# Preface

At the beginning of the 1990s research started in how to combine soft computing with reconfigurable hardware in a quite unique way. One of the methods that was developed has been called *evolvable hardware*. Thanks to evolutionary algorithms researchers have started to evolve electronic circuits routinely. A number of interesting circuits – with features unreachable by means of conventional techniques – have been developed. Evolvable hardware is quite popular right now; more than fifty research groups are spread out over the world. Evolvable hardware has become a part of the curriculum at some universities. Evolvable hardware is being commercialized and there are specialized conferences devoted to evolvable hardware.

On the other hand, surprisingly, we can feel the lack of a theoretical background and consistent design methodology in the area. Furthermore, it is quite difficult to implement really innovative and practically successful evolvable systems using contemporary digital reconfigurable technology.

This monograph deals with evolvable hardware and its mathematical generalization: evolvable computational machines. The aim is to introduce the concepts (missing in the field nowadays) that designers as well as theoreticians could benefit from. Nowadays it is more than evident that component technology plays a crucial role in engineering. And it seems that evolvable hardware could benefit from the component approach as well. Hence an original idea, a theory, and implementations of the *evolvable component* are developed and presented in this book. We do believe that the concept of the evolvable component will lead to a much deeper understanding of computer systems designed by methods inspired by evolutionary biology.

**Structure of the Book.** Because the book deals with various scientific areas such as evolutionary algorithms, hardware design and theoretical computer science, a relatively large portion of the text is devoted to the introductory chapters. We will start with a general overview of soft computing and bioinspired hardware in the first chapter, which – together with Chaps. 2, 3, and 4 – could also serve as an introduction to the field of (digital) evolvable hardware for those who are interested in this popular and topical area of computer engineering and computer science and who are now meeting evolvable hardware for the first time.

Chapter 2 briefly introduces the contemporary paradigm of digital circuit design (i.e. conventional circuit design). In particular, the basic characteristics of field programmable gate arrays (FPGA) and their reconfiguration options will be discussed. We have also included sections on reconfigurable computing and nanotechnology, which represent two recent stages of computational system design and implementation and which are closely related to evolvable hardware.

Chapter 3 provides a survey of evolutionary algorithms. We will emphasize evolutionary design in contrast to evolutionary optimization. A formal definition of an evolutionary algorithm is introduced because it will be utilized in Chap. 6.

It is possible to find in the literature a suitable survey of reconfigurable hardware and evolutionary algorithms for the purposes of this book. It is also the case of evolvable hardware. For instance, Gordon's and Bentley's paper [57] provides a good introduction to the field. According to our knowledge there exist only two books fully devoted to evolvable hardware. The first is Adrian Thompson's dissertation from 1996 [187] and the second is "Evolutionary Electronics" written by Zebulum, Pacheco and Vellasco [230]. However, we have decided to summarize the state-of-the-art of digital evolvable hardware in Chap. 4. This survey is mainly based on papers published during the last seven years on two evolvable hardware-related conference series (the Evolvable Systems: From Biology to Hardware Conferences and the NASA/DoD conferences on Evolvable Hardware), some journal papers, and our insight into the problem.

The component approach to evolvable hardware is introduced in Chap. 5. We will show how evolvable components support dynamic environment and reusability concepts. An automaton, which controls the behavior of the evolvable component, will be derived and considered as a basic reusable unit.

The formal definition of a general evolvable computational machine will be formulated in Chap. 6. Then some properties of evolvable computational machines will be investigated formally. Evolvable machines will be related to an emerging field of theoretical computer science: hypercomputation (or super-Turing computation), where well-defined computations are not exhausted by the computations that can be carried out by a Turing machine. In particular, we will prove that evolvable systems exhibit a super-Turing computational power. In this case some concepts and results of theoretical computer science (such as Turing machines, the Church–Turing thesis, cellular automata, computability, etc.) will be utilized and recalled.

We will develop the evolvable component for image pre-processing in Chap. 7 in order to illustrate that the component approach is beneficial for the solution of real-world problems. The various image operators evolved in using the component will be compared with conventional operators in terms of quality and implementation costs.

Chapter 8 describes an implementation of a virtual reconfigurable circuit utilized in the evolvable component for image pre-processing. This virtual reconfigurable circuit enables us to speed up the component adaptation substantially. We will show that it is possible to synthesize the virtual reconfigurable circuit into an ordinary FPGA.

Finally, Chap. 9 summarizes the results we present in this book and gives some directions for future research.

**Readers.** The reader is assumed to be familiar with the basics of theoretical computer science, software design and hardware design in the scope of a B.Sc. degree in computer engineering or equivalent. All readers will benefit from a unified and coherent approach to the evolvable systems presented in this book. In contrast to the mainstream single-orientation publications, the book is based on formal, software and hardware viewpoints. Academic and scientific readers should benefit from the system-level approach and formal concepts introduced for evolvable systems in the book. Practitioners, evolutionary designers, and hardware designers will probably like the results of experiments and the methods which can directly be applied in research or industry. The concept of the virtual reconfigurable circuit should be important for people from the reconfigurable computing community. Finally, teachers and students can utilize the first chapters on evolutionary algorithms, reconfigurable circuits and evolvable hardware during lectures and home reading.

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