

Index

- Abstract-HTN procedure, 248–250
 - generalizing, for temporal planning, 256
 - illustrated, 249
 - as “lifted” procedure, 249
 - nonprimitive tasks and, 249
 - planning graphs and, 256
 - See also* Hierarchical Task Network (HTN) planning
- abstraction hierarchies, 532–533
- Abstract-search procedure, 193, 194
 - as branch-and-bound procedure, 197
 - branching step, 194
 - extending, 196
 - illustrated, 195
 - with iterative-deepening control strategy, 195
 - nondeterministic step, 196
 - pruning step, 194
 - refinement step, 194
 - steps, 194, 195
- AC3 algorithm, 181, 190
- action axioms, 273
- Action Description Language (ADL), 50, 104
- action effects, 266
 - axioms, 268
 - conditional, 266
 - negative, 266
 - positive, 266
- action precondition axioms, 266
- actions, 6
 - adding, 86
 - applicable, 316, 336
 - applicable in states, 44
 - blocking, 481
 - classical representation, 28–30
 - concurrent, 13, 321–323, 351
 - conditional, 447
 - as conditional threats, 101
 - conflicting, 163
 - constraints encoding, 175–176
 - dependent, 119, 121
 - deterministic, 145
 - duration, 13
 - DWR domain, 15
 - encoding of, 160–164
 - executable, 380
 - as ground operators, 30, 44
 - inclusive disjunction of, 118
 - independent, 119–120, 134, 208, 309
 - mutex, 122
 - negative effects, 121
 - nominal outcomes, 376
 - nonblocking, 481
 - nonnominal outcomes, 376
 - nonpreemptive, 352
 - over time, 281
 - overlapping, 281–282
 - parallel, 138
 - partial plan, 93
 - as partially instantiated planning operators, 315
 - in planning graphs, 123
 - planning problems, 27
 - planning-graph techniques, 113
 - positive effects, 121
 - preconditions, 126, 266
 - preemptive, 352
 - relevant for goals, 22
 - resource requirements of, 354
 - search for, 128
 - sequence of sets of, 118
 - situation calculus, 265–267
 - state-variable representation, 43–44
 - test, 269
 - value maintenance, 282
 - without flaws, 93
- active CSPs, 185–186
 - example, 185–186
 - network illustration, 186
 - transforming, 186
 - See also* constraint satisfaction problems (CSPs)

- active variables, 185
- ad hoc operators, 321
- admissibility, 544
- admissible state-space heuristics, 205–207
- after-constraints, 245
- allowance relation, 134
 - benefit, 135
 - independence vs., 135
 - planning graphs for, 136
 - See also* relations
- alpha-beta algorithm, 553
- alternative resources, specifying, 354
- AND/OR graphs
 - acyclic subgraph of, 430
 - conditional graph correspondence, 431
 - illustrated, 548, 549
 - over belief states, 429
 - search space as, 430
 - searching, 431, 553
- AND/OR trees
 - basic pattern, 211
 - for flaw repair, 209
 - illustrated, 211
 - serialization of, 208, 209, 210
 - smallest possible serialization, 211
- AND-branches, 127
 - decomposition tree, 236
 - illustrated, 548
 - task decomposition, 234
- AND-connectors, 481
- applications, 449–540
 - bridge, 517–524
 - emergency evacuation planning, 505–516
 - manufacturing analysis, 493–503
 - robotics, 469–491
 - space, 451–467
- arc consistency, 181
 - AC3, 181, 190
 - algorithm illustration, 182
 - checking, 341
- arcs
 - negative, 118
 - plan-space planning, 85
 - positive, 118
 - precondition, 118
 - state-space planning, 85
- ASPEN, 466
- assumptions
 - A0, 9, 11
 - A1, 9, 11
 - A2, 10, 12
 - A3, 10, 12
 - A4, 10, 12
 - A5, 10, 12–13
 - A6, 10, 13
 - A7, 10, 13
 - closed-world, 28, 47, 50
 - default value, 47
 - restrictive, 9–10
- at-least-one axioms, 162
- atoms, 265, 557
 - classical planning, 265
- attached procedures, 253
 - computations with, 39
 - HTN planning, 253
 - STL-plan, 224
 - use of, 39
 - See also* procedures
- Automated Ground Vehicles (AGVs), 487–488
- automated planning. *See* planning
- automatic domain knowledge acquisition, 536
- Autonomous Remote Agent. *See* Remote Agent (RA)
- axiomatic inference, 38–39
- axioms
 - action, 273
 - action effect, 268
 - action precondition, 266
 - classical frame, 162–163
 - complete exclusion, 149, 177
 - domain, 273, 317–319
 - dynamic logic, 273
 - exclusion, 155, 163
 - frame, 162–164, 267, 268, 273, 274, 439
 - Horn-clause, 253, 254
 - HTN planning, 253
 - initial situation, 268
 - restricting, to Horn clauses, 253
 - STL-plan procedure, 224
 - unsatisfied, 325
- backjumping algorithm, 180
- backtracking, 178–180
 - algorithm illustration, 179
 - dependency-directed, 180
 - flaw with no resolver and, 338
 - improvements, 179–180

- intelligent, 180
- SHOP integrated with NaCoDAE (SiN), 510
- See also* constraint satisfaction problems (CSPs)
- backward search state-space algorithms, 73–76
 - example, 73–74
 - heuristically guided, 204–205
 - infinite branch failure, 75
 - lifted version, 75
 - loop iterations, 74
 - nondeterministic, 73
 - STRIPS algorithm vs., 76
 - TFD procedure comparison, 239
 - See also* state-space planning
- backward shifting, 568
- before-constraints, 245
- belief states, 393–395
 - action execution, 394–395
 - AND/OR graph over, 429
 - examples, 394, 395
 - nonempty, 428
 - plans as policies on, 395–396
 - transitions on, 394
- Bellman Equation, 387
- best-first iterative deepening, 547, 553
- best-first search, 545–546
- between-constraints, 245
- binary constraint network, 291–292, 296
- binary constraints, 97
- binary counters, 60–61
- binary CSPs, 169
 - algorithms for, 178
 - consistency problem of, 172
 - See also* constraint satisfaction problems (CSPs)
- binary decision diagrams (BDDs), 404, 570
 - for Boolean formulas, 570
 - in classical planners, 433
 - control automation implementation with, 421
 - symbolic model checking, 570–572
- binding constraints, 93, 311, 313
 - consistent, 91
 - variable, 88–90
- bitwise, 162
- BlackBox planning system, 165
- blocking actions, 481
- blocks world, 81
- bounded planning problem, 147, 151, 440
 - encoding, 148, 149
 - extending, 148
 - in state-variable representation, 174
 - strong encoding, 442
 - See also* planning problems
- branch-and-bound algorithms, 553
- branch-and-bound search, 197
- breadth-first iterative deepening, 547
- breadth-first search, 544–545
- bridge, 517–524
 - bidding, 517–518
 - game-tree search, 519–521
 - hands, 518
 - HTN planning for, 521–524
 - implementation and results, 524
 - introduction, 517
 - overview, 517–519
 - play, 518
 - tricks, 518
- Bridge Baron, 524
- CaMeL, 536
- CaPER, 528
- CAPlan/CbC, 528, 529
- case adaptation, 528–529
- CaseAdvisor, 516
- case-based planning, 527–529
 - case adaptation, 528–529
 - case library, 527
 - performance, 529
 - problem-solving cycle, 528
 - revisions, 529
 - similarity metrics, 528
- cases, 508
- cashing out, 524
- CASPER, 466
- casual links, 87
 - adding, 87–88
 - threats, 92
- CHEF, 515, 528
- chronicle planning operators, 334–336
 - classical planning operators vs., 335
 - example, 334–335
 - illustrated, 335
- chronicle recognition problem, 539
- chronicles, 330
 - applying instances to, 335
 - approach, 326
 - consistent, 331–334, 336, 365
 - CP procedure, 338–339
 - interpretation, 331

- chronicles (*continued*)
 - planning procedures, 336–339
 - planning with, 326–343
 - resource use in, 363
 - set of, 335, 336
 - support, 334
 - timelines, 330
- classical frame axioms, 162–163
- classical planning, 17–109
 - atoms, 265
 - classical representation, 19, 27–33
 - complexity, 55–67
 - dynamic logic vs., 271
 - extended goals and, 40
 - extending, 58
 - first-order language, 33
 - main issues, 18
 - neoclassical vs., 111
 - plan existence, 55
 - planning operators, 28–30
 - plan-space, 85–109
 - representations, 19–20
 - search space nodes, 111
 - set-theoretic representation, 19, 20–27
 - situation calculus vs., 265
 - states, 264
 - state-space, 69–83
 - state-variable representation, 19, 41–47
 - study motivations, 17–18
 - unrestricted, 61–65
- classical planning domains, 31
 - interpretation of, 33
 - as restricted state-transition system, 31
- classical planning problems, 31
 - mapping extended goals into, 40
 - statement of, 31
 - syntactical specification, 33
- classical representation, 19, 27–33
 - actions, 28–30
 - attached procedures, 39
 - axiomatic inference, 38–39
 - conditional planning operators, 34–36
 - disjunctive preconditions, 37
 - expressivity, 47, 48
 - extended goals, 39–41
 - extending, 34–41
 - function symbols, 39
 - ground, 48
 - operators, 28–30
 - plans, 32
 - quantified expressions, 36–37
 - semantics, 33
 - states, 27–28
 - syntactical extensions, 34
 - translating state-variable representation into, 47–48
 - typed variables and relations, 34
- closed formulas, 558
- closed-loop controllers, 471
- closed-world assumption, 28, 47, 50
- communication planning, 3
- complete exclusion axioms, 149, 177
- completeness, 544
- complexity
 - classes (space), 552
 - classes (time), 551–552
 - HTN planning, 231
 - of machine scheduling, 358–360
 - plan existence for HTN planning, 252
 - of problems, 551–552
 - of procedures, 550
- complexity (classical planning), 55–67
 - comparing, 64
 - parameters affecting, 63–64
 - propositional planning, 66
 - results, 59–65
 - worst-case, 65
- composition operations, 295
- compound tactics, 276
- compound tasks, 507
- computation
 - with attached procedures, 39
 - minimax, 520
 - set-theoretic representation, 25
- Computation Tree Logic (CTL), 416
 - AF operator, 417
 - formula AG, 417
 - goal planning, 418
 - weak until operator, 418
- Computer-Aided Process Planning (CAPP), 493
- conceptual planning model, 5–9
 - component interaction, 8
 - dynamic, 9
 - for goal-directed behavior, 9
 - illustrated, 8
- concurrent actions, 321–323
 - with interfering effects, 322
 - resource use, 351
 - See also* actions

- conditional actions, 447
- conditional effects, 132–133, 266
- conditional operators, 34–36
 - example, 36
 - ground instance, 35
 - plan-space planning and, 100–101
- conditional planning, 447
- conditional plans, 427
 - AND/OR graph corresponding to, 431
 - execution of, 429
- configuration space, 472
- conflict exclusion, 156
- conflicting actions, 163
- conformant planning, 12, 447
 - DWR domain for, 445
 - planning graphs for, 446
 - planning-graph techniques and, 447
 - uncertainty and, 447
 - weak, 444
- Conjunctive Normal Form (CNF), 556
- connectives, 555
- consistency conditions, 318–319
 - set of constraints, 319
- consistency problems, 172
- consistent chronicles, 331–334
 - assertion support, 332, 333
 - chronicle support, 332, 334
 - example, 332
 - See also* chronicles
- constant symbols
 - container-stacking problem, 222
 - partitioning, 310
 - See also* object symbols
- constraint management, 339–341
 - meta-CSP for pending enablers, 340–341
 - object constraints manager, 340
 - Time-Map Manager, 339–340, 344
 - See also* CP procedure
- constraint propagation, 180–181
 - filtering through, 181
 - operations, 180
- constraint satisfaction problems (CSPs), 168–172
 - active, 185–186
 - arc-consistent, 181
 - binary, 169, 178
 - consistent, 168
 - development, 189
 - extended models, 185–187
 - formulation, 167
 - heuristics, 178
 - instances, 167
 - k-consistent, 183
 - minimal, 170
 - mixed, 185
 - network, 170
 - over finite domains, 167
 - path-consistent, 183
 - planning problems as, 172–178
 - planning relevance, 167–168
 - for planning-graph techniques, 188–189
 - in plan-space search, 187–188
 - relaxing, 171
 - solutions, 170
 - solvers, 178
 - strongly *k*-consistent, 183
 - symmetrical, 169
 - tightening, 170, 171
 - valued, 187
 - variables, 128, 174
 - See also* CSP encoding; CSP techniques/algorithms
- constraint satisfaction techniques, 112, 167–191
 - See also* neoclassical planning
- constraints
 - after, 245
 - before, 245
 - between, 245
 - binary, 97
 - binding, 311, 313
 - conjunction of, 168
 - consistent, 171
 - consistent binding, 91
 - convex, 301
 - enabling conditions, 313
 - encoding, 175
 - encoding actions, 175–176
 - encoding frame axioms, 176
 - explicit specification, 168
 - IA, 302
 - implicit specification, 168–169
 - kinematics, 471
 - machine scheduling problem, 357
 - networks of, 287
 - object, 311
 - ordering, 86–87, 92, 499
 - precedence, 245
 - qualitative, 289
 - quantitative, 289
 - separation, 331

- constraints (*continued*)
 - space, 15–16
 - temporal, 302–306, 311, 313
 - unary, 97
 - universal, 169
 - utility values, 187
 - variable binding, 88–90
- consumable resources, 353
 - produced by actions, 353
 - See also* resources
- containers, 78–79
- container-stacking domain, 78–79
 - auxiliary piles, 79
 - containers, 78–79
 - deleted-condition interactions and, 80
 - as DWR adaptation, 81
 - language for, 78
 - piles, 78–79
 - planning algorithm, 79–81
 - primary piles, 79
 - Sussman anomaly and, 80
- container-stacking problems
 - constant symbols, 222
 - HTN planning representation, 253–254
 - solving, 217
- contingent temporal variables, 307, 340
- control automaton, 484
 - constructing, 421
 - illustrated example, 420
 - as MDP, 484
 - nondeterminism, 484
 - parameter estimation, 486
 - use, 420
- control policy, 486
- control rules, 217–228
 - extended goals, 224–226
 - extensions, 223–224
 - HTN methods vs., 251–252
 - introduction, 217–218
 - planning procedure, 222–223
 - progression, 220–222
 - Simple Temporal Logic (STL), 218–220
- control states, 484
 - as heuristic projection, 486
 - same color, 485
- control strategies
 - in deductive planning, 263–279
 - domain-dependent, 263
 - dynamic logic, 270–276
 - situation calculus, 264–270
 - user-defined, 275–276
- control variables, 483
 - choice of, 483
 - elements, 483–484
- controllers, 8
 - closed-loop, 471
 - open-loop, 11
 - plan-based, 491
 - reactive, 470
 - reactive loop, 406
 - robotics, 483–486, 491
 - robustness, 9
- convex constraints, 301
- convexity, 302
- cost functions, 384
- cost(s)
 - optimal, 386
 - resource setup, 355
 - rewards and, 384
 - of solving open goals, 342
 - utility function determined by, 389
- counters
 - binary, 60–61
 - n*-bit, 61
- coverage domains, 474
- covering model, 538
- CP procedure, 338–339
 - constraint management, 339–341
 - implementation into planners, 339
 - implementation steps, 338–339
 - meta-CSP for pending enablers, 340–341
 - object constraints manager, 340
 - search control in, 341–343
 - Time-Map Manager, 339–340, 344
 - See also* chronicles
- CPR procedure, 370–371
- CSP encoding, 174–177
 - analysis, 177–178
 - constraints encoding, 175
 - constraints encoding actions, 175–176
 - constraints encoding frame actions, 176
 - CSP variables, 174
 - plan extraction, 176–177
 - See also* constraint satisfaction
- problems (CSPs)
 - CSP techniques/algorithms, 178–185
 - filtering, 180–184
 - hybrid, 184–185

- local search, 184–185
- search, 178–180
 - See also* constraint satisfaction problems (CSPs)
- CSP-based planning
 - branching, 196
 - nodes, 194
 - See also* constraint satisfaction problems (CSPs)
- current-state variables, 568
- data gathering, 3
- Davis-Putnam procedure, 151, 152–156
 - depth-first search, 152
 - partial assignments, 156
 - search tree example, 153
 - sound and complete, 156
 - unit propagation, 152–154
 - variable selection, 153
 - See also* satisfiability problems
- decidability, 56
 - of plan-existence, 57
 - results, 57–59
- decomposition trees, 236–238
 - for DWR problem, 240
 - interleaved, 241
 - noninterleaved, 242
 - in partial-order STN domains, 241
 - production details, 237–238
 - root of, 237
 - See also* tasks
- deductive machinery, 273
- deductive planning, 263
 - advantages, 277
 - control strategies, 263–279
 - expressive frameworks, 264
- Deep Space One (DS1), 451, 461–462
 - 6 days high-level autonomy scenario, 463–464
 - 12 hours low-level autonomy scenario, 463
 - 2 days high-level autonomy scenario, 464
 - Autonomous RA, 451–453
 - experiment, 461–466
 - experimental results, 464–465
 - first alarm results, 464–465
 - pictures of Comet Borrelly, 452
 - PS architecture, 457–461
 - RA architecture, 453–457
 - scenarios, 463–464
 - second alarm results, 465
 - third alarm results, 465
 - validation objectives, 462–463
 - See also* space applications
- default value assumption, 47
- deleted-condition interactions, 77, 80
- Delta algorithm, 202
 - for computing, 205
 - generalization, 203
 - initial run, 205
 - reachability analysis, 207
 - use of, 204
- dependency-directed backtracking, 180
- dependent actions, 119, 121
- depth-first branch-and-bound search, 546
- depth-first search, 200, 545
- derivational analogy, 528
- DerSNLP, 515, 516, 528, 529
- derUCP, 528
- Descartes planner, 188
- design tolerance specifications, 494
- determinism, 375
 - of transition relations, 443
- deterministic effects, 438
- DIAL, 515, 528
- directed acyclic graphs (DAGs), 570
- directed layered graphs, 118
- DISCOPLAN, 534
- discount factor, 385
- discrete-event systems, 5
- disjunctive preconditions, 37, 101
 - backtrack point, 101
- disjunctive refinement, 113–114, 188
 - in planning-graph techniques, 114
 - techniques, 342
- distance-based heuristics, 213
- Dock-Worker Robots (DWR) domain, 13–16, 487–490
 - abstract version, 14
 - actions, 15
 - for conformant planning, 445
 - decomposition tree, 240
 - initial state, 240
 - planning operators, 29, 65
 - predicate instances, 14–15
 - Simplified, 15
 - space constraints and, 15–16
 - Sussman anomaly, 78
 - topology, 14
 - variants, 15–16
- domain analysis, 534–535

- domain axioms, 273, 317–319
 - consistency condition, 318
 - examples, 317–318
 - form, 317
 - semantics, 318
- Domain Description Language (DDL), 460
- Domain Model (DM), 457–458, 459
 - basis, 459
 - state variables, 459
 - timelines, 459
 - See also* Planner and Scheduler (PS)
- domain-independent planning, 3–5
 - computational tools, 4
 - models, 4
 - plan merging, 532
 - plan synthesis, 5
 - project planning, 4
 - scheduling and resource allocation, 5
- domains, 405, 406
 - application, 449
 - classical planning, 31, 33
 - coverage, 474
 - dynamic logic, 273
 - encoding, 440
 - extended goals, 414–415, 417
 - fully observable, 380–392
 - HTN planning, 247
 - as language-recognition problems, 552–553
 - nondeterministic, 376
 - partially observable, 392–393, 426
 - policies for, 406
 - policy execution in, 406, 407
 - reachability goals, 406–407
 - set-theoretic planning, 20
 - in situation calculus, 267
 - state-variable planning, 45
 - STN planning, 235
 - as stochastic systems, 380
 - temporal planning, 320
 - total-order planning, 236
- domain-specific state-space planning, 78–81
 - container-stacking domain, 78–79
 - planning algorithm, 79–81
 - See also* state-space planning
- downward monotonicity, 533
- dynamic logic, 270–276
 - axioms, 273
 - classical planning vs., 271
 - deductive machinery, 273
 - extensions, 274–275
 - language of, 271–272
 - planning domain, 273
 - planning problem, 274
 - semantics, 272
 - situation calculus vs., 271
 - user-defined control strategies, 275–276
- dynamic planning, 9
- dynamic similarity measures, 528
- eager commitment strategy, 103
- EaGle language, 423
- elastic band, 479
- emergency evacuation planning, 505–516
 - HICAP, 505, 507–512
 - introduction, 505–506
- enablers, 333, 334
- enabling conditions, 313
 - interactions, 65
- encoding(s), 160–164
 - action alternatives, 161–162
 - of actions, 160–161
 - bounded planning problem, 148, 149
 - classifications, 161
 - compact, 172
 - constraints, 175
 - constraints, actions, 175–176
 - constraints, frame axioms, 176
 - explanatory, 163
 - of frame problem, 161
 - Graphplan-based, 165
 - planning problems into CSPs, 174–177
 - regular, 161
 - SAT, 177
 - size, 164
 - states as propositional formulas, 145
 - strong, 442
- equivalent expressivity, 50
- evacuation
 - operations, 506–507
 - plan formulation, 505
 - See also* emergency evacuation planning
- events, 6, 329
- exclusion axioms, 155
 - complete, 155
 - limiting, 163
- executable actions, 380
- execution paths, 407

- execution structures, 407, 416
- Expand algorithm, 207
- explanation-based learning (EBL), 529
- explanatory frame axioms, 163–164
- exponentially bounded functions, 550
- expressivity
 - classical representation, 47, 48
 - equivalent, 50
 - HTN planning, 231
 - set-theoretic representation, 25
 - state-variable representation, 47, 48
- EXPSPACE-bounded Turing Machine problem, 39, 60
- extended goals, 12, 39–41, 224–226, 377–378
 - classical planning and, 40
 - control automation, 420
 - domain example, 419
 - HTN planning, 256–257
 - plan example, 415
 - planning algorithms, 418–421
 - planning domains, 414–415, 417
 - planning problems, 418
 - plans, 415–416
 - policies, 414
 - reachability and, 397–398
 - representation, 377
 - in STL planning problems, 225
 - temporally, 433
 - uncertainty and, 378
 - See also* goals
- extended models, 11–13
- extensions
 - classical representation, 34
 - control rules, 223–224
 - Graphplan algorithm, 131–137
 - HTN planning, 252–256
 - PFD procedure, 252–255
 - plan-space planning, 100–101
 - STL-plan procedure, 223–224
 - TFD procedure, 252–255
- external conditions, 535
- external preconditions, 255
 - declarations of, 258
- failure recovery, 456–457
 - at execution level, 456–457
 - illustrated, 456
 - at planning level, 457
 - See also* Remote Agent (RA)
- feasible solution, 530
- feature-based models (FBMs), 497
 - generating/testing, 499
 - illustrated example, 498
 - number of, 497
- features
 - end-milling, 497
 - extraction, 495–497
 - machining, 495
 - nonprimary, 496
 - primary, 495, 496
 - See also* manufacturing analysis
- fewest alternatives first (FAF) heuristics, 210
- filtering
 - arc consistency, 181, 182
 - constraint propagation operation and, 180
 - levels of, 172
 - path consistency, 181–184
 - problems, 172, 180
 - techniques for CSP, 180–184
- first-order logic, 555–560
 - formulas, 557–558
 - fundamental constituents, 555
 - resolution principle, 559
 - resolvent, 560
 - simplicity, 557
- fixed-point level, 125, 129
- Fixedpoint procedure, 129
- flaw agenda, 461
- flaw-ordering heuristics, 342
- flaw-repair refinement, 188
- flaws, 92, 95
 - with no resolvers, 338
 - open goals, 325, 337
 - processing order, 95–96
 - PSP procedure, 99
 - resolvers, 94
 - resource conflict, 367
 - selection of, 95
 - threats, 325, 326, 338
 - unsatisfied axioms, 325
- flaw-selection heuristics, 208–212
- FLECS planner, 103, 104
 - STRIPS vs., 103
- flow-shop machine problems, 357
- fluent relations, 28
- fluents, 148, 265
 - changed, 149
- FORBIN planner, 373

- formulas, 557–558
 - bound, 558
 - closed, 558
 - goal, 268, 269
 - quantified, 39
 - STL, 218, 219–220
- forward search state-space algorithms, 69–73
 - branching factor reduction, 72
 - deterministic implementations, 72–73
 - formal properties, 70–72
 - heuristically guided, 203
 - input, 69
 - loop iterations, 70–71
 - partial solution, 69
 - pruning technique, 71–72
 - recursive version, 82
 - search space size, 71
 - TFD procedure comparison, 239
 - See also* state-space planning
- forward shifting, 568
- forward-checking search algorithm, 180
- forward-checking technique, 134
- frame axioms, 162–164, 267, 273, 274
 - classical, 162–163
 - constraints encoding, 176
 - explanatory, 163–164, 439
 - situation calculus, 268
- frame problem, 266
 - encoding of, 161
- free-flying rigid bodies, 472
- full observability, 375
 - modeling, 425
 - planning under, 380–392
 - See also* observability
- function symbols, 39, 60
 - HTN planning, 253
 - PFD procedure, 253
 - STL-plan procedure, 223–224
 - TFD procedure, 253
 - use of, 39
- game trees, 519
 - branches, 524
 - leaf nodes, 519
 - size produced by bridge, 521
 - size reduction, 520
 - from task networks, 523
- game-tree search, 519–521
 - bridge adaptation, 520
 - minimax computation, 520
 - See also* bridge
- goal formula, 268, 269
- goal states, 7
 - in control space, 484–486
 - reachability, 23
 - See also* states
- goals
 - conditioning, 544
 - extended, 39–41, 224–226, 256–257, 377, 414–425
 - open, 325, 337
 - Planner and Scheduler (PS), 460
 - reachability, 375, 403, 404–414
 - regression sets, 22
 - relevant actions for, 22
 - states, 149
 - state-variable representation, 44
 - unground expressions, 45
 - as utility functions, 379, 383–385
- GOLOG, 278
- GP-Search procedure, 128
 - as CSP solver, 128
 - focus, 134
- Graphplan algorithm, 123–131
 - analysis, 129–131
 - attention, 137
 - backward constraint-directed search, 131
 - extensions and improvements, 131–137
 - features, 131
 - generalizing, 132
 - as heuristic search planner, 207–208
 - iterative loop, 123
 - nodes, 194
 - planning graph expansion, 123–125
 - planning graph search, 125–129
 - proof, 130
 - soundness, 129–130
 - specifying, 128–129
- Graphplan-based encoding, 165
- greedy search, 546
 - algorithms, 203
 - See also* searches
- ground atomic formulas, 148
- ground substitution, 559
- GSAT algorithm, 157–158
 - basic, 157–158
- Herbrand interpretation, 558
- Heuristic Scheduling and Testbed System (HSTS), 458

- heuristically guided backward-search algorithm, 204–205
- heuristics, 199–215
 - admissible state-space, 205–208
 - design principle for, 199–201
 - distance-based, 213
 - domain-independent, 196
 - domain-specific, 196
 - fewest alternatives first (FAF), 210
 - flaw-ordering, 342
 - flaw-selection, 208–212
 - node-selection, 199
 - for plan-space planning, 208–213
 - resolver-selection, 212–213, 342
 - for state-space planning, 201–208
- Hierarchical Interactive Case-Based Architecture for Planning (HICAP), 505
 - cases, 508
 - development, 515
 - HTE, 505, 508–509
 - HTNs, 507–508
 - integrated elements, 505
 - interface, 515
 - knowledge representation, 507–508
 - SiN, 505, 509–512, 514–515
 - system illustration, 506
 - See also* emergency evacuation planning
- Hierarchical Task Editor (HTE), 505, 508–509
 - interface, 513
 - knowledge base, 509
 - uses, 509
 - See also* Hierarchical Interactive Case-Based Architecture for Planning (HICAP)
- Hierarchical Task Network (HTN) planning, 103, 214, 229–261
 - Abstract-HTN procedure, 248–250
 - attached procedures, 253
 - axioms, 253
 - for bridge, 521–524
 - comparisons, 250–252
 - complexity, 231
 - container-stacking problem representation, 253–254
 - domain, 247
 - expressivity, 231
 - extended goals, 256–257
 - extensions, 252–256
 - external conditions, 535
 - external preconditions, 255
 - function symbols, 253
 - HICAP, 507–508
 - high-level effects, 255
 - introduction, 229–231
 - plan existence complexity, 252
 - planning graphs, 256
 - plans as programs approach vs., 276–277
 - problem description, 230
 - problems, 247–248
 - procedures, 248–249
 - solutions, 248
 - STN planning vs., 250–251
 - task networks, 244–245
 - theoretical model, 258
 - time, 256
 - use of, 229, 257
 - See also* HTN methods
- high-level effects, 255
 - history, 258
 - in practical applications, 255
- Hilare robot, 473
- hill-climbing search, 547
- histories, 382
 - policies and, 383
 - of stochastic systems, 382–383
 - utility of, 385
- Horn clauses, 253, 254
- HS algorithm, 553
- HSP planner, 213, 214
- HTN methods, 245–247
 - control rules vs., 251–252
 - rewriting STN methods as, 246–247
 - See also* Hierarchical Task Network (HTN) planning
- HTN planners, 229, 257
 - advantages/disadvantages, 259
 - comparing, 259
 - list of, 258
 - See also* Hierarchical Task Network (HTN) planning; planners
- ICAPS, 373
- identical parallel machines, 356
- IMACS (Interactive Manufacturability Analysis and Critiquing System), 493
 - algorithms, 495
 - approach illustration, 494
 - concluding remarks, 503
 - efficiency considerations, 502–503

- IMACS (Interactive Manufacturability Analysis and Critiquing System) (*continued*)
 - FBM generation/testing, 499
 - ordering constraints, 499
 - steps, 499–502
 - task decomposition in, 501
 - See also* manufacturing analysis
- inactive variables, 185
- incomplete satisfiability decision
 - procedures, 157
- independence relation
 - allowance vs., 135
 - extending, 134–137
 - planning graphs for, 136
 - See also* relations
- independent actions, 119–120, 208
 - applicable, 120
 - unordered, 309
- initial situation axiom, 268
- initial situations, 268
- initial states, 148, 150
 - encoding, 148
 - paths for, 439
- instants
 - network of numerical constraints over, 289
 - networks of constraints over, 287
- Integer Linear Programming (ILP), 190
- integer programs (IPs), 529–530
 - format, 529
 - formulation development, 530
- intelligent backtracking, 180
- intentional plan recognition problem, 538
- interactions
 - deleted-condition, 77, 80
 - enabling-condition, 65
 - between robots, 490
- interpretations, 33
- Interval Algebra (IA), 293–302
 - binary constraint network, 296
 - composition table, 295
 - constraints, 302
 - convex constraints in, 301
 - geometric interpretation, 299–301
 - inconsistent network, 298
 - incremental consistency checking of, 307
 - network illustration, 297
 - networks, 297
 - Point Algebra (PA) vs., 301–302
 - primitive relations, 294
 - subset restricted to convex constraints, 302
 - tractable subclasses, 307
 - See also* qualitative temporal relations
- intervals, 286
 - end points, 288
 - inspect, 296
 - networks of constraints over, 287, 288
 - seal, 296
 - transitive composition and conjunction over, 296
 - variables, 298, 299
- IPP planner, 138
- iterative deepening, 123, 129, 547
- iterative repair algorithms, 158–159
 - illustrated, 158
 - Random-walk, 158–159
- l^AT_EX system, 344
- job-shop machine problems, 357
 - example, 357
 - schedule for, 358
- JSHOP, 509–510
 - algorithm correctness, 511
 - task decomposition, 511
 - See also* SHOP integrated with NaCoDAE (SiN)
- k*-ary state variables, 42
- keyhole plan recognition problem, 538
- kinematics, 471
- kinematics steering algorithm, 473, 474
- Kripke Structures, 418, 561, 563
 - example, 563–564
 - illustrated, 564
 - states of, 567
- labeled constraints, 307
- language-recognition problems, 56, 551
 - EXPSpace-complete, 60
 - planning domains as, 552–553
- language(s), 551, 555
 - EaGle, 423
 - first-order, 557
 - PDDL planning, 34, 35
 - PLAN-EXISTENCE, 552
 - PLAN-LENGTH, 552, 553
 - state-variable representation, 45
- layered plans, 119–120
- LCGP planner, 138
- learning apprentices, 535
- least commitment principle, 85, 86, 113

- lifted backward search algorithm, 75
- Lifted-PFD procedure, 253, 258
- Lifted-TFD procedure, 253
- linear programs (LPs), 529–530
- Linear Temporal Logic (LTL), 226, 432
 - formulas, 433
 - temporal extended goal specification, 433
- liveness requirements, 563
- Livingstone, 455
- LLP, 278
- local propagation operations, 181
- local search method, 184
 - approximation approaches, 187
 - See also* CSP techniques/algorithms
- localization
 - absolute, 479
 - on visual landmarks, 478–479
 - segment-based, 478
- Local-Search-SAT, 157
- logarithmically bounded functions, 550
- logical connectives, 220
- look-ahead improvement, 180
- machine scheduling, 356–362
 - ad hoc model, 362
 - classes, 356–358
 - complexity, 358–360
 - conclusion, 362
 - constraints, 357
 - flow-shop, 357
 - job-shop, 357
 - makespan problem, 359
 - max-tardiness problem, 358–359
 - multi-stage, 357
 - open-shop, 357
 - optimization criteria, 357
 - planning and, 360–362
 - problem solving, 360
 - problems, 356–362
 - reductions between problems, 359
 - single-stage, 356
 - See also* scheduling; scheduling problems
- machined parts, 493–495
 - example, 493–494
 - machining feature, 495
 - workpiece, 494
 - See also* manufacturing analysis
- Machines, 356
 - identical parallel, 356
 - uniform parallel, 356
 - unrelated parallel, 357
- machining features, 495
- machining operations
 - elementary actions correspondence, 497
 - illustrated, 496
- Manhattan paths, 473
- manipulation planning, 3
- manufacturing analysis, 493–503
 - abstract plan generation, 497–499
 - efficiency considerations, 502–503
 - feature extraction, 495–497
 - goal interaction resolution, 499
 - introduction, 493
 - machined parts, 493–495
 - operation plan evaluation, 502
 - See also* IMACS (Interactive Manufacturability Analysis and Critiquing System)
- Markov Chains, 382
- Markov Decision Processes (MDPs), 379
 - factorized, 432
 - framework, 397
 - model checking vs., 432
 - over infinite horizons, 399
 - Partially Observable (POMDPs), 393–397
 - planning based on, 383
 - view, 398
 - See also* MDP planning
- Markov games, 400
- Martha project, 487–490
 - environment map, 488
 - transshipment task management, 488
- maximum distance, 205
- MCS-expand algorithm, 368–369
 - search tree, 369
 - sound and complete, 369
- MDP planning, 379–401
 - algorithms, 386–392
 - conventions, 379
 - in fully observable domains, 380–392
 - as heuristic search extension, 399
 - Policy-Iteration algorithm, 387–389
 - reachability and extended goals, 397–398
 - under partial observability, 392–397
 - Value-Iteration algorithm, 389–390
- MEDIC, 534
- memory management, 133
- merging plans, 431–432

- meta-CSP, 340–341
 - managing disjunctions, 341
 - for pending enablers, 340–341
 - update, 341
- method symbols, 232
- methods, 229
 - as 4-tuples, 233
 - HTN, 245–247
 - instances, 234
 - interleaved decomposition tree, 241–242
 - preconditions, 232, 242
 - STN planning, 231–235
 - subtasks, 233
 - totally ordered, 233, 242
- Minimal Critical Sets (MCSs), 367
 - detection search tree, 369
 - searching for, 368
- minimal distance algorithm, 305
- minimal reduction problems, 172
- minimum distance, 201
- Mission Manager (MM), 453
 - goal selection, 454
- mission planning, 471
- mixed CSPs, 185
- modal operators, 218, 220
 - handling, 220
 - STL, 226
- Modal Truth Criterion (MTC), 104
- modalities, 480–483
- Mode Identification and Recovery Module (MIR), 455
 - failure recovery, 456–457
 - Livingstone, 455
 - objectives, 462
 - responsibilities, 455–456
 - See also* Deep Space One (DS1)
- Model Based Planner (MBP), 432
- model checkers, 561–562
 - illustrated, 562
- model checking, 403–435, 561–572
 - advantages, 404
 - algorithms, 565–567
 - algorithms, symbolic representation of, 569–570
 - BDD-based, 424
 - conventions, 403–404
 - discussion and historical remarks, 432–434
 - explicit-state, 432
 - extended goals planning, 414–424
 - intuitions, 561–563
 - MDPs vs., 432
 - planning under partial observability, 425–431
 - problem, 563–565
 - reachability goals planning, 404–414
 - symbolic, 567–570
- modes of behavior, 477
- MOLGEN, 528
- motion planning, 2–3, 472
 - as advanced research, 490
 - See also* robotics
- multiagent planning (MAP), 530–531
 - approaches, 531
 - plan-space paradigm, 531
- mutual exclusive relations, 120–123, 134
 - example, 121
 - See also* relations
- navigation planning, 3
- negative effects, 266
- neoclassical planning, 111–191
 - classical vs., 111
 - constraint satisfaction techniques, 112, 167–191
 - planning-graph techniques, 112, 113–141
 - propositional satisfiability techniques, 112, 143–166
 - search space nodes, 111
 - uncertainty with, 437–447
- networks of constraints, 287
 - numerical, 289
 - over instants, 287
 - over intervals, 287, 288
- NEXSPACE, 62
- next-state variables, 568
- NOAH planner, 103
- nodes
 - classical planning, 111
 - CSP-based planning, 194
 - Graphplan algorithm, 194
 - neoclassical planning, 111
 - plan-space planning, 85, 193
 - pruning, 217
 - SAT-based planning, 194
 - search space, 102
 - state-space planning, 85, 193
- node-selection heuristics, 199–201
 - admissible, 201
 - plan-space planning and, 208
 - relaxation principle, 200
 - uses, 199
- node-selection techniques, 547

- nogood tuples, 134
- nonblocking actions, 481
- nondeterminism, 375–376
 - modeling, 376, 405
- nondeterministic domains, 376
- nondeterministic effects, 438
- nondeterministic iterations, 269
- nondeterministic problem solving, 543–544
- nondeterministic state-transition system, 405, 413
- nonempty belief states, 428
- NONLIN planner, 103–104, 258, 532
- nonpreemptive actions, 352
- nonprimitive task symbols, 231
- nonprimitive tasks, 229
- null observability, 425

- object constraints, 311
- object constraints manager, 340
- object symbols, 41, 45, 311
 - unrestricted classical planning, 62
- object variable symbols, 45, 173
- object variables 41, 328
 - range, 41
- observability
 - full, 375, 425
 - null, 425
 - partial, 376–377, 425–431
- observation function, 425
- observation variables
 - evaluation of, 426
 - evaluations of, 426
 - partial observability with, 427
- observations
 - given as input, 538
 - set of, 425
- open goals, 325, 337
 - cost of solving, 342
 - resolution of, 342
 - See also* goals
- OpenGoals procedure, 96
- open-loop controller, 11
- open-shop machine problems, 357
- operation plans, 494
 - cutting parameters for, 501
 - evaluation, 502
 - illustrated, 500
 - production time estimation, 502
- operations
 - composition, 295
 - for constraint satisfaction, 296
 - entering, 287
 - inspecting, 288
 - loading, 287, 288
 - machining, 496, 497
 - moving, 288
 - sealing, 288
 - set, 25
 - transshipment, 487
 - unloading, 288
- operator graphs, 534
- operator splitting, 161–162
 - overloaded, 162
 - simple, 161
- operators, 28–30, 43, 173, 544
 - actions as ground instances of, 30
 - chronicle planning, 334–336
 - chronicles as, 334–336
 - conditional, 34–36
 - with conditional effects, 132
 - defining, 29
 - DWR domain, 29, 65
 - extending, 64
 - flows in, 92
 - instances, 29
 - merging, 532
 - modal, 218, 220, 226
 - name, 29
 - partially instantiated, 315
 - precondition restriction, 64
 - state-transition, 11
 - state-variable representation, 43–44
 - STRIPS-style, 49
 - syntactic restrictions, 55
 - temporal, 314–317
 - unrestricted classical planning, 62–63
- O-Plan planner, 257, 258, 343
- optimal cost, 386
- optimal policies, 385
- optimal solutions, 530
- optimal values, 530
- optimization problems, 197, 379
 - planning problems as, 385–386
- OR-branches, 127
 - illustrated, 549
 - unary, 212
- ordering constraints, 92, 499
 - adding, 86–87
 - identifying, 499

- overconsuming clique, 367
- overlapping actions, 281–282
 - interacting effects, 282
 - joint effects, 282
- overloaded operator splitting, 162
- ParcPlan, 344
- PARIS, 515, 528, 529
- partial assignments, 156
- partial observability, 376–377
 - belief states, 393–395
 - domains, 392–393, 426
 - formalization, 425
 - modeling, 379
 - with observation variables, 427
 - planning algorithms, 396–397
 - planning problems as optimization problems, 396
 - planning under, 377, 392–397, 425–4321
 - plans as policies on belief states, 395–396
 - stochastic system, 393
 - technical consequence, 377
 - See also* observability
- Partial Observability in MDPs (POMDPs), 392
 - algorithms, 396–397
 - planning problem, 396
 - solving, 396
- partial plans, 85, 90
 - actions, 93
 - actions, adding, 86
 - casual links, adding, 87–88
 - for interchanging variable, 105
 - ordering constraints, adding, 86–87
 - refinement, 90, 94
 - search space of, 86–90
 - solution, 91
 - subgoals, 86, 87
 - update analysis, 86
 - variable binding constraints, adding, 88–90
 - for washing, 108
 - See also* plan-space planning
- partial solutions, 69
- partially specified functions, 327
- partial-order STN planning, 240–244
 - decomposition trees, 241–242
 - PFD procedure, 243
 - See also* Simple Task Network (STN) planning
- path consistency, 181–184
 - algorithm illustration, 183
 - algorithms, 292
 - incremental algorithm, 183–184
- path planning, 2, 471
 - problem, 472
 - problem configuration, 476
 - roadmap, 474, 475
 - See also* robotics
- paths
 - execution, 407
 - feasible geometric, 471
 - for initial states, 439
 - Manhattan, 473
- PDDL planning language, 34, 35
- perception planning, 3
- persistence conditions, 329
- PFD procedure, 243
 - extensions, 252–255
 - generalizing, for temporal planning, 256
 - STL-plan procedure vs., 251
- PHI system, 278
- piecewise constant functions, 329
- piles, 78–79
 - auxiliary, 79
 - primary, 79
- plan existence, 56
 - complexity comparison, 64
 - complexity for HTN planning, 252
 - complexity results, 63
 - decidable, 55, 56, 57
 - EXPSpace-complete, 61, 64
 - in polynomial time, 65
 - in PSPACE, 65
 - semidecidable, 55, 56, 57, 58
- plan length, 56
 - complexity, 65
 - complexity results, 63
 - decidable, 57
 - NEXPTIME-complete, 64
 - in PSPACE, 65
- plan recognition, 537–540
 - chronicle problem, 539
 - intentional problem, 538
 - keyhole problem, 538
 - settings, 537–538
- plan refinement operations, 85
- plan spaces, 88
 - planning in, 89
- PLAN-EXISTENCE, 552
- PLAN-LENGTH, 552, 553
- plan-merging technique, 489

- Planner and Scheduler (PS), 454
 - architecture, 457–461
 - architecture illustration, 458
 - Domain Model (DM), 457–458, 459
 - failure recovery, 456–457
 - functions, 454
 - goals, 460
 - Heuristic Scheduling and Testbed System (HSTS), 458
 - integration, 458
 - objectives, 462
 - plans, 461
 - Search Engine (SE), 457, 458, 461
 - Temporal Database (TDB), 457
 - See also* Deep Space One (DS1)
- planners, 8
 - Descartes, 188
 - FLECS, 103, 104
 - FORBIN, 373
 - Graphplan, 123–131
 - HSP, 213, 214
 - HTN, 229, 257
 - IPP, 138
 - LCGP, 138
 - MDP-based, 432
 - NOAH, 103
 - NONLIN, 103–104, 258, 532
 - O-Plan, 257, 258, 343
 - SAPA, 343
 - SHOP2, 258, 343
 - SIPE-2, 257, 258, 343
 - SIPE, 532
 - SPUDD, 434
 - STAN, 138
 - TALplanner, 227
 - TGP, 343
 - TLPlan, 226, 227
 - TPSYS, 343
 - TWEAK, 104
 - UCPOP, 138
 - UMCP, 190, 258
 - UMOP, 433
- Planning, 1
 - in bridge, 517–524
 - case-based, 527–529
 - classical, 17–109
 - communication, 3
 - conceptual model, 5–9
 - conditional, 447
 - conformant, 12
 - control rules in, 217–228
 - deductive, 263–279
 - domain-independent, 3–5
 - domains, 13
 - dynamic, 9
 - emergency evacuation, 505–516
 - for extended goals, 414–425
 - first institutions, 1–2
 - forms, 2–3
 - hierarchical task network, 229–261
 - HTN, 103, 214
 - learning and, 535–536
 - machine scheduling and, 360–362
 - manipulation, 3
 - manufacturing analysis, 493–503
 - MDP-based, 379–401
 - mission, 471
 - model checking-based, 403–435
 - motion, 2, 471–477
 - motivations, 1–2
 - multiagent, 530–531
 - navigation, 3
 - neoclassical, 111–191
 - paradigms, 449, 450
 - path, 2, 471–477
 - perception, 3
 - plan-space, 78, 85–109
 - process, 527
 - project, 4
 - propositional, 66
 - QBF, 442–443
 - for reachability goals, 404–414
 - in robotics, 469–491
 - as satisfiability, 437–443
 - scheduling and, 349–374
 - set-theoretic, 20–27
 - in social/economic realms, 3
 - state-space, 69–93
 - STN, 231–238
 - STRIPS-style, 49
 - strong, 408–410
 - strong cyclic, 411–414
 - temporal, 309–347
 - with temporal operators, 310–326
 - time for, 285–308
 - with time/resources, 281–374
 - uncertainty, 375–447
 - weak, 410–411

- planning algorithms
 - domain-specific state-space planning, 79–81
 - extended goals, 418–421
 - partial observability, 396–397
 - reachability goals, 408–414
 - symbolic, 421
- planning domains. *See* domains
- planning graphs, 112, 114–123, 443–446
 - Abstract-HTN procedure and, 256
 - allowance relation, 136
 - for conformant planning, 446
 - as directed layered graphs, 118
 - extending, 123–131
 - fixed-point level, 125
 - inclusive disjunction of actions, 118
 - independence relation, 136
 - independent actions, 119–120
 - layered plans, 119–120
 - monotonic properties, 133
 - mutual exclusive relations, 120–123
 - properties, 124
 - reachability trees, 114–117
 - reachability with, 117–119
 - searching, 125–129
 - size, 124
 - See also* planning-graph techniques
- planning operators. *See* operators
- planning problem encoding, 174–177
 - analysis, 177–178
 - constraints, 175
 - constraints encoding actions, 175–176
 - constraints encoding frame axioms, 176
 - CSP variables, 174
 - HTN, 247–248
 - plan extraction, 176–177
- planning problems, 438–439
 - bounded, 147, 151, 440
 - classical, 31, 33, 40
 - as CSPs, 172–178
 - dynamic logic, 274
 - encoded, 150–151
 - extended goals, 418
 - as optimization problems, 385–386
 - as propositional formulas, 147–151, 439–442
 - “pure,” 350
 - reachability goals, 407
 - as satisfiability problems, 144–151
 - situation calculus, 268
 - state-variable, 45–46
 - STL, 224–226
 - STN, 236
 - temporal, 320
- planning procedure, 222–223
- planning-graph techniques, 112–141
 - actions, 113
 - commitments, 113
 - conformant planning and, 447
 - CSPs for, 188–189
 - disjunctive refinement, 114
 - Graphplan algorithm, 123–131
 - Graphplan extensions/improvements, 131–137
 - reachability analysis, 113–114
- plans, 7
 - actions in, 92
 - classical representation, 32
 - conditional, 427, 429
 - extended goals, 415–416
 - extraction of, 127, 176–177
 - layered, 119–120
 - merging, 531–532
 - operation, 494, 500, 501
 - partial, 85, 86–90
 - Planner and Scheduler (PS), 461
 - as policies, 381–383
 - as policies on belief states, 395–396
 - provisional, 489
 - rewriting, 532
 - scheduled, 349
 - semantics, 272
 - set-theoretic representation, 21
 - situation calculus, 267
 - synthesis, 5
- plans as programs, 264, 269–270
 - HTN planning vs., 276–277
 - in logical frameworks, 277
 - modal logic reliance, 278
- plan-space planning, 78, 85–109
 - algorithms, 94–100
 - conditional operators, 100–101
 - disjunctive preconditions, 101
 - experimental comparisons, 214
 - extensions, 100–101
 - flaw-repair refinement, 188
 - heuristics for, 208–213
 - nodes, 193
 - node-selection heuristics, 208
 - partial plans, 85, 86–90

- plan refinement operations, 85
- PoP procedure, 99–100
- PSP procedure, 94–99
- quantified conditional effects, 101
- search space, 85
- solution plans, 91–94
- state-space planning vs., 85, 101–103
- See also* classical planning
- plan-space searches, 187–188
- Point Algebra (PA), 290–293
 - binary constraint network, 291–292
 - composition table, 291
 - incremental consistency checking of, 307
 - Interval Algebra (IA) vs., 301–302
 - introduction of, 306
 - networks, 292
 - path-consistent network, 293
 - time, 291
 - See also* qualitative temporal relations
- policies
 - control, 486
 - example, 381–382
 - execution, 382, 406, 407
 - execution structure, 407
 - expected utilities, 385, 386
 - extended goals, 414
 - generation, 381
 - histories and, 383
 - iteration, 387
 - on belief states, 395–396
 - optimal, 385
 - plans as, 381–383
 - reachability goals, 406–407
- Policy-Iteration algorithm, 387–389
 - example, 388–389
 - illustrated, 388
 - policy improvement phase, 387
 - value determination phase, 387
 - Value-Iteration algorithm vs., 390–391
- polynomially bounded functions, 550
- PoP procedure, 99–100
 - illustrated, 100
 - Providers procedure, 99
 - subgoals and, 99–100
 - threats and, 100
- positive effects, 266
- Possibly Intersecting Assertions (PIA), 367
- precedence constraints, 245
- precedence graphs, 293
- precondition arcs, 118
- precondition-elimination abstraction, 533
- preconditions
 - action, 266
 - disjunctive, 37, 101
 - external, 255, 258
 - methods, 232, 242
- preemptive actions, 352
- preference rules, 535
- PRIAR, 528
- primary relations, 38
- primitive relation symbols, 290, 294
- primitive relations
 - disjunction of, 294
 - Interval Algebra (IA), 294
 - single, 297
 - See also* relations
- primitive tactics, 275–276
 - illustrated, 276
 - See also* tactics
- primitive tasks, 229, 231, 507
- Probabilistic-Roadmap algorithm, 475–476
- problem-reduction searches, 548–550
- problem-solving procedures, 543
 - deterministic, 543
 - nondeterministic, 543–544
 - properties, 544
- Procedural Reasoning System (PRS), 537
- procedures
 - attached, 39, 224, 253
 - complexity, 550
 - HTN planning, 248–249
 - incomplete satisfiability decision, 157
 - problem-solving, 543–544
 - search, 543–544
 - stochastic, 156–160
 - See also specific procedures*
- process planning, 527
- PRODIGY, 226, 529
- PRODIGY/Analogy, 515, 516, 528
- programming by demonstration, 535
- programs, plans as, 264, 269–270, 276–277
- progression, 220–222
 - computing, 220
 - formula, 221
 - result, 221
- proof theory, 555
- Propositional Dynamic Logic (PDL), 274–275

- propositional formulas, 144–151
 - encoding states as, 145
 - examples, 556
 - intended model, 145
 - models of, 144
 - planning problems as, 147–151, 439–442
 - state transitions as, 145–147
 - states as, 144–145
 - translating elements to, 144
 - unintended model, 145
- propositional logic, 555–557
- propositional planning, 66
- propositional satisfiability problem, 143
 - planning problems as, 144–151
- propositional satisfiability techniques, 112, 143–166
 - encodings, 160–164
 - planning problems and, 144–151
 - satisfiability planning, 151–160
 - See also* neoclassical planning
- propositional variables, 146, 160, 555
 - in different states, 146
- propositions
 - consumer, 87
 - models of, 556
 - mutex, 122
 - in planning graphs, 123
 - provider, 87
 - reachable, 123
 - union of sets of, 117–118
- Providers procedure, 99, 101
- provisional plans, 489
- Prune function, 217
- pruning, 547
 - Abstract-search procedure step, 194
 - nodes, 217
 - rules, writing, 218
 - safe, 205–206
 - technique, 71–72
- PSP procedure, 94–99
 - base step, 98
 - calling, 95
 - deterministic implementation of, 99
 - flaws, 99
 - as generic schema, 99
 - illustrated, 95
 - induction step, 99
 - OpenGoals procedure, 96
 - organization, 98
 - proof, 98–99
 - Refine procedure, 97
 - Resolve procedure, 96
 - Threats procedure, 96
 - variables/procedures, 95
- qualitative temporal relations, 290–302
 - Interval Algebra (IA), 293–302
 - Point Algebra (PA), 290–293
 - See also* relations
- Quantified Boolean Formulas, 437, 442–443, 569
 - compact representation, 569
 - logic, 443
 - planning, 442–443
- quantified conditional effects, 101
- quantified expressions, 36–37
 - for specifying states/goals, 37
- quantified formulas, 39
- quantitative temporal constraints, 302–306
 - networks, 305–306
 - simple, 303–305
 - See also* temporal constraints
- railway switch example, 422
- ramification problem, 343
- randomized local search, 157
- Random-walk algorithm, 158–159
- reachability analysis, 113
 - as driving mechanism, 114
- reachability goals, 375, 403, 414
 - classical planning goals vs., 407
 - planning, 404–414
 - planning algorithms, 408–414
 - planning domains, 405
 - planning problems, 407
 - solution to, 404
- reachability trees, 114–117
 - example, 114–115
 - illustrated, 116
 - nodes, 115, 116
- reactive action packages (RAP), 536
- reactive controllers, 470
- readability
 - with planning graphs, 117–119
 - set-theoretic representation, 24–25

- real-time value iteration, 391–392
 - experimental results, 392
 - optimal solutions and, 391
 - trade-off, 392
- Reed&Shepp curves, 473
- Refine procedure, 97
- refinement
 - SAT-based planning, 195
 - search, 196
- refinement operation, 88
- regression principle, 342
- regression sets, 22
 - set of, 23, 32
- rejection rules, 535
- relation symbols, 45, 173
 - types, 311
- relations
 - allowance, 134
 - flexible, 38
 - fluent, 28
 - independence, 134–137
 - mutual exclusive, 120–123, 134
 - primary, 38
 - rigid, 28, 29, 366
 - secondary, 38
 - transition, 443
- relaxation, 199–201
 - principle, 200, 342
 - state reachability, 201–204
- Remote Agent (RA), 451–453
 - AI technique basis, 452
 - architecture, 453–457
 - architecture illustration, 454
 - autonomy levels, 463
 - EXEC, 453
 - failure recovery, 456–457
 - failures/anomalies and, 453
 - goal translation, 454
 - MIR, 453
 - Mission Manager (MM), 453
 - plan generation, 452
 - PS, 453
 - spacecraft autonomy and, 453
 - See also* Deep Space One (DS1)
- representations
 - ADL, 50
 - classical, 19, 27–33
 - classical planning, 19–20
 - comparison, 47–48
 - extension examples, 20
 - set-theoretic, 19, 20–27
 - state-variable, 19, 41–47
- resolution
 - goal interaction, 499
 - inference rule, 556
 - of open goals, 342
 - problems, 172
- Resolve procedure, 96
- resolvent, 560
- resolvers, 95
 - choice of, 95
 - of flaws, 94
 - for threats, 100
- resolver-selection heuristics, 212–213, 342
- resource allocation, 5
- resource conflict flaws, 367
 - detecting, 367–369
 - managing, 370–372
- resource constraints manager, 372
- resource profiles, 353
 - examples of, 353
 - initial, 366
- resource variables
 - changing, 354
 - finite set of, 362
 - move operator with, 366
 - set of, 362–363
 - temporal assertion on, 363
- resources, 352–354
 - allocations set, 352
 - alternative, 354
 - borrowing, 363
 - constraints, 355
 - consumable, 353
 - efficiency parameter, 354
 - independent, 364
 - nonconflicting, 370
 - possible states, 354
 - requirements of actions, 354
 - reusable, 353, 363
 - setup costs, 355
 - state variables vs., 351
 - states, 354
 - use in chronicles, 363
- restricted model, 9–11
 - restrictive assumptions, 9–10
- restricted state-transition systems, 17

- reusable resources, 353
 - continuous, 353
 - discrete, 353, 363
 - See also* resources
- reward functions, 384
- rewriting plans, 532
- rigid relations, 28, 29, 366
- roadmaps, 474
 - probabilistic, 475, 476
- ROBEL control system, 485
- robotics, 469–491
 - approach analysis, 487
 - control automation, 484
 - controller, 483–486
 - environments/tasks, 469
 - introduction, 469–471
 - modalities, 480–483
 - path and motion planning, 471–477
 - planning maturity, 470–471
 - planning requirements, 470
 - robust controller design, 477–487
 - sensory-motor functions, 478–480
- robots, 469
 - architecture, 491
 - carlike, 474
 - configuration, 472
 - configuration space, 472
 - Dock-Worker, 487–490
 - Hilare, 473, 476
 - planning capabilities and, 470
 - total interaction between, 490
 - variables, 472
- RS, 536
- SAPA planner, 343
- SAT-based planning
 - nodes, 194
 - refinement, 195
- satisfiability problems, 144
 - encoding planning problem to, 151
 - planning problems as, 144–151
- SATPLAN, 534
- scheduled plans, 349
- schedules, 352
 - for job-shop problems, 358
- scheduling
 - as active field, 372
 - costs, 355
 - decomposition scheme, 350
 - objective criteria, 355
 - planning integration, 362–372
 - systems, 372–373
 - tools, 5
- scheduling problems, 349
 - actions, 352
 - constraints and cost functions, 354–356
 - elements of, 351–356
 - machine, 356–362
 - resources, 352–354
 - specifying, 351–352
 - temporal constraints in, 354
 - types of, 352
- SCOPE, 535
- search algorithms (CSPs), 178–180
 - backjumping, 180
 - backtrack improvements, 179–180
 - backtracking, 178–179
 - forward-checking, 180
- Search Engine (SE), 457, 458, 461
 - candidate plan, 461
 - flaw agenda, 461
 - See also* Planner and Scheduler (PS)
- search space, 544
 - as AND/OR graph, 430
 - forward search state-space algorithms, 71
 - nodes, 102
 - partial plans, 86–90
 - plan-space planning, 85
 - problem-reduction, 548
 - state-space planning, 85
 - STRIPS algorithm, 77
- searches
 - for actions, 128
 - best-first, 545–546
 - breadth-first, 544–545
 - depth-first, 545
 - depth-first branch-and-bound, 546
 - focusing, 133–134
 - greedy, 546
 - hill-climbing, 547
 - nondeterministic procedures, 543–544
 - planning graphs, 125–129
 - plan-space, 187–188
 - problem-reduction, 548–550
 - refinement, 196
 - state-space, 544–547
- secondary relations, 38
- selection rules, 535

- semantics, 555
 - of domain axioms, 318
 - formulas, 272
 - plans, 272
- sensory-motor functions, 478–480
 - absolute localization, 479
 - elastic band for plan execution, 479
 - localization on visual landmarks, 478–479
 - reactive obstacle avoidance, 479–480
 - segment-based localization, 478
 - See also* robotics
- separation constraints, 331
- set operations, 25
- set-theoretic planning domain, 20
- set-theoretic planning problems, 20–21
 - actions, 27
 - solution, 22
 - stating, 23–24
- set-theoretic representation, 19, 20–27
 - computation, 25
 - example, 21
 - planning problem statement, 23–24
 - plans, 21
 - properties, 24–27
 - proposition symbols, 20
 - readability, 24
 - state reachability, 22–23
 - translating, 48
 - See also* classical planning; representations
- SHOP2 planner, 258, 343
- SHOP integrated with NaCoDAE (SiN), 505, 509
 - backtracking, 510
 - cases, 512
 - correctness, 511
 - functioning of, 509–510
 - imperfect world information, 511–512
 - JSHOP, 509–510
 - summary, 514–515
 - See also* Hierarchical Interactive Case-Based Architecture for Planning (HICAP)
- similarity metrics, 528
- SimPlan, 433
- simple operator splitting, 161
- Simple Task Network (STN) planning, 231–238
 - domain, 235
 - HTN planning vs., 250–251
 - partial-order, 240–244
 - PFD procedure, 243
 - problems and solutions, 235–238
 - tasks and methods, 231–235
 - total-order, 238–239
 - See also* hierarchical task network (HTN) planning
- simple task networks, 231
- simple temporal constraints (STP), 303–305
 - consistent, 303
 - distributivity, 304
 - path-consistency algorithm, 303
- Simple Temporal Logic (STL), 218–220, 226
 - control formula, 224
 - formulas, 218
 - formulas, writing, 219–220
 - modal operators, 226
- Simplified DWR domain, 15
- simplified path-consistency algorithm, 304
- Simultaneous Localization and Mapping (SLAM)
 - technique, 478, 490
- SIPE-2 planner, 257, 258, 343
- SIPE planner, 532
- situation calculus, 264–270
 - action effects, 266
 - actions, 265–267
 - classical planning vs., 265
 - dynamic logic vs., 271
 - frame problem and, 266
 - language of, 265
 - logical theory, 265
 - planning domains, 267
 - planning problems, 268
 - plans, 267
 - plans as programs in, 269–270
- situations, 147, 264–265
 - fluents, 265
 - initial, 268
- SKICAT system, 466
- Smart Executive (EXEC), 455
 - failure recovery, 456–457
 - objectives, 462
 - tasks, 455
 - See also* Deep Space One (DS1)
- solution plans, 91–94
 - consistent binding constraints, 91
 - consistent partial order, 91
 - example, 93
 - illustrated, 94, 126
 - incorrect sequence, 92
 - refining partial plans towards, 94
 - See also* plan-space planning
- solution trees, 208

- soundness, 544
- SPA, 528
- space applications, 451–467
 - Deep Space One (DS1), 451, 461–466
 - discussion and historical remarks, 466–467
 - introduction, 451
 - Remote Access (RA), 451–461
- SPUDD planner, 434
- STAN planner, 138
- state reachability
 - goal, 23
 - relaxation, 201–208
 - set-theoretic representation, 22–23
- state space, 544
 - size, 391
- state transitions, 6
 - deterministic, 6
 - example, 146
 - as propositional formulas, 145–147
- state variable symbols, 41, 45, 173
 - timeline for, 330
- state variables, 41–43, 173, 327
 - chronicles for, 330
 - current state and, 42
 - Domain Model (DM), 459
 - examples, 42–43, 328–329
 - functions, 41, 42
 - ground, 42
 - imprecise specification, 328
 - incomplete specification, 328
 - k -ary, 42
 - n -ary, 331
 - as partial functions of time, 328
 - as partially specified functions, 327
 - as piecewise constant functions, 329
 - resources vs., 351
 - temporal assertion on, 329
 - timeline for, 330, 331
- state-oriented view, 283
- states, 27
 - belief, 393–395
 - classical planning, 264
 - classical representation, 27–28
 - control, 484
 - goal, 46, 149, 484–486
 - initial, 148, 150, 439
 - intermediate, 101
 - of Kripke Structures, 567
 - as propositional formulas, 144–145
 - reachable, 114
 - resource, 354
 - symbolic representation of, 567–568
 - terminal, 407
- state-space planning, 69–83
 - arcs, 85
 - backward search, 73–76
 - domain-specific, 78–81
 - forward search, 69–73
 - heuristically guided, 202
 - nodes, 85, 193
 - plan-space planning vs., 85, 101–103
 - search space, 85
- state-space search, 544–547
 - best-first, 545–546
 - breadth-first, 544–545
 - depth-first, 545
 - depth-first branch-and-bound, 546
 - greedy, 546
 - hill-climbing, 547
 - See also* searches
- state-transition functions, 21
- state-transition operators, 11
- state-transition systems, 5
 - dynamics, 8
 - evolution, 8
 - illustrated, 7
 - nondeterministic, 405, 413
 - representation, 6
 - restricted, 17, 31
- state-variable planning domain, 45
- state-variable planning problem, 45–46
 - statement, 46
- state-variable representation, 19
 - actions, 43–44
 - advantages, 47
 - constant symbols, 45
 - elements, 44–45
 - expressivity, 47, 48
 - extending, 58
 - ground, 46, 48
 - object variable symbols, 45
 - planning domain, 45
 - planning language, 45
 - planning operators, 43–44, 45
 - properties, 46–47
 - relation symbols, 45
 - state variable symbols, 45

- state variables, 41–43
- translating, into classical representation, 47–48
- STATIC, 535
- static similarity measures, 528
- STL planning problem, 224
 - example, 226
 - expression as, 225
 - extended goals, 225
 - solution, 224–225
 - See also* Simple Temporal Logic (STL)
- STL-plan, 222–223
 - attached procedures, 224
 - axioms, 224
 - extensions, 223–224
 - function symbols, 223–224
 - illustrated, 223
 - modal formulas, 226
 - as nondeterministic, 226
 - PFD procedure vs., 251
 - soundness, 222
 - TFD procedure vs., 251
 - time, 223
- stochastic CSPs, 185
- stochastic procedures, 151, 156–160
 - example, 159–160
 - GSAT, 157–158
 - iterative repair algorithms, 158–159
 - randomized local search, 157
- stochastic systems, 379
 - for continuous delivery, 398
 - domains as, 380
 - histories of, 382–383
 - illustrated, 381
 - partially observable, 393
- STRIPS algorithm, 76–78
 - backward-search algorithm vs., 76
 - deleted-condition interactions, 77
 - example, 77
 - FLECS vs., 103
 - ground version, 76
 - incomplete, 77
 - original version, 81
 - recursive calls, 76
 - search space, 77
 - solutions, 77
 - Sussman anomaly, 77–78
- STRIPS-style operators, 49
- STRIPS-style planning, 49
- strong conformant solutions, 438, 440
 - generating/testing algorithm, 443
- strong cyclic solutions, 408
 - planning algorithm, 411–414
- strong solutions, 408
 - planning algorithm, 408–410
- Strong-Cyclic-Plan algorithm, 411–414
 - elimination loop, 412
 - example, 411–412
 - illustrated, 412
 - subroutines, 413
 - termination, 414
- Strong-Plan algorithm, 408–410
 - example, 409–410
 - illustrated, 409
 - termination, 409, 410
- subtasks, 232, 233
 - interleaved, 241
 - of root, 241
 - See also* tasks
- Sussman anomaly, 77–78
 - DWR version, 78
 - shortest plan for, 77
 - Stack-containers algorithm, 80
- symbolic model checking, 567–570
 - advantages, 568
 - BDD-based, 570–572
 - fundamental ideas, 567
 - representation of algorithms, 569–570
 - representation of sets of states, 567–568
 - representation of transition relations, 568–569
 - techniques, 403
 - See also* model checking
- symbolic planning algorithm, 421
- symmetrical binary CSPs, 169
- syntactic constructs, 50
- tactical theorem proving, 275
- tactics, 264, 275
 - compound, 276
 - primitive, 275
 - user-defined control strategies as, 275–276
- TALplanner, 227
- Task Control Architecture (TCA), 537
- task networks, 235, 244–245
 - constraints, 245

- task symbols, 231
- tasks, 231
 - compound, 507
 - decomposing, 234, 235
 - decomposing (IMACS), 501
 - decomposition trees, 237
 - ground, 231
 - nonprimitive nodes, 236
 - primitive, 231, 507
 - STN planning, 231–235
 - subtasks, 232, 241
 - unground, 231
- temporal assertions, 329
 - conflicting, 364
 - conjunction of, 331
 - on resource variables, 363
 - set of, 330, 364, 365
- temporal constraint network problems (TCSPs), 305–306
 - consistency, 305
 - minimality, 305
- temporal constraints, 302–306, 311, 313
 - in DDL, 460
 - networks, 305–306
 - in scheduling problems, 354
 - simple, 302–305
- temporal databases, 310–314
 - approach, 326
 - assertion representation, 312
 - entailing, 313
 - illustrated, 312
 - support, 313
- temporal expressions, 310–314
 - set of, 313
- temporal operators, 314–317
 - move, 315
- temporal planning, 309–347
 - Abstract-HTN procedure and, 256
 - with chronicles, 326–343
 - concurrent actions, 321–323
 - domains, 320, 336
 - operators, 310–326
 - PFD procedure and, 256
 - problem statements, 320
 - problems, 320, 336
 - procedure, 323–326
 - solutions, 320
 - STL-plan and, 224
 - temporal references, 285–289
 - example, 286
 - of propositions, 286
 - temporal relations between, 287
 - as time periods, 286
 - temporal relations, 285–289
 - handling, 285
 - qualitative, 290–302
 - quantitative, 289
 - between temporal references, 287
 - See also* relations
 - temporal variables, 311, 328
 - contingent, 307, 340
 - numerical instantiation, 339
- terminal states, 407
- terms, 557
- test actions, 269
- TFD procedure, 238–239
 - Backward-search comparison, 239
 - example, 238–239
 - extensions, 252–255
 - Forward-search comparison, 239
 - STL-plan procedure vs., 251
- TGP planner, 343
- threats, 92, 325, 326, 338
 - conditional, 101
 - managing, with disjunctive-refinement techniques, 342
 - PoP solution of, 99–100
 - resolver for, 100
- Threats procedure, 96
- Tignum 2 algorithm, 521–524
 - belief functions, 524
 - implementation, 524
 - structures, 521
 - task network generation, 522
 - value calculation, 524
- TIM, 534
- time, 285–308
 - actions over, 281
 - complexity classes, 551–552
 - as essential component, 306
 - forms, 282
 - HTN planning, 256
 - partial functions of, 328
 - as resource, 282
 - STL-plan, 223
- Timelines, 330
 - consistent, 331

- Domain Model (DM), 459
 - example, 332
 - for state variables, 330, 331
- Time-Map Manager, 339–340, 344
- time-oriented view, 283
 - advantages, 284
 - reasons for adopting, 284
- TLPlan system, 226, 227
- total assignments, 156
- total-order STN planning, 238–239
 - domain, 236
 - problem, 250–251
 - restricting, 251
 - TFD procedure, 238–239
 - See also* Simple Task Network (STN) planning
- TPS procedure, 323–336, 337
 - features, 324
 - as general schema, 326
 - illustrated, 324
- TPSYS planner, 343
- transformational analogy, 528
- transition function, 6
- transition probabilities, 399
- transition relations, determination, 443
- transshipment operations, 487
- Turing Machine
 - current state, 62
 - EXPSPACE-bounded, 60
- TWEAK planner, 104
- typed variables, 34
- UCPOP planner, 104
- UMCP planner, 190, 258
- unary constraints, 97
- uncertainty
 - conformant planning and, 447
 - dimensions, 377
 - extended goals and, 378
 - in initial conditions, 444
 - with neoclassical techniques, 437–447
 - planning under, 375–447
- undecidability results, 57–59
- uniform parallel machines, 356
- unit propagation, 152, 153
 - calls to, 155
 - example, 153–154
- universal constraints, 169
- unrelated parallel machines, 357
- unrestricted classical planning, 61–65
 - constant symbols, 62
 - goal condition, 63
 - initial state, 63
 - operators, 62–63
 - predicates, 62
 - See also* classical planning
- unsatisfied axioms, 325
- use assertions, 364
- utility functions, 379, 384
 - assumption, 399
 - determined by costs, 389
 - goals as, 383–385
- utility values, 187
- valued CSPs, 187
- Value-Iteration algorithm, 389–390
 - example, 390
 - illustrated, 390
 - Policy-Iteration algorithm vs., 390–391
- variable binding constraints, 88
 - adding, 88–90
- variable selection, 153
- variable symbols, 311
- variables
 - active, 185
 - control, 483
 - CSP, 128, 174
 - current-state, 568
 - flipping, 157
 - inactive, 185
 - interchanging, 105
 - interval, 298, 299
 - next-state, 568
 - observation, 426
 - propositional, 146, 160, 555
 - PSP procedure, 95
 - resource, 354, 362
 - state, 327
 - temporal, 307, 339, 340
- weak conformant solutions, 438
 - algorithms for, 444
- weak solutions, 408
 - planning algorithm, 410–411
- Weak-Plan algorithm, 410–411
 - example, 410
 - illustrated, 411
- ZENO, 344