Preface

Biologically inspired computing is the field of investigation that draws upon metaphors or theoretical models of biological systems in order to design computational tools or systems for solving complex problems. This research area is also referred to as *computing with biological metaphors*, *bio-inspired computing*, or *biologically motivated computing*. The attained outcomes are algorithms or systems that bear a (sometimes superficial) resemblance with the biological phenomena or model under study.

The main motivations behind bio-inspired computing are twofold. First, the incapability of already proposed solution strategies to deal appropriately with complex problems, in areas such as engineering, computing and bioinformatics. These problems are usually characterized by the absence of a complete mathematical model of the relevant phenomena, the existence of a large number of variables to be adjusted and conditions to be simultaneously satisfied, the presence of high degrees of non-linearity, and the formulation of multipurpose tasks with a combinatorial explosion of candidate solutions, among other challenging scenarios.

The second motivation behind biologically inspired algorithms is the realization that most of the complex problems we currently tackle have similar versions in the natural world. Adaptation, self-organization, setpoint control, prediction, communication, and optimization have to be performed by biological organisms, in parallel and in different scales and structural levels, in order to survive and maintain life. Nature is constantly developing efficient problem solving techniques and these are now beginning to be explored by engineers, computer scientists and biologists for the design of artificial systems and algorithms to be applied to the most varied types of problems.

To exemplify the types of problems solved by biological organisms and whose inspiration have been useful for the design of computational algorithms, with a wide range of applications, take the case of artificial neural networks as functional models of the human brain. Our brain is capable of identifying and classifying patterns (e.g., face, sound and voice recognition), it performs advanced control processes (e.g., motor and thermal control), it allows us to communicate effectively with each other (e.g., via words or signals), and the list goes on. Artificial neural networks have been applied to all these contexts, still with limited practical results, but generally overcoming alternative computer techniques not directly inspired by the human brain.

Essentially, this book concatenates the most recent developments in the area of biologically motivated algorithms, from models of biological evolution, to ant colonies, immune systems, endocrine systems, nervous cognition, social human organizations, fractal proteins, up to semiotic processes in higher animals. Rather than retracting isolated scenes, in the style of an exposition of a thematic collection of masterpieces from distinct authors, this book goes far beyond this and looks into biological and other natural systems and models with a different perspective, the perspective that nature got there first in the solution of very complicated problems.

This subject matter is intrinsically interdisciplinary, and opens up the possibility of developing completely novel computational algorithms for solving problems in the most varied domains, from engineering to biology. The contributions are varied in subject and scope, and come from researchers with a wholesome diversity of well-founded perspectives involving biologically inspired computing, in particular, and natural computing, as a whole. All chapters are self-contained, presenting first the biological motivation or model of the proposal, and usually bring pseudocodes that can be used as guidelines for implementing the algorithms presented and reproducing the results reported.

ORGANIZATION OF THE BOOK

The interaction between the natural sciences (e.g., biology) and computing requires knowledge from different domains, such as biology, ethology, computing, physics, engineering and others. This book contains 16 contributed chapters organized into five main sections, as follows:

Section I: Introduction

Chapter 1: From Biologically Inspired Computing to Natural Computing

Section II: Evolutionary Algorithms

Chapter 2: Evolutionary Turing Machines: The Quest for Busy Beavers

Chapter 3: Generalized Extremal Optimization: A New Meta-Heuristic Inspired by a Model of Natural Evolution

Chapter 4: Genetic Programming Using a Turing-Complete Representation: Recurrent Network Consisting of Trees

Chapter 5: Gene Expression Programming and the Evolution of Computer Programs

Chapter 6: The Clonal Selection Principle for In Silico and In Vitro Computing

Section III: Swarm Intelligence

Chapter 7: Integrating Evolutionary Computation Components in Ant Colony Optimization

Chapter 8: Ant Colony Algorithms for Steiner Trees: An Application to Routing in Sensor Networks

Chapter 9: The Influence of Pheromone and Adaptive Vision in the Standard Ant Clustering Algorithm

Chapter 10: Particle Swarms: Optimization Based on Sociocognition

Section IV: Artificial Life and Artificial Creatures

Chapter 11: Synthetic Approach to Semiotic Artificial Creatures

Chapter 12: Perspectives for Strong Artificial Life

Section V: Information Processing and Cognitive Systems
Chapter 13: Controlling Robots with Fractal Gene Regulatory Networks
Chapter 14: Once More Unto the Breach: Towards Artificial Homeostasis
Chapter 15: Biologically Inspired Collective Robotics
Chapter 16: Continuous Attractor Neural Networks

A BRIEF OVERVIEW OF THE CONTRIBUTIONS

Section I: Introduction

This section of the book is composed solely of Chapter I. In this chapter, natural computing is conceptualized and biologically inspired algorithms are placed in the broader context of natural computing. This short introductory chapter sets the scene for the book and characterizes the other fifteen contributions to this volume. It argues that although the book is titled *Recent Developments in Biologically Inspired Computing*, it contains contributions to all main branches of natural computing, though with a much greater emphasis on bio-inspired algorithms.

Section II: Evolutionary Algorithms

In Chapter II, the authors tested the viability of using Turing machines as models for the evolution of computer programs, and adopted the Busy Beavers problems to evaluate their proposal. Their contributions to biologically inspired computing include the study of alternative representation schemes for genotypes, the development of new genetic operators, and the demonstration that evolutionary algorithms can also provide viable and competitive approaches to solve theoretical problems in computer science.

The *generalized extremal optimization* (GEO) is a new meta-heuristic introduced in Chapter III by taking inspiration from a simple coevolutionary model developed to show the emergence of self-organized criticality in ecosystems. The algorithm is a global optimization technique designed to tackle multivariate non-convex problems. The authors claimed that their proposal is competitive with other methods such as genetic algorithms and simulated annealing, with the advantage of having a single input parameter to adjust. The authors illustrate the performance of the algorithm by applying it to a satellite thermal design problem. Studies about the hybridization of the algorithm with local search techniques, its parallelization and dynamics are currently being undertaken.

Chapter IV proposes a new representation scheme for genetic programming. They used a Turing complete type of representation based on a recurrent network consisting of trees. To assess the performance of their proposal they consider the design of a language classifier and a bit reverser. The authors obtained superior performance using their proposed representation scheme when compared with the standard genetic programming (GP) representation based on parse trees. The final objective of their work is to prove that a recurrent network of trees may be a good building block for GP.

Inspired by the natural genotype/phenotype systems, Chapter V presents a new bio-inspired approach named *gene expression programming* (GEP). The author characterizes genetic algorithms and genetic programming as the predecessors of GEP and provides a number of conceptual similarities and differences among them. The chapter then provides a detailed description of GEP detaching its architecture and genetic operators. To illustrate the behavior of the algorithm it is applied to perform a breast cancer diagnosis. As one of the main advantages of this new development in evolutionary algorithms, the author stresses the parsimony in the solutions obtained.

Clonal selection, expansion and affinity maturation are some of the main theories used to explain the behavior of an adaptive immune response. In Chapter VI the authors review several clonal selection algorithms, including their own proposal, and argue that these correspond to evolutionary algorithms by their very nature. They also used some tools, such as noisy channels and reaction diffusion systems, to model immune algorithms based on clonal selection. The chapter then follows with a description of the similarities between clonal selection and one experiment from molecular computing involving the dynamics of DNA evolution. The authors conclude their chapter by discussing several future research trends for the field of artificial immune systems.

Section III: Swarm Intelligence

In Chapter VII two new ant colony optimization (ACO) algorithms are proposed by integrating concepts from evolutionary algorithms. The objective of using concepts from EAs with ACO algorithms is to improve the performance of the latter. The chapter starts with a description of the basic principles of ACO and EAs and follows discoursing about some similarities and differences between them. The modified ACO algorithms are then presented, and several experiments are performed in order to assess the modifications introduced in the ACO algorithm. The results achieved by the modified algorithms are compared with those obtained by other algorithms from the literature.

In Chapter VIII the authors applied ant colony algorithms to data centric routing in sensor networks. This problem corresponds to finding paths from multiple sources in a sensor network to multiple destinations, with an intermediate aggregation in the paths for optimal dissemination. A minimum Steiner tree in the network results when a single destination is involved. Initially, an offline algorithm was proposed for the minimum Steiner tree problem, and then an online algorithm for data centric routing was introduced. The performance of the algorithms was presented for some problems and several trends for future research were suggested.

Chapter IX investigates the use of pheromone and progressive vision in the standard ant clustering algorithm (ACA). The standard algorithm is presented followed by a brief review from the literature concerning the applications and variations of the basic model. A sensitivity analysis of the standard algorithm in relation to its main user-defined parameters is presented, and two novel modifications of the original algorithm are proposed and discussed. A variation of a simple benchmark problem in the field is used to perform the sensitivity analysis of the algorithm and to assess the proposed modifications of the standard algorithm.

The last chapter (Chapter X) of Section III on swarm intelligence brings a sociocognitive perspective of particle swarm (PS) algorithms, describes its most important variations and compares it with related approaches, such as evolutionary algorithms. The emphasis of the chapter is on a description of PS as an algorithm inspired by the social psychological behavior of human beings. The author argues that it is our cognitive and social behaviors that allowed us to evolve to the level we have reached, and these were useful as inspiration for the development of another biologically motivated algorithm. The sociocognitive space is divided in three subspaces: parameter space, sociometric space, and evaluative space, and the role each of them plays in the PS algorithm is discussed.

Section IV: Artificial Life and Artificial Creatures

Section IV of the book is devoted to artificial life and artificial creatures. It starts with Chapter XI proposing a methodology based on Peircean semiotics to simulate the emergence of symbolic predator warning communication among artificial creatures in a virtual world. The authors based their computational experiments on the semiosis in East African vervet monkeys, a model chosen due to the vast literature available. The chapter provides the reader with a brief discussion about Peircean semiotics, the analysis of semiotic processes in the vervet monkey, and then describes the virtual environment that will be inhabited by the virtual creatures. To illustrate how the creatures interact with each other in the virtual environment the authors took two episodes related to symbol learning and use.

In Chapter XII the author discusses some perspectives for strong artificial life; that is, the creation of life in an artificial media, such as the computer. The author calls the difficulty in *defining life* and in *creating instances of life* as *the twin deadlocks of artificial life*. The chapter starts by setting a discussion about the difficulty in defining life and some of the many tentative concepts are presented. It then follows with a discussion about computationalism and realizations of life. The author argues that progress in ALife thoughts will necessarily contribute to the evolution of philosophical thinking in at least two ways: by helping to validate hypotheses and thought experiments, and by helping to discover unknown underlying processes and connections in natural systems. These are actually some of the contributions of Chapter XI as well.

Section V: Information Processing and Cognitive Systems

In Chapter XIII the author introduces the concept of *fractal proteins* as a new evolutionary method to map genotype into phenotype by using a developmental process. In this case genes are expressed into proteins composed of subsets of the Mandelbrot set, thus giving origin to fractal proteins. After introducing concepts about development, the Mandelbrot set, and fractal proteins, the work demonstrates, with applications to robotics autonomous navigation, that fractal gene regulatory networks can be successfully evolved with the objective of solving problems. The resultant system is not only capable of learning good solutions, but also of learning ways to build good solutions.

In Chapter XIV the authors propose a route to implement computational intelligence inspired by multiple biological systems. The authors suggest that current bio-inspired techniques are approaching their potential limit for application when implemented in isolation. The proposal is that the integration of different techniques into more structured and complex architectures may have a higher probability of achieving the level of sophistication and complexity required for the success of fields such as robotics. To accomplish this, the authors propose to integrate artificial neural networks, artificial immune systems and artificial endocrine systems in a single homeostatic system.

Work in Chapter XV describes several collective robotic experiments inspired by the collective behavior of social insects, in particular ant colonies. The authors provide a high-level description of multi-robot systems to perform tasks such as group transport, collective constructions, and collective sorting. The chapter starts with a brief survey of robotic systems inspired by social insects and follows with the description of the group's contributions to the field. Several experiments already reported in the literature are reviewed and original, unpublished, results are presented.

Chapter XVI provides a brief review of artificial neural networks with an emphasis on *continuous attractor neural networks*. These networks implement cooperation and competition between input stimuli and the network dynamics drives initial input to one of many attractor states based on some dominating input features. The focus of the chapter is on an introduction to continuous attractor neural networks. Although this type of network has not yet been broadly applied in domains such as computing and engineering, they are important as models of brain processing. However, examples of potential applications are also proposed in order to suggest future research.