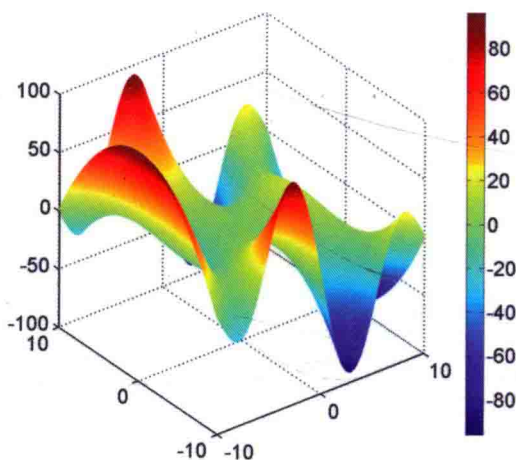
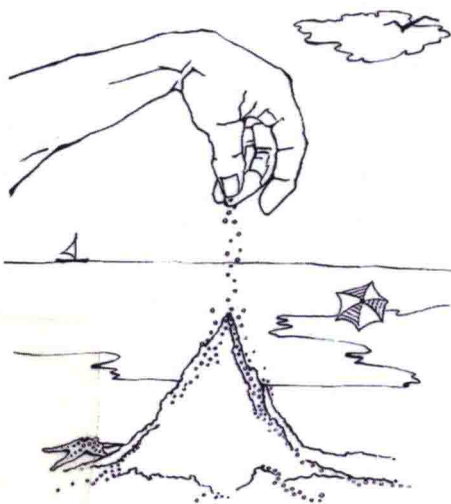


Extremal Optimization

Fundamentals,
Algorithms and Applications

极值优化：原理、算法和应用

吕勇哉 陈玉旺 陈泯融 陈 鹏 曾国强 著

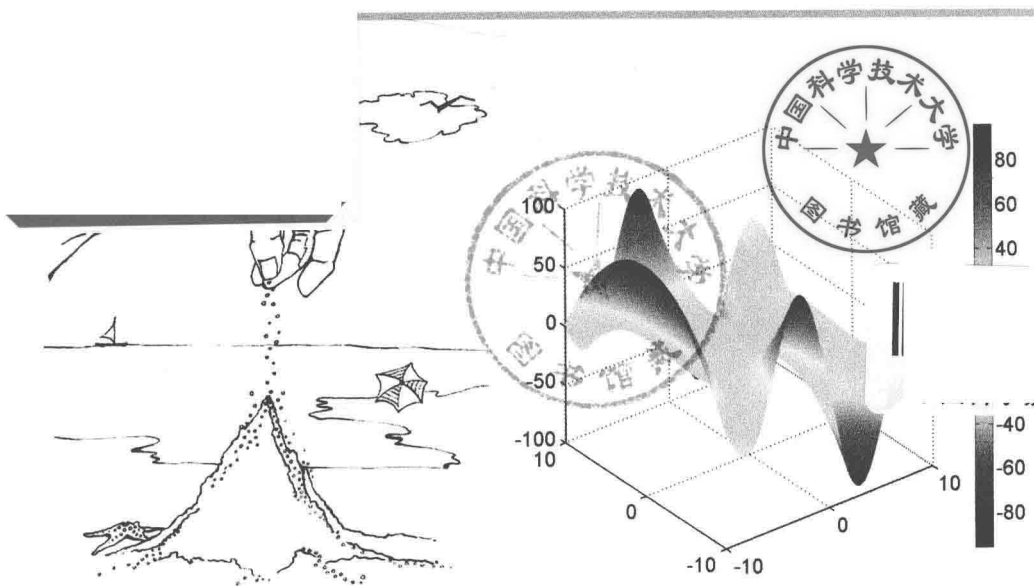


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Extremal Optimization

Fundamentals, Algorithms, and Applications

Yong-Zai Lu • Yu-Wang Chen
Min-Rong Chen • Peng Chen
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Preface

With the high demand and the critical situation of solving hard optimization problems we are facing in social, environment, bioinformatics, traffic, and industrial systems, the development of more efficient novel optimization solutions has been a serious challenge to academic and practical societies in an information-rich era. In addition to the traditional math-programming-inspired optimization solutions, computational intelligence has been playing an important role in developing novel optimization solutions for practical applications. On the basis of the features of system complexity, a new general-purpose heuristic for finding high-quality solutions to NP-hard (nondeterministic polynomial-time) optimization problems, the so-called “extremal optimization (EO),” was proposed by Boettcher and Percus. In principle, this method is inspired by the Bak–Sneppen model of self-organized criticality describing “far-from-equilibrium phenomena,” from statistical physics, a key concept describing the complexity in physical systems. In comparison with other modern heuristics, such as simulated annealing, genetic algorithm (GA), through testing on some popular benchmarks (TSP [traveling salesman problem], coloring, K-SAT, spin glass, etc.) of large-scale combinatory-constrained optimization problems, EO shows superior performance in the convergence and capability of dealing with computational complexity, for example, the phase transition in search dynamics and having much fewer tuning parameters.

The aim of this book is to introduce the state-of-the-art EO solutions from fundamentals, methodologies, and algorithms to applications based on numerous classic publications and the authors’ recent original research results, and to make EO more popular with multidisciplinary aspects, such as operations research, software, systems control, and manufacturing. Hopefully, this book will promote the movement of EO from academic study to practical applications. It should be noted that EO has a strong basic science foundation in statistical physics and bioevolution, but from the application point of view, compared with many other metaheuristics, the application of EO is much simpler, easier, and straightforward. With more studies in EO search dynamics, the hybrid solutions with the marriage of EO and other metaheuristics, and the real-world application, EO will be an additional weapon to

deal with hard optimization problems. The contents of this book cover the following four aspects:

1. General review for real-world optimization problems and popular solutions with a focus on computational complexity, such as “NP-hard” and the “phase transitions” occurring on the search landscape.
2. General introduction to computational extremal dynamics and its applications in EO from principles, mechanisms, and algorithms to the experiments on some benchmark problems such as TSP, spin glass, Max-SAT (maximum satisfiability), and graph partition. In addition, the comparisons of EO with some popular heuristics, for example, simulated annealing and GA, are given through analytical and simulation studies.
3. The studies on the fundamental features of search dynamics and mechanisms in EO with a focus on self-organized optimization, evolutionary probability distribution, and structure features (e.g., backbones) are based on the authors’ recent research results. Moreover, modified extremal optimization (MEO) solutions and memetic algorithms are presented.
4. On the basis of the authors’ research results, the applications of EO and MEO in multiobjective optimization, systems modeling, intelligent control, and production scheduling are presented.

The authors have made great efforts to focus on the development of MEO and its applications, and also present the advanced features of EO in solving NP-hard problems through problem formulation, algorithms, and simulation studies on popular benchmarks and industrial applications. This book can be used as a reference for graduate students, research developers, and practical engineers when they work on developing optimization solutions for those complex systems with hardness that cannot be solved with mathematical optimization or other computational intelligence, such as evolutionary computations. This book is divided into the following three parts.

Section I: Chapter 1 provides the general introduction to optimization with a focus on computational complexity, computational intelligence, the highlights of EO, and the organization of the book; Chapter 2 introduces the fundamental and numerical examples of extremal dynamics-inspired EO; and Chapter 3 presents the extremal dynamics-inspired self-organizing optimization.

Section II: Chapter 4 covers the development of modified EO, such as population-based EO, multistage EO, and modified EO with an extended evolutionary probability distribution. Chapter 5 presents the development of memetic algorithms, the integration of EO with other computational intelligence, such as GA, particle swarm optimization (PSO), and artificial bee colony (ABC). Chapter 6 presents the development of multiobjective optimization with extremal dynamics.

Section III includes the applications of EO in nonlinear modeling and predictive control, and production planning and scheduling, covered in Chapters 7 and 8, respectively.

Acknowledgments

This book was written based on the published pioneering research results on extremal dynamics-inspired optimization, and the authors' recent research and development results on the fundamentals, algorithms, and applications of EO during the last decade at both Shanghai Jiao Tong University (SJTU) and Zhejiang University, China. We wish to thank the Department of Automation, SJTU, the Research Institute of Cyber Systems and Control, Zhejiang University, and the Research Institute of Supcon Co. for their funding of PhD programs and research projects. We are most grateful to Professor J. Chu at Zhejiang University, Professors Y. G. Xi and G. K. Yang at SJTU, and Directors Y. M. Shi and Z. S. Pan of Supcon Co. for their strong support and encouragement.

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FUNDAMENTALS, METHODOLOGY, AND ALGORITHMS

I

Chapter 1

General Introduction

1.1 Introduction

With the revolutionary advances in science and technology during the last few decades, *optimization* has been playing a more and more important role in solving a variety of real-world systems for modeling, optimization, and decision problems. The major functions of optimization are to provide one or multiple solutions that are able to optimize (e.g., minimize or maximize) the desired objectives subject to the given constraints in the relevant search space. The optimization techniques have been popularly applied in business, social, environmental, biological, medical, man-made physical and engineering systems, etc. Due to the increase in computational complexity, traditional mathematics-inspired optimization solutions, such as mathematical programming (e.g., linear programming [LP], nonlinear programming [NLP], mix-integer programming [MIP]), can hardly be applied to solving some real-world complex optimization problems, such as the NP-hard (nondeterministic polynomial-time hard) problems (Korte and Vygen, 2012) defined in computational complexity theory.

To make optimization solutions applicable, workable, and realistic for those complex systems with roughing search landscape, and limited or no mathematical understanding (i.e., knowledge) between decision variables, desired criteria, and constraints, a number of alternative multidisciplinary optimization approaches have been developed. Instead of traditional optimization methodologies and algorithms, computer science and computational intelligence (CI)-inspired *meta-heuristics search* optimization solutions (Patrick and Michalewicz, 2008) have been developed. The CI (Engelbrecht, 2007) applied in optimization is to stimulate a set of natural ways to deal with complex computational problems in optimization solutions. The major features of CI are to model and stimulate the behaviors and features of