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Evolutionary predator and prey strategy for global optimization

J.J. Chen [a], Q.H. Wu [a,b], T.Y. Ji [a], P.Z. Wu [c], M.S. Li [a,*]

[a] School of Electric Power Engineering, South China University of Technology, Guangzhou 510641, China
[b] Department of Electrical Engineering and Electronics, University of Liverpool, Liverpool L69 3GJ, UK
[c] Institute of Advanced Technology (SIAT), Chinese Academy of Sciences, Institute of Biomedical and Health Engineering, Paul C. Lauterbur Research Center for Biomedical Imaging, Shenzhen 518055, China

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ABSTRACT

This paper presents a novel evolutionary predator and prey strategy (EPPS) for global optimization. The EPPS is based on a dynamic predator-prey model stemmed from the study of animal group living behaviors. In the model, concepts of experienced predators, strategic predators, the prey and its safe location are developed to simulate three typical animal behaviors: scanning, hunting and escaping. To validate the applicability and practicability of EPPS, experiments were undertaken on a set of 20 benchmark functions and three real-world problems, respectively. The results show that EPPS has a more superior performance in comparison with other recently developed methods reported in the literature.

1. Introduction

In the past decade, nature has served as a fertile source of concepts, principles and mechanisms for designing various artificial computation systems to optimize many types of complex computational problems [23,54,8,3]. Based on studying and simulating the search behaviors of animals in the wild, several different types of evolutionary algorithms (EAs) have been developed. For instance, ant colony optimization (ACO), which develops from the collective intelligent behaviors of real ants, has been investigated in both applications and theories [5,9]. Differential evolution (DE) stems from the study of adaptation in natural and artificial systems and has been widely used for problem solving [50,40]. Artificial bee colony (ABC) is one of the most recent swarm intelligence based optimization algorithms which simulates the foraging behavior of honey bee colonies [27,39]. Particle swarm optimization (PSO) takes inspiration from the social behaviors of bird flocking or fish schooling and has been shown as an effective tool for solving global optimization problems [29,32]. Group search optimizer (GSO), which works on the bases of animal search behaviors and group living theory, has been successfully applied for solving large-scale multimodal benchmark functions and real-world problems [23,60]. Recently, teaching-learning-based optimization (TLBO) has been developed based on the influence of a teacher on the output of learners in a class [43,7]. It is well known that local exploitation and global exploration abilities are the two critical criteria for evaluating the performance of the population-based optimization algorithms. However, most of the aforementioned EAs just involve one single species, which limits the interaction among multiple species in the evolutionary process. Therefore, the local exploitation and global exploration abilities of these EAs cannot be well balanced.

In animal kingdom, group living is a widespread phenomenon, and has been comprehensively studied during the last decade [24,46]. One consequence of living together is that group hunting allows group members to increase finding rates as well as to

* Corresponding author.
E-mail addresses: qhenrywu@gmail.com (Q.H. Wu), mengshili@scut.edu.cn (M.S. Li).

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reduce the variance of search success [41]. Another consequence of living together is that group escaping is able to develop the dilution protection effect, which can provide greater chance for group members to survive [49,19]. The dingoes and sheep are two representative group living species found mainly in Australia, as well as Southeast Asia [51]. As early as 1992s, Thomson [51] argued that dingoes could adjust their hunting paths to suit circumstances and mainly possess two kinds of behaviors: a directly hunting behavior once locking on the sheep, and an exploratory behavior by communicating with other dingoes for adjusting their hunting paths. In addition, Allen [1] argued that a dingo may have the ability to chase and outrun a sheep, only to turn away suddenly if the sheep escaped to a safe place or a more desirable sheep was found. Inspired by this natural phenomenon, this paper develops a dynamic predator-prey model, in which the concepts of experienced predators, strategic predators, the prey and its safe location are transplanted to design an evolutionary algorithm, and proposes an evolutionary predator and prey strategy (EPPS) to construct a good balance between the algorithm's local search and global search abilities.

The EPPS works on the philosophy of predator's hunting and prey's escaping, in which the interaction behaviors between the dingoes and the sheep have been comprehensively studied. In consideration of the two kinds of hunting behaviors of the dingoes and the escaping behavior of the sheep, this paper transplants the concepts of experienced predators, strategic predators, the prey and its safe location to simulate three typical scenarios: dingoes hunting, sheep scanning and sheep escaping. In EPPS, the experienced predators denote the dingoes associated with directly hunting and the strategic predators denote the dingoes that could adjust their hunting paths. The prey denotes the sheep pursued by the dingoes and the place which the prey scans for is denoted as its safe location. Based on these concepts, animal scanning strategy, animal hunting strategy and animal escaping strategy are employed metaphorically by EPPS to design the optimum search mechanisms. Numerical studies undertaken on a set of 20 well-known benchmark functions and three real-world problems show that EPPS has a superior performance in comparison with several other peer algorithms.

2. Evolutionary predator and prey strategy

The EPPS is a population-based optimization algorithm, which takes inspiration from the group living behaviors of dingo hunting and sheep escaping. The population of EPPS is called a group and each individual in the group is called a member. Each member represents a position vector of an $n-$dimensional search space and is randomly positioned in the beginning. Here, n is the dimension of the objective function. In each generation, the members of the group are classified into four different types, representing experienced predators, strategic predators, the prey and its safe location, to cope with three typical scenarios, predators hunting, prey scanning and prey escaping.

In EPPS, the member that corresponds to the best fitness value of the group is chosen as the prey, and the member that corresponds to the worst fitness value of the group is chosen as the safe location of the prey; the rest of the members are classified randomly as either the experienced predator or the strategic predator. The EPPS investigates three processes from the perspective of the predators' hunting and the prey's escaping. When a group of predators lock onto a prey, the experienced predators run experientially for hunting; the prey realizes the danger and tries to escape from its dilemma by scanning for its safe location; as for the strategic predators, they run strategically for hunting. The search behaviors of the predators and the prey are described in detail as follows.

2.1. Experienced predators' search mechanism

For each search generation, a number of group members are selected as the experienced predators. The experienced predators will determine their search paths by accumulatively learning for the successful paths of the predators of the group. Here, the successful paths indicate the directions of fitness value decreasing. In order to get a reliable estimator for the paths, the experienced predators adopt the concept of adaptive covariance matrix [22]. The adaptive mechanism is based on the assumption that the successful evolutionary paths of the predators used in recent past generations may also be successful in the following generation. Gradually, the most suitable evolutionary paths can be developed automatically to guide the search behavior of each experienced predator in different evolutionary stages. The predatory behavior of the ith experienced predator at generation $(g+1)$ can be modeled as follows:

$$\boldsymbol{x}_i^{(g+1)} = \boldsymbol{m}^{(g)} + \sigma^{(g)}\mathcal{N}(\mathbf{0}, \boldsymbol{C}^{(g)}), \quad i = 1, \ldots, \lambda \tag{1}$$

where $\boldsymbol{m}$ and $\boldsymbol{C}$ are mean value and covariance matrix of the predators, respectively, developed by the position vectors of the predators of the group, $\mathcal{N}(\mathbf{0}, \mathbf{I})$ corresponds to a multivariate normal distribution with zero mean and unity covariance matrix, $\sigma(\sigma > 0)$ is the step size and λ is the number of the experienced predators.

During the search process of EPPS, if an experienced predator finds a better location than the current prey and other predators, in the next search generation it will switch to be the prey and all the other predators, including the prey in the previous search generation, will perform hunting mechanism; and if an experienced predator finds a worse location than the current safe location, in the next search generation it will switch to be the safe location and the prey performs escaping mechanism to this location. The prey and the strategic predator, which will be introduced in the following paragraphs, are also implementing these switching mechanisms in each search process. Thus, different types of members can play different roles during each search generation, and even the same member can play different roles during different search generations. Thereupon, EPPS could escape from local minima in the earlier search bouts and obtain a good balance between its local exploration and global exploitation abilities.