

# Contents

<b>1 Complexity and Emergence</b> . . . . .	<b>1</b>
1.1 The Issue Considered. . . . .	3
1.2 A Basic Viewpoint . . . . .	4
1.2.1 The Main Claim . . . . .	5
1.2.2 Hierarchies . . . . .	6
1.2.3 Emergence . . . . .	7
1.3 Key Points of the Argument . . . . .	8
1.3.1 Multiple Types of Causation. . . . .	9
1.3.2 Hierarchy and Causation . . . . .	10
1.3.3 Types of Top-Down Causation . . . . .	11
1.3.4 The Nature of Variables. . . . .	12
1.3.5 The Causal Efficacy of Non-physical Entities . . . . .	13
1.3.6 Room at the Bottom . . . . .	14
1.3.7 Supervenience. . . . .	15
1.4 Is It Real? Testing the Proposal. . . . .	16
1.4.1 Causal Effects. . . . .	16
1.4.2 Experimental Tests . . . . .	17
1.4.3 Kinds of Data. . . . .	19
1.4.4 There Is No Other Option . . . . .	20
1.5 Significant Implications . . . . .	20
1.5.1 Health Care . . . . .	20
1.5.2 Mental Health. . . . .	21
1.5.3 Education: Learning to Read . . . . .	21
1.6 An Outline of the Book . . . . .	22
1.6.1 The Contents . . . . .	22
1.6.2 What Is New . . . . .	24
1.6.3 What Is Controversial . . . . .	24
1.7 The Necessity of the Conclusion . . . . .	27
1.7.1 The Conclusion. . . . .	28
1.7.2 The Necessity of the Conclusion . . . . .	28
References . . . . .	30



<b>2</b>	<b>Digital Computer Systems</b> . . . . .	<b>35</b>
2.1	Computational Basics. . . . .	35
2.2	Modular Hierarchical Structures . . . . .	38
2.2.1	Structures: Combination and Abstraction . . . . .	39
2.2.2	Decomposition and Modularity . . . . .	40
2.2.3	Encapsulation and Information-Hiding . . . . .	41
2.2.4	Naming, Combination, and Recursion . . . . .	42
2.2.5	Hierarchy: Class Structure and Object Structure . . . . .	43
2.2.6	Evolution . . . . .	45
2.3	Orthogonal Modular Hierarchical Structures . . . . .	45
2.3.1	The Two Kinds of Hierarchies . . . . .	46
2.3.2	The Implementation (Vertical) Hierarchies . . . . .	46
2.3.3	The Logical (Horizontal) Hierarchies . . . . .	49
2.3.4	The Relation Between the Two Hierarchies . . . . .	50
2.3.5	Causality in the Hierarchies . . . . .	52
2.4	Bottom-Up and Top-Down Causation . . . . .	52
2.4.1	The Combination of Bottom-Up and Top-Down Action . . . . .	53
2.4.2	TD1: Deterministic Top-Down Processes . . . . .	54
2.4.3	TD2: Non-adaptive Feedback Control Systems . . . . .	56
2.4.4	TD3: Adaptive Selection . . . . .	57
2.4.5	TD4: Feedback Control with Adaptive Goals . . . . .	59
2.4.6	TD5: Adaptive Selection of Adaptive Goals . . . . .	59
2.4.7	Goals and Learning in Relation to These Kinds of Causation . . . . .	60
2.5	The Core Feature: Equivalence Classes . . . . .	63
2.5.1	Multiple Realization . . . . .	63
2.5.2	The Link with Top-Down Causation . . . . .	64
2.5.3	The Ontological Nature of Computer Programs. . . . .	65
2.6	Resources: Memory and Deleting . . . . .	65
2.6.1	The Unphysical Nature of Infinity . . . . .	66
2.6.2	Deletion and Garbage Collection. . . . .	67
2.6.3	The Memory Hierarchy . . . . .	68
2.6.4	Modular Hierarchical Structure and Scoping of Variables . . . . .	68
2.6.5	Deletion, Adaptive Selection, and Irreversibility . . . . .	69
2.7	The Outcome: Causation in Digital Computers . . . . .	70
2.7.1	Computer Programs Are Non-physical, but Causally Effective . . . . .	70
2.7.2	Computer Programs Embody Abstract Logic, and Act Top-Down . . . . .	72
2.7.3	Room at the Bottom . . . . .	74
2.7.4	Predictable Outcome? . . . . .	76
2.7.5	Possibility Spaces and Their Causal Effects . . . . .	77



2.7.6	Top-Down Action from the Mind . . . . .	81
2.7.7	Genuine Emergence. . . . .	81
	References . . . . .	82
<b>3</b>	<b>The Basis of Complexity . . . . .</b>	<b>85</b>
3.1	The Nature of Emergence. . . . .	85
3.1.1	Emergence of Complexity Is Based on Structure. . . . .	86
3.1.2	Emergence Is Different in Different Contexts . . . . .	87
3.1.3	Emergence Results in a Structural/Functional Hierarchy . . . . .	88
3.1.4	Emergence Enables Logical Hierarchies, Information Flows. . . . .	91
3.1.5	Emergence Has Different Timescales . . . . .	93
3.1.6	Emergence Is Based on Modularity . . . . .	93
3.1.7	Emergence Is Based on Interlevel Relations . . . . .	95
3.2	Bottom-Up Effects. . . . .	96
3.2.1	Coarse-Graining . . . . .	96
3.2.2	Physics . . . . .	97
3.2.3	Biology . . . . .	97
3.2.4	Mathematics of Emergence. . . . .	98
3.2.5	Strong Reductionism . . . . .	99
3.3	Emergence and Higher-Level Variables . . . . .	100
3.3.1	Emergence of Higher Level Structure and Behavior. . . . .	100
3.3.2	Coherent Higher Level Dynamics . . . . .	102
3.3.3	Emergent Higher Level Variables . . . . .	105
3.3.4	Intrinsically Higher Level Variables. . . . .	108
3.4	Top-Down Effects . . . . .	109
3.4.1	Limits to Bottom-Up Emergence. . . . .	109
3.4.2	Top-Down Causation via Constraints. . . . .	110
3.4.3	Top-Down Action via Control Parameters . . . . .	112
3.4.4	Top-Down Effects in Logical Hierarchies. . . . .	114
3.4.5	Top-Down Effects in the Mind . . . . .	115
3.4.6	Top-Down Effects and Supervenience . . . . .	116
3.4.7	Top-Down Effects and Emergence. . . . .	117
3.5	The Key Concept: Equivalence Classes . . . . .	119
3.5.1	Equivalence Classes . . . . .	119
3.5.2	Equivalence Classes and Top-Down Causation . . . . .	120
3.5.3	Multiple Realisability and Supervenience . . . . .	122
3.6	Demonstrating Top-Down Causation . . . . .	122
3.6.1	Altering Context . . . . .	123
3.6.2	Identifying Equivalence Classes . . . . .	123
3.6.3	Identifying Dynamics. . . . .	124
3.6.4	Computer Modelling . . . . .	124
3.7	Constraints on Emergence . . . . .	125
3.7.1	Matter, Energy, and Entropy. . . . .	125



3.7.2	Constraints on Higher Level Possibilities . . . . .	126
3.7.3	Constraints on Higher Level Logic . . . . .	126
	References . . . . .	127
<b>4</b>	<b>Kinds of Top-Down Causation . . . . .</b>	<b>133</b>
4.1	Deterministic Top-Down Causation TD1 . . . . .	134
4.1.1	The Nature of the Process . . . . .	134
4.1.2	Machines . . . . .	137
4.1.3	Physical Systems. . . . .	138
4.1.4	Living Systems. . . . .	140
4.1.5	Logical Systems . . . . .	142
4.1.6	Mathematical Models: Boundary Conditions and Constraints. . . . .	144
4.1.7	Randomness and Noise . . . . .	149
4.2	Non-Adaptive Feedback Control (TD2) . . . . .	151
4.2.1	The Nature of the Process . . . . .	152
4.2.2	Engineering Systems . . . . .	157
4.2.3	Organisations . . . . .	158
4.2.4	Biology . . . . .	160
4.2.5	Mathematical Models: Control Theory. . . . .	162
4.2.6	The Nature of Goals . . . . .	163
4.3	Adaptive Selection of Outcomes (TD3) . . . . .	163
4.3.1	The Nature of the Process . . . . .	164
4.3.2	Physics and Chemistry. . . . .	169
4.3.3	Life. . . . .	169
4.3.4	The Mind: Learning and Perception. . . . .	172
4.3.5	Mathematical Models: Adaptive Selection . . . . .	174
4.3.6	Multilevel Selection. . . . .	176
4.3.7	The Nature of Selection Criteria . . . . .	182
4.4	Adaptive Selection of Goals (TD4) . . . . .	183
4.4.1	The Nature of the Process . . . . .	184
4.4.2	Evolution . . . . .	185
4.4.3	Microbiology . . . . .	185
4.4.4	Behaviour . . . . .	185
4.4.5	Engineering Systems . . . . .	186
4.4.6	Mathematical Models. . . . .	186
4.4.7	The Nature of Causality. . . . .	187
4.5	Adaptive Selection of Selection Criteria (TD5) . . . . .	187
4.5.1	The Nature of the Process . . . . .	188
4.5.2	Evolutionary Biology and Animal Behavior . . . . .	188
4.5.3	The Mind. . . . .	189
4.5.4	Mathematical Models. . . . .	189
4.5.5	Meta-Causation: Closing the Hierarchy . . . . .	190
4.5.6	The Hierarchy of Goals: Ethics and Meaning . . . . .	191
4.5.7	Occurrence of Meta-Reflection . . . . .	193



4.6	Complex Adaptive Systems . . . . .	193
4.6.1	The Process . . . . .	194
4.6.2	Evolutionary and Developmental Outcomes . . . . .	194
4.6.3	Adaptive Processes and Learning . . . . .	195
4.7	Intelligent Top-Down Causation . . . . .	195
4.7.1	The Nature of the Process . . . . .	196
4.7.2	Language . . . . .	197
4.7.3	Other Symbolic Systems . . . . .	201
4.7.4	The Power of Symbolic Thinking . . . . .	203
4.7.5	The Effectiveness of Abstract Variables . . . . .	204
4.7.6	The Mind, Intention, and Goals . . . . .	205
	References . . . . .	210
<b>5</b>	<b>Room at the Bottom?</b> . . . . .	<b>217</b>
5.1	Room at the Bottom: Over-Determination? . . . . .	217
5.2	Contextual Constraints . . . . .	219
5.2.1	Boundary Conditions . . . . .	219
5.2.2	Passing Higher Level Variables or Parameters . . . . .	221
5.3	Structure and Constraints . . . . .	222
5.3.1	Physical Systems. . . . .	222
5.3.2	Artefacts . . . . .	223
5.3.3	Biology . . . . .	223
5.3.4	The Brain. . . . .	224
5.3.5	Organisations . . . . .	224
5.4	Changing the Nature of Constituent Entities . . . . .	224
5.4.1	Physics and Chemistry. . . . .	225
5.4.2	Biology . . . . .	226
5.4.3	The Brain. . . . .	226
5.4.4	Society . . . . .	227
5.4.5	Logic. . . . .	227
5.5	Leading to Existence of the Elements. . . . .	228
5.5.1	Physics . . . . .	228
5.5.2	Biology . . . . .	229
5.5.3	Society . . . . .	230
5.5.4	Logical Hierarchies . . . . .	230
5.6	Deleting Lower Level Elements. . . . .	231
5.6.1	Biology . . . . .	231
5.6.2	Computers . . . . .	233
5.6.3	The Mind. . . . .	234
5.6.4	Society . . . . .	235
5.6.5	Physics and Chemistry. . . . .	235
5.6.6	Micro Indeterminism and Adaptive Selection . . . . .	236
5.7	Queries . . . . .	237
5.7.1	Criticism and Response . . . . .	238
	References . . . . .	240



<b>6 The Foundations: Physics and Top-Down Causation</b> . . . . .	243
6.1 The Bottom Level: Quantum Dynamics . . . . .	244
6.1.1 The Basic Dynamics . . . . .	244
6.1.2 Alternative Possibilities . . . . .	247
6.1.3 The Outcome . . . . .	248
6.1.4 Particle-Wave Duality . . . . .	248
6.2 The Emergence of Higher Level Behavior . . . . .	249
6.2.1 Examples of Emergence . . . . .	250
6.2.2 Statistical Mechanics . . . . .	253
6.2.3 Condensed Matter Physics . . . . .	255
6.2.4 Chemistry and Biology . . . . .	257
6.2.5 Bottom-Up Effects: Cosmology . . . . .	258
6.3 Top-Down Causation . . . . .	259
6.3.1 Equivalence Classes . . . . .	260
6.3.2 Changing or Creating the Basic Elements . . . . .	260
6.3.3 Types of Top-Down Causation in Physics . . . . .	260
6.4 Deterministic Top-Down Effects in Physics (TD1) . . . . .	261
6.4.1 Contextual Variables . . . . .	261
6.4.2 Effect of Boundary Conditions . . . . .	262
6.4.3 Structural Conditions and Effective Potentials . . . . .	263
6.4.4 Binding Energies and Altered Properties . . . . .	264
6.4.5 Computational Mechanics . . . . .	265
6.5 Adaptive Selection in Physics and Chemistry (TD3) . . . . .	265
6.5.1 Adaptive Selection . . . . .	265
6.5.2 Maxwell's Demon . . . . .	266
6.5.3 Separation and Purification Processes . . . . .	267
6.6 Top-Down Effects: Micro Physics . . . . .	267
6.6.1 Open Systems and Their Environment . . . . .	267
6.6.2 Decoherence . . . . .	269
6.6.3 Lattice Waves and Quasiparticles . . . . .	269
6.6.4 Topological Effects . . . . .	271
6.6.5 State Preparation . . . . .	271
6.6.6 Measurement . . . . .	273
6.7 Top-Down Effects: Cosmology . . . . .	274
6.7.1 Element Formation . . . . .	275
6.7.2 Structure Formation . . . . .	276
6.7.3 Olbers' Paradox . . . . .	278
6.7.4 Mach's Principle . . . . .	280
6.7.5 The Arrow of Time . . . . .	280
6.7.6 Existence of Isolated Systems . . . . .	284
References . . . . .	286



<b>7</b>	<b>The Mind and the Brain</b>	291
7.1	Introduction	292
7.1.1	Dynamical Systems Versus Plasticity and Learning	293
7.1.2	Modular Hierarchical Structure, Neural Nets	294
7.1.3	Rationality, Intuition, and Emotion in a Social Context	295
7.1.4	Bottom-Up and Top-Down Effects Both Occur	295
7.1.5	The Effectiveness of Thoughts: Symbolism and Language	296
7.1.6	The Key Role of Purpose and Meaning	296
7.1.7	The Relationship with Platonic Spaces	297
7.1.8	Mental Powers and Free Will	297
7.2	Basics of the Brain	297
7.2.1	Brain Anatomy	298
7.2.2	Basic Brain Function	302
7.2.3	Large Scale Function	310
7.2.4	Environmental and Genetic Influences: Brain Plasticity	314
7.2.5	The Origin of Humanity: The Social Mind and Language	320
7.3	Top-Down Processes	324
7.3.1	The Different Kinds	325
7.3.2	Memory, Learning, and Deleting	326
7.3.3	Vision	328
7.3.4	Language and Reading	331
7.3.5	Goal-Directed Behaviour and Attention	334
7.3.6	Health	336
7.3.7	Social Neuroscience	340
7.3.8	The Physical Substrate	344
7.4	Purpose and Meaning as the Key Driving Forces	347
7.4.1	Goals and Purpose	347
7.4.2	The Human Search for Meaning	348
7.4.3	Purpose, Ethics, and Understanding	349
7.4.4	The Meaningful Social Context	351
7.5	Symbolism and Effectiveness of Thought	351
7.5.1	Logical Functions	352
7.5.2	Naming, Symbolism and Language	354
7.5.3	Effectiveness of Thought	358
7.5.4	Thoughts and Neural Networks	360
7.5.5	Causal Power of Social Constructions	361
7.5.6	The Power of Emergent Levels	364
7.6	The Effects of Platonic Entities	365
7.6.1	Mathematical Relations	365
7.6.2	Computational Algorithms	367
7.6.3	Accessing Platonic Realms	368



7.7	The Complex Whole . . . . .	369
7.7.1	A Synthesis . . . . .	370
7.7.2	Genuine Emergence. . . . .	372
7.7.3	Crick's Fallacy . . . . .	375
7.7.4	Top-Down Action and the Free Will Debate. . . . .	375
7.7.5	Neuroscience and Humanity . . . . .	382
	References . . . . .	385
<b>8</b>	<b>The Broader View . . . . .</b>	<b>395</b>
8.1	The Necessity of True Emergence . . . . .	395
8.1.1	Cosmological Unpredictability . . . . .	396
8.1.2	Evolutionary History . . . . .	399
8.1.3	Conclusion: Genuine Emergence Must Occur . . . . .	399
8.1.4	The Alternative: The Demiurge. . . . .	400
8.2	The Sources of Emergence . . . . .	401
8.2.1	Self-Assembly: Emergence in the Natural World. . . . .	402
8.2.2	Natural Selection: Emergence in the Biological World . . . . .	402
8.2.3	Design and Construction: Emergence in the Man-Made World. . . . .	406
8.2.4	How Far Can Bottom-Up Emergence Succeed?. . . . .	407
8.2.5	Not by Physics Alone: The Missing Elements. . . . .	409
8.2.6	The Interconnected Causes: Chance, Necessity, and Purpose . . . . .	410
8.3	Types of Causation . . . . .	417
8.3.1	Levels of Causation and Aristotle . . . . .	417
8.3.2	Multiple Causes and Contextual Factors. . . . .	419
8.3.3	Causal Effects of Platonic (Non-Emergent) Entities . . . . .	421
8.4	Aristotle and Types of Knowledge. . . . .	422
8.5	A More Holistic View . . . . .	423
8.5.1	Recognising Emergence and Top-Down Causation . . . . .	423
8.5.2	Other Causal Influences Than Physics . . . . .	426
8.5.3	The Main Thesis. . . . .	427
8.5.4	The Counter View: Scientific Reductionism . . . . .	427
8.6	Implications: Learning to Read and Write. . . . .	430
8.6.1	The Broad Context: Underlying Views of Literacy . . . . .	430
8.6.2	The Brain, Prediction, and Reading . . . . .	436
8.6.3	Reading as Transacting with Texts . . . . .	438
8.6.4	Part to Whole: Skills-Based Approaches to Literacy . . . . .	440
8.6.5	The Contextual Approach to Learning . . . . .	444
8.6.6	Holistic Approaches to Literacy . . . . .	444
8.6.7	Educational Implications . . . . .	447



8.7 Conclusion . . . . . 449

    8.7.1 The Theses of this Book . . . . . 450

    8.7.2 To Be Done . . . . . 450

    8.7.3 Where Is Truth? . . . . . 453

References . . . . . 456

**Author Index** . . . . . 465

**Index** . . . . . 467

**Titles in This Series.** . . . . . 479

Page 5.1 Bottom-up and top-down causation . . . . . 95

Page 5.2 Relevance of higher level studies . . . . . 103

Page 5.3 Cyclic dynamics . . . . . 101

Page 5.4 Concrete higher level dynamics . . . . . 104

Page 5.5 Low level dynamics emergent from top-down and bottom-up actions . . . . . 104

Page 5.6 Supervenience relations . . . . . 116

Page 5.7 Feedback control . . . . . 154

Page 5.8 Top-down experiment . . . . . 276

Page 5.9 Psychological observations . . . . . 277

Page 7.1 The cortex-brain domains . . . . . 299

Page 7.2 Basis of neurons . . . . . 299

Page 7.3 Neuron networks . . . . . 300

Page 7.4 Cortical layers of neurons . . . . . 361

Page 7.5 A single neuron . . . . . 365

Page 7.6 The many aspects of brain function . . . . . 311

Page 7.7 Nucleus structures in the brain . . . . . 316

Page 7.8 The brain genetically determined affective systems . . . . . 318

Page 7.9 The brain selection process . . . . . 327

Page 7.10 Triangle illusion . . . . . 328

Page 7.11 Size comparison illusion . . . . . 329

Page 7.12 Top-down affects from organs to genes apply to the brain . . . . . 345

Page 7.13 Airbus flying . . . . . 350

Page 7.14 Airbus pilot . . . . . 350

Page 7.15 Maximalrotor . . . . . 360

Page 7.16 Factors affecting the function of the brain . . . . . 370

Page 7.17 Portrait . . . . . 384

Page 8.1 The unpredictability of the universe . . . . . 397

Page 8.2 Sky image of the LMS measured by the Planck Satellite . . . . . 397