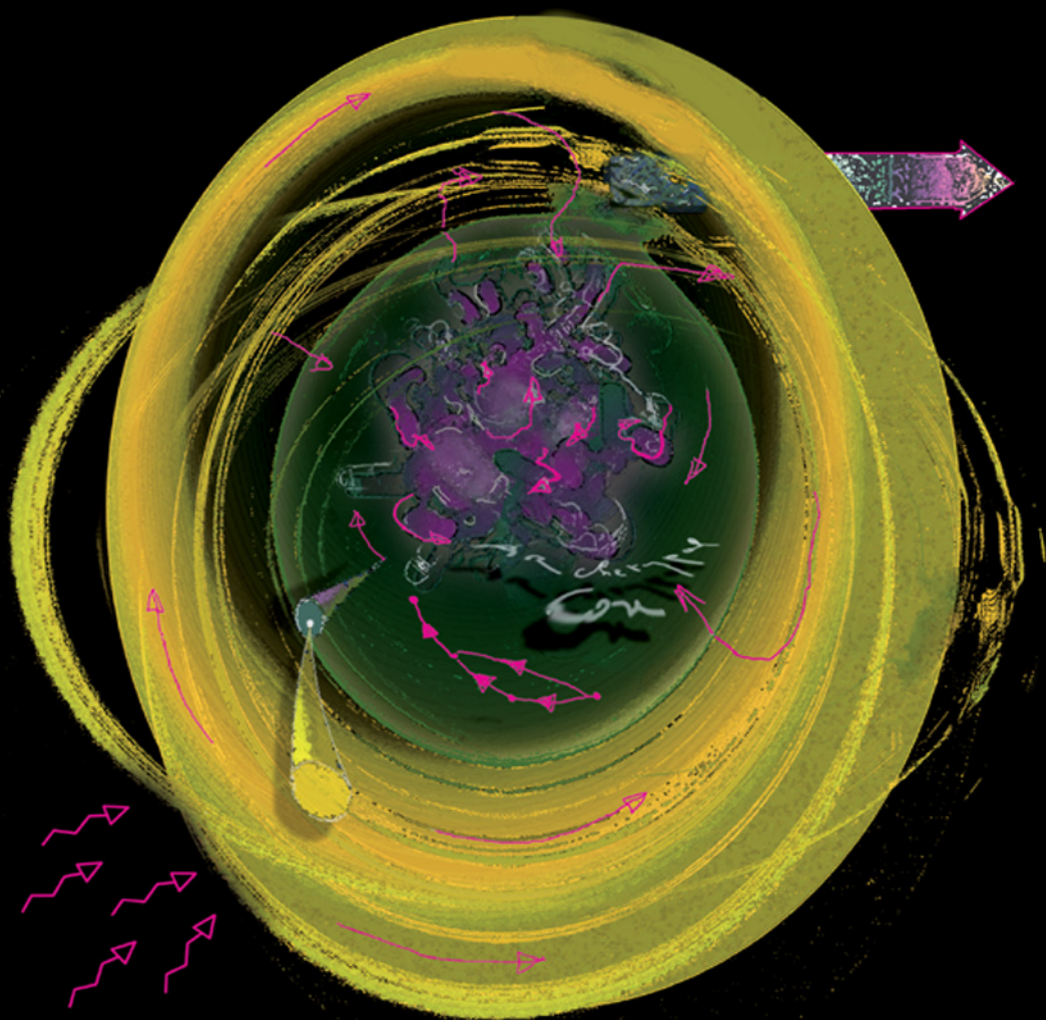




STUDIES IN MULTIDISCIPLINARITY
VOLUME 4

Andrée C. Ehresmann and
Jean-Paul Vanbremeersch

Memory Evolutionary Systems Hierarchy, Emergence, Cognition



STUDIES IN MULTIDISCIPLINARITY

VOLUME 4

Memory Evolutive Systems

Hierarchy, Emergence,
Cognition

S T U D I E S I N M U L T I D I S C I P L I N A R I T Y

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On the cover:

The artwork is by Jean-Paul Vanbremeersch and represents his view of the Archetypal Core which is at the root of the self in the Memory Evolutive Neural System modeling the mind. It filters the incoming information and dynamically interprets it by integration into reverberating circuits, to trigger the emergence of an adapted response

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Memory Evolutive Systems

Hierarchy, Emergence, Cognition

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Series Dedication

Studies in Multidisciplinarity is dedicated to the memory of Ray Paton.

Sure, he that made us with such large discourse,
Looking before and after, gave us not
That capability and god-like reason
To fust in us unused.

– William Shakespeare, Hamlet

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Table of Contents

Introduction	1
PART A. HIERARCHY AND EMERGENCE	
CHAPTER 1: NETS OF INTERACTIONS AND CATEGORIES	21
1. Systems Theory and Graphs	22
1.1. Objects and Relations	22
1.2. Definition of a Graph	23
1.3. Supplementary Properties.	24
2. Categories and Functors	25
2.1. Some History	26
2.2. Definition of a Category	27
2.3. Some More Definitions	29
2.4. Functors.	31
2.5. Universal Problems	32
3. Categories in Systems Theory	32
3.1. Configuration Categories of a System	33
3.2. Fields of an Object	35
3.3. Some Examples.	37
4. Construction of a Category by Generators and Relations.	37
4.1. The Category of Paths of a Graph	37
4.2. Comparison between Graphs and Categories	38
4.3. Labelled Categories	39
4.4. A Concrete Example	40
5. Mathematical Examples of Categories	42
5.1. Categories with at Most One Arrow between Two Objects	43
5.2. Categories with a Unique Object	44
5.3. Categories of Mathematical Structures	45
CHAPTER 2: THE BINDING PROBLEM	49
1. Patterns and Their Collective Links	49
1.1. Pattern in a Category	50

1.2. Collective Links	53
1.3. Operating Field of a Pattern	55
2. Colimit of a Pattern	56
2.1. The Mathematical Concept of a Colimit	57
2.2. The Binding Problem.	59
2.3. Decompositions of an Object	61
3. Integration vs. Juxtaposition	62
3.1. Comparison of the Sum to the Colimit	62
3.2. Some Concrete Examples.	64
3.3. Some Mathematical Examples	66
4. Interlude: A Transport Network	68
4.1. Characteristics of the Network	68
4.2. Local Area Nets, Selected Nets.	68
4.3. Central Node	69
4.4. Creation of a Central Node	70
4.5. Inter-Area Nets.	71
CHAPTER 3: HIERARCHY AND REDUCTIONISM	73
1. P-Factors of a Link Towards a Complex Object	73
1.1. Links Mediated by a Pattern	74
1.2. Link Binding a Perspective.	76
1.3. Examples of Perspectives	78
1.4. Field of a Pattern	79
2. Interactions between Patterns: Simple Links	80
2.1. Clusters	80
2.2. Composition of Clusters	82
2.3. Simple Links.	83
3. Representative Sub-Patterns	85
3.1. Comparison Link	86
3.2. Representative Sub-Pattern	87
4. Multiplicity Principle	89
4.1. Patterns with the Same Colimit	89
4.2. Connected Patterns	90
4.3. Multiplicity Principle and Complex Links	92
5. Hierarchies.	94
5.1. Hierarchical Categories	95

5.2. Examples	97
5.3. Ramifications of an Object and Iterated Colimits	99
6. Complexity Order of an Object: Reductionism	102
6.1. Obstacles to a Pure Reductionism	102
6.2. Reduction of an Iterated Colimit	104
6.3. Complexity Order of an Object	105
6.4. Examples	106
6.5. n -Multifold Objects	107
CHAPTER 4: COMPLEXIFICATION AND EMERGENCE	109
1. Transformation and Preservation of Colimits	110
1.1. Image of a Pattern by a Functor	110
1.2. Replacement of a Category by a Larger One	111
1.3. Preservation and Deformation of Colimits	113
1.4. Limits	114
2. Different Types of Complexifications	117
2.1. Options on a Category	117
2.2. Complexification	118
2.3. Examples	120
3. First Steps of the Complexification	121
3.1. Absorption and Elimination of Elements	121
3.2. Simple Adjoining of Colimits	122
3.3. ‘Forcing’ of Colimits	123
4. Construction of the Complexification	125
4.1. Objects of the Complexification	126
4.2. Construction of the Links	126
4.3. End of the Construction	128
5. Properties of the Complexification	128
5.1. Complexification Theorem	128
5.2. Examples	129
5.3. Mixed Complexification	130
6. Successive Complexifications: Based Hierarchies	131
6.1. Sequence of Complexifications	132
6.2. Based Hierarchies	134
6.3. Emergent Properties in a Based Hierarchy	136

7. Discussion of the Emergence Problem	138
7.1. Emergentist Reductionism	138
7.2. The Emergence Problem	139
7.3. Causality Attributions	140

PART B. MEMORY EVOLUTIVE SYSTEMS

CHAPTER 5: EVOLUTIVE SYSTEMS	147
1. Mechanical Systems vs. Living Systems	147
1.1. Mechanical Systems.	147
1.2. Biological and Social Systems.	148
1.3. Characteristics of the Proposed Model	149
2. Characteristics of an Evolutive System	150
2.1. Time Scale	150
2.2. Configuration Category at Time t	151
2.3. Transition from t to t'	152
3. Evolutive Systems.	153
3.1. Definition of an Evolutive System	153
3.2. Components of an Evolutive System.	155
3.3. Boundary Problems.	158
4. Hierarchical Evolutive Systems and Some Examples	161
4.1. Hierarchical Evolutive Systems.	161
4.2. The Quantum Evolutive System and the Cosmic Evolutive System	162
4.3. Hierarchical Evolutive Systems Modelling Natural Systems	162
5. Stability Span and Temporal Indices	163
5.1. Stability Span	164
5.2. Complex Identity	165
5.3. Other Spans	167
5.4. Propagation Delays.	170
6. Complement: Fibration Associated to an Evolutive System	171
6.1. Fibration Associated to an Evolutive System.	171
6.2. Particular Cases	173
6.3. The Large Category of Evolutive Systems	173

CHAPTER 6: INTERNAL REGULATION AND MEMORY

EVOLUTIVE SYSTEMS 175

1. Regulatory Organs in Autonomous Systems	176
1.1. General Behaviour	176
1.2. The Co-Regulators	177
1.3. Meaning of Information	178
2. Memory and Learning	180
2.1. Several Types of Memory	180
2.2. Different Properties of Memory	181
2.3. Formation and Development of the Memory.	182
3. Structure of Memory Evolutive Systems	183
3.1. Definition of a Memory Evolutive System	183
3.2. Function of a Co-Regulator	186
3.3. Propagation Delays and Time Lags	187
4. Local Dynamics of a Memory Evolutive System	188
4.1. Phase 1: Construction of the Landscape (Decoding).	189
4.2. Phase 2: Selection of Objectives	192
4.3. Phase 3: Commands (Encoding) of the Procedure, and Evaluation . . .	194
4.4. Structural and Temporal Constraints of a Co-Regulator.	198
5. Global Dynamics of a Memory Evolutive System	200
5.1. Conflict between Procedures.	200
5.2. Interplay Among the Procedures	201
6. Some Biological Examples.	203
6.1. Regulation of a Cell	204
6.2. Gene Transcription in Prokaryotes	204
6.3. Innate Immune System	205
6.4. Behaviour of a Tissue	206
7. Examples at the Level of Societies and Ecosystems	207
7.1. Changes in an Ecosystem.	207
7.2. Organization of a Business.	208
7.3. Publication of a Journal.	210

CHAPTER 7: ROBUSTNESS, PLASTICITY AND AGING 213

1. Fractures and Dyschrony	213
1.1. Different Causes of Dysfunction.	213
1.2. Temporal Causes of Fractures	214
1.3. Dyschrony	216

2. Dialectics between Heterogeneous Co-Regulators	217
2.1. Heterogeneous Co-Regulators	217
2.2. Several Cases	221
2.3. Dialectics between Co-Regulators	222
3. Comparison with Simple Systems.	224
3.1. Classical Analytic Models	224
3.2. Comparison of Time Scales	225
3.3. Mechanisms vs. Organisms.	226
4. Some Philosophical Remarks.	228
4.1. On the Problem of Final Cause	228
4.2. More on Causality in Memory Evolutive Systems	229
4.3. Role of Time	230
5. Replication with Repair of DNA	231
5.1. Biological Background.	231
5.2. The Memory Evolutive System Model	232
6. A Theory of Aging	234
6.1. Characteristics of Aging.	234
6.2. Theories of Aging at the Macromolecular Level.	237
6.3. Level of Infra-Cellular Structures	239
6.4. Cellular Level	240
6.5. Higher Levels (Tissues, Organs, Large Systems)	241
CHAPTER 8: MEMORY AND LEARNING	245
1. Formation of Records.	245
1.1. Storage and Recall	245
1.2. Formation of a Partial Record	247
1.3. Formation and Recall of a Record	249
1.4. Flexibility of Records	250
2. Development of the Memory	250
2.1. Interactions between Records.	251
2.2. Complex Records	251
2.3. Examples	252
3. Procedural Memory	253
3.1. Effectors Associated to a Procedure	254
3.2. Basic Procedures	256
3.3. Construction of the Procedural Memory	257
4. Functioning of the Procedural Memory	259
4.1. Activator Links.	259

4.2. Recall of a Procedure	260
4.3. Generalization of a Procedure	261
5. Selection of Admissible Procedures.	262
5.1. Admissible Procedures.	262
5.2. Procedure Associated to an Option.	263
5.3. Selection of a Procedure by a Co-Regulator	264
6. Operative Procedure and Evaluation	265
6.1. Interplay among the Procedures	266
6.2. Formation of New Procedures	266
6.3. Evaluation Process and Storage in Memory.	267
7. Semantic Memory.	269
7.1. How Are Records Classified?	270
7.2. Pragmatic Classification with Respect to a Particular Attribute	270
7.3. Formation of an E-Concept	272
7.4. Links between E-Concepts	275
7.5. Semantic Memory	277
8. Some Epistemological Remarks	280
8.1. The Knowledge of the System	280
8.2. Acquisition of Knowledge by a Society	281
8.3. The Role of the Interplay among Procedures.	282
8.4. Hidden Reality	283

PART C. APPLICATION TO COGNITION AND CONSCIOUSNESS

CHAPTER 9: COGNITION AND MEMORY EVOLUTIVE NEURAL SYSTEMS.	287
1. A Brief Overview of Neurobiology.	287
1.1. Neurons and Synapses.	287
1.2. Coordination Neurons and Assemblies of Neurons	288
1.3. Synchronous Assemblies of Neurons.	289
1.4. Binding of a Synchronous Assembly	290
2. Categories of Cat-Neurons	292
2.1. The Evolutive System of Neurons.	292
2.2. Cat-Neurons as Colimits of Synchronous Assemblies	293
2.3. Interactions between Cat-Neurons	295
3. The Hierarchical Evolutive System of Cat-Neurons	297
3.1. Higher Level Cat-Neurons	297
3.2. Extended Hebb Rule	299
3.3. The Evolutive System of Cat-Neurons.	300

4. The Memory Evolutive Neural System	302
4.1. The Memory of an Animal	303
4.2. The Memory as a Hierarchical Evolutive System	304
4.3. A Modular Organization: The Net of Co-Regulators	305
5. Development of the Memory via the Co-Regulators	307
5.1. Storage and Retrieval by a Co-Regulator	307
5.2. Formation of Records	309
5.3. Procedures and their Evaluation	312
6. Applications	315
6.1. Physiological Drives and Reflexes	315
6.2. Conditioning	316
6.3. Evaluating Co-Regulators and Value-Dominated Memory	318
 CHAPTER 10: SEMANTICS, ARCHETYPAL CORE AND CONSCIOUSNESS	 321
1. Semantic Memory	321
1.1. Perceptual Categorization	322
1.2. Concept with Respect to an Attribute	323
1.3. The Semantic Memory	326
1.4. Recall of a Concept	330
2. Archetypal Core	332
2.1. The Archetypal Core and Its Fans	332
2.2. Extension of the Archetypal Core: The Experiential Memory	334
3. Conscious Processes	337
3.1. Intentional Co-Regulators	338
3.2. Global Landscape	339
3.3. Properties of the Global Landscape	341
3.4. The Retrospection Process	342
3.5. Prospection and Long-Term Planning	343
4. Some Remarks on Consciousness	344
4.1. Evolutionary, Causal and Temporal Aspects of Consciousness	344
4.2. Qualia	345
4.3. The Role of Quantum Processes	346
4.4. Interpretation of Various Problems	347
4.5. Self-Consciousness and Language	347
5. A Brief Summary	348
5.1. Basic Properties of Neural Systems	348
5.2. Interpretation in Our Model	350

Table of Contents

xv

Appendix.	353
Bibliography	361
List of Figures	379
Index	383

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Introduction

This is a presentation of what we call *memory evolutive systems*. We offer these as mathematical models for autonomous evolutionary systems, such as biological or social systems, and in particular, nervous systems of higher animals. Our work is rooted in category theory, which is a particular domain of mathematics. We have spent some 20 years developing the concepts involved in memory evolutive systems, and over that time have presented them in a series of articles and several conferences. This book is a synthesis of these two decades of research.

1. Motivations

One of us, Jean-Paul Vanbremeersch, is a physician who specializes in gerontology. He has long been interested in explaining the complex responses of organisms to illness or senescence. The second of us, Andrée C. Ehresmann, is a mathematician, whose research areas have included analysis, optimization theory and category theory, in collaboration with her well-known mathematician husband, late Charles Ehresmann. In 1980, she organized an international conference on category theory in Amiens, France, in memory of her husband, who died in 1979. In doing so, she asked Vanbremeersch for assistance in writing an explanation of category theory for non-mathematicians. It was during these initial interactions that he first suggested that categories might have applications for problems related to complexity.

This is how our study of memory evolutive systems began. Our subsequent examination of the literature revealed that there had not yet been any real work done on this subject. Although Rosen (1958a) had promoted the use of category theory in biology, he considered only its basic notions and not its more powerful constructions. Hence, we decided to combine our interests and pursue research in this direction.

1.1. *How Can Complexity Be Characterized?*

During the late 1970s and early 1980s, there was a great deal of excitement around the question of ‘complexity’, with researchers discussing non-linear systems, chaos theory, fractal objects and other complex analytical

constructs. We quickly realized that category theory could provide tools to study concepts germane to complexity, such as the following.

- (i) *The binding problem*: how do simple objects bind together to form a ‘whole that is greater than the sum of its parts’?
- (ii) *The emergence problem*: how do the properties of a complex object relate to the properties of the more elementary objects that it binds?
- (iii) *The hierarchy problem*: how may we explain the formation of increasingly complex objects, beginning with elementary particles that form atoms, which in turn form molecules, up through increasingly complicated systems such as cells, animals and societies?

We considered these three problems in our first joint paper (Ehresmann and Vanbremeersch, 1987), in which we defined a model called *hierarchical evolutive systems*, based on the categorical concept of colimit, and the process of complexification.

1.2. Self-Regulation

In our 1987 paper, however, we did not introduce those characteristics of living systems that allow for autonomy through self-regulation; namely, some type of internal regulation systems, as well as a capacity to recognize, innately or through learning, those environmental characteristics that require the system to develop adequate and appropriate responses.

Our work in hierarchical evolutive systems had to be enriched to take these characteristics into account, and we did so in subsequent papers. Initially we introduced the concept of a single regulatory organ (Ehresmann and Vanbremeersch, 1989). However, soon we realized that it was not possible to have only a single regulatory organ, because of differences in laws and time scales across various levels of the hierarchy. Hence, we introduced (in Ehresmann and Vanbremeersch, 1990, 1991, 1992a) the concept of a net of such regulatory organs, individually called *co-regulators* (CR). To function, these co-regulators must rely on a central internal archive, a kind of ‘memory’. Such a memory would not be rigid, like that of a computer, but would instead be flexible enough to allow for successful adaptation to change over time, and the formation, possibly, of increasingly better adapted behaviours. From this work, we developed the model which we call a memory evolutive system.

1.3. Cognitive Systems

In 1989, we sketched some applications of memory evolutive systems to the nervous system and to cognition. In that same year, Gerald Edelman published *The Remembered Present: A Biological Theory of Consciousness*

(1989). We were amazed to see that Edelman's ideas corroborated many of the concepts we had arrived at through applying the methods of category theory to problems of cognition and consciousness. In particular, Edelman insists on a notion of degeneracy, which is readily modelled by what we now call the *multiplicity principle*, and which we place at the basis of emergent properties. Edelman's book also encouraged us to develop our study of semantics and higher cognitive processes within the framework of memory evolutive systems, and in particular to attempt to model consciousness. The issue of consciousness has been central in some of our recent articles (Ehresmann and Vanbremeersch, 1999, 2002, 2003), in which we have singled out some of its characteristics, and shown how they rely on the development of a personal memory, called the *archetypal core*, which forms the basis of the self.

2. Why Resort to a Model?

From whence came the interest in designing such models in the first place? Through memory evolutive systems, we propose a mathematical model that provides a framework to study and possibly simulate natural complex systems. Indeed, since their beginnings, the dream of philosophy and of science has been to give an explanatory account of the universe. In seeking deeper explanations for life and consciousness, scholars in many fields have become increasingly aware of the problem of complexity in biological systems. Computational science has played a very important role in pushing these understandings forward, but the pursuit requires increasingly elaborate mathematical tools. Our hope is that an adequate mathematical model will shed some light on the characteristics of complex evolutionary systems, on what distinguishes them from simple mechanisms or straightforward physical systems, and on the development of complex systems over time, from birth to death.

Moreover, the behaviour of such a system depends heavily on its experiences. In a memory evolutive system, we posit that the system may remember these experiences for later use. A model that represents a system over a certain time period, one that accounts for the system's responses to various situations that it encounters, might be able to anticipate the system's later behaviour and perhaps even predict some developmental alternatives for the system. This dream of developing a computational forecasting ability, which is rather like seeking a modern Pythia, has been considerably stimulated by the increasing power of computers, which makes it possible to deal with very large numerical and non-numerical data sets. However, computation also has its limits. Thus the role of a mathematical model is twofold: theoretical, for comprehending the fundamental nature of complex

systems; and practical, for applications in biology, medicine, sociology, ecology, economics, meteorology and other fields that trade in complexity.

2.1. *Different Types of Models*

There are many ways of designing models. For example, the traditional models in physics (*e.g.* those inspired by the Newtonian paradigm, or that are well known in thermodynamics, electromagnetism and quantum mechanics) generally use a representation based on ‘observables’ that satisfy systems of differential equations, which translate the laws of physics into a quantitative language.

Some of these traditional models include chaotic behaviour and have been imported into such fields as biology and ecology. The values (real numbers or vectors) of the observables are obtained empirically. Over the past five decades, such analytical models have assumed an increasingly important role in many scientific fields, as advances in computational science led to the development of powerful data processing systems, capable of handling large systems of equations with many parameters.

Another kind of model is the black box model, which does not try to reproduce the internal behaviour of a system. Rather, this kind of model takes into account only the inputs, the outputs and the change-of-state rules. These rules are formal, as in a Turing machine; or as in cellular automata, introduced by [von Neuman \(1966\)](#), one of the main architects of the modern digital computer. Black box models can be used to help develop decision trees that operate on variables issued from databases, according to usual Boolean logic: and/or; if ... then; not and so on. Such trees are useful in expert systems; for example, in those used in the diagnosis and treatment of diseases.

Cybernetics is a field comprising another class of mathematical models. The term was defined by [Wiener \(1948\)](#) to mean ‘the entire field of control and communication theory, whether in the machine or in the animal’ (p. 19). Its models use in an essential way the concept of feedback, and at times Shannon’s information theory ([Shannon and Weaver, 1949](#)). Cybernetics advanced throughout the 1940s, 1950s and 1960s, thanks to the collaboration of specialists in biology, neurobiology and economics, who compared their individual approaches, and found great similarity in the structure and the evolutionary modes of the systems they studied.

It is also in this multi-disciplinary environment that systems theory developed. Although it is related to cybernetics, systems theory focuses more on modelling the relations among the components of a system. As defined by [von Bertalanffy \(1926\)](#), a system is a set of interacting elements organized to achieve a particular goal. Today, in engineering or science, a system is