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An analysis of the migration rates for biogeography-based optimization

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A B S T R A C T

Biogeography-Based Optimization (BBO), inspired by the science of biogeography, is a novel population-based Evolutionary Algorithm (EA). For optimization problems, BBO builds the matching mathematical model of the organism distribution. In this evolutionary mechanism, species migrating among islands can be considered as the information transition among different solutions represented by habitats. Solutions are reassembled according to migration rates. However, so far, the migration models are generally designed by empirical studies. This leads to immature conclusions that are unreliable. To complete the previous works, this paper investigates transition probability matrices of BBO to clarify that the transition probability of median number of species is not the only determinant factor to influence performance. The impact of migration rates on BBO is mathematically discussed, which is helpful to design migration models. Using numerical simulations, the BBO and several other classical evolutionary algorithms are compared. The simulations also comprehensively explain the effect of the BBO's properties on its performance including dimension, population size, and migration models. The results validate the theoretical analysis in this paper.

1. Introduction

Research on optimization has been very active during the last decades in almost every field of science and engineering, ranging from efficiency maximization in job-shop scheduling problems [54] to cost minimization in robotic path planning [47]. There are also various optimization problems in our daily life, including minimizing charging the cost of Electrical Vehicles (EV) [22], maximizing profits from investments [6], etc. In recent years, a variety of Evolutionary Algorithms (EA) have been developed as feasible and effective methods for optimization problems [1,2,15,29,31,50], especially for Non-deterministic Polynomial (NP) problems [12]. Evolutionary Algorithms have several advantages such as robustness, reliability, global search capability and the fact that there is little or no prior knowledge required. [30]. Many of them, such as Evolutionary Strategies (ES) [14,16,17], Genetic Algorithms (GA) [7,18,19,32,41], Differential Evolution (DE) [29,34,35,42,55], have been successfully implemented in practical problems.

The main ideas of most EAs are inspired from nature. During the past decades, researchers have proposed novel heuristic algorithms by drawing inspiration from different natural phenomena. Genetic Algorithm (GA) mimics the biological process through producing generations of chromosomes [7,18,19,41]. Simulated Annealing (SA) was inspired by the annealing in metallurgy [21]. The idea of Particle Swarm Optimization (PSO) comes from the flocking behavior of birds [4,9,20,24,31,45]. Ant Colony Optimization (ACO) simulates the ecological behavior of ants in foraging [8,10], and Artificial

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Bee Colony (ABC) was inspired by the behavior of honeybees in collecting nectar [1,33]. With the development of these algorithms, several hybrid methods have been proposed as well [44,51,53]. This shows that nature does not only provide us with resources, but that it may also serve as inspiration for developing new methodologies.

Biogeography is the science of the distribution of species and ecosystems in geographic space and through geologic time [27,28,46]. The distribution of species across geographical areas can usually be explained by a combination of environmental reasons. In the natural world, species tend to explore more suitable environments. Islands that are suitable for species have a high habitat suitability index (HSI) while islands that not suitable for species have a low HSI. Throughout the progress of evolution, species instinctively migrate to the islands with high HSI. Over time, the islands with high HSI come to have more species, while those with low HIS come to have fewer. According to this idea, Dan Simon proposed a novel evolutionary algorithm named Biogeography-Based Optimization (BBO) [37]. BBO uses mathematical models of biogeography to describe such attributes as migration, mutation and the distribution of species.

In recent years, BBO has been studied and developed comprehensively. For some well-known benchmarks, BBO performs better than other widely used heuristic algorithms like GAs, ACO, PSO, DE, SA [13,25,26,37–39,45]. There are also several successful applications to practical problems, such as sensor selection problems for aircraft engine health diagnostics [37], groundwater possibility retrieval systems [23], and power flow problems [36]. Previous research has shown the strength of BBO.

Paper [25] discussed factors that can affect the performance of BBO by empirical studies including migration models and equilibrium species amount. However to date, the migration models have not been analyzed using mathematical studies. Although experience and empirical studies can be relied on sometimes, they are not long-term solutions to algorithm development. Therefore, further research regarding the migration models of BBO was conducted. According to our analysis, in some cases, the analysis of migration models of paper [25] is false. Therefore, we extend the work of paper [25] by mathematically analyzing the migration model of BBO, which is helpful to develop BBO further.

The rest of this paper is organized as follows. Section 2 briefly introduces the mathematical model of BBO. In this section, the transition probability matrix of BBO is investigated and relevant theorems are proved for subsequent discussion. Section 3 analyzes six different migration models cited from paper [25]. Based on the theorems introduced in Section 2, we use the migration models to clarify that the transition probability of median number of species is not the only key reason to affect BBO's performance. Subsequently, we discuss the effects of migration rates on the performance. The numerical simulation results and relevant analysis between different migration models and several other classical evolutionary algorithms are investigated in Section 4. Further, two new migration models are proposed based on the analysis in Section 4. We end this paper with conclusions and present our future work in Section 5.

2. Brief of BBO model and mathematical preliminary

Biogeography-based optimization mimics the species distribution in nature biogeography. In science of biogeography, one of criteria to see whether geographical areas are well suited as residences for biological species is habitat suitability index (HSI). It is affected by various factors including climate, temperature, humidity and topographic features. All the factors that influence habitability are called suitability index variables (SIVs). Fertile areas with a high HSI tend to have a large number of species, while the barren ones with low HSI have a small number of species. Habitats with a high HSI have a low immigration and high emigration rate since they are nearly saturated with species. In contrast, habitats with low HSI have a high immigration and low emigration rate. In BBO, a good solution equals to an area with a high HSI in natural biogeography and the poor solution is analogous an area with a low HSI. All the features in solutions are considered as SIVs. Good solutions tend to share their features with poor solutions, and the poor solutions will highly probably accept the features. This is very similar to species migrating between fertile areas and barren areas. In [37] that term "island" presents the area which is geographically isolated from other habitats. We follow the expression in this paper. The pseudo codes of BBO are given in Table 1.

The work in [37] states that there are k species in the habitat throughout the evolutionary process with immigrants entering the habitat at an immigration rate λ_k and emigrants leaving the habitat at an emigration rate μ_k. The largest possible species count that the habitat can support is n. Simon considered the probability P_k that the habitat contains exactly k species [37]. The term P_k changes from time t to time $t + \Delta t$ as follows [25],

$$P_k(t+\Delta t) = P_k(t)(1-\lambda_k\Delta t-\mu_k\Delta t)+P_{k-1}(t)\lambda_{k-1}\Delta t+P_{k+1}(t)\mu_{k+1}\Delta t \tag{1}$$

According to [37], (1) holds because in order to have k species at time $(t + \Delta t)$, one of the following conditions must hold: (i) There were k species at time t, and no immigration or emigration occurred between t and $(t + \Delta t)$; or, (ii) There were $k - 1$ species at time t, and one species immigrated; or, (iii) There were $k + 1$ species at time t, and one species emigrated.

By assuming that Δt is small enough, the probability of more than one immigration or emigration can be ignored. After taking the limit of Eq. (1) as $\Delta t \to 0$, we have

$$\dot{P}_k = \begin{cases} -\lambda_0 P_0 + \mu_1 P_1, & k = 0 \\ -(\lambda_k+\mu_k)P_k + \lambda_{k-1}P_{k-1} + \mu_{k+1}P_{k+1}, & 1 \leqslant k \leqslant n-1 \\ -\mu_n P_n + \lambda_{n-1}P_{n-1}, & k = n \end{cases} \tag{2}$$