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A novel class of niche hybrid Cultural Algorithms for continuous engineering optimization

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ABSTRACT

This paper proposes a novel class of niche hybrid Cultural Algorithms for solving engineering problems with continuous design variables. The first algorithm, Niche Cultural Algorithm (NCA), embeds niching within the cultural framework to maintain multiple groups within the population of agents in order to locate multiple optima. The second algorithm, hybridizes niche Cultural Algorithms with Tabu search (H-NCA). This technique offers a novel architecture of hybrid approaches, which combines Niche Cultural Algorithms (NCA) with Tabu search (TS). The proposed hybridization scheme enables the algorithm to overleap local optima and improve performance. The third algorithm, Improved Hybrid Niche Cultural Algorithms (IH-NCA), is employed to enhance convergence rate and accuracy of H-NCA with fewer computations. In IH-NCA, the algorithm switches between two selection strategies based on roulette wheel and stochastic tournament selection. This enhances the algorithm's ability to further escape stagnation and premature convergence with varying stochastic noise and selection pressure. Simulations were performed over miscellaneous engineering optimization problems that include minimization of constrained functions and structural engineering optimization. A comparative study is carried out with other state-of-the-art optimization techniques. The findings affirm the efficiency and robustness of the new methodologies over the other existing relevant approaches.

1. Introduction

Many engineering optimization problems can be considered as global optimization of multimodal functions with continuous variables. This type of problems usually includes manifold optima in the feasible search landscape. Basically, global optimization of multimodal functions aims at locating the global optima without being trapped in the region of a local minimum solution. When dealing with multimodal optimization problems, traditional methods like quasi-Newton [31], Tabu search [32,33], Nelder–Mead's simplex method [62], and classical evolutionary algorithms that are presented to locate single global optimal solution, easily get trapped into local optima.

Cultural Algorithms (CAs) [73], an adaptive evolutionary optimization algorithm derived from the cultural evolution process in nature, provide a general framework for solving intricate optimization problems [74,75]. CAs have alone shown their ability to successfully handle constrained and engineering optimization problems [4,5,11,17,46,49,75,81,93]. However, CAs suffer from a particular incompetency in optimizing multimodal functions with continuous variables. This is due to their weaknesses that relate to such landscapes as weak exploitation and premature convergence [39,43,87]. Premature

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convergence of CAs causes the algorithm to achieve local optimum instead of a global one during the optimization process, while weak exploitation of the algorithm results in slow convergence before obtaining an accurate and acceptable result.

A plethora of nature-inspired algorithms has been proposed to handle different types of optimization problems and applications [18,3,12,28,69,70,9,16,85,89,68]. Despite the fact that computational cost of using such algorithms has been reduced noticeably, the quest for more efficient techniques is still on the rise to meet the developing complexities of real-world problems and applications arising in different areas. In these new applications, finding global optima becomes a challenge, especially when the optimization problem includes features like ill-conditioning, high-dimensionality and multimodality of the objective function. Such conditions will usually make it hard to locate high-quality solutions and avoid getting stuck in local basins throughout the search process.

Hybridization, in context to evolutionary algorithms, mainly refers to producing a new algorithm through blending the best features of two or more techniques. This newly generated technique is expected to outperform the original algorithms over a certain optimization problems. Memetic algorithms provide a common template for hybridization which combines the corresponding benefits of global and local search [41]. This greatly depends on the types of benchmarks that one is trying to solve. Nevertheless, hybridization is getting very popular because of its ability to handle different types of problems with varying complexity, vagueness, and noisy environment.

A niching method is usually used modify the behavior of a classical algorithm to maintain various groups in the adopted population component in order to effectively find multiple optima. Niching techniques are considered very effective in maintaining the population diversity and enhancing the exploration of new large-scale domains [37,42,54,66,82]. The niching methods include fitness sharing [37], restricted tournament selection [42], clearing [66], crowding [82] and speciation [54]. The fittest individual at each niche gets a high fitness or has its fitness unchanged, while the other individuals in that niche will have their fitness modified to sharply decrease their fitness values [30,84,35,57,66,70]. This increases the chance that the agents in the population are dispersed in the entire search landscape. Therefore, the diversity among the individuals in the population will be preserved during the generations. Apropos of enhancing the exploitation abilities of techniques that suffer this drawback, a common tactic is to merge the classical evolutionary algorithm with a supplementary metaheuristic, as one can find in the literature [18,3,12,28,69,70,30,48]. This forms a hybrid framework for effectively approaching multimodal optimization problems [36,70].

Ghosh et al. [30] proposed a Differential Covariance Matrix Adaptation Evolutionary Algorithm (DCMA-EA) to efficiently approach non-convex and nonlinear functions. This form of blending enhances the explorative and exploitative abilities of the original DE [79] and original CMA-ES [40] during the optimization process for hybrid composition functions and other forms of complex landscapes. A hybrid form that is able to find better solutions with no serious increment in terms of the functions' evaluations (FEs). Qin and Suganthan [69] introduced a Self-Adaptive Differential Evolution with local search (L-SaDE) to speed up the convergence of the algorithm. This algorithm uses an adaptive selection of strategies for generating trial vectors together with their control parameters by learning from previous experiences. The algorithm produced competitive results compared with other state-of-the-art algorithms when tested on a set of constrained numerical optimization problems. Other evolutionary algorithms produced interesting performance when blended with local search [70,84]. Wang et al. [84] proposed a Memetic PSO with local search (LS) for locating multiple global and local optimal solutions in multimodal optimization landscapes. MPSO uses a special neighborhood structure based on a ring-shaped topologies and forms different species in an adaptive manner based on their indices in the population. This helps in searching different sub-regions in the landscape in parallel. The exploitative capacity of the algorithm is enhanced with the help of an adaptive local search operator that employs two different LS techniques in an adaptive cooperative manner.

On the other hand, Cultural Algorithm has been hybridized with many other techniques to avoid the premature convergence feature that arises when optimizing very complex and challenging landscapes [57,29,80,12]. Sharing of information will effectively reduce computational cost. Information sharing becomes a very expensive process if we do not find the appropriate information to share between these individuals to avoid propagating false information. This process should be planned in a categorical and systematic manner. The best way to enhance this process in CA is through supporting the work of the knowledge sources in the belief space with a proper type of local search. In this manner we utilize the strengths of both population-based and point-based optimization. This will adaptively modify the behavior of each agent during the optimization process. It also leads to inter-basin mutation steps that result in redistributing agents sporadically over the search landscape. This is done in a different manner from [63] where niching will enable the formation of different subgroups that cover larger spaces and preserve diversity more efficiently. Cultural Algorithms are known for evolving behaviors not solutions, and then natural selection is used to select only the best behaviors for searching individuals. Moreover, most previous works on CA focus on enhancing the exploitation capabilities of the algorithm, which affect the convergence rate of the search process. Such policy is not suitable for guiding the behavior of the algorithm in highly multimodal problems and complex engineering optimization benchmarks. Therefore, in this paper, we propose a novel class of niche hybrid Cultural Algorithms for solving multimodal functions, with application on continuous engineering optimization. This class contains three algorithms. The first algorithm, Niche Cultural Algorithm (NCA), uses multiple niches to group individuals based on their genetic likeness to locate multiple optima. The niche technique used in this work is the clearing procedure [66]. In comparison with the other niche methods, such as fitness sharing and speciation, clearing is simpler to implement and preserves the population diversity efficiently when using a small population size [66]. The second algorithm, Niche Hybrid Cultural Algorithm (H-NCA), improves the performance by combining Cultural Algorithms with Tabu search to overlook found local optima. Tabu search guarantees fine results when it has a good starting solution. Recent research has proved this type of