K. Watanabe, M. M. A. Hashem

Evolutionary Computations

Springer-Verlag Berlin Heidelberg GmbH

Studies in Fuzziness and Soft Computing, Volume 147

Editor-in-chief
Prof. Janusz Kacprzyk
Systems Research Institute
Polish Academy of Sciences
ul. Newelska 6
01-447 Warsaw
Poland
E-mail: kacprzyk@ibspan.waw.pl

Further volumes of this series can be found on our homepage: springeronline.com

Vol 128. J. Casillas, O. Cordón, F. Herrera, L. Magdalena (Eds.)
Interpretability Issues in Fuzzy Modeling, 2003
ISBN 3-540-02932-X

Vol 129. J. Casillas, O. Cordón, F. Herrera, L. Magdalena (Eds.)
Accuracy Improvements in Linguistic Fuzzy Modeling, 2003
ISBN 3-540-02933-8

Vol 130. P.S. Nair
Uncertainty in Multi-Source Databases, 2003
ISBN 3-540-03242-8

Vol 131. J.N. Mordeson, D.S. Malik, N. Kuroki
Fuzzy Semigroups, 2003
ISBN 3-540-03243-6

Vol 132. Y. Xu, D. Ruan, K. Qin, J. Liu
Lattice-Valued Logic, 2003
ISBN 3-540-40175-X

Vol. 133. Z.-Q. Liu, J. Cai, R. Buse
Handwriting Recognition, 2003
ISBN 3-540-40177-6

Vol 134. V.A. Niskanen
Soft Computing Methods in Human Sciences, 2004
ISBN 3-540-00466-1

Vol. 135. J.J. Buckley
Fuzzy Probabilities and Fuzzy Sets for Web Planning, 2004
ISBN 3-540-00473-4

Vol. 136. L. Wang (Ed.)
Soft Computing in Communications, 2004
ISBN 3-540-40575-5

Vol. 137. V. Loia, M. Nikravesh, L.A. Zadeh (Eds.)
Fuzzy Logic and the Internet, 2004
ISBN 3-540-20180-7

Vol. 138. S. Sirmakessis (Ed.)
Text Mining and its Applications, 2004
ISBN 3-540-20238-2

Vol. 139. M. Nikravesh, B. Azvine, I. Yager, L.A. Zadeh (Eds.)
Enhancing the Power of the Internet, 2004
ISBN 3-540-20237-4

Vol. 140. A. Abraham, L.C. Jain, B.J. van der Zwaag (Eds.)
Innovations in Intelligent Systems, 2004
ISBN 3-540-20265-X

Vol. 141. G.C. Onwubolu, B.V. Babu
New Optimzation Techniques in Engineering, 2004
ISBN 3-540-20167-X

Vol. 142. M. Nikravesh, L.A. Zadeh, V. Korotkikh (Eds.)
Fuzzy Partial Differential Equations and Relational Equations, 2004
ISBN 3-540-20322-2

Vol. 143. L. Rutkowski
New Soft Computing Techniques for System Modelling, Pattern Classification and Image Processing, 2004
ISBN 3-540-20584-5

Vol. 144. Z. Sun, G.R. Finnie
Intelligent Techniques in E-Commerce, 2004
ISBN 3-540-20518-7

Vol. 145. J. Gil-Aluja
Fuzzy Sets in the Management of Uncertainty, 2004
ISBN 3-540-20341-9

Vol. 146. J.A. Gámez, S. Moral, A. Salmerón (Eds.)
Advances in Bayesian Networks, 2004
ISBN 3-540-20876-3

Keigo Watanabe
M. M. A. Hashem

Evolutionary Computations

New Algorithms and their Applications to Evolutionary Robots

Springer

Prof. Keigo Watanabe
Saga University
Dept. of Advanced Systems
Control Engineering
Honjomachi 1
840-8502 Saga
Japan
E-mail: watanabe@me.saga-u.ac.jp

Prof. M. M. A. Hashem
Dept. of Computer Science and Engineering
Khulna University of Engineering
and Technology
Khulna 9203, Bangladesh
E-mail: mma_hashem@hotmail.com

ISBN 978-3-642-05887-5 ISBN 978-3-540-39883-7 (eBook)
DOI 10.1007/978-3-540-39883-7

Library of Congress Cataloging-in-Publication-Data

A catalog record for this book is available from the Library of Congress.
Bibliographic information published by Die Deutsche Bibliothek.
Die Deutsche Bibliothek lists this publication in the Deutsche Nationalbibliographie;
detailed bibliographic data is available in the Internet at http://dnb.ddb.de

Originally published by Springer-Verlag Berlin Heidelberg in 2004
Softcover reprint of the hardcover 1st edition 2004

Cover design: E. Kirchner, Springer-Verlag, Heidelberg
Printed on acid free paper 62/3020/M - 5 4 3 2 1 0

Preface

Evolutionary Computation (EC) is one of the most important emerging technologies of recent times. Over the last ten years there has been exponential growth of research activity in this field. Evolutionary computation has become the standard term that encompasses all of the Evolutionary Algorithms (EAs). The term is still relatively new and represents an effort to bring together different paradigms of EAs and their respective applications. EAs — the unifying term for Genetic Algorithms (GAs), Evolution Strategies (ESs), and Evolutionary Programming (EP) — have received considerable attention to scientists and engineers during last decade. Gleaned from biological metaphors, they are intended to serve as general-purpose easy-to-use optimization techniques capable of reaching globally optimal or at least nearly optimal solutions. This is realized by biologically inspired variation and selection rules. These rules are applied to a population (or several sub-populations) of candidate solutions (individuals) that are evaluated with respect to their fitness. Thus, it is possible by an evolutionary loop to successively approximate the optimal state of the system to be investigated.

Due to their robustness, EAs are well-suited techniques for industrial and management tasks. They do not need gradient information and they can operate on each kind of parameter space (continuous, discrete, combinatorial, or even mixed variants). By means of the population concept, EAs can easily be parallelized. This is why; they often exhibit superior speedup behavior compared to traditional optimization techniques. Essentially, the credibility of evolutionary algorithms relies on their ability to solve difficult, real-world problems with the minimal amount of human effort. If it cannot make the successful transition from academic exercise to industrial application it will be abandoned in favor of other optimizing tools and techniques. The overall goal of this book is to develop and analyze a class of evolutionary algorithms that can be applied to real-world problems of global optimization successfully. Thus the understanding and applications of evolutionary algorithms are clearly extended by this work.

EAs that constitute the evolutionary computation have emerged as the primary unifying principle of modern biological thought for global optimization. Classic Darwinian evolutionary theory, combined with the selectionism of Weismann and the genetics of Mendel, has now become a rather universally accepted set of arguments known as the neo-Darwinian paradigm. Under this paradigm, this book has discussed the development of a new class of evolutionary algorithms and their applications to robotic control. These algorithmic developments are more closely related to the biological metaphor and natural phenomena with respect to canonical EAs. Specifically, this book is the compilation of our recent research results to this field. The book is aimed at a large audience: graduate students, researchers, engineers, designers — who faces complicated but challenging optimization tasks. In particular, this book will be of interest to the robotic control engineers. An understanding of basic mathematics and concepts of programming is sufficient to follow all presented materials of this book.

The book is organized as follows: In **Chapter 1**, an attempt has been made to overview the basic constituents, similarities and differences, properties, merits and demerits of major evolutionary algorithms in terms of their canonical forms for clear understanding. But in practice the borders between these approaches are much more fluid. Until recently and as that of this book, it is observed a steady evolution in this field by modifying (mutating), (re)combing, and validating (evaluating) the current approaches, permanently improving the population of evolutionary algorithms.

In **Chapter 2**, a new evolutionary algorithm called a novel evolution strategy (NES) has been proposed and tested on various benchmark unconstrained test problems. This algorithm utilized two new genetic operators — stable subpopulation-based max-mean arithmetical crossover (SBMAC) and time-variant mutation (TVM) — which are more closely resembled to natural evolved systems. The effectiveness of this algorithm is compared with other evolutionary algorithm produced results. This preliminary investigation showed that this algorithm could outperform well-established evolutionary algorithms with respect to convergence reliability as well as to solution precision. Consequently, this algorithm showed considerably balance between exploration and exploitation trade-off. Empirical investigations, which are mostly followed by every evolutionary algorithm designer, are also carried out for optimal exogenous parameters of the proposed algorithm.

In **Chapter 3**, a general constraint optimization problem is defined and several methods for constraint-handling by evolutionary algorithms are reviewed. A new log-dynamic penalty function-based fitness function has been developed for the NES algorithm. The characteristics of the NES algorithm have been discussed by emphasizing them towards the constrained optimization. Finally, the effectiveness of the NES algorithm for constrained optimization has been compared with the TPEP and GENOCOP II systems against some complex constrained optimization problems. The performance of the NES algorithm seemed to be an effective method for constrained parameter optimization problems.

In **Chapter 4**, another new evolutionary algorithm called an incest prevented evolution strategy (IPES) by enhancing the novel evolution strategy (**Chapter 2**) has been proposed and tested on various unconstrained test functions. This incest prevented concept was directly related to the natural genetic metaphor. The effectiveness of this algorithm has also been compared with other evolutionary algorithms as well as with novel evolution strategy. The proposed algorithm outperformed other evolutionary algorithms and novel evolution strategy with respect to the evaluation time, solution precision and convergence reliability.

In **Chapter 5**, some optimal control problems have been solved using the NES for which dynamic programming techniques suffer from ill-conditioned dimensionality problem. The NES and the ESs consisting of either conventional crossover method or uniform mutation have also been investigated with different optimization modes. The exogenous parameters of the NES algorithm have been verified in these applications that confirmed the empirical investigated results on test functions that had been conducted in **Chapter 2**. Two discrete-time optimal control problems have been solved evolutionarily with different control steps. In particular, the results were encouraging because the closeness of the evolutionary solutions to analytical ones was perfectly satisfying. The simulation results indicate that the proposed operators in the NES can outperform the conventional ESs with respect to convergence and accuracy of the solutions. An optimal compromise was found between exploration and exploitation in the evolutionary process by the introduction of the proposed operators in the ES.

In **Chapter 6**, a novel optimal controller design technique using the IPES has been developed for mobile robots. A unique fitness function has been constructed based on the direct simulation of different controllers. As opposed to the traditional algebraic Riccati equation solution that requires certain trial and error, these controllers are designed evolutionarily using this unique fitness function. These evolutionarily designed controllers when simulated for the stipulated time, they produced quite satisfactory control responses. Thus, an automatic way was proposed and tested for designing robot controllers in this chapter.

In **Chapter 7**, an ES has been discussed using the statistical information of subgroups. In the method, the subgrouping has been obtained automatically by a similarity metric of individuals at each generation. The arithmetical crossover operation was performed with the elite individual and a mean individual within each subgroup to produce the offspring. The standard deviation calculated within a subgroup has been used in the mutation operation. The proposed ES was applied to the acquisition of a control system for a terminal control problem in an omnidirectional mobile robot, in which the control system of the robot was based on the fuzzy behavior-based control system that combines the concept of subsumption-like architecture and fuzzy reasoning technique.

In **Chapter 8**, a two-phase navigation architecture of intelligent autonomous robots has been proposed to take advantages of local and global planning. For the first phase, an evolutionary technique has been discussed for the collision free optimal trajectory planning of a point mobile robot considering its motions. The formulated problem was composed of a mixed integer and discrete constrained optimization problem. It was really difficult to solve such a problem with the conventional calculus based methods. The obstacles within the environment have been modeled/approximated as circles as well as ellipses from the visibility and sensor modeling concepts to construct a fitness function for the problem. An evolutionary trajectory-planning algorithm based on the NES algorithm has been proposed to solve the problem associated with the first phase of IAR navigation. The proposed algorithm responded well for all the simulation cases. The evolutionary approach was robust in the sense that it was guaranteed to yield a trajectory terminating at the goal with minimum time and distance while avoiding obstacles.

Acknowledgements

The second author is especially indebted to his scholarship donor, MONBUSHO (Ministry of Education, Science and Culture), Government of Japan, whose financial support made this book as well as his study in Saga University, Japan possible. Sincere appreciations are also due to the Board of Governors (BOG), Bangladesh Institute of Technology (BIT), Khulna for granting his deputation and giving this opportunity to study in Saga University.

The authors wish to convey their thanks to the contemporary great people of evolutionary computation field like Dr. David B. Fogel of Natural Selection Inc., USA (*http://www.natural.selection.com/people/dbf.html*), Prof. H.-P. Schwefel of University of Dortmund, Germany (*http://ls11-www.informatik.uni-dortmund.de/people/schwefel/*), Prof. Z. Michalewicz of University of North Carolina-Charlotte, USA (*http://www.coe.uncc.edu/~zbyszek/*), Prof. L. Darrell Whitley of Colorado State University, USA (*http://www.cs.colostate.edu/~whitley/*), Dr. Thomas Bäck of Informatik Centrum Dortmund, Germany (*http://ls11-www.informatik.uni-dortmund.de/people/baeck/*), Dr. Marc Schoenauer of Ecole Polytechnique, France (*http://www.cmap.polytechnique.fr/~marc/*), Dr. Xin Yao of University of Birmingham, UK (*http://www.cs.bham.ac.uk/~xin/*), Dr. Alice E. Smith of University of Pittsburgh, USA (*http://www.pitt.edu/~aesmith/*) and Dr. Kumar Chellapilla H. of University of California at San Diego, USA (*http://vision.ucsd.edu/~kchellap/*) for providing their recent published papers in their respective Internet Homepages from which the authors were able to expedite their research work.

March, 2003

Keigo Watanabe
M.M.A. Hashem

Contents

List of Figures

List of Tables