1 Array Implementation of Lists.....	94
4.2.2 Linked Implementation of Lists.....	95
4.3 LINKED LIST DEFINED.....	96
4.3.1 Linear Linked List.....	96
4.3.1.1 Representation of Linear Linked List.....	97
4.3.1.2 Operations on Linear Linked Lists.....	97
4.3.1.2.1 Creating an Empty List.....	97
4.3.1.2.2 Traversing a List.....	97
4.3.1.2.2.1 In-Order Traversal.....	98
4.3.1.2.2.2 Reverse-Order Traversal.....	98
4.3.1.2.3 Searching an Element.....	98
4.3.1.2.3.1 List is Unsorted.....	99
4.3.1.2.3.2 List is Sorted.....	100
4.3.1.2.3.3 Auxiliary Search Procedure.....	100
4.3.1.2.4 Inserting an Element.....	101
4.3.1.2.4.1 Inserting at the Beginning of the List.....	101
4.3.1.2.4.2 Inserting at the End of the List.....	102
4.3.1.2.4.3 Inserting after the Given Element of the List.....	102
4.3.1.2.5 Deleting an Element.....	103
4.3.1.2.5.1 Deleting from the Beginning of the List.....	104
4.3.1.2.5.2 Deleting from the End of the List.....	104
4.3.1.2.5.3 Deleting after the Given Element of the List.....	105
4.3.1.2.6 Reversing a List.....	106
4.3.1.2.7 Deleting Entire List.....	106
4.3.2 Doubly Linked List.....	107
4.3.2.1 Representation of Doubly Linked List.....	108
4.3.2.2 Operations on Doubly Linked Lists.....	109
4.3.2.2.1 Creating an Empty List.....	109
4.3.2.2.2 Traversing a List.....	109
4.3.2.2.2.1 In-Order Traversal.....	110
4.3.2.2.2.2 Reverse-Order Traversal.....	110
4.3.2.2.3 Searching an Element.....	110
4.3.2.2.4 Inserting an Element.....	111
4.3.2.2.4.1 Inserting after a Given Element.....	111

4.3.2.2.4.2	Inserting before a Given Element.....	112
4.3.2.2.5	Deleting an Element.....	112
4.3.2.2.5.1	Deleting after a Given Element.....	113
4.3.2.2.5.2	Deleting before a Given Element.....	113
4.3.2.2.6	Deleting Entire List.....	114
4.3.3	More Types of Lists.....	114
4.3.3.1	Circular Linked List.....	115
4.3.3.2	Header Linked Lists.....	115
4.4	APPLICATIONS OF LINKED LISTS.....	117
4.4.1	Polynomial Manipulation.....	117
4.4.1.1	Addition of Polynomials.....	118
4.4.1.2	Multiplication of Polynomials.....	122
4.4.2	Representing Sparse Matrices.....	127
4.5	A QUICK REVIEW.....	136
4.6	REVIEW EXERCISES.....	136
4.7	PROGRAMMING EXERCISES.....	137

**Chapter 5 : Stacks.....139-170**

5.1	INTRODUCTION.....	140
5.2	OPERATIONS ON STACKS.....	141
5.3	REPRESENTATION OF A STACK IN MEMORY.....	142
5.3.1	Representing a Stack using an Array.....	142
5.3.1.1	Creating an Empty Stack.....	143
5.3.1.2	Testing Stack for Underflow.....	143
5.3.1.3	Testing Stack for Overflow.....	144
5.3.1.4	Push Operation.....	145
5.3.1.5	Pop Operation.....	145
5.3.1.6	Accessing Top Element.....	146
5.3.2	Representing a Stack using a Linked List.....	147
5.3.2.1	Creating an Empty Stack.....	148
5.3.2.2	Testing Stack for Underflow.....	148
5.3.2.3	Testing Stack for Overflow.....	149
5.3.2.4	Push Operation.....	149
5.3.2.5	Pop Operation.....	149
5.3.2.6	Accessing Top Element.....	150
5.3.2.7	Dispose a Stack.....	150
5.4	MULTIPLE STACKS.....	151
5.4.1	Representing Two Stacks.....	151
5.4.2	Representing More than two Stacks.....	151
5.5	APPLICATIONS OF STACKS.....	152
5.5.1	Parenthesis Checker.....	152

5.5.2 Mathematical Notation Translation ..... 15

    5.5.2.1 Infix Notation ..... 15

    5.5.2.2 Polish (Prefix) Notation ..... 15

    5.5.2.3 Reverse Polish (Postfix) Notation ..... 15

    5.5.2.4 Evaluating Mathematical Expressions ..... 15

    5.5.2.5 Infix-to-Postfix Procedure ..... 15

    5.5.2.6 Evaluating Expression in Postfix Notation ..... 15

5.5.3 Quicksort Algorithm ..... 16

5.6 A QUICK REVIEW ..... 16

5.7 REVIEW EXERCISES ..... 16

5.8 PROGRAMMING EXERCISES ..... 16

**Chapter 6 : Queues** ..... 171-194

6.1 INTRODUCTION ..... 172

6.2 QUEUE DEFINED ..... 168

6.3 OPERATIONS ON QUEUES ..... 174

6.4 REPRESENTATION OF QUEUES IN MEMORY ..... 174

    6.4.1 Representing a Queue using an Array ..... 174

        6.4.1.1 Implementation of Operations on a Linear Queue ..... 179

            6.4.1.1.1 Creating an Empty Linear Queue ..... 179

            6.4.1.1.2 Testing a Linear Queue for Underflow ..... 179

            6.4.1.1.3 Testing a Linear Queue for Overflow ..... 179

            6.4.1.1.4 Enqueue Operation on Linear Queue ..... 181

            6.4.1.1.5 Dequeue Operation on a Linear Queue ..... 181

            6.4.1.1.6 Accessing Front Element ..... 181

        6.4.1.2 Limitations of a Linear Queue ..... 181

        6.4.1.3 Implementation of Operations on a Circular Queue ..... 181

            6.4.1.3.1 Testing a Circular Queue for Overflow ..... 181

            6.4.1.3.2 Enqueue Operation on a Circular Queue ..... 181

            6.4.1.3.3 Dequeue Operation on a Circular Queue ..... 181

        6.4.2 Representing a Queue using a Linked List ..... 181

            6.4.2.1 Implementation of Operations on a Linear Queue ..... 181

                6.4.2.1.1 Creating an Empty Queue ..... 181

                6.4.2.1.2 Testing Queue for Underflow ..... 181

                6.4.2.1.3 Testing Queue for Overflow ..... 181

                6.4.2.1.4 Enqueue Operation ..... 181

                6.4.2.1.5 Dequeue Operation ..... 181

                6.4.2.1.6 Accessing Front Element ..... 181

                6.4.2.1.7 Disposing a Queue ..... 181

    6.4 MULTIPLE QUEUES ..... 181

6.6 DEQUE ..... 191

6.7 PRIORITY QUEUE..... 191  
 6.7.1 Representing a Priority Queue in Memory..... 191  
     6.7.1.1 Linear Linked List Representation..... 191  
     6.7.1.2 Multiple Queue Representation..... 192  
     6.7.1.3 Heap Representation of a Priority Queue..... 192  
 6.8 APPLICATIONS OF QUEUES..... 193  
 6.9 A QUICK REVIEW..... 193  
 6.10 REVIEW EXERCISES..... 194  
 6.11 PROGRAMMING EXERCISES..... 194

**Chapter 7 : Trees..... 195-240**

8.1 INTRODUCTION..... 196  
 7.2 TREE DEFINED..... 199  
 7.3 TREE TERMINOLOGY..... 199  
 7.4 BINARY TREES..... 200  
     7.4.1 Properties of Binary Trees..... 201  
 7.5 TOURNAMENT TREES..... 203  
 7.6 BINARY SEARCH TREES..... 204  
     7.6.1 Representation of a Binary and Binary Search Tree..... 204  
         7.6.1.1 Array Representation..... 205  
         7.6.1.2 Linked Representation..... 207  
     7.6.2 Common Operations on Binary and Binary Search Trees..... 208  
         7.6.2.1 Creating an Empty Binary (Search) Tree..... 209  
         7.6.2.2 Traversing a Binary (Search) Tree..... 209  
             7.6.2.2.1 Pre-Order Traversal of a Binary (Search) Tree..... 211  
             7.6.2.2.2 In-Order Traversal of a Binary (Search) Tree..... 212  
             7.6.2.2.3 Post-Order Traversal of a Binary (Search) Tree..... 214  
             7.6.2.2.4 Level-Order Traversal of a Binary (Search) Tree..... 215  
         7.6.2.3 Determining Height a Binary (Search) Tree..... 219  
         7.6.2.4 Determining Number of Nodes/Elements..... 220  
         7.6.2.5 Determining Number of Internal/Non-leaf Nodes..... 220  
         7.6.2.6 Determining Number of External/Leaf Nodes..... 221  
         7.6.2.7 Determining Mirror Image..... 22  
         7.6.2.8 Removing Binary (Search) Tree from Memory..... 22  
         7.6.2.9 Inserting a New Element..... 22  
         7.6.2.10 Searching an Element..... 22  
         7.6.2.11 Finding Smallest Node..... 22  
         7.6.2.12 Finding Largest Node..... 22  
         7.6.2.13 Deleting a Node..... 22  
 7.7 AVL TREES..... 22  
     7.7.1 Representation of an AVL Tree..... 22



7.7.2	Height of an AVL Tree	227
7.7.3	Operations on an AVL Tree	228
7.7.3.1	Insertion of a Node	228
7.7.3.1.1	Rotations	228
7.7.3.2	Deletion of a Node	229
7.8	THREADED BINARY TREES	230
7.8.1	Representing a Threaded Binary Tree in Memory	231
7.8.2	Operations on a Threaded Binary Tree	232
7.8.2.1	In-order Traversal of Threaded Binary Tree	233
7.8.2.2	Insertion in a Threaded Binary Search Tree	234
7.8.2.3	Finding Largest Element a Threaded Binary Search Tree	235
7.8.2.4	Deleting An Element from a Threaded Binary Search Tree	236
7.8.2.5	Deleting a Threaded Binary Search Tree	237
7.9	A QUICK REVIEW	237
7.10	REVIEW EXERCISES	238
7.11	PROGRAMMING EXERCISES	239

**Chapter 8 : Heaps**..... 241-258

8.1	INTRODUCTION	242
8.2	REPRESENTING A HEAP IN MEMORY	243
8.3	OPERATIONS ON HEAPS	243
8.3.1	Deleting an Element From Heap	243
8.3.2	Inserting an Element into Heap	247
8.4	APPLICATIONS OF HEAPS	250
8.4.1	Priority Queues	250
8.5	BUILDING A HEAP	253
8.6	A QUICK REVIEW	256
8.7	REVIEW EXERCISES	256
8.9	PROGRAMMING EXERCISES	257

**Chapter 9 : Graphs**..... 259-310

9.1	INTRODUCTION	260
9.2	GRAPH TERMINOLOGY	261
9.3	REPRESENTATION OF GRAPHS	261
9.3.1	Adjacency Matrix Representation	261
9.3.2	Adjacency List Representation	261
9.3.2.1	Implementation of Adjacency List in C	261
9.4	OPERATIONS ON GRAPHS	261
9.4.1	Creating an Empty Graph	261
9.4.2	Entering Graph Information	261

9.4.3	Outputting a Graph	269
9.4.4	Deleting a Graph	270
9.4.5	Traversal	270
9.4.5.1	Breadth-First Search	274
9.4.5.2	Depth-First Search	279
9.5	APPLICATIONS OF GRAPHS	279
9.5.1	Topological Sort	285
9.5.2	Minimum Spanning Tree	291
9.5.3	Finding Shortest Paths	292
9.5.3.1	Shortest Path for Given Source and Destination	298
9.5.3.2	Shortest Paths Among All-Pair of Vertices	304
9.5.4	Transitive Closure of a Directed Graph	306
9.6	ARTICULATION POINTS, BRIDGES, AND BICONNECTED COMPONENTS	307
9.7	STRONGLY CONNECTED COMPONENTS	308
9.8	EULERIAN TOUR	308
9.9	HAMILTONIAN TOUR	308
9.10	A QUICK REVIEW	308
9.11	REVIEW EXERCISES	310
9.12	PROGRAMMING EXERCISES	310
<b>Chapter 10 : Hash Tables &amp; Hashing</b>		<b>311-344</b>
10.1	INTRODUCTION	312
10.2	DIRECT ADDRESS TABLES	313
10.2.1	Initializing a Direct-address Table	314
10.2.2	Searching an Element in Direct-address Table	314
10.2.3	Inserting a New Element in Direct-address Table	315
10.2.4	Deleting an Element from a Direct-address Table	315
10.3	HASH TABLE	316
10.4	WHAT IS A HASH FUNCTION?	317
10.4.1	Different Hash Functions	318
10.4.1.1	Division Method	318
10.4.1.2	Multiplication Method	319
10.4.1.3	Midsquare Method	320
10.4.1.4	Folding Method	320
10.5	RESOLVING COLLISIONS	321
10.5.1	Collision Resolution by Separating Chaining	321
10.5.1.1	Initializing a Chained-hash-table	322
10.5.1.2	Searching an Element in Chained-hash-table	323
10.5.1.3	Inserting a New Element in Chained-hash-table	323
10.5.1.4	Deleting an Element from a Chained-hash-table	324
10.5.2	Collision Resolution by Open Addressing	328

10.5.2.1 Linear Probing ..... 32  
10.5.2.2 Quadratic Probing ..... 33  
10.5.2.3 Double Hashing ..... 33  
10.6 REHASHING ..... 34  
10.7 A QUICK REVIEW ..... 34  
10.8 REVIEW EXERCISES ..... 34

**Chapter 11 : Sorting Algorithms..... 345-377**

11.1 INTRODUCTION ..... 34  
11.2 SELECTION SORT ..... 34  
    11.2.1 Analysis of Selection Sort ..... 34  
11.3 INSERTION SORT ..... 35  
    11.3.1 Analysis of Insertion Sort ..... 35  
11.4 BUCKET SORT ..... 35  
    11.4.1 Analysis of Bucket Sort ..... 35  
11.5 MERGE SORT ..... 36  
    11.5.1 Analysis of Merge Sort ..... 36  
11.6 QUICK SORT ..... 36  
    11.6.1 Analysis of Quick Sort ..... 36  
11.7 HEAP SORT ..... 37  
    11.7.1 Analysis of Heap Sort ..... 37  
11.8 A QUICK REVIEW ..... 37  
11.9 REVIEW EXERCISES ..... 37  
11.10 PROGRAMMING EXERCISES ..... 37

**INDEX..... 377-387**