

Index

- access graphs, 530–533, 536
 competitive analysis and, 531
 page request sequences and, 531
- active learning, 378
- adaptive analysis, 52
 competitive analysis of online algorithms
 and, 66
 input order and, 64
 input structure and, 64–65
 open research directions, 66–67
 output-sensitive algorithms, 64
 parameterized algorithms and, 66
- adaptive dissection, 179
- adaptive sorting, 64
- adaptivity
 holdout method and, 501
 to intrinsic dimension, 408–409
 as overparameterization, 501
- additive bidders, 600, 602
- adjacency matrices, 213, 217
- adversarial noise, 134–362, 378–379
- adversaries
 knapsack problem and, 343
 localization and, 373
 monotone, 190, 194, 196–200, 203–205,
 213–214, 229
 in semi-random models, 189
 statistical model of, 542
 weakening, 542–543
- agnostic learning, 362–364
 computational hardness of, 367
- algorithm development, 3
- algorithm performance, 1, 2. *See also*
specific topics
 parameterizing, 12
 resources and, 75
- algorithmic game theory, 19
- algorithmic regularization, 481
- algorithmic stability, 488–489
- algorithms with predictions, 20
- allocation rule, 587–589
- alternating least-squares, 440
- alternating minimization, 228, 229, 440, 441
- alternative RIP matrices, 160
- analysis of algorithms
 goals of, 2
 parameterized, 11
 worst-case, 1–3
- analysis of local search algorithms, 16
- analysis of social networks, 19
- anchor words algorithm, 458–460
- anchor words assumption, 459
- anti-concentration bounds, 437
- anti-concentration of Gaussians, 432
- anti-concentration of polynomials, 437
- application-specific, 628
- α -approximate kernels, 44–45
- approximate Nash equilibrium, 120
- approximate nearest neighbor search
 hashing for, 404–405
 tradeoffs of, 419
- approximate Pareto curves, 342
- approximately-optimal auctions, 598
- approximation guarantees
 for k -median, 121
 for min-sum, 132
 prior-independent auctions and, 598
 resource augmentation bounds and, 74
 smoothed analysis and, 434
 Stitch algorithm and, 177
 surrogate loss functions and, 369
- approximation ratio
 smoothed analysis of, 301–305
 2-opt bounds and, 302–303
- approximation stability, 13, 120, 379, 627
- algorithms and proofs for, 127–132
 clustering and, 121, 126, 133
 definitions for, 121–125

INDEX

- approximation stability (cont.)
 instance stability and, 122
 interesting parameter ranges in, 121
 k -means and, 133
 k -median problem and, 125–132
 min-sum clustering and, 133
 Nash equilibrium and, 135
 NP -hard problems and, 121
 open questions in, 136
 optimization problems and, 121
 perturbation stability and, 123, 135
 proxy objectives and, 124
 relaxations and, 137
 separability and, 124, 126
 small clusters and, 132
 without target solution, 122
- (c, ε) -approximation stability, 121
- approximations, 103, 105
 hardness of, 126–127
- arrays
 binary search and, 647
 Bloom filters and, 650
 chained hashing and, 576
 QuickSort and, 171–172
 sorting algorithms and, 1–2, 260–262, 264
 2D maxima and, 272
- arrival-order distributions, randomness of, 253
- asserting clause learning schemes, 553, 555
- assignment trails, 552–553, 555
- assortative case, 212
- auctions, 19
 approximately-optimal, 598
 average-case revenue maximization, 589–590
 basic problem of, 587
 competition-based, 586, 599
 deterministic, 600
 prior-free, 593
 revenue-maximizing, 587–590
 robustness and, 591
 sample complexity and, 597–598
 single sample, 596
 truthfulness and, 587–588
 VCG, 588, 599–602
 worst-case revenue maximization, 588–589
- augmented indexing problem, 155
- automatic inequality prover, 519–522
- automatizability of proof systems, 549
 CDCL solvers and, 557–558
- average stability, 489
- average-case analysis, 167, 226–230
 advantages of, 168
 alternating minimization, 228
 classical algorithm justifications and, 171–175
 disadvantages of, 169
 matrix completion, 227–228
 planted models and, 193
 semi-random models and, 193–194
- average-case revenue maximization, 589–590
- Averaging algorithm, 369, 378
- Azuma's inequality, 513
- backbones, 560
- backdoors, 560
 strong, 560
 weak, 560
- backjump levels, 553
- backjumping, 554
- backtracking algorithms, 609–610
- backup Bloom filters, 651
- backwards analysis technique, 255
- bag-of-words representation, 445
- balanced allocations, 569, 580
- ball growing approaches, 123
- bandit setting, 639
- basis pursuit, 153
- batch normalization, 479
- Bayes classifiers, 362, 412
- Bayesian assumptions, 508
- BCT model, 619–622
- Bélády's furthest-in-the-future algorithm, 7
- belief propagation, 213, 221–223
- Bellman-Ford algorithm, 339–341. *See also*
 Bicriteria Bellman-Ford algorithm
- benchmarks
 CIFAR-10, 496, 501
 economically meaningful, 593
 ImageNet, 501
 machine learning, 501
 Opt^* , 510–511
- BERT model, 461
- best fit algorithm, 249
- beyond competitive analysis, 529
- bias-variance decomposition, 414
- Bicriteria Bellman-Ford algorithm, 339–341,
 350
- bicriteria shortest path problem, 338, 340, 350
- bidders
 additive, 600, 602
 unit-demand, 600–601
- bids, 587
- bijjective analysis, 543
- bimatrix games, 134
 approximate equilibria in, 134
- bin packing, 176, 183
 distributional analysis of, 173–175
 RO models, 248–249

INDEX

- binary optimization problems
 - linear, 352
 - smoothed complexity of, 352–354
- binary search, 647
- binary search trees (BSTs), 264, 265n
 - rooted, 275
- binary symmetric channel (BSC), 194
- bipartite expander graphs, 155
- bisection
 - graph, 180
 - minimum, 190
 - planted, 181, 185, 190, 213, 216
- block source, 567, 572–573
 - entropy and, 569, 575
 - hash family selection and, 570
 - hashing, 575–576
 - optimal extraction, 577–578
- Bloom filters, 567, 569, 580
 - false negatives, 651
 - false positives, 650
 - learned, 650–652
- Boolean constraint propagation (BCP), 550–554
- Boolean formulas, parameteric understanding
 - of, 549, 558–562
- Boolean Satisfiability problem, 547
- Boolean satisfiability solvers (SAT), 19, 547–550
 - central questions for, 548–550
 - proof complexity of, 554–557
 - proof search and, 549
 - as proof systems, 548–549, 554
- boosting, 497
- Borgwardt’s algorithm, 322
- boundary functions, 638
- bounded model checkers, 560
- bounded noise, 374, 375
 - margin-based localization for, 376
 - non-persistent, 379
 - research directions in, 379
- bounded search tree, 28
- bounded treewidth, 560
- bounds. *See also* specific types
 - anti-concentration, 437
 - bias, 415
 - competition complexity, 603
 - instance specific, in randomized tree
 - structure, 409–411
 - interpolation, 500
 - margin, 497–499
 - variance, 415
- branching
 - algorithm for, 28, 29
 - extended sequences of, 555
 - learning to, 638
- broadcast tree model, 224–226
- BSC. *See* binary symmetric channel
- BSTs. *See* binary search trees
- bucket sort, 266
- bucketing, 241
- Buss rule, 35
 - generalization to matrix rank of, 38–39
- cache miss, 652
 - marking algorithms and, 653, 654
- cache replacement policies, 6, 8–9
- caching, 72. *See also* paging problem
 - loosely competitive algorithms and, 86
 - online, 279
 - online algorithms and, 6
 - with predictions, 652–655
 - in resource augmentation analysis, 74–75
- Carbery-Wright anti-concentration bounds, 437
- cardinality bounds, 492
- catch words, 461
- Cauchy-Schwarz inequality, 520
- c -closed condition, maximum clique and, 608
- c -closed graphs
 - cliques of, 607–612
 - defining, 608–609
 - maximal cliques of, 610–611
 - weakly, 608
- CDCL solvers. *See* conflict-driven clause-learning solvers
- center perturbation clusterability, 124
- center proximity
 - metric perturbation resilience and, 110
 - 2-center, 111
- λ -center proximity condition, 108
- center-based clusterings, 124
- centers
 - clustering and, 294
 - k -center, 108
- certificates
 - correctness and, 274
 - of instances, 56
 - maxima, 274
 - of optimality, 215–217
- γ -certified algorithm, 97, 115
- certified algorithms, 95–97
 - basic properties of, 99–101
 - $(3 + \epsilon)$ -certified local search, 113–115
 - constraints and, 101
 - convex relaxations and, 103–105
 - designing, 101–106
 - running time, 97
- chained hashing, 569, 576–577

INDEX

- Chebyshev's inequality, 518, 578
 chemometrics, 448
 Chernoff bound, 180, 185, 201, 229, 365, 415, 416, 513
 Chernoff-Hellinger divergence, 221
 Chernoff-Hoeffding concentration bound, 240, 245, 269
 chi-distribution, 290
 chi-squared test, 506, 517–518
 CIFAR-10 benchmark, 496, 501
 classification
 computational complexity and, 364–365
 current research directions for noise in, 134–135, 378–379
 defining, 361, 362
 linear programming and, 364
 localization and, 369–374
 nearest neighbor, 17, 403
 sample complexity and, 363–364
 classification errors, 6, 487, 497, 500
 classification risk
 k -NN classification, 415
 minimax, 413
 classification rules, 361
 classifier error
 estimating, 365
 sample complexity and, 363
 classifiers, 5, 362, 412
 bounding, 366
 polynomial regression and, 367–369
 clause density, 559
 clause learning, 553
 Clause/Variable Ratio (CVR), 559–560
 clique problem, 30, 40
 cliques, 129
 of c -closed graphs, 607–612
 planted, 14, 182, 185
 clustering, 4–5, 95
 applications of, 133
 approximation stability and, 13, 120, 121, 126, 133, 379
 with center based objective, 108
 centers and, 294
 $(3 + \epsilon)$ -certified local search algorithm for, 113–115
 correlation, 637
 data-driven algorithmic design and, 632–637
 distances between, 125
 with dynamic programming, 111–113
 ground-truth, 13
 k -means, 124, 293–301
 linkage-based families, 634–636
 min-sum, 125
 NP-hard, 12
 objective based, 633
 perturbation-resilient, 116
 proxy objectives and, 124
 single-linkage, 108, 111
 small clusters, 132
 CNF. *See* conjunctive normal form
 CNF-SAT problem, 30, 40, 547
 co-approximations, 103, 105
 coefficient decay, 141
 coherence, 149
 collaborative filtering, 447
 collisions
 block source extraction optimization and, 577–578
 counting sketches and, 649
 CountMinSketch and, 144
 linear probing and, 172
 probability of, 572–573, 577, 580
 color coding technique, 31, 33
 colorful clique, 40
 combinatorial algorithms, 626, 627
 combinatorial approaches, 181
 combinatorial optimization problems, 15, 95–100
 local search heuristic for, 285–286
 combinatorially defined graph classes, 622
 communication complexity, 154
 community detection, 224, 227
 community structure, 213, 561
 community-like structures, 606
 comparative analysis, 540–541
 comparative ratio, 540
 comparison trees, 264
 in self-improving sorters, 271
 competition complexity, 599–600, 602, 603
 competition-based auctions, 586, 599
 competitive algorithms, 89
 loosely competitive, 86–89
 competitive analysis, 523, 529
 access graphs and, 531
 adaptive analysis and, 66
 diffuse adversary model and, 534–537
 of online algorithms, 18, 66, 235, 542
 competitive ratio, 66, 73–74, 234, 235, 529
 for lazy marking algorithms, 534
 for LRU, 532
 of marking algorithms, 653
 PFIF and, 653
 smoothed, 540
 trees and, 532
 complementary objectives, 98
 complementary problems, 98
 complexity
 communication, 154

INDEX

- competition, 599–600, 602
 computational, 364–365
 model, effects of, 493–495
 parameterized, 27–31, 35, 37, 455
 proof, 550, 562–563
 Rademacher, 493, 497, 499
 sample, 363–364, 517, 594, 597–598, 638
 smoothed, 352–354
 spectral, 499
 statistical, of k -nearest neighbor
 classification, 411–419
 complexity measures, of neural networks, 498
 compressed sensing, 140, 148, 157, 160
 L1 minimization, 153–154
 compression, 36, 141
 compressive sampling, 148
 compressive sensing, 14
 computational biology, 133
 computational complexity, 12
 classification and, 364–365
 of hash functions, 567
 computational improvements
 localization and, 369–374
 nicer noise models and, 375–378
 polynomial regression and, 367–369
 concentration bounds, 240. *See also* Chernoff
 bound; Chernoff-Hoeffding concentration
 bound
 conflict-driven clause-learning solvers (CDCL
 solvers), 19, 547–554
 algorithm for, 551
 backjumping, 554
 Boolean constraint propagation and,
 551–552
 conflict analysis and clause learning,
 553–554
 decision levels, assignment trail, and
 antecedents, 552–553, 555
 lower and upper bounds for, 557–558
 resolution proof systems equivalence with,
 554–557
 restarts, 554
 variable- and value-selection heuristics, 552
 conjunctive normal form (CNF), 547
 conspiracies of outliers, 385
 constraint satisfaction problems (CSP), 100,
 365
 constraints
 Boolean constraint propagation, 550–554
 certified algorithm design and, 101
 Gaussian constraint perturbation models,
 319, 329
 hard, 100
 contamination model, 383, 384, 399
 continuous weighted majority, 640, 642
 convergence
 to local minimum, 466
 uniform, 492, 629
 convex hull problem, 53–55, 65
 distributional analysis of, 175–176, 179, 184
 Gaussian perturbed points and, 323, 331
 self-improving algorithms for, 278
 convex programming, 151, 223, 228, 399. *See*
 also semi-definite programming
 robust mean estimation and, 390
 convex relaxations, 103–105
 sparse estimation and, 399
 Correlated Topic Models, 460
 correlation clustering, 637
 ϵ -corrupted sets, 383–386
 cost functions
 flow-dependent, 77
 for network flow, 77, 79, 80
 counting sketches, 649–650
 CountMedianSketch, 146, 156
 Count-Min sketch, 649
 CountMinSketch algorithm, 144–148, 153,
 154, 156, 160
 Count-Sketch, 650
 CountSketch algorithm, 143, 146, 148, 149,
 154, 156, 158, 160
 coupled oscillators, 230
 covariance estimation, 382
 robust, 397
 cover trees, 408
 critical values, 632, 635
 cross-validation, 415
 crowdsourcing, 379
 crude SDP, 207
 cryptography
 distributional models and, 193
 hashing and, 570
 CSP. *See* constraint satisfaction problems
 curse of dimensionality, 413
 CVR. *See* Clause/Variable Ratio

 data augmentation, 496
 data distributions, neural networks and, 481
 data models
 deterministic, 13–20
 worst-case analysis lacking, 7
 data streams, 142
 counting sketches for, 649–650
 data structures. *See also specific types*
 data-driven algorithm design and, 279
 exact nearest neighbor search and, 405–406
 intrinsic dimensions and, 408–409
 lazy, 550

INDEX

- data structures (cont.)
 LSH and, 404–405
 machine learning improving, 650
 nearest neighbor, 17, 408
 nearest neighbor search and, 403
 self-improving algorithms and, 260,
 262–263, 279
 for self-improving sorter, 266
 stack, 553
 for 2D maxima algorithms, 275–278
- data-dependent covering arguments, 499
- data-driven algorithm design, 20, 279, 626–627
 clustering problems and, 632–637
 greedy algorithms for subset selection
 problems, 630–632
 linkage-based families, 634–636
 open directions for, 644
 parametrized Lloyd’s methods, 636–637
 self-improving algorithms and, 279
 statistical learning for, 628–638
- Davis-Kahan theorem, 432
- Davis-Putnam-Logemann-Loveland algorithm
 (DPLL), 19
- DD algorithm, 322–323, 331
- Decision Learning Scheme (DLS), 553
- decision levels, 552–553, 555
- decomposition. *See also* tensor decomposition
 bias-variance, 414
 low-rank, 424–426
 orthogonal, 440
 singular value, 230, 425, 447
- decoupling inequalities, 439
- deep learning, 479
- defeatist search, 406, 410
- degeneracy, 618, 619
- degree distributions
 heavy-tailed, 606, 607, 623
 power-law, 615–616, 621
- Delaunay triangulation, self-improving, 277
- de-noising, 508
 of empirical distributions, 507
- dense k -subgraph problem, 195
- derandomization, 34
- deterministic models of data, 13–20
- deterministic reweighting, 395
- Devex rule, 330
- Diaconis-Graham inequality, 655
- dictionaries, 142, 407
- diffuse adversary model, 534–537, 570
- Dijkstra’s algorithm, 340
- dimensionality
 curse of, 413
 of data, 383
- dimensionality reduction, 403
- dimension-independent error, 383
- direct comparison of online algorithms,
 540–541
- directed access graphs, 531
- directed acyclic graphs, 553
 general resolution proofs as, 556
- directed flow networks, 77
- Dirichlet distributions, 454, 456, 458, 459
- discrete Fourier matrices, 157
- discrete frechet distance problem, 66
- distance between clusterings, 125
- distance function, 122
- distribution dependence, 603
- distribution testing and learning, 184
 instance optimality and, 18, 507–515
- distributional analysis, 14
 of classical algorithms, 171–175
 Erdős-Rényi random graphs, 179–180
 Euclidean problems, 175–179
 learning near-optimal solutions, 184
 optimal stopping problems and, 168–169
 pros and cons of, 167–168
 robust, 183–184
 simultaneous near-optimality in, 183
 threshold rules and, 169–171
 TSP in plane, 176–179
 2D convex hull, 175–176
- distributional assumptions, 15, 167–168
 algorithm design and, 171
 consequences of incorrect, 179
 outlier removal and, 386
 robust mean estimation and, 382
 sparse recovery and, 141
 stability conditions and, 386
- distributional knowledge, 586
 robustness and, 591
- distributional learning, 638
- distributional models
 cryptography and, 193
 semi-random models and, 193–194
- distribution-independent error bounds, 379
- distribution-optimal sorters, 15
- distribution-specific optimization, 168
- divide-and-conquer algorithms, 54, 179
 for 2D convex hull problem, 175
- DLS. *See* Decision Learning Scheme
- DMark algorithm, 534–535
- Doob martingale, 513
- double descent curve, 494
- doubling dimension, 407, 409
- doubling measure, 407
- downward-closed families, 246
- DPLL. *See* Davis-Putnam-Logemann-
 Loveland algorithm

INDEX

- DPLL SAT solvers, 548, 554, 558
 d -regular spectral expander graphs, 208
 D^{scl} -linkage algorithms, 635
 dual certificates, 219
 dynamic objects, 553
 dynamic programming, 109
 clustering with, 111–113
 knapsack problem and, 336
 linkage-based families and, 634, 636
 Longest Path problem and, 33
 MST clustering and, 111–113
- eccentricity of vertices, 620
 economically meaningful benchmarks, 593
 edit distance, 66
 80/20 rule, 140
 ellipsoid method, 4, 7
 ELMo model, 461
 EM. *See* Expectation-Maximization algorithm
 empirical distributions, 506, 509
 de-noising, 507
 nearest neighbor models and, 415
 polynomial regression and, 367
 spherical Gaussians and, 387
 empirical error, 362
 empirical estimators, 509
 empirical means, 17, 382
 certificates for, 388
 robust mean estimation and, 385–391
 robust sparse mean estimation and, 398
 empirical Rademacher complexity, 493
 empirical risk, 479
 concentration of, 470
 generalization gap and, 487–488
 holdout method and, 500
 interpolation bounds and, 500
 margin bounds and, 497, 498
 empirical risk minimization (ERM)
 regularization and, 491, 496
 stability of, 490–491
 encoding, 264
 Enron email graph, 608
 ensemble methods, 494
 margin bounds for, 497
 entropy, 567
 block source and, 569, 575
 encoding and, 264
 hash function modeling and, 568
 joint, of random variables, 266
 in Maxima Set problem, 56
 min-entropy, 568, 572
 of random arrival order, 253
 Rényi, 568, 572, 580, 581
 Shannon, 264
 structural, 57
 vertical, 55–56, 65
 equilibrium flow, 77
 cost of, 78
 Erdős-Rényi random graphs, 179–180, 182,
 185, 191, 192, 226, 606
 sparse, 614
 triangle density of, 612
 ERM. *See* empirical risk minimization
 error
 Chernoff bound and estimating, 365
 classification, 6, 363, 365, 487, 497, 500
 dimension-independent, 383
 distribution-independent bounds on, 379
 empirical, 362
 estimation, 140
 expected, 362
 information-theoretic limit on minimum, 383
 margin, 497
 method-of-moments and robustness to, 428
 PFIF and, 653
 training, 488
 estimation error, 140
 estimators, 509
 ETH. *See* Exponential-Time Hypothesis
 Euclidean distances, 287, 292
 Euclidean problems, good-on-average
 algorithms for, 175–179
 Euclidean TSP, 176–179, 183, 184
 eviction rules, 654
 evolutionary trees, 136
 excess-risk, 412
 expansion constants, 408
 Expectation-Maximization algorithm (EM),
 231, 427, 529
 expected error, 362
 explicit regularization, 496–497
 exponential tail property, 366
 Exponential-Time Hypothesis (ETH), 40–42,
 134, 453
 extended branching sequences, 555
- Facebook, 606
 triangle density of graph, 612
 facility location problem, 113, 250
 factoring algorithms, 193
 failure probability, 436–437
 FAR algorithm, 533, 536
 Fast Fourier Transform (FFT), 157
 fast rates, k -nearest neighbor classification and,
 417–419
 FCFS. *See* first come first served
 feedforward linearized neural networks, 479
 FFD. *See* first-fit decreasing

INDEX

- FFT. *See* Fast Fourier Transform
- FIF algorithm. *See* Furthest-in-the-Future algorithm
- FIFO policy. *See* first-in first-out policy
- 50%-algorithm, 235, 237, 239, 242
- filtering, 391, 399
 - basic, 391–393, 596
 - collaborative, 447
 - multi-filters, 398
 - point removal methods for, 394–395
 - practical considerations for, 396
 - randomized, 393–394
 - for robust mean estimation, 391–396
 - robust sparse mean estimation, 398–399
 - universal, 395–396
- first come first served (FCFS), 658
- first-fit decreasing (FFD), 174–175, 184
- first-in first-out policy (FIFO policy), 6–11, 73, 530, 536, 658, 659
 - competitive ratios for, 533, 536
 - as lazy marking algorithm, 534
- fixed dissection, 179
- fixed points
 - of belief propagation equations, 222–223
- fixed-parameter algorithms (FPT algorithms), 29–31, 35, 610–611
 - kernelization and, 37
 - $W[1]$ -hardness and, 39–40
- FK model, 203–205
- flip heuristic, 306
 - for max cut problem, 304
- flow polytope, 315
- flush-when-full (FWF), 530
- FOOBI algorithm, 441
- 4CNF formulas, 202
- 4SAT, 203, 206
- 4-wise independent hash functions, 578
- Fourier matrices, 160
- Fourier measurements, 157–158
- Fourier transform, 140
- FPT algorithms. *See* fixed-parameter algorithms
- FPT-approximation, 43–45
- FPTAS, 342
- fractional solutions, 104–105
- frequency distributions, 143
- frequency spectrum recovery algorithm, 516
- FrequentDirections algorithm, 158, 159
- FrequentElements algorithm, 143, 148, 159
- Frobenius norm, 431, 438
- Furthest-in-the-Future algorithm (FIF algorithm), 73–74, 537, 652, 655
- FWF. *See* flush-when-full
- gap version, of multiobjective optimization problem, 342
- Gaussian constraint perturbation models, 309, 310, 319, 329
- Gaussian constraints, LPs with, 319–329
- Gaussian distributions, 288, 366
 - rotational symmetry, 290
 - sparse iterations of k -means and, 300
- Gaussian ensemble, 150
- Gaussian linear combinations, 431
- Gaussian matrices, 157
- Gaussian mixture model, 230–231, 428–429, 434
- Gaussian noise, 155
- Gaussian unit LPs, 329
- general and tree-like resolution proofs, 556
- general resolution proof systems (Res-proofs)
 - as directed acyclic graphs, 556
 - CDCL equivalence with, 554–557
 - lower and upper bounds for, 557–558
- generalization
 - of Buss rule, to matrix rank, 38–39
 - guarantees for, 628
 - in machine learning, 486
 - open research questions in, 502
 - optimization versus, 495–496
 - overparameterized models and, 18, 486
 - tools for reasoning about, 488–493
- generalization bounds
 - NTK approach and, 481
 - for overparameterized models, 497–500
 - Rademacher complexity and, 493
 - uniform convergence and, 492
- generalization gap, empirical risk and, 487–488
- generalized linear models, 468–470
- generative models, 19, 200, 202
 - social network structure studied with, 606
 - topic modeling and, 445–447
- generic tensors, 426, 442
- genetic testing, 148
- geometric structure, unsupervised learning and, 409
- Gershgorin disc theorem, 432
- ghost samples, 488
- global clustering coefficient, 612
- global optimality
 - local optimality and, 467–468, 477–478
 - non-convex optimization for, 476
- Goemans-Williamson max-cut algorithm, 637
- Goemans-Williamson relaxation, 220, 226
- Goldfarb's steepest edge rule, 309
- Good-Turing Denoising Algorithm, 508, 511–513
- Good-Turing frequency estimation, 511–513

INDEX

- gradient descent, 6, 397
 implicit regularization of, 499
 over-parameterized neural networks with, 480
 perturbed, 481
 stochastic, 18, 397, 472, 495
 gradient estimators, 397
 Graham's scan algorithm, 53–54, 56, 60
 sorted inputs and, 59
 Gram matrix, 459, 460
 graph bisection problem, 180
 graph classes, 621–622
 graph coloring problem, 34
 FK model and, 203
 hosted coloring framework, 207–208
 unbalanced k -colorable semi-random model, 197
 unbalanced 4-coloring semi-random model, 197
 vertex coloring problem, 29, 46
 graphical secretary problem, 241
 graphs. *See also* random graphs
 c -closed, 607–612
 combinatorially defined classes of, 622
 Enron email, 608
 Moon-Moser, 610–611
 social network analysis and, 19
 treewidth of, 560
 triangle-dense, 612–615
 variable-incidence, 561
 greedy algorithms, 642
 subset selection problems and, 630–632
 greedy heuristics, 43
 general analysis for, 631–632
 merge resolution and, 562
 ground-truth clustering, 13

 Haar wavelet, 140
 Hadamard matrices, 157
 halfspace
 learning, 374
 through origins, 363
 unknown, 16–17
 Hamiltonian path problems, 31
 Hamiltonian tour, 288
 Hamming distance, 38, 122, 154
 Hamming's noise model model, 194
 hard thresholding, 151
 hardness
 of agnostic learning, 367
 of approximations, 126–127
 kernelization optimality and, 42
 of NMF, 448–449
 parameterized algorithms and, 39–42

 Harris' Devex rule, 309
 Harshman's uniqueness theorem, 428
 hash families, 570, 571, 577
 hash functions, 172, 567
 applications of, 569
 4-wise independent, 578
 modeling, 568
 performance guarantees, 568–569
 pseudorandom data and, 184
 simple, 19
 truly random, 576
 hash tables, 567
 in CountMinSketch, 144
 linear probing and, 172–173
 hashing, 571–572
 for approximate nearest neighbor search, 404–405
 block sources, 575–576
 chained, 569, 576–577
 cryptography and, 570
 ideal, 568, 570, 579
 linear probing and, 579
 heavy-tailed degree distributions, 606
 hidden Markov models (HMMs), 439, 440
 learning, 429
 high dimensions
 adaptive analysis and, 66–67
 shadow bound in, 325–329
 high-dimensional robust statistics, 382
 high-dimensional unsupervised learning, 383
 higher-degree moments, robust estimation of, 399
 hinge loss, 372, 373, 377, 487
 HMMs. *See* hidden Markov models
 Hoeffding bound, 269. *See also*
 Chernoff-Hoeffding concentration bound
 Hölder conditions, 418
 Hölder inequality, 520–522
 holdout method, 500–501
 homogeneous linear threshold classifiers, 363
 Huber's contamination model, 384
 hybrid heuristics, 305
 hybrid samples, 489
 hypergraph max cut problem, 33
 hyperparameter tuning, 627
 hypothesis testing problems, 506, 517

 ideal hashing, 568, 570, 579
 identity testing, 506, 516, 523
 instance optimal algorithm for, 518–519
 interpretation of sample complexity, 517
 IHT. *See* IterativeHardThresholding

INDEX

- i.i.d. model, 251, 383, 537, 539, 590
 robust mean estimation and, 387
 Steiner tree problem in, 251–252
- ImageNet benchmark, 501
- implicit regularization, 481, 499
- improper learning, 365
- incoherence, 149, 150, 227
- incomparable algorithms, worst-case analysis
 of algorithms and, 1–2
- independent set problem, 43. *See also*
 Maximum Independent Set
- independent sets, planted, 192
- inequalities
 automatic prover for, 519–522
 Azuma's, 513
 Cauchy-Schwarz, 520
 Chebyshev's, 519, 578
 decoupling, 439
 Diaconis-Graham, 655
 Hölder, 520, 522
 Jensen's, 647
 Markov's, 128, 146, 351
 lp monotonicity, 520–522
 non-degenerate systems of, 312
 prophet, 169–171, 184
 proving without math, 521–522
 restricted secant, 468, 470
 triangle, 128
- information rent, 589–590
- information retrieval, nearest neighbor search
 in, 403
- information theoretic limits
 of exact recovery, 219–221, 223
 on minimum error, 383
 in semi-random models, 224
- information theory, 263–266
 self-improving algorithms and, 265
 sorting and, 260
- inliers, 383, 385
- input distributions, 167–168
- input order, adaptive analysis and, 64
- input structure
 adaptive analysis and, 64–65
- input-based parameters, 12
- insertion sort, 1, 266
- insertion time, 579
- insertion-only matrix recovery, 158–160
- insertion-only streams, 143
- instance optimal distribution learning, 506–515
- Instance Optimal Learning Algorithm,
 508–510, 513
- instance optimality, 12, 18, 60–61, 273, 279, 506
 for identity testing, 518–519
 order-oblivious, 56–60
- self-improving algorithms and, 279
 of Threshold Algorithm, 63
- instance stability, approximation stability and,
 122
- instance-optimal aggregation algorithms,
 60–64
- integer quadratic programs (IQPs), 637
- Intermediate Simplex problem, 449
- interpolation bounds, 500
- interval lemma, 317
- intrinsic dimension, 416
 adaptivity to, 408–409
 defining, 407
 nearest neighbor search and, 408–409
- inverse theorem for triangle-dense graphs,
 613–614
- IQPs. *See* integer quadratic programs
- islands of tractability, 13
- isotropic log-concave marginal, 373, 375
- iterative methods
 planted clique problem and, 198
 in sparse recovery, 151–153
- IterativeHardThresholding (IHT), 151–154,
 156, 157
- Jaccard similarity, 614, 615
- Jarvis march algorithm, 53, 54, 56
- Jennrich's algorithm, 434, 442, 457
 overcomplete settings and, 437
- Jennrich's algorithm, 430
 overcomplete settings and, 435
- Jensen's inequality, 647
- job service times, 657–658
- Johnson-Lindenstrauss Lemma, 150
- joint entropy of random variables, 266
- Kac-Rice formula, 482
- k -center, 108
- k -clustering, 125, 129
 linkage-based families and, 634
- k -clustering problems
 dynamic programming and, 111, 112
- k -CNF formulas, 559
- k -colorable graphs, 106, 108–111, 115
- k -coloring, 32, 196
- k -d tree, 405–406, 409
- k -dimensional simplex, 446
- k -means, 5, 108
 approximation stability and, 133
 bounds for, 293–301
 decrease of objective function, 295–296
 dense iterations and, 296–298
 polynomial bounds for, 301
 smoothed analysis of, 293–301, 304

INDEX

- sparse iterations, 298–300
 - worst-case running time, 294
- k -means clustering, 125
- k -median clustering, 4, 121, 130, 131
 - approximation guarantees for, 121
 - approximation stability and, 125–132
 - approximation stability for objectives, 127
 - $(3 + \epsilon)$ -certified local search algorithm for, 113–115
 - cost, 125
 - definitions for, 125
- knapsack problem, 335–338, 628
 - adversaries and, 343
 - greedy algorithms and, 630–632, 642
 - as linear binary optimization problem, 352
 - multidimensional, 341
 - number of Pareto-optimal solutions, 343–349
- k -nearest neighbor classification
 - adaptive rates versus worst-case rates, 413
 - cross-validation, 415
 - extensions of, 417
 - general metrics and intrinsic dimension, 416
 - low noise conditions and fast rates, 417–419
 - minimax optimality, 412
 - smoothness conditions, 416–417
 - statistical complexity of, 411–419
 - statistical learning frameworks for, 412
- k -sparse vectors, 141, 154
- kernel methods, over-parameterized models and, 480–481
- kernelization, 29, 35–36
 - FPT-approximation and, 44
 - hardness and optimality of, 42
- kernels
 - α -approximate, 44–45
 - lossy, 43–45
 - polynomial, 42
- Kesten-Stigum bound, 225
- Khatri-Rao product, 435
- Klee’s Measure problem, 65
- Kruskal’s algorithm, 111, 241, 243
- Kruskal’s uniqueness theorem, 428, 442
- k SAT, 203

- L1 minimization, 153–154, 156, 157, 160
- label-invariant properties, 514
- landscape property, 477, 479
- large-scale optimization problems, 285
- large-scale social networks, structure of, 606–607
- Lasserre hierarchy, 441
- LASSO, 153

- Latent Dirichlet Allocation model, 454, 456, 458, 460
- latent semantic indexing, 447
- latent variable models
 - HMMs and, 429
 - spherical Gaussian mixtures and, 428–429
 - tensor decomposition and learning, 426–430
- LCT. *See* linear comparison tree
- learned Bloom filters, 650–652
- learning
 - active, 378
 - agnostic, 362–364, 367
 - asserting clause learning schemes, 553
 - to branch, 638
 - clause, 553
 - deep, 479
 - distributional, 638
 - distributional analysis and near-optimal solutions, 184
 - halfspaces, 16–17, 374
 - improper, 365
 - instance optimal distribution, 507–515
 - latent variable models, 426–430
 - list-decodable, 398
 - no regret, 640
 - outlier presence and, 382
 - realizable, 363
 - unlabeled vectors of probabilities, 513–515
 - unsupervised, 4
- least recently used policy (LRU policy), 6–11, 73, 530, 536, 655
 - bijjective analysis and, 543
 - comparative analysis of, 541
 - competitive ratios for, 532–536
 - as lazy marking algorithm, 534
 - loosely competitive algorithms and, 86–89
 - page fault rates, 74
 - performance predictions, 74
- least squares problems, 228
- leave-one-out distance, 436
- Leftover Hash Lemma, 573, 575, 578
- limited-access prophet model, 254
- linear binary optimization problems, 352, 353
- linear comparison tree (LCT), 275
- linear models, margin bounds for, 498
- linear probing, 569, 578–580
 - distributional analysis of, 172–173
- linear programming (LP), 7, 309
 - classification and, 364
 - ellipsoid method for, 4
 - with Gaussian constraints, 319–329
 - relaxation and, 103, 106
 - shadow vertex simplex method, 310–314
 - simplex method for, 3–4, 16

INDEX

- linear programming (LP) (cont.)
 smoothed complexity and, 329
 smoothed unit, 320–321
 two-phase interpolation method, 321–322
- linear sketching algorithms, 141, 143–144
- linear sparse recovery algorithms, 154
- linear threshold classifiers, 362, 365
- linear thresholds, learning in presence of noise, 361
- linearized neural networks, 479
- linear-time median finding algorithms, 54
- linkage-based families, 634–636
- Lin-Kernighan heuristic, 304, 305
- Lipschitz continuity, 413, 414, 419, 514
- L-Lipschitz continuous gradients, 467
- Lipschitz functions, 640
- list update problem, 539
- list-decodable learning, 398
- Lloyd’s algorithm, 5, 124, 231
 parametrized, 636–637
- local improvement step, 285
- local methods, 18, 465
- local minimum, convergence to, 466
- local neighborhoods
 broadcast tree model and, 225, 226
 community guesses and, 221
- local optimality, global optimality and, 467–468, 477–478
- local optimum, 286, 301
 monotone adversaries for, 203–205
- local search algorithms, 113, 285–286, 301
 analysis of, 16
 $(3 + \epsilon)$ -certified, 113–115
 smoothed number of iterations for, 286
- locality of reference, 530
 parameterizing by, 8–9
- locality-sensitive hashing (LSH), 409
- localization
 adversaries and, 373
 computational improvements via, 369–374
 key technical ideas, 370–371
 margin-based, 371, 376, 378
 power of, 373
- localized optimization, 376
- log-concave distributions, 366, 370
- log-Lipschitz probability distributions, 330
- log-normal distributions, 140
- longest path problem, 31–33
 derandomization and, 34
 ETH and SETH and, 41
 kernelization optimality and, 42
- loosely competitive algorithms, 86–89
- loss functions, 487
- lossy kernels, 43–45
- lower bounds
 for self-improving sorters, 271–272
 prior-independent auctions and, 598
 sparse recovery and, 154–155
- low-rank decompositions, 424–426, 433
- low-rank matrix estimation, 141
- low-rank matrix recovery, 140, 158
- low-rank tensor decomposition, 17
- LP. *See* linear programming
- LRU policy. *See* least recently used policy
- LSH. *See* locality-sensitive hashing
- machine learning
 applications in, 16–18
 benchmarks for, 501
 classification, 361
 distributions classes in, 366
 generalization in, 486
 learned Bloom filters and, 650
 non-convex optimization and, 465
 predictions from, 646
 sample complexity and, 597–598
 self-improving algorithms and, 279
 solver design and, 550, 562–563
 unreasonable effectiveness, 5–6
- malicious noise, 373, 379
- manifold gradient and Hessian, 468, 477–478
- manifold-constrained optimization, 468
- MapleSAT, 563
- maps. *See* dictionaries
- margin bounds
 for ensemble methods, 497
 for linear models, 498
 for neural networks, 498–499
- marginal distribution
 assumptions on, benefits of, 365–374
 localization and, 369–374
 polynomial regression and, 367–369
- margin-based localization, 371, 378
 for bounded noise, 376
- marking algorithms, 533
 cache miss and, 653, 655
 competitive ratio of, 653
 lazy, 534
 prediction and, 653–655
- Markov chains, 213, 537
- Markov paging algorithms, 536–539
- Markov’s inequality, 128, 146, 351, 578
- marriage before conquest algorithm, 54–57, 59, 60
 horizontal version, 55
 vertical entropy and, 55–56
- martingales, 513
- Massart’s noise condition, 418

INDEX

- matrix completion, 227–228, 472–476
 semirandom, 229–230
- matrix decomposition, rotation problem and, 426
- matrix factorization problems, 471–476
- matrix rank, Buss rule generalization to, 38–39
- matrix recovery, 158–160
- matrix rigidity problem, 38–39
- matroid secretary problem, 242, 255
- max-2SAT, IQPs and, 637
- Max 2-Horn SAT, 101, 116
- max cut problem, 33, 100, 101, 115
 flip heuristic for, 304, 306
 IQPs and, 637
- max probability, 572, 573
- maxima set problems, 52–60, 274
 adaptive analysis and, 67
 Graham’s scan and, 53–54, 56
 impossibility result and, 60
 instance optimality and, 56–59
 Jarvis march and, 53, 56
 layers of, 67
 marriage before conquest and, 54–57
 partially sorted inputs and, 59
 sorts inputs and, 59
 vertical entropy and, 55–56
- maximal cliques, of c -closed graphs, 610–611
- maximal depth problem, 65
- maximization CSPs, 101
- maximum clique problem, 180
 backtracking algorithm for, 609–610
 c -closed condition and, 608
 fixed-parameter tractability for, 610–611
- Maximum Independent Set (MIS), 99, 106, 108–112, 115, 116, 191
 monotone adversary with, 197–200
 noise contamination and, 195
 planted, 198
 refutation heuristic for, 202–203
- maximum k -cut problem, 221
- maximum likelihood estimation, 427
- maximum weighted independent set (MWIS), 631–632. *See also* Maximum Independent Set
- maximum-weight forest problem, 241–242
- MAX-SAT, 121, 136
- max-weight matching, 246–247
- mean estimation, 382
 robust, 383–396
- measurement matrix, 149
- merge resolution, 561–562
- MergeSort algorithm, 1, 2, 65, 260
- meta-learning, 627
- method-of-moments approach
 robustness and, 428
 semirandom mixture models and, 230
 tensor decomposition and, 427–428
- metric dimension, 407
- metric perturbation resilience
 center proximity implied by, 110
 defining, 109
- min uncut problem, 100–102
- min-cost matching, 253
- min-entropy, 568, 572
- minimax optimality, 412
- minimization CSPs, 100
- minimum bisection, 190, 214, 215, 218
- minimum cut problem, multiobjective version, 341
- minimum multiway cut problem, 99, 106–107, 115
- minimum spanning tree (MST), 111–113, 252
 self-improving algorithms and, 279
- minimum vertex cover, 99
- min-sum clustering, 125
 approximation stability and, 133
- MIPs. *See* mixed integer programs
- MIS. *See* Maximum Independent Set
- misprediction, price of, 656–659
- mixed integer programs (MIPs), 638
- mixture models, 446
 semirandom, 230–231
 topic modeling and, 456–458
- MNIST data set, 405
- model complexity, effects of, 493–495
- modularity, 561
- monopoly price, 589, 595
- monotone adversaries, 190, 194, 196, 197, 213–214
 for locally optimal solutions, 203–205
 partial recovery limits and, 224
 planted clique and MIS with, 197–200
 robustness against, 218–219
 SDP and, 216
 stochastic block model and, 229
- Moon-Moser graphs, 610–611
- Moore-Penrose inverse, 431
- MRI machines, 148, 157
- MST. *See* minimum spanning tree
- multi-class settings, k -nearest neighbor classification and, 418
- multi-filters, 398
- multidimensional discrete Fourier matrices, 157
- multidimensional knapsack problem, 341
- multiobjective optimization problems, 340–342, 351–352
 Pareto curves for, 16

INDEX

- multiobjective optimization problems (cont.)
 - shortest path problem, 354
 - spanning tree problem, 342
- multiple-secretary problem, 254, 255
 - order-adaptive algorithms, 243–244
 - order-oblivious algorithms, 239–240
- multi-sample models, 184
- Murphy’s Law data model, 7
- MWIS. *See* maximum weighted independent set
- Myerson’s Lemma, 589, 596, 598

- Nash equilibria, 120, 123
- nearest neighbor classification
 - adaptive rates versus worst-case rates, 413–417
 - cross-validation, 415
 - general metrics and intrinsic dimension, 416
 - interpolation bounds and, 500
 - low noise conditions and fast rates, 417–419
 - minimax optimality, 413
 - smoothness conditions, 416–417
 - statistical complexity of, 411–419
 - statistical learning frameworks for, 412
- nearest neighbor data structures, 17, 408
- nearest neighbor search, 17, 403
 - algorithmic problem of, 403–405, 411
 - analyzing algorithms for, 411
 - approximate, 404–405
 - canonical bad case in, 404
 - exact, 405–406
 - intrinsic dimension and, 408–409
- Nemhauser-Ullman algorithm, 336–337, 341, 348, 351
- networks
 - BCT model and, 619
 - cost functions for, 77, 79, 80
 - equilibrium flow in, 77–79
 - of parallel edges, 79
 - power-law bounded, 615–619
 - selfish routing and, 77–80
- neural networks, 18
 - complexity measures of, 498
 - data distributions and, 481
 - learned Bloom filters and, 650
 - linearized, 479
 - margin bounds for, 498–499
 - optimization of, 478–482
 - over-parameterization and, 479
 - regularized, 481
 - residual, 479
 - training, 6, 495
- neural tangent kernel (NTK), 480–481
- nicer noise models
 - computational improvements and, 375–378
 - statistical improvements from, 374–375
- NMF. *See* nonnegative matrix factorization
- no regret learning, 639, 640
- noise
 - adversarial, 361–362, 378–379
 - benefits of assumptions on, 374–378
 - bounded, 374, 375, 379
 - Gaussian, 155
 - k -nearest neighbor classification and, 417–419
 - learning linear thresholds in presence of, 361
 - malicious, 135, 373, 379
 - modeling, 194
 - post-measurement versus pre-measurement, 151
 - probability density functions for, 349
 - random classification, 374, 375
 - recovering signal contaminated by, 194–195
 - research directions for classification and, 378–379
 - statistical improvements for nicer models of, 374–375
- non-backtracking walks, 223
- non-clairvoyant scheduling, 81
- non-convex optimization, 18, 465
 - convergence to local minimum, 466
 - for orthogonal tensor decomposition and global optimality, 476
 - stochastic gradient descent training and, 495
 - tensor decomposition and, 476–478
- non-degenerate inequality system, 312
- nonnegative matrix factorization (NMF), 17, 445, 447
 - algorithm for separable, 451–453
 - further applications, 453
 - geometric interpretation of separability, 450–451
 - hardness of, 448–449
 - robustness of algorithms for, 452–453
 - separability and, 450
 - topic models and, 454, 458, 460
 - uniqueness of, 449–450
- nonparametric estimation, 411
- non-pathological inputs, 14, 167
 - input distributions and, 167, 171
- not-all-equal 3SAT, 192
- NP -hard problems
 - clustering and sparse recovery, 13
 - optimization problems, 4–5
 - parameterized complexity and, 27
 - $W[1]$ -hardness and, 39
 - semi-random models and, 195
 - tensor rank as, 454

INDEX

- approximation stability and, 121
- refutation algorithms and, 201
- semi-random models and, 196
- NTK. *See* neural tangent kernel
- nuclear norm, 159, 160, 228
 - minimizing, 229
 - monotone adversary and, 229
- objective based clustering, 633
- oblivious random models, 192, 193
- observation matrix, 149
- online ad allocation, 253
- online algorithms, 529, 648
 - adaptive analysis and, 66
 - adversary weakening and, 542–543
 - analysis of, 7
 - changing performance measurement of, 543
 - comparative analysis of, 540–541
 - competitive analysis of, 18, 235, 542
 - competitive ratios for, 531
 - direct comparison of, 540–541
 - loosely competitive, 86–89
 - Markov, 537–539
 - oracles and, 539
 - random-order models and, 15
 - resource augmentation and, 542
 - scheduling, 89
 - self-improving algorithms and, 260
 - threshold rules and, 169–171
- online matching, 247, 255
 - bipartite matching problem, 247
 - minimizing augmentations in, 247–248
- online paging, 6, 72–75
 - model for, 72–73. *See also* caching; paging problem
 - parameterized bounds in, 8–12
- online Steiner tree problem, 251
- optimal algorithm identification, 3
- optimal block source extraction, 577–578
- optimal estimators, 509
- optimal maxima algorithms, 274
- optimal online algorithms, 537
- optimal stopping problems, 168–169, 254
- optimality
 - instance, 18, 56–61
 - minimax, 413
 - parameterized algorithms and, 39–42
- optimality ratios, 61
 - for Threshold Algorithm, 63–64
 - matching lower bounds on, 63–64
- optimization
 - distribution-specific, 168
 - generalization versus, 495–496
 - localized, 376
 - manifold-constrained, 468
 - of neural networks, 478–482
 - of non-convex functions, 465
 - robust, 592
- optimization problems
 - approximation stability and, 121
 - binary, 352–354
 - certified algorithm design and, FPT-approximation and, 43–45
 - hard constraints in, 100
 - multiobjective, 16, 340–342, 351–352
- oracles, 364
 - online algorithms with, 539
 - random, 570
 - separation, 390
- order-adaptive algorithms, 255
 - max-weight matching, 246–247
 - multiple-secretary problem, 243–244
 - solving packing integer programs, 244–246
- order-oblivious algorithms, 238–243, 254
 - multiple-secretary problem, 239–240
- order-oblivious instance optimality, 56–60
- orthogonal decomposition, 440
- orthonormal columns, 149
- orthonormal representations, 199
- outliers, 383
 - consequential, 385
 - conspiracies of, 385
 - learning in presence of, 382
- output-sensitive algorithms, 64
- overcomplete settings
 - application implications of tensor decompositions in, 439–440
 - Jennrich’s algorithm and, 435, 437
 - tensor decomposition and, 433–440
- overfitting, 167, 168, 494
 - semi-random noise and, 194
- overparameterization
 - adaptivity as, 501
 - empirical phenomena, 493–497
 - model complexity and, 493–495
 - optimization versus generalization, 495–496
- overparameterized models, 6, 18, 479
 - future research directions, 502
 - generalization and, 486
 - generalization bounds for, 497–500
 - holdout method, 500–501
 - implicit regularization, 499
 - interpolation bounds, 500
 - kernel method and, 480–481
 - margin bounds for ensemble methods, 497
 - margin bounds for linear models, 498

INDEX

- PAC model, 628
 PACE challenge, 46
 packing integer programs, 244–246
 page faults, 72, 537
 loosely competitive algorithms and, 86
 LRU policy and, 86
 resource augmentation bounds on, 74–75
 page request sequences, 9, 10, 72, 73, 652
 access graphs and, 531
 locality of reference and, 8, 11
 loosely competitive algorithms and, 86
 partitioning into phases, 535
 PFIF and, 653
 PageRank, 61
 paging problem, 530. *See also* caching
 comparative analysis and, 540
 stochastic models for, 537–540
 trees and, 531
 parameteric understanding of Boolean
 formulas, 549, 558–562
 parameterization
 by locality of references, 8–9
 input-based, 12
 solution-based, 12
 parameterized algorithms, 12–13, 27, 39–41
 adaptive analysis and, 66
 application domains, 46
 FPT-approximation, 43–45
 hardness and optimality and, 39–42
 kernelization and, 35–36
 lossy kernels, 43–45
 randomization and, 31–34
 structural parameterizations, 34–35
 parameterized analysis of algorithms, 8, 11, 12, 536, 539
 parameterized complexity, 27, 35, 37
 vertex cover and, 27–31
 parametrized Lloyd’s methods, 636–637
 Pareto curves, 335
 approximate, 342
 computing, 334–342
 for multi-objective optimization problems, 16
 smoothed analysis of, 334
 Pareto frontier, 272
 Pareto-optimal solutions, 334, 336
 general model for, 349–351
 knapsack problem and, 335, 343–349
 multiple objectives, 340–342
 number of, 342–352
 shortest path problem and, 338–340
 partial recovery, 221–222
 belief propagation and, 222
 broadcast tree model and, 225
 monotone adversary and limit of, 224
 SDP for, 224
 semirandom model and, 225
 partial vertex cover problem, 43
 α -approximate kernels and, 44–45
 partially sorted inputs
 input order and, 64
 Maxima Set problems and, 59
 synergy between order and structure and, 65
 payment rule, 587
 PCA. *See* principle component analysis
 PCA tree. *See* principle component analysis
 tree
 Pearson’s chi-squared test, 506, 516–518
 peg game, 521–522
 Perceptron algorithm, 487
 performance guarantees, 2
 alternating minimization and, 229
 data-driven algorithm design and, 626–629
 hash functions and, 568
 instance optimal algorithms and, 518
 loosely competitive algorithms and, 87
 online paging and, 8
 order-oblivious algorithms and, 239
 parameterized, 8, 11, 12
 of prior-independent auctions, 596
 performance measures, 1
 changing, for online algorithms, 543
 performance prediction, 2
 γ -perturbation, 95–96, 102, 109
 perturbation bounds in matrix theory, 433
 SVD and, 447
 perturbation models, 316
 Gaussian constraint, 309, 310, 320, 329
 perturbation resilience, 13, 95–96, 100, 105, 109, 115, 627
 approximation stability and, 123
 center proximity implied by metric, 110–111
 clustering problems, 116
 single-linkage clustering and, 111
 perturbation-resilient clustering problems
 and,
 2-perturbation-resilient instances and,
 111–113
 weak, 96
 γ -weakly, 105
 perturbations, 350, 351
 random, 15–16, 434
 zero-preserving, 352
 perturbed gradient descent, 481
 Pflam dataset, 133
 PFIF algorithm. *See* Predicted
 Furthest-in-the-Future algorithm
 PHP. *See* Propositional Pigeonhole Principle
 phylogenetic tree reconstruction, 136

INDEX

- physical sensing apparatus, 149
 PIE model, 209
 planted bisection, 181, 185, 190, 213, 216
 exact recovery limits and, 219–220
 partial recovery and, 221
 planted clique problem, 14, 182, 185, 213
 monotone adversary with, 197–200
 spectral algorithm for, 198, 200
 planted community structure, 212
 planted graph models, 180–182
 planted independent set, 192, 198, 199
 planted models, 14, 192
 average case analysis and, 193
 distributional, 191
 noise contamination and, 194
 PLB graphs. *See* power-law bounded graphs
 PLS. *See* polynomial local search
 point removal methods, 394–395
 poisoning attack, 373, 379
 polar (of a polytope), 313–314
 Polyak-Lojasiewicz condition, 467, 471
 polynomial compression, 37
 polynomial kernels, 42
 polynomial local search (PLS), 286
 polynomial regression, 376–378
 computational improvements via, 367–369
 polynomial thresholds, 368, 376
 polynomials, anti-concentration of, 437
 population risk, 469–470, 479. *See also*
 generalization
 NTK approach and, 481
 power-law bounded graphs (PLB graphs),
 615–619, 622
 defining, 617
 triangle counting and, 617–619
 power-law degree distributions, 615–616, 622
 power-law distributions, 140, 509, 606
 recovery guarantees and, 147–148
 PPAD, 134
 Predicted Furthest-in-the-Future algorithm
 (PFIF algorithm), 653
 predictions, 646
 caching with, 652–655
 general job service times and, 657–658
 marking algorithms and, 653–655
 scheduling with, 655–659
 PredictiveMarker, 654–655
 preemptive shortest predicted job first
 (PSPJF), 658–659
 preferential attachment, 193
 price
 of anarchy, 77
 of misprediction, 656–659
 of prior-dependence, 594
 principle component analysis (PCA), 471–473
 principle component analysis tree (PCA tree),
 406
 prior-free auctions, 593
 prior-independent auctions, 19, 184, 586,
 591–593
 competition complexity and, 599–600, 602
 competitions-based approach, 598–602
 lower bounds and tightness, 598, 601–602
 multiple bidder, single sample, 596
 multiple samples, 597–598
 open questions for, 603
 sample-based, single item, 593–598
 single bidder, single sample, 595
 unit-demand bidders in, 600–601
 probabilistic latent semantic indexing, 446
 probability distributions, 167
 problem
 CLIQUE, 30, 31
 LONGEST PATH, 42
 MATRIX RIGIDITY, 38, 39
 VERTEX COLORING, 29, 31
 VERTEX COVER, 27–31, 35–38, 40, 47, 48,
 50
 CNF-SAT, 30
 proof complexity, solver design and, 550,
 562–563
 proof search, 549
 proof systems
 automatizability of, 549, 557–558
 SAT solvers as, 548–549
 prophet inequality, 169–171, 184, 254
 Propositional Pigeonhole Principle (PHP), 557
 proximity conditions
 λ -center, 108, 109
 2-center, 111
 proxy objectives, 124
 pseudo-dimension, 629–630, 634, 644
 pseudoinverse, 431
 pseudorandomness
 hash functions and, 184
 randomness extractors and, 573
 simple hash functions and, 19
 PSPJF. *See* preemptive shortest predicted job
 first
 public key cryptography, 193
 pure topic models, 446, 455
 quantile space, 595
 revenue curve in, 595
 quasi-convexity, 469, 470, 482
 weak, 467
 query order, 65
 queues, scheduling, 658–659

INDEX

- QuickSort, 14, 184
 distributional analysis of, 171–172
- Rademacher complexity, 493, 497, 499
- radio telescopes, 148, 157
- random arrival order, 253
- random classification noise, 374, 375
- random forests, 497
- random functions, hash functions and, 19
- random graphs
 Erdős-Rényi, 179–180, 182, 185, 191, 192, 606, 612, 614
 sparse, 223
 statistical physics and, 193
- random linear projections, 404
- random matrix theory, 217–218, 436
- random models, oblivious, 193
- random oracle model, 570
- random order ratio, 543
- random perturbations, 15–16
 smoothed analysis and, 434
- random projection tree (RP tree), 410
- random walk matrix, 395
 non-backtracking, 223
- random walks, 249
- Random-Threshold algorithm, 241
- randomization
 competitive ratios and, 530
 parameterized algorithms and, 31–34
- randomization tests, 495
- randomness extractors, 568, 573–575
 strong, 573
- random-order models (RO model), 15, 234–236
 bin packing and, 248–249
 extending to other models, 254
 increasing randomness, 251–252
 maximization problems and, 238–247
 maximum-weight forest problem, 241–242
 minimization problems, 247–250
 minimizing augmentations in online matching, 247–248
 multiple-secretary problem, 239–240
 online facility location problem, 250
 reducing randomness, 252–254
 robustness and, 253–254
 Steiner tree in, 251
- rank, of tensors, 424–426, 454
- rank-1 matrix completion, 472–474
- Rayleigh quotients, 198, 200
- realizable learning, 363
- reconstructing distributions, 513–515
- recovery
 general stochastic block models and, 221
 information theoretic limits of exact, 219–221, 223
 partial, 221–222
 planted bisection and, 219–220
 via semidefinite programming, 215–218
- recovery guarantees, 147–148, 513
- reduction rules, 36, 38, 47
- reductions
 dimensionality, 403
 from Exact NMF to Intermediate Simplex, 449
 maxima sets and, 54–56
 parameterized, 39–41
 from 3SAT to MIS, 202
- refutation heuristics, 201–203, 209
- regression, polynomial, 367–369, 376–378
- regularity, 590, 592, 595
- regularization, 491
 algorithmic, 481
 explicit, 496–497
 implicit, 499
 l₂, 491, 496
 of neural networks, 481
- relaxation
 approximation stability and, 137
 convex, 103
 Goemans-Williamson, 220, 226
 linear programming and, 103, 106
- Rényi entropy, 568, 572, 580, 581
- request sequences. *See* page request sequences
- resolution proof systems
 CDCL equivalence with, 554–557
 merges and, 561–562
 resolution width, 561
- resource augmentation, 13, 89, 592
 competition complexity and, 600
 guarantees of, 75–78, 81–83, 87
 online paging and, 72–75
 page fault bounds, 74
 scheduling problems and, 81–86
 selfish routing and, 77–80
 worst-case analysis of algorithms and, 75
- resources
 algorithm performance and, 75
 scheduling problems and, 81–82
- Res-proofs. *See* general resolution proof systems
- Restricted Isometry Property (RIP), 149–151
 alternative matrices, 160
 RIP-1, 155–156
 uniformity versus nonuniformity of, 153
- restricted secant inequality, 468, 470
- revelation principle, 593
- revenue, 587

INDEX

- data-driven algorithms and maximization of, 644
- worst-case maximization of, 588–589
- revenue curve
 - in quantile space, 595
 - in value space, 589, 595
- revenue-maximizing auctions, 587–590
- reweighting, 396
 - deterministic, 395
- Riemannian manifolds, 468
- RIP. *See* Restricted Isometry Property
- risk
 - classification, 413
 - empirical, 470, 479, 487–488
 - ERM, 490–491
 - excess, 412
 - minimax classification, 413
 - population, 469–470, 479, 481
 - predictors and minimization of, 487
 - supervised learning and minimizing, 487–488, 412
- RO model. *See* random-order models
- robust covariance estimation, 397
- robust distributional analysis, 183–184
- robust estimation of higher-degree moments, 399
- robust high-dimensional statistics, 17, 382
 - recently developed estimators, 396–399
- robust mean estimation
 - filtering method, 391–396
 - good sets and stability, 386–390
 - i.i.d. model and, 387
 - key difficulties and high-level intuition, 385–386
 - recursive dimension-halving and, 399
 - sample efficient robust estimation, 383–384
 - unknown convex programming method and, 390
- robust optimization, 592
- robust simplex, 452–453
- robust sparse mean estimation, 398–399
- robust stochastic optimization, 397
- robustness
 - auctions and, 591
 - distributional knowledge and, 591
 - Jennrich’s algorithm and, 434
 - method-of-moments and, 428
 - against monotone adversaries, 218–219
 - RO model and, 253–254
- rounding schemes, 103, 104, 106, 107
- RP forests, 411
- RP tree. *See* random projection tree
- RSA, 193
- running time
 - of simplex method, 16
 - smoothed analysis of, 286–301, 304–305
- sample complexity, 594
 - auctions and, 597–598
 - classification and, 363–364
 - interpretation of, 517
- SAT. *See* Boolean satisfiability solvers
- scheduling, 89
 - non-clairvoyant, 81
 - resources in, 81–82
 - speed scaling in, 81–86
 - with predictions, 655–659
- SCOP dataset, 133
- SDP. *See* semi-definite programming
- search
 - CDCL loops for, 553
 - nearest neighbor, 17
 - proof, 549, 557–558
- search algorithms
 - analysis of, 16
 - $(3 + \epsilon)$ -certified, 113–115
 - 1-local, 113
- search trees
 - bounded, 28
 - in self-improving sorter, 269
 - vertex cover problem and, 28
- second price, 588
- secretary problem, 235, 237–238, 254. *See also*
 - multiple-secretary problem
 - graphical, 241
 - matroid, 242, 255
 - optimal stopping theory and, 254
- self-improving 2D convex hulls, 278
- self-improving 2D Delaunay triangulations, 277
- self-improving algorithms, 15, 20, 184, 259
 - critiques of, 278–280
 - future research directions, 280
 - information theory and, 265
 - phases of, 260
 - sorting and, 260–263
 - for 2D maxima, 272–277
- self-improving sorters, 262–263, 265–272
 - comparison trees in, 271
 - limiting phase, 267–268
 - lower bound for, 271–272
 - beyond product distributions, 278
 - training phase, 268–271
- selfish routing, 89
 - model for, 77
 - resource augmentation guarantees and, 78
- self-modeling curve resolution, 448

INDEX

- semi-definite programming (SDP), 181, 199
 FK model and, 203
 information-theoretic threshold for exact recovery and, 223
 IQPs and, 637
 list-decodable learning and, 398
 monotone adversaries and, 216
 for partial recovery, 224
 recovery via, 215–218
 robustness against monotone adversaries and, 218–219
 sum-of-squares algorithms and, 441
 synchronization problems and, 230
- semicircle laws, 217
- semirandom gaussian mixture model, 230–231
- semirandom matrix completion, 229–230
- semirandom mixture models, 230–231
- semirandom models, 14–15, 183, 226, 570
 adversaries in, 189–190
 average-case analysis and, 193–194
 competition-based auction approach and, 599
 defining, 189
 examples of, 189–192
 hosted coloring framework and, 207–208
 information theoretic limits in, 224
 monotone adversary for locally optimal solutions, 203–205
 NP-hardness and, 195–196
 open problems in, 209–210
 partial recovery and, 225
 PIE model, 209
 planted clique and MIS with monotone adversaries, 197–200
 preliminary results on, 196–197
 rationale for studying, 192–196
 refutation heuristics and, 201–203
 separable, 205
 signal recovery from noise contamination and, 194–195
 smoothed analysis and, 286
 worst case instances and, 195
- semirandom stochastic block models, 212
 average-case analysis and, 226–230
 recovery via semidefinite programming, 215–218
 robustness against monotone adversaries, 218–219
- separability
 approximation stability and, 124, 126
 geometric interpretation of, 450–451
 NMF and, 450
 3-coloring models and, 191
- separable models for unique games, 206–207
- separable NMF
 algorithm for, 451–453
 geometric interpretation of, 450–451
- separable semi-random models, 205
- separation oracles, 390
- set splitting problem, 33, 34
 ETH and SETH and, 41
- SETF. *See* shortest elapsed time first
- SETH. *See* Strong Exponential-Time Hypothesis
- shadow bound
 for Gaussian unit LPs, 329
 in higher dimensions, 325–329
 open problems in, 330
 in two dimensions, 323–325
- shadow path
 interpreting, 311
 SSP and, 317
 structure of, 310–312
- shadow plane, 313–314, 320, 321
- shadow vertex pivot rule, 330
- shadow vertex simplex method, 309–314, 319, 330, 331
 algorithm for, 312–313
 shadow path structure, 310–312
 SSP and, 315–316
- Shannon entropy, 263
- Shannon's encoding theorem, 262, 264
- shortest augmenting path algorithm, 248
- shortest elapsed time first (SETF), 81–85
- shortest job first, 656, 658
- shortest path problem, 338–340
 multiobjective, 354
- shortest predicted job first (SPJF), 656–659
- shortest predicted remaining processing time (SPRPT), 658–659
- shortest remaining processing time (SRPT), 81, 84, 656, 658–659
- signals
 noise contamination, recovering, 194–195
 sparse, 140
- simple hash functions, 19
- simplex method, 3–4, 7. *See also* shadow vertex simplex method
 probabilistic analysis of, 330
 robust, 452–453
 running time of, 16
 smoothed analysis of, 309
- simultaneous near-optimality, 183
- single sample auctions, 596
- single-linkage clustering, 108, 111
- single-parameter family of scoring rules, 632
- single-pixel camera architecture, 148
- single-sample models, 183

INDEX

- singular value decomposition (SVD), 230, 425, 447
- SkiRental problem, 648
- slice-wise polynomial algorithms (XP algorithms), 29
- small-world property, 606
- smoothed analysis, 4, 11, 15–16, 183, 189, 285, 286
- of approximation ratio, 301–305
 - failure probability and, 436–437
 - hybrid heuristics and, 305
 - Jennrich’s algorithm and, 435, 437
 - of Pareto curves, 334
 - random perturbations and, 434
 - of running time, 286–301, 304–305
 - of simplex method, 309
 - of SSP, 316–319
 - tensor decomposition and, 433–440
 - of 2-opt, 306
- smoothed approximation ratio, 303
- smoothed competitive ratio, 540
- smoothed complexity, 329
- linear binary optimization problems, 352
 - of binary optimization problems, 352–354
- smoothed LP, 320–321
- smoothed models, 194
- smoothness conditions, 416–417
- SMP. *See* SparseMatchingPursuit
- social media posts
- adversarial noise and, 362
 - automatic classification of, 361
- social network analysis, 19
- social networks, 193
- generative models in studying, 606
 - PLB graphs and, 617
 - power-law distributions and, 615
 - stochastic block model and, 212
 - structure of, 606–607
 - triangle-dense graphs and, 612
- social welfare, 587
- soft outlier removal, 373
- solution-based parameterization, 12
- solver design
- machine learning and, 550, 562–563
 - proof complexity and, 550, 562–563
- solving packing integer programs, 244–246
- sorters
- distribution-optimal, 15
 - self-improving, 262–263, 265–272, 278
- sorting, 66
- bucket, 266
 - self-improving models and, 260–263
- Sorting Multisets problem, 55, 56
- spanning tree problem, 350. *See also* minimum spanning tree
- multiobjective, 342
- sparse Fourier transforms, 140
- sparse matrices, RIP-1 and, 155–156
- sparse mean estimation, robust, 398–399
- sparse random graphs, 223
- belief propagation and, 222
- sparse recovery, 13, 140–141
- compressed sensing and, 149
 - Fourier measurements, 157–158
 - iterative methods, 151–153
 - lower bounds and, 154–155
 - matrix recovery, 158–160
 - measurement models, 155–158
 - NP*-hard, 13
 - RIP and, 149–151
- sparse signals, 140
- sparse vectors
- Dirichlet distribution and, 454
 - RIP uniformity versus nonuniformity for, 153
- SparseMatchingPursuit (SMP), 156
- sparsest cut problem, 102, 213
- approximation stability and, 136
- sparsity-aware bounds, 143
- spectral algorithms, 181, 182
- hosted coloring framework and, 207
 - planted clique and, 198, 200
 - robust sparse estimation with, 399
- speed scaling in scheduling, 81–86
- spherical Gaussian distributions, 382, 384, 387, 400
- mixtures of, 428–429
- Spielman-Teng analysis, 16
- SPJF. *See* shortest predicted job first
- SPRPT. *See* shortest predicted remaining processing time
- SRPT. *See* shortest remaining processing time
- SSP. *See* successive shortest path algorithm
- stability
- algorithmic, 488–489
 - average, 489
 - of empirical risk minimization, 490–491
 - robust mean estimation and, 386–390
 - uniform, 489
- stationary points, 466, 467
- statistical adversary model, 542
- statistical distance, 573, 574
- statistical learning, 628
- for data-driven algorithmic design, 628–638
 - frameworks, 412
 - greedy algorithms for subset selection problems, 630–632

INDEX

- Statistical Query model, 399, 400
 statistics. *See also specific topics*
 applications in, 16–18
 robust high-dimensional, 17, 382, 396–399
 Steiner tree problem, 46
 in i.i.d. model, 251–252
 in RO model, 251
 Stitch algorithm for Euclidean TSP, 176–179, 184
 stochastic block model, 14, 185, 212, 224, 227
 average-case analysis and, 226–230
 general, 221
 monotone adversary and, 229
 stochastic gradient descent, 18, 397, 472, 487, 495
 stochastic models, 234, 236
 paging problem and, 537–540
 stochastic optimization
 generalization gap and, 487
 robust, 397
 streaming algorithms, 140, 141, 148, 157
 matrix recovery and, 159
 post-measurement versus pre-measurement noise, 151
 RIP and, 149–151
 streams
 insertion-only, 143
 strict turnstile, 143
 turnstile, 143
 strict saddle condition, 18
 strong backdoors, 560
 Strong Exponential-Time Hypothesis (SETH), 40–42, 66
 strongly NP-hard problems, 353
 strongly s -universal hash functions, 571
 structural parameterizations, 34–35
 sublinear algorithms, 157
 successive shortest path algorithm (SSP), 315–319, 331
 as shadow vertex, 315–316
 smoothed analysis of, 316–319
 sum-of-squares algorithms, 441
 supervised learning, 18, 184, 486
 risk minimization in, 487
 SVD. *See* singular value decomposition
 s -way cut problem, 44
 sweep line approach, 272, 274
 s -wise independent, 571
 symmetric distributional properties, 514
 synchronization problems, 230
 TA. *See* Threshold Algorithm
 tail bounds, 291. *See also* Chernoff bound;
 Chernoff-Hoeffding concentration bound
 filtering and, 392–393, 395
 for Gaussian random variables, 289
 shadow bounds and, 324, 328, 330
 uniform convergence and, 492
 tangent cone, 310
 tensor decomposition, 424, 482
 efficient algorithms in full rank setting, 430–433
 factors of, 425
 iterative algorithms, 441
 Jennrich’s algorithm, 430–433
 latent variable model learning and, 426–430
 low-rank, 424–426
 method-of-moments via, 427–428
 mixed models and, 456–458
 non-convex optimization for, 476–478
 open questions in, 441
 orthogonal, 440
 other algorithms for, 440–441
 overcomplete setting and, 433–440
 power method, 440–441
 pure topic models and, 456
 smoothed analysis model for, 433–440
 topic models and, 454–455
 tensors, 424–426
 defining, 424
 generic, 426, 442
 modes of, 424
 order of, 424
 rank, 424–426, 454
 symmetric, 425
 test sets
 holdout method and, 501
 machine learning benchmarks with, 501
 model accuracy and, 502
 37%-algorithm, 237, 242
 3CNF formulas. *See* 3SAT
 3-coloring, 191, 207–209
 3SAT, 190, 192, 195, 201, 202, 205
 Threshold Algorithm (TA), 62
 instance optimality of, 63
 optimality ratio lower bound for, 63–64
 threshold rules, 169–171, 184
 thresholding
 hard, 151
 IHT algorithm, 151–154, 157
 randomized, 394, 396
 Tikhonov regularization, 491
 TimeStamp algorithm, 539
 TM. *See* truncate and match
 topic modeling, 17, 445–447
 anchor words algorithm, 458–460
 mixed models, 456–458
 NMF and, 454, 458, 460

INDEX

- pure, 455
- tensor decomposition and, 454–455
- training error, 488
- training sets, 6, 593
 - holdout method and, 501
- transitivity (of a graph), 612
- Traveling Salesman Problem (TSP), 1, 16, 115, 350
 - 2-opt heuristic for, 287–302
 - as strongly NP-hard, 353
 - Euclidean, 176–179, 183, 184
- trees
 - belief propagation and, 222
 - binary, 264
 - binary search, 28–29, 265n, 270
 - bounded search, 28
 - broadcast, 224–226
 - comparison, 264, 271
 - cover, 408
 - evolutionary, 136
 - exact nearest neighbor search and, 405–406
 - k -d, 405–406, 409
 - LRU competitive ratio for, 532–533
 - minimum spanning, 111–113, 252
 - multiobjective spanning, 342
 - paging and, 531
 - PCA, 406
 - phylogenetic reconstruction of, 136
 - randomized, 409–411
 - rooted binary, 275
 - spanning, 350
 - Steiner, 46, 251–252
- treewidth, 46, 560
- triadic closure, 606–607, 621
- triangle counting, 617–619
- triangle inequality, 128
- triangle-dense graphs, 612
 - inverse theorem for, 613–614
 - visualizing, 613
- truly random functions, 571, 576
- truncate and match (TM), 174
- truthfulness, 593
 - auctions and, 587–588
- TSP. *See* Traveling Salesman Problem
- Tsybakov noise condition, 418
- Tukey’s median, 384
- 2/3-norm testing algorithm, 519
- 2-center proximity condition, 111
- 2D maxima
 - certificates and linear decision trees and, 274–275
 - coordinate-wise, 272
 - self-improving algorithms for, 272–277
 - sweep line approach, 272, 274
- 2-opt heuristic, 16, 285
 - approximation ratio bounds, 302–303
 - improved smoothed approximation ratio of, 303
 - improving initial tour length, 292
 - linked pairs of steps, 293
 - smoothed analysis of, 295, 306
 - for TSP, 287–302
- 2SAT, 207
- 2-perturbation-resilient instances, 111–113
- 2-universal hash families, 567–568, 570, 571, 577
- 2D convex hull problem, 175–176, 179, 184
- TwoSweep algorithm, 620, 621
- UGC. *See* unique games conjecture
- unbalanced bipartite expander graphs, 155
- underparameterized regime, 494
- uniform algorithms, 148–154
- uniform convergence, 492, 629
- uniform distribution over convex sets, 366
- uniform stability, 489
- uniformity, 153, 590
- union bounds, 146, 150, 201
 - in order-adaptive algorithms, 244
 - in self-improving algorithms, 269
- unique games conjecture (UGC), 206
- unique games, separable models for, 206–207
- unit consistency, 556
- unit resolution rule, 551
- unit-cost RAM, 337
- unit-demand bidders, 600–601
- universal filtering, 395–396
- universal hashing, 568, 570
- unknown convex programming method, 390
- unknown halfspaces, learning, 16–17
- unlabeled vectors of probabilities
 - expected error and, 513
 - learning, 508, 510, 513–515
 - reconstructing, 516
- unsupervised learning, 4, 426, 633
 - geometric structure and, 409
 - high-dimensional, 383
 - matrix completion, 227
 - outliers and, 382
- value-selection heuristics, 552
- Vapnik–Chervonenkis dimension (VC dimension), 492, 629
- variable-incidence graph (VIG), 561
- variable-selection heuristics, 552
- variance bounds, 415
- variational inference, 461

INDEX

- VC dimension. *See* Vapnik-Chervonenkis dimension
 VCG auctions, 588, 599–602
 vertex cover problem, 27–31, 40
 kernelization and, 35, 37
 VIG. *See* variable-incidence graph
 virtual values, 589, 590
 virtual welfare, 590
 Voronoi diagram, 277
- W[1]-hardness, 30, 39–40
 s -Way Cut problem and, 44
 weak backdoors, 560
 weak perturbation resilience, 96
 weak quasi-convexity, 467
 weakly c -closed graphs, 608
 Weibull distributions, 659
 weight decay, 491
 weighted majority, 640, 642
 welfare maximization, 588, 600
 whitening, 441
 Wilson’s doctrine, 591
 wireless communication, 157
 word embeddings, 461
 word frequency, 509
 vectors for, 445
 worst-case analysis of algorithms
- benefits of, 2
 cons of, 7
 famous failures of, 3–8
 incomparable algorithms and, 1–2
 as modeling choice, 2
 refinements of, 12–13
 resource augmentation and, 75
 worst-case bounds
 intrinsic dimension and, 406, 408
 nearest-neighbor search and, 403, 408
 revenue maximization, 588–589
- XP algorithms. *See* slice-wise polynomial algorithms
- Yao’s minimax lemma, 235, 244
- 01-risk, 412
 zero-error probabilistic polynomial time (ZPP), 353
 zero-preserving perturbations, 352
 Zipfian distributions, 140, 507, 509
 counting sketches and, 649
 recovery guarantees and, 147
 Zipf’s law, 140, 143
 ZPP. *See* zero-error probabilistic polynomial time