

Index

A page number ending in *ex* refers to a topic that is discussed in an exercise.

Numbers

- 3-Coloring Problem
 - NP-completeness, 487–490
 - as optimization problem, 782 *ex*
- 3-Dimensional Matching Problem
 - NP-completeness, 481–485
 - polynomial time approximation algorithm for, 656 *ex*
 - problem, 481
- 3-SAT Problem, 459–460
 - assignments in, 459, 594–596 *ex*
 - as Constraint Satisfaction Problem, 500
 - in Lecture Planning exercise, 503–504 *ex*
- MAX-3-SAT
 - algorithm design and analysis for, 725–726
 - good assignments in, 726–727
 - notes, 793
 - problem, 724–725
 - random assignment for, 725–726, 787 *ex*
- NP completeness, 471
- polynomial space algorithm for, 532
- Quantified. *See* QSAT (Quantified 3-SAT)
- reductions in, 459–463
- 4-Dimensional Matching Problem, 507 *ex*

A

- Aarts, E., 705
- (a,b)-skeletons, 517–518 *ex*

- ABL (average bits per letter) in encoding, 165
- Absolute weight of edges, 671
- Ad hoc networks, 435–436 *ex*
- Adaptive compression schemes, 177
- Add lists in planning problems, 534, 538
- Adenine, 273
- Adjacency lists, 87–89, 93
- Adjacency matrices, 87–89
- Adopters in human behaviors, 523 *ex*
- Ads
 - advertising policies, 422–423 *ex*
 - Strategic Advertising Problem, 508–509 *ex*
- Affiliation network graphs, 76
- Agglomerative clustering, 159
- Ahuja, Ravindra K., 449–450
- Airline route maps, 74
- Airline Scheduling Problem, 387
 - algorithm for
 - analyzing, 390–391
 - designing, 389–390
 - problem, 387–389
- Alignment, sequence. *See* Sequence alignment
- Allocation
 - random, in load balancing, 761–762
 - register, 486
 - resource. *See* Resource allocation
- Alon, N., 793–794
- Alternating paths in Bipartite Matching Problem, 370
- Altofer, Ingo, 207
- Ambiguity in Morse code, 163

- Ancestors
 - lowest common, 96
 - in trees, 77
- Anderberg, M., 206
- Annealing, 669–670
- Anshelevich, E., 706
- Antigens, blood, 418–419 *ex*
- Apartments, expense sharing in, 429–430 *ex*
- Appalachian Trail exercise, 183–185 *ex*
- Appel, K., 490
- Approximate medians, 791 *ex*
- Approximate time-stamps, 196–197 *ex*
- Approximation algorithms, 599–600
 - in caching, 751
 - greedy algorithms for
 - Center Selection Problem, 606–612
 - Interval Scheduling Problem, 649–651 *ex*
 - load balancing, 600–606
 - Set Cover Problem, 612–617
 - Knapsack Problem, 644
 - algorithm analysis for, 646–647
 - algorithm design for, 645–646
 - problem, 644–645
 - linear programming and rounding. *See* Linear programming and rounding
 - load balancing, 637
 - algorithm design and analysis for, 638–643
 - problem, 637–638

- Approximation algorithms (*cont.*)
 Maximum-Cut Problem, 676, 683–684
 algorithm analysis for, 677–679
 algorithm design for, 676–677
 for graph partitioning, 680–681
 notes, 659
 pricing methods
 Disjoint Paths Problem, 624–630
 Vertex Cover Problem, 618–623
 Approximation thresholds, 660
 Arbitrage opportunities for shortest paths, 291
 Arbitrarily good approximations for Knapsack Problem, 644
 algorithms for
 analyzing, 646–647
 designing, 645–646
 problem, 644–645
 Arborescences, minimum-cost, 116, 177
 greedy algorithms for
 analyzing, 181–183
 designing, 179–181
 problem, 177–179
 Arc coloring. *See* Circular-Arc Coloring Problem
 Arithmetic coding, 176
 Arora, S., 660
 Arrays
 in dynamic programming, 258–259
 for heaps, 60–61
 in Knapsack Problem, 270–271
 in Stable Matching Algorithm, 42–45
 for Union-Find structure, 152–153
 ASCII code, 162
 Assignment penalty in Image Segmentation Problem, 683
 Assignments
 3-SAT, 459, 594–596 *ex*
 in bipartite matching, 15
 for linear equations mod 2, 780–781 *ex*
 in load balancing, 637
 for MAX-3-SAT problem, 725–726, 787 *ex*
 partial, 591–594 *ex*
 wavelength, 486
 Astronomical events, 325–326 *ex*
- Asymmetric distances in Traveling Salesman Problem, 479
 Asymmetry of NP, 495–497
 Asymptotic order of growth, 35–36
 in common functions, 40–42
 lower bounds, 37
 notes, 70
 properties of, 38–40
 tight bounds, 37–38
 upper bounds, 36–37
 Asynchronous algorithms
 Bellman-Ford, 299
 Gale-Shapley, 10
 Atmospheric science experiment, 426–427 *ex*
 Attachment costs, 143
 Auctions
 combinatorial, 511 *ex*
 one-pass, 788–789 *ex*
 Augment algorithm, 342–343, 346
 Augmentation along cycles, 643
 Augmenting paths, 342–343
 choosing, 352
 algorithm analysis in, 354–356
 algorithm design in, 352–354
 algorithm extensions in, 356–357
 finding, 412 *ex*
 in Minimum-Cost Perfect Matching Problem, 405
 in neighbor relations, 680
 Average bits per letter (ABL) in encoding, 165
 Average-case analysis, 31, 707
 Average distances in networks, 109–110 *ex*
 Awerbuch, B., 659
 Azar, Y., 659
- B**
- Back-up sets for networks, 435–436 *ex*
 Backoff protocols, 793
 Backward edges in residual graphs, 341–342
 Backward-Space-Efficient-Alignment, 286–287
 Backwards analysis, 794
 Bacon, Kevin, 448 *ex*
 Bank cards, fraud detection, 246–247 *ex*
 Bar-Yehuda, R., 659
 Barabasi, A. L., 113
 Barter economies, 521–522 *ex*
 Base of logarithms, 41
 Base-pairing in DNA, 273–275
 Base stations
 for cellular phones, 190 *ex*, 430–431 *ex*
 for mobile computing, 417–418 *ex*
 Baseball Elimination Problem, 400
 algorithm design and analysis for, 402–403
 characterization in, 403–404
 notes, 449
 problem, 400–401
 Bases, DNA, 273–275
 Beckmann, M., 706
 Belady, Les, 133, 206
 Bell, T. C., 206
 Bellman, Richard, 140, 292, 335
 Bellman-Ford algorithm
 in Minimum-Cost Perfect Matching Problem, 408
 for negative cycles in graphs, 301–303
 for router paths, 298–299
 for shortest paths, 292–295
 Berge, C., 113
 Berlekamp, E. R., 551
 Bern, M., 659
 Bertsekas, D.
 backoff protocols, 793
 shortest-path algorithm, 336
 Bertsimas, Dimitris, 336
 Best achievable bottleneck rate, 198–199 *ex*
 Best-response dynamics, 690, 693–695
 definitions and examples, 691–693
 Nash equilibria and, 696–700
 notes, 706
 problem, 690–691
 questions, 695–696
 Best valid partners in Gale-Shapley algorithm, 10–11
 BFS (breadth-first search), 79–82
 for bipartiteness, 94–96
 for directed graphs, 97–98
 implementing, 90–92
 in planning problems, 541
 for shortest paths, 140
 BGP (Border Gateway Protocol), 301
 Bicriteria shortest path problems, 530

- Bidding agents, 789 *ex*
 - Bids
 - in combinatorial auctions, 511 *ex*
 - in one-pass auctions, 788–789 *ex*
 - Big-improvement-flips, 678
 - Billboard placement, 307–309 *ex*
 - Bin-packing, 651 *ex*
 - Binary search
 - in arrays, 44
 - in Center Selection Problem, 610
 - sublinear time in, 56
 - Binary trees
 - nodes in, 108 *ex*
 - for prefix codes, 166–169
 - Biology
 - genome mapping, 279, 521 *ex*, 787 *ex*
 - RNA Secondary Structure Prediction Problem, 272–273
 - algorithm for, 275–278
 - notes, 335
 - problem, 273–275
 - sequences in, 279
 - Bipartite graphs, 14–16, 337, 368–370
 - 2-colorability of, 487
 - notes, 449
 - testing for, 94–96
 - Bipartite Matching Problem, 337, 367
 - algorithm for
 - analyzing, 369–371
 - designing, 368
 - extensions, 371–373
 - costs in, 404–405
 - algorithm design and analysis for, 405–410
 - algorithm extensions for, 410–411
 - problem, 405
 - description, 14–16
 - in Hopfield neural networks, 703 *ex*
 - neighbor relations in, 679–680
 - in packet switching, 798
 - problem, 368
 - Bipartiteness testing, breadth-first search for, 94–96
 - Bits in encoding, 162–163
 - Blair Witch Project*, 183–185 *ex*
 - Blocking
 - in Disjoint Paths Problem, 627
 - in Interval Scheduling Problem, 650 *ex*
 - in packet switching, 798–799
 - Blood types, 418–419 *ex*
 - Boese, K., 207
 - Boies, David, 503 *ex*
 - Bollobas, B., 113
 - Boolean formulas
 - with quantification, 534
 - in Satisfiability Problem, 459–460
 - Border Gateway Protocol (BGP), 301
 - Borodin, Allan
 - caching, 794
 - greedy algorithms, 207
 - Bottleneck edges, 192 *ex*
 - Bottlenecks
 - in augmenting paths, 342–345, 352
 - in communications, 198–199 *ex*
 - Bounds
 - in asymptotic order of growth
 - lower, 37
 - tight, 37–38
 - upper, 36–37
 - Chernoff, 758–760
 - for load balancing, 762
 - for packet routing, 767–769
 - in circulations, 382–384, 414 *ex*
 - in Load Balancing Problem
 - algorithm analysis for, 601–604
 - algorithm design for, 601
 - algorithm extensions for, 604–606
 - problem, 600
 - Boxes, nesting arrangement for, 434–435 *ex*
 - Boykov, Yuri, 450, 706
 - Breadth-first search (BFS), 79–82
 - for bipartiteness, 94–96
 - for directed graphs, 97–98
 - implementing, 90–92
 - in planning problems, 541
 - for shortest paths, 140
 - Broadcast Time Problem, 527–528 *ex*
 - Brute-force search
 - and dynamic programming, 252
 - in worst-case running times, 31–32
 - Buffers in packet switching, 796–801
 - Butterfly specimens, 107–108 *ex*
- C**
- Cache hits and misses, 132–133, 750
 - Cache Maintenance Problem
 - greedy algorithms for
 - designing and analyzing, 133–136
 - extensions, 136–137
 - notes, 206
 - problem, 131–133
 - Caching
 - optimal
 - greedy algorithm design and analysis for, 133–136
 - greedy algorithm extensions for, 136–137
 - problem, 131–133
 - randomized, 750–751
 - marking algorithm for, 753–755
 - notes, 794
 - problem, 750–752
 - randomized algorithm for, 755–758
 - Capacity and capacity conditions
 - in circulation, 380, 383
 - of cuts, 346, 348
 - of edges, 338
 - in integer-valued flows, 351
 - in network models, 338–339
 - of nodes, 420–421 *ex*
 - for preflows, 357
 - in residual graphs, 342
 - Card guessing
 - with memory, 721–722
 - without memory, 721
 - Carpool scheduling, 431 *ex*
 - Carter, L. J., 794
 - Cascade processes, 523 *ex*
 - Cellular phone base stations, 190 *ex*, 430–431 *ex*
 - Center Selection Problem, 606
 - algorithms for, 607–612
 - limits on approximability, 644
 - local search for, 700–702 *ex*
 - notes, 659
 - problem, 606–607
 - and representative sets, 652 *ex*
 - Central nodes in flow networks, 429 *ex*
 - Central splitters
 - in median-finding, 729–730
 - in Quicksort, 732
 - Certifiers, in efficient certification, 464
 - Chain molecules, entropy of, 547–550 *ex*
 - Chandra, A. K., 551
 - Change detection in Segmented Least Squares Problem, 263

- ChangeKey operation
 - for heaps, 65
 - for Prim's Algorithm, 150
 - for shortest paths, 141–142
- Chao, T., 207
- Character encoding. *See* Huffman codes
- Character sets, 162
- Characterizations
 - notes, 529
 - in NP and co-NP, 496–497
- Charged particles, 247–248 *ex*
- Check reconciliation, 430 *ex*
- Cherkassky, Boris V., 336
- Chernoff, H., 794
- Chernoff bounds, 758–760
 - for load balancing, 762
 - for packet routing, 767–769
- Chernoff-Hoeffding bounds, 794
- Chess, 535
- Chew, L. P., 794
- Children
 - in heaps, 59–61
 - in trees, 77
- Chor, Benny, 794
- Chromatic number. *See* Coloring Problems
- Chromosomes
 - DNA, 279
 - in genome mapping, 521 *ex*, 787 *ex*
- Chu, Y. J., 206
- Chuang, S.-T., 799
- Chvatal, V., 659
- Circuit Satisfiability Problem
 - in NP completeness, 466–470
 - relation to PSPACE-completeness, 543
- Circular-Arc Coloring Problem, 563
 - algorithms for
 - analyzing, 572
 - designing, 566–571
 - notes, 598
 - problem, 563–566
- Circulations
 - in Airline Scheduling Problem, 390
 - with demands, 379–384, 414 *ex*
 - with lower bounds, 382–384, 387, 414 *ex*
 - in survey design, 387
- Citation networks, 75
- Classification via local search, 681–682
 - algorithm analysis for, 687–689
 - algorithm design for, 683–687
 - notes, 706
 - problem, 682–683
- Clause gadgets, 483–484
- Clauses with Boolean variables, 459–460
- Cleary, J. G., 206
- Clock signals, 199 *ex*
- Clones 'R' Us exercise, 309–311 *ex*
- Close to optimal solutions, 599
- Closest-Pair algorithm, 230
- Closest pair of points, 209, 225
 - algorithm for
 - analyzing, 231
 - designing, 226–230
 - notes, 249
 - problem, 226
 - randomized approach, 741–742
 - algorithm analysis for, 746–747
 - algorithm design for, 742–746
 - linear expected running time for, 748–750
 - notes, 794
 - problem, 742
 - running time of, 51–52
- Clustering, 157–158
 - formalizing, 158, 515–516 *ex*
 - greedy algorithms for
 - analyzing, 159–161
 - designing, 157–158
 - notes, 206
 - problem, 158
- CMS (Course Management System), 431–433 *ex*
- Co-NP, 495–496
 - for good characterization, 496–497
 - in PSPACE, 532–533
- Coalition, 500–502 *ex*
- Cobham, A., 70
- Coherence property, 575
- Cohesiveness of node sets, 444 *ex*
- Collaborative filtering, 221–222
- Collecting coupons example, 722–724
- Collective human behaviors, 522–524 *ex*
- Collisions in hashing, 736–737
- Coloring problems
 - 3-Coloring Problem
 - NP-completeness, 487–490
 - as optimization problem, 782 *ex*
- Circular-Arc Coloring Problem, 563
 - algorithm analysis for, 572
 - algorithm design for, 566–571
 - notes, 598
 - problem, 563–566
- Graph Coloring Problem, 485–486, 499
 - chromatic number in, 597 *ex*
 - computational complexity of, 486–487
 - notes, 529
 - NP-completeness, 487–490
 - for partitioning, 499
- Combinatorial auctions, 511 *ex*
- Combinatorial structure of spanning trees, 202–203 *ex*
- Common running times, 47–48
 - cubic, 52–53
 - linear, 48–50
 - $O(n \log n)$, 50–51
 - $O(n^k)$, 53–54
 - quadratic, 51–52
 - sublinear, 56
- Communication networks
 - graphs as models of, 74–75
 - switching in, 26–27 *ex*, 796–804
- Compatibility
 - of configurations, 516–517 *ex*
 - of labelings and preflows, 358
 - of prices and matchings, 408
- Compatible intervals, 116, 253
- Compatible requests, 13, 116, 118–119
- Competitive 3-SAT game, 544–547
- Competitive Facility Location Problem, 17
 - games in, 536–537
 - in PSPACE completeness, 544–547
- Compiler design, 486
- Complementary base-pairing in DNA, 273–275
- Complementary events, 710
- Complex plane, 239
- Complex roots of unity, 239
- Component array, 152–153
- Component Grouping Problem, 494–495
- Compression. *See* Data compression
- Computational steps in algorithms, 35–36

- Computational biology
 - RNA Secondary Structure
 - Prediction Problem, 272–273
 - algorithm for, 275–278
 - notes, 335
 - problem, 273–275
 - sequence alignment. *See* Sequence alignment
- Computational complexity. *See* Computational intractability; Computational tractability
- Computational geometry
 - closest pair of points, 226, 741
 - notes, 249
- Computational intractability, 451–452
- Circuit Satisfiability Problem, 466–470
 - efficient certification in, 463–466
- Graph Coloring Problem, 485–486
 - computational complexity of, 486–487
 - notes, 529
 - NP-completeness, 487–490
- numerical problems, 490
 - in scheduling, 493–494
- Subset Sum Problem, 491–495
- partitioning problems, 481–485
- polynomial-time reductions, 452–454
 - Independent Set in, 454–456
 - Turing, 473
 - Vertex Cover in, 456–459
- Satisfiability Problem, 459–463
- sequencing problems, 473–474
 - Hamiltonian Cycle Problem, 474–479
 - Hamiltonian Path Problem, 480–481
 - Traveling Salesman Problem, 474, 479
- Computational tractability, 29–30
 - efficiency in, 30–31
 - polynomial time, 32–35
 - worst-case running times, 31–32
- Compute-Opt algorithm, 255–256
- Computer game-playing
 - chess, 551
 - PSPACE for, 535–536
- Computer vision, 226, 391, 681
- Concatenating sequences, 308–309 *ex*, 517 *ex*
- Conditional expectation, 724
- Conditional probability, 771–772
- Conditions, in planning problems, 534, 538
- Configurations
 - in Hopfield neural networks, 671, 676, 700, 702–703 *ex*
 - in planning problems, 538–539
- Conflict graphs, 16
- Conflicts
 - in 3-SAT Problem, 461
 - contention resolution for, 782–784 *ex*
 - in Interval Scheduling Problem, 118
- Congestion
 - in Minimum Spanning Tree Problem, 150
 - of packet schedule paths, 765
- Conjunction with Boolean variables, 459
- Connected components, 82–83
- Connected undirected graphs, 76–77
- Connectivity in graphs, 76–79
 - breadth-first search for, 79–82
 - connected components in, 82–83, 86–87, 94
 - depth-first search for, 83–86
 - directed graphs, 97–99
- Conservation conditions
 - for flows, 339
 - for preflows, 357
- Consistent check reconciliation, 430 *ex*
- Consistent k-coloring, 569
- Consistent metrics, 202 *ex*
- Consistent truth assignment, 592 *ex*
- Constraint Satisfaction Problems
 - in 3-SAT, 500
 - in Lecture Planning Problem, 503 *ex*
- Constraints in Linear Programming Problem, 632–634
- Consumer preference patterns, 385
- Container packing, 651 *ex*
- Contention resolution, 708–709
 - algorithm for
 - analyzing, 709–714
 - designing, 709
 - notes, 793
 - problem, 709
 - randomization in, 782–784 *ex*
- Context-free grammars, 272
- Contingency planning, 535
- Contraction Algorithm
 - analyzing, 716–718
 - designing, 715–716
 - for number of global minimum cuts, 718–719
- Control theory, 335
- Convergence of probability functions, 711
- Convolutions, 234
 - algorithms for, 238–242
 - computing, 237–238
 - problem, 234–237
- Conway, J. H., 551
- Cook, S. A., NP-completeness, 467, 529, 543
- Cook reduction, 473
- Cooling schedule in simulated annealing, 669–670
- Corner-to-corner paths for sequence alignment, 284–285, 287–288
- Cost function in local search, 663
- Cost-sharing
 - for apartment expenses, 429–430 *ex*
 - for edges, 690
 - for Internet services, 690–700, 785–786 *ex*
- Coulomb’s Law, 247–248 *ex*
- Counting inversions, 222–223, 246 *ex*
- Counting to infinity, 300–301
- Coupon collecting example, 722–724
- Course Management System (CMS), 431–433 *ex*
- Cover, T., 206
- Coverage Expansion Problem, 424–425 *ex*
- Covering problems, 455–456, 498
- Covering radius in Center Selection Problem, 607–608, 700–702 *ex*
- Crew scheduling, 387
 - algorithm for
 - analyzing, 390–391
 - designing, 389–390
 - problem, 387–389
- Crick, F., 273
- Cross-examination in Lecture Planning Problem, 503 *ex*
- Cryptosystem, 491
- Cubic time, 52–53

- Cushions in packet switching, 801
- Cut Property
 characteristics of, 187–188 *ex*
 in Minimum Spanning Tree Problem, 146–149
- Cuts. *See* Minimum cuts
- Cycle Cover Problem, 528 *ex*
- Cycle Property
 characteristics of, 187–188 *ex*
 in Minimum Spanning Tree Problem, 147–149
- Cytosine, 273
- D**
- DAGs (directed acyclic graphs), 99–104
 algorithm for, 101–104
 problem, 100–101
 topological ordering in, 104 *ex*, 107 *ex*
- Daily Special Scheduling Problem, 526 *ex*
- Das, Gautam, 207
- Dashes in Morse code, 163
- Data compression, 162
 greedy algorithms for
 analyzing, 173–175
 designing, 166–173
 extensions, 175–177
 notes, 206
 problem, 162–166
- Data mining
 for event sequences, 190 *ex*
 in Segmented Least Squares Problem, 263
 for survey design, 385
- Data stream algorithms, 48
- Data structures
 arrays, 43–44
 dictionaries, 734–735
 in graph traversal, 90–94
 for representing graphs, 87–89
 hashing, 736–741
 lists, 44–45
 notes, 70
 priority queues. *See* Priority queues
 queues, 90
 in Stable Matching Problem, 42–47
 stacks, 90
 Union-Find, 151–157
- De Berg, M., 250
- Deadlines
 minimizing lateness, 125–126
 algorithm analysis for, 128–131
 algorithm design for, 126–128
 algorithm extensions for, 131
 notes, 206
 in schedulable jobs, 334 *ex*
 in NP-complete scheduling problems, 493, 500
- Decentralized algorithm for shortest paths, 290–291
- Decision-making data, 513–514 *ex*
- Decision problem
 for efficient certification, 463
 vs. optimization version, 454
- Decision variables in Weighted Vertex Cover problem, 634
- Decisive Subset Problem, 513–514 *ex*
- Decomposition
 path, 376
 tree. *See* Tree decompositions
- Deep Blue program
 in chess matches, 535
 notes, 552
- Degrees
 of nodes, 88
 of polynomials, 40
- Delete lists in planning problems, 534, 538
- Delete operation
 for dictionaries, 735–736, 738
 for heaps, 62, 64–65
 for linked lists, 44–45
- DeLillo, Don, 400
- Demands
 in circulation, 379–384, 414 *ex*
 in survey design, 386
- Demers, Al, 450
- Demographic groups, advertising policies for, 422–423 *ex*
- Dense subgraphs, 788 *ex*
- Dependencies in directed acyclic graphs, 100
- Dependency networks, graphs for, 76
- Depth
 of nodes, 167
 of sets of intervals, 123–125, 566–567
- Depth-first search (DFS), 83–86
 for directed graphs, 97–98
 implementing, 92–94
 in planning problems, 541
- Descendants in trees, 77
- Determined variables, 591 *ex*
- DFS. *See* Depth-first search (DFS)
- Diagonal entries in matrices, 428 *ex*
- Diameter of networks, 109–110 *ex*
- Dictionaries
 hashing for, 734
 data structure analysis for, 740–741
 data structure design for, 735–740
 problem, 734–735
 sequence alignment in, 278–279
- Diestel, R.
 graph theory, 113
 tree decomposition, 598
- Differentiable functions, minimizing, 202 *ex*, 519–520 *ex*
- Dijkstra, Edsger W., 137, 206
- Dijkstra's Algorithm
 in Minimum-Cost Perfect Matching Problem, 408
 for paths, 137–141, 143, 290, 298
- Dilation of paths in packet schedules, 765
- Dinitz, A., 357
- Directed acyclic graphs (DAGs), 99–104
 algorithm for, 101–104
 problem, 100–101
 topological ordering in, 101, 104 *ex*, 107 *ex*
- Directed Disjoint Paths Problem. *See* Disjoint Paths Problem
- Directed Edge-Disjoint Paths Problem, 374, 624–625
- Directed edges for graphs, 73
- Directed graphs, 73
 connectivity in, 97–99
 disjoint paths in, 373–377
 representing, 97
 search algorithms for, 97
 strongly connected, 77, 98–99
 World Wide Web as, 75
- Directed Hopfield networks, 672
- Discovering nodes, 92
- Discrete Fourier transforms, 240
- Disjoint Paths Problem, 373–374, 624
 algorithms for
 analyzing, 375–377

- designing, 374–375
 - extensions, 377–378
 - greedy approximation, 625–627
 - greedy pricing, 628–630
 - notes, 449, 659
 - NP-complete version of, 527 *ex*
 - problem, 374, 624–625
 - for undirected graphs, 377–378, 597 *ex*
 - Disjunction with Boolean variables, 459
 - Disks in memory hierarchies, 132
 - Distance function
 - in clustering, 158
 - for biological sequences, 279–280, 652 *ex*
 - Distance vector protocols
 - description, 297–300
 - problems with, 300–301
 - Distances
 - in breadth-first search, 80
 - in Center Selection Problem, 606–607
 - for closest pair of points, 226, 743–745
 - between graph nodes, 77
 - in Minimum Spanning Tree Problem, 150
 - in networks, 109–110 *ex*
 - in Traveling Salesman Problem, 479
 - Distinct edge costs, 149
 - Distributed systems, 708
 - Diverse Subset Problem, 505 *ex*
 - Divide-and-Conquer-Alignment algorithm, 288–289
 - Divide-and-conquer approach, 209, 727
 - closest pair of points, 225
 - algorithm analysis for, 231
 - algorithm design for, 226–230
 - convolutions, 234
 - algorithms for, 238–242
 - computing, 237–238
 - problem, 234–237
 - integer multiplication, 231
 - algorithm analysis for, 233–234
 - algorithm design for, 232–233
 - problem, 231–232
 - inversions in, 221
 - algorithms for, 223–225
 - problem, 221–223
 - limitations of, 251
 - median-finding, 727
 - algorithm analysis for, 730–731
 - algorithm design for, 728–730
 - problem, 727–728
 - Mergesort Algorithm, 210–211
 - approaches to, 211–212
 - substitutions in, 213–214
 - unrolling recurrences in, 212–213
 - Quicksort, 731–734
 - related recurrences in, 220–221
 - sequence alignment
 - algorithm analysis for, 282–284
 - algorithm design for, 281–282
 - problem, 278–281
 - subproblems in, 215–220
 - DNA, 273–275
 - genome mapping, 521 *ex*
 - RNA. *See* RNA Secondary Structure Prediction Problem
 - sequence alignment for, 279
 - Dobkin, David, 207
 - Doctors Without Weekends, 412–414 *ex*, 425–426 *ex*
 - Domain Decomposition Problem, 529 *ex*
 - Dominating Set Problem
 - Minimum-Cost, 597 *ex*
 - in wireless networks, 776–779 *ex*
 - definition, 519 *ex*
 - Dormant nodes in negative cycle detection, 306
 - Dots in Morse code, 163
 - Doubly linked lists, 44–45
 - Douglas, Michael, 115
 - Downey, R., 598
 - Downstream nodes in flow networks, 429 *ex*
 - Downstream points in communications networks, 26–27 *ex*
 - Dreyfus, S., 336
 - Drezner, Z., 551, 659
 - Droid Trader! game, 524 *ex*
 - Dubes, R., 206
 - Duda, R., 206
 - Duration of packet schedules, 765
 - Dyer, M. E., 659
 - Dynamic programming, 251–252
 - for approximation, 600
 - for Circular-Arc Coloring, 569–571
 - in interval scheduling, 14
 - over intervals, 272–273
 - algorithm for, 275–278
 - problem, 273–275
 - for Knapsack Problem, 266–267, 645, 648
 - algorithm analysis for, 270–271
 - algorithm design for, 268–270
 - algorithm extension for, 271–272
 - for Maximum-Weight Independent Set Problem, 561–562
 - notes, 335
 - in planning problems, 543
 - principles of, 258–260
 - Segmented Least Squares Problem, 261
 - algorithm analysis for, 266
 - algorithm design for, 264–266
 - problem, 261–264
 - for sequence alignment. *See* Sequence alignment
 - for shortest paths in graphs. *See* Shortest Path Problem
 - using tree decompositions, 580–584
 - Weighted Interval Scheduling Problem, 252
 - algorithm design, 252–256
 - memoized recursion, 256–257
- E**
- Earliest Deadline First algorithm, 127–128
 - Edahiro, M., 207
 - Edge congestion, 150
 - Edge costs
 - distinct, 149
 - in Minimum Spanning Tree Problem, 143
 - sharing, 690
 - Edge-disjoint paths, 374–376, 624–625
 - Edge lengths in shortest paths, 137, 290
 - Edge-separation property, 575–577
 - Edges
 - bottleneck, 192 *ex*
 - capacity of, 338
 - in graphs, 13, 73–74
 - in Minimum Spanning Tree Problem, 142–150

- Edges (*cont.*)
 in n -node trees, 78
 reduced costs of, 409
- Edmonds, Jack
 greedy algorithms, 207
 minimum-cost arborescences, 126
 NP-completeness, 529
 polynomial-time solvability, 70
 strongly polynomial algorithms, 357
- Efficiency
 defining, 30–31
 of polynomial time, 32–35
 of pseudo-polynomial time, 271
- Efficient certification in NP-completeness, 463–466
- Efficient Recruiting Problem, 506 *ex*
- El Goog, 191–192 *ex*
- El-Yaniv, R., 794
- Electoral districts, gerrymandering in, 331–332 *ex*
- Electromagnetic observation, 512–513 *ex*
- Electromagnetic pulse (EMP), 319–320 *ex*
- Encoding. *See* Huffman codes
- Ends of edges, 13, 73
- Entropy of chain molecules, 547–550 *ex*
- Environment statistics, 440–441 *ex*
- Eppstein, D., 659
- Equilibrium
 Nash. *See* Nash equilibria
 of prices and matchings, 411
- Erenrich, Jordan, 450
- Ergonomics of floor plans, 416–417 *ex*
- Error of lines, 261–262
- Escape Problem, 421 *ex*
- Euclidean distances
 in Center Selection Problem, 606–607
 in closest pair of points, 226, 743–745
- Euler, Leonhard, 113
- Evasive Path Problem, 510–511 *ex*
- Even, S., 659
- Events
 in contention resolution, 709–712
 independent, 771–772
 in infinite sample spaces, 775
 in probability, 769–770
- Eviction policies and schedules
 in optimal caching, 132–133
 in randomized caching, 750–751
- Excess of preflows, 358
- Exchange arguments
 in greedy algorithms, 116, 128–131
 in Minimum Spanning Tree Problem, 143
 in optimal caching, 131–137
 for prefix codes, 168–169
 proving, 186 *ex*
- Expectation Maximization approach, 701 *ex*
- Expectation, 708
 conditional, 724
 linearity of, 720–724
 of random variables, 719–720, 758–762
- Expected running time
 for closest pair of points, 748–750
 for median-finding, 729–731
 for Quicksort, 732–733
- Expected value in voting, 782 *ex*
- Expenses, sharing
 apartment, 429–430 *ex*
 Internet services, 690–700, 785–786 *ex*
- Exploring nodes, 92
- Exponential functions in asymptotic bounds, 42
- Exponential time, 54–56, 209, 491
- ExtractMin operation
 for heaps, 62, 64
 for Prim's Algorithm, 150
 for shortest paths, 141–142
- F**
- Facility Location Problem
 games in, 536–537
 in PSPACE completeness, 544–547
 for Web servers, 658–659 *ex*
- Factorial growth of search space, 55
- Factoring, 491
- Failure events, 711–712
- Fair driving schedules, 431 *ex*
- Fair prices, 620–621
- Fano, Robert M., 169–170, 206
- Farthest-in-Future algorithm, 133–136, 751
- Fast Fourier Transform (FFT), 234
 for convolutions, 238–242
 notes, 250
- FCC (Fully Compatible Configuration) Problem, 516–517 *ex*
- Feasible assignments in load balancing, 637
- Feasible circulation, 380–384
- Feasible sets of projects, 397
- Feedback, stream ciphers with, 792 *ex*
- Feedback sets, 520 *ex*
- Feller, W., 793
- Fellows, M., 598
- FFT (Fast Fourier Transform), 234
 for convolutions, 238–242
 notes, 250
- Fiat, A., 794
- Fiction, hypertext, 509–510 *ex*
- FIFO (first-in, first-out) order, 90
- Fifteen-puzzle, 534
- Filtering, collaborative, 221–222
- Financial trading cycles, 324 *ex*
- Find operation in Union-Find structure, 151–156
- Find-Solution algorithm, 258–259
- FindMin operation, 64
- Finite probability spaces, 769–771
- First-in, first-out (FIFO) order, 90
- Fixed-length encoding, 165–166
- Flooding, 79, 140–141
- Floor plans, ergonomics of, 416–417 *ex*
- Flows. *See* Network flows
- Floyd, Robert W., 70
- Food webs, 76
- Forbidden pairs in Stable Matching Problem, 19–20 *ex*
- Forcing partial assignment, 592–593 *ex*
- Ford, L. R.
 dynamic programming, 292
 flow, 344, 448
 shortest paths, 140, 335
- Ford-Fulkerson Algorithm, 344–346
 augmenting paths in, 352, 356
 for disjoint paths, 376
 flow and cuts in, 346–352
 for maximum matching, 370
 neighbor relations in, 680
 vs. Preflow-Push algorithm, 359
- Foreground/background segmentation, 391–392
 algorithm for, 393–395
 local search, 681–682

- problem, 392–393
 - tool design for, 436–438 *ex*
- Forests, 559
- Formatting in pretty-printing, 317–319 *ex*
- Forward edges in residual graphs, 341–342
- Four-Color Conjecture, 485, 490
- Fraud detection, 246–247 *ex*
- Free energy of RNA molecules, 274
- Free-standing subsets, 444 *ex*
- Frequencies
 - of letters in encoding, 163, 165–166
- Fresh items in randomized marking algorithm, 756–757
- Frieze, A. M., 659
- Fulkerson, D. R., 344, 448
- Full binary trees, 168
- Fully Compatible Configuration (FCC) Problem, 516–517 *ex*
- Funnel-shaped potential energy landscape, 662–663

- G**
- G-S (Gale-Shapley) algorithm, 6
 - analyzing, 7–9
 - data structures in, 43
 - extensions to, 9–12
 - in Stable Matching Problem, 20–22 *ex*
- Gadgets
 - in 3-Dimensional Matching Problem, 482–484
 - in Graph Coloring Problem, 487–490
 - in Hamiltonian Cycle Problem, 475–479
 - in PSPACE-completeness reductions, 546
 - in SAT problems, 459–463
- Galactic Shortest Path Problem, 527 *ex*
- Gale, David, 1–3, 28
- Gale-Shapley (G-S) algorithm, 6
 - analyzing, 7–9
 - data structures in, 43
 - extensions to, 9–12
 - in Stable Matching Problem, 20–22 *ex*
- Gallager, R.
 - backoff protocols, 793
 - shortest-path algorithm, 336
- Gambling model, 792 *ex*
- Game theory, 690
 - definitions and examples, 691–693
 - and local search, 693–695
 - Nash equilibria in, 696–700
 - questions, 695–696
 - notes, 706
- Games
 - Droid Trader!, 524 *ex*
 - Geography, 550–551 *ex*
 - notes, 551
 - PSPACE, 535–538, 544–547
- Gaps
 - in Preflow-Push Algorithm, 445 *ex*
 - in sequences, 278–280
- Gardner, Martin, 794
- Garey, M., 529
- Gaussian elimination, 631
- Gaussian smoothing, 236
- Geiger, Davi, 450
- Gelatt, C. D., Jr., 669, 705
- Generalized Load Balancing Problem
 - algorithm design and analysis for, 638–643
 - notes, 660
- Genomes
 - mapping, 521 *ex*, 787 *ex*
 - sequences in, 279
- Geographic information systems,
 - closest pair of points in, 226
- Geography game, 550–551 *ex*
- Geometric series in unrolling recurrences, 219
- Gerrymandering, 331–332 *ex*
- Ghallab, Malik, 552
- Gibbs-Boltzmann function, 666–667
- Global minimum cuts, 714
 - algorithm for
 - analyzing, 716–718
 - designing, 715–716
 - number of, 718–719
 - problem, 714–715
- Global minima in local search, 662
- Goal conditions in planning problems, 534
- Goel, A., 799
- Goemans, M. X., 659
- Goldberg, Andrew V.
 - Preflow-Push Algorithm, 449
 - shortest-path algorithm, 336
- Golin, M., 794
- Golovin, Daniel, 530
- Golumbic, Martin C., 113, 205
- Good characterizations
 - notes, 529
 - in NP and co-NP, 496–497
- Gorbunov, K. Yu., 598
- Gradient descents in local search, 665–666, 668
- Graham, R. L.
 - greedy algorithms, 659
 - minimum spanning tree, 206
- Granovetter, Mark, 522 *ex*
- Graph Coloring Problem, 485–486, 499
 - chromatic number in, 597 *ex*
 - computational complexity of, 486–487
 - notes, 529
 - NP-completeness, 487–490
 - for partitioning, 499
- Graph partitioning
 - local search for, 680–681
 - notes, 705
- Graphics
 - closest pair of points in, 226
 - hidden surface removal in, 248 *ex*
- Graphs, 12–13, 73–74
 - bipartite, 14–16, 337, 368–370
 - 2-colorable, 487
 - bipartiteness of, 94–96
 - notes, 449
- breadth-first search in, 90–92
- connectivity in, 76–79
 - breadth-first search in, 79–82
 - connected components in, 82–83, 86–87, 94
 - depth-first search in, 83–86
- depth-first search in, 92–94
- directed. *See* Directed graphs
- directed acyclic (DAGs), 99–104
 - algorithm for, 101–104
 - problem, 100–101
 - topological ordering in, 101, 104 *ex*, 107 *ex*
- examples of, 74–76
- grid
 - greedy algorithms for, 656–657 *ex*
 - local minima in, 248–249 *ex*
 - for sequence alignment, 283–284
- paths in, 76–77

- Graphs (*cont.*)
 queues and stacks for traversing, 89–90
 representing, 87–89
 shortest paths in. *See* Shortest Path Problem
 topological ordering in, 101–104
 algorithm design and analysis for, 101–104
 in DAGs, 104 *ex*, 107 *ex*
 problem, 100–101
 trees. *See* Trees
 Greedy algorithms, 115–116
 for Appalachian Trail exercise, 183–185 *ex*
 for approximation, 599
 Center Selection Problem, 606–612
 load balancing, 600–606
 Set Cover Problem, 612–617
 Shortest-First, 649–651 *ex*
 for clustering
 analyzing, 159–161
 designing, 157–158
 for data compression, 161–166
 analyzing, 173–175
 designing, 166–173
 extensions, 175–177
 for Interval Scheduling Problem, 14, 116
 analyzing, 118–121
 designing, 116–118
 extensions, 121–122
 for Interval Coloring, 121–125
 limitations of, 251
 for minimizing lateness, 125–126
 analyzing, 128–131
 designing, 126–128
 extensions, 131
 for minimum-cost arborescences, 177–179
 analyzing, 181–183
 designing, 179–181
 for Minimum Spanning Tree Problem, 142–143
 analyzing, 144–149
 designing, 143–144
 extensions, 150–151
 for NP-hard problems on trees, 558–560
 for optimal caching, 131–133
 designing and analyzing, 133–136
 extensions, 136–137
 pricing methods in Disjoint Paths Problem, 624
 analyzing, 626, 628–630
 designing, 625–626, 628
 problem, 624–625
 Shortest-First, 649–651 *ex*
 for shortest paths, 137
 analyzing, 138–142
 designing, 137–138
 Greedy-Balance algorithm, 601–602
 Greedy-Disjoint-Paths algorithm, 626
 Greedy-Paths-with-Capacity algorithm, 628–630
 Greedy-Set-Cover algorithm, 613–616
 Greig, D., 449
 Grid graphs
 greedy algorithms for, 656–657 *ex*
 local minima in, 248–249 *ex*
 for sequence alignment, 283–284
 Group decision-making data, 513–514 *ex*
 Growth order, asymptotic, 35–36
 in common functions, 40–42
 lower bounds, 37
 notes, 70
 properties of, 38–40
 tight bounds, 37–38
 upper bounds, 36–37
 Guanine, 273
 Guaranteed close to optimal solutions, 599
 Guessing cards
 with memory, 721–722
 without memory, 721
 Gusfield, D. R.
 sequence analysis, 335
 stable matching, 28
 Guthrie, Francis, 485
 Guy, R. K., 551

H
 Haken, W., 490
 Hall, L., 659–660
 Hall, P., 449
 Hall’s Theorem, 372
 and Menger’s Theorem, 377
 notes, 449
 for NP and co-NP, 497
 Hamiltonian Cycle Problem, 474
 description, 474–475
 NP-completeness of, 475–479
 Hamiltonian Path Problem, 480
 NP-completeness of, 480–481
 running time of, 596 *ex*
 Hard problems. *See* Computational intractability; NP-hard problems
 Harmonic numbers
 in card guessing, 722
 in Nash equilibrium, 695
 Hart, P., 206
 Hartmanis, J., 70
 Hash functions, 736–737
 designing, 737–738
 universal classes of, 738–740, 749–750
 Hash tables, 736–738, 760
 Hashing, 734
 for closest pair of points, 742, 749–750
 data structures for
 analyzing, 740–741
 designing, 735–740
 for load balancing, 760–761
 notes, 794
 problem, 734–735
 Haykin, S., 705
 Head-of-line blocking in packet switching, 798–799
 Heads of edges, 73
 Heap order, 59–61
 Heapify-down operation, 62–64
 Heapify-up operation, 60–62, 64
 Heaps, 58–60
 operations for, 60–64
 for priority queues, 64–65
 for Dijkstra’s Algorithm, 142
 for Prim’s Algorithm, 150
 Heights of nodes, 358–359
 Hell, P., 206
 Hidden surface removal, 248 *ex*
 Hierarchical agglomerative clustering, 159
 Hierarchical metrics, 201 *ex*
 Hierarchies
 memory, 131–132
 in trees, 78
 High-Score-on-Droid-Trader! Problem (HSoDT!), 525 *ex*

- Highway billboard placement, 307–309 *ex*
- Hill-climbing algorithms, 703 *ex*
- Hirschberg, Daniel S., 206
- Histograms with convolution, 237
- Hitting Set Problem
 defined, 506–507 *ex*
 optimization version, 653 *ex*
 set size in, 594 *ex*
- Ho, J., 207
- Hochbaum, Dorit, 659–660
- Hoeffding, H., 794
- Hoey, D., 226
- Hoffman, Alan, 449
- Hopcroft, J., 70
- Hopfield neural networks, 671
 algorithms for
 analyzing, 674–675
 designing, 672–673
 notes, 705
 problem, 671–672
 stable configurations in, 676, 700, 702–703 *ex*
- Hospital resident assignments, 23–24 *ex*
- Houses, floor plan ergonomics for, 416–417 *ex*
- HSoDT! (High-Score-on-Droid-Trader! Problem), 525 *ex*
- Hsu, Y., 207
- Huffman, David A., 170, 206
- Huffman codes, 116, 161
 greedy algorithms for
 analyzing, 173–175
 designing, 166–173
 extensions, 175–177
 notes, 206
 problem, 162–166
- Human behaviors, 522–524 *ex*
- Hyperlinks in World Wide Web, 75
- Hypertext fiction, 509–510 *ex*
- I**
- Ibarra, Oscar H., 660
- Identifier Selection Problem, 770
- Idle time in minimizing lateness, 128–129
- Image Segmentation Problem, 391–392
 algorithm for, 393–395
 with depth, 437–438 *ex*
 local search, 681–682
 problem, 392–393
 tool design for, 436–438 *ex*
- Implicit labels, 248 *ex*
- Inapproximability, 660
- Independent events, 709–710, 771–772
- Independent random variables, 758
- Independent Set Problem, 16–17, 454
 3-SAT reduction to, 460–462
 contention resolution with, 782–784 *ex*
 with Interval Scheduling Problem, 16, 505 *ex*
 notes, 205
 in $O(n^k)$ time, 53–54
 in a path, 312–313 *ex*
 in polynomial-time reductions, 454–456
 running times of, 54–55
 using tree decompositions, 580–584
 relation to Vertex Cover, 455–456, 619
- Independent sets
 for grid graphs, 657 *ex*
 in packing problems, 498
 strongly, 519 *ex*
 in trees, 558–560
- Indifferences in Stable Matching Problem, 24–25 *ex*
- Inequalities
 linear
 in Linear Programming Problem, 631
 for load balancing, 638
 for Vertex Cover Problem, 634
 triangle, 203 *ex*, 334–335 *ex*
- Infinite capacities in Project Selection Problem, 397
- Infinite sample spaces, 774–776
- Influence Maximization Problem, 524 *ex*
- Information networks, graphs for, 75
- Information theory
 for compression, 169
 notes, 206
- Initial conditions in planning problems, 534, 538
- Input buffers in packet switching, 797–801
- Input cushions in packet switching, 801
- Input/output queueing in packet switching, 797
- Insert operation
 for closest pair of points, 746–747
 for dictionaries, 734–736
 for heaps, 64
 for linked lists, 44–45
- Instability in Stable Matching Problem, 4, 20–25 *ex*
- Integer multiplication, 209, 231
 algorithm for
 analyzing, 233–234
 designing, 232–233
 notes, 250
 problem, 231–232
- Integer programming
 for approximation, 600, 634–636
 for load balancing, 638–639
 for Vertex Cover Problem, 634
- Integer Programming Problem, 633–635
- Integer-valued circulations, 382
- Integer-valued flows, 351
- Interference-free schedules, 105 *ex*
- Interference in Nearby Electromagnetic Observation Problem, 512–513 *ex*
- Interior point methods in linear programming, 633
- Interleaving signals, 329 *ex*
- Internal nodes in network models, 339
- Internet routers, 795
- Internet routing
 notes, 336
 shortest paths in, 297–301
- Internet services, cost-sharing for, 690–700, 785–786 *ex*
- Interpolation of polynomials, in Fast Fourier Transform, 238, 241–242
- Intersection Interface Problem, 513 *ex*
- Interval Coloring Problem, 122–125, 566
 from Circular-Arc Coloring Problem, 566–569

- Interval Coloring Problem (*cont.*)
 notes, 598
- Interval graphs, 205
- Interval Partitioning Problem,
 122–125, 566
- Interval Scheduling Problem, 13–14,
 116
 decision version of, 505 *ex*
 greedy algorithms for, 116
 for Interval Coloring, 121–125
 analyzing, 118–121
 designing, 116–118
 extensions, 121–122
 Multiple Interval Scheduling, 512 *ex*
 notes, 206
 for processors, 197 *ex*
 Shortest-First greedy algorithm for,
 649–651 *ex*
- Intervals, dynamic programming
 over
 algorithm for, 275–278
 problem, 273–275
- Inventory problem, 333 *ex*
- Inverse Ackermann function, 157
- Inversions
 algorithms for counting, 223–225
 in minimizing lateness, 128–129
 problem, 221–223
 significant, 246 *ex*
- Investment simulation, 244–246 *ex*
- Irving, R. W., 28
- Ishikawa, Hiroshi, 450
- Iterative-Compute-Opt algorithm,
 259
- Iterative procedure
 for dynamic programming,
 258–260
 for Weighted Interval Scheduling
 Problem, 252
- J**
- Jagged funnels in local search, 663
- Jain, A., 206
- Jars, stress-testing, 69–70 *ex*
- Jensen, T. R., 529, 598
- Jobs
 in Interval Scheduling, 116
 in load balancing, 600, 637–638,
 789–790 *ex*
 in Scheduling to Minimize
 Lateness, 125–126
 in Scheduling with Release Times
 and Deadlines, 493
- Johnson, D. S.
 circular arc coloring, 529
 MAX-SAT algorithm, 793
 NP-completeness, 529
 Set Cover algorithm, 659
- Jordan, M., 598
- Joseph, Deborah, 207
- Junction boxes in communications
 networks, 26–27 *ex*
- K**
- K-clustering, 158
- K-coloring, 563, 569–570
- K-flip neighborhoods, 680
- K-L (Kernighan-Lin) heuristic, 681
- Kahng, A., 207
- Karatsuba, A., 250
- Karger, David, 715, 790 *ex*, 793
- Karmarkar, Narendra, 633
- Karp, R. M.
 augmenting paths, 357
 NP-completeness, 529
 Randomized Marking algorithm,
 794
 Karp reduction, 473
- Kasparov, Garry, 535
- Kempe, D., 530
- Kernighan, B., 681, 705
- Kernighan-Lin (K-L) heuristic, 681
- Keshav, S., 336
- Keys
 in heaps, 59–61
 in priority queues, 57–58
- Khachiyan, Leonid, 632
- Kim, Chul E., 660
- Kirkpatrick, S., 669, 705
- Kleinberg, J., 659
- Knapsack algorithm, 266–267,
 648–649
- Knapsack-Approx algorithm, 646–647
- Knapsack Problem, 266–267, 499
 algorithms for
 analyzing, 270–271
 designing, 268–270
 extensions, 271–272
 approximations, 644
 algorithm analysis in, 646–647
 algorithm design in, 645–646
 problem, 644–645
 total weights in, 657–658 *ex*
 notes, 335, 529
- Knuth, Donald E., 70, 336
 recurrences, 249–250
 stable matching, 28
- Kolmogorov, Vladimir, 449
- König, D., 372, 449
- Korte, B., 659
- Kruskal's Algorithm, 143–144
 with clustering, 159–160
 data structures for
 pointer-based, 154–155
 simple, 152–153
 improvements, 155–157
 optimality of, 146–147
 problem, 151–152
 valid execution of, 193 *ex*
- Kumar, Amit, 598
- L**
- Labeling Problem
 via local search, 682–688
 notes, 706
- Labels and labeling
 gap labeling, 445 *ex*
 image, 437–438 *ex*
 in image segmentation, 393
 in Preflow-Push Algorithm,
 360–364, 445 *ex*
- Landscape in local search, 662
 connections to optimization,
 663–664
 notes, 705
 potential energy, 662–663
 Vertex Cover Problem, 664–
 666
- Laptops on wireless networks,
 427–428 *ex*
- Last-in, first-out (LIFO) order, 90
- Lateness, minimizing, 125–126
 algorithms for
 analyzing, 128–131
 designing, 126–128
 extensions for, 131
 notes, 206
 in schedulable jobs, 334 *ex*
- Lawler, E. L.
 matroids, 207
 NP-completeness, 529
 scheduling, 206
- Layers in breadth-first search, 79–81

- Least-Recently-Used (LRU) principle
 - in caching, 136–137, 751–752
 - notes, 794
 - Least Squares, Segmented Least Squares Problem, 261
 - algorithm for
 - analyzing, 266
 - designing, 264–266
 - notes, 335
 - problem, 261–264
 - Leaves and leaf nodes, in trees, 77, 559
 - Lecture Planning Problem, 502–505 *ex*
 - LEDA (Library of Efficient Algorithms and Datastructures), 71
 - Lee, Lillian, 336
 - Leighton, F. T., 765, 794
 - Lelewer, Debra, 206
 - Lengths
 - of edges and paths in shortest paths, 137, 290
 - of paths in Disjoint Paths Problem, 627–628
 - of strings, 463
 - Lenstra, J. K.
 - local search, 705
 - rounding algorithm, 660
 - scheduling, 206
 - Levin, L., 467, 529, 543
 - Library of Efficient Algorithms and Datastructures (LEDA), 71
 - Licenses, software, 185–187 *ex*
 - LIFO (last-in, first-out) order, 90
 - Light fixtures, ergonomics of, 416–417 *ex*
 - Likelihood in image segmentation, 393
 - Limits on approximability, 644
 - Lin, S., 681, 705
 - Line of best fit, 261–262
 - Linear equations
 - mod 2, 779–782 *ex*
 - solving, 631
 - Linear programming and rounding, 630–631
 - for approximation, 600
 - general techniques, 631–633
 - Integer Programming Problem, 633–635
 - for load balancing, 637
 - algorithm design and analysis for, 638–643
 - problem, 637–638
 - notes, 659–660
 - for Vertex Cover, 635–637
 - Linear Programming Problem, 631–632
 - Linear space, sequence alignment in, 284
 - algorithm design for, 285–288
 - problem, 284–285
 - Linear time, 48–50
 - for closest pair of points, 748–750
 - graph search, 87
 - Linearity of expectation, 720–724
 - Linked lists, 44–45
 - Linked sets of nodes, 585–586
 - Lists
 - adjacency, 87–89, 93
 - merging, 48–50
 - in Stable Matching Algorithm, 42–45
 - Liu, T. H., 206
 - Llewellyn, Donna, 250
 - Lo, Andrew, 336
 - Load balancing
 - greedy algorithm for, 600–606
 - linear programming for, 637
 - algorithm design and analysis for, 638–643
 - problem, 637–638
 - randomized algorithms for, 760–762
 - Local minima in local search, 248–249 *ex*, 662, 665
 - Local optima
 - in Hopfield neural networks, 671
 - in Labeling Problem, 682–689
 - in Maximum-Cut Problem, 677–678
 - Local search, 661–662
 - best-response dynamics as, 690, 693–695
 - definitions and examples, 691–693
 - Nash equilibria in, 696–700
 - problem, 690–691
 - questions, 695–696
 - classification via, 681–682
 - algorithm analysis for, 687–689
 - algorithm design for, 683–687
 - notes, 706
 - problem, 682–683
 - Hopfield neural networks, 671
 - algorithm analysis for, 674–675
 - algorithm design for, 672–673
 - local optima in, 671
 - problem, 671–672
 - for Maximum-Cut Problem
 - approximation, 676–679
 - Metropolis algorithm, 666–669
 - neighbor relations in, 663–664, 679–681
 - notes, 660
 - optimization problems, 662
 - connections to, 663–664
 - potential energy, 662–663
 - Vertex Cover Problem, 664–666
 - simulated annealing, 669–670
 - Locality of reference, 136, 751
 - Location problems, 606, 659
 - Logarithms in asymptotic bounds, 41
 - Lombardi, Mark, 110 *ex*
 - Lookup operation
 - for closest pair of points, 748–749
 - for dictionaries, 735–736, 738
 - Loops, running time of, 51–53
 - Lovász, L., 659
 - Low-Diameter Clustering Problem, 515–516 *ex*
 - Lower bounds
 - asymptotic, 37
 - circulations with, 382–384, 387, 414 *ex*
 - notes, 660
 - on optimum for Load Balancing Problem, 602–603
 - Lowest common ancestors, 96
 - LRU (Least-Recently-Used) principle
 - in caching, 136–137, 751–752
 - notes, 794
 - Luby, M., 794
 - Lund, C., 660
- M**
- M-Compute-Opt algorithm, 256–257
 - Maggs, B. M., 765, 794
 - Magnanti, Thomas L., 449–450
 - Magnets, refrigerator, 507–508 *ex*
 - Main memory, 132
 - MakeDictionary operation
 - for closest pair of points, 745–746
 - for hashing, 734
 - Makespans, 600–605, 654 *ex*
 - MakeUnionFind operation, 152–156
 - Manber, Udi, 450

- Mapping genomes, 279, 521 *ex*, 787 *ex*
- Maps of routes for transportation networks, 74
- Margins in pretty-printing, 317–319 *ex*
- Marketing, viral, 524 *ex*
- Marking algorithms for randomized caching, 750, 752–753
analyzing, 753–755
notes, 794
randomized, 755–758
- Martello, S., 335, 529
- Matching, 337
3-Dimensional Matching Problem
NP-completeness, 481–485
polynomial time in, 656 *ex*
problem, 481
4-Dimensional Matching Problem, 507 *ex*
base-pair, 274
in bipartite graphs. *See* Bipartite Matching Problem
in load balancing, 638
Minimum-Cost Perfect Matching Problem, 405–406
algorithm design and analysis for, 405–410
economic interpretation of, 410–411
notes, 449
in packet switching, 798, 801–803
in sequences, 278–280
in Stable Matching Problem. *See* Stable Matching Problem
- Mathews, D. H., 335
- Matrices
adjacency, 87–89
entries in, 428 *ex*
in linear programming, 631–632
- Matroids, 207
- MAX-3-SAT
algorithm design and analysis for, 725–726
good assignments for, 726–727
notes, 793
problem, 724–725
random assignment for, 725–726, 787 *ex*
- Max-Flow Min-Cut Theorem, 348–352
for Baseball Elimination Problem, 403
for disjoint paths, 376–377
good characterizations via, 497
with node capacities, 420–421 *ex*
- Maximum 3-Dimensional Matching Problem, 656 *ex*
- Maximum, computing in linear time, 48
- Maximum-Cut Problem in local search, 676, 683
algorithms for
analyzing, 677–679
designing, 676–677
for graph partitioning, 680–681
- Maximum Disjoint Paths Problem, 624
greedy approximation algorithm for, 625–627
pricing algorithm for, 628–630
problem, 624–625
- Maximum-Flow Problem
algorithm for
analyzing, 344–346
designing, 340–344
extensions, 378–379
circulations with demands, 379–382
circulations with demands and lower bounds, 382–384
with node capacities, 420–421 *ex*
notes, 448
problem, 338–340
- Maximum Matching Problem. *See* Bipartite Matching Problem
- Maximum spacing, clusterings of, 158–159
- Maximum-Weight Independent Set Problem
using tree decompositions, 572, 580–584
on trees, 560–562
- Maze-Solving Problem, 78–79
- McGeoch, L. A., 794
- McGuire, C. B., 706
- McKeown, N., 799
- Median-finding, 209, 727
algorithm for
analyzing, 730–731
designing, 728–730
approximation for, 791 *ex*
problem, 727–728
- Medical consulting firm, 412–414 *ex*, 425–426 *ex*
- Mehlhorn, K., 71
- Memoization, 256
over subproblems, 258–260
for Weighted Interval Scheduling Problem, 256–257
- Memory hierarchies, 131–132
- Menger, K., 377, 449
- Menger's Theorem, 377
- Merge-and-Count algorithm, 223–225
- Mergesort Algorithm, 210–211
as example of general approach, 211–212
notes, 249
running times for, 50–51
recurrences for, 212–214
- Merging
inversions in, 221–225
sorted lists, 48–50
- Meta-search tools, 222
- Metropolis, N., 666, 705
- Metropolis algorithm, 666–669
- Meyer, A., 543, 551
- Miller, G., 598
- Minimum-altitude connected subgraphs, 199 *ex*
- Minimum-bottleneck spanning trees, 192 *ex*
- Minimum Cardinality Vertex Cover Problem, 793 *ex*
- Minimum-Cost Arborescence Problem, 116, 177
greedy algorithms for
analyzing, 181–183
designing, 179–181
problem, 177–179
- Minimum-Cost Dominating Set Problem, 597 *ex*
- Minimum-Cost Path Problem. *See* Shortest Path Problem
- Minimum-Cost Flow Problem, 449
- Minimum-Cost Perfect Matching Problem, 405–406
algorithm design and analysis for, 405–410
economic interpretation of, 410–411
notes, 449
- Minimum cuts
in Baseball Elimination Problem, 403–404
global, 714
algorithm analysis for, 716–718
algorithm design for, 715–716

- number of, 718–719
 - problem, 714–715
 - in image segmentation, 393
 - Karger's algorithm for, 790 *ex*
 - in local search, 684
 - in Maximum-Flow Problem, 340
 - in networks, 346
 - algorithm analysis for, 346–348
 - maximum flow with, 348–352
 - notes, 793
 - in Project Selection Problem, 397–399
 - Minimum Spanning Tree Problem, 116
 - greedy algorithms for
 - analyzing, 144–149
 - designing, 143–144
 - extensions, 150–151
 - notes, 206
 - problem, 142–143
 - Minimum spanning trees
 - for clustering, 157–159
 - membership in, 188 *ex*
 - Minimum-weight Steiner trees, 204 *ex*, 335 *ex*
 - Minimum Weight Vertex Cover Problem, 793 *ex*
 - Mismatch costs, 280
 - Mismatches in sequences, 278–280
 - Mitzenmacher, M., 793–794
 - Mobile computing, base stations for, 417–418 *ex*
 - Mobile robots, 104–106 *ex*
 - Mobile wireless networks, 324–325 *ex*
 - Mod 2 linear equations, 779–782 *ex*
 - Modified Quicksort algorithm, 732–734
 - Molecules
 - closest pair of points in, 226
 - entropy of, 547–550 *ex*
 - protein, 651–652 *ex*
 - RNA, 273–274
 - Monderer, D., 706
 - Monitoring networks, 423–424 *ex*
 - Monotone formulas, 507 *ex*
 - Monotone QSAT, 550 *ex*
 - Monotone Satisfiability, 507 *ex*
 - Morse, Samuel, 163
 - Morse code, 163
 - Most favorable Nash equilibrium solutions, 694–695
 - Motwani, R., 793–794
 - Multi-phase greedy algorithms, 177
 - analyzing, 181–183
 - designing, 179–181
 - problem, 177–179
 - Multi-way choices in dynamic programming, 261
 - algorithm for
 - analyzing, 266
 - designing, 264–266
 - problem, 261–264
 - for shortest paths, 293
 - Multicast, 690
 - Multicommodity Flow Problem, 382
 - Multigraphs in Contraction Algorithm, 715
 - Multiple Interval Scheduling, 512 *ex*
 - Multiplication
 - integer, 209, 231
 - algorithm analysis for, 233–234
 - algorithm design for, 232–233
 - notes, 250
 - problem, 231–232
 - polynomials via convolution, 235, 238–239
 - Multivariable Polynomial Minimization Problem, 520 *ex*
 - Mutual reachability, 98–99
 - Mutually reachable nodes, 98–99
- N**
- N-node trees, 78
 - Nabokov, Vladimir, 107 *ex*
 - Näher, S., 71
 - Nash, John, 692
 - Nash equilibria
 - definitions and examples, 691–693
 - finding, 696–700
 - notes, 706
 - problem, 690–691
 - questions, 695–696
 - National Resident Matching Problem, 3, 23–24 *ex*
 - Natural brute-force algorithm, 31–32
 - Natural disasters, 419 *ex*
 - Nau, Dana, 552
 - Near-trees, 200 *ex*
 - Nearby Electromagnetic Observation Problem, 512–513 *ex*
 - Needleman, S., 279
 - Negation with Boolean variables, 459
 - Negative cycles, 301
 - algorithms for
 - designing and analyzing, 302–304
 - extensions, 304–307
 - in Minimum-Cost Perfect Matching Problem, 406
 - problem, 301–302
 - relation to shortest paths, 291–294
 - Neighborhoods
 - in Hopfield neural networks, 677
 - in Image Segmentation Problem, 682
 - in local search, 663–664, 685–687
 - in Maximum-Cut Problem, 680
 - Nemhauser, G. L., 206
 - Nesetril, J., 206
 - Nested loops, running time of, 51–53
 - Nesting arrangement for boxes, 434–435 *ex*
 - Network design, in Minimum Spanning Tree Problem, 142–143, 150
 - Network flow, 337–338
 - Airline Scheduling Problem, 387
 - algorithm analysis for, 390–391
 - algorithm design for, 389–390
 - problem, 387–389
 - Baseball Elimination Problem, 400
 - algorithm design and analysis for, 402–403
 - characterization in, 403–404
 - problem, 400–401
 - Bipartite Matching Problem. *See* Bipartite Matching Problem
 - Disjoint Paths Problem, 373–374
 - algorithm analysis for, 375–377
 - algorithm design for, 374–375
 - algorithm extensions for, 377–378
 - problem, 374
 - good augmenting paths for, 352
 - algorithm analysis for, 354–356
 - algorithm design for, 352–354
 - algorithm extensions for, 356–357
 - finding, 412 *ex*
 - Image Segmentation Problem, 391–392
 - algorithm for, 393–395

- Network flow (*cont.*)
 Image Segmentation Problem (*cont.*)
 problem, 392–393
 Maximum-Flow Problem. *See* Maximum-Flow Problem
 Preflow-Push Maximum-Flow Algorithm, 357
 algorithm analysis for, 361–365
 algorithm design for, 357–361
 algorithm extensions for, 365
 algorithm implementation for, 365–367
 Project Selection Problem, 396–399
- Networks
 graphs as models of, 75–76
 neural. *See* Hopfield neural networks
 routing in. *See* Routing in networks
 social, 75–76, 110–111 *ex*
 wireless, 108–109 *ex*, 324–325 *ex*
- Newborn, M., 551–552
- Nielsen, Morten N., 207
- Node-Disjoint Paths Problem, 597 *ex*
- Node-separation property, 575–576
- Nodes
 in binary trees, 108 *ex*
 central, 429 *ex*
 degrees of, 88
 depth of, 167
 discovering, 92
 in graphs, 13, 73–74
 for heaps, 59–60
 heights of, 358–359
 linked sets of, 585–586
 local minimum, 248 *ex*
 in network models, 338–339
 prices on, 407–410
 in shortest paths, 137
- Nonadopters in human behaviors, 523 *ex*
- Noncrossing conditions in RNA base-pair matching, 274
- Nondeterministic search, 464n
- Nonsaturating push operations, 363–364, 446 *ex*
- Norvig, P., 552
- Nowakowski, R., 551
- NP and NP-completeness, 451–452, 466
 Circuit Satisfiability Problem, 466–470
 co-NP and asymmetry in, 495–497
 efficient certification in, 463–466
 Graph Coloring, 485–490
 independent sets, 17
 notes, 529, 659
 numerical problems, 490–495
 partitioning problems, 481–485
 polynomial-time reductions, 452–454
 Independent Set in, 454–456
 Turing, 473
 Vertex Cover in, 456–459
 proofs for, 470–473
 Satisfiability Problem in, 459–463
 sequencing problems, 473–474
 Hamiltonian Cycle Problem, 474–479
 Hamiltonian Path Problem, 480–481
 Traveling Salesman Problem, 474, 479
 taxonomy of, 497–500
- NP-hard problems, 553–554
 taxonomy of, 497–500
 on trees, 558
 Circular-Arc Coloring Problem. *See* Circular-Arc Coloring Problem
 decompositions. *See* Tree decompositions
 greedy algorithm for, 558–560
 Maximum-Weight Independent Set Problem, 560–562
 Vertex Cover Problem, 554–555
 algorithm analysis for, 557
 algorithm design for, 555–557
- Null pointers in linked lists, 44
- Number Partitioning Problem, 518 *ex*
- Numerical problems, 490, 499
 in scheduling, 493–494
 Subset Sum Problem, 491–495
- O**
- O notation
 in asymptotic order of growth, 36–38
 exercise for, 65–66 *ex*
- $O(n^2)$ time, 51–52
 $O(n^3)$ time, 52–53
 $O(n^k)$ time, 53–54
 $O(n \log n)$ time, 50–51
- Objective function in Linear Programming Problem, 632
- Odd cycles and graph bipartiteness, 95
- Off-center splitters in median-finding, 730
- Offering prices in combinatorial auctions, 511 *ex*
- Ofman, Y., 250
- Omega notation
 in asymptotic order of growth, 37–38
 exercise, 66 *ex*, 68 *ex*
- On-line algorithms, 48
 for caching, 751
 for Interval Scheduling Problem, 121
 notes, 794
- One-pass auction, 788–789 *ex*
- Open-Pit Mining Problem, 397
- Operators in planning problems, 534, 538–540
- Opportunity cycles, 324 *ex*
- Optimal caching
 greedy algorithms for
 designing and analyzing, 133–136
 extensions, 136–137
 notes, 206
 problem, 131–133
- Optimal prefix codes, 165–166, 170–173
- Optimal radius in Center Selection Problem, 607–610
- Optimal schedules in minimizing lateness, 128–131
- Oral history study, 112 *ex*
- Order of growth, asymptotic. *See* Asymptotic order of growth
- Ordered graphs, characteristics of, 313 *ex*
- Ordered pairs as representation of directed graph edges, 73
- Ordering, topological, 102
 computing, 101
 in DAGs, 102, 104 *ex*, 107 *ex*
 node deletions in, 102–104
- Orlin, James B., 449–450
- Output buffers in packet switching, 796–801
- Output cushions in packet switching, 801

- Output queuing in packet switching, 796–797
- Overlay networks, 784–785 *ex*
- Overmars, M., 250
- P**
- P class. *See* Polynomial time
- Packet routing, 762–763
algorithm for
analyzing, 767–769
designing, 765–767
notes, 794
problem, 763–765
- Packet switching
algorithm for
analyzing, 803–804
designing, 800–803
problem, 796–800
- Packets, 763
- Packing problems, 456, 498
- Pairs of points, closest. *See* Closest pair of points
- Papadimitriou, Christos H.
circular arc coloring, 529
complexity theory, 551
game theory, 706
- Parameterized complexity, 598
- Parents in trees, 77
- Parsing algorithms for context-free grammars, 272
- Partial assignment, 591–594 *ex*
- Partial products in integer multiplication, 232
- Partial substitution
in sequence alignment recurrence, 289
in unrolling recurrences, 214, 217–219, 243–244 *ex*
- Partial tree decomposition, 588–590
- Partitioning problems, 498–499
3-Dimensional Matching Problem, 481–485
Graph Coloring Problem, 485–486
Interval Partitioning Problem, 121–125, 566
local search for, 680–681
Maximum Cut Problem, 676
notes, 705
Number Partitioning Problem, 518 *ex*
Segmented Least Squares Problem, 263–265
- Path Coloring Problem, 563–565
- Path decomposition, 376
- Path Selection Problem, 508 *ex*
- Path vector protocols, 301
- Paths, 76–77
augmenting. *See* Augmenting paths
disjoint. *See* Disjoint Paths Problem
shortest. *See* Shortest Path Problem
- Patterns
in related recurrences, 221
in unrolling recurrences, 213, 215, 218
- Pauses in Morse code, 163
- Peer-to-peer systems, 784–785 *ex*
- Peering relationships in communication networks, 75
- Perfect Assembly Problem, 521 *ex*
- Perfect matching, 337
in Bipartite Matching Problem, 14–16, 371–373, 404–405
in Gale-Shapley algorithm, 8
in Stable Matching Problem, 4–5
- Permutations
of database tables, 439–440 *ex*
in sequencing problems, 474
- Phases for marking algorithms, 752–753
- Picard, J., 450
- Picnic exercise, 327 *ex*
- Pieces in tree decompositions, 574
- Ping commands, 424 *ex*
- Pixels
compression of images, 176
in image segmentation, 392–394
in local search algorithm, 682
- Placement costs, 323–324 *ex*
- Planning
contingency, 535
notes, 552
in PSPACE, 533–535, 538
algorithm analysis for, 542–543
algorithm design for, 540–542
problem, 538–540
- Plot Fulfillment Problem, 510 *ex*
- Plotkin, S., 659
- P = NP question, 465
- Pointer-based structures for Union-Find, 154–156
- Pointer graphs in negative cycle detection algorithm, 304–306
- Pointers
for heaps, 59–60
in linked lists, 44
in Union-Find data structure, 154–157
- Points, closest pairs of. *See* Closest pair of points
- Politics, gerrymandering in, 331–332 *ex*
- Polymer models, 547–550 *ex*
- Polynomial Minimization Problem, 520 *ex*
- Polynomial space. *See* PSPACE
- Polynomial time, 34, 463–464
approximation scheme, 644–645
in asymptotic bounds, 40–41
as definition of efficiency, 32–35
in efficient certification, 463
notes, 70–71
reductions, 452–454
Independent Set in, 454–456
Turing, 473
Vertex Cover in, 456–459
- Polynomial-time algorithm, 33
- Polynomially bounded numbers, subset sums with, 494–495
- Polynomials, recursive procedures for, 240–241
interpolation, 238, 241–242
multiplication, 235
- Porteous, B., 449
- Porting software, 433 *ex*
- Potential functions
in Nash equilibrium, 700
notes, 706
for push operations, 364
- Prabhakar, B., 799
- Precedence constraints in Project Selection Problem, 396–397
- Precedence relations in directed acyclic graphs, 100
- Preference lists in Stable Matching Problem, 4–5
- Preferences in Stable Matching Problem, 4
- Prefix codes, 164–165
binary trees for, 166–169
optimal, 165–166, 170–173
- Prefix events in infinite sample spaces, 775
- Preflow-Push Maximum-Flow Algorithm, 357
analyzing, 361–365
designing, 357–361

- Preflow-Push Maximum-Flow Algorithm (*cont.*)
 extensions, 365
 implementing, 365
 notes, 449
 variants, 444–446 *ex*
- Preflows, 357–358
- Preparata, F. P., 249
- Preprocessing for data structures, 43
- Prerequisite lists in planning
 problems, 534, 538
- Press, W. H., 250
- Pretty-printing, 317–319 *ex*
- Price of stability
 in Nash equilibrium, 698–699
 notes, 706
- Prices
 economic interpretation of, 410–411
 fair, 620–621
 in Minimum-Cost Perfect Matching Problem, 407–410
- Pricing (primal-dual) methods, 206
 for approximation, 599–600
 Disjoint Paths Problem, 624–630
 Vertex Cover Problem, 618–623
 notes, 659
- Primal-dual methods. *See* Pricing methods
- Prim's Algorithm
 implementing, 149–150
 optimality, 146–147
 for spanning trees, 143–144
- Printing, 317–319 *ex*
- Priority queues, 57–58
 for Dijkstra's Algorithm, 141–142
 heaps for. *See* Heaps
 for Huffman's Algorithm, 175
 notes, 70
 for Prim's Algorithm, 150
- Priority values, 57–58
- Probabilistic method
 for MAX-3-SAT problem, 726
 notes, 793
- Probability, 707
 Chernoff bounds, 758–760
 conditional, 771–772
 of events, 709–710, 769–770
 probability spaces in
 finite, 769–771
 infinite, 774–776
 Union Bound in, 772–774
- Probability mass, 769
- Probing nodes, 248 *ex*
- Process Naming Problem, 770
- Progress measures
 for best-response dynamics, 697
 in Ford-Fulkerson Algorithm, 344–345
 in Gale-Shapley algorithm, 7–8
 in Hopfield neural networks, 674
- Project Selection Problem, 396
 algorithm for
 analyzing, 398–399
 designing, 397–398
 problem, 396–397
- Projections of database tables, 439–440 *ex*
- Proposed distances for closest pair of points, 743–745
- Protein molecules, 651–652 *ex*
- Pseudo-code, 35–36
- Pseudo-knotting, 274
- Pseudo-polynomial time
 in augmenting paths, 356–357
 efficiency of, 271
 in Knapsack Problem, 645
 in Subset Sum Problem, 491
- PSPACE, 531–533
 completeness in, 18, 543–547
 for games, 535–538, 544–547
 planning problems in, 533–535, 538
 algorithm analysis for, 542–543
 algorithm design for, 540–542
 problem, 538–540
 quantification in, 534–538
- Pull-based Bellman-Ford algorithm, 298
- Pure output queueing in packet switching, 796
- Push-based Bellman-Ford algorithm, 298–299
- Push-Based-Shortest-Path algorithm, 299
- Push operations in preflow, 360, 446 *ex*
- Pushing flow in network models, 341
- Q**
- QSAT (Quantified 3-SAT), 535–536
 algorithm for
 analyzing, 537–538
 designing, 536–537
 extensions, 538
 monotone, 550 *ex*
 notes, 551
 in PSPACE completeness, 543–545
- Quadratic time, 51–52
- Quantification in PSPACE, 534–538
- Quantifiers in PSPACE completeness, 544
- Queue management policy, 763
- Queues
 for graph traversal, 89–90
 for Huffman's Algorithm, 175
 in packet routing, 763
 in packet switching, 796–797
 priority. *See* Priority queues
- Quicksort, 731–734
- R**
- Rabin, M. O., 70, 794
- Rackoff, Charles, 207
- Radio interference, 512–513 *ex*
- Radzik, Tomasz, 336
- Raghavan, P., 793
- Random assignment
 for linear equations mod 2, 780–781 *ex*
 for MAX-3-SAT problem, 725–726, 787 *ex*
- Random variables, 719–720
 with convolution, 237
 expectation of, 719–720
 linearity of expectation, 720–724
- Randomized algorithms, 707–708
 for approximation algorithms, 660, 724–727, 779–782 *ex*, 787–788 *ex*, 792–793 *ex*
 caching. *See* Randomized caching
 Chernoff bounds, 758–760
 closest pair of points, 741–742
 algorithm analysis for, 746–747
 algorithm design for, 742–746
 linear expected running time for, 748–750
 notes, 794
 problem, 742
 contention resolution, 708–709
 algorithm analysis for, 709–714
 algorithm design for, 709
 notes, 793
 problem, 709

- randomization in, 782–784 *ex*
- divide-and-conquer approach, 209, 727
- median-finding, 727–731
- Quicksort, 731–734
- global minimum cuts, 714
 - algorithm analysis for, 716–718
 - algorithm design for, 715–716
 - number of, 718–719
 - problem, 714–715
- hashing, 734
 - data structure analysis for, 740–741
 - data structure design for, 735–740
 - problem, 734–735
- for load balancing, 760–762
- for MAX-3-SAT, 724–727
- notes, 793
- for packet routing, 762–763
 - algorithm analysis for, 767–769
 - algorithm design for, 765–767
 - notes, 794
 - problem, 763–765
- probability. *See* Probability
- random variables and expectations in, 719–724
- Randomized caching, 750
 - marking algorithms for, 752–753
 - analyzing, 753–755
 - notes, 794
 - randomized, 755–758
 - notes, 794
 - problem, 750–752
- Rankings, comparing, 221–222
- Ranks in Stable Matching Problem, 4
- Rao, S., 765, 794
- Ratcliff, H., 450
- Rearrangeable matrices, 428 *ex*
- Rebooting computers, 320–322 *ex*
- Reconciliation of checks, 430 *ex*
- Recurrences and recurrence relations, 209
 - for divide-and-conquer algorithms, 210–211
 - approaches to, 211–212
 - substitutions in, 213–214
 - unrolling recurrences in, 212–213, 244 *ex*
- in sequence alignment, 285–286, 289–290
- subproblems in, 215–220
- in Weighted Interval Scheduling Problem, 257
- Recursive-Multiple algorithm, 233–234
- Recursive procedures
 - for depth-first search, 85, 92
 - for dynamic programming, 259–260
 - for Weighted Interval Scheduling Problem, 252–256
- Reduced costs of edges, 409
- Reduced schedules in optimal caching, 134–135
- Reductions
 - polynomial-time, 452–454
 - Turing, Cook, and Karp, 473
 - in PSPACE completeness, 546
 - transitivity of, 462–463
- Reed, B., 598
- Refrigerator magnets, 507–508 *ex*
- Register allocation, 486
- Relabel operations in preflow, 360–364, 445 *ex*
- Release times, 137, 493, 500
- Representative sets for protein molecules, 651–652 *ex*
- Requests in interval scheduling, 13–14
- Residual graphs, 341–345
 - in Minimum-Cost Perfect Matching Problem, 405
 - for preflows, 358–359
- Resource allocation
 - in Airline Scheduling, 387
 - in Bipartite Matching, 14–16
 - in Center Selection, 606–607
 - in Interval Scheduling, 13–14, 116
 - in Load Balancing, 600, 637
 - in Wavelength-Division Multiplexing, 563–564
- Resource Reservation Problem, 506 *ex*
- Reusing space, 537–538, 541
- Reverse-Delete Algorithm, 144, 148–149
- Rinnooy Kan, A. H. G., 206
- Rising trends, 327–328 *ex*
- RNA Secondary Structure Prediction Problem, 272–273
 - algorithm for, 275–278
 - notes, 335
- problem, 273–275
- Robertson, N., 598
- Robots, mobile, 104–106 *ex*
- Rosenbluth, A. W., 666
- Rosenbluth, M. N., 666
- Rooted trees
 - arborescences as, 177–179
 - for clock signals, 200 *ex*
 - description, 77–78
 - for prefix codes, 166
 - rounding fractional solutions via, 639–643
- Roots of unity with convolution, 239
- Rosenthal, R. W., 706
- Ross, S., 335
- ROTC picnic exercise, 327 *ex*
- Roughgarden, T., 706
- Rounding
 - for Knapsack Problem, 645
 - in linear programming. *See* Linear programming and rounding
- Route maps for transportation networks, 74
- Router paths, 297–301
- Routing in networks
 - game theory in, 690
 - definitions and examples, 691–693
 - and local search, 693–695
 - Nash equilibria in, 696–700
 - problem, 690–691
 - questions, 695–696
- Internet
 - disjoint paths in, 624–625
 - notes, 336
 - shortest paths in, 297–301
- notes, 336
- packet, 762–763
 - algorithm analysis for, 767–769
 - algorithm design for, 765–767
 - problem, 763–765
- Routing requests in Maximum Disjoint Paths Problem, 624
- RSA cryptosystem, 491
- Rubik's Cube
 - as planning problem, 534
 - vs. Tetris, 795
- Run forever, algorithms that
 - description, 795–796
 - packet switching
 - algorithm analysis for, 803–804

- Run forever, algorithms that (*cont.*)
 packet switching (*cont.*)
 algorithm design for, 800–803
 problem, 796–800
- Running times, 47–48
 cubic, 52–53
 exercises, 65–69 *ex*
 linear, 48–50
 in Maximum-Flow Problem,
 344–346
 $O(n^k)$, 53–54
 $O(n \log n)$, 50–51
 quadratic, 51–52
 sublinear, 56
 worst-case, 31–32
- Russell, S., 552
- S**
- S-t connectivity, 78, 84
 S-t Disjoint Paths Problem, 374
- Sahni, Sartaj, 660
- Sample space, 769, 774–776
- Sankoff, D., 335
- Satisfiability (SAT) Problem
 3-SAT. *See* 3-SAT Problem
 NP completeness, 466–473
 relation to PSPACE completeness,
 543
 reductions and, 459–463
- Satisfiable clauses, 459
- Satisfying assignments with Boolean
 variables, 459
- Saturating push operations, 363–364,
 446 *ex*
- Savage, John E., 551
- Savitch, W., 541, 552
- Scaling behavior of polynomial time,
 33
- Scaling Max-Flow Algorithm,
 353–356
- Scaling parameter in augmenting
 paths, 353
- Scaling phase in Scaling Max-Flow
 Algorithm, 354–356
- Schaefer, Thomas, 552
- Scheduling
 Airline Scheduling Problem, 387
 algorithm analysis for, 390–391
 algorithm design for, 389–390
 problem, 387–389
 carpool, 431 *ex*
- Daily Special Scheduling Problem,
 526 *ex*
 interference-free, 105 *ex*
 interval. *See* Interval Scheduling
 Problem
 Knapsack Problem. *See* Knapsack
 Problem
 Load Balancing Problem. *See* Load
 Balancing Problem
 for minimizing lateness. *See*
 Lateness, minimizing
 Multiple Interval Scheduling,
 NP-completeness of, 512 *ex*
 numerical problems in, 493–494,
 500
 optimal caching
 greedy algorithm design and
 analysis for, 133–136
 greedy algorithm extensions for,
 136–137
 problem, 131–133
 in packet routing. *See* Packet
 routing
 processors, 442–443 *ex*
 shipping, 25–26 *ex*
 triathalons, 191 *ex*
 for weighted sums of completion
 times, 194–195 *ex*
- Schoning, Uwe, 598
- Schrijver, A., 449
- Schwartzkopf, O., 250
- Search space, 32, 47–48
- Search
 binary
 in arrays, 44
 in Center Selection Problem, 610
 sublinear time in, 56
 breadth-first, 79–82
 for bipartiteness, 94–96
 for connectivity, 79–81
 for directed graphs, 97–98
 implementing, 90–92
 in planning problems, 541
 for shortest paths, 140
 brute-force, 31–32
 depth-first, 83–86
 for connectivity, 83–86
 for directed graphs, 97–98
 implementing, 92–94
 in planning problems, 541
 local. *See* Local search
- Secondary structure, RNA. *See* RNA
 Secondary Structure Prediction
 Problem
- Segmentation, image, 391–392
 algorithm for, 393–395
 local search in, 681–682
 problem, 392–393
 tool design for, 436–438 *ex*
- Segmented Least Squares Problem,
 261
 algorithm for
 analyzing, 266
 designing, 264–266
 notes, 335
 problem, 261–264
 segments in, 263
- Seheult, A., 449
- Seidel, R., 794
- Selection in median-finding, 728–730
- Self-avoiding walks, 547–550 *ex*
- Self-enforcing processes, 1
- Separation for disjoint paths, 377
- Separation penalty in image
 segmentation, 393, 683
- Sequence alignment, 278, 280
 algorithms for
 analyzing, 282–284
 designing, 281–282
 for biological sequences, 279–280,
 652 *ex*
 in linear space, 284
 algorithm design for, 285–288
 problem, 284–285
 notes, 335
 problem, 278–281
 and Segmented Least Squares,
 309–311 *ex*
- Sequencing problems, 473–474, 499
 Hamiltonian Cycle Problem,
 474–479
 Hamiltonian Path Problem,
 480–481
 Traveling Salesman Problem, 474,
 479
- Set Cover Problem, 456–459, 498,
 612
 approximation algorithm for
 analyzing, 613–617
 designing, 613
 limits on approximability, 644
 notes, 659

- problem, 456–459, 612–613
 - relation to Vertex Cover Problem, 618–620
- Set Packing Problem, 456, 498
- Seymour, P. D., 598
- Shamir, Ron, 113
- Shamos, M. I.
 - closest pair of points, 226
 - divide-and-conquer, 250
- Shannon, Claude E., 169–170, 206
- Shannon-Fano codes, 169–170
- Shapley, Lloyd, 1–3, 28, 706, 786 *ex*
- Shapley value, 786 *ex*
- Sharing
 - apartment expenses, 429–430 *ex*
 - edge costs, 690
 - Internet service expenses, 690–700, 785–786 *ex*
- Shmoys, David B.
 - greedy algorithm for Center Selection, 659
 - rounding algorithm for Knapsack, 660
 - scheduling, 206
- Shortest-First greedy algorithm, 649–651 *ex*
- Shortest Path Problem, 116, 137, 290
 - bicriteria, 530
 - distance vector protocols
 - description, 297–300
 - problems, 300–301
 - Galactic, 527 *ex*
 - greedy algorithms for
 - analyzing, 138–142
 - designing, 137–138
 - with minimum spanning trees, 189 *ex*
 - negative cycles in graphs, 301
 - algorithm design and analysis, 302–304
 - problem, 301–302
 - with negative edge lengths
 - designing and analyzing, 291–294
 - extensions, 294–297
 - notes, 206, 335–336
 - problem, 290–291
- Signals and signal processing
 - clock, 199 *ex*
 - with convolution, 235–236
 - interleaving, 329 *ex*
 - notes, 250
 - smoothing, 209, 236
- Significant improvements in neighbor labeling, 689
- Significant inversion, 246 *ex*
- Similarity between strings, 278–279
- Simple paths in graphs, 76
- Simplex method in linear programming, 633
- Simulated annealing
 - notes, 705
 - technique, 669–670
- Single-flip neighborhood in Hopfield neural networks, 677
- Single-flip rule in Maximum-Cut Problem, 680
- Single-link clustering, 159, 206
- Sink conditions for preflows, 358–359
- Sink nodes in network models, 338–339
- Sinks in circulation, 379–381
- Sipser, Michael
 - polynomial time, 70
 - P = NP question, 529
- Six Degrees of Kevin Bacon game, 448 *ex*
- Skeletons of graphs, 517–518 *ex*
- Skew, zero, 201 *ex*
- Slack
 - in minimizing lateness, 127
 - in packet switching, 801–802
- Sleator, D. D.
 - LRU, 137
 - Randomized Marking algorithm, 794
- Smid, Michiel, 249
- Smoothing signals, 209, 236
- Social networks
 - as graphs, 75–76
 - paths in, 110–111 *ex*
- Social optimum vs. Nash equilibria, 692–693, 699
- Solitaire puzzles, 534
- Sort-and-Count algorithm, 225
- Sorted-Balance algorithm, 605
- Sorted lists, merging, 48–50
- Sorting
 - for Load Balancing Problem, 604–606
 - Mergesort Algorithm, 210–211
 - approaches to, 211–212
 - running times for, 50–51
 - substitutions in, 213–214
 - unrolling recurrences in, 212–213
- $O(n \log n)$ time, 50–51
- priority queues for, 58
- Quicksort, 731–734
 - topological, 101–104, 104 *ex*, 107 *ex*
- Source conditions for preflows, 358–359
- Source nodes, 338–339, 690
- Sources
 - in circulation, 379–381
 - in Maximum-Flow Problems, 339
- Space complexity, 531–532
- Space-Efficient-Alignment algorithm, 285–286
- Spacing of clusterings, 158–159
- Spanning Tree Problem. *See* Minimum Spanning Tree Problem
- Spanning trees
 - and arborescences. *See* Minimum-Cost Arborescence Problem
 - combinatorial structure of, 202–203 *ex*
- Sparse graphs, 88
- Spell-checkers, 279
- Spencer, J., 793–794
- Splitters
 - in median-finding, 728–730
 - in Quicksort, 732
- Stability in generalized Stable Matching Problem, 23–24 *ex*
- Stable configurations in Hopfield neural networks, 671, 676, 700, 702–703 *ex*
- Stable matching, 4–5
- Stable Matching Problem, 1, 802–803
 - algorithms for
 - analyzing, 7–9
 - designing, 5–6
 - extensions, 9–12
 - implementing, 45–47
 - lists and arrays in, 42–45
 - exercises, 19–25 *ex*
 - and Gale-Shapley algorithm, 8–9
 - notes, 28
 - problem, 1–5
 - search space for, 32
 - truthfulness in, 27–28 *ex*
- Stacks for graph traversal, 89–90

- Stale items in randomized marking algorithm, 756–757
- Star Wars* series, 526–527 *ex*
- Start nodes in shortest paths, 137
- StartHeap operation, 64
- State-flipping algorithm
in Hopfield neural networks, 673–677
as local search, 683
- State flipping neighborhood in Image Segmentation Problem, 682
- Statistical mechanics, 663
- Staying ahead in greedy algorithms, 115–116
in Appalachian Trail exercise, 184 *ex*
in Interval Scheduling Problem, 119–120
for shortest paths, 139
- Stearns, R. E., 70
- Steepness conditions for preflows, 358–359
- Steiner trees, 204 *ex*, 334–335 *ex*, 527 *ex*
- Steps in algorithms, 35–36
- Stewart, John W., 336
- Stewart, Potter, 207
- Stochastic dynamic programming, 335
- Stockmeyer, L., 543, 551
- Stocks
investment simulation, 244–246 *ex*
rising trends in, 327–328 *ex*
- Stopping points in Appalachian Trail exercise, 183–185 *ex*
- Stopping signals for shortest paths, 297
- Stork, D., 206
- Strategic Advertising Problem, 508–509 *ex*
- Stream ciphers with feedback, 792 *ex*
- Stress-testing jars, 69–70 *ex*
- Strings
chromosome, 521 *ex*
concatenating, 308–309 *ex*, 517 *ex*
encoding. *See* Huffman codes
length of, 463
similarity between, 278–279
- Strong components in directed graphs, 99
- Strong instability in Stable Matching Problem, 24–25 *ex*
- Strongly connected directed graphs, 77, 98–99
- Strongly independent sets, 519 *ex*
- Strongly polynomial algorithms, 356–357
- Subgraphs
connected, 199 *ex*
dense, 788 *ex*
- Sublinear time, 56
- Subproblems
in divide-and-conquer techniques, 215–220
in dynamic programming, 251, 258–260
in Mergesort Algorithm, 210
with Quicksort, 733
for Weighted Interval Scheduling Problem, 254, 258–260
- Subsequences, 190 *ex*
- Subset Sum Problem, 266–267, 491, 499
algorithms for
analyzing, 270–271
designing, 268–270
extensions, 271–272
hardness in, 493–494
relation to Knapsack Problem, 645, 648, 657–658 *ex*
NP-completeness of, 492–493
with polynomially bounded numbers, 494–495
- Subsquares for closest pair of points, 743–746
- Substitution
in sequence alignment, 289
in unrolling recurrences, 213–214, 217–219, 243–244 *ex*
- Success events, 710–712
- Sudan, Madhu, 794
- Summing in unrolling recurrences, 213, 216–217
- Sums of functions in asymptotic growth rates, 39–40
- Supernodes
in Contraction Algorithm, 715
in minimum-cost arborescences, 181
- Supervisory committee exercise, 196 *ex*
- Supply in circulation, 379
- Surface removal, hidden, 248 *ex*
- Survey Design Problem, 384–385
algorithm for
analyzing, 386–387
designing, 386
problem, 385–386
- Suspicious Coalition Problem, 500–502 *ex*
- Swapping rows in matrices, 428 *ex*
- Switched data streams, 26–27 *ex*
- Switching
algorithm for
analyzing, 803–804
designing, 800–803
in communications networks, 26–27 *ex*
problem, 796–800
- Switching time in Broadcast Time Problem, 528 *ex*
- Symbols, encoding. *See* Huffman codes
- Symmetry-breaking, randomization for, 708–709
- ## T
- Tables, hash, 736–738, 760
- Tails of edges, 73
- Tardos, É.
disjoint paths problem, 659
game theory, 706
network flow, 448
rounding algorithm, 660
- Target sequences, 309
- Tarjan, R. E.
graph traversal, 113
LRU, 137
online algorithms, 794
polynomial time, 70–71
Preflow-Push Algorithm, 449
- Taxonomy of NP-completeness, 497–500
- Telegraph, 163
- Teller, A. H., 666
- Teller, E., 666
- Temperature in simulated annealing, 669–670
- Terminal nodes, 690
- Terminals in Steiner trees, 204 *ex*, 334–335 *ex*
- Termination in Maximum-Flow Problem, 344–346
- Testing bipartiteness, 94–96
- Tetris, 795

- Theta in asymptotic order of growth, 37–38
- Thomas, J., 206
- Thomassen, C., 598
- Thresholds
 approximation, 660
 in human behaviors, 523 *ex*
- Thymine, 273
- Tight bounds, asymptotic, 37–38
- Tight nodes in pricing method, 621
- Time-series data mining, 190 *ex*
- Time-stamps for transactions, 196–197 *ex*
- Time to leave in packet switching, 800
- Time-varying edge costs, 202 *ex*
- Timing circuits, 200 *ex*
- Toft, B., 598
- Top-down approach for data compression, 169–170
- Topological ordering, 102
 computing, 101
 in DAGs, 102, 104 *ex*, 107 *ex*
- Toth, P.
 Knapsack Problem, 335
 Subset Sum, 529
- Tours in Traveling Salesman Problem, 474
- Tovey, Craig, 250
- Trace data for networked computers, 111 *ex*
- Tracing back in dynamic programming, 257
- Trading in barter economies, 521–522 *ex*
- Trading cycles, 324 *ex*
- Traffic
 in Disjoint Paths Problem, 373
 in Minimum Spanning Tree Problem, 150
 in networks, 339, 625
- Transactions
 approximate time-stamps for, 196–197 *ex*
 via shortest paths, 290
- Transitivity
 of asymptotic growth rates, 38–39
 of reductions, 462–463
- Transmitters in wireless networks, 776–779 *ex*
- Transportation networks, graphs as models of, 74
- Traveling Salesman Problem, 499
 distance in, 474
 notes, 529
 NP-completeness of, 479
 running times for, 55–56
- Traversal of graphs, 78–79
 breadth-first search for, 79–82
 connected components via, 82–83, 86–87
 depth-first search for, 83–86
- Traverso, Paolo, 552
- Tree decompositions, 572–573
 algorithm for, 585–591
 dynamic programming using, 580–584
 notes, 598
 problem, 584–585
 properties in, 575–580
 tree-width in, 584–590
 defining, 573–575, 578–579
 notes, 598
- Trees, 77–78
 and arborescences. *See* Minimum-Cost Arborescence Problem
 binary
 nodes in, 108 *ex*
 for prefix codes, 166–169
 breadth-first search, 80–81
 depth-first search, 84–85
 in Minimum Spanning Tree Problem. *See* Minimum Spanning Tree Problem
 NP-hard problems on, 558
 decompositions. *See* Tree decompositions
 Maximum-Weight Independent Set Problem, 560–562
 of possibilities, 557
- Tree-width. *See* Tree decompositions
- Triangle inequality, 203 *ex*, 334–335 *ex*, 606
- Triangulated cycle graphs, 596–597 *ex*
- Triathlon scheduling, 191 *ex*
- Trick, Michael, 250
- Truth assignments
 with Boolean variables, 459
 consistent, 592 *ex*
- Truthfulness in Stable Matching Problem, 27–28 *ex*
- Tucker, A., 598
- Turing, Alan, 551
- Turing Award lecture, 70
- “Twelve Days of Christmas,” 69 *ex*
- Two-Label Image Segmentation, 391–392, 682
- U**
- Underspecified algorithms
 graph traversal, 83
 Ford-Fulkerson, 351–352
 Gale-Shapley, 10
 Preflow-Push, 361
- Undetermined variables, 591 *ex*
- Undirected Edge-Disjoint Paths Problem, 374
- Undirected Feedback Set Problem, 520 *ex*
- Undirected graphs, 74
 connected, 76–77
 disjoint paths in, 377–378
 in image segmentation, 392
 number of global minimum cuts in, 718–719
- Unfairness in Gale-Shapley algorithm, 9–10
- Uniform-depth case of Circular Arc Coloring, 566–567
- Unimodal sequences, 242 *ex*
- Union Bound, 709, 712–713
 for contention resolution, 712–713
 for load balancing, 761–762
 for packet routing, 767–768
 in probability, 772–774
- Union-Find data structure, 151–152
 improvements, 155–157
 pointer-based, 154–157
 simple, 152–153
- Union operation, 152–154
- Universal hash functions, 738–740, 749–750
- Unrolling recurrences
 in Mergesort Algorithm, 212–213
 subproblems in, 215–220
 substitutions in, 213–214, 217–219
 in unimodal sequence exercise, 244 *ex*
- Unweighted case in Vertex Cover Problem, 618
- Upfal, E., 793–794
- Uplink transmitters, 776–777 *ex*
- Upper bounds, asymptotic, 36–37
- Upstream nodes in flow networks, 429 *ex*
- Upstream points in communications networks, 26–27 *ex*
- User-friendly houses, 416–417 *ex*

Using up All the Refrigerator Magnets Problem, 507–508 *ex*

V

Valid execution of Kruskal's algorithm, 193 *ex*

Valid partners in Gale-Shapley algorithm, 10–12

Valid stopping points in Appalachian Trail exercise, 183–184 *ex*

Validation functions in barter economy, 522 *ex*

Values

of flows in network models, 339

of keys in priority queues, 57–58

Van Kreveld, M., 250

Variable-length encoding schemes, 163

Variables

adding in dynamic programming, 266, 276

Boolean, 459–460

random, 719–720

with convolution, 237

linearity of expectation, 720–724

Vazirani, V. V., 659–660

Vecchi, M. P., 669, 705

Vectors, sums of, 234–235

Veksler, Olga, 449–450, 706

Vertex Cover Problem, 498, 554–555
and Integer Programming Problem, 633–635

linear programming for. *See* Linear programming and rounding

in local search, 664–666

notes, 659–660

optimal algorithms for

analyzing, 557

designing, 555–557

in polynomial-time reductions, 454–459

pricing methods, 618

algorithm analysis for, 622–623

algorithm design for, 620–622

problem, 618–619

problem, 555

randomized approximation

algorithm for, 792–793 *ex*

Vertices of graphs, 74

Viral marketing phenomenon, 524 *ex*

Virtual places in hypertext fiction, 509 *ex*

Virus tracking, 111–112 *ex*

VLSI chips, 200 *ex*

Von Neumann, John, 249

Voting

expected value in, 782 *ex*

gerrymandering in, 331–332 *ex*

W

Wagner, R., 336

Walks, self-avoiding, 547–550 *ex*

Wall Street, 115

Water in shortest path problem, 140–141

Waterman, M., 335

Watson, J., 273

Watts, D. J., 113

Wavelength assignment for wireless networks, 486

Wavelength-division multiplexing (WDM), 563–564

Wayne, Kevin, 449

Weak instability in Stable Matching Problem, 25 *ex*

Weaver, W., 206

Wegman, M. L., 794

Weighted Interval Scheduling Problem, 14, 122, 252

algorithms for

designing, 252–256

memoized recursion, 256–257

relation to billboard placement, 309 *ex*

subproblems in, 254, 258–260

Weighted sums of completion times, 194–195 *ex*

Weighted Vertex Cover Problem, 618, 631

as generalization of Vertex Cover, 633–635

notes, 659–660

Weights

of edges in Hopfield neural networks, 671

in infinite sample spaces, 775

in Knapsack Problem, 267–272, 657–658 *ex*

of nodes, 657 *ex*

in Set Cover Problem, 612

of Steiner trees, 204 *ex*
in Vertex Cover Problem, 618

Well-centered splitters

in median-finding, 729–730

in Quicksort, 732

Width, tree, in tree decompositions.
See Tree decompositions

Williams, J. W. J., 70

Williams, Ryan, 552

Williamson, D. P., 659

Winner Determination for Combinatorial Auctions problem, 511–512 *ex*

Winsten, C. B., 706

Wireless networks

ad hoc, 435–436 *ex*

for laptops, 427–428 *ex*

nodes in, 108–109 *ex*, 324–325 *ex*

transmitters for, 776–779 *ex*

wavelength assignment for, 486

Witten, I. H., 206

Woo, Maverick, 530, 552

Word-of-mouth effects, 524 *ex*

Word processors, 317–319 *ex*

Word segmentation problem, 316–318 *ex*

World Wide Web

advertising, 422–423 *ex*, 508–508 *ex*
diameter of, 109–110 *ex*

as directed graph, 75

meta-search tools on, 222

Worst-case analysis, 31–32

Worst-case running times, 31–32

Worst valid partners in Gale-Shapley algorithm, 11–12

Wosley, L. A., 206

Wunsch, C., 279

Y

Young, N. E., 794

Z

Zabih, Ramin D., 449–450, 706

Zero skew, 201 *ex*

Zero-Weight-Cycle problem, 513 *ex*

Zones

in Competitive Facility Location Problem, 18

in Evasive Path Problem, 510–511 *ex*

Zucker, M., 335