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REASSURE: Requirements elicitation for adaptive socio-technical systems using repertory grid☆

Sangeeta Dey, Seok-Won Lee*

Department of Computer Engineering, Department of Software and Computer Engineering, Ajou University, Suwon City 443-749, Republic of Korea

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ABSTRACT

Context: Socio-technical systems are expected to understand the dynamics of the execution environment and behave accordingly. Significant work has been done on formalizing and modeling requirements of such adaptive systems. However, not enough attention is paid on eliciting requirements from users and introducing flexibility in the system behavior at an early phase of requirements engineering. Most of the work is based on an assumption that general users' cognitive level would be able to support the inherent complexity of variability acquisition.
Objective: Our main focus is on providing help to the users with ordinary cognitive level to express their expectations from the complex system considering various contexts. This work also helps the designers to explore the design variability based on the general users' preferences.
Method: We explore the idea of using a cognitive technique Repertory Grid (RG) to acquire knowledge from users and experts along multiple dimensions of problem and design space. We propose REASSURE methodology which guides requirements engineers to explore the intentional and design variability in an organized way. We also provide a tool support to analyze the knowledge captured in multiple repertory grid files and detect potential conflicts in the intentional variability. Finally, we evaluate the proposed idea by performing an empirical study using smart home system domain.
Results: The result of our study shows that a greater number of requirements can be elicited after applying our approach. With the help of the provided tool support, it is even possible to detect a greater number of conflicts in user's requirements than the traditional practices.
Conclusion: We envision RG as a technique to filter design options based on the intentional variability in various contexts. The promising results of empirical study open up new research questions: "how to elicit requirements from multiple stakeholders and reach consensus for multi-dimensional problem domain".

1. Introduction

Technological advances in past few decades have altered human lives beyond our expectation. With the help of such advancements, most of the systems are now greatly integrated with various aspects of human lives, including user's comfort, leisure activity and other personal goals. Such systems are expected to change their behaviors based on the dynamic context [1]. Most of these Self-adaptive systems (SAS) are extremely complex and often called as Socio-technical System (STS) as the social, technical and economic aspects are all intertwined with each other. To make the systems behave accordingly in a changing environment, it is important to understand the context of the user and intention of the user in that context. Therefore, the driving force for designing such adaptive STS should be society, user: more precisely 'human'. This motivates us to consider human knowledge and intentions as the main sources of variability in the system behavior.

Requirements are believed to be the bridge between the problem space and the solution space. The design of a solution is always dependent on the completeness and correctness of the problem space exploration. Especially, for complex adaptive system, it is imperative to discover the scope of variations in the behavior of the system-to-be and focus the design activities in the right direction at an early phase of Requirements Engineering (RE). Goal-based approaches for variability acquisition have discovered variability from the user goals [2–4]. However it is often overlooked that there is a huge gap between the levels of cognition of the stakeholders involved in constructing the problem and solution space. General users and their expectation play key role in forming the problem space, whereas it is the experts' responsibility to design a solution space that can meet

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* Corresponding author.
E-mail address: leesw@ajou.ac.kr (S.-W. Lee).

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users' expectation. Most of the existing work is based on a strong assumption that each stakeholder's cognitive ability would be able to support the intended complexity of the whole process of variability acquisition. However, in reality for many complex domains general users find it difficult to describe their expectation in a systematic way. This hinders a natural start to RE activity. There has not been enough research on "how to start requirements elicitation involving general users in such a way that eventually leads to the design of solutions in SAS environment."

We attempt to solve this problem by choosing a right requirements elicitation technique as a first step. We propose a novel approach of using a cognitive technique, Repertory Grid (RG) for knowledge acquisition from stakeholders [5–8]. Our main focus is on providing help to general users with ordinary cognitive level to express their expectation from the system in the light of various contexts. However, we further extend the applicability of this technique to analyze the design knowledge from the experts. We discuss how RG can be useful for capturing intentional and technical variability by building a problem and design space of socio-technical systems. We visualize these two spaces as multi-dimensional based on the concerned domain and corresponding influential aspects. We provide a stepwise methodology REASSURE (Requirements Elicitation for Adaptive Socio-technical Systems Using REpertory grid), which can guide the requirements engineer throughout the process of requirements elicitation and variability analysis.

However, for a large domain, it may be troublesome for requirements engineers to analyze the captured knowledge and extract the required information. Therefore, we developed a tool support for REASSURE which can analyze multiple RG files containing the knowledge of general user or experts. Two main functionalities of this tool are: finding the required set of features and detecting potential conflicts in the intentional variability based on a given scenario. Finally, we evaluate the proposed approach by following case study designed methodology [9,10] and analyze the research propositions, study questions and supporting evidences. We also perform an empirical study with the help of experienced software engineers. The result of our study shows that a greater number of requirements could be elicited after applying our approach. With the help of the provided tool support, it is even possible to detect a greater number of conflicts in user's requirements than the traditional practices.

This paper is the extended version of our previous work [11]. We expand our contribution by providing more examples from different domains, tool support and empirical study results. The rest of the paper is organized as follows. In Section 2 we discuss some of the existing work done to support the variability analysis and highlight our motivation for this work. The principle of RG is described in Section 3. In Section 4, we discuss how problem space and design space of socio-technical systems are conceptualized. A stepwise methodology REASSURE is proposed in Section 5. We describe the functionalities of the tool support for REASSURE in Section 6. The evaluation of the proposed approach is discussed in Section 7. Finally, we conclude the paper with remarks on our proposed idea as well as possible future work for further improvement.

2. Related work

In the past decade, many researchers focused on how to satisfy a number of possible behaviors in order to meet the users' requirements. The notable work done so far can be categorized based on their approaches and perspectives. Fig. 1 shows the contribution of the remarkable work with respect to different phases of requirements engineering or variability management process. In this section we discuss about origin of the concept 'variability' and how gradually many researchers shifted their focus from a solution based approach to problem based approach in order to elicit the scope of variations in system behavior.

2.1. Solution oriented approach

2.1.1. Feature models variability

The idea of using features for analyzing the commonality and variability originates from the concept of software product line. Feature Oriented Domain Analysis (FODA) [12] was the first attempt to model features for capturing and analyzing commonality and variability among multiple applications in a domain. Many domain and product line engineering approaches consider domain experts as the main sources of variability [13]. However, context can also play an important role to model a set of features. The study by Hartman et al. shows the relation between features and context to support software supply chain [14]. It has been argued that, in order to accommodate a lot of information related to feature and context, semantics have been overlooked in case of feature modeling. Mohan and Ramesh focused on acquisition and management of knowledge related to variability in product family [15]. However, these approaches are extremely solution oriented. Variation points and corresponding variabilities have not been considered from requirements perspective.

2.2. Problem oriented approach

We discover the scope of variability in a system's features by exploring feature space. However, the feature space will be incomplete without exploring the problem space and intentional variability of the users. This motivated researchers to shift the focus from solution space to problem space to understand the nature of the problem in an early stage of RE.

2.2.1. Requirements driven adaptation in SAS

The key challenge for any adaptive system is to introduce variability in its behavior based on the changeable requirements. As argued by I. Jureta et al. in [16], the requirements problem in case of SAS is more complex compared to other domains as it involves exploration of a large problem space with potential variability. Few efforts have been made to facilitate RE of SAS. Four different levels of RE have been identified by Berry et al. in [17]. The researchers argue that in order to make a system truly dynamic, some RE activity needs to be done at run-time by the system. Silva Souza et al. attempt to operationalize adaptivity by proposing a run-time monitoring framework which exploits the feedback loop control based on the satisfaction/failure or evolution of other requirements [18,19]. Modeling and formalization of requirements of such systems have also been studied recently. Baresi et al. introduce the concept of fuzzy goal in order to model the variations of system behavior by leaving some space for relaxation of non-crisp goals [20]. Based on the fuzzy logic, Whittle et al. proposes a new requirements specification language especially for SAS [21]. The intuition behind this approach is also capturing the scope of variations or relaxation of the system behavior in a formal way. However, most of this work is overloaded with complex formalization which hinders the natural way of the elicitation of user's needs for SAS.

2.2.2. Goal based variability

Significant work has been done on variability acquisition based on either problem descriptions [22] or annotated goal modeling [3,23–26]. Ali et al. mainly focused on contextual goal model for the systems operating in changing context [27]. Alexei and Mylopoulos extended i* modeling technique to accommodate all possible effects of domain variability by augmenting the goal