An insight into evolutionary algorithms for continuous optimization: Learning by competitions

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***Abstract*—During the recent years, continuous optimization has significantly evolved to become a mature research field, in which evolutionary and bio-inspired algorithms have an important role thanks to their good results with limited resources. Through the last ten years, there have been a number of competitions associated to special sessions in this area. In this study, we summarize, for different real-parameter competitions, the results, highlighting the most relevant algorithms and techniques, presenting the trajectory they have followed and how some of these works have deeply influenced the top performing algorithms of today. The aim is to be both a useful reference for researchers new to this interesting research topic and a useful guide for current researchers in the field.**

***Index Terms*—Continuous optimization, global optimization, real-parameter optimization, large-scale global optimization.**

I. Introduction

Global optimization, also referred to as continuous or real-parameter optimization, is a growing research topic for its wide number of real-world applications. This optimization implies to optimize an *objective* function (we can consider minimize without loss of generality): to obtain x^* where $f(x^*) \leq f(x), \forall x \in [a, b]$, where $a, b \in \mathbb{R}^N$ and $f : \mathbb{R}^N \rightarrow \mathbb{R}$.

Due to the immense domain search of some problems, it is usually not possible to perform an exhaustive search in the entire domain, so meta-heuristic algorithms [1], [2] or evolutionary algorithms [3] are usually applied. The recent and growing interest on this type of optimization has fostered the development of a huge number of optimization algorithms that deal with this type of optimization (and many more proposals arise each year). Unfortunately, the great number of proposals makes following the evolution of this field difficult, and there is no clear criterion to select the most adequate algorithms.

In order to give more visibility to the field, many special sessions have been proposed in international conferences. These special sessions have, frequently, an associated real-parameter optimization competition, in which multiple algorithms are evaluated on a specific benchmark to allow fair comparisons among them. Taking into consideration the results obtained in these competitions, the evolution of this research topic can be analyzed, and many interesting conclusions can be drawn.

In a recent work [4], we described the different real-coding optimization competitions, noting the benchmark used for each one and briefly describing for each year the winners, obtaining several conclusions of the evolution of the competition. Also, we discussed several issues that we consider interesting about the research topic, the influence of winning algorithms over the years, and the evolution of real-parameter optimization. In this work, we summarize the main conclusions obtained in that paper. Due to the space limit, we have removed the references to the algorithms in this short summary. We refer the readers to the aforementioned full paper [4] for details.

II. Several optimization competitions

In our paper [4], we present the different global optimization competitions held at multiple international conferences and briefly describe the main algorithms (winner and runner-ups) for each year, according to the conclusions of the organizers. This review covers real-parameter, constraints, multi-modal and large-scale competitions.

As previously mentioned, space limits do not allow us to go into details in this paper. Instead, we preferred to focus on the main conclusions derived from our study. For the details on the results of each competition, we refer the readers to [4].

III. Current trends after a decade of competitions

In this section, we use the historical information after a decade of competitions in real-optimization to study which are the most influential algorithms, and the most successful components of those algorithms that have been, since their proposal, incorporated to other methods.

A. Competitions winners and most influential algorithms

In any research field, a good indication of its evolution is to what extent some algorithms have influenced others over the years, reusing ideas from previous successful proposals. In this particular case, we concluded that there are three very influential algorithms: CMA-ES, L-SHADE and MVMO. Not only they have inspired an important number of variants, but they are also the roots of the majority of winners.

Since 2005, the most influential algorithm has been CMA-ES. Algorithms based on this approach, such as BIPOP-CMA-ES or Ni-BIPOP-aCMA, were the winners of the CEC'2005,

BBOB'2009 and CEC'2013 competitions, respectively. Furthermore, there are many algorithms inspired by CMA-ES that have won several editions of the BBOB competition. It has been used as a local search method (see DRMA-LSCh-CMA) or as a component in a hybrid algorithm such as, for example, in iCMAES-ILS, the winner of the CEC'2013 competition.

A second algorithm with an increasing influence is L-SHADE, the winner in 2014. Its good results have favored an interesting list of winners using it in CEC'2015 (two of the three best algorithms), CEC'2016 and CEC'2017 (the three winners, and also other algorithms).

A third algorithm with good results was the MVMO scheme algorithm, which proves that being a scheme is not only good for global optimization, but also when the number of allowed fitness evaluations is very scarce (as shown by its good behavior in the expensive benchmark). In this case, the different proposals came from the same authors, maybe because this method is still not as popular as the DE scheme.

Obviously, the algorithms with the best results in the competitions are the most influential. However, sometimes, such as with the SHADE or VMO algorithms, their first versions were not among the winners, but they were evolved and, over the next few years, other methods based on them performed better achieving winning positions. Furthermore, it is remarkable that the metaheuristics with the best results in these competitions are far from being bio-inspired algorithms. In this sense, these results remind us that the *novelty* of new metaheuristics is very important but also subordinated to their performance in solving optimization problems.

B. Techniques/components for winner algorithms

One of the most interesting issues when studying successful algorithms is the identification of the different components that each algorithm uses, as they can be further used by other methods to boost their performance. In the following, we highlight several popular techniques/components that seem to provide good results:

- A frequent problem with many algorithms is the selection of appropriate values for their parameters. There are two alternatives: to be carefully chosen or an automatic parameter tuning tool. Another option, very popular in competitive algorithms, is to use self-adaptive criteria to adjust them, using an adaptive probability or a memory to enforce good parameter values.
- Several algorithms not only self-adapt their parameters, but also their components, having several components that provide the same functionality and then selecting one of them according to their performance.
- When the self-adaptive component is not a part of an optimization algorithm but of a complete algorithm, the proposal can be considered as a framework of algorithms. One proposal can be designed to have a particular combination, such as in the case of iCMAES-ILS, or allow a more open selection of optimization methods, as in MOS, the state-of-art algorithm in large-scale global optimization for more than six years.
- Most of the proposals are memetic algorithms. The local search method used relies on many different types of methods, from more general to specific approaches, such as the ones used in MTS and other LSGO algorithms.
- In order to increase the selective pressure in the populations, one approach popularized by L-SHADE and adopted by other algorithms is to decrease the population size during the run. In conjunction with a memory of solutions, it increases the exploitation ability of the algorithm, maintaining certain diversity in the search.
- Traditionally, in most of the best-performing methods only the best solutions were considered to guide the search. This means that a lot of information was being wasted in each generation. In more recent algorithms, bad solutions are also used to guide the search. Similarly, in the MVMO family of algorithms, not only is the best solution is considered, but also the average of a group of good solutions.

IV. Conclusions

The use of Bio-inspired and Evolutionary Algorithms for real-parameter optimization is of great interest today, and thus many approaches based on this type of optimization are proposed each year. This large number of proposals makes it difficult for researchers to follow the evolution of the field. In this paper, we have presented some conclusions after a decade of competitions on this type of real-parameter optimization problems. We have observed that there are several algorithms, such as CMA-ES, L-SHADE, MVMO and MOS, that have exercised a strong influence over other algorithms. We have also suggested several techniques that are being widely adopted among the winning proposals, and which could be used for more competitive algorithms.

The objective of this review and analysis of the evolution of the competitions is to offer a useful reference to new researchers in this research topic, and to help them to continue improving the field.

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