Ivan Zelinka, Sergej Celikovsky, Hendrik Richter, and Guanrong Chen (Eds.)

Evolutionary Algorithms and Chaotic Systems

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and Guanrong Chen (Eds.)

Evolutionary Algorithms and Chaotic Systems

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Ivan Zelinka dedicates this book to his wonderful wife Martina, his beautiful daughters Marketa and Katerina, and to his parents.

Sergej Celikovsky dedicates this book to his parents Karel and Galina, his wife Avgustina, daughter Klara and son Viktor.

Guanrong Chen dedicates this book to the memory of his mentor Professor Mingjun Chen (1934-2008).

Foreword

Ever since the historical discovery of the now-famous Lorenz system in 1963, a large number of nonlinear systems that can produce chaos have been observed, constructed and analyzed. In fact, chaos theory has become indispensable for science and engineering at all levels of research today. The most active recent research includes chaos control and chaos synchronization, among others, with a visible trend toward real-world applications.

The book titled "Evolutionary Algorithms and Chaotic Systems", edited by Ivan Zelinka, Sergej Celikovsky, Hendrik Richter and Guanrong Chen, is a timely volume to be welcome by the chaos community as well as computational intelligence community and beyond. This book is devoted to the studies of common and related subjects in two intensive research fields of chaos theory and evolutionary computation. It was not typical that evolutionary computing techniques are used for effective chaos control, chaos synchronization, chaos identification, and in particular for chaos analysis and synthesis, therefore this edition of collective state-of-the-art articles on such interdisciplinary subjects is especially valuable for the scientific and engineering communities. For these reasons, I enthusiastically recommend this book to our scientists and engineers working in the fields of nonlinear dynamics, evolutionary algorithms, control theory, circuits and systems, and scientific computing alike.

University of California at Berkeley, September 2009 Leon O. Chua

Preface

Deterministic chaos is a fairly active area of research in the last few decades. Well known chaotic attractors can even be produced by some simple three-dimensional autonomous systems of ordinary differential equations, for example the Lorenz system, which originates from modelling of atmospheric dynamics. For discrete chaos, there is another famous chaotic system, called logistic equation, which was found based on a predator-prey model showing complex dynamical behaviors. These simple models are widely used in the study of chaos today, while other similar models exist (e.g., canonical logistic equation and 1D or 2D coupled map lattices). To date, a large set of nonlinear systems that can produce chaotic behaviors have been observed and analyzed. Chaotic systems thus have become a vitally important part of science and engineering at the theoretical as well as the practical level of research. The most interesting and applicable notions are, for example, chaos control and chaos synchronization related to secure communications, among others. Recently, the study of chaos is focused not only along the traditional trends but also on the understanding and analyzing principles, with the new intention of controlling and utilizing chaos toward real-world applications.

This book discusses the mutual intersection of two interesting fields of research, i.e. deterministic chaos and evolutionary computation. Evolutionary techniques are discussed in this book, which are able to handle tasks such as control of various chaotic systems and synthesis of their structures (i.e., handling symbolic objects to create more complex structures). In this way, evolutionary techniques are capable of synthesizing chaotic behavior in the sense that mathematical descriptions of chaotic systems are generated symbolically. Another capability of evolutionary computation - identification of chaotic system structure-is also discussed in this book. Part of the book is focused on how chaos can be observed in the dynamics of evolutionary algorithms and used to improve performance of selected evolutionary techniques.

Chapter authors background: Chapter authors are to the best of our knowledge the originators or closely related to the originators of the above

mentioned applications of evolutionary computation as well as the applications of chaos principles in selected evolutionary algorithms. Hence, this book will be one of the few books discussing the benefit from intersection of two modern and fruitful scientific fields of research.

Organization of the Chapters and Book Structure: The book consist of three parts. The first part is presented by Zelinka and Chen as a motivation for the application of evolutionary computation on chaotic systems (Chapter 1). It is followed by a brief introduction of evolutionary algorithms for chaos researchers (Zelinka and Richter, Chapter 2). The next chapter is a complementary and serves as an introduction of chaos theory for evolutionary algorithms researchers (Celikovsky and Zelinka, Chapter 3). The last chapter of this first part discusses the appearance of the so-called edge of chaos in evolutionary algorithms (Davendra, Chapter 4).

The second part discusses the use of evolutionary algorithms on chaotic dynamics. A reader can find here an approach of evolutionary algorithms to 1D chaos control (Senkerik et. al., Chapter 5), spatiotemporal chaos control (Zelinka, Chapter 6) or chaos reconstruction by means of standard methods (Chapter 7, Chadli), which is followed by Chapter 8 (Zelinka, Raidl) in which evolutionary algorithms are used to reconstruct chaotic systems from measured data. Chapter 9 (Ping Li et. al.) is focused on the use of chaos in encryption, Chapter 10 (Zelinka, Jasek) demonstrates possible benefit and drawback of the usage of evolution on decryption of chaotically encrypted information. In Chapter 11 (Zelinka, Chen, Celikovsky) synthesis of chaotic structure by means of genetic programming like techniques is discussed. Furthermore, Chapter 12 is centered on the application of evolutionary algorithms on chaos synchronization (Zelinka, Raidl). Finally, the application of evolutionary optimization in chaotic CML-based fitness landscapes by Richter (Chapter 13) is discussed.

The third part discuss the appearance and use of deterministic chaos in evolutionary techniques. Chapter 14 (Davendra, Zelinka) describes the impact of various chaotic systems use on mutation of individuals and Chapter 15 shows the appearance of chaos in selected evolutionary techniques (Davendra, Zelinka and Onwubolu) and discusses the impact of chaos on permutative optimization.

The book is based on original research and contains all important results including more than 589 pictures.

Audience: The book will be an instructional material for senior undergraduate and entry-level graduate students in computer science, physics, applied mathematics and engineering, who are working in the area of deterministic chaos and evolutionary algorithms. Researchers who want to investigate how evolutionary algorithms can be used for chaos control as well as researchers interested in the appearance of chaos in evolutionary algorithms will find this book a very useful handbook and starting step-stone. The book will also be

a resource and material for practitioners who want to apply these methods to solve real-life problems in their challenging applications.

Appendix: The appendix contains description of Mathematica software and user manual for 40 notebooks. Their actual versions can also be downloaded from www.fai.utb.cz/people/zelinka/evolutionarychaos or www.ivanzelinka.eu/evolutionarychaos. It consist Mathematica notebooks of different evolutionary (or random-like) algorithms and test functions, interactive notebooks allowing manipulation of different chaotic systems and notebooks supporting selected case studies reported in this book.

Motivation: The decision as why to write this book was based on a few facts. The main one is that the research field on evolutionary algorithms and deterministic chaos is an interesting area, which is under intensive research from many other branches of science today. Evolutionary algorithms with its applications can be found in biology, physics, economy, chemical technologies, air industry, job scheduling, space research (i.e. antena design for space mission), amongst others. The same can be stated for deterministic chaos. This kind of behavior can be observed in physical as well as biological, economical systems etc. Due to the fact that evolutionary algorithms are capable of solving many problems including problems containing imprecise information or uncertanities, it is obvious that it can also be used on chaotic systems to control, synchronize or/and synthesize them. On the other hand, chaotic systems and their behavior are very important in engineering, because such behavior can be used to encrypt important information or, for example, cause damage if not expected or desired in designed device. Together with "classical" techniques, evolutionary algorithms can be used to solve various tasks based on deterministic chaos. This book was written to contain simplified versions of our experiments with the aim to show how, in principle, evolutionary algorithms can be used on chaotic systems, and vice versa.

It is obvious that this book does not encompass all aspects of these two fields of research due to limited space. Only the main ideas and results are reported here. The authors and editors hope that the readers will be inspired to do their own experiments and simulations, based on information reported in this book, thereby moving beyond the scope of the book.

September 2009

Czech Republic — Ivan Zelinka
Czech Republic — Sergej Celikovsky
Germany — Hendrik Richter
Hong Kong — Guanrong Chen

Acknowledgements

We are grateful to all the contributors of this book, for their willingness to work on this interdisciplinary book project which focuses on intersection of two interesting fields of research: deterministic chaos and evolutionary algorithms. To write such a book was a little bit complicated due to the fact that both areas are quite special and researchers are usually experts only of one of the two areas. Fortunately, we were able to establish a very good team of contributors, who were interested in participation and were working professionaly and quickly. Also, the help and support of other colleagues and friends are indispensable to this book. Thus, we would like to thank all of them.

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