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JOCS-611; No. of Pages 6
ARTICLE IN PRESS
Journal of Computational Science xxx (2017) xxx–xxx
Contents lists available at ScienceDirect
Journal of Computational Science
journal homepage: www.elsevier.com/locate/jocs

Buffered local search for efficient memetic agent-based continuous optimization

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ARTICLE INFO

Article history:
Received 15 September 2016
Received in revised form 28 January 2017
Accepted 4 February 2017
Available online xxx

Keywords:
Memetic algorithms
Agent-based computing
Continuous optimization
Meta-heuristics

ABSTRACT

In this paper, a memetic search in classic and agent-based evolutionary algorithms are discussed. A local search is applied in an innovative way; namely, during an agent's life and in a classic way during the course of reproduction. Moreover, in order to efficiently utilize the computing power available, an efficient mechanism based on caching parts of the fitness function in the local search is proposed. The experimental results obtained for selected high-dimensional benchmark functions (with 5000 dimensions) show the apparent advantage of the proposed mechanism.

1. Introduction

Some problems are too difficult to be efficiently explored by common optimization methods because they are too complex or their search space is too big. Therefore, there is an ongoing need for the creation of meta-heuristics and other general-purpose algorithms that will provide adequate solutions for such 'black-box' problems [1,2] in a reasonable amount of time.

The first successful experiments using meta-heuristics (conducted by Davis [3] and Moscato [4]) revealed the necessity of adjusting the solver to the problem characteristics in accordance with the so-called 'no-free-lunch' theorem [5,6] (which proclaims the impossibility of discovering a meta-heuristic method that would be an ultimate solution for all problems, no matter how excellent it works for a certain one). Therefore, the search for novel meta-heuristics adjusted for the given problems is still indispensable.

These meta-heuristics are often inspired by various domains of life, such as biology, evolution, or genetics. An example of such a method is a well-known evolutionary algorithm that has been thoroughly researched in recent times. In 1996, Cetnarowicz [7,8] enriched the evolutionary algorithm by introducing the notion of agency and proposed the Evolutionary Multi-Agent System (EMAS), in which the main task is decomposed into sub-tasks entrusted to agents—intelligent objects [9] that are able to interact with one another, as well as with the environment and make decisions autonomously. It is to note that EMAS ability to be an universal optimization algorithm has been formally proven [10,11]. The EMAS has also been successfully applied to a number of optimization and related tasks (see, e.g. [12,13]) and efficiently implemented using both imperative [14] as functional programming paradigms [15,16].

In this paper, the idea of hybridizing EMAS with local search algorithms is discussed. The inspiration for these local search algorithms is the meme theory, which allows us to introduce memetic algorithms (MAs) [17–19]. Initially popularized by Radcliffe and Surry [20] and others, MAs are joined with local and population-based search engines to create new hybrids. Despite providing remarkable success [21], these hybrids turned out to be computationally demanding. Therefore, further improvements have been proposed, such as that described in [22] (which we follow in order to efficiently realize a local search in the solution space).

In our research, we focused on two variants of the memetic Evolutionary Multi-Agent System—one with a local search applied in the course of agent mutation and the other with a local search carried out at every evolutionary step. This EMAS hybridization with MAs is discussed in detail in Section 3. First, in Section 2, the EMAS itself as well as its main assumptions have been brought closer. Our experiments and their results are presented in Section 4. Section 5 is comprised of the paper's conclusion and a discussion about future work.

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http://dx.doi.org/10.1016/j.jocs.2017.02.001
1877-7503/

Please cite this article in press as: W. Korczynski, et al., Buffered local search for efficient memetic agent-based continuous optimization, J. Comput. Sci. (2017), http://dx.doi.org/10.1016/j.jocs.2017.02.001

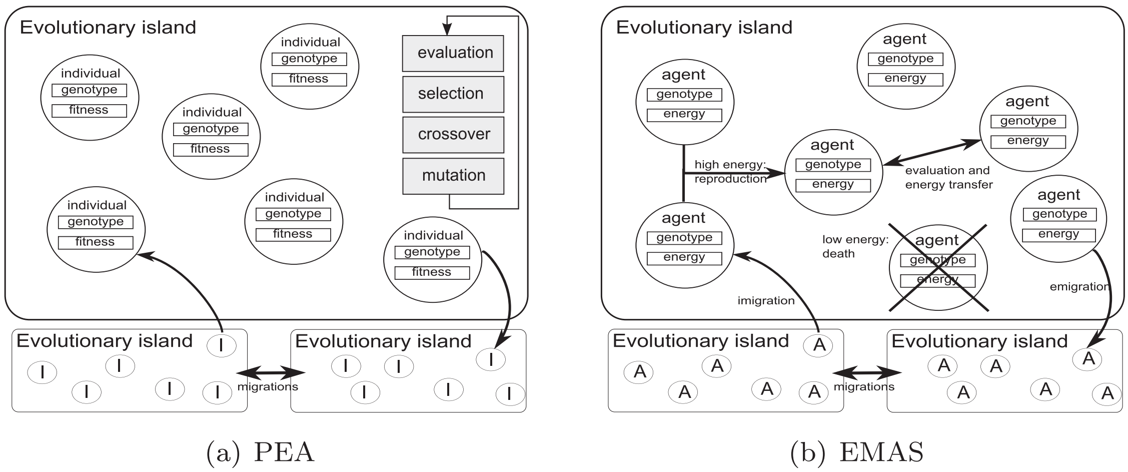

Fig. 1. Schematic presentation of Parallel Evolutionary Algorithm (PEA) and Evolutionary Multi-Agent System (EMAS).

This paper is an extended version of the work published in [23]. A new memetic algorithm has been proposed (memetization during an EMAS agent's life), and two new benchmark problems have been solved. Moreover, the memetic algorithm applied in our work is thoroughly described, and its pseudo-code has been provided. In addition, the obtained results have been studied more precisely—statistical and time-consumption tests have been performed.

2. Evolutionary agent-based computing

Evolutionary algorithms [24] belong to the group of population-based meta-heuristics. In the most-popular variant (called a genetic algorithm), solutions are encoded into genotypes owned by individuals that form populations (groups of potential solutions) that are evaluated based on the fitness function. Poor solutions are eliminated in the process of selection, and those remaining create a mating pool. A subsequent population is created based on this mating pool by using variation operators such as crossover or mutation. The whole process continues until some stop condition is reached (e.g., a predefined number of iterations, or reaching an acceptable solution).

To preserve the population's diversity during the search, several techniques have to be applied, such as the distribution of individuals among evolutionary islands, which allows for the parallelization of the algorithm [25]. Fig. 1(a) schematically illustrates the Parallel Evolutionary Algorithm (PEA) used as a reference in this paper.

Agency brought decentralization to the evolutionary meta-heuristics by providing autonomy for the individuals. EMAS [7] allows us to achieve effective results [26,27] and decrease the computation cost computed as the number of fitness evaluation events [28].

In EMAS, the phenomena of inheritance and selection are modeled by agent reproduction and death (as illustrated in Fig. 1(b)). An instance of the solution is encoded in an agent's genotype, which is inherited from its parent(s) with the use of variation operators of mutation and recombination. Noteworthy is the fact that it is easy to add mechanisms of diversity enhancement to EMAS (such as allopatric speciation [cf. [25]]) by introducing population decomposition and an action of agent migration.

In numerous research projects, EMAS has proven to be an efficient method for solving different problems—classic continuous benchmark optimization [28], inverse problems [29], optimization of neural network architecture [30], multi-objective optimization [31], multimodal optimization [32], and financial optimization [33]. Moreover, a number of EMAS variants have been constructed and used for obtaining the above-mentioned results; e.g., immunological EMAS [34], co-evolutionary EMAS [32], and elitist EMAS [35]. EMAS has thus been proven to be a versatile optimization mechanism for practical situations. Moreover, research on scalability and massive parallelization of EMAS has been performed [16,36]. A summary of EMAS-related reviews is given in [8]. Compared to the classic evolutionary algorithm, EMAS provides satisfactory results with less computation time, requiring fewer evaluations.

3. Efficient mechanism of local search in EMAS

Evolutionary algorithms can be enhanced by hybridization with local search memetic algorithms, which can then be applied in the course of evaluation (according to the Baldwin effect [37]) or mutation (according to the Lamarckian model [38]). When handled with care, local search algorithms can gradually bring the individuals closer to (local) extrema, enhancing their genotypes.

There are a few works that concern continuous optimization using evolutionary or memetic algorithms. As usual, the search space is possible to undergo at least a little analysis; thus, the process of a local search does not have to be completely blind (contrary to black-box problems [1]); e.g., the need to continue or stop a local search can be appropriately calculated [39], or the variation operator being efficiently tuned (minding the convergence possibility) [40]. A good review of tackling continuous problems with memetic algorithms can be found in [19]. At the same time, there is a vast number of evolutionary-related algorithms tackling such optimization problems (for which solving such problems became natural after applying real-value encoding; see e.g., [24]). A good recent review of these is presented in [41]. In our recent works, we have tried to apply memetization to EMAS (which brought promising results at the expense of efficiency [26]). A more-profound study of the hybridization of EMAS with memetic algorithms is presented below.

Agents are autonomous entities, and they can conduct searches for solutions on their own, freely using the means available. In such a way, a local search could be applied more often than usual (during evaluation [42] or reproduction [38]) when handled with care. One has to remember, however, that increasing local search capabilities can be followed with the introduction of a classic memetic handicap into the search; namely, early loss of diversity [19]. Meta-heuristics are already treated as methods of last resort [24], so this is important to keep it in mind when constructing such hybrids. Thus, the agents could detect certain changes in the environment (for example, getting to know about the loss or increase of relative diversity of an evolutionary island and reacting to this information,