
CONTENTS

Foreword	xiii
Preface	xv
Acknowledgments	xxiii
Acronyms	xxv
Introduction	1
1 THE CORRELATIVE BRAIN	8
1.1 Background / 8	
1.1.1 Spiking Neurons / 8	
1.1.2 Neocortex / 14	
1.1.3 Receptive Fields / 16	
1.1.4 Thalamus / 18	
1.1.5 Hippocampus / 18	
1.2 Correlation Detection in Single Neurons / 19	
1.3 Correlation in Ensembles of Neurons: Synchrony and Population Coding / 25	
1.4 Correlation is the Basis of Novelty Detection and Learning / 31	
1.5 Correlation in Sensory Systems: Coding, Perception, and Development / 38	
1.6 Correlation in Memory Systems / 47	
1.7 Correlation in Sensorimotor Learning / 52	
1.8 Correlation, Feature Binding, and Attention / 57	
1.9 Correlation and Cortical Map Changes after Peripheral Lesions and Brain Stimulation / 59	
1.10 Discussion / 67	

2 Correlation in Signal Processing 72

- 2.1 Correlation and Spectrum Analysis / 73
 - 2.1.1 Stationary Process / 73
 - 2.1.2 Nonstationary Process / 79
 - 2.1.3 Locally Stationary Process / 81
 - 2.1.4 Cyclostationary Process / 83
 - 2.1.5 Hilbert Spectrum Analysis / 83
 - 2.1.6 Higher Order Correlation-Based Bispectra Analysis / 85
 - 2.1.7 Higher Order Functions of Time, Frequency, Lag, and Doppler / 87
 - 2.1.8 Spectrum Analysis of Random Point Process / 89
- 2.2 Wiener Filter / 91
- 2.3 Least-Mean-Square Filter / 95
- 2.4 Recursive Least-Squares Filter / 99
- 2.5 Matched Filter / 100
- 2.6 Higher Order Correlation-Based Filtering / 102
- 2.7 Correlation Detector / 104
 - 2.7.1 Coherent Detection / 104
 - 2.7.2 Correlation Filter for Spatial Target Detection / 106
- 2.8 Correlation Method for Time-Delay Estimation / 108
- 2.9 Correlation-Based Statistical Analysis / 110
 - 2.9.1 Principal-Component Analysis / 110
 - 2.9.2 Factor Analysis / 112
 - 2.9.3 Canonical Correlation Analysis / 113
 - 2.9.4 Fisher Linear Discriminant Analysis / 118
 - 2.9.5 Common Spatial Pattern Analysis / 119
- 2.10 Discussion / 122
- Appendix 2A: Eigenanalysis of Autocorrelation Function of Nonstationary Process / 122
- Appendix 2B: Estimation of Intensity and Correlation Functions of Stationary Random Point Process / 123
- Appendix 2C: Derivation of Learning Rules with Quasi-Newton Method / 125

3 correlation-based neural learning and machine learning 129

- 3.1 Correlation as a Mathematical Basis for Learning / 130
 - 3.1.1 Hebbian and Anti-Hebbian Rules (Revisited) / 130
 - 3.1.2 Covariance Rule / 131
 - 3.1.3 Grossberg's Gated Steepest Descent / 132

3.1.4	Competitive Learning Rule / 133
3.1.5	BCM Learning Rule / 135
3.1.6	Local PCA Learning Rule / 136
3.1.7	Generalizations of PCA Learning / 140
3.1.8	CCA Learning Rule / 144
3.1.9	Wake—Sleep Learning Rule for Factor Analysis / 145
3.1.10	Boltzmann Learning Rule / 146
3.1.11	Perceptron Rule and Error-Correcting Learning Rule / 147
3.1.12	Differential Hebbian Rule and Temporal Hebbian Learning / 149
3.1.13	Temporal Difference and Reinforcement Learning / 152
3.1.14	General Correlative Learning and Potential Function / 156
3.2	Information-Theoretic Learning / 158
3.2.1	Mutual Information versus Correlation / 159
3.2.2	Barlow's Postulate / 159
3.2.3	Hebbian Learning and Maximum Entropy / 160
3.2.4	Imax Algorithm / 163
3.2.5	Local Decorrelative Learning / 164
3.2.6	Blind Source Separation / 167
3.2.7	Independent-Component Analysis / 169
3.2.8	Slow Feature Analysis / 174
3.2.9	Energy-Efficient Hebbian Learning / 176
3.2.10	Discussion / 178
3.3	Correlation-Based Computational Neural Models / 182
3.3.1	Correlation Matrix Memory / 182
3.3.2	Hopfield Network / 184
3.3.3	Brain-State-in-a-Box Model / 187
3.3.4	Autoencoder Network / 187
3.3.5	Novelty Filter / 190
3.3.6	Neuronal Synchrony and Binding / 191
3.3.7	Oscillatory Correlation / 193
3.3.8	Modeling Auditory Functions / 193
3.3.9	Correlations in the Olfactory System / 198
3.3.10	Correlations in the Visual System / 199
3.3.11	Elastic Net / 200
3.3.12	CMAC and Motor Learning / 205
3.3.13	Summarizing Remarks / 207
	Appendix 3A: Mathematical Analysis of Hebbian Learning* / 208
	Appendix 3B: Necessity and Convergence of Anti-Hebbian Learning / 209
	Appendix 3C: Link between Hebbian Rule and Gradient Descent / 210
	Appendix 3D: Reconstruction Error in Linear and Quadratic PCA / 211

4 Correlation-Based Kernel Learning 218

- 4.1 Background / 218
- 4.2 Kernel PCA and Kernelized GHA / 221
- 4.3 Kernel CCA and Kernel ICA / 225
- 4.4 Kernel Principal Angles / 230
- 4.5 Kernel Discriminant Analysis / 232
- 4.6 Kernel Wiener Filter / 235
- 4.7 Kernel-Based Correlation Analysis: Generalized Correlation Function and Correntropy / 238
- 4.8 Kernel Matched Filter / 242
- 4.9 Discussion / 243

5 Correlative Learning in a Complex-Valued Domain 249

- 5.1 Preliminaries / 250
- 5.2 Complex-Valued Extensions of Correlation-Based Learning / 257
 - 5.2.1 Complex-Valued Associative Memory / 257
 - 5.2.2 Complex-Valued Boltzmann Machine / 258
 - 5.2.3 Complex-Valued LMS Rule / 259
 - 5.2.4 Complex-Valued PCA Learning / 262
 - 5.2.5 Complex-Valued ICA Learning / 269
 - 5.2.6 Constant-Modulus Algorithm / 273
- 5.3 Kernel Methods for Complex-Valued Data / 277
 - 5.3.1 Reproducing Kernels in the Complex Domain / 277
 - 5.3.2 Complex-Valued Kernel PCA / 279
- 5.4 Discussion / 280

6 ALOPEX: A CORRELATION-BASED LEARNING PARADIGM 283

- 6.1 Background / 283
- 6.2 The Basic ALOPEX Rule / 284
- 6.3 Variants of ALOPEX / 286
 - 6.3.1 Unnikrishnan and Venugopal's ALOPEX / 286
 - 6.3.2 Bia's ALOPEX-B / 287
 - 6.3.3 Improved Version of ALOPEX-B / 288
 - 6.3.4 Two-Timescale ALOPEX / 289
 - 6.3.5 Other Types of Correlation Mechanisms / 290
- 6.4 Discussion / 290
- 6.5 Monte Carlo Sampling-Based ALOPEX / 295
 - 6.5.1 Sequential Monte Carlo Estimation / 295

6.5.2	Sampling-Based ALOPEX / 298	
6.5.3	Remarks / 302	
	Appendix 6A: Asymptotic Analysis of ALOPEX Process / 303	
	Appendix 6B: Asymptotic Convergence Analysis of 2t-ALOPEX / 304	
7	Case Studies	307
7.1	Hebbian Competition as Basis for Cortical Map Reorganization? / 308	
7.2	Learning Neurocompensator: Model-Based Hearing Compensation Strategy / 320	
7.2.1	Background / 320	
7.2.2	Model-Based Hearing Compensation Strategy / 320	
7.2.3	Optimization / 326	
7.2.4	Experimental Results / 330	
7.2.5	Summary / 333	
7.3	Online Training of Artificial Neural Networks / 333	
7.3.1	Background / 333	
7.3.2	Parameter Setup / 334	
7.3.3	Online Option Price Prediction / 334	
7.3.4	Online System Identification / 336	
7.3.5	Summary / 339	
7.4	Kalman Filtering in Computational Neural Modeling / 340	
7.4.1	Background / 340	
7.4.2	Overview of Kalman Filter in Modeling Brain Functions / 342	
7.4.3	Kalman Filter for Learning Shape and Motion from Image Sequences / 346	
7.4.4	General Remarks and Implications / 354	
8	Discussion	356
8.1	Summary: Why Correlation? / 356	
8.1.1	Hebbian Plasticity and the Correlative Brain / 357	
8.1.2	Correlation-Based Signal Processing / 358	
8.1.3	Correlation-Based Machine Learning / 358	
8.2	Epilogue: What Next? / 359	
8.2.1	Generalizing the Correlation Measure / 359	
8.2.2	Deciphering the Correlative Brain / 360	
	Appendix A Autocorrelation and Cross-Correlation Functions	363
A.1	Autocorrelation Function / 363	

- A.2 Cross-Correlation Function / 364
- A.3 Derivative Stochastic Processes / 367

Appendix B Stochastic Approximation 368

Appendix C Primer on Linear Algebra 371

- C.1 Eigenanalysis / 372
- C.2 Generalized Eigenvalue Problem / 375
- C.3 SVD and Cholesky Factorization / 375
- C.4 Gram–Schmidt Orthogonalization / 376
- C.5 Principal Correlation / 377

Appendix D Probability Density and Entropy Estimators 378

- D.1 Gram–Charlier Expansion / 379
- D.2 Edgeworth Expansion / 381
- D.3 Order Statistics / 381
- D.4 Kernel Estimator / 382

Appendix E Expectation–Maximization Algorithm 384

- E.1 Alternating Free-Energy Maximization / 384
- E.2 Fitting Gaussian Mixture Model / 385

Index 441