Applied Mathematics and Computation 231 (2014) 329–346

Contents lists available at ScienceDirect

Applied Mathematics and Computation

journal homepage: www.elsevier.com/locate/amc

An ensemble algorithm with self-adaptive learning techniques for high-dimensional numerical optimization ☆

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ARTICLE INFO

Keywords:
Ensemble
Self-adaptation
Evolutionary algorithm
High-dimensional
Numerical optimization

ABSTRACT

There are many evolutionary algorithms for numerical optimization problems. However, the universality and robustness of existing algorithms are still unsatisfactory, and the performance of these algorithms deteriorates significantly as the dimensionality of the optimization problems increases. In this paper, an ensemble of evolution algorithm based on self-adaptive learning population search techniques (EEA-SLPS) is presented to overcome these defects on the numerical optimization problems. The EEA-SLPS integrates three self-adaptive learning based stochastic search algorithms which are termed as sub-algorithms. In the EEA-SLPS, the population is divided into three sub-populations, and the sub-algorithms are employed to evolve the sub-populations in parallel. Among the three sub-algorithms, one is designed in this paper and the other two are proposed by relevant literature, and eighteen information exchanging manners (IEMs) between sub-populations are investigated in order to make use of the sub-algorithms efficiently. We have found the most suitable IEM for the EEA-SLPS according to experimental investigations. Finally, the EEA-SLPS is tested on a suite of 26 bound-constrained functions with low and high dimensionality. The experimental results indicate that the universality and robustness performance of EEA-SLPS is better. Meanwhile, the results clearly verify the advantages of EEA-SLPS on the numerical optimization problems with low or high dimensionality.

1. Introduction

Differential evolution (DE) [1], particle swarm optimization (PSO) [2] and artificial immune systems (AIS) [3] are three population based stochastic search techniques. They have been successfully applied to solve many optimization problems [4–6]. However, the performance of one evolutionary algorithm in hand may vary significantly. Besides, the performance of existing algorithms deteriorates significantly as the dimensionality of the numerical optimization problems increases [7,8].

In order to enhance the universality and robustness performance of evolutionary algorithms, some algorithms with self-adaptive mechanism have independently arisen in recent years. For example, Qin and Suganthan et al. proposed a self-adaptive DE (SaDE) algorithm [9], and their experimental results indicated that the self-adaptive techniques and

☆ Foundation item: Funding by the Priority Academic Program Development of Jiangsu Higher Education Institutions; The Research Foundation of Nanjing University of Information Science and Technology (2013x034); Jiangsu Innovation Program for Graduate Education (CXLX11_0203); Aviation Science Funds of China (2010ZC13012); National Defense Foundation of China (Q072006C002-1).
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http://dx.doi.org/10.1016/j.amc.2013.12.130

learning mechanism can improve the performance of DE significantly. Moreover, Wang et al. proposed a self-adaptive learning based particle swarm optimization (SLPSO) [10] and their experimental results demonstrated that the performance of PSO was improved significantly by the self-adaptive learning mechanism. Besides, some other self-adaptive based algorithms were proposed too [11,12]. Although the strategy and parameter adaptation have been experimentally proven to be able to remarkably improve the performance of the evolutionary algorithms, the implementation of only one evolutionary technique cannot solve all problems even when the potential capability is fully explored. Moreover, all the self-adaptive based algorithms are tested only by the numerical optimization problems with low-dimensionality. It is unknown that how about their performance on the numerical optimization problems with high-dimensionality. Recently, Refs. [7,13,14] indicate that the performance of these algorithms deteriorates significantly as the dimensionality of the optimization problems increases. More recently, the idea of hybridizing multiple low-level heuristic to form high-level heuristic method has gained much attention of researchers and has shown pretty good effect [9,10,15–17].

In this paper, we present an ensemble of evolution algorithm based on self-adaptive learning population search techniques (EEA-SLPS) in detail. The EEA-SLPS integrates three self-adaptive learning population-based algorithms which are from different stochastic search research fields. In the EEA-SLPS, the population is divided into three sub-populations and three sub-algorithms are adopted to evolve the sub-populations, respectively. We at first proposed a variant of AIS. Then we combined it with two novel and meantime complementary algorithms together to get a robust and universal hybrid algorithm, i.e., EEA-SLPS. Since the ensemble methodology similar to Ref. [18], we provided further investigation on the information exchanging manners (IEMs) and offered the optimal one, which is the work that Ref. [18] has not done. To design the EEA-SLPS, there are three key issues that needed to be addressed, i.e., (1) When to exchange information between the sub-populations? (2) How to exchange information between the sub-populations? (3) How much information to be exchanged is suitable? Our work focuses on investigating the IEMs whereas the work of Ref. [18] mainly on demonstrating the efficacy of the PAP. Different from the work of Refs. [9,10,18–22] in which all search techniques have access to the whole population, EEA-SLPS only allows its sub-algorithms to evolve the sub-populations, respectively. Hence, information exchange is the only way by which the sub-populations communicate with each other. This scheme reduces the likelihood of different sub-algorithms repeating similar search behavior.

In order to evaluate the performance of EEA-SLPS, we conduct experiments on 26 numerical function optimization problems which are with different characteristics such as rotation, ill-condition, mis-scale, uni-modality, multi-modality and noise [10]. Then, the performance of EEA-SLPS is compared with some state-of-the-art algorithms.

The remainder of this paper is organized as follows: The related works are reviewed in Section 2. We presented the self-adaptive learning algorithm based on clonal selection (SALA-CS) in Section 3. Section 4 describes the idea of EEA-SLPS, and describes the ensemble scheme and IEMs. Experimental investigations of IEMs and demonstrating the performance of EEA-SLPS by comparing with several state-of-the-art algorithms over a suite of 26 bound constrained numerical optimization problems with low and high dimensionality are presented in Section 5. Section 6 concludes this paper.

2. Previous work related to self-adaptive learning algorithms

The technique of simultaneously using multiple offspring generation strategies has been studied [9–11,15,16]. It has been proven that it is useful for the evolutionary algorithms to obtain good performance on different kinds of problems by applying multiple evolution strategies in one algorithm. The researches attempt to integrate multiple search techniques from operators, all the operators work on a shared population, every operator can access to any solution in the population. The major effort for designing such a method is to decide which operator to choose and when to employ [9,10,23]. As suggested in Ref. [18], complementary sub-algorithms in parallel lead to better performance than applying the same algorithms. So in EEA-SLPS, we adopt three different search techniques as sub-algorithms, and steer them work on the sub-populations in parallel manner. Furthermore, the three sub-algorithms are from different optimization research fields.

2.1. Differential evolution techniques

DE is reported by Storn and Price as a optimization technique in 1995 [24] and extensively described by them in 1997 [1]. From the year of 2000, DE and its variants have been achieving top ranks of EAs.

Because the performance of the conventional DE algorithms mainly depend on the chosen trial vector generation strategy and their associated parameter values, researchers have done a lot of work for choosing trial vector generation strategies and their associated control parameter settings in early years [25,26]. Thus, various conflicting conclusions have been drawn with regard to the rules for manually choosing the strategies and control parameters, this may be due to most of these conclusions lack sufficient justifications as their validity is possibly restricted to the problems, strategies and parameter values considered in the investigations. Therefore, researchers have developed some techniques to avoid manually tuning of the control parameters. For example, Das et al. linearly reduced the scaling factor with increasing generation count from a maximum value to a minimum value, or randomly varied scaling factor in the range [0.5,1] [27].

Recently, there are some works investigated approaches for adapting the probabilities of applying different operators [28]. For example, the SaDE algorithm was proposed by Qin et al. [9], which combines multiple effective individual evolution strategies and steers them in a parallel and adaptive manner.