

Index

Page numbers in **bold** indicate the primary source of information for the corresponding topic.

- 1-of- K coding scheme, 424
- acceptance criterion, **538**, 541, 544
- activation function, **180**, 213, 227
- active constraint, 328, **709**
- AdaBoost, 657, **658**
- adaline, 196
- adaptive rejection sampling, 530
- ADF, *see* assumed density filtering
- AIC, *see* Akaike information criterion
- Akaike information criterion, **33**, 217
- α family of divergences, 469
- α recursion, 620
- ancestral sampling, **365**, 525, 613
- annular flow, 679
- AR model, *see* autoregressive model
- arc, 360
- ARD, *see* automatic relevance determination
- ARMA, *see* autoregressive moving average
- assumed density filtering, 510
- autoassociative networks, 592
- automatic relevance determination, 259, 312, **349**, 485, 582
- autoregressive hidden Markov model, 632
- autoregressive model, 609
- autoregressive moving average, 304
- back-tracking, **415**, 630
- backgammon, 3
- backpropagation, 241
- bagging, 656
- basis function, **138**, 172, 204, 227
- batch training, 240
- Baum-Welch algorithm, 618
- Bayes' theorem, 15
- Bayes, Thomas, 21
- Bayesian analysis, vii, 9, **21**
 - hierarchical, 372
 - model averaging, 654
- Bayesian information criterion, 33, **216**
- Bayesian model comparison, **161**, 473, 483
- Bayesian network, 360
- Bayesian probability, 21
- belief propagation, 403
- Bernoulli distribution, **69**, 113, 685
 - mixture model, 444
- Bernoulli, Jacob, 69
- beta distribution, **71**, 686
- beta recursion, 621
- between-class covariance, 189
- bias, **27**, 149
- bias parameter, **138**, 181, 227, 346
- bias-variance trade-off, 147
- BIC, *see* Bayesian information criterion
- binary entropy, 495
- binomial distribution, **70**, 686

- biological sequence, 610
- bipartite graph, 401
- bits, 49
- blind source separation, 591
- blocked path, 374, **378**, 384
- Boltzmann distribution, 387
- Boltzmann, Ludwig Eduard, 53
- Boolean logic, 21
- boosting, 657
- bootstrap, **23**, 656
- bootstrap filter, 646
- box constraints, **333**, 342
- Box-Muller method, 527
- C4.5, 663
- calculus of variations, 462
- canonical correlation analysis, 565
- canonical link function, 212
- CART, *see* classification and regression trees
- Cauchy distribution, **527**, 529, 692
- causality, 366
- CCA, *see* canonical correlation analysis
- central differences, 246
- central limit theorem, 78
- chain graph, 393
- chaining, 555
- Chapman-Kolmogorov equations, 397
- child node, 361
- Cholesky decomposition, 528
- chunking, 335
- circular normal, *see* von Mises distribution
- classical probability, 21
- classification, 3
- classification and regression trees, 663
- clique, 385
- clustering, 3
- clutter problem, 511
- co-parents, **383**, 492
- code-book vectors, 429
- combining models, 45, **653**
- committee, 655
- complete data set, 440
- completing the square, 86
- computational learning theory, 326, 344
- concave function, 56
- concentration parameter, **108**, 693
- condensation algorithm, 646
- conditional entropy, 55
- conditional expectation, 20
- conditional independence, 46, **372**, 383
- conditional mixture model, *see* mixture model
- conditional probability, 14
- conjugate prior, 68, 98, **117**, 490
- convex duality, 494
- convex function, **55**, 493
- convolutional neural network, 267
- correlation matrix, 567
- cost function, 41
- covariance, 20
 - between-class, 189
 - within-class, 189
- covariance matrix
 - diagonal, 84
 - isotropic, 84
 - partitioned, **85**, 307
 - positive definite, 308
- Cox's axioms, 21
- credit assignment, 3
- cross-entropy error function, **206**, 209, 235, 631, 666
- cross-validation, **32**, 161
- cumulative distribution function, 18
- curse of dimensionality, **33**, 36
- curve fitting, 4
- D map, *see* dependency map
- d-separation, 373, **378**, 443
- DAG, *see* directed acyclic graph
- DAGSVM, 339
- data augmentation, 537
- data compression, 429
- decision boundary, **39**, 179
- decision region, **39**, 179
- decision surface, *see* decision boundary
- decision theory, 38
- decision tree, 654, **663**, 673
- decomposition methods, 335
- degrees of freedom, 559
- degrees-of-freedom parameter, **102**, 693
- density estimation, 3, **67**

- density network, 597
- dependency map, 392
- descendant node, 376
- design matrix, **142**, 347
- differential entropy, 53
- digamma function, 687
- directed acyclic graph, 362
- directed cycle, 362
- directed factorization, 381
- Dirichlet distribution, **76**, 687
- Dirichlet, Lejeune, 77
- discriminant function, 43, 180, **181**
- discriminative model, **43**, 203
- distortion measure, 424
- distributive law of multiplication, 396
- DNA, 610
- document retrieval, 299
- dual representation, **293**, 329
- dual-energy gamma densitometry, 678
- dynamic programming, 411
- dynamical system, 548

- E step, *see* expectation step
- early stopping, 259
- ECM, *see* expectation conditional maximization
- edge, 360
- effective number of observations, **72**, 101
- effective number of parameters, 9, **170**, 281
- elliptical K -means, 444
- EM, *see* expectation maximization
- emission probability, 611
- empirical Bayes, *see* evidence approximation
- energy function, 387
- entropy, 49
 - conditional, 55
 - differential, 53
 - relative, 55
- EP, *see* expectation propagation
- ϵ -tube, 341
- ϵ -insensitive error function, 340
- equality constraint, 709
- equivalent kernel, **159**, 301
- erf function, 211
- error backpropagation, *see* backpropagation
- error function, **5**, 23
 - error-correcting output codes, 339
 - Euler, Leonhard, 465
 - Euler-Lagrange equations, 705
 - evidence approximation, **165**, 347, 581
 - evidence function, 161
 - expectation, 19
 - expectation conditional maximization, 454
 - expectation maximization, 113, **423**, 440
 - Gaussian mixture, 435
 - generalized, 454
 - sampling methods, 536
 - expectation propagation, 315, 468, **505**
 - expectation step, 437
 - explaining away, 378
 - exploitation, 3
 - exploration, 3
 - exponential distribution, **526**, 688
 - exponential family, 68, **113**, 202, 490
 - extensive variables, 490

 - face detection, 2
 - face tracking, 355
 - factor analysis, 583
 - mixture model, 595
 - factor graph, 360, **399**, 625
 - factor loading, 584
 - factorial hidden Markov model, 633
 - factorized distribution, **464**, 476
 - feature extraction, 2
 - feature map, 268
 - feature space, **292**, 586
 - Fisher information matrix, 298
 - Fisher kernel, 298
 - Fisher's linear discriminant, 186
 - flooding schedule, 417
 - forward kinematics, 272
 - forward problem, 272
 - forward propagation, **228**, 243
 - forward-backward algorithm, 618
 - fractional belief propagation, 517
 - frequentist probability, 21
 - fuel system, 376
 - function interpolation, 299
 - functional, 462, **703**
 - derivative, 463

- gamma densitometry, 678
- gamma distribution, 529, **688**
- gamma function, 71
- gating function, 672
- Gauss, Carl Friedrich, 79
- Gaussian, 24, **78**, 688
 - conditional, **85**, 93
 - marginal, **88**, 93
 - maximum likelihood, 93
 - mixture, 110, 270, 273, **430**
 - sequential estimation, 94
 - sufficient statistics, 93
 - wrapped, 110
- Gaussian kernel, 296
- Gaussian process, 160, **303**
- Gaussian random field, 305
- Gaussian-gamma distribution, **101**, 690
- Gaussian-Wishart distribution, **102**, 475, 478, **690**
- GEM, *see* expectation maximization, generalized
- generalization, 2
- generalized linear model, **180**, 213
- generalized maximum likelihood, *see* evidence approximation
- generative model, **43**, 196, 297, 365, 572, 631
- generative topographic mapping, 597
 - directional curvature, 599
 - magnification factor, 599
- geodesic distance, 596
- Gibbs sampling, 542
 - blocking, 546
- Gibbs, Josiah Willard, 543
- Gini index, 666
- global minimum, 237
- gradient descent, 240
- Gram matrix, 293
- graph-cut algorithm, 390
- graphical model, 359
 - bipartite, 401
 - directed, 360
 - factorization, 362, 384
 - fully connected, 361
 - inference, 393
 - tree, 398
 - treewidth, 417
 - triangulated, 416
 - undirected, 360
- Green's function, 299
- GTM, *see* generative topographic mapping
- Hamilton, William Rowan, 549
- Hamiltonian dynamics, 548
- Hamiltonian function, 549
- Hammersley-Clifford theorem, 387
- handwriting recognition, 1, 610, 614
- handwritten digit, 565, 614, **677**
- head-to-head path, 376
- head-to-tail path, 375
- Heaviside step function, 206
- Hellinger distance, 470
- Hessian matrix, 167, 215, 217, 238, **249**
 - diagonal approximation, 250
 - exact evaluation, 253
 - fast multiplication, 254
 - finite differences, 252
 - inverse, 252
 - outer product approximation, 251
- heteroscedastic, **273**, 311
- hidden Markov model, 297, **610**
 - autoregressive, 632
 - factorial, 633
 - forward-backward algorithm, 618
 - input-output, 633
 - left-to-right, 613
 - maximum likelihood, 615
 - scaling factor, 627
 - sum-product algorithm, 625
 - switching, 644
 - variational inference, 625
- hidden unit, 227
- hidden variable, 84, **364**, 430, 559
- hierarchical Bayesian model, 372
- hierarchical mixture of experts, 673
- hinge error function, 337
- Hinton diagram, 584
- histogram density estimation, 120
- HME, *see* hierarchical mixture of experts
- hold-out set, 11
- homogeneous flow, 679
- homogeneous kernel, 292
- homogeneous Markov chain, **540**, 608

- Hooke's law, 580
- hybrid Monte Carlo, 548
- hyperparameter, **71**, 280, 311, 346, 372, 502
- hyperprior, 372
- I map, *see* independence map
- i.i.d., *see* independent identically distributed
- ICA, *see* independent component analysis
- ICM, *see* iterated conditional modes
- ID3, 663
- identifiability, 435
- image de-noising, 387
- importance sampling, 525, **532**
- importance weights, 533
- improper prior, **118**, 259, 472
- imputation step, 537
- imputation-posterior algorithm, 537
- inactive constraint, 328, **709**
- incomplete data set, 440
- independence map, 392
- independent component analysis, 591
- independent factor analysis, 592
- independent identically distributed, **26**, 379
- independent variables, 17
- independent, identically distributed, 605
- induced factorization, 485
- inequality constraint, 709
- inference, 38, **42**
- information criterion, 33
- information geometry, 298
- information theory, 48
- input-output hidden Markov model, 633
- intensive variables, 490
- intrinsic dimensionality, 559
- invariance, 261
- inverse gamma distribution, 101
- inverse kinematics, 272
- inverse problem, 272
- inverse Wishart distribution, 102
- IP algorithm, *see* imputation-posterior algorithm
- IRLS, *see* iterative reweighted least squares
- Ising model, 389
- isomap, 596
- isometric feature map, 596
- iterated conditional modes, **389**, 415
- iterative reweighted least squares, **207**, 210, 316, 354, 672
- Jacobian matrix, **247**, 264
- Jensen's inequality, 56
- join tree, 416
- junction tree algorithm, 392, **416**
- K nearest neighbours, 125
- K -means clustering algorithm, **424**, 443
- K -medoids algorithm, 428
- Kalman filter, 304, **637**
 - extended, 644
- Kalman gain matrix, 639
- Kalman smoother, 637
- Karhunen-Loève transform, 561
- Karush-Kuhn-Tucker conditions, 330, 333, 342, **710**
- kernel density estimator, **122**, 326
- kernel function, 123, **292**, 294
 - Fisher, 298
 - Gaussian, 296
 - homogeneous, 292
 - nonvectorial inputs, 297
 - stationary, 292
- kernel PCA, 586
- kernel regression, 300, **302**
- kernel substitution, 292
- kernel trick, 292
- kinetic energy, 549
- KKT, *see* Karush-Kuhn-Tucker conditions
- KL divergence, *see* Kullback-Leibler divergence
- kriging, *see* Gaussian process
- Kullback-Leibler divergence, **55**, 451, 468, 505
- Lagrange multiplier, 707
- Lagrange, Joseph-Louis, 329
- Lagrangian, 328, 332, 341, **708**
- laminar flow, 678
- Laplace approximation, **213**, 217, 278, 315, 354
- Laplace, Pierre-Simon, 24
- large margin, *see* margin
- lasso, 145
- latent class analysis, 444
- latent trait model, 597
- latent variable, 84, **364**, 430, 559

- lattice diagram, **414**, 611, 621, 629
- LDS, *see* linear dynamical system
- leapfrog discretization, 551
- learning, 2
- learning rate parameter, 240
- least-mean-squares algorithm, 144
- leave-one-out, 33
- likelihood function, 22
- likelihood weighted sampling, 534
- linear discriminant, 181
 - Fisher, 186
- linear dynamical system, 84, **635**
 - inference, 638
- linear independence, 696
- linear regression, 138
 - EM, 448
 - mixture model, 667
 - variational, 486
- linear smoother, 159
- linear-Gaussian model, 87, **370**
- linearly separable, 179
- link, 360
- link function, 180, 213
- Liouville's Theorem, 550
- LLE, *see* locally linear embedding
- LMS algorithm, *see* least-mean-squares algorithm
- local minimum, 237
- local receptive field, 268
- locally linear embedding, 596
- location parameter, 118
- log odds, 197
- logic sampling, 525
- logistic regression, **205**, 336
 - Bayesian, 217, 498
 - mixture model, 670
 - multiclass, 209
- logistic sigmoid, 114, 139, **197**, 205, 220, 227, 495
- logit function, 197
- loopy belief propagation, 417
- loss function, 41
- loss matrix, 41
- lossless data compression, 429
- lossy data compression, 429
- lower bound, 484
- M step, *see* maximization step
- machine learning, vii
- macrostate, 51
- Mahalanobis distance, 80
- manifold, **38**, 590, 595, 681
- MAP, *see* maximum posterior
- margin, 326, **327**, 502
 - error, 334
 - soft, 332
- marginal likelihood, **162**, 165
- marginal probability, 14
- Markov blanket, **382**, 384, 545
- Markov boundary, *see* Markov blanket
- Markov chain, 397, **539**
 - first order, 607
 - homogeneous, **540**, 608
 - second order, 608
- Markov chain Monte Carlo, 537
- Markov model, 607
 - homogeneous, 612
- Markov network, *see* Markov random field
- Markov random field, 84, 360, **383**
- max-sum algorithm, **411**, 629
- maximal clique, 385
- maximal spanning tree, 416
- maximization step, 437
- maximum likelihood, 9, **23**, 26, 116
 - Gaussian mixture, 432
 - singularities, 480
 - type 2, *see* evidence approximation
- maximum margin, *see* margin
- maximum posterior, **30**, 441
- MCMC, *see* Markov chain Monte Carlo
- MDN, *see* mixture density network
- MDS, *see* multidimensional scaling
- mean, 24
- mean field theory, 465
- mean value theorem, 52
- measure theory, 19
- memory-based methods, 292
- message passing, 396
 - pending message, 417
 - schedule, 417
 - variational, 491
- Metropolis algorithm, 538
- Metropolis-Hastings algorithm, 541

- microstate, 51
- minimum risk, 44
- Minkowski loss, 48
- missing at random, **441**, 579
- missing data, 579
- mixing coefficient, 111
- mixture component, 111
- mixture density network, **272**, 673
- mixture distribution, *see* mixture model
- mixture model, 162, **423**
 - conditional, 273, **666**
 - linear regression, 667
 - logistic regression, 670
 - symmetries, 483
- mixture of experts, 672
- mixture of Gaussians, 110, 270, 273, **430**
- MLP, *see* multilayer perceptron
- MNIST data, 677
- model comparison, 6, 32, **161**, 473, 483
- model evidence, 161
- model selection, 162
- moment matching, **506**, 510
- momentum variable, 548
- Monte Carlo EM algorithm, 536
- Monte Carlo sampling, 24, **523**
- Moore-Penrose pseudo-inverse, *see* pseudo-inverse
- moralization, **391**, 401
- MRF, *see* Markov random field
- multidimensional scaling, 596
- multilayer perceptron, 226, **229**
- multimodality, 272
- multinomial distribution, 76, 114, **690**
- multiplicity, 51
- mutual information, 55, **57**

- Nadaraya-Watson, *see* kernel regression
- naive Bayes model, 46, **380**
- nats, 50
- natural language modelling, 610
- natural parameters, 113
- nearest-neighbour methods, 124
- neural network, 225
 - convolutional, 267
 - regularization, 256
 - relation to Gaussian process, 319

- Newton-Raphson, **207**, 317
- node, 360
- noiseless coding theorem, 50
- nonidentifiability, 585
- noninformative prior, 23, **117**
- nonparametric methods, 68, **120**
- normal distribution, *see* Gaussian
- normal equations, 142
- normal-gamma distribution, **101**, 691
- normal-Wishart distribution, **102**, 475, 478, 691
- normalized exponential, *see* softmax function
- novelty detection, 44
- ν -SVM, 334

- object recognition, 366
- observed variable, 364
- Occam factor, 217
- oil flow data, 34, 560, 568, **678**
- Old Faithful data, 110, 479, 484, **681**
- on-line learning, *see* sequential learning
- one-versus-one classifier, **183**, 339
- one-versus-the-rest classifier, **182**, 338
- ordered over-relaxation, 545
- Ornstein-Uhlenbeck process, 305
- orthogonal least squares, 301
- outlier, 44, 185, 212
- outliers, **103**
- over-fitting, **6**, 147, 434, 464
- over-relaxation, 544

- PAC learning, *see* probably approximately correct
- PAC-Bayesian framework, 345
- parameter shrinkage, 144
- parent node, 361
- particle filter, 645
- partition function, **386**, 554
- Parzen estimator, *see* kernel density estimator
- Parzen window, 123
- pattern recognition, vii
- PCA, *see* principal component analysis
- pending message, 417
- perceptron, 192
 - convergence theorem, 194
 - hardware, 196
- perceptron criterion, 193
- perfect map, 392

- periodic variable, 105
- phase space, 549
- photon noise, 680
- plate, 363
- polynomial curve fitting, 4, 362
- polytree, 399
- position variable, 548
- positive definite covariance, 81
- positive definite matrix, 701
- positive semidefinite covariance, 81
- positive semidefinite matrix, 701
- posterior probability, 17
- posterior step, 537
- potential energy, 549
- potential function, 386
- power EP, 517
- power method, 563
- precision matrix, 85
- precision parameter, 24
- predictive distribution, **30**, 156
- preprocessing, 2
- principal component analysis, **561**, 572, 593
 - Bayesian, 580
 - EM algorithm, 577
 - Gibbs sampling, 583
 - mixture distribution, 595
 - physical analogy, 580
- principal curve, 595
- principal subspace, 561
- principal surface, 596
- prior, 17
 - conjugate, 68, 98, **117**, 490
 - consistent, 257
 - improper, **118**, 259, 472
 - noninformative, 23, **117**
- probabilistic graphical model, *see* graphical model
- probabilistic PCA, 570
- probability, 12
 - Bayesian, 21
 - classical, 21
 - density, 17
 - frequentist, 21
 - mass function, 19
 - prior, 45
 - product rule, 13, **14**, 359
 - sum rule, 13, **14**, 359
 - theory, 12
- probably approximately correct, 344
- probit function, **211**, 219
- probit regression, 210
- product rule of probability, 13, **14**, 359
- proposal distribution, **528**, 532, 538
- protected conjugate gradients, 335
- protein sequence, 610
- pseudo-inverse, **142**, 185
- pseudo-random numbers, 526
- quadratic discriminant, 199
- quality parameter, 351
- radial basis function, 292, **299**
- Rauch-Tung-Striebel equations, 637
- regression, 3
- regression function, **47**, 95
- regularization, 10
 - Tikhonov, 267
- regularized least squares, 144
- reinforcement learning, 3
- reject option, **42**, 45
- rejection sampling, 528
- relative entropy, 55
- relevance vector, 348
- relevance vector machine, 161, **345**
- responsibility, 112, **432**, 477
- ridge regression, 10
- RMS error, *see* root-mean-square error
- Robbins-Monro algorithm, 95
- robot arm, 272
- robustness, **103**, 185
- root node, 399
- root-mean-square error, 6
- Rosenblatt, Frank, 193
- rotation invariance, **573**, 585
- RTS equations, *see* Rauch-Tung-Striebel equations
- running intersection property, 416
- RVM, *see* relevance vector machine
- sample mean, 27
- sample variance, 27
- sampling-importance-resampling, 534
- scale invariance, 119, **261**

- scale parameter, 119
- scaling factor, 627
- Schwarz criterion, *see* Bayesian information criterion
- self-organizing map, 598
- sequential data, 605
- sequential estimation, 94
- sequential gradient descent, 144, 240
- sequential learning, **73**, 143
- sequential minimal optimization, 335
- serial message passing schedule, 417
- Shannon, Claude, 55
- shared parameters, 368
- shrinkage, 10
- Shur complement, 87
- sigmoid, *see* logistic sigmoid
- simplex, 76
- single-class support vector machine, 339
- singular value decomposition, 143
- sinusoidal data, 682
- SIR, *see* sampling-importance-resampling
- skip-layer connection, 229
- slack variable, 331
- slice sampling, 546
- SMO, *see* sequential minimal optimization
- smoother matrix, 159
- smoothing parameter, 122
- soft margin, 332
- soft weight sharing, 269
- softmax function, 115, **198**, 236, 274, 356, 497
- SOM, *see* self-organizing map
- sparsity, 145, 347, **349**, 582
- sparsity parameter, 351
- spectrogram, 606
- speech recognition, **605**, 610
- sphereing, 568
- spline functions, 139
- standard deviation, 24
- standardizing, 425, **567**
- state space model, 609
 - switching, 644
- stationary kernel, 292
- statistical bias, *see* bias
- statistical independence, *see* independent variables
- statistical learning theory, *see* computational learning theory, 326, 344
- steepest descent, 240
- Stirling's approximation, 51
- stochastic, 5
- stochastic EM, 536
- stochastic gradient descent, 144, 240
- stochastic process, 305
- stratified flow, 678
- Student's t-distribution, **102**, 483, 691
- subsampling, 268
- sufficient statistics, 69, 75, **116**
- sum rule of probability, 13, **14**, 359
- sum-of-squares error, **5**, 29, 184, 232, 662
- sum-product algorithm, 399, **402**
 - for hidden Markov model, 625
- supervised learning, 3
- support vector, 330
- support vector machine, 225
 - for regression, 339
 - multiclass, 338
- survival of the fittest, 646
- SVD, *see* singular value decomposition
- SVM, *see* support vector machine
- switching hidden Markov model, 644
- switching state space model, 644
- synthetic data sets, 682
- tail-to-tail path, 374
- tangent distance, 265
- tangent propagation, 262, **263**
- tapped delay line, 609
- target vector, 2
- test set, 2, **32**
- threshold parameter, 181
- tied parameters, 368
- Tikhonov regularization, 267
- time warping, 615
- tomography, 679
- training, 2
- training set, 2
- transition probability, **540**, 610
- translation invariance, 118, **261**
- tree-reweighted message passing, 517
- treewidth, 417

- trellis diagram, *see* lattice diagram
- triangulated graph, 416
- type 2 maximum likelihood, *see* evidence approximation
- undetermined multiplier, *see* Lagrange multiplier
- undirected graph, *see* Markov random field
- uniform distribution, 692
- uniform sampling, 534
- uniquenesses, 584
- unobserved variable, *see* latent variable
- unsupervised learning, 3
- utility function, 41
- validation set, 11, **32**
- Vapnik-Chervonenkis dimension, 344
- variance, **20**, 24, 149
- variational inference, 315, **462**, 635
 - for Gaussian mixture, 474
 - for hidden Markov model, 625
 - local, 493
- VC dimension, *see* Vapnik-Chervonenkis dimension
- vector quantization, 429
- vertex, *see* node
- visualization, 3
- Viterbi algorithm, 415, **629**
- von Mises distribution, **108**, 693
- wavelets, 139
- weak learner, 657
- weight decay, 10, **144**, 257
- weight parameter, 227
- weight sharing, 268
 - soft, 269
- weight vector, 181
- weight-space symmetry, **231**, 281
- weighted least squares, 668
- well-determined parameters, 170
- whitening, 299, **568**
- Wishart distribution, **102**, 693
- within-class covariance, 189
- Woodbury identity, 696
- wrapped distribution, 110
- Yellowstone National Park, 110, **681**