Improving Computational Mechanics Optimum Design Using Helper Objectives: An Application in Frame Bar Structures

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Abstract. Considering evolutionary multiobjective algorithms for improving single objective optimization problems is focused in this work on introducing the concept of helper objectives in a computational mechanics problem: the constrained mass minimization in real discrete frame bar structures optimum design. The number of different cross-section types of the structure is proposed as a helper objective. It provides a discrete functional landscape where the non-dominated frontier is constituted of a low number of discrete isolated points. Therefore, the population diversity treatment becomes a key point in the multiobjective approach performance. Two different-sized test cases, four mutation rates and two codifications (binary and gray) are considered in the performance analysis of four algorithms: single-objective elitist evolutionary algorithm, NSGAII, SPEA2 and DENSEA. Results show how an appropriate multiobjective approach that makes use of the proposed helper objective outperforms the single objective optimization in terms of average final solutions and enhanced robustness related to mutation rate variations.

Keywords: Helper objectives, Multiobjectivization, Structural optimization, Evolutionary multiobjective optimization, population diversity.

1 Introduction

The recently developed evolutionary multiobjective algorithms [7][10] have shown a capacity to solve optimization problems in countless fields in science and engineering, and frequently without any increase in cost compared to single objective optimization [9]. Moreover, new possibilities recently opened up by evolutionary multiobjective optimization tools have been proposed to improve the search in single objective problems [26][33]. They include concepts such as 'multiobjectivization' or 'helper objectives'.

In Knowles et al. [32], two ways are proposed to diminish the number of local optima in a search (multiobjectivization): 1) By adding new objectives which allow the problem to be solved as a multiobjective one; 2) By decomposing the problem into simpler sub-problems, whose solutions are optimizing objectives in the multiobjective problem, with the purpose of increasing the number of paths to the

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global optimum, which are not opened in the single-criteria optimization. Therefore, the non-dominated solutions are coincident with the optima of the original problem. Two examples are solved in the referenced article: the hierarchical-if-and-only-if-function and the travelling salesman problem. They are solved using the first and second aforementioned strategies, respectively, showing improvements with respect to the single objective strategy.

In Abbass and Deb [1], the introduction of a new criterion helping the population diversity is proposed. The following additional criteria are suggested and analyzed: maximization of the objective function inverse, the maximization or minimization of a random value assigned to each individual in its creation and the maximization of the age of the chromosome. With no mutation, the multiobjective approach maintains better the genetic diversity and surpasses the single criteria results. Also, in E. de Jong et al. [31] and in S. Bleuer et al. [4], an additional criterion is added to genetic programming optimization for increasing the population diversity, in order to solve simultaneously the minimization of the tree size and the resolution of the n-parity problem. Other authors have also focused on using diversity-based new objectives in the context of dynamic environments [5][6].

In M. Jensen [29][30], it is emphasized how the inclusion of new additional objectives or criteria called ‘helper objectives’ and the solving of the problem as a multiobjective one can lead to the decrease or even the disappearance of certain difficulties inherent to the single objective optimization, such as: 1º) avoidance of local minima; 2º) maintenance of diversity at suitable levels; 3º) identification of good building blocks. Jensen applies this new concept to the job shop scheduling problem, where minimizations of individual jobs are generated dynamically with the algorithm evolution, as helper objectives. Using this strategy, the obtained solution is improved in a set of 18 test cases compared with the single criteria optimization.

This new perspective that evolutionary multiobjective optimization algorithms can provide is applied to different types of problems, such as mathematical and classical test functions, combinatorial problems (job shop, travelling salesman) or computational biology and bioinformatics [27]. Developed helper objectives are focused on the diversity item, as well as specific ad-hoc objectives, inherent to each particular problem.

In this work, we introduce the application of the ‘helper objectives’ concept to a real design optimization problem belonging to the field of computational mechanics. A new type of helper objective is proposed with advantages for the problem resolution, concretely applied to the bar frame optimum design problem of constrained mass minimization. The single criteria optimization is compared with three multiobjective evolutionary algorithms in two different-sized well referenced test cases, considering four different mutation rates and two distinct chromosome codifications.

The organization of this paper is as follows: First, the frame structural optimum design problem is described. Section 3 explains the new proposal of helper objectives. Section 4 sets out the evolutionary multiobjective algorithms considered in the analysis. Following this, both test cases are shown in section 5, continuing with the results and discussion in section 6. Finally, the paper ends with the conclusions section.