A new mutation operator with the ability to adjust exploration and exploitation for DE algorithm

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ABSTRACT

This paper proposes a new mutation operator $Current-to-better$-AC with an angle control rule for DE algorithm. This new mutation operator has the potential to automatically adjust the exploration and exploitation based on the angle control rule. Under the control of this rule, the individuals pair for generating mutation vector is tendentiously selected. In $Current-to-better$-AC, only high-ranking individuals are permitted to use the angle control rule, while low-ranking individuals are encouraged to move to a random high-ranking individual. This method is embedded into JADE as a new algorithm AC-JADE, and its performance is tested by COCO benchmarks. Experimental results show that AC-JADE performs better than JADE.

CCS CONCEPTS

• **Numerical Analysis**; • **Optimization**; • **Analysis of Algorithms and Problem Complexity**; • **Numerical Algorithms and Problems**;

KEYWORDS

Benchmarking, Black-box optimization

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1 INTRODUCTION

In mutation operators, usually a random vector is needed to acquire evolutionary information. This random vector is often provided by an individuals pair among the current population. The influence of this random vector on algorithm performance is considered in this paper, and the random vector is associated with an angle rule. This rule regards the current best individual as the start point, and regards the selected individual pair for producing random vector as the end points, hence the angle between these two vectors (abbreviated as *Ang*) has a range between 0° and 180°. Obviously, when *Ang* is 0°, the obtained moving length will be relatively shorter than in other cases; on the contrary, when *Ang* is 180°, the moving length will be relatively longer. Under these two cases, the algorithm will have higher exploitation and exploration abilities respectively. To test this mutation operator, it is embedded into JADE [5] to become a new algorithm AC-JADE (JADE with a angle control rule). JADE algorithm is an improved version of Differential Evolution with adaptive parameter setting. It has good performance on the optimization benchmarks, so is a suitable and convincing comparison with AC-JADE. In order to study the influence of $Current-to-better$-AC on JADE, and not destroy the original process and pattern of JADE, the employments rates of $Current-to-better$-AC and original mutation operator in JADE are 20% and 80% respectively.

The rest of this paper is organized as follows: Section 2 introduces the proposed region learning in details. The experimental procedure is presented in section 3. Section 4 is devoted to the result analysis of experiment. The paper is concluded in section 5 with a future outlook.

2 ALGORITHM PRESENTATION

As shown in figure 1, denoting the current best individual in generation G as $x_{O,G}$, and regarding it as the reference point of angle rule. For individual $x_{O,G}$, assuming the individuals pair selected for generating a random moving vector consists of $x_{C,G}$ and $x_{D,G}$, $\angle COD$ is defined as "mutation angle", and is denoted as *Ang*. Obviously, $\angle COD$ is larger than 90°, and the length of $\vec{DC}$ is close to the length sum of $\vec{OC}$ and $\vec{OD}$. In this case, the population will have better ability on exploration. Conversely, if $Ang < 90^\circ$, such as $\angle AOB$, the length of generated $\vec{BA}$ will be shorter, and thus the

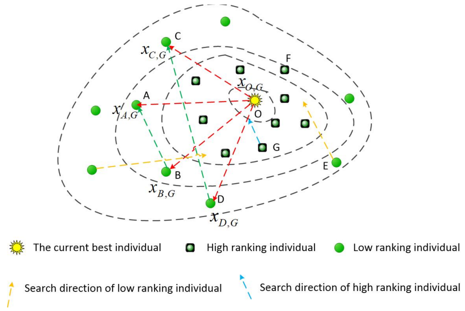

Figure 1: Illustration of mutation operator $Current - to - better$**-AC**

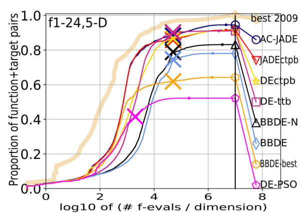

Figure 2: The performances of all the compared algorithms

population tends to have higher exploitation ability. Therefore, by setting different range of Ang, the individuals pair for generating the mutation vector is tendentiously selected. In the mutation operator $Current - to - better$-AC, the whole population is divided to two part: high ranking individuals (better half), and low ranking individuals (worse half). The angle control rule is only applied to high-ranking individuals. While low-ranking individuals will move toward a not fixed high-ranking individual. In this paper, denote $rank_{i,G} \in [1, NP]$ as the rank of individual $x_{i,G}$ in generation G, and a mutated vector is generated as

$$v_{i,G} = \begin{cases} x_{i,G} + F_i \cdot (x_{r1,G} - x_{r2,G}) & rank_{i,G} < NP/2 \\ x_{i,G} + F_i \cdot (x_{r3,G} - x_{i,G}) & otherwise \end{cases}$$

where $r1$ and $r2$ are randomly selected from the whole population according to the angle control rule. To improve the exploitation ability, this paper sets $Ang < 90^{\circ}$. The ranking (lower value means higher ranking) of $x_{r3,G}$ meets $rank_{r3,G} < NP/2$, where NP is population size. F_i is amplification factor in mutation operator controlling the movement scale.

3 EXPERIMENTAL PROCEDURE

The performance of RL-JADE on COCO benchmark functions is compared with JADEctpb, DEctpb, DE-ttb, BBDE, BBDE-N, BBDE-best, and DE-PSO. The test code is written in MATLAB based on work in paper [4], and the CPU of computation machine is Intel(R) Core(TM) i5-7200U with 2.50GHz. The RAM is 8.00GB, and the operation system is 64-bit WIN10. The test data of compared algorithms are obtained from the webpage of COCO [1]. The configuration for RL-JADE is as follows: the max function evaluation times = $5e4 \times D$, $\mu_F = 0.5$, $\mu_{CR} = 0.5$, learning rate for $\mu_C R = 0.1$, and learning rate for $\mu_F = 0.1$. The population size is $5 \times D$. P is set to be 10%, and the dimension of tested problems is 5.

[1] http://coco.gforge.inria.fr/doku.php?id=algorithms-bbob

4 RESULTS

Results from experiments according to papers [2] [3] on the benchmark functions given in paper [1] are presented in figure 2. Algorithms are tested with the rank-sum test for a given target Δf_t (10^{-8}) for each trial. Figure 2 shows the bootstrapped empirical cumulative distribution of the number of objective function evaluations divided by dimension ($\#f - evals/dimension$) for 50 targets in $10^{[-8..2]}$ for all functions and subgroups in 5-D. The **best 2009** line corresponds to the best ERT observed during BBOB 2009 for each single target. Among all the compared algorithms, AC-JADE performs best, and has significantly improved the performance of JADE. The superiority is obvious after $\log(\#f - evals/dimension) > 4$, while $\log(\#f - evals/dimension) < 4$, AC-JADE and JADE have the similar performances.

5 CONCLUSIONS AND FUTURE WORK

This paper proposes an angle based rule to control the movement length for individuals in DE algorithm. Experimental results show that when setting $Ang < 90^{\circ}$, the angle control-based mutation operator $Current - to - better$-AC can effectively improve the performance of JADE. Theoretically, if setting $90^{\circ} < Ang < 180^{\circ}$, and applying this rule to low-ranking individuals, the whole population will have a higher exploration ability. This method is also possibilly feasible to coorperate with the failed exploration directions for direction circumvention. If ensuring the angle between moving direction and current known failed direction for an individual is larger than a certain threshold, this individual can effectively avoid the invalid search directions, and step into a more promising area.

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