

Contents

1	Introduction to Cellular Automata and Conway’s Game of Life	1
	Carter Bays	
1.1	A Brief Background	1
1.2	The Original Glider Gun	4
1.3	Other GoL Rules in the Square Grid	5
1.4	Why Treat All Neighbors the Same?	5
	References	7

Part I Historical

2	Conway’s Game of Life: Early Personal Recollections	11
	Robert Wainwright	
3	Conway’s <i>Life</i>	17
	Harold V. McIntosh	
3.1	Introduction	17
3.2	The Rules of the Game	18
3.3	Still Lives	20
3.4	Period Two	21
3.5	Gliders	22
3.6	Oscillators	23
3.7	Glider Guns	25
3.8	Puffer Trains	27
3.9	Life on a Torus	28
3.10	Cycles of Finite Periodicity	30
4	<i>Life</i>’s Still Lives	35
	Harold V. McIntosh	
4.1	Introduction	35
4.2	Cellular Automata	36
4.3	Still Life	37

4.4	De Bruijn Diagram	38
4.5	First Stage	39
4.6	Second Stage	43
4.7	Comments	49
	References	50
5	A Zoo of Life Forms	51
	Harold V. McIntosh	
5.1	Introduction	51
5.2	(0, 0, 1) — Still Lives	52
5.2.1	First Level de Bruijn Matrix	52
5.2.2	Powers of the Still Life de Bruijn Matrix	53
5.2.3	Sample Still Life Strips	57
5.3	(0, 1, 1) — Longitudinal Creepers	58
5.3.1	First Level de Bruijn Matrix	58
5.3.2	Powers of the Longitudinal de Bruijn Matrix	59
5.3.3	Sample Strips with Longitudinal Movement	61
5.4	(1, 0, 1) — Transversal Creepers	62
5.4.1	First Level de Bruijn Matrix	62
5.4.2	Powers of the Transversal de Bruijn Matrix	62
5.4.3	Sample Strips with Transversal Movement	65
5.5	(1, 1, 1) — Diagonal Creepers	66
5.5.1	First Level de Bruijn Matrix	66
5.5.2	Powers of the Diagonal de Bruijn Matrix	66
5.5.3	Sample Strips with Diagonal Movement	68
	Part II Classical Topics	
6	Growth and Decay in Life-Like Cellular Automata	71
	David Eppstein	
6.1	Introduction	71
6.2	Life-Like Rules	72
6.3	Natural Evolution or Intelligent Design?	73
6.4	Growth	76
6.5	Decay	79
6.6	The Life-Like Menagerie	83
6.7	Beyond Growth and Decay	93
	References	95
7	The B36/S125 “2x2” Life-Like Cellular Automaton	99
	Nathaniel Johnston	
7.1	Introduction	99
7.2	Ash and Common Patterns	100
7.3	Oscillators and Spaceships	102
7.4	As a Block Cellular Automaton	104
7.5	Block Oscillators	106

Appendix: Pattern Collection 111
References 114

8 Object Synthesis in Conway’s Game of Life and Other Cellular Automata 115

Mark D. Niemiec

8.1 Introduction 115
8.2 Simple Object Synthesis 116
8.3 Art Imitates Life 116
8.4 Life Imitates Art 117
8.4.1 Wishing for the Impossible 117
8.4.2 Altering the Laws of Physics 119
8.4.3 The Butterfly Effect 119
8.5 Incremental Synthesis 120
8.5.1 Better Living Through Chemistry 120
8.5.2 The Joy of Cooking 121
8.5.3 Fireworks 122
8.5.4 Open Heart Surgery 124
8.6 Synthesis of Moving Objects 126
8.6.1 Spaceships and Flotillas 126
8.6.2 Puffer Trains 127
8.6.3 Glider Guns 128
8.6.4 Breeders and Other Large Patterns 129
8.7 Other Rules 130
8.7.1 B34/S34 Life 130
8.7.2 B2/S2 Life 132
8.8 Remaining Issues 133
8.8.1 General Problems 133
8.8.2 Problems with Still-Lifes 133
8.8.3 Problems with Pseudo-objects 133
8.8.4 Problems with Oscillators 134
8.8.5 Problems with Spaceships and Puffer Trains 134
8.8.6 Problems with Glider Guns 134
References 134

9 Gliders and Glider Guns Discovery in Cellular Automata 135

Emmanuel Sapin

9.1 Formalisations of Cellular Automata 136
9.1.1 Set of Cellular Automata 136
9.1.2 Evolution of Cellular Automata 136
9.1.3 Isotropy 137
9.1.4 Number of Automata 137
9.1.5 Game of Life 140
9.1.6 Quiescent State 141
9.2 Definitions of Patterns 141
9.2.1 Definition 141

9.2.2	Periodic Pattern	141
9.2.3	Glider	142
9.2.4	Glider Gun	143
9.2.5	Symmetric Pattern	144
9.3	Automata and Patterns	145
9.3.1	Automata Accepting Patterns	145
9.3.2	Automata of \mathcal{E} Accepting Patterns	146
9.3.3	Automata of \mathcal{S} Accepting Patterns	146
9.4	Searching for Gliders	148
9.4.1	Rational	148
9.4.2	Algorithm	148
9.4.3	Gliders	149
9.5	Searching for Glider Guns	152
9.5.1	Algorithm	153
9.5.2	Results	156
9.6	Guns of a Specific Glider	157
9.6.1	Different Guns	159
9.6.2	Results	161
9.7	Synthesis and Perspectives	162
	References	163
10	Constraint Programming to Solve Maximal Density Still Life	167
	Geoffrey Chu, Karen Elizabeth Petrie, and Neil Yorke-Smith	
10.1	Introduction	167
10.2	Maximum Density Still Life	168
10.3	Constraint Programming	169
10.4	Constraint Programming Models for Still Life	170
10.5	Solving Still Life	171
10.5.1	Density as Board Size Increases	172
10.6	Conclusion	173
	References	174
Part III Asynchronous, Continuous and Memory-Enriched Automata		
11	Larger than Life’s Extremes: Rigorous Results for Simplified Rules and Speculation on the Phase Boundaries	179
	Kellie Michele Evans	
11.1	Introduction and History	179
11.2	Larger than Life: Definition and Notation	181
11.3	Initial States	182
11.4	LtL Definitions	185
11.4.1	Local Configurations	186
11.4.2	Ergodic Classifications for the Infinite System	187
11.5	LtL Rules with Simplifying Features	188
11.5.1	Symmetric LtL Rules	188
11.5.2	Monotone LtL Rules	196

- 11.5.3 Birth or Death Only LtL Rules 203
- 11.6 Snapshots from the Boundaries 205
 - 11.6.1 Bootstrapping 205
 - 11.6.2 Self-organized Batik 206
 - 11.6.3 Global Tilings and Waterbed Dynamics 207
 - 11.6.4 Slow Convergence 208
 - 11.6.5 Slow Growth 209
 - 11.6.6 Ladders 211
 - 11.6.7 Bugs with Trails 214
 - 11.6.8 Bug Logic, Bosco, and Open Questions 215
 - 11.6.9 LtL’s Bugs: Threshold-Range Scaling 217
- 11.7 Software 219
- 11.8 Conclusion and Long-Term Goals 220
 - References 220
- 12 RealLife 223**
 - Marcus Pivato
 - 12.1 What Happens in RealLife 224
 - 12.1.1 RealLife vs. Larger than Life 227
 - 12.1.2 Still Lives 228
 - 12.1.3 Robustness of Still Lives in the Hausdorff Metric 230
 - 12.2 The Anatomy of Bugs 230
 - 12.3 Open Questions 232
 - References 233
- 13 Variations on the Game of Life 235**
 - Ferdinand Peper, Susumu Adachi, and Jia Lee
 - 13.1 Asynchronously Timed Game of Life 236
 - 13.2 Game of Life with Continuous States 241
 - 13.3 Game of Life with an Enlarged Neighborhood 247
 - 13.4 Conclusions and Discussion 253
 - References 254
- 14 Does *Life* Resist Asynchrony? 257**
 - Nazim Fatès
 - 14.1 Introduction 257
 - 14.2 A Brief History of the Problem 258
 - 14.3 Asynchronous Life 259
 - 14.4 Assessing Life’s Robustness to Asynchrony 260
 - 14.4.1 First Experiment 260
 - 14.4.2 A Quantification of the Changes 261
 - 14.4.3 A Second-Order Phase Transition 262
 - 14.5 Initial Conditions and Asymptotic Behaviour 264
 - 14.5.1 Experimental Approach 264
 - 14.5.2 Mean-Field Analysis 265
 - 14.5.3 A Close-up on Small Initial Densities 266

- 14.5.4 When Germs Colonise the Grid 267
- 14.6 Extensions of the Asynchronous Game of Life 269
 - 14.6.1 How Important Is a Regular Topology? 269
 - 14.6.2 Are Life-Like Rules Affected by Asynchrony? 270
- 14.7 Discussion and Openings 271
 - References 273
- 15 LIFE with Short-Term Memory 275**
 - Ramón Alonso-Sanz
 - 15.1 Cellular Automata with Memory 275
 - 15.2 Life with Short-Term Majority Memory 277
 - 15.3 Life with Elementary Rules as Memory 281
 - 15.4 Life with Minimal Memory 286
 - 15.5 Conclusion 289
 - References 289
- 16 Localization Dynamics in a Binary Two-Dimensional Cellular Automaton: The Diffusion Rule 291**
 - Genaro J. Martínez, Andrew Adamatzky, and Harold V. McIntosh
 - 16.1 Introduction 291
 - 16.2 Basic Notations 293
 - 16.3 Mean Field Approximation 293
 - 16.4 The Diffusion Rule Universe 295
 - 16.4.1 Mobile Self-localizations 296
 - 16.4.2 Oscillators 298
 - 16.4.3 Avalanches 298
 - 16.4.4 Puffer Trains 299
 - 16.4.5 Mobile Glider Guns 300
 - 16.4.6 Glider Gun and Puffer Train 302
 - 16.4.7 Avalanche Gun 302
 - 16.5 Collisions Between Localized Patterns 303
 - 16.5.1 Forming Diffusing Patterns by Collisions 303
 - 16.5.2 Reactions Between Propagating Patterns 303
 - 16.5.3 Computation Capacities in the Diffusion Rule 307
 - 16.6 Discussion 310
 - References 314
- Part IV Non-orthogonal Lattices**
- 17 The Game of Life in Non-square Environments 319**
 - Carter Bays
 - 17.1 One Dimensional Rules 319
 - 17.2 The Game of Life in Two Dimensional Non-square Grids 322
 - 17.3 Three Dimensional Game of Life Rules 326
 - 17.4 Conclusion 327
 - References 329

18 The Game of Life Rules on Penrose Tilings: Still Life and Oscillators 331

Nick Owens and Susan Stepney

- 18.1 Penrose Tiling 331
 - 18.1.1 Kites and Darts, and Rhombs 331
 - 18.1.2 Matching Rules 331
 - 18.1.3 Valid Vertex Configurations 332
- 18.2 The Game of Life on a Penrose Tiling 334
 - 18.2.1 Regular Game of Life Rules 334
 - 18.2.2 Generalising the Neighbourhood and the Rules 334
 - 18.2.3 Identifying Oscillators 338
- 18.3 Still Life 340
 - 18.3.1 Blocks and Tubs 340
 - 18.3.2 Five and More Cell Still Lives 343
 - 18.3.3 Large Rings 345
 - 18.3.4 Large Snakes 348
- 18.4 Period 2 Oscillators 349
 - 18.4.1 Blinkers and Plinkers 349
 - 18.4.2 Other p2 Oscillators 351
- 18.5 Period 3 Oscillators 351
- 18.6 Period 4 Oscillators 354
- 18.7 Higher Period Oscillators 356
 - 18.7.1 Kite and Dart High Period Oscillators 356
 - 18.7.2 Rhomb High Period Oscillators 358
- 18.8 Oscillator Analysis 363
 - 18.8.1 Oscillator Detection 364
 - 18.8.2 Oscillator Classification 370
- 18.9 Summary and Conclusions 377
 - References 378

19 A Spherical XOR Gate Implemented in the Game of Life 379

Jeffrey Ventrella

- 19.1 Introduction 379
 - 19.1.1 Grid Distortion 380
- 19.2 Spheres and Computation 381
 - 19.2.1 A Spherical XOR Gate 383
 - 19.2.2 Exploiting Grid Discontinuity 384
- 19.3 Conclusion 384
 - References 385

Part V Complexity

20 Emergent Complexity in Conway’s Game of Life 389

Nick Gotts

- 20.1 Introduction 389
- 20.2 Preliminaries 391
- 20.3 The Finite Case: Diverging Puffer Pairs 394

- 20.3.1 Pairs of Patterns 394
- 20.3.2 Diverging Puffer Pairs, Expanding Feedback Loops,
and Ramifying Feedback Networks 395
- 20.3.3 Emergence of Additional Puffers 402
- 20.3.4 Interacting Secondary Puffers: Emergence
of a Quasi-population 404
- 20.4 The Infinite Case: Sparse Life 410
 - 20.4.1 Random Configurations 410
 - 20.4.2 Arbitrarily Sparse Random Configurations 411
 - 20.4.3 Large Sparse Random GoL Arrays: The Short Term . . . 412
 - 20.4.4 Large Sparse Random GoL Arrays: The Medium Term . 414
- 20.5 Discussion 429
- References 435

21 Macroscopic Spatial Complexity of the Game of Life Cellular Automaton: A Simple Data Analysis 437

A.R. Hernández-Montoya, H.F. Coronel-Brizio,
and M.E. Rodríguez-Achach

- 21.1 Introduction 437
 - 21.1.1 Game of Life Cellular Automaton 438
 - 21.1.2 Complex Systems Science 439
 - 21.1.3 Power Law Distribution and GoL’s Complexity
and Criticality 439
- 21.2 Generating the Sample Data 440
- 21.3 Data Analyses 443
 - 21.3.1 Power Law of $S(t)$ Distribution 445
 - 21.3.2 Autocorrelation Function 445
 - 21.3.3 Detrended Fluctuation Analysis 446
- 21.4 Summary 447
- References 449

Part VI Physics

22 The Enlightened Game of Life 453

Claudio Conti

- 22.1 The Model 453
 - 22.1.1 Electromagnetic Field Equations 454
 - 22.1.2 Parameters 455
- 22.2 Field and CA Evolution 456
- 22.3 Stationary Properties of the CA 457
- 22.4 Dynamics 459
- 22.5 Self-healing After a Catastrophic Event 460
- 22.6 Topology and Self-organization 460
- 22.7 Introducing a Genetic Code and Inheritance 462
- 22.8 Energy Dissipating CA 463
- 22.9 Conclusion 463
- References 464

23 Towards a Quantum Game of Life 465
 Adrian P. Flitney and Derek Abbott

23.1 Introductory Concepts of Quantum Mechanics 465

23.2 Background and Motivation for Quantum *Life* 468

 23.2.1 Classical Cellular Automata 468

 23.2.2 Conway’s Game of *Life* 470

 23.2.3 Quantum Cellular Automata 470

23.3 Semi-quantum *Life* 471

 23.3.1 The Idea 471

 23.3.2 A First Model 472

 23.3.3 A Semi-quantum Model 474

 23.3.4 Discussion 475

23.4 Conclusion 478

 Appendix 478

 References 485

Part VII Music

24 Game of Life Music 489
 Eduardo R. Miranda and Alexis Kirke

24.1 A Brief Introduction to GoL 490

24.2 Rending Musical Forms from GoL 490

24.3 CAMUS: Cartesian Representation of Note Sets 491

 24.3.1 Temporal Morphology 493

24.4 CAMUS 3D: Cartesian Representation for Three Dimensional
 GoL 496

24.5 Radial Representation for Two Dimensional GoL 496

24.6 Concluding Remarks 499

 References 501

Part VIII Computation

25 Universal Computation and Construction in GoL Cellular Automata 505
 Adam P. Goucher

25.1 History 505

 25.1.1 Birth of Self-replication 505

 25.1.2 Early Attempts at GoL Self-replication 506

 25.1.3 Stable Reflectors 508

 25.1.4 Chapman’s Universal Computer 510

25.2 Components 510

 25.2.1 The Construction Arm 511

 25.2.2 The Memory Tape 512

 25.2.3 Registers 512

 25.2.4 Switches, Latches and Gates 513

25.3 An Overview of the Design 514

 25.3.1 The Layout 514

- 25.3.2 The Control Section 515
- 25.3.3 The Operation Cycle 515
- 25.3.4 The Instruction Set 515
- 25.3.5 Proposed Method of Replication 516
- 25.4 Conclusion 516
- References 517
- 26 A Simple Universal Turing Machine for the Game of Life Turing Machine 519**
 - Paul Rendell
 - 26.1 Introduction 519
 - 26.2 Turing Machines 520
 - 26.2.1 Turing Machine Operation 520
 - 26.2.2 Example Turing Machine 522
 - 26.2.3 Universal Turing Machines 526
 - 26.3 Four State Six Symbol Universal Turing Machine 527
 - 26.3.1 Universal 2-Tag System 527
 - 26.3.2 Rogozhin’s 2-Tag UTM 531
 - 26.4 A Universal Turing Machine for the GoL Turing Machine 534
 - 26.4.1 Eight Symbol Sixteen State Universal Turing Machine . 534
 - 26.4.2 Eight Symbol Thirteen State Universal Turing Machine . 538
 - 26.5 Conclusion 543
 - References 544
- 27 Computation with Competing Patterns in Life-Like Automaton . . . 547**
 - Genaro J. Martínez, Andrew Adamatzky, Kenichi Morita,
and Maurice Margenstern
 - 27.1 Introduction 547
 - 27.2 Life Rule $B2/S2345$ 549
 - 27.2.1 Indestructible Pattern in $B2/S2345$ 551
 - 27.3 Computing with Propagating Patterns 552
 - 27.3.1 Implementation of Logic Gates and Beyond 553
 - 27.3.2 Majority Gate 555
 - 27.3.3 Implementation of Binary Adders 556
 - 27.4 Conclusions 559
 - References 571
- Index 573**



<http://www.springer.com/978-1-84996-216-2>

Game of Life Cellular Automata

Adamatzky, A. (Ed.)

2010, XIX, 579 p., Hardcover

ISBN: 978-1-84996-216-2