Data Structures and Algorithms ¹

A Study Guide for Students of Sorsogon State University - Bulan Campus 2

Jarrian Vince G. Gojar³

September 1, 2024

¹A course in the Bachelor of Science in Computer Science

 $^{^2}$ This book is a study guide for students of Sorsogon State University - Bulan Campus taking up the course Data Structures and Algorithms.

³https://github.com/godkingjay



Contents

C	onter	nts	ii
1	Intr	roduction to Data Structures and Algorithms	2
	1.1	What are Data Structures?	2
	1.2	What are Algorithms?	2
	1.3	Why Study Data Structures and Algorithms?	2
	1.4	Basic Terminologies	2
		1.4.1 Data	2
		1.4.2 Data Object	2
		1.4.3 Data Structure	2
		1.4.4 Data Type	2
		1.4.4.1 Primitive Data Types	2
		1.4.4.2 Non-primitive Data Types	2
		1.4.5 Abstract Data Type	2
		1.4.6 Algorithm	2
		1.4.7 Complexity of an Algorithm	2
		1.4.7.1 Time Complexity	2
		1.4.7.2 Space Complexity	2
	1.5	Asymptotic Notations	2
		1.5.1 Big-O Notation	2
		1.5.2 Omega Notation	2
		1.5.3 Theta Notation	$\overline{2}$
	1.6	Summary	$\overline{2}$
2		rays and Linked Lists	3
	2.1	Arrays	3
		2.1.1 Types of Arrays	3
		2.1.1.1 One-dimensional Array	3
		2.1.1.2 Multi-dimensional Array	3
		2.1.2 Array Operations	3
		2.1.2.1 Insertion	3
		2.1.2.2 Deletion	3
		2.1.2.3 Searching	3
		2.1.3 Complexity Analysis of Arrays	3
	2.2	Linked Lists	3
		2.2.1 Types of Linked Lists	3
		2.2.1.1 Singly Linked List	3
		2.2.1.2 Doubly Linked List	3
		2.2.1.3 Circular Linked List	3

CONTENTS iii

		2.2.2	Operation	ns on Linke	ed Lists					 	 					3
				Insertion												3
				Deletion .												3
				Searching												3
		2.2.3		ity Analysis												3
	2.3		_	Arrays and 1												3
	$\frac{2.0}{2.4}$	_														3
	2.4	Dullilli	ary						• •	 • •	 • •	• •	•	 •	•	9
3	Stac	cks and	l Queues													4
	3.1		-							 	 					5
		3.1.1		ns on Stack												5
			-	Push												5
				Pop												5
				Peek												5
				isEmpty .												5
																5
		3.1.2		ity Analysis												5
		3.1.3		ntation of S												5
		3.1.4		ntation of S												5 5
	3.2		_			_										
	3.2	•														5
		3.2.1		Queues .												5
				Linear Que												5
				Circular Q												5
				Priority Qu												5
				Double-end												5
		3.2.2	-	ns on Queu												5
				Enqueue												5
				Dequeue												5
				Front												5
				Rear												5
		3.2.3		ity Analysis	•											5
		3.2.4		ntation of C												5
		3.2.5	Implemen	ntation of C	Jueues U	Jsing 1	Linke	d Lis	ts.	 	 					5
	3.3	Compa	arison of S	tacks and (Queues					 	 					5
	3.4	Summa	ary							 	 					5
4	Tree															6
	4.1			ees												7
		4.1.1		de												7
		4.1.2		ode												7
		4.1.3		de												7
		4.1.4	Leaf Nod	le						 	 					7
		4.1.5	Ancestors	5						 	 					7
		4.1.6	Siblings							 	 					7
		4.1.7	Descenda	nts						 	 					7
		4.1.8	Height of	a Tree .						 	 					7
		4.1.9		a Node .												7
		4.1.10	•	f a Node .												7
		4.1.11		a Node												7
																7
	4.2															7
			Binary T													7

CONTENTS iv

		4.2.1.1 Types of Binary Trees	7
		Left-skewed Binary Tree	7
		Right-skewed Binary Tree	7
		Complete Binary Tree	7
		4.2.2 Ternary Tree	7
		4.2.3 N-ary Tree	7
		4.2.4 Binary Search Tree	7
		4.2.5 AVL Tree	7
		4.2.6 Red-Black Tree	7
	4.3	Basic Operations on Trees	7
		4.3.1 Creation of a Tree	7
		4.3.2 Insertion	7
		4.3.3 Deletion	7
		4.3.4 Searching	7
		4.3.5 Traversal	7
		4.3.5.1 Preorder Traversal	7
		4.3.5.2 Inorder Traversal	7
		4.3.5.3 Postorder Traversal	7
		4.3.5.4 Level-order Traversal	7
	4.4	Complexity Analysis of Trees	7
	4.5	Summary	7
			·
5	Gra	ohs —	8
	5.1	Properties of Graphs	9
		5.1.1 Vertex	9
		5.1.2 Edge	9
		5.1.3 Degree of a Vertex	9
		5.1.4 Path	9
	5.2	Types of Graphs	9
		5.2.1 Finite Graph	9
		5.2.2 Infinite Graph	9
		5.2.3 Trivial Graph	9
		5.2.4 Simple Graph	9
		5.2.5 Multi Graph	9
		5.2.6 Null Graph	9
		5.2.7 Complete Graph	9
		5.2.8 Pseudo Graph	9
		5.2.9 Regular Graph	9
		5.2.10 Bipartite Graph	9
		5.2.11 Labelled Graph	9
		5.2.12 Weighted Graph	9
		5.2.13 Directed Graph	9
		5.2.14 Undirected Graph	9
		5.2.15 Connected Graph	9
		5.2.16 Disconnected Graph	9
		5.2.17 Cyclic Graph	9
		5.2.18 Acyclic Graph	9
		5.2.19 Directed Acyclic Graph (DAG)	9
		5.2.20 Digraph	9
		5.2.21 Subgraph	9
	- 0	Operations on Graphs	9

CONTENTS v

		5.3.1	Creation	of a Graph	
		5.3.2	Insertion		
			5.3.2.1	Insertion of a Vertex	
			5.3.2.2	Insertion of an Edge	
		5.3.3			
				Deletion of a Vertex	
			5.3.3.2	Deletion of an Edge	
		5.3.4			
				Depth First Search (DFS)	
				Breadth First Search (BFS)	
		5.3.5		Path	
		5.3.6		Spanning Tree	
	5.4			lysis of Graphs	
	5.5				
			J		
6	Sort	ting an	nd Search	ing	10
	6.1	Sortin	g		11
		6.1.1	Types of	Sorting Algorithms	11
			6.1.1.1	Bubble Sort	11
			6.1.1.2	Selection Sort	11
			6.1.1.3	Insertion Sort	11
			6.1.1.4	Merge Sort	11
			6.1.1.5	Quick Sort	11
			6.1.1.6	Heap Sort	11
			6.1.1.7	Radix Sort	11
			6.1.1.8	Counting Sort	11
			6.1.1.9	Bucket Sort	11
		6.1.2	Comparis	son of Sorting Algorithms	11
	6.2	Search	ning		11
		6.2.1	Types of	Searching Algorithms	11
			6.2.1.1	Linear Search	11
			6.2.1.2	Binary Search	11
			6.2.1.3	Jump Search	11
			6.2.1.4	Interpolation Search	11
				Exponential Search	
			6.2.1.6	Fibonacci Search	11
			6.2.1.7	Ternary Search	11
		6.2.2	Comparis	son of Searching Algorithms	11
	6.3	Summ	ary		11
7		hing			12
	7.1	Hash '			
	7.2				
	7.3			tion Techniques	
		7.3.1		Chaining	
		7.3.2		dressing	
				Linear Probing	
				Quadratic Probing	
				Double Hashing	
	7.4	_	•	lysis of Hashing	
	7.5	Summ	ary		12

CONTENTS vi

8	Adv	anced	Data Structures and Algorithms	13
	8.1	Advan	ced Data Structures	. 14
		8.1.1	Segment Tree	. 14
		8.1.2	Fenwick Tree	. 14
		8.1.3	Suffix Tree	. 14
		8.1.4	Suffix Array	. 14
		8.1.5	Trie	. 14
		8.1.6	Heap	. 14
		8.1.7	Disjoint Set	. 14
		8.1.8	Skip List	. 14
		8.1.9	Splay Tree	. 14
		8.1.10	Bloom Filter	. 14
		8.1.11	KD Tree	. 14
		8.1.12	Quad Tree	. 14
		8.1.13	Octree	. 14
		8.1.14	B-Tree	. 14
			B+ Tree	
		8.1.16	R-Tree	. 14
		8.1.17	X-Tree	. 14
			Y-Tree	
			Z-Tree	
	8.2		ced Algorithms	
		8.2.1	Dynamic Programming	
		8.2.2	Greedy Algorithms	
		8.2.3	Backtracking	
		8.2.4	Divide and Conquer	
		8.2.5	Branch and Bound	
		8.2.6	Randomized Algorithms	
		8.2.7	Approximation Algorithms	
		8.2.8	String Matching Algorithms	
		8.2.9	Pattern Searching Algorithms	
		8.2.10	Cryptography Algorithms	
		8.2.11	Geometric Algorithms	
			Graph Algorithms	
			Network Flow Algorithms	
			Game Theory Algorithms	
			Quantum Algorithms	
	8.3		ary	
	0.0	.5		
9	App	olicatio	ns of Data Structures and Algorithms	15
	9.1	Applic	ations in Computer Science	. 16
		9.1.1	Operating Systems	. 16
		9.1.2	Database Management Systems	. 16
		9.1.3	Compiler Design	. 16
		9.1.4	Networking	. 16
		9.1.5	Artificial Intelligence	
		9.1.6	Machine Learning	. 16
		9.1.7	Computer Graphics	. 16
		9.1.8	Computer Vision	
		9.1.9	Robotics	
		9.1.10	Web Development	. 16

	9.1.11	Mobile Development	16
	9.1.12	Game Development	16
	9.1.13	Cybersecurity	16
	9.1.14	Quantum Computing	16
9.2	Applic	ations in Real Life	16
	9.2.1	Social Media	16
	9.2.2	E-commerce	16
	9.2.3	Healthcare	16
	9.2.4	Finance	16
	9.2.5	Transportation	16
	9.2.6	Education	16
	9.2.7	Agriculture	16
	9.2.8	Manufacturing	16
	9.2.9	Entertainment	16
	9.2.10	Sports	16
	9.2.11	Travel	16
	9.2.12	Telecommunications	16
	9.2.13	Energy	16
	9.2.14	Environment	16
	9.2.15	Politics	16
	9.2.16	Military	16
9.3	Summ	ary	16
10 Refe	erences	5	17

Preface

"Bad programmers worry about the code. Good programmers worry about data structures and their relationships."

– Linus Torvalds

Jarrian Vince G. Gojar https://github.com/godkingjay

Introduction to Data Structures and Algorithms

- 1.1 What are Data Structures?
- 1.2 What are Algorithms?
- 1.3 Why Study Data Structures and Algorithms?
- 1.4 Basic Terminologies
- 1.4.1 Data
- 1.4.2 Data Object
- 1.4.3 Data Structure
- 1.4.4 Data Type
- 1.4.4.1 Primitive Data Types
- 1.4.4.2 Non-primitive Data Types
- 1.4.5 Abstract Data Type
- 1.4.6 Algorithm
- 1.4.7 Complexity of an Algorithm
- 1.4.7.1 Time Complexity
- 1.4.7.2 Space Complexity
- 1.5 Asymptotic Notations
- 1.5.1 Big-O Notation
- 1.5.2 Omega Notation
- 1.5.3 Theta Notation
- 1.6 Summary

Arrays and Linked Lists

2.1	Arrays
4 • 1	Allays

- 2.1.1 Types of Arrays
- 2.1.1.1 One-dimensional Array
- 2.1.1.2 Multi-dimensional Array
- 2.1.2 Array Operations
- **2.1.2.1** Insertion
- 2.1.2.2 Deletion
- 2.1.2.3 Searching
- 2.1.3 Complexity Analysis of Arrays
- 2.2 Linked Lists
- 2.2.1 Types of Linked Lists
- 2.2.1.1 Singly Linked List
- 2.2.1.2 Doubly Linked List
- 2.2.1.3 Circular Linked List
- 2.2.2 Operations on Linked Lists
- **2.2.2.1** Insertion
- 2.2.2.2 Deletion
- 2.2.2.3 Searching
- 2.2.3 Complexity Analysis of Linked Lists
- 2.3 Comparison of Arrays and Linked Lists
- 2.4 Summary

3.1. STACKS 5

3

3.3

Stacks and Queues

3.1 Stacks
3.1.1 Operations on Stacks
3.1.1.1 Push
3.1.1.2 Pop
3.1.1.3 Peek
3.1.1.4 isEmpty
3.1.1.5 is Full
3.1.2 Complexity Analysis of Stacks
3.1.3 Implementation of Stacks Using Arrays
3.1.4 Implementation of Stacks Using Linked Lists
3.2 Queues
3.2.1 Types of Queues
3.2.1.1 Linear Queue
3.2.1.2 Circular Queue
3.2.1.3 Priority Queue
3.2.1.4 Double-ended Queue (Deque)
3.2.2 Operations on Queues
3.2.2.1 Enqueue
3.2.2.2 Dequeue
3.2.2.3 Front
3.2.2.4 Rear
3.2.3 Complexity Analysis of Queues
3.2.4 Implementation of Queues Using Arrays
3.2.5 Implementation of Queues Using Linked Lists

Comparison of Stacks and Queues

Trees

4.1 Properties of Tree	4.1
------------------------	-----

- 4.1.1 Root Node
- 4.1.2 Parent Node
- 4.1.3 Child Node
- 4.1.4 Leaf Node
- 4.1.5 Ancestors
- 4.1.6 Siblings
- 4.1.7 Descendants
- 4.1.8 Height of a Tree
- 4.1.9 Depth of a Node
- 4.1.10 Degree of a Node
- 4.1.11 Level of a Node
- **4.1.12** Subtree

4.2 Types of Trees

- 4.2.1 Binary Tree
- 4.2.1.1 Types of Binary Trees

Left-skewed Binary Tree

Right-skewed Binary Tree

Complete Binary Tree

- 4.2.2 Ternary Tree
- 4.2.3 N-ary Tree
- 4.2.4 Binary Search Tree
- **4.2.5** AVL Tree
- 4.2.6 Red-Black Tree

4.3 Basic Operations on Trees

131 Creation of a Tree

Graphs

5.1	Properties of Graphs
5.1.1	Vertex
5.1.2	Edge
5.1.3	Degree of a Vertex
5.1.4	Path
5.2	Types of Graphs
5.2.1	Finite Graph
5.2.2	Infinite Graph
5.2.3	Trivial Graph
5.2.4	Simple Graph
5.2.5	Multi Graph
5.2.6	Null Graph
5.2.7	Complete Graph
5.2.8	Pseudo Graph
5.2.9	Regular Graph
5.2.10	Bipartite Graph
5.2.11	Labelled Graph
5.2.12	Weighted Graph
5.2.13	Directed Graph
5.2.14	Undirected Graph
5.2.15	Connected Graph
5.2.16	Disconnected Graph
5.2.17	Cyclic Graph

5.2.18 Acyclic Graph

Digraph

Directed Acyclic Graph (DAG)

5.2.19

5.2.20

6.1. SORTING 11

6

Sorting and Searching

6.1	Sorting
-----	---------

- 6.1.1 Types of Sorting Algorithms
- 6.1.1.1 Bubble Sort
- 6.1.1.2 Selection Sort
- 6.1.1.3 Insertion Sort
- 6.1.1.4 Merge Sort
- **6.1.1.5** Quick Sort
- **6.1.1.6** Heap Sort
- 6.1.1.7 Radix Sort
- 6.1.1.8 Counting Sort
- 6.1.1.9 Bucket Sort
- 6.1.2 Comparison of Sorting Algorithms

6.2 Searching

- 6.2.1 Types of Searching Algorithms
- 6.2.1.1 Linear Search
- 6.2.1.2 Binary Search
- 6.2.1.3 Jump Search
- 6.2.1.4 Interpolation Search
- 6.2.1.5 Exponential Search
- 6.2.1.6 Fibonacci Search
- 6.2.1.7 Ternary Search
- 6.2.2 Comparison of Searching Algorithms

6.3 Summary

Hashing

- 7.1 Hash Table
- 7.2 Hash Function
- 7.3 Collision Resolution Techniques
- 7.3.1 Separate Chaining
- 7.3.2 Open Addressing
- 7.3.2.1 Linear Probing
- 7.3.2.2 Quadratic Probing
- 7.3.2.3 Double Hashing
- 7.4 Complexity Analysis of Hashing
- 7.5 Summary

Advanced Data Structures and Algorithms

8.1	Advanced	Data	Structures
().		Dava	

- 8.1.1 Segment Tree
- 8.1.2 Fenwick Tree
- 8.1.3 Suffix Tree
- 8.1.4 Suffix Array
- 8.1.5 Trie
- 8.1.6 Heap
- 8.1.7 Disjoint Set
- 8.1.8 Skip List
- 8.1.9 Splay Tree
- 8.1.10 Bloom Filter
- 8.1.11 KD Tree
- 8.1.12 Quad Tree
- 8.1.13 Octree
- 8.1.14 B-Tree
- 8.1.15 B+ Tree
- 8.1.16 R-Tree
- 8.1.17 X-Tree
- 8.1.18 Y-Tree
- 8.1.19 **Z-Tree**

8.2 Advanced Algorithms

- 8.2.1 Dynamic Programming
- 8.2.2 Greedy Algorithms
- 8.2.3 Backtracking
- 824 Divide and Conquer

Applications of Data Structures and Algorithms

9.1	Applications	in	Computer	Science
9.1	Applications	111	Computer	Science

- 9.1.1 Operating Systems
- 9.1.2 Database Management Systems
- 9.1.3 Compiler Design
- 9.1.4 Networking
- 9.1.5 Artificial Intelligence
- 9.1.6 Machine Learning
- 9.1.7 Computer Graphics
- 9.1.8 Computer Vision
- 9.1.9 Robotics
- 9.1.10 Web Development
- 9.1.11 Mobile Development
- 9.1.12 Game Development
- 9.1.13 Cybersecurity
- 9.1.14 Quantum Computing

9.2 Applications in Real Life

- 9.2.1 Social Media
- 9.2.2 E-commerce
- 9.2.3 Healthcare
- **9.2.4** Finance
- 9.2.5 Transportation
- 9.2.6 Education
- 9.2.7 Agriculture
- 9.2.8 Manufacturing
- 0.2.0 Entertainment

References

A. Books

- Vishwas R. (2023). Data Structure Handbook. Dr. Vishwas Raval. ISBN: 978-9359063591
- Cormen, T. H., Leiserson, C. E., Rivest, R. L., & Stein, C. (2022). Introduction to algorithms. MIT press. ISBN: 978-0262046305
- Erickson, J. (2019). Algorithms. ISBN: 978-1792644832

B. Other Sources

- Tutorialspoint. (n.d.). Data Structures Basics. Data Structure Basics. https://www.tutorialspoint.com/data_structures_algorithms/data_structures_basics.htm
- Algorithm Archive · Arcane Algorithm Archive. (n.d.). https://www.algorithm-archive.org/