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Bacterial colony foraging algorithm: Combining chemotaxis, cell-to-cell communication, and self-adaptive strategy

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ABSTRACT

Inspired by the colony foraging behavior of *Escherichia coli* bacteria, this paper proposes a novel bacterial colony foraging optimization (BCFO) algorithm for complex optimization problems. The main idea of BCFO is to develop an adaptive and cooperative life-cycle model by combining bacterial chemotaxis, cell-to-cell communication, and self-adaptive searching strategies. The proposed BCFO is a more bacterially-realistic model that the bacteria split and die dynamically throughout the foraging process and the population size varies as the algorithm runs. The cell-to-cell communication enables the bacteria tumble towards better directions in the chemotactic steps to speed up convergence. With the self-adaptive searching strategy, each bacterium can maintain an appropriate balance between exploration and exploitation. Seven versions of BCFO combined by different strategies under the model were proposed and tested on both static and dynamic benchmarks. Then the proposed algorithm is applied to a real-world application of dynamic RFID network optimization. Statistical analysis of all these tests highlights the significant performance improvement due to the beneficial combination and shows that the proposed algorithm outperforms the reference algorithms.

1. Introduction

The field of natural computing is increasingly being utilized by engineers and scientists to obtain optimization solutions to complex problems that are intractable using conventional methods or otherwise require massive computing resources. In recent years a considerable amount of natural computing research has been undertaken to exploit the analogy between mathematical optimization algorithms and the natural foraging processes [1]. Examples of such bio-inspired optimization approaches include the ant colony optimization (ACO) [2,3], which is developed based on the foraging behaviors of real ant colonies; the particle swarm optimization (PSO) [4,5] that glean ideas from social foraging behaviors of bird flocking and fish schooling; the artificial bee colony (ABC) [6] that mimic the foraging behavior of honey bees. These algorithms have been found to perform better than the classical heuristic or gradient-based methods, especially for optimizing the nondifferentiable, multimodal and discrete complex functions. Currently, these nature-inspired paradigms have already come to be widely used in many areas. The aim of this work is look to nature and the bacterial foraging and communication strategies that have evolved over millennia, and to produce more bacterially-realistic and powerful optimization model.

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Recent studies of microorganisms have revealed diverse complex social behaviors, including cooperation in foraging, building, reproducing, dispersing and communicating. Among them, the computational models of the bacterial foraging have attracted more and more attention, due to its research potential in engineering applications. A few models have been developed to mimic bacterial foraging behavior and have been applied for solving some practical problems [7,8]. Among them, bacterial foraging optimization (BFO) is a successful population-based numerical optimization algorithm that mimics the foraging behavior of *Escherichia coli* bacteria [8]. Until now, BFO has been applied to some engineering problems, such as optimal control [9], optimal power flow [10], color image enhancement [11] and machine learning [12]. However, classical BFO algorithm suffers from three major drawbacks: (1) as a bacterial colony evolves, the fixed run-length unit of each bacterium may lead them trap in local optima or oscillate about the optima; (2) due to the fixed population size, the algorithm cannot fully explore the potential of searching ability and are time consuming; (3) there is no information sharing among the bacterial colony. Thus, experimentation with complex and multimodal benchmark functions reveals that the BFO algorithm possesses a poor convergence behavior and its performance heavily decreases with the growth of search space dimensionality and problem complexity.

Several BFO variants have been developed to improve its optimization performance. In [13], Tripathy and Mishra proposed an improved BFO algorithm using two approaches: (1) in order to speed up the convergence, the average value is replaced by the minimum value of all the chemotactic cost functions for deciding the bacterium's health; (2) for swarming, the distances of all the bacteria in a new chemotactic step are evaluated from the globally optimal bacterium to these points and not the distances of each bacterium from the rest of the others. Mishra [14] proposed a fuzzy bacterial foraging (FBF) algorithm using Takagi–Sugeno type fuzzy inference scheme to select the optimal chemotactic step size in BFO. The FBF algorithm was shown to outperform both classical BFO and a genetic algorithm when applied to the harmonic estimation problem. Kim et al. proposed a hybrid approach involving GA and BFO for function optimization [15]. The proposed algorithm outperformed both GA and BFO over a few numerical benchmarks and a practical PID controller design problem. Biswas et al. proposed a synergism of BFOA with the particle swarm optimization [16]. The new algorithm, named by the authors as bacterial swarm optimization (BSO), was shown to perform in a statistically better way as compared to both of its classical counterparts over several numerical benchmarks. In [17], instead of simply considering chemotaxis behavior of single bacterium, MCBFO also introduced the communication strategies employs by natural multi-colony bacterial community in order to coordinate pattern emerges, which is lacking from the mentioned chemotaxis inspired algorithms. In [18], the proposed CBFO applied two cooperative approaches to the original BFO, namely the serial heterogeneous cooperation on the implicit space decomposition level and the serial heterogeneous cooperation on the hybrid space decomposition level.

Whereas these algorithms contain the fundamental concepts of bacteria foraging, more recent biological findings have provided further details and models of the process. This paper presents a novel optimization strategy called bacterial colony foraging optimization (BCFO), whose roots are found in several extended life-cycle models of bacterial colony evolving [19]. The basic model and the resulting optimization algorithm differ from the previous bacterial foraging algorithms by incorporating the following three strategies of bacterial colony behaviors: (1) Enhanced chemotaxis with cell-to-cell communication, which offers the basic search principle of BCFO. Here the cell-to-cell communication strategy enables the bacteria tumble towards better directions in the chemotactic steps. (2) Self-adaptive foraging strategy, which enable each bacterium strike a balance between the exploration and the exploitation of the search space during its evolution, by adaptively tuning the magnitude of its chemotactic step size. (3) Life-cycle model, which result in a dynamic population. That is, bacteria will split or die depending on the nutrition obtained in the foraging processes. By this mechanism, the computational complexity of the optimization process can be reduced.

Seven versions of BCFO algorithm combined by different strategies, namely the cell-to-cell communication, self-adaptive foraging, and life-cycle model, are proposed and tested. Several experiments were performed to evaluate the performance of the seven BCFO variants.

In the first experiment, these BCFO variants have been evaluated on fifth benchmark functions, which including eight classical benchmark functions and seven CEC05 problems [20]. The CEC05 test function suite were especially designed to test optimization algorithms providing many desirable properties, namely shifted, non-continuous, rotated, and narrow global basin of attraction. Moreover, this work used the moving peaks benchmark (MPB) [21] test bed to illustrative the inherent adaptive mechanism in the proposed model of surviving in a changing environment. Lastly, we investigate an interesting real-world application of the BCFO scheme to solve the dynamic RFID network optimization problem, which focusing on minimizing two specific objective functions in a dynamic RFID tag environment. The proposed BCFO has been compared with its classical counterpart, the classical BFO algorithm [8], and the very popular swarm intelligence algorithm known as PSO over both benchmarks and the real-world problem with respect to the statistical performance measures of solution quality and convergence speed.

The proposed BCFO and its application on RFID network optimization problem described in this paper enhance the previously proposed methods in the following aspects:

- The proposed BCFO is a more bacterially-realistic model of bacterial colony foraging patterns, which incorporates a bacterial life-cycle framework and the underlying mechanisms of bacterial chemotaxis, cell-to-cell communication, and self-adaptive foraging. This more bacterially-realistic model successfully cast the bacterial foraging algorithm into adaptive, cooperative, and varying population fashion.