Fundamentals of Artificial Neural Networks

Mohamad H. Hassoun

A Bradford Book

The MIT Press Cambridge, Massachusetts London, England Contents

	Preface			
	Acknowledgments			
	Abbreviations			
	Symb	ols	xxiii	
1	Thres	hold Gates	1	
1.1	Thres	hold Gates	2	
	1.1.1	Linear Threshold Gates	2	
	1.1.2	Quadratic Threshold Gates	7	
	1.1.3	Polynomial Threshold Gates	8	
1.2	Comp	outational Capabilities of Polynomial Threshold Gates	9	
1.3	Gene	ral Position and the Function Counting Theorem	15	
	1.3.1	Weierstrass's Approximation Theorem	15	
	1.3.2	Points in General Position	16	
	1.3.3	Function Counting Theorem	17	
	1.3.4	Separability in ϕ -Space	20	
1.4	Minimal PTG Realization of Arbitrary Switching Functions		21	
1.5	Ambiguity and Generalization			
1.6	Extre	me Points	27	
1.7	Summ	nary	29	
	Probl	ems	30	
2	Comp	outational Capabilities of Artificial Neural Networks	35	
2.1	Some	Preliminary Results on Neural Network Mapping Capabilities	35	
	2.1.1	Network Realization of Boolean Functions	35	
	2.1.2	Bounds on the Number of Functions Realizable by a		
		Feedforward Network of LTG's	38	
2.2	Neces	ssary Lower Bounds on the Size of LTG Networks	41	
	2.2.1	Two Layer Feedforward Networks	41	
	2.2.2	Three Layer Feedforward Networks	44	
	2.2.3	Generally Interconnected Networks with No Feedback	45	
2.3	Approximation Capabilities of Feedforward Neural Networks for			
	Continuous Functions			
	2.3.1	Kolmogorov's Theorem	46	
	2.3.2	Single-Hidden-Layer Neural Networks Are		
		Universal Approximators	47	
	2.3.3	Single-Hidden-Layer Neural Networks Are Universal Classifiers	50	

Å

2.4	Com	putational Effectiveness of Neural Networks	51
	2.4.1	Algorithmic Complexity	51
	2.4.2	Computational Energy	52
2.5	Summ	nary	53
	Prob	ems	54
3	Learr	ning Rules	57
3.1	Super	rvised Learning in a Single-Unit Setting	57
	3.1.1	Error Correction Rules	58
	3.1.2	Other Gradient-Descent-Based Learning Rules	67
	3.1.3	Extension of the μ -LMS Rule to Units with Differentiable	
		Activation Functions: Delta Rule	76
	3.1.4	Adaptive Ho-Kashyap (AHK) Learning Rules	78
	3.1.5	Other Criterion Functions	82
	3.1.6	Extension of Gradient-Descent-Based Learning to Stochastic	
		Units	87
3.2	Reinf	orcement Learning	88
	3.2.1	Associative Reward-Penalty Reinforcement Learning Rule	89
3.3	Unsu	pervised Learning	90
	3.3.1	Hebbian Learning	90
	3.3.2	Oja's Rule	92
	3.3.3	Yuille et al. Rule	92
	3.3.4	Linsker's Rule	95
	3.3.5	Hebbian Learning in a Network Setting: Principal-Component	
		Analysis (PCA)	97
	3.3.6	Nonlinear PCA	101
3.4	Com	petitive Learning	103
	3.4.1	Simple Competitive Learning	103
	3.4.2	Vector Quantization	109
3.5	Self-Organizing Feature Maps: Topology-Preserving Competitive		
	Learr	•	112
	3.5.1	Kohonen's SOFM	113
	3.5.2	Examples of SOFMs	114
3.6	Sumr	•	126
	Prob	lems	134

4	Mathematical Theory of Neural Learning		143
4.1	Learning as a Search/Approximation Mechanism		
4.2	Mathematical Theory of Learning in a Single-Unit Setting		145
	4.2.1	General Learning Equation	146
	4.2.2	Analysis of the Learning Equation	147
	4.2.3	Analysis of Some Basic Learning Rules	148
4.3	Chara	cterization of Additional Learning Rules	152
	4.3.1	Simple Hebbian Learning	154
	4.3.2	Improved Hebbian Learning	155
	4.3.3	Oja's Rule	156
	4.3.4	Yuille et al. Rule	158
	4.3.5	Hassoun's Rule	161
4.4	Princi	pal-Component Analysis (PCA)	163
4.5	Theor	y of Reinforcement Learning	165
4.6	Theor	y of Simple Competitive Learning	166
	4.6.1	Deterministic Analysis	167
	4.6.2	Stochastic Analysis	168
4.7	Theor	y of Feature Mapping	171
	4.7.1	Characterization of Kohonen's Feature Map	171
	4.7.2	Self-Organizing Neural Fields	173
4.8	Gener	alization	180
	4.8.1	Generalization Capabilities of Deterministic Networks	180
	4.8.2	Generalization in Stochastic Networks	185
4.9	Comp	plexity of Learning	187
4.10	Summ	nary	190
	Probl	ems	190
5	Adapt	ive Multilayer Neural Networks I	197
5.1	Learn	ing Rule for Multilayer Feedforward Neural Networks	197
	5.1.1	Error Backpropagation Learning Rule	199
	5.1.2	Global-Descent-Based Error Backpropagation	206
5.2	Backr	prop Enhancements and Variations	210
	5.2.1	Weights Initialization	210
	5.2.2	Learning Rate	211
	5.2.3	Momentum	213

	5.2.4	Activation Function	219
	5.2.5	Weight Decay, Weight Elimination, and Unit Elimination	221
	5.2.6	Cross-Validation	226
	5.2.7	Criterion Functions	230
5.3	Appli	cations	234
	5.3.1	NETtalk	234
	5.3.2	Glove-Talk	236
	5.3.3	Handwritten ZIP Code Recognition	240
	5.3.4	ALVINN: A Trainable Autonomous Land Vehicle	244
	5.3.5	Medical Diagnosis Expert Net	246
	5.3.6	Image Compression and Dimensionality Reduction	247
5.4	Exter	sions of Backprop for Temporal Learning	253
	5.4.1	Time-Delay Neural Networks	254
	5.4.2	Backpropagation Through Time	259
	5.4.3	Recurrent Backpropagation	267
	5.4.4	Time-Dependent Recurrent Backpropagation	271
	5.4.5	Real-Time Recurrent Learning	274
5.5	Summ	•	275
	Probl	ems	276
6	Adaptive Multilayer Neural Networks II		285
6.1	Radial Basis Function (RBF) Networks		285
	6.1.1	RBF Networks versus Backprop Networks	294
	6.1.2	RBF Network Variations	296
6.2	Cerebeller Model Articulation Controller (CMAC)		301
	6.2.1	는 것 같은 것 같은 것 같은 것 같은 것 같은 것이 있었다. 것은 것은 것 같은 것 같은 것 같은 것 같은 것 같은 것 같은 것	
		Other Models	304
6.3	Unit-	Allocating Adaptive Networks	310
	6.3.1		311
	6.3.2	Cascade-Correlation Network	318
6.4	Clust	ering Networks	322
	6.4.1	Adaptive Resonance Theory (ART) Networks	323
	6.4.2	Autoassociative Clustering Network	328
65			
6.5	Sumn	nary	337

x

Contents

7	Assoc	iative Neural Memories	345
7.1	Basic	Associative Neural Memory Models	345
	7.1.1	Simple Associative Memories and their Associated	
		Recording Recipes	346
	7.1.2	Dynamic Associative Memories (DAMs)	353
7.2	DAM	Capacity and Retrieval Dynamics	363
	7.2.1	Correlation DAMs	363
	7.2.2	Projection DAMs	369
7.3	Chara	acteristics of High-Performance DAMs	374
7.4	Other DAM Models		375
	7.4.1	Brain-State-in-a-Box (BSB) DAM	375
	7.4.2	Nonmonotonic Activations DAM	381
	7.4.3	Hysteretic Activations DAM	386
	7.4.4	Exponential-Capacity DAM	389
	7.4.5	Sequence-Generator DAM	391
	7.4.6	Heteroassociative DAM	392
7.5	The I	DAM as a Gradient Net and Its Application to	
	Com	pinatorial Optimization	394
7.6	Summ	nary	400
	Probl	ems	401
8	Globa	al Search Methods for Neural Networks	417
8.1	Local	versus Global Search	417
	8.1.1	A Gradient Descent/Ascent Search Strategy	419
	8.1.2	Stochastic Gradient Search: Global Search via Diffusion	421
8.2	Simul	lated Annealing–Based Global Search	424
8.3	Simulated Annealing for Stochastic Neural Networks		428
	8.3.1	Global Convergence in a Stochastic Recurrent Neural Net:	
		The Boltzmann Machine	429
	8.3.2	Learning in Boltzmann Machines	431
8.4	Mear	-Field Annealing and Deterministic Boltzmann Machines	436
	8.4.1	Mean-Field Retrieval	437
	8.4.2	Mean-Field Learning	438
8.5	Gene	tic Algorithms in Neural Network Optimization	439
	8.5.1	Fundamentals of Genetic Algorithms	439
	8.5.2	Application of Genetic Algorithms to Neural Networks	452

Contents

24

8.6	Genetic Algorithm-Assisted Supervised Learning		454
	8.6.1	Hybrid GA/Gradient-Descent Method for Feedforward	
		Multilayer Net Training	455
	8.6.2	Simulations	458
8.7	Summary		462
	Problems		463
	References		469
	Index		501

xii