Capabilities of EMOA to Detect and Preserve Equivalent Pareto Subsets

Günter Rudolph, Boris Naujoks, and Mike Preuss

Universität Dortmund, Lehrstuhl für Algorithm Engineering
44221 Dortmund, Germany
{mike.preuss,boris.naujoks,guenter.rudolph}@uni-dortmund.de
http://ls11-www.cs.uni-dortmund.de

Abstract. Recent works in evolutionary multiobjective optimization suggest to shift the focus from solely evaluating optimization success in the objective space to also taking the decision space into account. They indicate that this may be a) necessary to express the users requirements of obtaining distinct solutions (distinct Pareto set parts or subsets) of similar quality (comparable locations on the Pareto front) in real-world applications, and b) a demanding task for the currently most commonly used algorithms. We investigate if standard EMOA are able to detect and preserve equivalent Pareto subsets and develop an own special purpose EMOA that meets these requirements reliably.

1 Introduction

Almost all publications about evolutionary multiobjective algorithms (EMOA) put their emphasis on approximating the Pareto front in the objective space whereas the relevance of an appropriate approximation of the Pareto set is widely neglected. The knowledge about the Pareto front is important for the product designer. But as soon as a solution in objective space has been selected it is important to know for the product engineer if there are alternative solutions in the decision space that lead to the same objective vector. Such Pareto-optimal solutions in decision space exist if there are symmetries in the objective function. This phenomenon occurs for example in the test problems considered by Chan and Ray [1] or Preuss et al. [2]. Basically, the Pareto set could be partitioned into subsets where the images of each subset are identical, i.e., each Pareto subset of this partition represents the entire Pareto front. Figure 1 illustrates and distinguishes different cases that may occur in multiobjective problems.

Apart from artificial test problems, there are of course real-world problems that exhibit such symmetries. For example, consider the problem of designing a proper diet for people with special needs. Besides taking into account nutrient and non-nutrient requirements, there are also aesthetic standards regarding shape, colors and others (cf. Seljak [3]). Of course, there are numerous ways to compile alternative but equally valuable meals that differ only in the exchange of some vegetables.

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Here, we are interested in the capabilities of standard EMOA of detecting and/or preserving Pareto subsets of equivalent quality. A more detailed view of our aims and methods is given in section 2. For our analysis, we construct an artificial problem class that exploits symmetries in the objective function in an extreme manner along with various geometric transformations. The same blue print can be used to construct further test classes in future. This approach is presented in section 3, which is enriched with an experimental investigation of the problem hardness via *design of experiment* (DOE) methods. Section 4 evaluates standard EMOA and a special purpose EMOA on this problem class which leads to the observation that standard EMOA and even the special purpose EMOA do not provide fully satisfying results. Therefore, we develop a new EMOA approach that is based on the multistart technique along with several scalarization methods. We can show empirically that this approach delivers a reliable and accurate approximation of all Pareto subsets with equivalent quality. We finish with our conclusions in section 6.

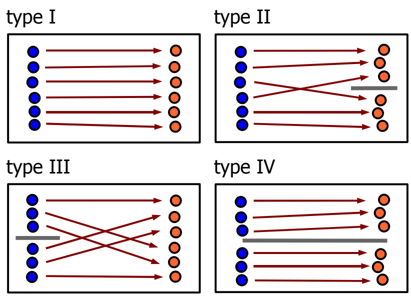

Fig. 1. Different Pareto set and Pareto front type combinations: One Pareto set and one Pareto front (type I), one Pareto set and multiple Pareto front parts (type II), multiple Pareto subsets and one Pareto front (type III), and multiple Pareto subsets and Pareto front parts (type IV). Type III problems are rarely investigated, although they potentially provide multiple preimages for every objective vector of interest.

2 Aims and Methods

To investigate the behavior of EMOA and their operators in presence of multiple Pareto set parts (type III problems), we concentrate on three main questions:

- Which properties make these problems especially hard or simple for standard EMOA?
- What are the mechanisms in EMOA that lead to better or worse performance in terms of Pareto set preservation and Pareto front approximation?
- How can Pareto set preservation in EMOA be improved?

Obviously, standard performance measures for multiobjective optimization algorithms disregard how Pareto sets are dealt with; they only refer to population distributions in the objective space. We therefore define two simple new measures