Preface

Synthetic methodologies (as opposed to analytical ones — cf. Braitenberg, 1984) are characterized by a "reverse" methodology, which allows one to build systems capable of performing cognitive tasks to test and evaluate hypotheses and theories. They have been used to model and simulate cognitive processes (e.g., perception, planning, navigation, inference, communication and language) from many different perspectives. Evolutionary robotics, cognitive robotics, artificial life, animat research, adaptive behavior, computational neuroethology and computational semiotics are some of the interdisciplinary areas of research dedicated to the synthetic design of **artificial cognition systems**. These areas have been designing environments that work as experimental labs, where it is possible to test the predictions derived from theoretical models. They are based on different computational tools and have various ambitions, being heavily influenced by formal theoretical constraints and empirical constraints in the design of the environment, the morphological definitions of sensors and effectors and the implementation of cognitive architecture and processes of the conceived systems.

In their turn, simulations offer the opportunity to quantify and formalize ideas, concepts and propositions constituting a theory in terms of programming (Parisi, 2001). Importantly, artificial cognition systems provide scientists the means to perform "mental experiments" about the necessary and sufficient conditions to observe processes of interest (Bedau, 1998; Dennett, 1998) — How would a certain system change, given different initial conditions and/or developmental path? What set of conditions is sufficient for the emergence of specific traits of the system?

Moreover, research into modeling cognition in artificial systems provides a new generation of ever more flexible and robust systems able to interact with an unpredictable dynamical world. It is almost a consensus among researchers that when building such systems, one fundamental issue, among others, needs to be faced sooner or later in models and experiments — *meaning*. How could cognitive processes be meaningful to the artificial systems? An early concern regarding meaning was the statement of the symbol grounding problem (Harnad, 1990). Thus, new approaches to artificial cognition systems either implicitly or explicitly try to address problems and critics to the symbolic approach and overcome them presenting new learning, adaptation and evolving autonomous agents. There is, however, a tendency to focus on low-level cognitive processes, like sensorial and motor abilities. Much of this restriction is due to epistemological questions not being clearly answered yet, especially the question about how these processes could be meaningful to the intelligent agents. While going through this book, the watchful reader will notice the problem of *meaning* in artificial cognition systems, even centrally addressed in all the chapters presented here. It appears related to diverse issues — embodiment, situatedness, learning, spatial cognition, language and communication, intentionality and emotion — thus providing contributions to the understanding of meaning in a magnitude of cognitive levels.

Organization and Overview of This Book

Section I: Modeling Cognition

This section focuses on the proposal of original models for cognition based on different computational approaches but aiming at describing how general cognitive processes can be modeled in artificial systems.

Chapter I: *The Goose, the Fly, and the Submarine Navigator: Interdisciplinarity in Artificial Cognition Research,* is by Alexander Riegler.

In this chapter, the importance of interdisciplinary research for an alternative path to artificial cognition systems is argued. The author starts by describing four problems in the new approaches to model artificial cognition: the anthropomorphical definition of simulated entities, the use of behaviorist stateless models, the application of crisp symbolic production systems rules and the poor explanatory power of connectionist.

In order to build an alternative road, accounts from ethology, evolutionary theory and epistemology of constructivism are brought forth and condensed into four boundary conditions. They lead to the outline of an architecture for genuine cognitive systems, which seeks to overcome traditional problems known from artificial intelligence research paragraphs and to avoid the pitfalls pointed out in the new approaches. Two major points in the architecture are stressed: the maintenance of explanatory power by favoring an advanced rule-based system rather than neuronal systems and the organizational closure of the cognitive apparatus, with far-reaching implications for the creation of meaningful agents. The proposed model framework is evaluated and compared with other, mainly neural network-related, approaches. The chapter concludes with a description of future trends and problems that still need to be addressed.

Chapter II: *An Embodied Logical Model for Cognition in Artificial Cognition Systems,* is by Guilherme Bittencourt and Jerusa Marchi. An original logic-based generic model for a cognitive agent is described in this chapter. This model found inspiration in several sources: systemic approach, autopoiesis theory, theory of evolution and memetics theory, neurobiology, Piaget's genetic epistemology, logicist school, cognitive robotics and Wittgenstein's work. The syntactical definition of the model consists of logical propositions, but the semantic definition includes, besides the usual truth value assignments, what is called emotional flavors, which correspond to the state of the agent's body translated into cognitive terms. The combination between logical propositions and emotional flavors allows the agent to learn and memorize relevant propositions that can be used for reasoning. These propositions are represented in a specific format — prime implicants/implicates — which is enriched with annotations that explicitly store the internal relations among the propositions' literals. Based on this representation, a memory mechanism is described and algorithms are presented that learn a proposition from the agent's experiences in the environment and that are able to determine the degree of robustness of the propositions, given a partial assignment representing the environment state. The logic-based approach to model cognition in behavior-based artificial creatures situated in the world constitutes a quite original contribution in this chapter and brings back this formal computational approach into a new perspective for artificial cognition systems.

Chapter III: *Modeling Field Theory of Higher Cognitive Functions,* is by Leonid Perlovsky. This chapter presents a mathematical theory of higher cognitive functions, the modeling field theory (MFT) and also dynamic logic, which would govern their temporal evolution. It discusses specific difficulties encountered by previous attempts at mathematical modeling of the mind and how the new theory overcomes these difficulties.

An example of problem solving, which was unsolvable in the past, is shown. The author argues that the theory is related to an important mechanism behind workings of the mind, which is called "the knowledge instinct" as well as to other cognitive functions. The mathematical descriptions are complemented with detailed conceptual discussions so the content of the chapter can be understood without necessarily following mathematical details. The author relates mathematical results and computational examples to cognitive and philosophical discussions of the mind. Also discussed are neurobiological foundations, cognitive, psychological and philosophical connections, experimental verifications and an outline of emerging trends and future directions. This chapter provides an original view of how mathematical principles can be used to understand and model different cognitive functions, including concepts, emotions, instincts, understanding, imagination and intuition.

Section II: Methodological Issues

In this section, methodological discussions about modeling and experimenting with artificial cognition systems are presented that concern how interdisciplinary sources can or should be taken together to model such systems.

Chapter IV: *Reconstructing Human Intelligence within Computational Sciences: An Introductory Essay*, is by Gerd Doeben-Henisch. This chapter outlines a possible research program for computational systems representing human-like intelligence. After a short historical introduction, a possible theoretical framework is described showing how it is possible to integrate heterogeneous disciplines like neurobiology, psychology and phenomenology within the same computational framework. Concrete examples are given by reconstructing behavioural (Morris) and phenomenal semiotics (Peirce) with the aid of formal theories. The author contributes to the interdisciplinary discussion about adaptive computational models of human-like intelligence through a unified theoretical framework.

Chapter V: *Stratified Constraint Satisfaction Networks in Synergetic Multi-Agent Simulations of Language Evolution*, is by Alexander Mehler. In this chapter, a simulation model of language evolution that integrates synergetic linguistics with multi-agent modeling is described. This model permits the use of knowledge about the distribution of parameter values of system variables to constrain the model itself and to establish a criterion of simulation validity. It also accounts for synergetic interdependencies of microscopic system variables and macroscopic order parameters. The relevant levels of linguistic dynamics to be modeled are identified as those of single information processing agents, communication processes, social system and language system. The chapter also identifies reliable sources of evaluating these simulation models, discussing several starting points of falsification on the level of single agents, of interpersonal learning and of the speech community as a whole. Important semiotic constraints of sign processing in multi-agent systems are described in terms of system variables and order parameters that describe and control the unfolding of language acquisition in multi-agent systems. The paper concentrates on conceptual modeling, leaving its implementation for future work.

Section III: Cognition and Robotics

The use of robotic agents as a platform for experiments in artificial cognition are discussed in this section, which presents their use to model language evolution and spatial cognition, in addition to a describing the limitations of current robotic systems.

Chapter VI: *Language Evolution and Robotics: Issues on Symbol Grounding and Language Acquisition*, is by Paul Vogt. This chapter focuses on recent studies of the origins and evolution of language that have used multiple robot systems as their primary platform. The aim is to present why robotics is a fruitful approach to study language origins and evolution, identify the main topics, report the major achievements and problems and provide a roadmap for future studies. The chapter starts by providing some theoretical background on language evolution and discussing an alternative view on the symbol-grounding problem. Next, some foundations toward studying language evolution using robots are presented, together with a number of themes within the evolutionary linguistics that have been the subject of robotic studies thus far. These themes include categorisation, the formation of vocabularies, the evolution of grammar and the emergence of meaningful communication. Following this review, future avenues for research are discussed. Finally, it is pointed out that robotics is, indeed, a very promising methodology to study language evolution and that, although many insights have been gained, research is still closer to the starting point than to the endpoint.

Chapter VII: *Evolutionary Robotics as a Tool to Investigate Spatial Cognition in Artificial and Natural Systems*, is by Michela Ponticorvo, Richard Walker, and Orazio Miglino. Chapter VII presents evolutionary robotics as a means of studying spatial cognition in artificial and natural systems. This approach is used to replicate quantitative observations of spatial behavior in laboratory animals, and it is argued that it offers a powerful tool to understand the general mechanisms underlying animal orientation. In particular, the authors show that "artificial organisms," with controller architecture that precludes the presence of "cognitive maps," can accurately replicate the observed behavior of animals in classical experimental set-ups, thus suggesting that spatial orientation may not require abstract spatial representations and that sensory-motor coordination, in the presence of environment constraints, may be enough on its own to generate complex spatial behavior. The chapter starts by describing examples of spatial behavior in animals, briefly outlining the debate between "cognitivist" versus "action-based" explanations and introducing a number of methodological issues. Next, evolutionary robotics (ER) and its potential role in cognitive research are discussed. Four ER simulations of animal spatial behavior (environmental shape recognition, detour behavior, landmark navigation and spatial learning) are described. The chapter concludes by summarizing what has been achieved and outlining the advantages and limitations of ER as a tool in cognitive research.

Chapter VIII: *The Meaningful Body: On the Differences Between Artificial and Organic Creatures*, is by Willem Haselager and Maria Eunice Q. Gonzalez. This chapter, directly related with what is called situated and embodied cognition, discusses how cognitive processes can be meaningful to artificial agents in the light of recent developments in AI robotics, specifically, in the area of reactive and evolutionary approaches. The authors argue that the embodied and embedded nature of these systems and the interactions between these robots and their environment do not guarantee the emergence of meaningful cognitive processes. Robots seem to lack any sensitivity to the significance of these processes. The authors suggest that the artificiality of the body of current robots precludes the emergence of meaning. Moreover, they question whether the label "embodied" genuinely applies to current robots. Such robots should be seen as "physicalized," given that the types of matter used in creating robots bear more similarity to machines like cars or airplanes than to organisms. Thus, the chapter investigates how body and meaning relate. It is suggest that meaning is closely related to the strengths and weaknesses of organic bodies of cognitive systems in relation to their struggle for survival. Specifically, four essential characteristics of organic bodies (autopoiesis, metabolism, centrifugal development and self-organization) are said to be lacking in artificial systems, therefore there will be little possibility of the emergence of meaningful processes.

Section IV: Cognition in Virtual Agents

Experiments with virtual agents, which are embedded in simulated environments, are presented in this section. Such systems of artificial cognition are discussed in the light of a biologically- inspired methodology called synthetic ethology and used in experiments concerning the emergence of meaning and signaling influenced by environmental variability.

Chapter IX: *Making Meaning in Computers: Synthetic Ethology Revisited*, is by Bruce MacLennan. This chapter describes synthetic ethology, a scientific methodology in which is constructed synthetic worlds wherein synthetic agents evolve and become coupled to their environment. First, the motivations for synthetic ethology as an experimental methodology are reviewed and its use to investigate intentionality and meaning; then the mechanisms from which the motivations emerge is explained. Second, several examples of such experiments are presented in which genuine (i.e., not simulated), meaningful communication evolved in a population of simple agents. The author explains that in these experiments the communications were meaningful to the artificial agents themselves, but they were only secondarily and partly meaningful to the experimenters. Finally, the chapter discusses the extension of the synthetic ethology paradigm to the problems of structured communications and mental states, complex environments and embodied intelligence, and one way is suggested in which this extension could be accomplished. Synthetic ethology would offer a new tool in a comprehensive research program investigating the neuro-evolutionary basis of cognitive processes.

Chapter X: *Environmental Variability and the Emergence of Meaning: Simulational Studies Across Imitation, Genetic Algorithms, and Neural Networks*, is by Patrick Grim and Trina Kokalis. In Chapter X, a development of earlier work in which we study the emergence of simple signaling in simulations involving communities of interacting individuals is presented. The model involves an environment of wandering food sources and predators, with agents "embodied" in this artificial environment and subject to its spatial and temporal contingencies. Individuals develop coordinated behavioral strategies in which they make and respond to "sounds" in their immediate neighborhoods using any of a variety of mechanisms: imitation of successful neighbors, localized genetic algorithms and partial neural net training on successful neighbors. Crucial to variations of the model explored are different updating mechanisms of strategy change, all of which are key to the behavior of the most successful neighbors. The models are biologically inspired in emphasizing strategy changes across a community of individuals embodied in a common environment. The authors introduce a further characteristic of environments: variability. The essential question posed is what role environmental variability — and environmental variability of what type — may play in the emergence of simple communication. Inspiration comes from the role that environmental variability seems to play in a range of apparently disparate phenomena, from species diversity to individual learning. Results for environments with (a) constant resources, (b) random resources and (c) cycles of "boom and bust" are compared. In the models presented, across all mechanisms for strategy change applied by individuals, the emergence of communication is strongly favored by cycles of "boom and bust," where resources vary cyclically, increasing and decreasing throughout time. These results are particularly intriguing given the importance of environmental variability in fields as diverse as psychology, ecology and cultural anthropology.

Section V: Theoretical and Philosophical Issues

In this section, the Central-European phenomenological tradition and Peircean pragmatic semeiotic provide theoretical and philosophical support in speculations on the structure of the psyche and approaches to the problem of meaning formation.

Chapter XI: *Mimetic Minds: Meaning Formation through Epistemic Mediators and External Representations*, is by Lorenzo Magnani. The chapter maintains that we can overcome many of the difficulties of creativity and meaning formation studies by developing a theory of abduction, in the light of Charles Sanders Peirce's first insights. According to the author, the "computational turn" and the creation of "artificial cognition systems" provide a new way to understand cognitive processes. The creation of new meanings through creative processes is no longer seen as a mysterious process but as a complex relationship among different inferential steps that can be clearly analyzed and identified.

Artificial intelligence and cognitive science tools allow us to test concepts and ideas previously conceived in abstract terms. It is in the perspective of these *actual models* that we find the central role of *abduction* in the explanation of meaning formation.

Chapter XII: *First Steps in Experimental Phenomenology*, is by Roberto Poli. The chapter uses some of the ideas developed by early phenomenologists in order to sketch fragments of a new architecture for artificial minds. The main objective is to show that at least some of the ideas developed by Central-European thinkers can still be fruitfully exploited for the scientific advancement of our understanding of the world and our experience of it. This work has mixed experimental data on the structure of the specious present with categorical analyses conducted within the framework of the theory of levels of reality and some bold speculation on the general structure of the psyche.

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