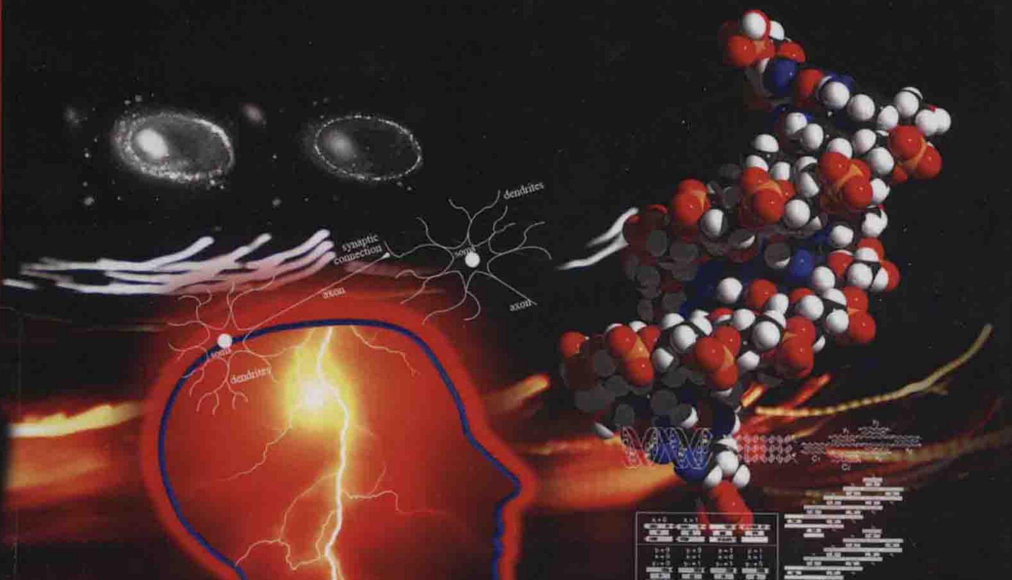
Nature-Inspired Computation

Mario D'Acunto



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To Ovidio Salvetti

PREFACE

Nature inspired computation is an old idea, first proposed in the early fifties by Alan Turing, one of the founders of the computer science. Turing suggested computational models of pattern formation in living systems based on systems of coupled reaction-diffusion equations giving rise to spatial patterns due to self-organization of substances in chemical concentrations.

Since the pioneering work by Turing, many optimization algorithms stimulated by real-world features have gained great popularity and impact in all scientific topics, thanks to their efficiency in solving nonlinear design problems. Nature-inspired computation has permeated into almost all areas of sciences, engineering and industries, from data mining to optimization, from computational intelligence to signal processing, from image analysis and vision systems to industrial applications, giving also the possibility to approach to wide multidisciplinary connections.

Nature is full of examples of computation and intelligence, complex systems and optimal solutions, so looking at natural systems, nature-inspired computation is a term that encompasses the entire range of the computational version of the process of extracting ideas from Nature to develop or improve computational systems, or using natural systems (like DNA, atoms, molecules, ant colony, reaction-diffusion systems, etc.) to perform computation. Just to give an example, any sensory systems that responds and adapts can naturally be viewed as an information device. Sensory systems can be characterized by fast response and slow adaption to varying environmental cues. As sensory adaptive systems map environmental changes to changes of their internal degrees of freedom, they can be regarded as computational devices manipulating information.

The book provides an introductory tour of the most popular nature inspired computational strategies. The book is subdivided in two parts, anyone briefly describing the inspiration and motivation by natural processes and phenomena, main players, design principles, scope of each branch, current trends and open problems. After an introductive description of some basic ideas underlying the nature-inspired computation, chapter 1, in the first part of the book, we focus the attention on the long tradition computing inspired by nature as Artificial and Spiking Neural Networks (chapter 2), Evolutionary and Genetic Algorithms (chapter 3), and Swarm Intelligence algorithms (chapter 4). In the second part, we present the emergent knowledge and technologies in Multiscale Nature processes (chapter 5), Quantum Computing and Quantum Cryptography (chapter 6), Encryption and Secure Communication system (chapter 7), Image processing and Vision systems (chapter 8), and finally on Nanophotonics Information (chapter 9).

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About the Author

Mario D'Acunto. M. Sci. degree in Physics from the University of Pisa in 1994, PhD degree in Materials Science at the Dept. of Mechanical and Nuclear Engineering, University of Pisa in 1999. Research Assistant at the Dept. of Physics, Dept. of Chemical Engineering and Materials Science, Dept. of Earth Science at the University of Pisa. Since 2009, he joined the Italian National Research Council (CNR) with a pioneering research activity connecting Machine Learning and Artificial Intelligence with Nanostructures. Currently, he is permanent researcher at the Institute of Structure of Matter (ISM-CNR), in Rome, and at the Institute of Information Science and Technologies, (ISTI-CNR), Pisa, Italy. His main interests, past and present, include theoretical and experimental skills in Surface Physics, Materials Science and Tribology, Image Processing and Analysis, Nonlinear dynamics, Microscopy techniques ranging from the molecular scale to optical range such as Scanning Probe Microscopy, Electron Microscopy, etc.

He is internationally recognized as a leading pioneer in the field of nanotribology, and his model on atomic wear has been named *D'Acunto model* by independent authors. He is the co-founder (with Ovidio Salvetti) since 2012 of the NanoICT laboratory, a *distributed-laboratory* with the main purpose to apply artificial intelligence and machine learning to nanostructures, in a special way on nanophotonic systems.

CONTENTS

Chapter 1

INTRODUCTION: TAKING INSPIRATION FROM NATURE TO SOLVE COMPUTATION PROBLEMS

Nature-inspired Computation, and in a special way, bio-inspired computation, have attracted great interest in the last two decades, and, in particular, many optimization algorithms stimulated by real-world features have gained huge popularity. There are many reasons for such popularity and attention, and two main reasons are probably that such algorithms are flexible and versatile, and that they are very efficient in solving nonlinear design problems with real-world application. Nature-inspired computation has permeated into almost all areas of sciences, engineering and industries, from data mining to optimization, from computational intelligence to signal processing, from image analysis and vision systems to industrial applications. In fact, such algorithms due to their nature inspiration are one of the most active and popular research subjects with wide multidisciplinary connections.

The basic ideas underlying the nature-inspired computation can be backdated to the pioneering work of Church and Turing in the thirties of the last century. Indeed, a prevailing paradigm in classical computation theory, commonly recognized Church-Turing Thesis, affirms that no realizable computing device can be more powerful and efficient, aside from relative speedups, than a universal Turing machine (Church, 1932; Church, 1936, Turing, 1937; Calude and Păun, 2001, Ben Aman, 2005). As it is known for Turing machine is intended a hypothetical device that manipulates symbols on a strip of a physical recording tape according to a table of rules (Calude and

Păun, 2001). The Church-Turing Thesis is a precisely a thesis and not a theorem, nevertheless, many logicians and physicists challenged to define some insights from the Church-Turing Thesis into mathematical notion of probabilistic Turing machine adapted to simulate the logic of any computer algorithm. As a consequence, the Church-Turing Thesis has been used to approach formally the notion of intelligent being, that is stated with the following expression: *What is human computable is computable by a universal Turing machine*. This sentence equates information-processing capabilities of a human being with the *intellectual* capacities of a universal Turing machine. Moreover, this sentence implies also some questions on what types of computations are physically realizable and on the general problem on how translates in physical systems (electronic computers, for example) arithmetic operations, such as addition, subtraction, multiplication and division. Coherently with the Church-Turing Thesis, the notion of intelligence can be extended to the natural systems that can be traduced in terms of computational tasks and capability of Nature to operate as a *natural computer*.

In, this sense, nature-inspired computation is the computational version of the process of extracting ideas from nature to develop or improve computational systems, or using natural systems (like, DNA, atoms or molecules) to perform computation. Nature-inspired computing is a sub-branch of the most general natural computing, and can be defined as the field of research that, based or inspired by nature, allows the development of new computational tools, both hardware and software, The nature-inspired computation can be divided into two main branches (de Castro, 2007): *Computing inspired by nature* or *Computing with natural materials*.

In the first case, the basic idea is to develop computational tools, like algorithms, by taking inspiration from nature for the solution of complex problems. Through millions of years of trial-and-error using the mechanism of natural selection, nature has chosen specific solutions to problems such as survival and foraging for food in a hostile environment, involving the adaptation to totally different habitats.

In the latter case, computation is performed by using novel natural materials, where a novel computing paradigm comes out substituting or integrating the current silicon-based computers. Nature-inspired computation differs from natural computing, because does not consider a priority of inspiration from the *nature the simulation and emulation of nature by means of computing*. Nevertheless, both natural computing and nature-inspired computation represent multidisciplinary areas of investigation, involving computer scientists, physicists, chemists, engineers, biologists due to the