Guest Editorial
Evolutionary Many-Objective Optimization

I. Aim and Scope

OVER the past two decades, evolutionary algorithms have successfully been applied to single and multiobjective optimization problems having up to three objectives. Compared to traditional mathematical programming techniques, evolutionary multiobjective algorithms (MOEAs) are particularly powerful in achieving multiple nondominated solutions in a single run. However, the performance of most existing algorithms seriously degrades when the number of objectives is larger than three. Such optimization problems, often referred to as many-objective optimization problems (MaOPs) in the evolutionary computation community, are widely seen in the real-world and therefore it is of great practical importance to efficiently solve them. Challenges to evolutionary algorithms and other meta-heuristics in solving MaOPs include the inability of dominance-based MOEAs to converge to the Pareto frontier while maintaining good diversity, the prohibitively high computational complexity for MOEAs based on performance indicators, and the difficulty for human users or decision makers to clearly understand the relationship between objectives and articulate preferences. In addition, existing performance indicators for multiobjective optimization may become incapable of accurately assessing and comparing the quality of solution sets. Finally, visualization of the solutions of MaOPs also becomes a grand challenge.

This Special Issue aims to give a reflection over the research done so far, thereby gaining more insights into the research area and discussing possible philosophical changes needed in tackling MaOPs using evolutionary algorithms and in evaluating the quality of the solution sets they achieved.

II. Overview of the Special Issue

We received 27 high-quality manuscripts in total submitted to the Special Issue, of which six have been accepted based on a peer-review process. They represent the most recent advances in evolutionary many-objective optimization, analyzing scalability and efficiency of evolutionary algorithms for MaOPs empirically or theoretically, developing more efficient algorithms or considering uncertainties in real-world many-objective optimization.

Converting a multiobjective optimization problem or MaOP into multiple single objective optimization problems using weighted aggregation is an intuitive and straightforward idea and such ideas were reported in evolutionary multiobjective optimization a decade ago. This idea is revisited in the paper titled "Localized weighted sum method for many-objective optimization using plain weighed aggregation" by Wang *et al.* for solving MaOPs. To enable the weighted sum method for achieving solutions in the concave regions of the Pareto frontier, selections are made among solutions in the neighborhood defined by a hypercone. The proposed algorithm is compared with three decomposition-based methods and a few others for many-objective optimization to demonstrate its competitiveness.

The dominance-based approach is a class of most robust approaches in evolutionary optimization for bi- or three-objective problems. It has been recognized that the dominance-based MOEAs fail to work effectively due to the loss of selection pressure given a limited population size. However, a deep understanding of the exact mechanism behind the performance degradation when the number of objectives increases remains missing. The paper "On the performance degradation of dominance-based evolutionary algorithms in many-objective optimization" by Santos and Takahashi takes an impressive step toward an analytical understanding of this issue. By using quadratic objective functions with spherical contour curves and symmetrically located minima, the probability of the progress of optimization procedure as a function of the distance to the exact Pareto frontier can be analytically derived, supporting the findings empirically observed in the literature.

The loss of selection pressure is a known problem for the dominance-based MOEAs when the number of objectives increases. This is further studied in the context of particle swarm optimization in the paper "Particle swarm optimization with a balanceable fitness estimation for many-objective optimization problems" by Lin *et al*. To increase the selection pressure, a new fitness function balancing diversity and convergence is introduced on the top of a revised velocity update rule and an extra search carried out on an external archive. The competitiveness of the proposed algorithm is shown by empirical comparisons with a few state-of-the-art evolutionary algorithms for MaOPs.

Many real-world optimization problems are subject to a large amount of uncertainty but not much work on evolutionary many-objective optimization has taken uncertainty into account in algorithm design. "A set-based genetic algorithm for interval many-objective optimization problems" by Gong *et al.* considers interval type of uncertainty and transforms interval MaOPs into a deterministic bi-objective one. Then a set-based dominance relationship is defined and the fast nondominated sorting is modified to perform selection. Existing deterministic benchmark problems are extended to

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interval MaOPs to verify the benefit of the set-based evolutionary algorithm.

Multiple multi- and many-objective test suites have been designed for assessing the performance of evolutionary algorithms. Typically, these test suites are meant for examining the capability of evolutionary algorithms for handling Pareto frontiers of various structures in terms of convexity, continuity, uniformity and complexity, or scalability, or multimodality and correlation. The paper titled "Multi-line distance minimization: A visualized many-objective test problem suite" by Li *et al.*, however, proposes a set of test problems for visually understanding the search behaviors of evolutionary algorithms. Two main characteristics of the test problems are that their Pareto optimal solutions lie in a regular polygon in the 2-D decision space, and that the solutions are similar to their images in the high-dimensional objective space. Insights are gained by running various MOEAs on these test problems, for example, decomposition-based MOEA may encounter difficulties in diversifying their population over a degenerate Pareto frontier and it is often useful to combine decomposition methods with dominance-based approaches.

Although metaheuristics such as evolutionary algorithms and particle swarm optimization algorithms have shown to be effective in solving complex optimization problems, their scalability to the increase in the number of decision variables and the number of objective functions has not been systematically studied. The paper "A scalability study of many-objective optimization algorithms" by Maltese *et al.* performs a thorough investigation on scalability by benchmarking the performance of nine MOEAs for solving MaOPs on two suites of test problems. Their results suggest that particle swarm algorithms scale better to the increase in the number of decision variables, whereas, among scalarization-based, dominance-based, and performance indicator-based algorithms, those which use a combination of dominance and localized scalalization perform the best. These findings are helpful for practitioners who have difficulties in choosing a right algorithm for solving problems at hand.

We would like to thank the Editor-in-Chief, Prof. K. C. Tan, for offering us the opportunity to organize the Special Issue. We are also grateful to authors for submitting their work to the Special Issue and reviewers for their constructive and insightful comments. We hope the papers included in the special issue are able to provide inspiring findings and insightful evidence for further promoting fundamental research and successful applications in the area of evolutionary many-objective optimization.

YAOCHU JIN, *Guest Editor*
Department of Computer Science
University of Surrey
Guildford GU2 7XH, U.K.
e-mail: yaochu.jin@surrey.ac.uk

KAISA MIETTINEN, *Guest Editor*
University of Jyväskylä
Faculty of Information Technology
FI-40014 University of Jyväskylä, Finland
e-mail: kaisa.miettinen@jyu.fi

HISAO ISHIBUCHI, *Guest Editor*
Department of Computer Science and Engineering
Southern University of Science and Technology
Shenzhen 518055, China
e-mail: hisao@sustc.edu.cn