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Empirical evaluation of distributed Differential Evolution on standard benchmarks

Javier Apolloni [a,*], José García-Nieto [b], Enrique Alba [b,c], Guillermo Leguizamón [a]

[a] LIDIC, Departamento de Informática, Universidad Nacional de San Luis, Ejército de los Andes 950, 5700 San Luis, Argentina
[b] Lenguajes y Ciencias de la Computación, University of Málaga, Campus de Teatinos s/n, 29071 Málaga, Spain
[c] Faculty of Electrical Engineering and Computer Science, VŠB-Technical University of Ostrava, Czech Republic

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ABSTRACT

This paper presents a new distributed Differential Evolution (dDE) algorithm and provides an exhaustive evaluation of it by using two standard benchmarks. One of them was proposed in the special session of Real-Parameter Optimization of CEC'05, and the other was proposed in the special session of Large Scale Global Optimization of CEC'08. We statistically validate and compare our results versus all other techniques presented in these special sessions. This means that more than 25 problems, with different dimensions: 30, 50, 100, and 500 variables, are evaluated; and 15 algorithms are compared in the experiments. Our dDE is simple, accurate, and competitive when applied to a wide variety of problems, with scaling dimensions, and different function features: noisy, non-separable, multimodal, rotated, etc.

1. Introduction

Metaheuristics [1,2] are optimization algorithms that allow experts to tackle complex problems by iteratively trying to improve a candidate solution, with regard to a given measure of quality (fitness). Possibly, the main feature of metaheuristics is that they make few or no assumptions about the problem being optimized and can search very large spaces of candidate solutions. However, although metaheuristics do not guarantee an optimal solution is ever found, they are usually able to obtain high quality solutions with moderate computational cost.

In the last decade, Differential Evolution (DE) [3,4] has emerged as a prominent metaheuristic for multidimensional real-valued functions. This technique was designed by Storn and Price in 1997 and has attracted a great attention from the research community since, it is simple and easy to understand, and it shows a special ability to deal with non-differentiable and multimodal optimization problems. In addition, there exists a number of works on theoretical and practical aspects of DE (multiobjective, constrained, dynamic, parallel, etc.) and has been applied on a wide range of real-world problems [4].

Besides the temporal complexity of some (NP-Hard) problems, they can be handled by canonical sequential metaheuristics (including DE), although the exploration procedure (of the search space) performed by them is also time-consuming. In addition, the size of the problem solution space, as well as its complexity, turn increasingly larger with the number of decision variables. As a result, more efficient search strategies are required to explore all the promising regions with limited computational resources.

* Corresponding author.
E-mail addresses: javierma@unsl.edu.ar (J. Apolloni), jnieto@lcc.uma.es (J. García-Nieto).

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Parallel distributed models are very useful tools to improve the performance of such techniques during the search process. In particular, DE methods can be easily distributed in a parallel model, since they are based in the evolution of a population of individuals. This population can be partitioned into small subsets known as islands, each subset evolving independently from each other, usually exploring different regions. These islands are spatially structured and exchange information among them to hopefully increase the accuracy and efficiency of the resulting algorithm. When run in a parallel computer, the time reduction is an additional advantage [5]. Furthermore, the latest advances in computing architectures and telecommunication networks allow us to link computers to create a powerful tool for low-cost computing. According to this, the parallel DE algorithm we are proposing here could be used at any granularity, i.e., at the computer, core, or thread levels. For instance, each core could process an island whose set of individuals is evolved by a DE algorithm.

In this work, our main motivation is to develop and evaluate a set of distributed versions of Differential Evolution (dDE) with the aim of empirically assess whether these kinds of optimizers are competitive with the current state of the art, or not. Our conjecture is that, a periodical migration of individuals in a given topology leads to a high exploration ability in DE, since the foreign solutions could provide diversity to the island population. We are also interested to analyze the behavior of dDE versions on a set of many problems with different properties: separable/non-separable, unimodal/multimodal, shifted, rotated, hybrid/composed, and on a scaling benchmark with large dimension landscapes.

Therefore, in this work we perform a thorough experimentation with our distributed versions of Differential Evolution (dDE) by following the standard procedures applied in two well-known special sessions: Real-Parameter Optimization of CEC'05 [6] and Large Scale Global Optimization of CEC'08 [7]. We statistically assess and compare our results against all the other techniques presented in these sessions, summing up 15 efficient algorithms in the top of the state of the art. The resulted distributions lead us to claim the competitive performance of our dDE, even on specially hard problems with intricate shapes and deceptive landscapes.

The contributions of this work can be enumerated as follows:

1. We have analyzed the performance of several distributed versions of DE, and considered also a sequential canonical one. A version with two populations seems to show the best results.
2. Our proposed dDE has been evaluated in the CEC'05 experimental framework and compared with the eight proposed algorithms in this benchmark, for problem dimensions of 30 and 50 variables. These comparisons show the competitive performance of our distributed approach, statistically better than other DE versions, and similar to G-CMA-ES (the winner in this special session).
3. In an extensive experimentation, we have evaluated our dDE in the scope of CEC'08 test suite. In this benchmark, a number of 7 large scale problem functions with dimensions 100 and 500 variables are optimized. After statistical comparisons with regards to all presented algorithms in this special session, we can observe that our dDE is again located in the top level of techniques with the best performances.
4. Further analysis concerning the problem function properties show the ability of our dDE to obtain an excellent behavior on non-separable and multimodal functions.

The remaining of this paper is organized as follows. Next section offers a review of distributed DE approaches found in the current literature. In Sections 3 and 4, the Canonical DE and the parallel distributed model proposed in this study are described, respectively. Experiments, comparisons, and analysis are presented in Section 5. Finally, concluding remarks and future work are provided in Section 6.

2. Literature overview: distributed DE approaches

This section presents a brief overview of the main existing works dealing with distributed population DE algorithms in the literature. Practically all of them consist on island distributed models, with different topologies, and trying to induce diversification/intensification search mechanisms by means of the migration policy of solutions. It is worth mentioning that the use of parallel resources to improve the computational cost is an additional advantage only exploded in some of these works.

A first approach was proposed by Zaharie and Petcu [8] consisting on a distributed DE, in which the population is divided into several sub-populations and one DE algorithm is executed in parallel on each sub-population. The motivation of this work was to tackle each optima in multimodal problems with different DE islands, following a random topology for solution exchange. A number of 6 functions were solved by this method. After this, Tasoulis et al. [9] proposed a dDE with islands physically assigned to different processors. In this proposal, a ring topology is established to connect islands and different mutation strategies were also analyzed in the scope of 7 optimization functions and few dimensions (2 to 30). Following this parallel scheme Kozlov and Samsonov [10] used a dDE approach to optimize segment determination gene network, although making a slight adaptation to the migration policy. A modified version of distributed DE was developed by De Falco et al. [11,12] for the registration of 2-D satellite images and for determining the optimal mapping of resource on grid computing, respectively. This proposal used slave processors to execute DE instances and one master processor to collect the information concerning each island. After this, Apolloni et al. [13] made a first preliminary analysis on a bi-population DE with