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Including preferences into a multiobjective evolutionary algorithm to deal with many-objective engineering optimization problems

Antonio López-Jaimes *, Carlos A. Coello Coello

CINVESTAV-IPN, Computer Science Department, Mexico City, Mexico

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ABSTRACT

In this paper, we introduce a new preference relation based on a reference point approach. This relation offers an easy approach to integrate decision maker's preferences into a MOEA without modifying its basic structure. Besides finding the optimal solution of the achievement scalarizing function, the new preference relation allows the decision maker to find a set of solutions around that optimal solution. Then, a MOEA equipped with the proposed preference relation can be integrated into an interactive optimization method. One of the main advantages of the new method is that setting its parameters is an intuitive task to the decision maker. The other advantage is that, since our preference relation induces a finer order on vectors of objective space than that achieved by the Pareto dominance relation, it is appropriate to cope with problems having a high number of objectives. We evaluated the proposed preference relation an engineering problem, the optimization of an airfoil design with 6 objectives.

1. Introduction

MOEAs rely on preference relations to identify high-potential regions of the search space in order to approximate the optimal solution set. A preference relation is a mean to decide if a solution **x** is preferable over another solution **y** in the search space.

In single-objective optimization, the determination of the optimum among a set of given solutions is clear. However, in the absence of preference information, in multiobjective optimization, there does not exist a unique preference relation to determine if a solution is better than other. The most common preference relation adopted is known as the *Pareto dominance relation* [34], which leads to the best possible trade-offs among the objectives. Thus, by using this relation, it is normally not possible to obtain a single optimal solution (except when there is no conflict among the objectives), but instead, a set of good solutions can be produced. This set is called the *Pareto optimal set* and its image in objective space is known as the *Pareto optimal front*.

Multiobjective optimization involves three stages: model building, search, and decision making (preference articulation). Having a good approximation of the Pareto optimal set does not completely solve a multiobjective optimization problem. The DM still has the task of choosing the most preferred solution out of the approximation set. This task requires preference

* Corresponding author. Tel.: +52 50 3362 5271; fax: +52 42 759 8461.
E-mail addresses: tonio.jaimes@gmail.com (A. López-Jaimes), ccoello@cs.cinvestav.mx (C.A. Coello Coello).

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information from the DM. Following this need, there are several methodologies available for defining how and when to incorporate preferences from the DM into the search process. These methodologies can be classified in the following categories [32,7]:

1. Prior to the search (*a priori* approaches).
2. During the search (interactive approaches).
3. After the search (*a posteriori* approaches).

Although interactive approaches for incorporating preferences have been widely used for a long time in Operations Research (see e.g., [6,32]), it was only until very recently that the inclusion of preference information into MOEAs started to attract a considerable amount of interest among researchers (see for example, [7,2]).

On the other hand, as noted by several researchers [28,26,49,35,36,29,46], the Pareto dominance relation has an important drawback when it is applied to multiobjective optimization problems with a high number of objectives (these are the so-called *many-objective problems*, e.g., [30]). That is, the deterioration of its ability to discern between good and bad solutions as the number solutions increases. A widely accepted explanation for this problem is that the proportion of nondominated solutions (i.e., incomparable solutions according to the Pareto dominance relation) in a population increases rapidly with the number of objectives (see e.g., [1,20]).

Being aware of the need of integrating MOEAs into interactive methods in many-objective optimization problems, in this paper, we present a new preference relation based on an *achievement scalarizing function* [52]. The main purpose of the new preference relation is to offer a simple approach to integrate decision maker's preferences into a MOEA without modifying the original structure of the MOEA.

There are other proposed schemes to incorporate user's preferences into a MOEA. However, the proposed preference relation, although can be applied for a general Multiobjective Optimization Problem (MOP), it is specially suited to deal with many-objective problems since it has some particular features: (i) the location and size of the region of interest can be easily controlled during the search of a MOEA, (ii) the new relation is scalable with respect to the number of objectives in terms of effectiveness, computational efficiency and amount of information required from the DM. As shown in Section 3, in other preference relations the number of questions asked to the DM quickly grows with the number of objectives, which makes these techniques difficult to use in many-objectives problems. In addition, in a general sense, our approach successfully overcomes some of the drawbacks of similar methods (see Section 3).

The new preference relation divides the objective function space into two subspaces. The solutions in one of these subspaces are compared using the usual Pareto dominance relation, while the others are compared using the achievement scalarizing function. By means of a *reference point*, the proposed preference relation allows the decision maker to guide the search towards a certain region of the Pareto optimal front. Each component of the reference point represents the aspiration levels that the decision maker requires for each objective. Later on, the new preference relation is embedded into an interactive optimization scheme in which a sample of the current approximation of the Pareto front is presented, at each interaction point, to the DM in order to change the reference point and the size of the region of interest.

Since, by using an achievement scalarizing function, the developed preference relation induces a finer order (in terms of number of dominance ranks) on vectors of the objective space than that achieved by the Pareto dominance relation, we believe that the use of the new preference relation is a promising approach to deal with many-objective problems. Additionally, by using an interactive optimization technique we can avoid the generation of millions or even billions of nondominated points in many-objective problems.

The main contributions of this work can be summarized as follows:

- A new preference relation to incorporate decision maker's preferences into a MOEA without modifying the original structure of the MOEA.
- A variant of the new preference relation which is able to naturally converge towards the central part of the Pareto front with no need of DM's information.
  - Both variants of the preference relation can be used just by replacing the dominance-checking procedure in a given Pareto-based MOEA.
  - The preference relations proposed are not affected if the DM provides a feasible or infeasible reference point. Furthermore, the relations take into account the magnitude by which a solution over- or under-attains the reference point.
  - Since the relations are based on a reference point, unlike other methods, the amount of information required from the DM is low even for more than 3 objectives.
  - In addition, these relations have a lower time complexity than that of the Pareto dominance relation and other existing relations that perform component-wise comparisons.
- An interactive optimization scheme using the proposed preference relation.
- Experimentation of the interactive scheme using an airfoil design problem with 6 objectives.

The results show that the new preference relation is able to guide the search towards the region defined by the reference point given by the decision maker, even if the reference point is infeasible. In addition, the experiments show that the proposed relation improves notably the convergence ability of a MOEA in problems with a high number of objectives.