Ahlaly

ALGORITHMS • ABSTRACTION • ANALYSIS • ART

"From ancient counting stones to quantum algorithms every data structure tells the story of human ingenuity."

LIVING FIRST EDITION

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THE ART OF ALGORITHMIC ANALYSIS: ALGORITHMIC COST ANALYSIS AND ASYMPTOTIC REASONING

A Living Architecture of Computing

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Part I

Preface

Purpose and Scope of This Book

- 1.1 What This Book Covers
- 1.2 What This Book Does Not Cover
- 1.3 Target Audience: Students, Researchers, and Practitioners

Why "Precise Analysis" Matters — From Theory to Engineering

- 2.1 The Gap Between Theoretical Complexity and Real-World Performance
- 2.2 Case Studies: When Big-O Isn't Enough
- 2.3 The Role of Constants, Lower-Order Terms, and Hardware

Mathematical and Algorithmic Prerequisites

- 3.1 Discrete Mathematics
- 3.1.1 Sets, Functions, and Relations
- 3.1.2 Combinatorics: Permutations, Combinations, and Binomial Coefficients
- 3.1.3 Graph Theory Basics
- 3.1.4 Proof Techniques: Induction, Contradiction, and Contrapositive
- 3.2 Elementary Probability Theory
- 3.2.1 Sample Spaces, Events, and Probability Measures
- 3.2.2 Random Variables and Expectations
- 3.2.3 Basic Distributions: Uniform, Bernoulli, Geometric, Binomial
- 3.2.4 Linearity of Expectation
- 3.2.5 Conditional Probability and Independence
- 3.2.6 Variance and Standard Deviation
- 3.2.7 Moment Generating Functions (Brief Introduction)
- 3:3:00-20 Mathematical Analysis

Structure of the Book: Theorems, Proofs, Examples, and Exercises

- 4.1 How to Read This Book
- 4.2 Notation and Conventions
- 4.3 Types of Exercises: Conceptual, Computational, and Proof-Based
- 4.4 Using Examples Effectively
- 4.5 The Role of Rigor vs. Intuition

Primary References and Parallel Reading Guide

- 5.1 Classic Textbooks (CLRS, Sedgewick, Kleinberg-Tardos)
- 5.2 Research Papers and Monographs
- 5.3 Online Resources and Lecture Notes
- 5.4 Recommended Reading Order and Study Plans

Part II

Foundations of Algorithmic Analysis

Introduction to Algorithm Analysis

6.1	What Is Algorithm Analysis?
6.1.1	Correctness vs. Efficiency
6.1.2	Resource Measures: Time, Space, Energy, I/O
6.1.3	The Need for Mathematical Models
6.2	The RAM Model of Computation
6.2.1	Basic Operations and Unit-Cost Assumption
6.2.2	Memory Access Model
6.2.3	Limitations and Extensions of the RAM Model
6.3	Measuring Algorithm Performance
6.3.1	Input Size and Problem Instances
6.3.2	Counting Basic Operations
6.3.3	Exact vs. Asymptotic Analysis
6.4	Overview of Complexity Classes
6.4.1	P, NP, NP-Complete, and NP-Hard (Brief Introduction)
6.4.2	Why We Focus on Polynomial-Time Algorithms

Asymptotic Notation

7.1	The Need	for Asym	ptotic Analysis

- 7.1.1 Why Exact Counts Are Often Impractical
- 7.1.2 Growth Rates and Scalability
- 7.2 Big-O Notation (O)
- 7.2.1 Formal Definition
- 7.2.2 Intuition: Upper Bounds
- 7.2.3 Common Functions and Their Growth Rates
- 7.2.4 Examples and Non-Examples
- 7.2.5 Properties of Big-O

Transitivity

Addition and Multiplication Rules

Reflexivity and Asymmetry

7.3 Big-Omega Notation (Ω)

- 7.3.1 Formal Definition
- 7.3.2 Intuition: Lower Bounds
- 7.3.3 Examples and Applications
- 7.3.4 Relationship Between O and Ω

7.4 Big-Theta Notation (⊕)

Recurrence Relations and Their Solutions

8.1 Introduction to Recurrence Relation

- 8.1.1 What Are Recurrences?
- 8.1.2 Why They Arise in Algorithm Analysis
- 8.1.3 Examples from Divide-and-Conquer Algorithms

8.2 The Substitution Method

- 8.2.1 Guessing the Solution
- 8.2.2 Proving by Induction
- 8.2.3 Examples: Mergesort, Binary Search
- 8.2.4 Strengthening the Inductive Hypothesis

8.3 The Recursion-Tree Method

- 8.3.1 Visualizing the Recurrence
- 8.3.2 Summing Over Levels
- 8.3.3 Examples and Illustrations
- 8.3.4 Limitations and When to Use

8.4 The Master Theorem

8.4.1 Statement of the Master Theorem (Standard Form)

Best-Case, Worst-Case, and Average-Case Analysis

9.1	Defining	Input	Classes
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- 9.1.1 What Constitutes an "Input"?
- 9.1.2 Problem Instances and Instance Distributions
- 9.2 Best-Case Analysis
- 9.2.1 Definition and Purpose
- 9.2.2 Examples: Insertion Sort, Linear Search
- 9.2.3 When Best-Case Matters (and When It Doesn't)
- 9.3 Worst-Case Analysis
- 9.3.1 Definition and Motivation
- 9.3.2 Guarantees and Robustness
- 9.3.3 Examples: Quicksort, Searching in Unsorted Arrays
- 9.3.4 Lower Bounds and Optimality
- 9.4 Average-Case Analysis
- 9.4.1 Definition: Expected Running Time
- 9.4.2 Assumptions About Input Distributions
- 9.4.3 Probabilistic Models: Uniform, Gaussian, etc.
- 7.4.5 I Tobabilistic Widacis. Offitolini, Gaussian, etc.

Examples: Quicksort, Hashing, Skip Lists

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11.2	Aggregate Analysis
11.2.1	Definition and Methodology
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11.2.3	Example: Binary Counter Increment
11.2.4	Example: Stack with Multipop
11.3	The Accounting Method
11.3.1	Conceptual Framework: Credits and Debits
11.3.2	Defining Amortized Costs
11.3.3	Example: Dynamic Array via Accounting
11.3.4	Example: Splay Trees (Introduction)
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12.1.2	Types of Memory: Stack, Heap, Static
12.1.3	In-Place vs. Out-of-Place Algorithms
12.2	Measuring Space Usage
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12.3.3	Dynamic Programming: Memoization vs. Tabulation
12.3.4	Graph Algorithms: BFS, DFS, Shortest Paths
12.4	Space-Time Tradeoffs
12.4.1	Caching and Memoization
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FrsPEdAn 3202	Compression and Succinct Data Structures

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Cache-Aware and I/O Complexity

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13.1.1	Registers, Cache (L1, L2, L3), RAM, Disk
13.1.2	Latency and Bandwidth Characteristics
13.1.3	Why Algorithm Design Must Consider Memory
13.2	The External Memory Model (I/O Model)
13.2.1	Parameters: N (data size), M (memory size), B (block size)
13.2.2	I/O Complexity: Counting Block Transfers
13.2.3	Comparison with RAM Model
13.3	I/O-Efficient Algorithms
13.3.1	Scanning and Sorting
Externa	l Merge Sort

13.3.2 Matrix Operations

I/O Complexity: $O((N/B)\log_{M/B}(N/B))$

Matrix Transposition

Matrix Multiplication

13.3.3 Graph Algorithms

I/O-Efficient BFS and DFS

Minimum Spanning Tree

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Cache-Aware Scheduling and Analysis for Multicores

Introduction to Multicore and Parallel Computing
Shared vs. Distributed Memory
Parallel Models: PRAM, Fork-Join, Work-Stealing
Performance Metrics: Work, Span, Parallelism
Cache Coherence and Consistency
MESI and MOESI Protocols
False Sharing in Multicore Systems
Impact on Algorithm Design
Cache-Aware Parallel Algorithms
Parallel Sorting with Cache Awareness
Parallel Matrix Multiplication (Strassen, Coppersmith-Winograd)

14.4.1 WCET Analysis in Cache-Aware Contexts

Real-Time and Embedded Systems

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15.1.2	Height of Decision Trees and Worst-Case Complexity
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15.2.3	Implications and Optimal Algorithms
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15.3.1 15.3.2 15.3.3	Finding the Minimum: $\Omega(n)$ Finding Median: Adversary Arguments
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16.1.1	Extending Beyond Comparisons
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16.3	Cell-Probe Model
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Analysis of Specific Algorithm Paradigms

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17.1.2	Examples: Mergesort, Quicksort, Strassen's Algorithm
17.1.3	Optimality and Lower Bounds
17.2	Greedy Algorithms
17.2.1	Correctness via Exchange Arguments
17.2.2	Matroid Theory (Brief Introduction)
17.2.3	Examples: Huffman Coding, Kruskal's MST
17.3	Dynamic Programming
17.3.1	Optimal Substructure and Overlapping Subproblems
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18.1.2	Competitive Ratio
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18.2.2	Load Balancing
18.2.3	Online Scheduling
18.3	Competitive Analysis Techniques
18.3.1	Deterministic vs. Randomized Algorithms
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Approximation Algorithms

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Appendix A

Mathematical Background

- A.1 Summation Formulas
- A.2 Logarithms and Exponentials
- A.3 Recurrence Relations (Quick Reference)
- A.4 Probability Distributions
- A.5 Matrix Operations

Appendix B

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- **B.1** Notation and Style
- **B.2** Common Data Structures

Appendix C

Solutions to Selected Exercises

Appendix D

Glossary of Terms

Appendix E Index of Algorithms

Appendix F

Annotated Bibliography

- F.1 Foundational Texts
- F.2 Research Papers by Topic
- F.3 Online Courses and Resources