Guest Editorial: Special Issue on Engineering Applications of Memetic Computing

IN an attempt to solve mathematically intractable search and optimization problems using metaheuristics, scientists and engineers have been constantly looking toward nature for inspiration. Within this growing trend, the methodology, which is collectively known as *Memetic Computing* [1], [2], marks one of the most recent success stories of mimicking nature. This special issue attempts to capture the essence of this growing trend through a collection of some recent developments and successful applications. Not surprisingly, the response to this special issue had been overwhelming. With almost 50 papers submitted for consideration, it was therefore not an enviable task to manage the review of the manuscripts. As guest editors, it was a welcome relief when we were granted an increase of 20% page budget to accommodate more papers for this issue.

To provide a unified framework that governs the evolution of any complex system, Dawkins in the late 1980s put forward the concept of *Universal Darwinism* [3], which suggests that evolution need not remain stipulated to biological systems only, i.e., to the narrow context of genes, but applicable to any complex systems that exhibit the principles of inheritance, variation, and selection, thus fulfilling the traits of an evolving system. Dawkins also coined the term *meme* as the fundamental unit of cultural transmission, or imitation, and according to the English Oxford Dictionary as "an element of culture that may be considered to be passed on by non-genetic means." Inspired by both Darwinian principles of natural evolution and Dawkins' notion of a meme, memetic algorithm (MA) was first introduced by Moscato [4] in 1989 as being close to a form of population-based hybrid genetic algorithm (GA) synergized with an individual learning procedure capable of performing local refinements. Within a short span of time, the MAs grew as an important paradigm of computational intelligence and started to find many important applications of engineering optimization problems of varied range of complexities [5]. Nowadays, MAs are designed to capture the metaphorical parallel; on the one hand, to Darwinian evolution and, on the other hand, between memes and domain-specific (local search) heuristics. This way, they try to achieve balance between generality and problem specificity. In a wider sense, MAs are currently being used under various names including hybrid evolutionary algorithms, Baldwinian evolutionary algorithms, Lamarckian evolutionary algorithms, cultural algorithms, or genetic local search.

In general, memetic computing captures the traits of Universal Darwinism in a more appropriate sense. Viewed from this angle, MA is a more constrained notion of memetic computing. More specifically, MA covers one area of memetic computing, in particular dealing with areas of evolutionary algorithms that marry other deterministic refinement techniques to solve optimization problems. The latter, however, extends the notion of memes to cover conceptual entities of knowledge-enhanced procedures or representations. Thus, memetic computing captures the power of both biological selection and cultural selection. The idea of going beyond biological evolution toward a dual-track approach comprising biological–cultural selection has indeed transcended the field of combinatorial and continuous optimization. Most importantly, the recent literature continues to indicate that the concept of "meme" dispersal and selection can be exploited in, for example, robotics engineering, multiagent systems, robotics, optimization, software engineering, computational biology, business intelligence, and the social sciences.

The past few decades have witnessed a rapidly growing research interest in MA as demonstrated by the significant increase in the number of research publications on MA in the form of books, monographs, and archival articles. To date, MAs have successfully been applied to a multitude of real-world problems. Researchers have used memetic algorithms to tackle many classical NP-complete problems such as graph partitioning, multidimensional knapsack, traveling salesman problem, quadratic assignment problem, set cover problem, minimal graph coloring, max independent set problem, bin packing problem, and generalized assignment problem. More recent applications include (but are not limited to) training of artificial neural networks, pattern recognition, robotic motion planning, beam orientation, signal processing, medical expert systems, single-machine scheduling, automatic timetabling (notably, the timetable for the National Hockey League), nurse rostering and function optimization, processor allocation, maintenance scheduling (for example, of an electric distribution network), very large scale integration design, clustering of gene expression profiles, feature/gene selection, multiclass, multiobjective feature selection, and chemical engineering optimization.

Although the application-oriented research with memetic computing has reached an impressive state by now, nevertheless, there exist a number of critical issues regarding the design of MAs for specific problems and with the rapidly growing complexity of real-world scenarios, challenging application areas are continually emerging. Some of the design issues for MAs may include the following. How often individual learning should be applied? On which solutions the individual refinements should be used? For how long the individual learning should be used?

And what individual learning method or meme should be used for a particular problem or individual? Moreover, the second-generation MAs, such as multimeme [6], hyperheuristic [7], and meta-Lamarckian MA [8], and the applications of third-generation MAs such as coevolution [7] and self-generation [9] MAs are yet to be popularized among researchers as much as the first-generation MAs which simply mean a hybridization between a global optimization algorithm with some local search techniques. The exploration of the full potential of MAs in handling constrained, multiobjective, large-scale, and dynamic optimization problems is another very important issue that will need attention in the years to come.

For this special issue, we selected seven full papers and one technical correspondence for publication. The first paper by Chen *et al*. investigated the conceptual modeling of meme complexes (termed as *memplexes* by authors) to solve challenging optimization problems efficiently. The authors made a detailed presentation of the memeplex representation, credit assignment criteria for meme co-adaptation, as well as studied the role of emergent memeplexes in the lifetime learning process of an MA. The conceptual modeling of memplexes is embedded in a co-adapted memetic algorithm and applied to the capacitated vehicle routing problems of diverse characteristics.

In the second paper, Li *et al*. presented a quantum memetic algorithm (QMA) that integrates the principles of quantum computing with the notions of the cultural evolution. To boost population diversity of the genetic search, the authors resorted to the quantum bit structure to represent the chromosomes instead of the classical gene-based encoding. The chromosomes are then updated in parallel by using the quantum gate rotating. The quantum gate rotation-based local search is incorporated in the lifetime learning of the population members to further refine their performance as well as to improve their convergence characteristics. The QMA is applied to develop a non-coherent receiver for large-scale underwater sensor networks. The suggested detection scheme at the receiver includes two sequential phases: features extraction and patterns classification. Through well-designed experiments the authors demonstrate how QMA comfortably addresses this hard computational optimization problem and helps the underwater signals detection process.

An MA which is based on the biogeography-based optimization (BBO) is proposed in the third paper by Panigrahi to solve both complex and noncomplex economic load dispatch problems of a thermal plant. Under the suggested memetic framework, the performance of BBO is enhanced by using a modified mutation and clear duplicate operators. Furthermore, a modified differential evolution (mDE) is embedded as the neighborhood search operator to improve the fitness of an individual based on a predefined threshold. The length of the local search is set to achieve a balance between the required search capability and the required excess computational cost. Effectiveness of the proposed algorithm is tested on four different benchmark systems with varying degrees of complexity and compared with other existing techniques.

Sakai *et al*. in the fourth paper deal with a method using multivalued decision diagrams (MDDs) to obtain motion representation of humanoid robots. The authors first point out that the non-terminal vertices of the multiterminal binary decision diagrams (MTBDDs), which are previously proposed for acquiring robot controllers, can only treat values of 0 or 1, while multiple variables are needed to represent a single joint angle. This increases the number of non-terminal vertices, and the MTBDDs that represent the controller become more complex. To circumvent such jeopardy, the authors consider the use of MDD, whereby the non-terminal vertices can take on multiple output values. The authors present evolutionary MDDs (EMDDs) to obtain humanoid robot motion representation as well as investigate whether the evolution of MDD using an MA is effective through simulation-based experiments.

The fifth paper, which is written by Al-Betar *et al*., addresses a challenging combinatorial optimization problem of university course timetabling. The authors propose an MA which is based on the music-inspired harmony search (HS) algorithm to solve the timetabling problem elegantly. Under their framework, HS is hybridized with hill climbing to improve local exploitation, and the concept of globally best individual taken from the particle swarm optimization algorithm to improve convergence. The results were compared against 27 other methods using 11 benchmarking datasets which comprise five small, five medium, and one large datasets. The proposed MA is observed to achieve the optimal solution for the small dataset with comparable results for the medium datasets. Even for the most complex and large datasets, the proposed method succeeds in attaining the best results.

Shim *et al*., in the sixth paper, present a multiobjective memetic optimizer which is based on the estimation of distribution algorithm (EDA) and decomposition scheme where the algorithm is not required to differentiate between the dominated and non-dominated solutions. The authors attempt to improve the search behavior of the algorithm by hybridizing local search metaheuristic approaches with the decomposition EDA. Typically, they consider three local search techniques, including hill-climbing, simulated annealing, and evolutionary gradient search. The algorithm is applied to solve multiple traveling salesperson problems with a novel multiobjective formulation with different number of objective functions, salesmen, and problem sizes.

In the seventh paper, Hrnčič *et al*. proposed an MA for grammatical inference in the field of domain-specific languages (DSLs). DSLs are often designed by domain experts who have no knowledge about the syntax and semantics of programming languages. However, they are able to write sample programs to accomplish their goals and illustrate the features of their language. The objective of grammatical inference is to infer a context-free grammar from a set of positive (and negative) samples. The authors illustrate that the grammatical inference may assist domain experts and software language engineers in developing DSLs by automatically producing a grammar that describes a set of sample DSL programs. They develop an MA-based tool which significantly improves results and robustness of the inference process.

Finally, in the eighth paper, Garcia-Valverde *et al*. come up with a multiobjective MA to improve the location-based service using radio-frequency identification technology within an intelligent building. In the multiobjective formulation of the problem, one searches for the best configuration of antennas that minimizes the set of antennas but maximizes the precision of the prediction. The MA provides the exploitation of domain knowledge and the combination of metaheuristics. Through experiments, the authors show that the approach obtains a configuration of antennas that optimally preserves the number and position of the antennas while keeping a high quality of the precision in the location prediction based on hidden Markov models.

The eight papers included in this Special Issue are representative of the current research trends in the application domains of memetic computing, and should also provide insights regarding the trends that follow in the years to come. Going forward as highlighted in [10], the increase in the number of hits based on a Google worldwide web search is strongly indicative of the growing awareness in this field.

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