

Subject Index

- A** algorithm, 62-64, 71-85
 - admissibility of, 77-78, 85, 106, 111, 164
 - definition, 64
 - expected performance, 140-150, 169-193
 - optimality of, 85, 107, 111, 112, 206-207
 - properties, 73-85
 - references for, 70, 110
 - variations to, 49, 65, 70, 85-99, 111, 112, 125, 145
- ABSTRIPS, 29, 131
- Accuracy of heuristic estimates, 53, 79, 87, 91, 145, 149, 169, 170, 334, 351
- Add list, in STRIPS, 119
- Admissibility, of search algorithms, 75, 86, 105, 162, 194, 331
 - ϵ -admissibility, 88-91, 104-106, 111, 128, 164
 - of *A**, 77-78, 106, 111, 164
 - of *AO**, 62
 - of *GBF**, 55, 78
 - relaxation-based, 11
 - risk admissibility, 94-99, 112
 - set-splitting proof of, 55, 62, 78
 - See also Optimality of solutions
- Admissible heuristics, 77, 113, 169-193
- Air-distance heuristic, 9, 114, 140, 145, 163
- Alpha-Beta (α - β) procedure, for games, 231-239, 287
 - branching factor, 269, 296-298
 - for computing quantiles, 277
 - definition, 234
 - expected performance, 235, 293-299, 307-310
 - history of, 273, 286, 293-294
 - influence-analysis view of, 235-239
 - pruning power of, 235, 298-299
 - for searching flow trees, 281, 287
- Alpha bound, 233, 238
- Analogical models, 117-118
- Ancestor nodes, 34
- AND links, 22, 26-27, 222
- AND nodes, 25
- AND/OR graphs and trees, 19, 22-32
 - best-first search of (*GBF*, *GBF**), 49-56, 63, 240-245
 - cost of solutions, 50-54, 57-58
 - cycles in, 46
 - definition, 22
 - examples, 23-24, 30, 47, 223, 279
 - labeling procedures for, 51, 58-60
 - node selection in, 53-54
 - to represent games, 26, 32, 222-223, 279
 - uninformed search of, 44-46
- AO* Algorithm, 62-63
- AO** Algorithm, 62-64, 70, 72, 240, 286
- Approximate-optimization, 15, 90-99, 129, 154
- Arcs, 33
- Artificial intelligence (AI), 4, 19, 137
- Assignment problem, 11, 31, 115, 176, 210
- Asymptotic optimality, 260, 264, 270
- Attractors, 322, 325, 352
- Backed-up values, 58, 60, 227, 332
- Backmarking, 40
- Backtracking, 36, 40, 65, 71, 121, 190, 230
 - analysis, 190-192
 - in AND/OR graphs, 45-47
 - definition, 40
 - illustration, 42
 - informed, 40, 42, 190
 - references for, 69
 - variations of, 40-42, 66, 69, 152, 162
- Bernoulli theorem, 126-127
- Best-first strategies, 46-56, 63, 65, 111, 112, 240, 326
 - for AND/OR graphs, 49, 240
 - generalized, 50-51, 99-110
 - for OR graphs, 48-49, 72
 - provisions for optimality, 54-55
 - specialized, 61-65
- β -bound, 234, 238, 239
- BF* algorithm, 74, 87
 - definition, 48
 - relation to *GBF*, 55, 63

- BF** algorithm, 56, 63, 100, 102-110, 112, 326
- Bidirectional search, 70
- Blind (uninformed) search, 34, 36-46
- Bounding functions, 10, 31, 70
- Branch-and-bound, 19, 31, 55, 70, 131, 286
- Branching processes
 - applications, 155-161, 284
 - definition and properties, 154-155, 165-167
 - nonhomogeneous, 173
- Branching degree, 33, 318, 324
- Branching factor, 259
- Breadth-first strategies, 42-44, 65, 69, 141
- Capacity (in flow trees), 280-285, 326
- C*-bounded paths, 112
- Characteristic distribution, for games, 289, 297, 304, 325, 328
- Cheapest-first, 44. *See also* Uniform cost
- CLOSED list, 34, 37
- Closed nodes, 34
 - reopening of, 49, 72, 76, 82, 111, 194
- Clusters of strategies, 240
- Codes; *See also* Representations
 - for solutions, 15, 23, 26, 29
 - for subsets, 16, 18-21, 49, 240
- Combining rules (or functions), 13, 57, 58, 227, 359-360
- Commutativity, 35, 123
- Completeness, 16, 19, 75-77, 99, 103
- Connectors, in hypergraphs, 25
- Consistent (monotone) heuristics, 82-85, 111, 148
 - and reopening closed nodes, 83
 - and the optimality of A^* , 85, 107, 111, 112
 - produced by relaxed models, 115, 131, 140
 - relation to admissibility, 83, 111
- Constraint-satisfaction problems, 4, 14, 21, 31, 69
- Control strategies, 13, 16, 20, 34
- Cost, of arcs, 34
- Cost labeling, 58-60, 99, 102
- Cost measures, of paths
 - max-cost, 34, 58, 62, 99, 101, 281
 - median, 57, 76
 - mode, 99
 - multiplicative, 99
 - nonadditive, 57, 61, 99, 102
 - range, 72, 99, 101
 - recursive, 100
 - sum-cost, 34, 58, 61, 62, 74, 151
- Counterfeit coin problem, 12, 19, 22, 26, 31, 32, 38, 59, 72, 133
- Cutoffs, in game searching
 - deep and shallow, 233, 294
 - conditions for, 238, 295
- Database, 16, 20
- Dead ends, 6, 18, 31, 37
- Debiasing heuristics, 106, 203, 205, 213
 - optimal way of, 205, 210
- Decomposability, 121-124
- Degree of a node, 33
- Delayed termination, 54-56, 62, 63
- Delete list, in STRIPS, 119
- Depth
 - of a node, 37, 39, 88, 164
 - of search, 188, 227, 333
- Depth-bound, 37
- Depth-first search, 36-42, 65, 151, 160, 230, 260, 266
 - definition, 37
 - examples, 38, 230
 - in graphs, 39, 44
 - informed version of, 38, 67, 190
- Descendant nodes, 34
- Directed search. *See* Informed search
- Directional search algorithms, 260, 265
- Dominance
 - between algorithms, 75, 81, 85, 112, 199-202, 209, 249, 301
 - pruning by, 21
 - stochastic, 176-179
- Dynamic ordering, 286
- Dynamic programming, 60, 69, 76, 102
- Dynamic weighting, 88, 105, 213
- Edges, in graphs, 33, 52
- 8-Puzzle, 6, 18, 20, 27, 31, 39, 71, 79, 81, 87, 113, 119, 138, 164
- 8-Queens, 4, 14, 17, 20, 31, 38
- Errors
 - effects on search complexity, 145, 169-217
 - order of, 184, 189, 205, 213
 - overestimation, 195, 199-202
 - ϕ -normalized, 184
 - proportional, 179-183, 205, 210, 211
 - subproportional, 186-189, 193, 205, 207
- Error propagation, in minimaxing, 333-346
- Euclidean distance, 9, 114
- Evaluation functions, 35, 48, 50, 56, 60, 70, 102, 226
 - additive, 99, 101
 - examples of, 6-13
 - nonadditive, 99-110

- optimistic, 11, 55, 62, 70, 72
- order-preserving, 100–102
- path-dependent, 100, 102, 112
- recursive, 56–65
- static, 227, 334
- weighted, 87, 106, 145, 202, 210, 213
- Exhaustive search, 7, 229
- Expanding nodes, 34, 36
 - by SSS*, 244
- Explicated graphs, 49, 75, 101
- Exploring nodes, 34
- Extinct family, size, 154, 164, 166–167, 183
- Extinction probability, 165

- Face-value principle, 53, 60, 86, 227, 332
- Fallible opponent, 357–358
- FIFO search strategies, 42
- Filtering argument, in games, 332
- Flow trees, 281, 326
- Forward checking, 31, 286

- GBF* algorithm, 50–51, 63
 - example of applying, 52–54
 - relations to BF, 55, 63
- GBF** algorithm, 54–55, 63, 72, 100, 102
 - admissibility of, 55
- Games
 - books about, 31
 - decision quality in, 227, 332–361
 - duality with mazes, 277–285
 - evaluating, 268
 - examples of, 32, 270, 273
 - mathematical models of, 251–259, 270–273, 318–322
 - perfect information, 222, 225
 - as problem-solving laboratory, 4, 221
 - searching of, 231–250, 271–272
 - size considerations, 226, 293, 299
 - solving, 224, 230, 259
 - value of, 60, 226–227, 255, 322
- Game trees, 222
 - nonuniform, 318–322, 351
- Game-playing strategies, 222–226
 - quality of, 58, 240
- Generate-and-test paradigm, 19, 31
- Generating nodes, 34, 40
- Goal nodes, 6, 74
- GODDESS, 29
- Golden ratio, 254
- GPS*, 29, 122, 124
- Graph notation, 33, 73
- Greedy algorithms, 36, 120–121, 123
- Guided search. *See* Informed search

- HARPY, 163
- Heuristics
 - admissible, 77
 - consistent (monotone), 82–85
 - definition, 3, 53
 - in constraint-satisfaction problems, 5
 - in game playing, 227
 - mechanical generation of, 118–124
 - origin, 113–115
 - in path-seeking problems, 6–12, 48, 64
 - power of, 73, 79, 139–140, 144
 - probability-based, 117, 124–131
 - relaxation-based, 11, 113–116, 118–124
 - as sources of noisy signals, 47, 169–171
 - in strategy-seeking problems, 12–13, 50, 63
 - typical uses, 6–13, 52–54
- Hill-climbing, 35, 65, 71, 121
- Huffman code, 26, 32, 133
- Hybrid strategies, 65–69, 126, 151, 281
- Hypergraphs, 23
- Hyperpaths, 25

- Immortality, in branching processes, 155, 165
- Incremental search, 4, 10
- Influence functions, in games, 235
- Informed search, 34, 46–56
- Informed ordering, in games, 287, 294, 299, 310–317, 324–325
- Informedness, of heuristic functions, 79, 81, 111, 169, 177, 200, 311, 334, 337
- Irrevocable strategies, 35, 68

- Kalah, 249–250

- Labeling procedures, 45, 51, 58–60, 224
- Labeling rules, 25, 58
- Lagrange relaxation, 131
- Largely dominates, 85, 107, 112
- Law of large numbers, 125
- Leaf nodes, 33
 - of a search tree, 49
 - deep and shallow, 319
- LIFO search strategies, 36, 39
- Links (arcs), in graphs, 22, 33
- Locally finite graphs, 33, 73, 77
- Logical reasoning, 27, 31
- Look-ahead, bounded, 162, 227, 229, 286, 332, 347, 351, 357

- Manhattan distance, 8, 71, 79, 114, 120
- Max-cost, 34, 58, 62, 101, 281
- Maximum-likelihood decisions, 71
- Means-end analysis, 29, 122

- Merge problem, 32
- Merit labeling, of solution graphs, 58-60
- Metaphorical models, 117-118
- MINIMAX algorithms
 - backtracking version, 229
 - depth-first version, 230
- Minimax convergence theorem, 256-257, 272-273, 286
 - applications, 273-277
 - for nonuniform trees, 322
- Minimax rule, 60, 227-228, 286, 332, 358
 - alternatives to, 358-360
 - error propagation for, 333-347
- Minimum spanning tree, 11, 33, 36, 79, 115, 124, 176, 210
- Monotone. *See* Consistent heuristics
- More efficient than, 199-202
- More informed than, 79, 81, 111, 177, 200
- Most promising solution-base, G_0 , 51-53, 60

- Near-optimization, 15, 88-90, 150, 162
- NEG-MAX notation, 228, 234
- NP-hard problems, 10, 15, 162
- Node expansion, 34, 36
 - condition for, 79-81, 84, 107-110, 141, 146, 148, 173, 194-199
- Node generation, 34, 40
 - condition for, 238, 295
- Nodes, in graphs, 22, 33
 - critical, 287, 296, 302
 - dummy, 74
 - frontier, 50, 167
 - goal, 6, 74, 191
 - mortal, 155, 160, 164-165
 - off-track, 76, 191
- Normalized errors, 184
- Number-scrabble, 117

- Off-course subtrees, 171-172
- Off-track nodes, 76, 191
- OPEN list, 34, 37, 40
- Open nodes, 34
- Operations research, 19, 31, 55, 70, 131
- Operators, 16, 20, 35, 74
 - in STRIPS, 119, 122, 133
 - See also* Production rules
- Optimal solution graph G^* , 60
- Optimality, of search algorithms, 75, 111, 134, 260
 - of A^* , 85, 107, 111-112, 206-207
 - of α - β , 294, 298
 - asymptotic, 260, 264
 - of SOLVE, 264-266
- Optimality of solutions, 19, 43
 - near optimality, 15, 88-90, 128
 - approximate optimality, 15, 90-99, 129, 150, 162, 164
 - See also* Admissibility
- Optimization tasks, 14, 41, 54, 70, 128-134, 192
- OR links, 22, 26, 27, 222
- OR nodes, 25
- Order of typical errors, 184, 189
- Order-preserving heuristics, 62, 78, 100-102
- Ordering of successors, in games, 287, 294, 299, 310-317, 324-325
 - dynamic, 286
- Overconstrained models, 116-117

- Pathology in game searching, 332-361
- Parent discarding, 55-62
- Parent nodes, in graphs, 33
- Path-seeking problems, 10, 19, 21, 25-27, 32, 140-163
- Paths, in graphs, 34, 74
 - C-bounded, 80, 81, 84, 111, 112
 - cheapest, 74, 150-163
 - cost of, 34, 74, 151
 - infinite, 77, 104, 155, 165
 - shortest, 62, 69, 140-150
 - solution, 75, 103, 104
- Perfect discrimination function, f^* , 75-76
- Pointer-paths, 34, 49, 74, 101, 104
- Pointers, 34, 74
 - redirecting, 48, 49
- Policy, of search. *See* Search procedure
- Precision and accuracy, 199-201
- Precision-complexity exchange, 184, 189-190, 198
- Precondition list, in STRIPS, 119-121, 123-124
- Principle of optimality, 76, 102
- Probabilistic algorithms, 127
- Probabilistic models for performance analysis
 - of A^* and backtracking, 146, 150, 171-172
 - of game searching, 251-259, 318-325, 351
 - rationale for, 139-140, 170-171, 309-310
- Probability-based heuristics, 124-131
 - examples, 13, 129, 162-163, 164
- Problem-reduction representation, 21, 23, 26, 29, 222
- Product-propagation rules, 358-360
- Production rules, 16, 20, 25, 40
- Program synthesis, 26, 137

- Pruning, 17, 41, 64, 79, 126, 229
 by dominance, 21
 power, 17, 147, 149, 163, 169
- Puzzles, 4, 31, 32
- Quantiles, 256, 274, 277, 286
- R_δ^* algorithm, 90–97
 $R_{\delta,\epsilon}^*$ algorithm, 98
- Range, as a cost measure, 90, 99, 101
- Recovery of pursuit, 65
- Recursive weight functions, 57, 100
- Relaxed models, 11, 115, 118–124
- Reopening nodes, 49, 72, 76, 82, 111, 194
- Representations, 14
 problem reduction, 21, 23, 26, 121–124
 selection of, 26, 31
 state space, 20, 24, 26
- Reproduction process, 173, 183
- Risk-admissibility, 94, 112
- Risk of leaving nodes unexplored, 93–94
- Road map problem, 9, 114, 146–150
- Rollback function, 58
- Root node, 33, 225, 259
- Rule of thumb, 3
- Sampling, 126
- Satisficing, 14, 54, 69, 86, 128, 171, 192, 206
- Scope of evaluation, 65
- SCOUT algorithm, 246–250, 286–287
 branching factor, 291–292, 317, 326
 definition, 247
 flowchart, 248
 motivation for, 246, 247
 performance analysis, 289–293
 relation to α - β , 249–250, 285, 307–310, 326
 for searching flow trees, 282
- Search graph, 49, 53
- Search procedures, 33, 34
 blind, 34, 36–46
 exhaustive, 7, 229
 hierarchy of, 63
 hybrid, 65–69, 126, 151, 192
 informed, 34, 46–56
 irrevocable, 35, 68, 131, 151
 performance analysis, 137–140
 systematic, 4, 16, 35
 tentative, 36
- Search spaces, 14
- Search tree, 48, 74–75
- Seed nodes, 349, 361
- Semi-decomposable problems, 122
- Semi-optimization tasks, 15, 41, 86–99, 128–134
- Set-splitting argument, 55, 62, 78
- Set-splitting problem, 26
- Small-is-quick principle, 15, 52, 53, 62, 86, 206
- Solution bases, 49–52, 240
 scoring of, 50–54, 240
 most promising, 51, 53
- Solution graph, 23–25
 for an arbitrary node, 51, 57
 optimal, 60
- Solution trees, 19, 224
- SOLVE algorithm, 230
 branching factor, 263, 266–267, 317, 323, 326
 expected complexity, 260–267, 288, 313, 323, 326, 327
 optimality of, 264–265
 with successor ordering, 311–317, 324–325
- Solving games, 230
- Split-and-prune paradigm, 17, 19, 31, 240
- SSS* algorithm, 240–245, 281, 287, 326
 branching factor, 304–306
 definition, 243
 description, 240–243
 example, 244–245
 history of, 286, 325
 performance analysis, 300–310, 329–331
 relation to α - β , 301, 306–310, 325
- Staged search, 68, 150
- Start node, 33, 74
- State, 19, 21
- State-space, 20–21, 24, 26
- State-space graphs, 21
- Static evaluation function, 227, 334
- Status, of game position, 224
- Stochastically more efficient, 177
- Stochastically greater, 176, 199
- Stochastically more informed, 177, 200
- Strategies, 12, 19
 in games, 26, 224
 trees, for representing, 19, 30, 224, 240
 winning, 225
- Strategy-seeking tasks, 12, 19, 21, 26, 32
- STRIPS, 29, 119, 122, 133
- Subgoals
 auxiliary, 29
 hierarchy of, 28–31, 123
 independence of, 27, 121–124
- Subproblems, 13, 222
 codes for, 22
 conjunction of, 21, 222
 interacting, 27

- Subproportional errors, 186–189, 193, 205, 207
- Subsets of potential solutions, 17
 codes for, 17, 18, 20
See also Solution bases
- Successor nodes, 33, 74
- Successor operator, 74
- Sum-cost, 34, 58, 74
- Symbolic-integration, 27, 32
- Systematic search, 4, 16, 35
- Tentative strategies, 36
- TEST algorithm, 246–247, 268
- Test tubes, 139
- Theorem proving, 15, 20, 27, 31
- Tie-breaking rules, 81, 85, 112
- Tip nodes, 33, 64
- Tower of Hanoi, 27–31, 123
- Tic-tac-toe, 117
- Trajectories of error parameters, 333–346
- Traveling salesman problem (TSP), 10, 15, 20, 31, 70, 79, 114, 115, 124, 176, 210
- Traversal path, 39–40
- Traversal tree, 49, 74
- Trees, 19, 33
 action, 26, 29, 30
 game, 222–226, 251
 strategy, 19, 224
 uniform, 33, 150
 unordered, 26, 27, 32
- Triangle inequality, 82, 116
- Typical errors, 184
- Uniform cost algorithm, 44, 65, 69, 71, 87, 150, 151, 162
- Uniform tree, 33, 150
- Uninformed (blind) search, 34, 36–46
- Upper supports, 197, 199, 201, 322
- Vertices, in graphs, 33
- Visibility argument for look-ahead, 332, 347–348
- Weight labeling procedure, 58
 examples, 58
- Weights on arcs, 33
- Winning strategies, 224–225
- Winning probability, 251–254, 322, 357–358
- Worst case analysis, 162, 170, 179–180, 294
- Z and Z* algorithms, 61–63, 65