Index

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

Chess, 2	Critical temperature, 599
Chord, 575	Cross-correlation, 329
Chordal graph, 575	Cross-entropy, 74, 131
Class-based language models, 460	Cross-validation, 121
Classical dynamical system, 372	CTC, see connectionist temporal classifica-
Classification, 99	tion
Clique potential, see factor (graphical model)	Curriculum learning, 326
CNN, see convolutional neural network	Curse of dimensionality, 153
Collaborative Filtering, 474	Cyc, 2
Collider, see explaining away	- 5 - 7 -
Color images, 357	D-separation, 568
Complex cell, 362	DAE, see denoising autoencoder
Computational graph, 202	Data generating distribution, 110, 130
Computer vision, 449	Data generating process, 110
Concept drift, 533	Data parallelism, 444
Condition number, 277	Dataset, 103
Conditional computation, see dynamic struc-	Dataset augmentation, 268, 454
ture	DBM, see deep Boltzmann machine
Conditional independence, xiii, 59	DCGAN, 547, 548, 695
Conditional probability, 58	Decision tree, 144, 544
Conditional RBM, 679	Decoder, 4
Connectionism, 17, 440	Deep belief network, 26, 525, 626, 651, 654
Connectionist temporal classification, 457	678, 686
Consistency, 128, 509	Deep Blue, 2
Constrained optimization, 92, 235	Deep Boltzmann machine, 23, 26, 525, 626
Content-based addressing, 416	647, 651, 657, 666, 678
Content-based recommender systems, 475	Deep feedforward network, 166, 422
Context-specific independence, 569	Deep learning, 2, 5
Contextual bandits, 476	Denoising autoencoder, 506, 683
Continuation methods, 324	Denoising score matching, 615
Contractive autoencoder, 516	Density estimation, 102
Contrast, 451	Derivative, xiii, 82
Contrastive divergence, 289, 606, 666	Design matrix, 105
Convex optimization, 140	Detector layer, 336
Convolution, 327, 677	Determinant, xii
Convolutional network, 16	Diagonal matrix, 40
Convolutional neural network, 250, 327, 422,	Differential entropy, 73, 641
456	Dirac delta function, 64
Coordinate descent, 319, 665	Directed graphical model, 76, 503, 559, 685
Correlation, 60	Directional derivative, 84
Cost function, <i>see</i> objective function	Discriminative fine-tuning, see supervised
Covariance, xiii, 60	fine-tuning
Covariance matrix, 61	Discriminative RBM, 680
Coverage, 421	Distributed representation, 17, 149, 542
2010. ago, 121	Domain adaptation, 532

Dot product, 33, 139	F-score, 420
Double backprop, 268	Factor (graphical model), 563
Doubly block circulant matrix, 330	Factor analysis, 486
Dream sleep, 605, 647	Factor graph, 575
DropConnect, 263	Factors of variation, 4
Dropout, 255 , 422, 427, 428, 666, 683	Feature, 98
Dynamic structure, 445	Feature selection, 234
,	Feedforward neural network, 166
E-step, 629	Fine-tuning, 321
Early stopping, 244, 246, 270, 271, 422	Finite differences, 436
EBM, see energy-based model	Forget gate, 304
Echo state network, 23, 26, 401	Forward propagation, 201
Effective capacity, 113	Fourier transform, 357, 359
Eigendecomposition, 41	Fovea, 363
Eigenvalue, 41	FPCD, 610
Eigenvector, 41	Free energy, 567 , 674
ELBO, see evidence lower bound	Freebase, 479
Element-wise product, see Hadamard prod-	Frequentist probability, 54
uct, see Hadamard product	Frequentist statistics, 134
EM, see expectation maximization	Frobenius norm, 45
Embedding, 512	Fully-visible Bayes network, 699
Empirical distribution, 65	Functional derivatives, 640
Empirical risk, 274	FVBN, see fully-visible Bayes network
Empirical risk minimization, 274	. V 211, ood rung violate Buyes nections
Encoder, 4	Gabor function, 365
Energy function, 565	GANs, see generative adversarial networks
Energy-based model, 565, 591, 648, 657	Gated recurrent unit, 422
Ensemble methods, 252	Gaussian distribution, see normal distribu-
Epoch, 244	tion
Equality constraint, 93	Gaussian kernel, 140
Equivariance, 335	Gaussian mixture, 66, 187
Error function, <i>see</i> objective function	GCN, see global contrast normalization
ESN, see echo state network	GeneOntology, 479
Euclidean norm, 38	Generalization, 109
Euler-Lagrange equation, 641	Generalized Lagrange function, see general-
Evidence lower bound, 628, 655	ized Lagrangian
Example, 98	Generalized Lagrangian, 93
Expectation, 59	Generative adversarial networks, 683, 693
Expectation maximization, 629	Generative moment matching networks, 696
Expected value, see expectation	Generator network, 687
Explaining away, 570, 626, 639	Gibbs distribution, 564
Exploitation, 477	Gibbs sampling, 577, 595
Exploration, 477	Global contrast normalization, 451
Exponential distribution, 64	GPU, see graphics processing unit
-	Gradient, 83

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

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

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

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