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Adaptive multiple-elites-guided composite differential evolution algorithm with a shift mechanism

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ABSTRACT

The performance of differential evolution (DE) has been significantly influenced by trial vector generation strategies and control parameters. Various powerful trial vector generation strategies with adaptive parameter adjustment methods such that the population generation is guided by the elites have been proposed. This paper aims to strengthen the performance of DE by compositing these powerful trial vector generation strategies, making it possible to obtain the guidance of each individual from multiple elites concurrently and independently. In this manner, the deleterious behavior in which an individual is misguided by various local optimal solutions into unpromising areas could be restrained to a certain extent. An adaptive multiple-elites-guided composite differential evolution algorithm with a shift mechanism (abbreviated as AMECoDEs) has been proposed in this paper. This algorithm concurrently employs two elites-guided trial vector generation strategies for each individual to generate two candidate solutions accordingly, and the best one is adopted to participate in the selection. Moreover, a novel shift mechanism is established to handle stagnation and premature convergence issues. AMECoDEs has been tested on the CEC2014 benchmark functions. Experimental results show that AMECoDEs outperforms various classic state-of-the-art DE variants and is better than or at least comparable to various recently proposed DE methods.

1. Introduction

The need to identify global optimal solutions for problems is often encountered in many scientific research and engineering applications. Therefore, the design of effective methods to solve optimization problems is always a hot research topic in the field of scientific research and engineering applications. However, with the development of science and technology, more and more problems with characteristics such as multimodality, high non-linearity, non-differentiability and non-convexity arise in various fields. The use of conventional derivative-based methods [14,15] to solve these complex problems is becoming ineffective and even infeasible. Therefore, various effective derivative-free methods, named evolutionary algorithms (EAs), such as genetic algorithms (GAs) [50], particle swarm optimization (PSO) [32,35], artificial bee colony algorithms (ABCs) [1,3,19] and differential evolution (DE) [36,37], have been proposed. DE is a population-based stochastic

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search algorithm and was proposed by Storn and Price in 1995 [36,37]. Similar to other EAs [28,41], DE quickly attracted the attention of many researchers from diverse fields and has been successfully employed to solve a variety of optimization problems, such as multiobjective optimization problems [21] and many real-world engineering optimization problems [5]. This paper focuses on global numerical optimization problems.

The performance of DE mainly relies on its trial vector generation strategies (*i.e.,* mutation and crossover operators) and associated control parameters (*i.e.,* population size *NP*, scale factor *F* and crossover rate *CR*) [42]. Therefore, some traditional mutation operators (*i.e.,* DE/rand/1, DE/rand/2, DE/best/1, DE/best/2, DE/current-to-rand/1, and DE/current-to-best/1) and crossover operators (*i.e.,* binary crossover and exponent crossover) have been invented for DE [33]. The detailed mathematical definitions of these mutation and crossover operators will be given in the next section. To enhance DE's performance, researchers first concentrated their efforts on designing new mutation operators [8,18] and parameter control methods [25,29]. Then, some empirical guidelines such that different trial vector generation strategies and parameters are suitable for different problems were provided by researchers [16,34]. Therefore, there has been increasing interest in the design of new DE variants that employ multiple trial vector generation strategies cooperatively or competitively [2,7,9,20,26,27,33,42,43] to generate candidate solutions. Moreover, many auxiliary techniques or methods are hybridized with DE to improve DE's performance [12,30]. These new DE methods significantly improve the performance of DE and have promoted the development of DE [10]. A detailed review of these improved DE variants is beyond the scope of this paper, and elaborate surveys have been provided in [5,6].

Particularly during the past decade, various powerful and effective mutation strategies that exploit the information of elites (good individuals) have been proposed to obtain a balance between exploration and exploitation of DE. Das et al. [4] proposed a neighborhood-based mutation operator to allow the population to be guided by the best individual among the neighbors and the global best individual simultaneously (DEGL). Zhang et al. [49] treated the top $p \times 100\% \times NP (p \in (0, 1))$ individuals as the leaders, which are randomly selected by other individuals to lead their own search direction, and correspondingly proposed a very powerful and effective mutation operator "DE/current-to-*p*best/1" (JADE). Islam et al. [17] used the best of a group of randomly selected solutions from the current population to perturb the parent (target) vector and designed a new DE mutation operator called "DE/current-to-gr_best/1" (MDE_*p*best). Inspired by the natural phenomenon that good species always contain good information and hence have a greater chance of being utilized to guide other species, Gong et al. [11] presented ranking-based mutation operators for DE in which the higher ranking an individual is, the more opportunity it will have to be selected by other individuals to participate in their search. Moreover, other mutation operators that take advantage of superior individuals have been invented persistently [2,46]. Obviously, these state-of-the-art DE variants have a common feature in that all of them treat the elites as leaders that guide the evolution of the entire population. The main distinction between them is the selection method of the leader for each individual. As claimed in some state-of-the-art PSO methods [22], the method of selecting the leaders for search is very crucial to the performance of PSO. Similarly, the leaders in a DE population may also be able to guide the search direction of DE and significantly affect the performance of DE. Although the above DE variants [4,11,17,49] have made attempts to guide DE populations via various elites (good solutions) and have obtained very positive effects, there is the common issue that an individual is guided by only one elite at a time in all of these methods, which may easily lure the individual into an unpromising area when the selected elite is located in a locally optimal area. Therefore, to address this issue, we attempt to use multiple elites to guide an individual simultaneously and independently by compositing multiple elite-guided trial vector generation strategies with different selection methods for elites. In addition, DE usually suffers from stagnation in that it gradually stops generating better solutions even though the population has not converged to a fixed point, as well as premature convergence in that the entire population converges to an inaccurate fixed point [44]. Therefore, to solve these issues, we put forward a shift mechanism (**SM**) to make the population disperse when the population suffers from premature convergence and make the population converge when the population encounters stagnation. Overall, to improve the performance of DE, we propose an adaptive multiple-elites-guided composite differential evolution algorithm with a shift mechanism (AMECoDEs for short). The contributions of this paper are summarized as follows.

(1) Each individual in the population is simultaneously guided by two elites via the combination of two elites-guided trial vector generation strategies with distinct selection methods for the elites, which can reduce the likelihood of being misled and effectively make the individuals evolve towards more promising areas. Moreover, the parameters (scale factor *F* and crossover rate *CR*) of each trial vector generation strategy are independently and adaptively adjusted based on the previous successful experience.
(2) A novel shift mechanism (**SM**) is established to allow the population to avoid the situations of stagnation and premature convergence. In **SM**, if the population does not converge to a small area, some unpromising solutions will be shifted to a neighborhood of promising solutions to promote convergence. If the population has converged to a small area, some unpromising solutions will be shifted to random positions unconditionally to enhance the population's diversity.

To test the performance of our proposed algorithm AMECoDEs, we compare AMECoDEs with various state-of-the-art DE variants and various recently proposed DE methods on 30 CEC2014 test functions with different dimensions. The experimental results show that AMECoDEs is significantly better than the state-of-the-art DE variants and is better than or at least very competitive with the recently proposed DE methods.