

# Contents

<b>Acknowledgements</b>	xi
<b>Introduction</b>	1
<b>I Overview</b>	<b>3</b>
<b>1 Cellular automata</b>	<b>5</b>
1.1 Basic concepts . . . . .	5
1.2 Animate-by-numbers . . . . .	6
1.3 Cellular automata machines . . . . .	7
1.4 Historical notes and references . . . . .	8
<b>2 The CAM environment</b>	<b>13</b>
2.1 The CAM-6 machine . . . . .	14
2.2 Basic hardware resources . . . . .	14
2.2.1 Storage: the bit-planes . . . . .	14
2.2.2 Display: the color map . . . . .	15
2.2.3 Dynamics: the rule tables . . . . .	15
2.2.4 Geometry in the small: the neighborhood . . . . .	16
2.2.5 Geometry in the large: wrap-around . . . . .	16
2.3 Software: CAM Forth . . . . .	16
<b>3 A live demo</b>	<b>19</b>
3.1 The game of "life" . . . . .	20
3.2 Echoing . . . . .	22
3.3 Tracing . . . . .	23
3.4 How to breed gliders . . . . .	24
<b>4 The rules of the game</b>	<b>27</b>
4.1 The choices of creation . . . . .	27
4.2 Rules in words . . . . .	30

<b>II</b>	<b>Resources</b>	<b>35</b>
<b>5</b>	<b>Our first rules</b>	<b>37</b>
5.1	Unconstrained growth . . . . .	37
5.2	Constrained growth . . . . .	39
5.3	Competitive growth . . . . .	40
5.4	Voting rules . . . . .	41
5.5	Bank's computer . . . . .	42
5.6	"Random" rules . . . . .	45
<b>6</b>	<b>Second-order dynamics</b>	<b>47</b>
6.1	Firing of neurons: a three-state rule . . . . .	47
6.2	Going into reverse gear . . . . .	50
6.3	An impenetrable shield . . . . .	52
6.4	Other examples . . . . .	53
<b>7</b>	<b>Neighbors and neighborhoods</b>	<b>55</b>
7.1	A weakly coupled pair . . . . .	56
7.2	The magic number twelve . . . . .	57
7.3	Neighborhood declarations . . . . .	59
7.3.1	Major assignments . . . . .	60
7.3.2	Minor assignments . . . . .	61
7.4	Summary of neighborhoods . . . . .	63
7.5	Custom neighborhoods . . . . .	63
7.6	Making tables . . . . .	64
7.7	The color map and the event counter . . . . .	65
<b>8</b>	<b>Randomness and probabilistic rules</b>	<b>67</b>
8.1	Exponential decay . . . . .	68
8.2	A simple noise generator . . . . .	69
8.3	Voting rules, revisited . . . . .	70
8.4	Remarks on noise . . . . .	72
8.5	Caveat emptor! . . . . .	73
8.6	A noise-box . . . . .	74
<b>9</b>	<b>A sampler of techniques</b>	<b>77</b>
9.1	Particle conservation . . . . .	77
9.2	Differential effects . . . . .	80
9.3	Coupling the two halves . . . . .	82
9.4	Genetic drift . . . . .	84
9.5	Poisson updating . . . . .	86
9.6	Asynchronous deterministic computation . . . . .	90
9.7	One-dimensional cellular automata . . . . .	94
9.8	Neighborhood expansion tricks . . . . .	98

<b>10 Identity and motion</b>	<b>101</b>
10.1 A random walk . . . . .	102
10.2 A random shuffle . . . . .	103
<b>11 Pseudo-neighbors</b>	<b>109</b>
11.1 Spatial phases . . . . .	110
11.2 Temporal phases, and phase control . . . . .	111
11.3 A two-phase rule . . . . .	112
11.4 Incremental phase control . . . . .	114
11.5 The run cycle . . . . .	115
11.6 Alternating spatial textures . . . . .	117
<b>12 The Margolus neighborhood</b>	<b>119</b>
12.1 Block rules . . . . .	119
12.2 Particles in motion . . . . .	120
12.3 Collisions . . . . .	122
12.4 How to turn a block rule into a cell rule . . . . .	124
12.5 The Margolus neighbors . . . . .	126
12.6 Even/odd grid selection . . . . .	128
12.7 A phase-sensitive gas . . . . .	129
12.8 Examples . . . . .	132
12.8.1 Fractals . . . . .	132
12.8.2 Critters . . . . .	132
12.8.3 Asynchronous computation . . . . .	134
12.8.4 Digital logic . . . . .	136
<b>III Physical modeling</b>	<b>139</b>
<b>13 Symptoms vs causes</b>	<b>141</b>
13.1 Fine-grained models of physics . . . . .	141
<b>14 Reversibility</b>	<b>145</b>
14.1 Invertible cellular automata . . . . .	146
14.2 Second-order technique . . . . .	147
14.3 Alternating sublattices . . . . .	149
14.4 Guarded-context technique . . . . .	149
14.5 Partitioning technique . . . . .	150
14.6 Reversibility and randomness . . . . .	153
<b>15 Diffusion and equilibrium</b>	<b>155</b>
15.1 Noise-driven diffusion . . . . .	155
15.2 Expansion and thermalization . . . . .	159
15.3 Self-diffusion . . . . .	161

BIBLIOTECA

15.4	Mean free path . . . . .	162
15.5	A tour de force . . . . .	163
15.6	A tuneable noise source . . . . .	165
15.7	Diffusion-limited aggregation . . . . .	167
<b>16</b>	<b>Fluid dynamics</b>	<b>171</b>
16.1	Sound waves . . . . .	171
16.2	Hydrodynamics . . . . .	173
16.3	Tracing the flow . . . . .	174
16.4	Flow past an obstacle . . . . .	176
16.5	Other lattice gases . . . . .	177
16.6	Autocorrelations . . . . .	179
16.7	Wave optics . . . . .	182
<b>17</b>	<b>Collective phenomena</b>	<b>185</b>
17.1	Critical parameters and phase transitions . . . . .	186
17.2	Ising systems . . . . .	186
17.3	Spins only . . . . .	190
17.4	Energy banks . . . . .	193
17.5	Heat bath . . . . .	197
17.6	Displaying the energy . . . . .	200
17.7	Bonds only . . . . .	203
17.8	Spin glasses . . . . .	205
<b>18</b>	<b>Ballistic computation</b>	<b>209</b>
18.1	The billiard-ball model of computation . . . . .	210
18.2	A reversible cellular-automaton computer . . . . .	213
18.3	Some billiard-ball experiments . . . . .	217
18.3.1	A magic gas . . . . .	217
18.3.2	The end of the world . . . . .	219
	<b>Conclusions</b>	<b>221</b>
<b>A</b>	<b>A minimal Forth tutorial</b>	<b>223</b>
A.1	The command interpreter . . . . .	223
A.2	The compiler . . . . .	224
A.3	The dictionary . . . . .	225
A.4	Numbers . . . . .	226
A.5	The stack . . . . .	227
A.6	Expressions . . . . .	228
A.7	Editing and loading . . . . .	229
A.8	“Constants” and “variables” . . . . .	231
A.9	Iteration . . . . .	233
A.10	Stack comments . . . . .	234

A.11 DUP, DROP, etc. . . . .	236
A.12 Case selection . . . . .	236
A.13 Conditional statements . . . . .	237
A.14 Logical expressions . . . . .	238
A.15 Further readings . . . . .	240
<b>B Basic CAM architecture</b>	<b>243</b>
B.1 The plane-module . . . . .	243
B.2 Larger arrays: edge gluing . . . . .	244
B.3 More states per cell: sheet ganging . . . . .	245
B.4 More dimensions: layer stacking . . . . .	245
B.5 Display and analysis . . . . .	245
B.6 Modularity and expandability . . . . .	246
<b>Bibliography</b>	<b>249</b>
<b>Index</b>	<b>255</b>