

Contents

1. Introduction	1
1.1. Emergent computation as a universal phenomena	1
1.2. Emergence	2
1.3. Cellular computing systems	2
1.4. Universality	4
1.5. Designing for emergence, the essence of this book	4
1.6. Detecting the potential for emergence: the local activity theory	6
2. Cellular paradigms: theory and simulation	9
2.1. Cellular systems	9
2.2. Major cellular systems paradigms	11
The Cellular Neural Network (CNN) model	12
The Generalized Cellular Automata	13
Reaction-Diffusion Cellular Nonlinear Networks	14
2.3. Matlab simulation of generalized cellular automata	15
Uncoupled GCAs	15
Coupled GCAs	17
Simulation of standard cellular neural networks	18
2.4. Simulation of Reaction-Diffusion Cellular Neural Networks	18
2.5. Concluding remarks	20
3. Universal Cells	21
3.1. Universality and cellular computation, basic ideas	21
Boolean universal cells	22
The simplicial cell – universality expanded to continuous states	22
3.2. Binary cells	23
3.2.1. What would be an “ideal” binary CNN cell ?	24
Universality	24
Compactness	24
Robustness	25
Capability of evolution	26
3.2.2. Orientations and Projection Tapes	26
Local binary computation	26
Projections	28
Orientations	29
Projection tapes	30
Default orientations	31
Valid and non-valid projection tapes	32
Transitions and robust transitions	35
Finding the optimal orientation	38
Optimal orientations for totalistic and semi-totalistic Boolean functions	42
3.2.3. Universal cells with canonical discriminants	46

3.2.4. Compact universal cells with multi nested discriminants	48
Bifurcation tree for multi-nested discriminant function	49
Uniform multi-nested cells and their bifurcation trees	52
The uniform multi-nested discriminant as an analog-to-digital converter	52
Uniform orientations and projection tapes	53
Boolean realizations: an analytic approach	53
Finding the genes for arbitrary Boolean functions	58
Other random search methods	68
3.3. Continuous state cells	73
3.3.1. Overview	73
3.3.2. Some theoretical issues on simplicial neural cells	79
Relationships with fuzzy logic	79
Training and testing samples	79
Quantization of gene's coefficients	80
3.3.3. Circuit implementation issues	81
Considerations regarding the implementation of the local Boolean logic	82
Software implementations	83
3.3.4. A general procedure for training the simplicial cell	84
3.3.5. Functional capabilities and applications	84
Square scratch removal	84
Median Filters	86
Edge detection	88
Pattern classification	89
3.3.6. Nonlinear expansion of the input space	90
3.3.7. Comparison with multi-layer perceptrons	91
3.4. Concluding remarks	93

4. Emergence in continuous-time systems:

Reaction-Diffusion Cellular Neural Networks	95
4.1. The theory of local activity as a tool for locating emergent behaviors	95
4.2. Narrowing the search, "Edge of chaos" domains	96
4.3. The methodology of finding "edge of chaos" domains	98
4.3.1. Four steps precluding the local activity testing	98
4.3.2. The concept of local activity	102
4.3.3. Testing for stable and unstable local activity	103
Local activity test for one diffusion coefficient	104
Local activity test for two diffusion coefficients	108
4.3.4. Unrestricted versus restricted local activity, the edge of chaos	109
Unrestricted local activity and passivity	109
The Edge of Chaos	112
4.3.5. Bifurcation diagrams	118
One-diffusion coefficient case	118
The two-diffusion case	121
4.3.6. Emergent behaviors near and within the "edge of chaos"	121
Mapping the Edge of Chaos	122
Static and dynamic patterns on the Edge of Chaos	125
Homogeneous static patterns	128
Turing-like patterns	129

Spiral wave patterns	136
Information computation patterns	137
Periodic dynamic patterns	139
Chaotic dynamic patterns	139
4.4. Emergent behaviors within the "edge of chaos" domains of the Brusselator CNN	143
4.4.1. Local Activity and Edge of Chaos Domains	143
The cell parameter projection profile (CPPP)	146
Bifurcation diagrams	146
Local activity and edge of chaos domain, two diffusion coefficients	148
4.4.2. Emergence at the edge of chaos	150
The one-diffusion coefficient case	150
Dynamic patterns	153
Static patterns	157
The two-diffusion coefficients case	159
4.5. Emergent behaviors within the "edge of chaos" domains of the Gierer-Meinhardt CNN	160
4.5.1. Local Activity and Edge of Chaos Domains	160
The cell parameter projection profile (CPPP)	165
Bifurcation diagrams	165
Local activity and edge of chaos domain, two diffusion coefficients	167
4.5.2. Emergence at the edge of chaos	168
The one-diffusion coefficient case	168
Static patterns	173
Dynamic patterns	173
The two-diffusion coefficients case	176
4.6. Concluding remarks and engineering perspectives	177
Heuristics in determining cell parameter points leading to emergence	178
Uncertainties in locating emergent behaviors	179
Engineering perspectives and potential applications of the edge of chaos analysis	181

5. Emergence in discrete-time systems:

Generalized cellular automata **183**

5.1 Emergent phenomena in binary cellular automata	184
5.1.1. Introduction	184
5.1.2. Generalized Cellular Automata	187
Uncoupled GCA	189
Generalized Cellular Automata for the "Game of Life"	190
5.1.3. Failure boundaries and paving stones in the cell's parameter space	191
5.1.4. Locating emergent behaviors and their dynamics	193
Cellular Disorder Measure	195
Three Qualitative Classes of Dynamic Behaviors	196
Examples of dynamic behaviors	198

5.2. Emergent phenomena in continuous state cellular automata	210
5.2.1. Introduction	210
5.2.1. The cellular model	211
5.2.2. Emergence of autopoietic patterns by mutations in the “game of life”	211
The influence of initial condition	212
The influence of cells parameters	215
Other cell models	216
5.3. Emergence in coupled generalized cellular automata	218
5.3.1 Introduction	218
5.3.2. The cellular model	218
5.3.3. An application in pattern detection from extremely noisy background	220
5.4. Concluding remarks	222
6. Unconventional applications:	
Biometric authentication	225
6.1. Introduction	225
6.2. Generating the stimuli	227
6.3. Experimental results	229
6.4. Concluding remarks	232
References	233
Index	245