Studies in Computational Intelligence

Volume 501

Series Editor

J. Kacprzyk, Warsaw, Poland

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Automated Design of Analog and High-frequency Circuits

A Computational Intelligence Approach

Springer

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ISSN 1860-949X
ISSN 1860-9503 (electronic)
ISBN 978-3-642-39161-3
ISBN 978-3-642-39162-0 (eBook)
DOI 10.1007/978-3-642-39162-0
Springer Heidelberg New York Dordrecht London

Library of Congress Control Number: 2013942654

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

Computational intelligence techniques are becoming more and more important for automated problem solving nowadays. Due to the growing complexity of industrial applications and the increasingly tight time-to-market requirements, the time available for thorough problem analysis and development of tailored solution methods is decreasing. There is no doubt that this trend will continue in the foreseeable future. Hence, it is not surprising that robust and general automated problem solving methods with satisfactory performance are needed.

Some major problems that highlight the weakness of current computational intelligence techniques are appearing because of the increasing complexity of real-world systems:

- Long computational time for candidate evaluations: due to the increasing number of equations to be solved in real-world problems, the evaluation of candidate solutions may become computationally expensive.
- Large uncertainty: the simulations or physical experimental results may be very inaccurate because the human-designed model can only catch the most critical parts of the system.
- High dimensionality: because of the increasing complexity, many currently good human-designed simplified models may no longer be useful, and, hence, the analysis based on these models does not work. Therefore, full models with a large number of decision variables may be encountered in many real-world applications.

From the points above, it can be concluded that new methods with the ability to efficiently solve the problems, methods that can bear large uncertainty and methods that can handle large-scale problems, while at the same time providing high quality solutions, will be useful in the foreseeable future. The purpose of this book is to discuss these problems and to introduce state-of-the-art solution methods for them, which tries to open up fertile ground for further research.

Instead of using many kinds of real-world application problems from various fields, this book concentrates on a single but challenging application area, analog and high-frequency integrated circuit design automation. Since this decade, computational intelligence techniques are becoming more and more important in the electronic design automation (EDA) research area and are applied to many

EDA tools. EDA research is also stimulating the development of new computational intelligence techniques. For example, when searching "robust optimization" or "variation-aware design optimization", it can be found that a large number of research papers are from the EDA field. Moreover, many difficult problems from the EDA area are also cutting-edge problems for intelligent algorithm research.

Therefore, this book: "Automated Design of Analog and High-frequency Circuits: A Computational Intelligence Approach", is intended for researchers and engineers in both the computational intelligence area and the electronic design automation area.

For the computational intelligence researchers, this book covers evolutionary algorithms for single and multi-objective optimization, hybrid methods, constraint handling, fuzzy constraint handling, uncertain optimization, regression using machine learning methods, and computationally expensive optimization. Surrogate model assisted evolutionary algorithm for computationally expensive optimization problems is one of the main topics of this book. For robust optimization in uncertain environments and fuzzy constrained optimization, the state-of-the-art is reviewed; some promising solution methods are introduced elaborately, which complements the available literature. Evolutionary computation spreads throughout this book, but it is not our purpose to elaborate this specific research area, since numerous books and reports are available. Instead, we cover fundamentals, a general overview of the state-of-the-art related to the types of problems for the applications considered, and popular solution methods. In Chaps. 1, 2 and introductory sections of Chaps. 5 and 7, we try to make the beginners to catch the main ideas more easily and then provide a global picture for a specific topic for the use of further research and application. Professional computational intelligence researchers can escape the above mentioned contents.

For the electronic design automation researchers, this book tries to provide a tutorial on how to develop specific EDA methods based on advanced computational intelligence techniques. In many papers and books in this area, computation intelligence algorithms are often used as tools without deep analysis. This book, on the other hand, pays much attention to the computational intelligence techniques themselves. General concepts, details and practical algorithms are provided. The broad range of computational intelligence and complex mathematical derivations are introduced but are not described in detail. Instead, we put much effort on the general picture and the state-of-art techniques, as well as the method to use them in their EDA related tasks. The authors believe that EDA researchers can save much time on performing "data mining" from the computational intelligence literature to solve challenging problems at hand, and even develop their own methods with the help of this book. In addition, to the best of our knowledge, this is the first book covering systematic high-frequency integrated circuit design automation.

The concepts, techniques and methods introduced in this book are not limited to the EDA field. The properties and challenges from the real-world EDA problems are extracted. Researchers from other fields can also benefit from this book by using the practical real-world problems in this book as examples.

Chapter 1 provides the basic concepts and background in both computational intelligence and EDA fields. Their relationships are discussed and the challenging problems which will be addressed in this book are introduced.

The main content of this book, Chaps. 2–10, can be divided into three parts.

The first part includes Chaps. 2–4, focusing on the global optimization of highly constrained problems.

Chapter 2 introduces the basics or fundamentals of evolutionary algorithms and constraint handling methods with the practical application of analog integrated circuit sizing. This chapter covers evolutionary algorithms for single and multi-objective optimization and basic constraint handling techniques. Popular methods are introduced with practical examples.

Chapter 3 discusses advanced techniques for high performance design optimization. This chapter reviews advanced constraint handling methods and hybrid methods and introduces some popular methods. Practical examples are also provided.

Chapter 4 introduces optimization problems with fuzzy constraints to integrate the humans' flexibility and high optimization ability of evolutionary algorithms. Fuzzy sets, fuzzy constraint handling methods and the integration of fuzzy constraint handling methods into previous techniques are presented. The application field is fuzzy analog circuit sizing.

The second part includes Chaps. 5 and 6, and focuses on efficient global optimization in uncertain environments, or robust design optimization.

Chapter 5 provides an overview of uncertain optimization, and the application area: variation-aware analog circuit sizing. Two common efficiency enhancement methods for uncertain optimization are then introduced, including some basics of computational statistics.

Chapter 6 introduces ordinal optimization-based efficient robust design optimization methods. The method to cooperate ordinal optimization with hybrid methods, single and multi-objective constrained optimization methods is then discussed with practical examples.

The third part includes Chaps. 7–10, and focuses on efficient global optimization of computationally expensive black-box problems.

Chapter 7 reviews surrogate model assisted evolutionary algorithms and the application area: design automation of mm-wave integrated circuits and complex antennas. Two machine learning methods, Gaussian process and artificial neural networks are introduced.

Chapter 8 introduces the fundamentals of surrogate model assisted evolutionary algorithms that are applied to high-frequency integrated passive component synthesis. Three popular methods to handle the prediction uncertainty, which is the fundamental problem when integrating machine learning techniques with evolutionary algorithms, are introduced with practical examples.

Chapter 9 introduces a method for mm-wave linear amplifier design automation. The methods to analyze the problem from the computation aspect, to utilize its properties and to transform it to a problem that can be solved by the techniques introduced in Chap. 8 are discussed. Instead of introducing new computational

intelligence techniques, this chapter concentrates on how to make use of the basic techniques to solve complex problems.

Chapter 10 focuses on the cutting-edge problem in surrogate model assisted evolutionary algorithms: handling of high dimensionality. Two state-of-the-art techniques, dimension reduction and surrogate model-aware evolutionary search mechanism are introduced. The practical examples are the synthesis of mm-wave nonlinear integrated circuits and complex antennas.

Finally, we would like to thank the Alexander von Humboldt Foundation, Professor Guenter Rudolph, Professor Helmut Graeb, Professor Tom Dhaene, Professor Qingfu Zhang, Professor Guy A. E. Vandenbosch, Dr. Trent McConaghy, Dr. Patrick Reynaert, Dixian Zhao, Dr. Hadi Aliakbarian, Dr. Brecht Machiels, Zhongkun Ma, Noel Deferm, Wan-ting Lo, Bohan Yang, Borong Su, Chao Li, Jarir Messaoudi, Xuezhi Zheng and Ying He. We also express our appreciation to Professor Janusz Kacprzyk and Dr. Thomas Ditzinger for including this book in the Springer series on "Studies in Computational Intelligence".

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