Goal-Oriented Modeling of Requirements Engineering for Dynamically Adaptive Systems*

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Abstract

Increasingly, Dynamically Adaptive Systems (DASs) are addressing complex problems that require a high degree of assurance. The inherent complexity of DASs and the safety critical applications they are addressing necessitates rigorous requirements engineering (RE). This problem is further complicated by the multiple stakeholders involved in the RE process. Berry et al. have identified four levels of RE done for a DAS, in which each level implicitly corresponds to the objectives of a different stakeholder. This paper presents a goal-oriented approach to specifying the four levels of RE using the KAOS specification language. This approach enhances the understanding of the role and contributions of each stakeholder and their complex relationships.

1. Introduction

Increasingly, Dynamically Adaptive Systems (DASs) are addressing complex problems that require high assurance. Studies have shown that errors introduced in the requirements stage are the most costly to fix for traditional (i.e., non-adaptive) systems. Given the complexity of DASs, the need to apply rigorous requirements engineering (RE) is further heightened. In general, a DAS has three main RE concerns: what *conditions are to be monitored* for adaptation, what *adaptations* are needed to achieve a desired new behavior, and what *decision-making procedure* should be used to link the monitored conditions to the appropriate adaptations. This paper presents an approach to goal-oriented RE modeling for DASs that addresses all three concerns from the perspective of multiple stakeholders.

While there are numerous techniques used to model software requirements, only a few have targeted DASs. To date, there are two notable goal-oriented approaches to modeling DASs. Specifically, Feather *et al.* [3] model DASs using the KAOS specification language [2]. Lapouchnian *et al.* [4] model DASs using a hybrid goal-oriented modeling technique, which borrows concepts and notations from KAOS and i* [5], to model system-wide goals. Their models depict the concerns of one stakeholder, the system developer, and focus on specifying the conditions to monitor for adaptation, but do not explicitly model the other two RE concerns.

A key factor in developing more robust DASs is to have a solid understanding of the requirements for DASs, particularly, the RE goals of each stakeholder involved in the creation of a DAS. Berry *et al.* [1] have identified four levels of RE done for a DAS, in which each level implicitly corresponds to the objectives of a different DAS stakeholder. The four levels are:

Level 1 is the traditional RE work done for a system by the *system developer*. Specifically, it is concerned with eliciting information about the domain of the DAS and identifying all the possible target systems of the DAS, where each target system, S_i, is a program that can be adopted by the DAS after adapting.

Level 2 is the RE work done by the *DAS* at runtime to use environmental conditions to determine how to adapt.

Level 3 is the RE work done by the *adaptation developer* to use domain and application-specific information to select particular adaptation techniques from the work done at Level 4 RE.

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Level 4 is the research done by the *DAS research community* to discover adaptation techniques. We assessed that each adaptation technique addresses a specific RE concern and includes an *adaptation infrastructure element*, e.g., a monitoring mechanism, a decision-making mechanism, an adaptation mechanism, or an adaptive step.

Our contribution is a goal-oriented approach to modeling each of the four levels of RE using the KAOS specification language [2]. This approach enhances the understanding of the role and contributions of each stakeholder and their complex relationships. This improved understanding enables more rigorous development of DASs and provides a means to help manage the complexity of DAS development. The remainder of this paper is organized as follows. **Section 2** describes our approach. **Section 3** concludes with a brief summary and discussion of future work.

2. Goal-Oriented Modeling of the Levels of RE

This section describes the KAOS specifications of the levels of RE and how the three adaptive concerns are systematically refined between RE levels.

2.1. KAOS Models of the Levels of RE

We describe our KAOS specifications of the four levels of RE in terms of the temporal ordering of RE activities. This does not correspond to the numbering of the levels, which "are listed in order of increasing metaness" [1].

Level 1 is specified with a goal model for each S_i. A terminal goal is an expectation that represents a facet of the DAS that the system developer is expected to specify, e.g., the adaptation conditions to monitor and the collection of acceptable target systems to be adapted to next.

Level 4 is specified with a goal model and four object models. Within the goal model, there is an expectation regarding the discovery of each type of adaptation infrastructure element and an entity representing each type of adaptation infrastructure element. Each entity is then further elaborated by an object model.

Level 3 is specified with a goal model that comprises expectations regarding the selection of adaptation infrastructure elements and entities representing the selected adaptation infrastructure elements.

Level 2 is specified with a goal model for each DAS execution. Each model identifies the environmental conditions detected by its monitoring mechanism and an appropriate target system given those conditions.

2.2. Relationships between Model Elements

We describe the three refinement relationships that exist between the elements of the levels of RE specifications. These will hold for any DAS modeled using our approach.

The *subset refinement* describes the relationship between the KAOS elements of the Level 4 model and the KAOS elements of the Level 3 model where the objective is to identify the specific subset of adaptation infrastructure elements to be used for a particular DAS.

The *scenario refinement* describes the relationship between the KAOS elements of the Level 3 model and the KAOS elements of the Level 2 model where a subset of the application infrastructure mechanisms are "activated" as agents or operations.

The *adaptation refinement* describes the relationship between the KAOS elements of the Level 2 model and the Level 1 model where a specific target system, S_i, specified at Level 1 is the target of the adaptation process at runtime.

3. Discussion

This paper provided an overview of a goal-oriented approach to modeling RE concerns from four different types of stakeholders involved in the construction and evolution of DASs. This more holistic approach provides context for the various RE tasks and helps the DAS research community identify how to integrate the three DAS concerns at each of the four RE levels and the areas warranting increased efforts. Currently, we are working to validate this specification approach and the relationships we have defined between these specifications on more extensive case studies. Additionally, we are exploring how these models can be used to ensure safe adaptation goals for DASs.

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