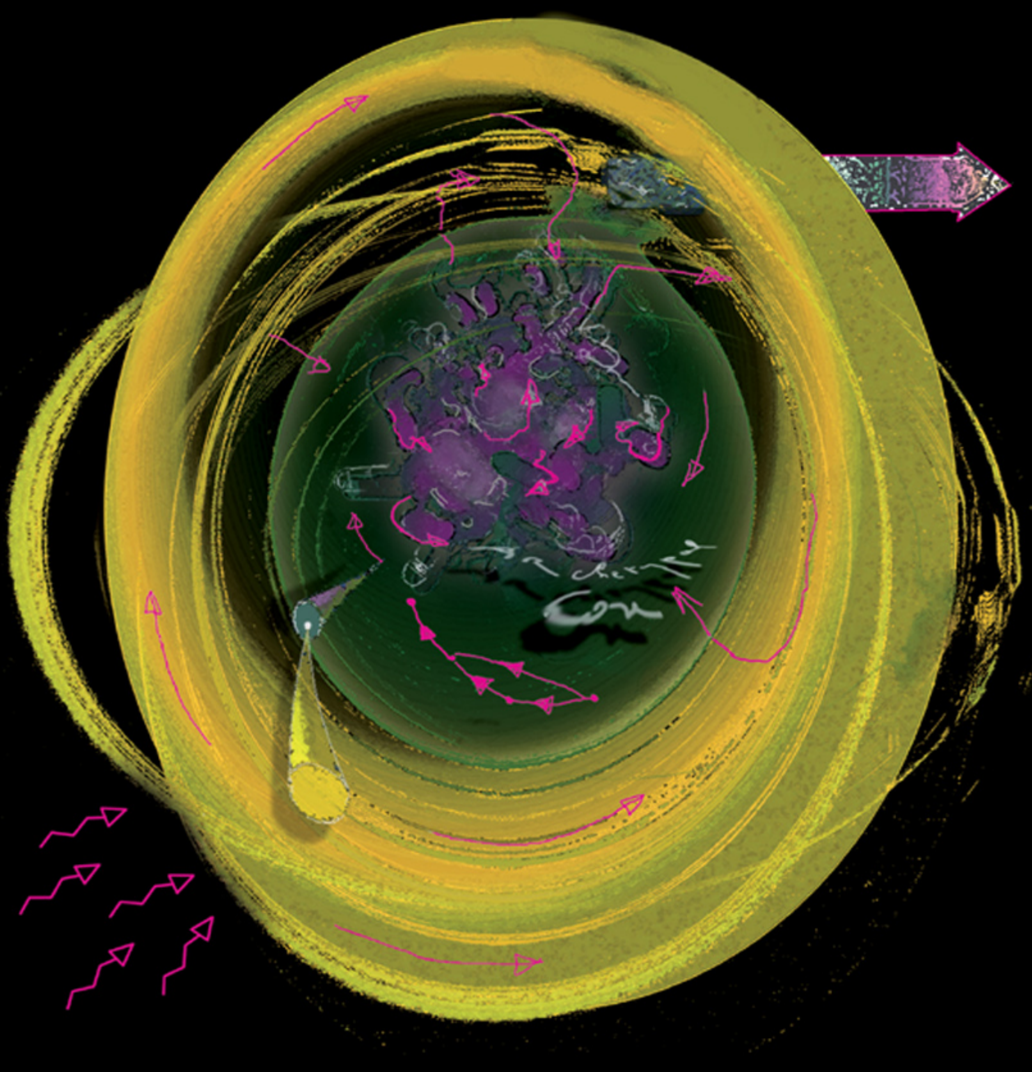
STUDIES IN MULTIDISCIPLINARITY

VOLUME 4

Memory Evolutive Systems
Hierarchy, Emergence, Cognition

Andrée C. Ehresmann and Jean-Paul Vanbremeersch



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SERIES EDITORS

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

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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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PART B. MEMORY EVOLUTIVE SYSTEMS

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