

# Contents

## Preface

### 1

## Introduction

Objectives	1-1
History	1-2
Applications	1-5
Biological Inspiration	1-8
Further Reading	1-10

### 2

## Neuron Model and Network Architectures



Objectives	2-1
Theory and Examples	2-2
Notation	2-2
Neuron Model	2-2
Single-Input Neuron	2-2
Transfer Functions	2-3
Multiple-Input Neuron	2-7
Network Architectures	2-9
A Layer of Neurons	2-9
Multiple Layers of Neurons	2-10
Recurrent Networks	2-13
Summary of Results	2-16
Solved Problems	2-20
Epilogue	2-22
Exercises	2-23

# 3

## An Illustrative Example



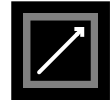
Objectives	3-1
Theory and Examples	3-2
Problem Statement	3-2
Perceptron	3-3
Two-Input Case	3-4
Pattern Recognition Example	3-5
Hamming Network	3-8
Feedforward Layer	3-8
Recurrent Layer	3-9
Hopfield Network	3-12
Epilogue	3-15
Exercise	3-16

# 4

## Perceptron Learning Rule



Objectives	4-1
Theory and Examples	4-2
Learning Rules	4-2
Perceptron Architecture	4-3
Single-Neuron Perceptron	4-5
Multiple-Neuron Perceptron	4-8
Perceptron Learning Rule	4-8
Test Problem	4-9
Constructing Learning Rules	4-10
Unified Learning Rule	4-12
Training Multiple-Neuron Perceptrons	4-13
Proof of Convergence	4-15
Notation	4-15
Proof	4-16
Limitations	4-18
Summary of Results	4-20
Solved Problems	4-21
Epilogue	4-33
Further Reading	4-34
Exercises	4-36

**5****Signal and Weight Vector Spaces**

Objectives	5-1
Theory and Examples	5-2
Linear Vector Spaces	5-2
Linear Independence	5-4
Spanning a Space	5-5
Inner Product	5-6
Norm	5-7
Orthogonality	5-7
Gram-Schmidt Orthogonalization	5-8
Vector Expansions	5-9
Reciprocal Basis Vectors	5-10
Summary of Results	5-14
Solved Problems	5-17
Epilogue	5-26
Further Reading	5-27
Exercises	5-28

**6****Linear Transformations for Neural Networks**

Objectives	6-1
Theory and Examples	6-2
Linear Transformations	6-2
Matrix Representations	6-3
Change of Basis	6-6
Eigenvalues and Eigenvectors	6-10
Diagonalization	6-13
Summary of Results	6-15
Solved Problems	6-17
Epilogue	6-28
Further Reading	6-29
Exercises	6-30

**7****Supervised Hebbian Learning**

Objectives	7-1
Theory and Examples	7-2
Linear Associator	7-3
The Hebb Rule	7-4
Performance Analysis	7-5
Pseudoinverse Rule	7-7
Application	7-10
Variations of Hebbian Learning	7-12
Summary of Results	7-14
Solved Problems	7-16
Epilogue	7-29
Further Reading	7-30
Exercises	7-31

**8****Performance Surfaces and Optimum Points**

Objectives	8-1
Theory and Examples	8-2
Taylor Series	8-2
Vector Case	8-4
Directional Derivatives	8-5
Minima	8-7
Necessary Conditions for Optimality	8-9
First-Order Conditions	8-10
Second-Order Conditions	8-11
Quadratic Functions	8-12
Eigensystem of the Hessian	8-13
Summary of Results	8-20
Solved Problems	8-22
Epilogue	8-34
Further Reading	8-35
Exercises	8-36

**9****Performance Optimization**

Objectives	9-1
Theory and Examples	9-2
Steepest Descent	9-2
Stable Learning Rates	9-6
Minimizing Along a Line	9-8
Newton's Method	9-10
Conjugate Gradient	9-15
Summary of Results	9-21
Solved Problems	9-23
Epilogue	9-37
Further Reading	9-38
Exercises	9-39

**10****Widrow-Hoff Learning**

Objectives	10-1
Theory and Examples	10-2
ADALINE Network	10-2
Single ADALINE	10-3
Mean Square Error	10-4
LMS Algorithm	10-7
Analysis of Convergence	10-9
Adaptive Filtering	10-13
Adaptive Noise Cancellation	10-15
Echo Cancellation	10-21
Summary of Results	10-22
Solved Problems	10-24
Epilogue	10-40
Further Reading	10-41
Exercises	10-42

# 11

## Backpropagation



Objectives	11-1
Theory and Examples	11-2
Multilayer Perceptrons	11-2
Pattern Classification	11-3
Function Approximation	11-4
The Backpropagation Algorithm	11-7
Performance Index	11-8
Chain Rule	11-9
Backpropagating the Sensitivities	11-11
Summary	11-13
Example	11-14
Using Backpropagation	11-17
Choice of Network Architecture	11-17
Convergence	11-19
Generalization	11-21
Summary of Results	11-24
Solved Problems	11-26
Epilogue	11-40
Further Reading	11-41
Exercises	11-43

# 12

## Variations on Backpropagation



Objectives	12-1
Theory and Examples	12-2
Drawbacks of Backpropagation	12-3
Performance Surface Example	12-3
Convergence Example	12-7
Heuristic Modifications of Backpropagation	12-9
Momentum	12-9
Variable Learning Rate	12-12
Numerical Optimization Techniques	12-14
Conjugate Gradient	12-14
Levenberg-Marquardt Algorithm	12-19
Summary of Results	12-28
Solved Problems	12-32
Epilogue	12-46
Further Reading	12-47
Exercises	12-50

# 13

## Associative Learning



Objectives	13-1
Theory and Examples	13-2
Simple Associative Network	13-3
Unsupervised Hebb Rule	13-5
Hebb Rule with Decay	13-7
Simple Recognition Network	13-9
Instar Rule	13-11
Kohonen Rule	13-15
Simple Recall Network	13-16
Outstar Rule	13-17
Summary of Results	13-21
Solved Problems	13-23
Epilogue	13-34
Further Reading	13-35
Exercises	13-37

# 14

## Competitive Networks



Objectives	14-1
Theory and Examples	14-2
Hamming Network	14-3
Layer 1	14-3
Layer 2	14-4
Competitive Layer	14-5
Competitive Learning	14-7
Problems with Competitive Layers	14-9
Competitive Layers in Biology	14-10
Self-Organizing Feature Maps	14-12
Improving Feature Maps	14-15
Learning Vector Quantization	14-16
LVQ Learning	14-18
Improving LVQ Networks (LVQ2)	14-21
Summary of Results	14-22
Solved Problems	14-24
Epilogue	14-37
Further Reading	14-38
Exercises	14-39

**15****Grossberg Network**

Objectives	15-1
Theory and Examples	15-2
Biological Motivation: Vision	15-3
Illusions	15-4
Vision Normalization	15-8
Basic Nonlinear Model	15-9
Two-Layer Competitive Network	15-12
Layer 1	15-13
Layer 2	15-17
Choice of Transfer Function	15-20
Learning Law	15-22
Relation to Kohonen Law	15-24
Summary of Results	15-26
Solved Problems	15-30
Epilogue	15-42
Further Reading	15-43
Exercises	15-45

**16****Adaptive Resonance Theory**

Objectives	16-1
Theory and Examples	16-2
Overview of Adaptive Resonance	16-2
Layer 1	16-4
Steady State Analysis	16-6
Layer 2	16-10
Orienting Subsystem	16-13
Learning Law: L1-L2	16-17
Subset/Superset Dilemma	16-17
Learning Law	16-18
Learning Law: L2-L1	16-20
ART1 Algorithm Summary	16-21
Initialization	16-21
Algorithm	16-21
Other ART Architectures	16-23
Summary of Results	16-25
Solved Problems	16-30
Epilogue	16-45
Further Reading	16-46
Exercises	16-48

# 17

## Stability



Objectives	17-1
Theory and Examples	17-2
Recurrent Networks	17-2
Stability Concepts	17-3
Definitions	17-4
Lyapunov Stability Theorem	17-5
Pendulum Example	17-6
LaSalle's Invariance Theorem	17-12
Definitions	17-12
Theorem	17-13
Example	17-14
Comments	17-18
Summary of Results	17-19
Solved Problems	17-21
Epilogue	17-28
Further Reading	17-29
Exercises	17-30

# 18

## Hopfield Network



Objectives	18-1
Theory and Examples	18-2
Hopfield Model	18-3
Lyapunov Function	18-5
Invariant Sets	18-7
Example	18-7
Hopfield Attractors	18-11
Effect of Gain	18-12
Hopfield Design	18-16
Content-Addressable Memory	18-16
Hebb Rule	18-18
Lyapunov Surface	18-22
Summary of Results	18-24
Solved Problems	18-26
Epilogue	18-36
Further Reading	18-37
Exercises	18-40

# 19

## Epilogue

Objectives	19-1
Theory and Examples	19-2
Feedforward and Related Networks	19-2
Competitive Networks	19-8
Dynamic Associative Memory Networks	19-9
Classical Foundations of Neural Networks	19-10
Books and Journals	19-10
Epilogue	19-13
Further Reading	19-14

## Appendices

### A

### Bibliography

### B

### Notation

### C

### Software

### I

### Index