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Incremental user-interface development for interactive multiobjective optimization

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ABSTRACT

Interactive multiobjective optimization (IMO) is a subfield of multiple criteria decision making. In multiobjective optimization, the optimization problem is formulated with a mathematical model containing several conflicting objectives and constraints depending on decision variables. By using IMO methods, a decision maker progressively provides preference information in order to find the most satisfactory compromise between the conflicting objectives. In this paper, we consider implementation challenges of IMO methods. In particular, we consider what kind of interaction techniques can support the decision making process and information exchange between IMO methods and the decision maker. The implementation of an IMO method called Pareto Navigator is used as an example to demonstrate concrete challenges of interaction design. This paper focuses on describing the incremental development of the user interface for Pareto Navigator including empirical validation by user testing evaluation.

1. Introduction

Many decision making situations involve multiple conflicting criteria or objectives that should be optimized simultaneously and, thus, need approaches of multiple criteria decision making (MCDM) (Belton & Stewart, 2002; Köksalan et al., 2011). The MCDM field deals with various problem types but here we concentrate on nonlinear multiobjective optimization problems (Miettinen, 1999) involving continuous variables. Both objective and constraint functions of the problem are based on (possibly complex) mathematical models, and their values may be obtained e.g., from the output of a simulator. For this reason, the problems considered can also be called simulation-based optimization problems. For example, the simulator involved may model complex industrial processes as in Eschenauer, Koski, and Osyczka (1990), Hakanen, Miettinen, and Sahlstedt (2011), Rangaiah (2009), Stewart et al. (2008) and Berger, Piringer, Filzmoser, and Gröll (2011).

Because of the conflicting nature of the objectives, there does not exist a single solution that could be optimal for all the objectives. Instead, we can identify compromise solutions, so-called Pareto optimal solutions, where none of the objectives can be improved without impairing at least one of the others (Miettinen, 1999). In continuous problems, we typically have an infinite number of such Pareto optimal solutions and we need some preference information given by a human domain expert, called a decision maker (DM) to direct the search for the most preferred Pareto optimal solution which can be defined as the final one. In practice, the DMs can be, for example, designers or operators. We can say that the goal of multiobjective optimization (and MCDM) methods is to support the DM in finding the most preferred Pareto optimal solution (according to her/his preferences). Different method types can be identified based on the role of the DM in the solution process (Hwang & Masud, 1979; Miettinen, 1999). When supporting a DM, the implementation of the multiobjective optimization method used plays an important role.

In this paper, we consider implementation challenges of interactive multiobjective optimization (IMO) methods Miettinen et al., 2008 which include intensive interaction between the DM and the method. To be more specific, in IMO, the solution process is iterative and highly interactive, and the DM progressively provides preference information and analyzes information gained until a preferred Pareto optimal solution is found. The idea is not only to find the final solution but also to enable the domain expert acting as a DM to gain understanding and insight about the trade-offs available and the interdependencies between the conflicting objectives.

Even though many multiobjective optimization methods have been proposed in the literature during the years (see e.g., (Branke, Deb, Miettinen, & Slowinski, 2008; Hwang & Masud, 1979; Miettinen, 1999) and references therein), surprisingly few user-friendly software implementations exist. For example, in Kaliszewski (2004) it is suggested that the present user interfaces may be too complex for real DMs and, thus, it may be difficult for them to utilize these potentially beneficial methods in order to solve real-life multiobjective optimization problems. Hence, there is a need for developing intuitive and easy-to-use user interfaces. As mentioned, in simulation-based multiobjective optimization

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we deal with complex systems in the presence of conflicting objectives. As the type of the data is numeric, the amount of information is vast and as the problems are open-ended as well as cognitively burdensome to solve, we need efficient and user-friendly decision support tools. Main questions here are how to make the massive data cognitively available to the DM and how to make the decision making process faster and more focused.

From the interface design point of view, a clear connection between IMO and visual analytics (VA) can be seen. Visual analytics is characterized as "the science of analytical reasoning supported by highly interactive visual interfaces" (Thomas & Cook, 2005). As stated in Thomas and Cook (2005), an analysis session, i.e., a decision making process, is more of a dialogue between the DM and the data: "The analyst observes the current data representation, interprets and makes sense of what he or she sees, and then thinks of the next question to ask, essentially formulating a strategy for how to proceed. Undoubtedly, new questions occur to the analyst and new factors must be considered". Here, the term analyst refers to a DM.

The challenges of interface design of IMO methods include supporting the DM in practical decision making (Pomerol, 2001) following inferential and intuitive thought processes (Chen & Lee, 2003) both in specifying one's preference information in an intuitive way and analyzing the information generated by the method. At each iteration of IMO methods, new Pareto optimal solutions are generated based on the preference information given, thus, enabling the DM to concentrate only on such solutions that are interesting to her/him. This should decrease the cognitive load as the amount of information to be processed at each iteration is limited. On the other hand, the DM should be supported in directing the solution process towards more preferred solutions by specifying new preference information after having analyzed the strengths and weaknesses of the current Pareto optimal solutions. During the solution process, the DM wants to gain insight into the data available representing the infinitely many Pareto optimal solutions. In this, the DM using IMO methods obviously needs appropriate interaction techniques in order to make the decision making process more efficient and less burdensome. So far, when implementing IMO methods, interaction techniques have not been utilized to the fullest. In this paper, we aim at taking up the gauntlet by means of theories offered by the field of VA in order to design well-reasoned representation and interaction techniques for the user interfaces of IMO methods.

To give more concrete understanding of the challenges of implementing IMO methods, we consider a method called Pareto Navigator introduced in Eskelinen, Miettinen, Klamroth, and Hakanen (2010) and describe design sketches for implementing its user interface. To be more specific, we propose visual representation and interaction techniques for the different steps of the algorithm. The objective is to develop an intuitive and easy-to-use user interface by which the DM is able to utilize the full strength of the Pareto Navigator method efficiently and easily without requiring too much cognitive load. Noteworthy is that many of the design solutions presented can be generalized to other IMO methods as well as to any systems involving multidimensional data visualization. Pareto Navigator is only used as a concrete example of implementation challenges and neither the details of the method nor its underlying philosophy are essential for our design process. The focus is rather user related than technology related, and the research is based on the principles of cognitive, perceptual and graphic design.

Rarely in the literature, user interface design is described in a way that shows intermediate phases of the design process. On the other hand, such information may be very useful for other software developers to, e.g., avoid possible shortcomings in the user interface. In this paper, we aim to provide such information by describing phases of incremental user interface development. We construct a user interface design and prototype version of the Pareto Navigator user interface including elements of VA and validate them by the following approaches: visual encoding and interaction technique design is presented as a form of a design study, where encoding and interaction design is justified by design sketches and free-form discussion of choices. The implemented prototype is then validated by qualitative result image analysis along with a typical workflow related to an example problem. In addition, we validate the prototype implementation by expert review (cognitive walkthrough) with evaluators having relevant expertise in IMO methods. This leads the way to functional software (Juristo, Moreno, & Sanchez-Segura, 2007).

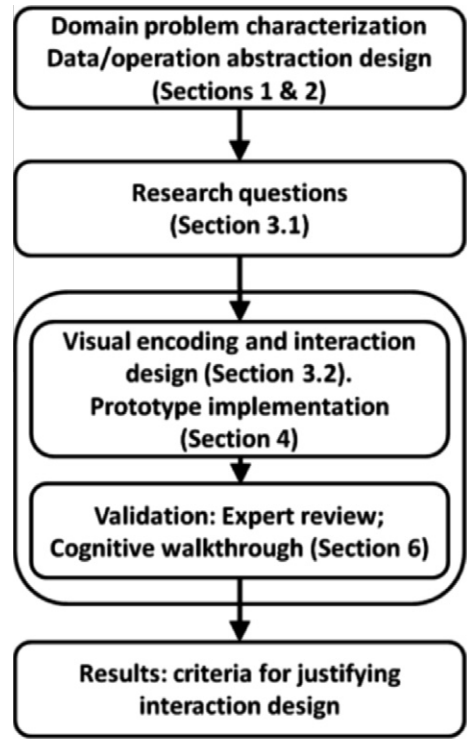

Fig. 1. Design science research setting in this paper.

The incremental development of visual analytics tools for interactive multiobjective optimization in the rest of this paper is structured according to Fig. 1, which corresponds to the nested layers introduced by Munzner (2009). We first lay background in Section 2 by presenting some basic concepts of multiobjective optimization. In addition, we provide a brief characterization of IMO including human–computer interaction and discuss the desire of gaining insight into problems considered. After introducing IMO in general, we briefly introduce the interactive Pareto Navigator method as an example for user interface design. For Pareto Navigator, we describe visual encoding and interaction technique design processes including research questions, i.e., output of the operation and data abstraction level in Section 3. A functional prototype based on the user interface design is presented in Section 4 along with a typical workflow of an example problem. As a validation for the prototype, an empirical user testing was carried out and is described in Section 5. The results highlighting the design of implemented interaction techniques are presented in Section 6. Section 7 is then devoted to discussion and analysis of design challenges of IMO methods and future research directions. Finally, we conclude in Section 8.

2. Interactive multiobjective optimization

Multiobjective optimization problems involve objective and constraint functions depending on decision variables. Here we mainly