

Algorithms

THIRD EDITION

in Java

PARTS 1-4
FUNDAMENTALS
DATA STRUCTURES
SORTING
SEARCHING

Robert Sedgewick
Princeton University

• Addison-Wesley

Boston • San Francisco • New York • Toronto • Montreal
London • Munich • Paris • Madrid
Capetown • Sydney • Tokyo • Singapore • Mexico City

Contents

Fundamentals

Chapter 1. Introduction	3
1.1 Algorithms • 4	
1.2 A Sample Problem: Connectivity • 7	
1.3 Union-Find Algorithms • 11	
1.4 Perspective • 22	
1.5 Summary of Topics • 24	
Chapter 2. Principles of Algorithm Analysis	27
2.1 Implementation and Empirical Analysis • 28	
2.2 Analysis of Algorithms • 33	
2.3 Growth of Functions • 36	
2.4 Big-Oh Notation • 44	
2.5 Basic Recurrences • 49	
2.6 Examples of Algorithm Analysis • 53	
2.7 Guarantees, Predictions, and Limitations • 60	

Data Structures

Chapter 3. Elementary Data Structures	69
3.1 Building Blocks • 70	
3.2 Arrays • 84	
3.3 Linked Lists • 91	
3.4 Elementary List Processing • 97	
3.5 Memory Allocation for Lists • 107	
3.6 Strings -111	
3.7 Compound Data Structures • 116	
Chapter 4. Abstract Data Types	127
4.1 Collections of Items • 137	
4.2 Pushdown Stack ADT • 139	
4.3 Examples of Stack ADT Clients • 142	
4.4 Stack ADT Implementations • 148	
4.5 Generic Implementations • 154	
4.6 Creation of a New ADT • 157	
4.7 FIFO Queues and Generalized Queues • 165	
4.8 Duplicate and Index Items • 273	
4.9 First-Class ADTs • 177	
4.10 Application-Based ADT Example • 188	
4.11 Perspective • 194	
Chapter 5. Recursion and Trees	197
5.1 Recursive Algorithms • 198	
5.2 Divide and Conquer • 206	
5.3 Dynamic Programming -219	
5.4 Trees • 227	
5.5 Mathematical Properties of Trees • 236	
5.6 Tree Traversal • 240	
5.7 Recursive Binary-Tree Algorithms • 246	
5.8 Graph Traversal • 251	
5.9 Perspective -257	

Sorting

Chapter 6. Elementary Sorting Methods	263
6.1 Rules of the Game • 265	
6.2 Generic Sort Implementations • 270	
6.3 Selection Sort • 283	
6.4 Insertion Sort • 285	
6.5 Bubble Sort • 288	
6.6 Performance Characteristics of Elementary Sorts • 289	
6.7 Algorithm Visualization • 295	
6.8 Shellsort • 300	
6.9 Sorting Linked Lists • 308	
6.10 Key-Indexed Counting • 312	
Chapter 7. Quicksort	315
7.1 The Basic Algorithm -316	
7.2 Performance Characteristics of Quicksort • 321	
7.3 Stack Size • 325	
7.4 Small Subfiles • 328	
7.5 Median-of-Three Partitioning • 331	
7.6 Duplicate Keys • 336	
7.7 Strings and Vectors • 339	
7.8 Selection • 341	
Chapter 8. Merging and Mergesort	347
8.1 Two-Way Merging • 348	
8.2 Abstract In-Place Merge • 351	
8.3 Top-Down Mergesort • 353	
8.4 Improvements to the Basic Algorithm • 357	
8.5 Bottom-Up Mergesort • 359	
8.6 Performance Characteristics of Mergesort • 363	
8.7 Linked-List Implementations of Mergesort • 366	
8.8 Recursion Revisited • 370	
Chapter 9. Priority Queues and Heapsort	373
9.1 Elementary Implementations • 377	
9.2 Heap Data Structure • 381	

- 9.3 Algorithms on Heaps • 383
- 9.4 Heapsort • 389
- 9.5 Priority-Queue ADT • 396
- 9.6 Priority Queues for Client Arrays • 402
- 9.7 Binomial Queues • 406

Chapter 10. Radix Sorting 417

- 10.1 Bits, Bytes, and Words • 419
- 10.2 Binary Quicksort • 423
- 10.3 MSD Radix Sort • 427
- 10.4 Three-Way Radix Quicksort • 435
- 10.5 LSD Radix Sort • 441
- 10.6 Performance Characteristics of Radix Sorts • 444
- 10.7 Sublinear-Time Sorts • 448

Chapter 11. Special-Purpose Sorting Methods 453

- 11.1 Batcher's Odd-Even Mergesort • 455
- 11.2 Sorting Networks • 460
- 11.3 Sorting In Place • 468
- 11.4 External Sorting • 474
- 11.5 Sort-Merge Implementations • 480
- 11.6 Parallel Sort-Merge • 486

Searching

Chapter 12. Symbol Tables and BSTs 495

- 12.1 Symbol-Table Abstract Data Type • 497
- 12.2 Key-Indexed Search • 507
- 12.3 Sequential Search • 511
- 12.4 Binary Search • 519
- 12.5 Index Implementations with Symbol Tables • 524
- 12.6 Binary Search Trees • 531
- 12.7 Performance Characteristics of BSTs • 537
- 12.8 Insertion at the Root in BSTs • 542
- 12.9 BST Implementations of Other ADT Operations • 546

Chapter 13. Balanced Trees	555
13.1 Randomized BSTs • 559	
13.2 Splay BSTs • 566	
13.3 Top-Down 2-3-4 Trees • 572	
13.4 Red-Black Trees • 577	
13.5 Skip Lists • 587	
13.6 Performance Characteristics • 595	
Chapter 14. Hashing	599
14.1 Hash Functions • 600	
14.2 Separate Chaining • 610	
14.3 Linear Probing • 615	
14.4 Double Hashing • 620	
14.5 Dynamic Hash Tables • 625	
14.6 Perspective • 629	
Chapter 15. Radix Search	635
15.1 Digital Search Trees • 637	
15.2 Tries • 641	
15.3 Patricia Tries • 650	
15.4 Multiway Tries and TSTs • 660	
15.5 Text-String-Index Applications • 679	
Chapter 16. External Searching	685
16.1 Rules of the Game • 687	
16.2 Indexed Sequential Access • 690	
16.3 B Trees • 692	
16.4 Extendible Hashing • 706	
16.5 Perspective • 718	
Appendix	723
Index	727