

# Index

- 0-1 loss, [102](#), [274](#)
- Absolute value rectification, [191](#)
- Accuracy, [420](#)
- Activation function, [169](#)
- Active constraint, [94](#)
- AdaGrad, [305](#)
- ADALINE, *see* adaptive linear element
- Adam, [307](#), [422](#)
- Adaptive linear element, [15](#), [23](#), [26](#)
- Adversarial example, [265](#)
- Adversarial training, [266](#), [268](#), [526](#)
- Affine, [109](#)
- AIS, *see* annealed importance sampling
- Almost everywhere, [70](#)
- Almost sure convergence, [128](#)
- Ancestral sampling, [576](#), [591](#)
- ANN, *see* Artificial neural network
- Annealed importance sampling, [621](#), [662](#), [711](#)
- Approximate Bayesian computation, [710](#)
- Approximate inference, [579](#)
- Artificial intelligence, [1](#)
- Artificial neural network, *see* Neural network
- ASR, *see* automatic speech recognition
- Asymptotically unbiased, [123](#)
- Audio, [101](#), [357](#), [455](#)
- Autoencoder, [4](#), [353](#), [498](#)
- Automatic speech recognition, [455](#)
- Back-propagation, [201](#)
- Back-propagation through time, [381](#)
- Backprop, *see* back-propagation
- Bag of words, [467](#)
- Bagging, [252](#)
- Batch normalization, [264](#), [422](#)
- Bayes error, [116](#)
- Bayes' rule, [69](#)
- Bayesian hyperparameter optimization, [433](#)
- Bayesian network, *see* directed graphical model
- Bayesian probability, [54](#)
- Bayesian statistics, [134](#)
- Belief network, *see* directed graphical model
- Bernoulli distribution, [61](#)
- BFGS, [314](#)
- Bias, [123](#), [227](#)
- Bias parameter, [109](#)
- Biased importance sampling, [589](#)
- Bigram, [458](#)
- Binary relation, [478](#)
- Block Gibbs sampling, [595](#)
- Boltzmann distribution, [566](#)
- Boltzmann machine, [566](#), [648](#)
- BPTT, *see* back-propagation through time
- Broadcasting, [33](#)
- Burn-in, [593](#)
- CAE, *see* contractive autoencoder
- Calculus of variations, [178](#)
- Categorical distribution, *see* multinoulli distribution
- CD, *see* contrastive divergence
- Centering trick (DBM), [667](#)
- Central limit theorem, [63](#)
- Chain rule (calculus), [203](#)
- Chain rule of probability, [58](#)

- Chess, [2](#)
- Chord, [575](#)
- Chordal graph, [575](#)
- Class-based language models, [460](#)
- Classical dynamical system, [372](#)
- Classification, [99](#)
- Clique potential, *see* factor (graphical model)
- CNN, *see* convolutional neural network
- Collaborative Filtering, [474](#)
- Collider, *see* explaining away
- Color images, [357](#)
- Complex cell, [362](#)
- Computational graph, [202](#)
- Computer vision, [449](#)
- Concept drift, [533](#)
- Condition number, [277](#)
- Conditional computation, *see* dynamic structure
- Conditional independence, [xiii](#), [59](#)
- Conditional probability, [58](#)
- Conditional RBM, [679](#)
- Connectionism, [17](#), [440](#)
- Connectionist temporal classification, [457](#)
- Consistency, [128](#), [509](#)
- Constrained optimization, [92](#), [235](#)
- Content-based addressing, [416](#)
- Content-based recommender systems, [475](#)
- Context-specific independence, [569](#)
- Contextual bandits, [476](#)
- Continuation methods, [324](#)
- Contractive autoencoder, [516](#)
- Contrast, [451](#)
- Contrastive divergence, [289](#), [606](#), [666](#)
- Convex optimization, [140](#)
- Convolution, [327](#), [677](#)
- Convolutional network, [16](#)
- Convolutional neural network, [250](#), [327](#), [422](#), [456](#)
- Coordinate descent, [319](#), [665](#)
- Correlation, [60](#)
- Cost function, *see* objective function
- Covariance, [xiii](#), [60](#)
- Covariance matrix, [61](#)
- Coverage, [421](#)
- Critical temperature, [599](#)
- Cross-correlation, [329](#)
- Cross-entropy, [74](#), [131](#)
- Cross-validation, [121](#)
- CTC, *see* connectionist temporal classification
- Curriculum learning, [326](#)
- Curse of dimensionality, [153](#)
- Cyc, [2](#)
- D-separation, [568](#)
- DAE, *see* denoising autoencoder
- Data generating distribution, [110](#), [130](#)
- Data generating process, [110](#)
- Data parallelism, [444](#)
- Dataset, [103](#)
- Dataset augmentation, [268](#), [454](#)
- DBM, *see* deep Boltzmann machine
- DCGAN, [547](#), [548](#), [695](#)
- Decision tree, [144](#), [544](#)
- Decoder, [4](#)
- Deep belief network, [26](#), [525](#), [626](#), [651](#), [654](#), [678](#), [686](#)
- Deep Blue, [2](#)
- Deep Boltzmann machine, [23](#), [26](#), [525](#), [626](#), [647](#), [651](#), [657](#), [666](#), [678](#)
- Deep feedforward network, [166](#), [422](#)
- Deep learning, [2](#), [5](#)
- Denoising autoencoder, [506](#), [683](#)
- Denoising score matching, [615](#)
- Density estimation, [102](#)
- Derivative, [xiii](#), [82](#)
- Design matrix, [105](#)
- Detector layer, [336](#)
- Determinant, [xii](#)
- Diagonal matrix, [40](#)
- Differential entropy, [73](#), [641](#)
- Dirac delta function, [64](#)
- Directed graphical model, [76](#), [503](#), [559](#), [685](#)
- Directional derivative, [84](#)
- Discriminative fine-tuning, *see* supervised fine-tuning
- Discriminative RBM, [680](#)
- Distributed representation, [17](#), [149](#), [542](#)
- Domain adaptation, [532](#)

- Dot product, 33, 139
- Double backprop, 268
- Doubly block circulant matrix, 330
- Dream sleep, 605, 647
- DropConnect, 263
- Dropout, 255, 422, 427, 428, 666, 683
- Dynamic structure, 445
  
- E-step, 629
- Early stopping, 244, 246, 270, 271, 422
- EBM, *see* energy-based model
- Echo state network, 23, 26, 401
- Effective capacity, 113
- Eigendecomposition, 41
- Eigenvalue, 41
- Eigenvector, 41
- ELBO, *see* evidence lower bound
- Element-wise product, *see* Hadamard product, *see* Hadamard product
- EM, *see* expectation maximization
- Embedding, 512
- Empirical distribution, 65
- Empirical risk, 274
- Empirical risk minimization, 274
- Encoder, 4
- Energy function, 565
- Energy-based model, 565, 591, 648, 657
- Ensemble methods, 252
- Epoch, 244
- Equality constraint, 93
- Equivariance, 335
- Error function, *see* objective function
- ESN, *see* echo state network
- Euclidean norm, 38
- Euler-Lagrange equation, 641
- Evidence lower bound, 628, 655
- Example, 98
- Expectation, 59
- Expectation maximization, 629
- Expected value, *see* expectation
- Explaining away, 570, 626, 639
- Exploitation, 477
- Exploration, 477
- Exponential distribution, 64
  
- F-score, 420
- Factor (graphical model), 563
- Factor analysis, 486
- Factor graph, 575
- Factors of variation, 4
- Feature, 98
- Feature selection, 234
- Feedforward neural network, 166
- Fine-tuning, 321
- Finite differences, 436
- Forget gate, 304
- Forward propagation, 201
- Fourier transform, 357, 359
- Fovea, 363
- FPCD, 610
- Free energy, 567, 674
- Freebase, 479
- Frequentist probability, 54
- Frequentist statistics, 134
- Frobenius norm, 45
- Fully-visible Bayes network, 699
- Functional derivatives, 640
- FVBN, *see* fully-visible Bayes network
  
- Gabor function, 365
- GANs, *see* generative adversarial networks
- Gated recurrent unit, 422
- Gaussian distribution, *see* normal distribution
- Gaussian kernel, 140
- Gaussian mixture, 66, 187
- GCN, *see* global contrast normalization
- GeneOntology, 479
- Generalization, 109
- Generalized Lagrange function, *see* generalized Lagrangian
- Generalized Lagrangian, 93
- Generative adversarial networks, 683, 693
- Generative moment matching networks, 696
- Generator network, 687
- Gibbs distribution, 564
- Gibbs sampling, 577, 595
- Global contrast normalization, 451
- GPU, *see* graphics processing unit
- Gradient, 83

- Gradient clipping, 287, 411
- Gradient descent, 82, 84
- Graph, xii
- Graphical model, *see* structured probabilistic model
- Graphics processing unit, 441
- Greedy algorithm, 321
- Greedy layer-wise unsupervised pretraining, 524
- Greedy supervised pretraining, 321
- Grid search, 429
  
- Hadamard product, xii, 33
- Hard tanh, 195
- Harmonium, *see* restricted Boltzmann machine
- Harmony theory, 567
- Helmholtz free energy, *see* evidence lower bound
- Hessian, 221
- Hessian matrix, xiii, 86
- Heteroscedastic, 186
- Hidden layer, 6, 166
- Hill climbing, 85
- Hyperparameter optimization, 429
- Hyperparameters, 119, 427
- Hypothesis space, 111, 117
  
- i.i.d. assumptions, 110, 121, 265
- Identity matrix, 35
- ILSVRC, *see* ImageNet Large Scale Visual Recognition Challenge
- ImageNet Large Scale Visual Recognition Challenge, 22
- Immortality, 573
- Importance sampling, 588, 620, 691
- Importance weighted autoencoder, 691
- Independence, xiii, 59
- Independent and identically distributed, *see* i.i.d. assumptions
- Independent component analysis, 487
- Independent subspace analysis, 489
- Inequality constraint, 93
- Inference, 558, 579, 626, 628, 630, 633, 643, 646
- Information retrieval, 520
- Initialization, 298
- Integral, xiii
- Invariance, 339
- Isotropic, 64
  
- Jacobian matrix, xiii, 71, 85
- Joint probability, 56
  
- $k$ -means, 361, 542
- $k$ -nearest neighbors, 141, 544
- Karush-Kuhn-Tucker conditions, 94, 235
- Karush-Kuhn-Tucker, 93
- Kernel (convolution), 328, 329
- Kernel machine, 544
- Kernel trick, 139
- KKT, *see* Karush-Kuhn-Tucker
- KKT conditions, *see* Karush-Kuhn-Tucker conditions
- KL divergence, *see* Kullback-Leibler divergence
- Knowledge base, 2, 479
- Krylov methods, 222
- Kullback-Leibler divergence, xiii, 73
  
- Label smoothing, 241
- Lagrange multipliers, 93, 641
- Lagrangian, *see* generalized Lagrangian
- LAPGAN, 695
- Laplace distribution, 64, 492
- Latent variable, 66
- Layer (neural network), 166
- LCN, *see* local contrast normalization
- Leaky ReLU, 191
- Leaky units, 404
- Learning rate, 84
- Line search, 84, 85, 92
- Linear combination, 36
- Linear dependence, 37
- Linear factor models, 485
- Linear regression, 106, 109, 138
- Link prediction, 480
- Lipschitz constant, 91
- Lipschitz continuous, 91
- Liquid state machine, 401

- Local conditional probability distribution, 560
- Local contrast normalization, 452
- Logistic regression, 3, 138, 139
- Logistic sigmoid, 7, 66
- Long short-term memory, 18, 24, 304, 407, 422
- Loop, 575
- Loopy belief propagation, 581
- Loss function, *see* objective function
- $L^p$  norm, 38
- LSTM, *see* long short-term memory
- M-step, 629
- Machine learning, 2
- Machine translation, 100
- Main diagonal, 32
- Manifold, 159
- Manifold hypothesis, 160
- Manifold learning, 160
- Manifold tangent classifier, 268
- MAP approximation, 137, 501
- Marginal probability, 57
- Markov chain, 591
- Markov chain Monte Carlo, 591
- Markov network, *see* undirected model
- Markov random field, *see* undirected model
- Matrix, xi, xii, 31
- Matrix inverse, 35
- Matrix product, 33
- Max norm, 39
- Max pooling, 336
- Maximum likelihood, 130
- Maxout, 191, 422
- MCMC, *see* Markov chain Monte Carlo
- Mean field, 633, 634, 666
- Mean squared error, 107
- Measure theory, 70
- Measure zero, 70
- Memory network, 413, 415
- Method of steepest descent, *see* gradient descent
- Minibatch, 277
- Missing inputs, 99
- Mixing (Markov chain), 597
- Mixture density networks, 187
- Mixture distribution, 65
- Mixture model, 187, 506
- Mixture of experts, 446, 544
- MLP, *see* multilayer perception
- MNIST, 20, 21, 666
- Model averaging, 252
- Model compression, 444
- Model identifiability, 282
- Model parallelism, 444
- Moment matching, 696
- Moore-Penrose pseudoinverse, 44, 237
- Moralized graph, 573
- MP-DBM, *see* multi-prediction DBM
- MRF (Markov Random Field), *see* undirected model
- MSE, *see* mean squared error
- Multi-modal learning, 535
- Multi-prediction DBM, 668
- Multi-task learning, 242, 533
- Multilayer perception, 5
- Multilayer perceptron, 26
- Multinomial distribution, 61
- Multinoulli distribution, 61
- $n$ -gram, 458
- NADE, 702
- Naive Bayes, 3
- Nat, 72
- Natural image, 555
- Natural language processing, 457
- Nearest neighbor regression, 114
- Negative definite, 88
- Negative phase, 466, 602, 604
- Neocognitron, 16, 23, 26, 364
- Nesterov momentum, 298
- Netflix Grand Prize, 255, 475
- Neural language model, 460, 472
- Neural network, 13
- Neural Turing machine, 415
- Neuroscience, 15
- Newton's method, 88, 309
- NLM, *see* neural language model
- NLP, *see* natural language processing
- No free lunch theorem, 115

- Noise-contrastive estimation, 616
- Non-parametric model, 113
- Norm, xiv, 38
- Normal distribution, 62, 63, 124
- Normal equations, 108, 108, 111, 232
- Normalized initialization, 301
- Numerical differentiation, *see* finite differences
  
- Object detection, 449
- Object recognition, 449
- Objective function, 81
- OMP- $k$ , *see* orthogonal matching pursuit
- One-shot learning, 534
- Operation, 202
- Optimization, 79, 81
- Orthodox statistics, *see* frequentist statistics
- Orthogonal matching pursuit, 26, 252
- Orthogonal matrix, 41
- Orthogonality, 40
- Output layer, 166
  
- Parallel distributed processing, 17
- Parameter initialization, 298, 403
- Parameter sharing, 249, 332, 370, 372, 386
- Parameter tying, *see* Parameter sharing
- Parametric model, 113
- Parametric ReLU, 191
- Partial derivative, 83
- Partition function, 564, 601, 663
- PCA, *see* principal components analysis
- PCD, *see* stochastic maximum likelihood
- Perceptron, 15, 26
- Persistent contrastive divergence, *see* stochastic maximum likelihood
- Perturbation analysis, *see* reparametrization trick
- Point estimator, 121
- Policy, 476
- Pooling, 327, 677
- Positive definite, 88
- Positive phase, 466, 602, 604, 650, 662
- Precision, 420
- Precision (of a normal distribution), 62, 64
- Predictive sparse decomposition, 519
  
- Preprocessing, 450
- Pretraining, 320, 524
- Primary visual cortex, 362
- Principal components analysis, 47, 145, 146, 486, 626
- Prior probability distribution, 134
- Probabilistic max pooling, 677
- Probabilistic PCA, 486, 487, 627
- Probability density function, 57
- Probability distribution, 55
- Probability mass function, 55
- Probability mass function estimation, 102
- Product of experts, 566
- Product rule of probability, *see* chain rule of probability
- PSD, *see* predictive sparse decomposition
- Pseudolikelihood, 611
  
- Quadrature pair, 366
- Quasi-Newton methods, 314
  
- Radial basis function, 195
- Random search, 431
- Random variable, 55
- Ratio matching, 614
- RBF, 195
- RBM, *see* restricted Boltzmann machine
- Recall, 420
- Receptive field, 334
- Recommender Systems, 474
- Rectified linear unit, 170, 191, 422, 503
- Recurrent network, 26
- Recurrent neural network, 375
- Regression, 99
- Regularization, 119, 119, 176, 226, 427
- Regularizer, 118
- REINFORCE, 683
- Reinforcement learning, 24, 105, 476, 683
- Relational database, 479
- Relations, 478
- Reparametrization trick, 682
- Representation learning, 3
- Representational capacity, 113
- Restricted Boltzmann machine, 353, 456, 475, 583, 626, 650, 651, 666, 670,



- 672, 674, 677
- Ridge regression, *see* weight decay
- Risk, 273
- RNN-RBM, 679
- Saddle points, 283
- Sample mean, 124
- Scalar, xi, xii, 30
- Score matching, 509, 613
- Second derivative, 85
- Second derivative test, 88
- Self-information, 72
- Semantic hashing, 521
- Semi-supervised learning, 241
- Separable convolution, 359
- Separation (probabilistic modeling), 568
- Set, xii
- SGD, *see* stochastic gradient descent
- Shannon entropy, xiii, 73
- Shortlist, 462
- Sigmoid, xiv, *see* logistic sigmoid
- Sigmoid belief network, 26
- Simple cell, 362
- Singular value, *see* singular value decomposition
- Singular value decomposition, 43, 146, 475
- Singular vector, *see* singular value decomposition
- Slow feature analysis, 489
- SML, *see* stochastic maximum likelihood
- Softmax, 182, 415, 446
- Softplus, xiv, 67, 195
- Spam detection, 3
- Sparse coding, 319, 353, 492, 626, 686
- Sparse initialization, 302, 403
- Sparse representation, 145, 224, 251, 501, 552
- Spearmint, 433
- Spectral radius, 401
- Speech recognition, *see* automatic speech recognition
- Sphering, *see* whitening
- Spike and slab restricted Boltzmann machine, 674
- SPN, *see* sum-product network
- Square matrix, 37
- ssRBM, *see* spike and slab restricted Boltzmann machine
- Standard deviation, 60
- Standard error, 126
- Standard error of the mean, 126, 276
- Statistic, 121
- Statistical learning theory, 109
- Steepest descent, *see* gradient descent
- Stochastic back-propagation, *see* reparametrization trick
- Stochastic gradient descent, 15, 149, 277, 292, 666
- Stochastic maximum likelihood, 608, 666
- Stochastic pooling, 263
- Structure learning, 578
- Structured output, 100, 679
- Structured probabilistic model, 76, 554
- Sum rule of probability, 57
- Sum-product network, 549
- Supervised fine-tuning, 525, 656
- Supervised learning, 104
- Support vector machine, 139
- Surrogate loss function, 274
- SVD, *see* singular value decomposition
- Symmetric matrix, 40, 42
- Tangent distance, 267
- Tangent plane, 511
- Tangent prop, 267
- TDNN, *see* time-delay neural network
- Teacher forcing, 379, 380
- Tempering, 599
- Template matching, 140
- Tensor, xi, xii, 32
- Test set, 109
- Tikhonov regularization, *see* weight decay
- Tiled convolution, 349
- Time-delay neural network, 364, 371
- Toeplitz matrix, 330
- Topographic ICA, 489
- Trace operator, 45
- Training error, 109
- Transcription, 100
- Transfer learning, 532

- Transpose, [xii](#), [32](#)
- Triangle inequality, [38](#)
- Triangulated graph, *see* chordal graph
- Trigram, [458](#)
  
- Unbiased, [123](#)
- Undirected graphical model, [76](#), [503](#)
- Undirected model, [562](#)
- Uniform distribution, [56](#)
- Unigram, [458](#)
- Unit norm, [40](#)
- Unit vector, [40](#)
- Universal approximation theorem, [196](#)
- Universal approximator, [549](#)
- Unnormalized probability distribution, [563](#)
- Unsupervised learning, [104](#), [144](#)
- Unsupervised pretraining, [456](#), [524](#)
  
- V-structure, *see* explaining away
- V1, [362](#)
- VAE, *see* variational autoencoder
- Vapnik-Chervonenkis dimension, [113](#)
- Variance, [xiii](#), [60](#), [227](#)
- Variational autoencoder, [683](#), [690](#)
- Variational derivatives, *see* functional derivatives
- Variational free energy, *see* evidence lower bound
- VC dimension, *see* Vapnik-Chervonenkis dimension
- Vector, [xi](#), [xii](#), [31](#)
- Virtual adversarial examples, [266](#)
- Visible layer, [6](#)
- Volumetric data, [357](#)
  
- Wake-sleep, [646](#), [655](#)
- Weight decay, [117](#), [176](#), [229](#), [428](#)
- Weight space symmetry, [282](#)
- Weights, [15](#), [106](#)
- Whitening, [452](#)
- Wikibase, [479](#)
- Wikibase, [479](#)
- Word embedding, [460](#)
- Word-sense disambiguation, [480](#)
- WordNet, [479](#)
  
- Zero-data learning, *see* zero-shot learning
- Zero-shot learning, [534](#)