

Neural and Adaptive Systems



• **Fundamentals
Through Simulations**

José C. Principe
Neil R. Euliano
W. Curt Lefebvre

Suranaree University of Technology



31051000606125

CONTENTS

CHAPTER 1 ***DATA FITTING WITH LINEAR MODELS*** **1**

- 1.1 Introduction **2**
- 1.2 Linear Models **8**
- 1.3 Least Squares **10**
- 1.4 Adaptive Linear Systems **17**
- 1.5 Estimation of the Gradient: the LMS Algorithm **24**
- 1.6 A Methodology for Stable Adaptation **31**
- 1.7 Regression for Multiple Variables **41**
- 1.8 Newton's Method **56**
- 1.9 Analytic versus Iterative Solutions **59**
- 1.10 The Linear Regression Model **59**
- 1.11 Conclusions **63**
- 1.12 Exercises **64**
- 1.13 NeuroSolutions Examples **65**
- 1.14 Concept Map for Chapter 1 **66**
- References **67**

CHAPTER 2 ***PATTERN RECOGNITION*** **68**

- 2.1 The Pattern-Recognition Problem **68**
- 2.2 Statistical Formulation of Classifiers **71**
- 2.3 Linear and Nonlinear Classifier Machines **88**
- 2.4 Methods of Training Parametric Classifiers **94**
- 2.5 Conclusions **97**
- 2.6 Exercises **97**
- 2.7 NeuroSolutions Example **98**
- 2.8 Concept Map for Chapter 2 **98**
- References **99**

CHAPTER 3 ***MULTILAYER PERCEPTRONS*** **100**

- 3.1 Artificial Neural Networks (ANNs) **101**
- 3.2 Pattern-Recognition Ability of the McCulloch-Pitts PE **102**
- 3.3 The Perceptron **122**
- 3.4 One-Hidden-Layer Multilayer Perceptrons **132**
- 3.5 MLPs With Two Hidden Layers **144**
- 3.6 Training Static Networks with the Backpropagation Procedure **149**
- 3.7 Training Embedded Adaptive Systems **160**

3.8	MLPs as Optimal Classifiers	163
3.9	Conclusions	167
3.10	NeuroSolutions Examples	167
3.11	Exercises	168
3.12	Concept Map for Chapter 3	171
	References	172

CHAPTER 4 *DESIGNING AND TRAINING MLPs* **173**

4.1	Introduction	174
4.2	Controlling Learning in Practice	174
4.3	Other Search Procedures	184
4.4	Stop Criteria	195
4.5	How Good Are MLPs as Learning Machines?	198
4.6	Error Criterion	202
4.7	Network Size and Generalization	208
4.8	Project: Application of the MLP to Real-World Data	213
4.9	Conclusion	218
4.10	List of NeuroSolutions Examples	219
4.11	Exercises	219
4.12	Concept Map for Chapter 4	221
	References	222

CHAPTER 5 *FUNCTION APPROXIMATION WITH MLPs, RADIAL BASIS FUNCTIONS, AND SUPPORT VECTOR MACHINES* **223**

5.1	Introduction	224
5.2	Function Approximation	226
5.3	Choices for the Elementary Functions	229
5.4	Probabilistic Interpretation of the Mappings: Nonlinear Regression	244
5.5	Training Neural Networks for Function Approximation	245
5.6	How to Select the Number of Bases	249
5.7	Applications of Radial Basis Functions	257
5.8	Support Vector Machines	261
5.9	Project: Applications of Neural Networks as Function Approximators	269
5.10	Conclusion	274
5.11	Exercises	274
5.12	NeuroSolutions Examples	275
5.13	Concept Map for Chapter 5	277
	References	278

CHAPTER 6 *HEBBIAN LEARNING AND PRINCIPAL COMPONENT ANALYSIS* **279**

6.1	Introduction	280
6.2	Effect of the Hebbian Update	281

6.3	Oja's Rule	292
6.4	Principal Component Analysis	296
6.5	Anti-Hebbian Learning	304
6.6	Estimating Cross-Correlation with Hebbian Networks	306
6.7	Novelty Filters and Lateral Inhibition	309
6.8	Linear Associative Memories (LAMs)	312
6.9	LMS Learning as a Combination of Hebbian Rules	316
6.10	Autoassociation	319
6.11	Nonlinear Associative Memories	324
6.12	Project: Use of Hebbian Networks for Data Compression and Associative Memories	325
6.13	Conclusions	327
6.14	Exercises	328
6.15	NeuroSolutions Examples	329
6.16	Concept Map for Chapter 6	331
	References	332

CHAPTER 7 *COMPETITIVE AND KOHONEN NETWORKS* **333**

7.1	Introduction	334
7.2	Competition and Winner-Take-All Networks	335
7.3	Competitive Learning	337
7.4	Clustering	341
7.5	Improving Competitive Learning	344
7.6	Soft Competition	347
7.7	Kohonen Self-Organizing Map	348
7.8	Creating Classifiers from Competitive Networks	354
7.9	Adaptive Resonance Theory (ART)	357
7.10	Modular Networks	358
7.11	Conclusions	360
7.12	Exercises	360
7.13	NeuroSolutions Examples	361
7.14	Concept Map for Chapter 7	362
	References	363

CHAPTER 8 *PRINCIPLES OF DIGITAL SIGNAL PROCESSING* **364**

8.1	Time Series and Computers	365
8.2	Vectors and Discrete Signals	369
8.3	The Concept of Filtering	376
8.4	Time Domain Analysis of Linear Systems	382
8.5	Recurrent Systems and Stability	388
8.6	Frequency Domain Analysis	392
8.7	The Z Transform and the System Transfer Function	404
8.8	The Frequency Response	407

8.9	Frequency Response and Poles and Zeros	410
8.10	Types of Linear Filters	415
8.11	Project: Design of Digital Filters	418
8.12	Conclusions	423
8.13	Exercises	424
8.14	NeuroSolutions Examples	425
8.15	Concept Map for Chapter 8	427
	References	428

CHAPTER 9 ***ADAPTIVE FILTERS*** **429**

9.1	Introduction	430
9.2	The Adaptive Linear Combiner and Linear Regression	430
9.3	Optimal Filter Weights	431
9.4	Properties of the Iterative Solution	439
9.5	Hebbian Networks for Time Processing	442
9.6	Applications of the Adaptive Linear Combiner	445
9.7	Applications of Temporal PCA Networks	463
9.8	Conclusions	469
9.9	Exercises	469
9.10	NeuroSolutions Examples	470
9.11	Concept Map for Chapter 9	471
	References	472

CHAPTER 10 ***TEMPORAL PROCESSING WITH NEURAL NETWORKS*** **473**

10.1	Static versus Dynamic Systems	474
10.2	Extracting Information in Time	477
10.3	The Focused Time-Delay Neural Network (TDNN)	479
10.4	The Memory PE	486
10.5	The Memory Filter	491
10.6	Design of the Memory Space	495
10.7	The Gamma Memory PE	497
10.8	Time-Lagged Feedforward Networks	502
10.9	Focused TLFNs Built From RBFs	515
10.10	Project: Iterative Prediction of Chaotic Time Series	518
10.11	Conclusions	520
10.12	Exercises	520
10.13	NeuroSolutions Examples	521
10.14	Concept Map for Chapter 10	523
	References	524

CHAPTER 11 ***TRAINING AND USING RECURRENT NETWORKS*** **525**

11.1	Introduction	526
11.2	Simple Recurrent Topologies	527

11.3	Adapting the Feedback Parameter	529
11.4	Unfolding Recurrent Networks in Time	531
11.5	The Distributed TLFN Topology	544
11.6	Dynamic Systems	550
11.7	Recurrent Neural Networks	553
11.8	Learning Paradigms for Recurrent Systems	556
11.9	Applications of Dynamic Networks to System Identification and Control	561
11.10	Hopfield Networks	567
11.11	Grossberg's Additive Model	574
11.12	Beyond First-Order Dynamics: Freeman's Model	577
11.13	Conclusions	583
11.14	Exercises	583
11.15	NeuroSolutions Examples	585
11.16	Concept Map for Chapter 11	586
	References	587

APPENDIX A *ELEMENTS OF LINEAR ALGEBRA AND PATTERN RECOGNITION* **589**

A.1	Introduction	589
A.2	Vectors: Concepts and Definitions	590
A.3	Matrices: Concepts and Definitions	596
A.4	Random Vectors	602
A.5	Conclusions	611

APPENDIX B *NEUROSOLUTIONS TUTORIAL* **613**

B.1	Introduction to Neurosolutions	613
B.2	Introduction to the Interactive Examples	614
B.3	Basic Operation of Neurosolutions	616
B.4	Probing the System	623
B.5	The Input Family	627
B.6	Training a Network	632
B.7	Summary	635

APPENDIX C *DATA DIRECTORY* **637**

GLOSSARY **639**

INDEX **647**
