Modeling Software Product Lines with AoURN

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ABSTRACT
The Aspect-oriented User Requirements Notation (AoURN) is a modeling framework that combines aspect-oriented, goal-oriented, and scenario-based modeling. AoURN is built on URN, a standardization effort of the International Telecommunication Union (ITU), and contains the Aspect- and Goal-oriented Requirement Language (AoGRL) for goal modeling and Aspect-oriented Use Case Maps (AoUCM) for scenario modeling. With AoURN, the impact of variabilities on stakeholder goals and on the overall system goals, the reasons for choosing one variability over another variability as well as the dependencies between variabilities are modeled with GRL goal graphs. The behavior and structure of variabilities as well as commonalities are modeled with UCMs. The aspect-oriented extensions to URN allow variabilities and commonalities to be properly encapsulated and managed across both model types. At the same time, SPL models benefit from better modularity, reusability, scalability, and maintainability since AoURN models can exhibit better results in these areas compared to URN models.

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D.2.1 [Software Engineering]: Requirements/Specifications – languages, methodologies.

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Documentation, Languages.

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Requirements Engineering; Early Aspects; Aspect-Oriented Requirements Engineering; Aspect-Oriented Modeling; Software Product Lines

1. INTRODUCTION
The Aspect-oriented User Requirements Notation (AoURN) [13] extends the User Requirements Notation (URN) [2][18][19] with aspect-oriented concepts to better encapsulate crosscutting concerns in URN models. URN combines goal-oriented and scenario-based models in one language.

Software Product Lines (SPL) [14] is a planned reuse technique that focuses on capturing and managing the commonalities of a product family and the variabilities of each anticipated member of the product family. URN has been successfully used to model service-oriented, concurrent, distributed, and reactive systems such as telecommunication systems, agent systems, e-commerce systems, operating systems, health information systems, and business processes over the last decade [18]. Therefore, URN can certainly be applied to model the commonalities of a wide variety of SPL. Since goal models and URN scenario models have been suggested to model variability ([7][8] and [4]), URN is also a good candidate for modeling all facets of SPL. Furthermore, initial qualitative [10][12] and quantitative [11] assessments indicate that AoURN can improve the modularity, reusability, scalability, and maintainability of URN models. Therefore, we have recently started to explore AoURN as a modeling technique for SPL to leverage the extended modeling capabilities of AoURN for SPL. This paper reports on initial work on the overall approach for modeling SPL with AoURN.

In the remainder of this paper, section 2 gives an overview of AoURN. Section 3 presents how AoURN can be used to model SPL and section 4 compares related work on aspect-oriented or URN-based SPL to the AoURN-based approach to SPL. Finally, section 5 concludes the paper and identifies future work.

2. BACKGROUND
The Aspect-oriented User Requirements Notation (AoURN) [9][10][11][12][13] unifies goal-oriented, scenario-based, and aspect-oriented concepts in one framework by building on the User Requirements Notation (URN) [2][18][19]. URN is the first and currently only standardization effort that contains two complementary graphical modeling languages for goals (GRL) and scenarios (UCMs). AoURN adds aspect concepts to both of these languages, i.e., Aspect-oriented GRL (AoGRL) and Aspect-oriented UCMs (AoUCM).

The Goal-oriented Requirement Language (GRL) is a visual modeling notation for business goals and non-functional requirements (NFRs) of many stakeholders (actors), for alternatives to be considered, for decisions that were made, and for rationales that helped make these decisions. GRL supports reasoning about goals and NFRs with the help of GRL strategies. A strategy describes a particular configuration of alternatives in the GRL model. An evaluation mechanism propagates these low-level decisions regarding alternatives to satisfaction ratings of high-level stakeholder goals and NFRs.

Use Case Maps (UCMs) are a visual scenario notation that focuses on the causal flow of behavior, optionally superimposed...
Pointcut deletion marker: [x]

Models in URN. Current tool support for URN is available with the Eclipse-based jUCMNav tool to UCM models establish traceability between goal and scenario model elements (Figure 3). In particular, links from GRL models called aspectual properties and are indicated with small, filled diamonds as aspects. Matched join points represent insertion points of match join points, allowing any URN node to be transformed by Pointcut expressions are defined visually on standard URN graphs or UCMs optionally residing within the boundary of a GRL actor or UCM component (except for purely visual nodes such as direction arrows on UCM paths). Pointcut expressions match join points, allowing any URN node to be transformed by aspects. Matched join points represent insertion points of aspectual properties and are indicated with small, filled diamonds called aspect markers (Figure 1 and Figure 2).

Pointcut expressions are defined visually on standard URN diagrams called pointcut diagrams (graphs and maps), can be parameterized for increased matching power with wildcards (“*”), and can contain logical expressions (“and”, “or”, “not”). The goals, behavior, and structure of aspects are defined on standard URN diagrams called advice diagrams (graphs and maps) which are loosely coupled to pointcut diagrams, allowing advice diagrams and pointcut diagrams to be reused independently from each other. Note that URN diagrams like all other URN modeling elements are uniquely identified by an automatically assigned ID and can also be given a name. Flexible composition rules are defined with URN itself and are therefore as expressive as URN and not restricted by the capabilities of any particular pointcut language (which for example could only allow standard before/after/around rules).

A concern is simply an organizational construct that contains all URN diagrams required to describe a concern. In the case of an aspect (i.e., a crosscutting concern), it contains (a) any number of advice diagrams and (b) any number of pointcut diagrams required to describe the aspect. The order in which aspects are applied to an AoURN model can also be specified.

All nodes and links in a pointcut expression on AoGRL pointcut graphs are identified by pointcut markers or pointcut deletion markers (Figure 1). Actors are implicitly included in the pointcut expression when an element of a pointcut expression resides within the boundary of the actor. For example, the pointcut graph in Figure 1 matches against all goal graphs that contain a softgoal Stakeholder Goal C1 which is an OR decomposition of a softgoal ending with Goal B and has a correlation with another softgoal, all of which have to reside within an actor. Pointcut graphs contain not just the pointcut expression, but also other elements not identified with a pointcut marker. These elements either reference elements in the aspect’s advice graph or are new pointcut-specific elements introduced by the aspect. Connecting these elements with elements of the pointcut expression defines the composition rule for the aspect. The composition rule is applied to each join point matched by the pointcut expression. For example, the composition rule in Figure 1 stipulates that Task of Aspect and Pointcut Specific Goal are to be connected to Stakeholder Goal C1 and the matched softgoal, respectively. Furthermore, the correlation between Stakeholder Goal C1 and the matched softgoal is to be removed due to the pointcut deletion marker.

AoUCM pointcut expressions are described with pointcut stubs (Figure 2) which are structurally the same as dynamic stubs but have a slightly different semantic meaning. While dynamic stubs contain plug-in maps that further describe the structure and behavior of a system, pointcut stubs contain zero or more pointcut maps that visually describe pointcut expressions. For example, the
A success case and fail case, respectively. The composed system may be a complementary feature of any portion of the diagram is highlighted. Of course, visualization of requirements engineer to the advice diagram where the relevant requirements engineer. Selecting one of them then takes the aspect-oriented way. For example, double-clicking on an aspect expressions to navigate and reason about the AoURN model in an must retain the aspect markers and the mappings of pointcut expressions that indicate the insertion of aspect behavior). Any AoURN tool figures. For UCMs, shown with a traditional URN model on the right hand side of the The result of applying the aspects in Figure 1 and Figure 2 is of describing common and variable features and their dependencies such as which feature contradicts another feature and which feature requires another feature. With AoURN, the dependencies of all features are modeled on a GRL graph (Figure 3.a). Depending on the nature of a feature, a feature may be modeled with a task, goal, or softgoal. For feature modeling, tasks, goals, and softgoals represent a sliding scale from more concrete to more abstract features. In general, tasks will be found at the leaves of a feature model whereas softgoals will be found at the top and goals somewhere in-between. AoURN also models dependencies between features. For example, Feature A requires both Feature B and C ("Help" contribution link), while Feature D requires either Feature C or E (OR decomposition link) but the presence of Feature B contradicts Feature D ("Break" contribution link). The Common Feature also needs Feature E. In this case a "Make" contribution link indicates that Feature E is the only feature required for the Common Feature. While a cyclic dependency of two elements cannot be modeled directly with AoURN, such a dependency can be modeled with the help of an intermediate element. Note that XOR decomposition links are currently not supported but could easily be so by URN. AoURN, however, can model AND decompositions which can be used to indicate hierarchical composition of features. Finally, AoURN allows metadata to be associated with any modeling element. Metadata is used to differentiate between mandatory and optional features (indicated by the word optional in Figure 3.a).

Each stakeholder’s goal hierarchy is described in separate GRL graphs (Figure 3.b/c). In addition for each individual feature, its impact on the overall system goals and stakeholder goals is modeled on separate GRL graphs (only Feature A, D, and the Common Feature are shown in Figure 3.d/e/f). For example, Feature A and Common Feature impact one low level goal for each stakeholder whereas Feature D impacts two low level goals of Stakeholder Two. The impact of features on overall system and stakeholder goals is typically not modeled in feature models.

3. SOFTWARE PRODUCT LINES AND AoURN
Managing and analyzing the commonalities and variabilities of product family members is an important part of building a Software Product Line (SPL). Feature models are a common way of describing common and variable features and their...
Each task in the GRL model is linked with URN links to scenario-based models defined with UCMs that further describe the behavior and structure of the feature, regardless of whether it is a commonality or a variability (Figure 3.g/h/i/j). For example, task Common Feature is linked to the UCM with responsibility respCF while task Feature D is linked to the UCM with responsibility respFD. Feature E is linked to the Feature E UCM and the Feature E Pointcut Expression UCM. These two aspectual UCMs add an
additional responsibility before the responsibilities of Common Feature and Feature D (as indicated by the two aspect markers in the Common Feature UCM and Feature D UCM).

Furthermore, all GRL graphs and UCMs related to a particular feature are grouped into a concern, allowing both goal models and scenario models of a feature to be managed together. For example, the following concerns are shown for the sample AoURN model in Figure 3:

- Stakeholder One (Stakeholder One GRL graph)
- Stakeholder Two (Stakeholder Two GRL graph)
- Feature A (Impact of Feature A GRL graph)
- Feature D (Impact of Feature D GRL graph, Feature D UCM)
- Feature E (Feature E UCM, Feature E Pointcut Expression UCM)
- Common Feature (Impact of Common Feature GRL graph, Common Feature UCM)

Out of the listed concerns, Feature A, Feature D, and Common Feature are crosscutting other goal graphs and Feature E is crosscutting other UCMs. Note that the stakeholders are also treated as separate concerns since AoURN in general views crosscutting other UCMs. Note that the stakeholders are also treated as separate concerns since AoURN in general views stakeholders, use cases, and non-functional requirements as separate concerns.

Figure 4 shows AoURN applied to a simplified example of a Weather Station product line. The feature dependencies goal graph (Figure 4.a) shows two main features of the weather station: collecting measurements and issuing alarms. Optionally, different types of measurements and alarms may be supported. The stakeholder goal graph for the mayor of a city at the equator (Figure 4.b) shows the high-level goals of this stakeholder and that, in the context of this city, only flood warnings but no freeze point alarms are required to fulfill the specified high level stakeholder goals. The installation of a flood warning system, however, has a negative impact on the cost for tax payers. A further goal graph (Figure 4.c) shows that any individual alarm feature translates into further cost for any stakeholder. The last goal graph (Figure 4.d) shows the impact of an individual feature on the high level stakeholder goals. It specifies that the capability to issue flood warnings is sufficient to satisfy the Install flood warning system goal, and also describes that issuing flood warnings requires certain measurement capabilities. A goal graph like the last goal graph exists for each individual feature but only the “flood” feature is shown in the figure.

The UCM in Figure 4.e describes the common behavior of the measurements (i.e., sensor) and alarm components. Note that URM links trace the Collect measurements goal from Figure 4.a to the Sensor component in Figure 4.e as well as the Issue alarms goal to the Alarm component. Figure 4.f,g define an aspect for the “flood” feature. Aspects are defined for each variable feature but only the flood” feature is shown in the figure. If required in a particular member of the Weather Station product family, the feature’s aspect adds its behavior to the overall behavior, thereby configuring the particular member of the SPL (e.g., the “flood” features aspect adds getDataFromMoistureSensor after the timer on the timeout path as well as an OR-fork and issueFloodWarning after processSensorInfo as indicated by the small diamonds in Figure 4.e).

The simplified Weather Station product line in Figure 4 depicts the following concerns:

- Mayor (Stakeholder Mayor GRL graph)
- NFR: Cost (Impact on Cost GRL graph)
- “Flood” Feature (Impact of “Flood” Features GRL graph, “Flood” Features UCM, “Flood” Features Pointcut Expressions UCM)
- Common Features Collect measurements and Issue alarms (Commonalities UCM)

4. COMPARISON OF RELATED WORK

Software Product Lines (SPL) [14] is a technique aimed at easing the development and maintenance of a product family where a significant portion of the product’s capabilities is shared among the members of the family but where significant differences also exist. The applicability of aspect-orientation to SPL has attracted more interest over recent years, leading to the organization of a first workshop on Early Aspects and SPL in 2005 and to a series of follow-up workshops in 2007.

Alfert [1] reports on his experience with modeling variability in requirements models with feature models, observing that non-functional requirements and new technology concepts crosscut FODA-like feature models. It is stated that feature models only provide immature support for aspects as there is no way to identify an aspect or concern in feature models and support for aspect composition operators is also limited. AoURN-based SPL models address these issues as concerns and aspects are first-class modeling elements in AoURN and AoURN employs an exhaustive composition technique that can fully transform URN models.

Apel, Leich, and Saake [3] investigate the applicability of Aspect-oriented Programming (AOP) to SPL and introduce bounding quantification into AHEAD, an architectural model for feature-based SPL, to scope aspects only to features of previous product versions but not to future product versions. Compared to this approach, AoURN-based SPL addresses much earlier phases of the software development lifecycle and is thus a complementary technique.

Chastek and McGregor [5] discuss the use of aspects in product production environments for SPL, consisting among other things of production plans and processes describing how products are to be produced from core assets. This topic, however, is orthogonal to the one of this paper.

Groher, Bleicher, and Schwanninger [6] use aspectual collaborations to model and compose features of a SPL with the help of a domain-specific language called sUFA (standard UML for Aspects). sUFA specifies the relationships between features (i.e., the aspectual collaborations) using UML stereotypes and a generator tool then automatically creates the bindings between these features. Aspectual collaborations focus on design and not on the requirements which is the domain of AoURN. AoURN additionally captures the goals of stakeholders and links them to features in the SPL. Furthermore, sUFA allows for only a limited number of composition rules compared to the exhaustive and flexible composition technique of AoURN.

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Nyßen, Tyszberowicz, and Weiler [15] report on a case study about aspects and SPL, using feature models, architectural styles, and transformation rules. The authors conclude that there is no need for aspects during requirements engineering and design. However, the example focuses on functional features and disregards other more intrinsically crosscutting concerns such as non-functional requirements for which aspects provide much better encapsulation. The authors also investigate the applicability of aspects to implement variabilities. While the authors agree that aspects allow variabilities to be added and removed quite
elegantly, it is argued that the implicit relationship of aspects with the base makes it difficult to manage traceability from feature models to design and implementation. The authors claim that the same can be achieved with more sophisticated tool support without clearly stating how that could be achieved.

Siy, Zand, and Winter [17] discuss where aspect-oriented extensions to domain engineering could be useful and present an initial framework for the identification and classification of aspects during domain analysis. This topic, however, is again orthogonal to the one of this paper.

Brown et al. [4] use UCMs to elaborate behavioral details of features. The authors conclude that the combination of feature models and UCM models yields more valuable information for design activities. AoURN-based SPL models go one step further and also model the overall system and stakeholder goals that should be satisfied by a selection of features while at the same time leveraging the benefits of aspect-oriented modeling.

Metzger et al. [8] use GRL to model dependencies of high-level features of a software product line in the context of automatic detection of feature interactions. Again, AoURN-based SPL models go beyond just modeling feature dependencies with GRL as explained in the previous paragraph.

5. CONCLUSION

This paper introduces the general structure for AoURN-based modeling of SPL. Applying AoURN to SPL does not require new extensions to AoURN, but can be accomplished with generic aspect-oriented modeling facilities already available in AoURN. Feature models are specified with GRL graphs and include the impact of a feature on overall system and stakeholder goals. A more detailed description of behavior and structure of a feature is defined with UCMs. This allows for traceability links from high level system and stakeholder goals to a feature’s detailed behavioral and structural description. With AoURN, all features, whether they are crosscutting or not, are encapsulated and managed across all model types, which can lead to more modular, reusable, scalable, and maintainable models. Future work will focus on applying the approach to a number of case studies and evaluating the results with respect to the aforementioned qualities.

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7. REFERENCES


