Contents

1 Introduction **7**

1.1 Introduction . . . 7
1.2 Neuronal network approaches versus connectionism . . . 7
1.3 Neurons in the brain, and their representation in neuronal networks . . 7
1.4 A formalism for approaching the operation of single neurons in a network . . . 7
1.5 Synaptic modification . . . 7
1.6 Long-term potentiation and long-term depression as biological models of synaptic modification that occur in the brain . . . 7
1.7 Distributed representations . . . 7
1.8 Introduction to three simple neuronal network architecture . . . 7
1.9 System-level analysis of brain functions . . . 7

2 Pattern association memory **7**

2.1 Architecture and operation . . . 7
2.2 A simple model . . . 7
2.3 The vector interpretation . . . 7
2.4 Properties . . . 7
2.4.1 Generalization . . . 7
2.4.2 Graceful degradation or fault tolerance . . . 7
2.4.3 The importance of distributed representation for pattern associators . . . 7
2.4.4 Prototype extraction, extraction of central tendency, and noise reduction . . . 7
2.4.5 Speed . . . 7
2.4.6 Local learning rule . . . 7
2.4.7 Capacity
– Linear associative neuronal networks
– Associative neuronal networks with non-linear neurons . . 7
2.4.8 Interference . . . 7
2.4.9 Expansion recoding . . . 7
2.4.10 Implications of different types of coding for storage in pattern associators . . . 7

3 Autoassociation memory **7**

3.1 Architecture and operation . . . 7
3.1.1 Learning . . . 7

3.2 Recall . . . 7
3.3 Introduction to the analysis of the operation of autoassociative networks 7
3.4 Properties . . . 7
3.4.1 Completion . . . 7
3.4.2 Generalization . . . 7
3.4.3 Graceful degradation or fault tolerance . . . 7
3.4.4 Prototype extraction, extraction of central tendency, and noise reduction . . . 7
3.4.5 Speed . . . 7
3.4.6 Local learning rule . . . 7
3.4.7 Capacity . . . 7
3.4.8 Context . . . 7
3.4.9 Mixture states . . . 7
3.4.10 Memory for sequences . . . 7
3.5 Use of the autoassociation networks in the brain . . . 7

4 Competitive networks, including self-organizing maps 7
4.1 Function . . . 7
4.2 Architecture and algorithm . . . 7
4.2.1 Architecture . . . 7
4.2.2 Algorithm . . . 7
4.3 Properties . . . 7
4.3.1 Feature discovery by self-organization . . . 7
4.3.2 Removal of redundancy . . . 7
4.3.3 Orthogonalization and categorization . . . 7
4.3.4 Sparsification . . . 7
4.3.5 Capacity . . . 7
4.3.6 Separation of non-linearly separable patterns . . . 7
4.3.7 Stability . . . 7
4.3.8 Frequency of presentation . . . 7
4.3.9 Comparison to principal component analysis (PCA) and cluster analysis . . . 7
4.4 Utility of competitive networks in information processing by the brain 7
4.4.1 Orthogonalization . . . 7
4.4.2 Sparsification . . . 7
4.4.3 Brain systems in which competitive networks may be used for orthogonalization and sparsification . . . 7
4.4.4 Removal of redundancy . . . 7
4.4.5 Feature analysis and preprocessing . . . 7

4.5 Guidance of competitive learning 7
4.6 Topographic map formation 7
4.7 Radial basis function networks 7
4.8 Appendix on the algorithms used in competitive networks 7
4.8.1 Normalization of the inputs 7
4.8.2 Normalization of the length of the synaptic weight vector on each dendrite 7
4.8.3 Non-linearity in the learning rule 7
4.8.4 Competition 7
4.8.5 Soft competition 7
4.8.6 Untrained neurons 7
4.8.7 Large competitive nets: further aspects 7

5 Error-correcting networks: perceptrons, backpropagation of error in multilayer networks, and reinforcement learning algorithms 7
5.1 Perceptrons and one-layer error correcting networks 7
5.1.1 Architecture and general description 7
5.1.2 Generic algorithm (for one-layer network taught by error correction) 7
5.1.3 Variations on the single-layet errorcorrecting network:
– Rosenblat's (1961) perceptron
– Adaline
– Adaptive filter
– Capability and limitations of single-layer error-correcting networks
– Output neurons with continuous values, random patterns
– Output neurons with binary threshold activation functions
– Gradient descent for neurons with continuous-valued outputs 7
5.1.4 Properties
– Generalization
– Graceful degradation or fault tolerance
– Prototype extraction, extraction of central tendency, and noise reduction
– Speed
– Non-local learning rule
– Interference
– expansion recoding 7
5.1.5 Utility of a single-layer error correcting networks in information processing by the brain 7

5.2 Multilayer perceptrons: backpropagation of error networks 7
5.2.1 Introduction 7
5.2.2 Architecture and algorithm 7
5.2.3 Properties of multilayer networks trained by error backpropagation
– Arbitrary mapping
– Fast operation
– Learning speed
– Number of hidden neurons and generalization
– Non-local learning rule 7
5.3 Reinforcement learning 7
5.3.1 Associative reward-penalty algorithm of Barto and Sutton
– Architecture
– Operation 7
5.4 Contrastive Hebbian learning: the Boltzmann machine 7
5.5 Conclusion 7

6 The hippocampus and memory **7**
6.1 What functions are performed by the hippocampus? Evidence from the effect of damage to the brain 7
6.2 Relation between spatial and non-spatial aspects of hippocampal function, episodic memory, and long-term semantic memory 7
6.3 Neurophysiology of the hippocampus 7
6.3.1 Primate hippocampal cells which respond to a combination of spatial ('where') and object ('what') information 7
6.3.2 Spatial views are encoded by primate hippocampal neurons . 7
6.4 Architecture of the hippocampus 7
6.5 Plasticity 7
6.6 Outline of the computational hypothesis of hippocampal operation . . 7
6.7 The CA3 network as an autoassociative memory 7
6.7.1 Analysis of storage capacity 7
6.7.2 The requirement of the input systems for efficient storage of new information 7
6.7.3 The role of the perforant path input in initiating retrieval . . . 7
6.7.4 Predictions arising from the analysis of CA3 7
6.7.5 Dynamics and the speed of operation of autoassociation in the brain 7
6.8 The dentate granule cells 7
6.9 The CA1 network 7

6.9.1 Recoding in CA1 7
6.9.2 Preserving the information content of CA3 patterns 7
6.9.3 The perforant path projection to CA1 7
6.10 Backprojection to the neocortex, and recall from the hippocampus . . 7

7 Pattern association in the brain: amygdala and orbitofrontal cortex 7

8 Cortical networks for invariant pattern recognition 7

9 Motor systems: cerebellum and basal ganglia 7

10 Cerebral neocortex 7

A1 Introduction to linear algebra for neural networks 7

A2 Information theory 7

A3 Pattern associators 7

A4 Autoassociators 7

A5 Recurrent dynamics 7