

Editorial scalability of evolutionary algorithms and other metaheuristics for large-scale continuous optimization problems

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Abstract This editorial note presents the motivations, objectives, and structure of the special issue on scalability of evolutionary algorithms and other metaheuristics for large-scale continuous optimization problems. In addition, it provides the link to an associated Website where complementary material to the special issue is available.

Keywords Large-scale continuous optimization problems · Evolutionary algorithms · Metaheuristics

Many real-world problems may be formulated as optimization problems of parameters with variables in continuous domains (*continuous optimization problems*). Some examples are neural networks optimization, aerospace design, biotechnology, control, economic, signal processing, microwave, industrial electronics, industrial engineering, water resources management, etc. Over the past few years, an increasing interest has arisen in solving this kind of problems using *evolutionary algorithms* and *metaheuristics*. A first attempt to collect outstanding information on the huge work on this active research avenue is the Website “Evolutionary Algorithms and other Metaheuristics for Continuous Optimization Problems” (<http://sci2s.ugr.es/EAMHCO>).

Large-scale continuous optimization problems have been one of the most interesting trends in the last years for what concerns research on evolutionary algorithms and metaheuristics for continuous optimization problems, because they appear in many real-world problems (bio-computing, data mining, etc.). Unfortunately, the performance of most available optimization algorithms deteriorates very quickly when the dimensionality increases. The reasons appear to be twofold. First, complexity of the problem usually increases with the size of problem, and second, the solution space of the problem increases exponentially with the problem size, and a more efficient search strategy is required to explore all the promising regions in a given time budget. Thus, scalability for high-dimensional problems becomes an essential requirement for modern continuous optimization algorithm approaches.

This special issue is primarily intended to bring together the works of active researchers of this emerging field to present the latest developments. Its main motivation was to identify key mechanisms that may make evolutionary algorithms and metaheuristics to be scalable on those problems. An interesting added feature is that it accompanies with an associated Website where the source codes and results of the proposals are available to the specialized research community. In order to do this, a set of scalable benchmark function optimization problems were considered as test suite and particular requirements on the simulation procedure were specified. All the authors executed their algorithms following these guidelines and provided the obtained results. Specifically, the common experimental framework was the following:

- A set of 19 scalable function optimization problems were provided (6 functions of the CEC’2008 test suite, 5 shifted functions, and 8 hybrid composition

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functions). The details of the set of scalable functions are available at <http://sci2s.ugr.es/EAMHCO/testfunctions-SOCO.pdf>.

- Each algorithm is run 25 times for each test function.
- The performance measures that were provided by the authors are: (1) average of error of the best individuals found in the 25 runs (for a solution x , the error measure is defined as $f(x) - f(\text{op})$, where op is the optimum of the function), (2) maximum error achieved in the 25 runs, (3) minimum error achieved in the 25 runs, and (4) median of the error achieved in the 25 runs.
- The study was made with dimensions $D = 50$, $D = 100$, $D = 200$, $D = 500$, and $D = 1,000$. The maximum number of fitness evaluations was $5,000D$. Each run stops when the maximal number of evaluations is achieved.

Mainly, the authors were requested to make an analysis of the scalability behavior of their proposed algorithms, and a comparison (by applying non-parametric tests) against three baseline evolutionary algorithms for continuous optimization problems, real-coded CHC, G-CMA-ES, and differential evolution (their implementations are available at <http://sci2s.ugr.es/EAMHCO/>).

In the following, we shortly outline the content and contribution of the 13 papers that were finally chosen for publication. They can be divided roughly into four groups attending on the type of algorithm they analyze. Specifically, the first group of papers of this special issue is composed of six papers on differential evolution. An outstanding number of these papers are devoted to explore adaptive mechanisms that control the strategies and parameter setting. The second group consists of two papers focused on memetic algorithms. The papers in the third group investigate the performance of particle swarm optimization algorithms. Finally, the fourth group consists in three papers that describe the application of other types of optimization algorithms.

In the first paper, *Weber, Neri, and Tirronen* argue that the differential evolution framework, thanks to its simple structure and flexibility, can be easily modified and become an efficient solver of high-dimensional problems. They propose a parallel differential evolution approach that employs a structured population, where each sub-population evolves independently. In addition, new search logics are introduced into the sub-population functioning in order to avoid a diversity loss and thus premature convergence.

Traditionally, the operators of differential evolution combine the information of randomly chosen members of the population. However, four different roles may be clearly identified from their formulations: receiving, placing, leading, and correcting vectors. *García-Martínez, Rodríguez, and Lozano* study two mechanisms that emphasize the proper selection of vectors for each role in

crossover and mutation operations, a role differentiation mechanism that determines the attributes for which vectors are selected for each role, and, assortative mating, which ensures some similarity relations between chosen vectors.

Opposition-based learning is a machine intelligence strategy that considers current estimate and its opposite estimate at the same time in order to achieve a better approximation for a current candidate solution. *Wang, Wu, and Rahnamayan* advocate the use of this strategy to enhance the performance of differential evolution. Specifically, they propose a novel differential evolution variation based on generalized opposition-based learning to solve high-dimensional continuous optimization problems more efficiently.

It is desirable to adaptively determine appropriate strategies and associated parameter values at different stages of evolution. In this line, *Yang, Tang, and Yao* assure that parameter adaptations are one of the most commonly considered techniques to improve the performance of differential evolution. These authors focus on investigating the performance and scalability of a number of recently published adaptive differential evolution variants and propose a generalized parameter adaptation scheme, and employ it to design a new adaptive differential evolution approach. The paper by *Brest and Maučec* proposes a self-adaptive differential evolution algorithm with population size reduction for solving large-scale optimization problems with continuous variables. With the aim of overcoming the hand-tuning problems of the differential evolution control parameters, the authors apply a self-adaptive control mechanism to make the associated parameters self-adaptive by learning from their previous experiences in generating improved solutions. Consequently, suitable generation strategies along with parameter settings can be determined adaptively to match different search phases. *Zhao, Suganthan, and Das* advocate the use of the JADE mutation strategy and a multi-trajectory search algorithm as a way to improve the performance of self-adaptive differential evolution. The JADE mutation strategy was employed for generating the mutant vectors, with the objective of diversifying the population so that the problems such as premature convergence can be alleviated. The multi-trajectory search algorithm is applied frequently to refine several diversely distributed solutions at different search stages.

Memetic algorithms with continuous local search methods have arisen as effective tools to address the difficulty of obtaining reliable solutions of high precision for complex continuous optimization problems. The paper by *LaTorre, Muelas, and Peña* explores the use of a memetic algorithm that combines the explorative/exploitative strength of differential evolution and MTS-LS1, which is a specific continuous local search procedure. The hybridization is made

by following the multiple offspring framework, which provides the functional formalization necessary to design dynamic hybrid evolutionary algorithms, as well as the tools to identify and select the best performing configuration for the problem under study.

Recently, a memetic algorithm for continuous optimization problems was proposed that is based on the concept of local search chain. One of the most outstanding features of this algorithm is that it forces the local search method to act more intensely in the visited search zones that show highest quality. *Molina* et al. provide a comprehensive study of the scalability of memetic algorithms based on local search chains with different local search methods, the Solis and Wets' algorithm, the Nelder and Mead's simplex method, the MTS-LS1 and MTS-LS2 methods, the CMA-ES algorithm, and a new local search method specifically designed to deal with large-scale problems.

Other authors have paid respect to the use of particle swarm optimization algorithms. Specifically, *García-Nieto* and *Alba* incorporate two new mechanisms to the particle swarm optimization with the aim of enhancing its scalability. First, a velocity modulation method is applied in the movement of particles in order to guide them within the feasible region. Second, a restarting mechanism avoids the early convergence and redirects the particles to promising areas in the search space. The paper by *Montes de Oca*, *Aydin*, and *Stützle* concerns the study of a tuning-in-the-loop approach for redesigning a particle swarm-based optimization algorithm. It is an incremental particle swarm optimizer in which the population size increases according to a particle addition schedule. In addition, the authors investigate the effects of embedding a local search method in the algorithm to improve some particle's solutions.

The special issue ends with three papers that advocate the use of other algorithms as effective solvers for large-scale optimization. Specifically, the paper by *Duarte*, *Marti*, and *Gortazar* analyzes the performance of two path relinking variants: the static and the evolutionary path relinking. Both are based on the strategy of creating trajectories of moves passing through high-quality solutions in order to incorporate their attributes to the explored solutions. *Gardeux* et al. devise a specific one-dimensional search algorithm for solving general high-dimensional optimization problems. It decomposes the n -dimensional problem into n one-dimensional problems, optimizing the objective function on each dimension separately. Finally, the paper by *Neumaier* et al. introduces a number of new techniques for unconstrained derivative-free optimization: local and global line searches, orthogonal search in evolving orthonormal frames, and local quadratic models in adaptively constructed affine subspaces. In addition, it presents an optimization algorithm that invokes these techniques.

We should highlight that an associated Website is provided to offer complementary material to the researchers interested in this important research trend (<http://sci2s.ugr.es/EAMHCO/index.php#LSCOP-special-issue-SOCO>). It has the source code of all the presented algorithms and their results on the proposed test suite. This material may help for future developments and investigations, because researchers may hybridize easily the available algorithms (or parts of them) and may compare directly the results of new approaches with the ones of the proposals in the special issue.

We would like to thank all the authors for their submissions and all the reviewers for their careful work and constructive comments.