
Contents

Part I Basic Ideas and Fundamentals: Why are complex-valued neural networks inevitable?

1	Complex-valued neural networks fertilize electronics	3
1.1	Imitate the brain, and surpass the brain	3
1.2	Create a “Superbrain” by enrichment of the information representation	4
1.3	Application fields expand rapidly and steadily	6
1.4	Book organization	8
2	Neural networks: The characteristic viewpoints	9
2.1	Brain, artificial brain, artificial intelligence (AI), and neural networks	9
2.2	Physicality of brain functions	12
2.3	Neural networks: General features	13
3	Complex-valued neural networks: Distinctive features	17
3.1	Activation functions in neurons	17
3.1.1	Nonlinear activation functions in real-valued neural networks	17
3.1.2	Problem concerning activation functions in complex-valued neural networks	18
3.1.3	Construction of CVNNs with partial derivatives in complex domain	20
3.1.4	Real-Imaginary-type activation function	22
3.1.5	Amplitude-phase-type activation function	23
3.1.6	Significance in complex-domain treatment in relation to the amplitude-phase-type activation function	25
3.2	What is the sense of complex-valued information and its processing?	26
3.3	In what fields are CVNNs effective?	28

3.3.1	Electromagnetic and optical waves, electrical signals in analog and digital circuits	28
3.3.2	Electron wave	32
3.3.3	Superconductors	33
3.3.4	Quantum computation	33
3.3.5	Sonic and ultrasonic waves	33
3.3.6	Compatibility of controllability and adaptability	34
3.3.7	Periodic topology and metric	34
3.3.8	Direct use of polar coordinates	36
3.3.9	High stability in recurrent dynamics	36
3.3.10	Preservation of relative directions and segmentation boundaries in two-dimensional information transform . .	37
3.3.11	Chaos and fractals in complex domain	37
3.3.12	Quaternion and other higher-order complex numbers . . .	37
3.4	Investigations in complex-valued neural networks	38
3.4.1	History	38
3.4.2	Recent progress	40
4	Constructions and dynamics of neural networks	43
4.1	Processing, learning, and self-organization	43
4.1.1	Pulse-density signal representation	43
4.1.2	Neural dynamics	45
4.1.3	Task processing	45
4.1.4	Learning and self-organization	45
4.1.5	Changes in connection weights	46
4.2	Hebbian rule	46
4.3	Associative memory	49
4.3.1	Function: Memory and recall of pattern information . . .	49
4.3.2	Network construction and processing dynamics	49
4.3.3	Energy function	53
4.3.4	Use of generalized inverse matrix	55
4.3.5	Weight learning by sequential correlation learning	55
4.3.6	Complex-valued associative memory	56
4.3.7	Amplitude–phase expression of Hebbian rule	57
4.3.8	Lightwave neural networks and carrier-frequency- dependent learning	59
4.4	Function approximation	61
4.4.1	Function: Generation of desirable outputs for given inputs	61
4.4.2	Network construction and processing dynamics	62
4.4.3	Learning by steepest descent method	64
4.4.4	Backpropagation learning	65
4.4.5	Learning by complex-valued steepest descent method . .	67
4.4.6	Function approximation by use of complex-valued Hebbian rule	72

4.4.7	Backpropagation learning by backward propagation of teacher signals instead of errors	73
4.5	Adaptive clustering and visualization of multidimensional information	76
4.5.1	Function: Vector quantization and visualization	76
4.5.2	Network construction, processing, and self-organization	76
4.5.3	Complex-valued self-organizing map: C-SOM	79
4.6	Markov random field estimation	80
4.6.1	Function: Signal estimation from neighbors	80
4.6.2	Network construction and processing dynamics	80
4.6.3	Learning correlations between signals at a pixel and its neighbors	81
4.7	Principal component analysis	82
4.7.1	Function: Extraction of principal information in statistical data	82
4.7.2	Network construction and dynamics of task processing and self-organization	83
4.8	Independent component analysis	85

Part II Applications: How wide are the application fields?

5	Land-surface classification with unevenness and reflectance taken into consideration	89
5.1	Interferometric radar	89
5.2	CMRF model	90
5.3	CMRF model and complex-valued Hebbian learning rule	93
5.4	Construction of C-SOM image classification system	94
5.5	Generation of land-surface classification map	96
5.6	Summary	97
6	Adaptive radar system to visualize antipersonnel plastic landmines	99
6.1	Ground penetrating radars	99
6.2	Construction of C-SOM plastic landmine visualization system dealing with frequency- and space-domain texture	100
6.3	Adaptive signal processing in C-SOM	101
6.3.1	Feature vector extraction by paying attention to frequency domain information	101
6.3.2	Dynamics of C-SOM classification	103
6.4	Visualization of antipersonnel plastic landmines	104
6.4.1	Measurement parameters	104
6.4.2	Results of observation and classification	106
6.4.3	Performance evaluation by visualization rate	107
6.5	Summary	107

7	Removal of phase singular points to create digital elevation map	109
7.1	Phase unwrapping	109
7.2	Noise reduction with a complex-valued cellular neural network	111
7.3	System construction	113
7.4	Dynamics of singular-point reduction	115
7.5	DEM quality and calculation cost	116
7.6	Summary	117
8	Lightwave associative memory that memorizes and recalls information depending on optical-carrier frequency	119
8.1	Utilization of wide frequency bandwidth in optical neural networks	119
8.2	Optical-carrier-frequency dependent associative memory: The dynamics	122
8.2.1	Recalling process	122
8.2.2	Memorizing process	122
8.3	Optical setup	123
8.4	Frequency-dependent learning	124
8.5	Frequency-dependent recall experiment	127
8.6	Summary	128
9	Adaptive optical-phase equalizer	129
9.1	System construction	129
9.2	Optical setup	130
9.3	Dynamics of output phase-value learning	132
9.4	Performance of phase equalization	133
9.5	Summary	134
10	Developmental learning with behavioral-mode tuning by carrier-frequency modulation	135
10.1	Development, context dependence, volition, and developmental learning	135
10.2	Neural construction and human-bicycle model	137
10.3	Developmental learning in bicycle riding	140
10.3.1	Task 1: Ride as long as possible	141
10.3.2	Task 2: Ride as far as possible	144
10.3.3	Comparative experiment: Direct FML in Task 2	145
10.3.4	Comparison between the results	145
10.4	Summary	146

**11 Pitch-asynchronous overlap-add waveform-concatenation
speech synthesis
by optimizing phase spectrum in frequency domain 147**

11.1 Pitch-synchronous and -asynchronous methods
in waveform concatenation 147

11.1.1 Pitch mark and pitch-synchronous method 147

11.1.2 Human senses sound spectrum 149

11.1.3 Problem in simple asynchronous speech synthesis 149

11.1.4 Pitch-asynchronous methods: Single phase-adjustment
method and stepwise phase-adjustment method 150

11.1.5 Convolutions and neural networks 151

11.2 Construction of stepwise phase-adjustment system 151

11.3 Optimization of pulse sharpness 154

11.4 Experimental results 156

11.5 Summary 158

References 163

Index 173