A META-MODEL FOR REQUIREMENTS VARIABILITY ANALYSIS
Application to Tool Generation and Model Composition

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Abstract: Variability analysis techniques have an important drawback: the analysis of Non-Functional Requirements. Usually, these techniques do not fully deal with them and only mention that they should be considered. In our framework, we use an intentional model-based approach where the functional models are used to define the variability space and the non-functional models are the criteria for choosing a variant. We found two problems using this approach: a) integration of functional and non-functional models, and b) scalability due to the number of variants. Our proposed solution is to use ideas from aspect oriented software development. Therefore, we use aspectual relationships to relate functional and non-functional models, and we obtain a better separation of concerns that allows scalability to be improved. In this paper we define the meta-model to set the modeling language used by our framework, and we show how meta-models can be applied to: a) generate modeling environments (using a meta-modeling tool); and b) define rules to describe model transformations. Model transformations are used to compose aspectual models creating new models.

1 INTRODUCTION

Recently, interest in software variability has been growing. This interest is based on the necessity to provide higher levels of functionality, extensibility and adaptability of the software product to improve its competitivity, as in Software Product Lines. This problem was initially dealt with in design, searching for the mechanism to allow its implementation, but without studying its necessity. Analyzing the variability from the requirements analysis viewpoint allows this necessity to be studied, under the premise that the sooner the variability is detected, the better it can be dealt with. There are several proposals in this subject, using feature models (Kang et al., 1990), use-cases (Halmans and Pohl, 2003), or both (Griss et al., 1998). In any case, there is an important drawback in all of them; they do not deal with the analysis of Non-Functional Requirements (NFR). This limitation is very important, even more than in traditional software, because NFR are one of the main causes of variability, e.g. different security levels. In our approach, we propose the use of techniques from Requirements Engineering (RE), specifically from goal-oriented (GO) approaches, to variability. Goal-oriented RE proposes an intentional analysis of requirements, which (among other things) allows a more natural study of alternatives and to analyze the impact on NFR using the NFR Framework (Chung et al., 1999). Also, its application to variability has already been explored successfully in (Gonzalez-Baixauli et al., 2004; Yijun et al., 2004), which use functional goals to define the variability space, and softgoals to select alternatives.

We have found some problems using goal models: a) the integration of functional and non functional models; b) a combinatorial explosion in the number of variants to analyze. The first problem is due to operationalizations, i.e. functional elements that solve, to some degree, the NFR. These functional elements are inside non-functional models, and there is no mechanism to integrate them into functional ones. Thus, all elements are usually modelled in a unique model. The second problem is because each variation produces a combinatorial increment of the variants, therefore even simple models have a great number of

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them (Gonzalez-Baixauli et al., 2004).

The solution we propose is to apply ideas from aspect-oriented (AO) approaches (Kiczales et al., 1997), specifically from the early stages techniques (early-aspects (Brito and Moreira, 2004)). To solve the integration, we use an aspectual relationship that allows each concern to be put into separate models, and composition rules to generate new models integrating the operationalizations into the functional model. This separation into models solves the problem, but it requires a definition of the way they are composed. We get a higher scalability since we can make local selections in models before they are composed, and we can compose only the models we are interested in.

This proposal is part of our on-going requirements variability analysis using the stakeholders' goals and desires. In this article we focus on the first step: the definition and description of the modeling elements by means of a meta-model and the definition of the composition rules. There are several proposals taking into account goal models, but inside agent-oriented approaches as reported by Susi et Al. (Grau et al., 2006). These proposals usually use the meta-model only to specify elements and relationship, but (Susi et al., 2005) apply it to develop a tool in Eclipse. We focus on GO modeling, and clarify their concepts by simplifying them and defining the meta-model (Section 2). Then, in Section 3 we apply the meta-model to generate a modeling framework; and to the definition of the composition rules (Section 4). Finally, in Section 5, the conclusions and future work are set.

2 META-MODEL FOR VARIABILITY ANALYSIS

In this Section we define the elements, relationships and constraints of these models using a meta-model. The initial premises were to allow:

1. The modeling of fundamental GO concepts.
2. The relating of functional models and the operationalizations (solutions) of non-functional models.
3. The modularizing of models using two mechanisms: a classical one, where a model can refer to another one as part of the main model; and another aspectual, i.e. the NFR solutions that affect functional elements.
4. The generating of new models as a composition of previous models, whose elements and relationships reference the original models.

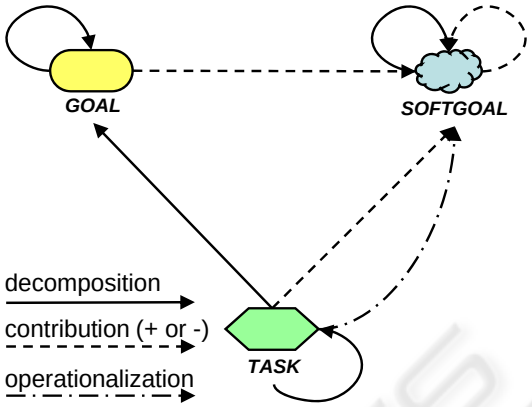


Figure 1: Elements and relationships of the V-Graph language. Adapted from (Yijun et al., 2004).

5. The modifying (deleting) of elements and relationships of combined models (e.g. to select an alternative) without affecting the original models.

With these premises in mind, the main design decisions are:

Concerning the modeling of GO concepts (Premise 1), we take as our source the components of the V-Graph language (Yijun et al., 2004). Figure 1 shows the model elements and relationships adapted to our proposal. The elements are Goals to achieve, Softgoals to satisfy (in some degree), and Tasks that solve Goals or Softgoals. The differences with respect to the original model are in the relationships that, as shown in (da Silva, 2006), have several problems of understandability. So we rename the previous *Correlation* relationship *Contribution* (with types *Make* and *Help* if positive, and *Break* and *Hurt* if negative), and we split the *Contribution* relationship, used originally to relate *Task* to *Goals* and *Softgoals*, into *Decomposition* (types *And*, *Or*, and *Xor*) for *Goals* and *Operationalizations* (types *WeakOp* and *StrongOp*) for *Softgoals*. Note the differences between *Decomposition* and *Operationalizations*, although both have the idea of giving a more specific solution, the second allows us to go from the fuzzy nature of *softgoals* to the clear satisfaction of *tasks* with a certain degree (it is at the same time a decomposition and a positive contribution).

Another important difference with respect to the V-Graph is that we introduce the idea of models, allowing the definition of different concerns separately. Hence, initial elements are grouped into GO models called *Concerns*, defined as a hierarchical decomposition from a root element, that represents the *Concern*.

To solve the problem of relating functional and non-functional models (Premise 2), we use an aspec-

tual based relationship (*AO_Relationship*). It models how an NFR (represented by a softgoal) can affect a functional element. Therefore, if we want to take into account the NFR, the solutions of the softgoal (*Operationalization* in NFR Framework notation) should be included in the functional model as possible decompositions of the functional element. We use here a simple approach where the tasks operationalizating the softgoal are added to the functional part as alternative solutions, focusing on increasing the model variability.

With modularizing (Premise 4), the aspectual mechanism is obtained by the *AO_Relationship*, and the composition rules (see Section 4). As for the "classical" mechanism, we take advantage of the fact that *Concerns* are represented by the root element. Therefore, we implement this modularization allowing the use of hierarchical relationships (decomposition or operationalization) to relate concerns elements and root elements of other models. This represents the model of the root element as part of the main model. Note that this relationship type relates elements owned by different models. While this is not a problem defining the meta-model, it will cause problems in tool generation that can be solved using references to elements as shown in the next Section.

As for composed models, we define a new meta-class: *ComposedModel*, whose components are references to elements and relationships defined in the *Concerns*, but also new elements/relationships. The references are generated by composition, and can be deleted without affecting the sources (Premises 4 and 5).

The metamodel in Fig. 2 is the result of these decisions. Part a) shows the main meta-classes and relationships: we introduce the idea of *Project* to group *Models* and aspectual relationships between them (*AO_Relationships*). There are two kinds of models required by modularization: *Concerns*, where GO elements and relationships are modeled (explained in Fig. 2b)); and *ComposedModels* that are generated from one or two models, and that are composed of element and relationship references (*ElementRef* and *RelationshipRef* respectively), and possible new elements/relationships generated by the composition.

In Fig 2b) the GO elements and the relationships in Fig. 1 are defined. The *target* and *source* associations between *Element* and *GO_Relationship* are refined by sub-types constraining the kind of elements that can be related by each one. *Element* is refined in soft (*Softgoal*) and hard elements (*HardElements*) with a clear distinction of satisfaction, i.e. *Goal* and *Task*. The *GO_Relationship* is refined in *Hierarchy*, which expresses the refinement of elements, and *Correlation* which defines how elements affect softgoals. *Decomposition* and *Contribution* are the main types of *Hierarchy* and *Correlation* respectively. *Operationalization* is considered to be a hierarchy since it provides possible solutions to softgoals, but also as a *Correlation*, because it affects the softgoal satisfaction. *GO_Relationships* sub-classes are abstract since there is another inheritance level (not shown in the figure) described in Table 1. *Decomposition* targets and sources are defined by means of an OCL constraint because it is easier than defining it as specifics relationships (it relates elements of the same kind or goals with tasks). A more detailed description can be found in (Gonzalez-Baixauli, 2006).

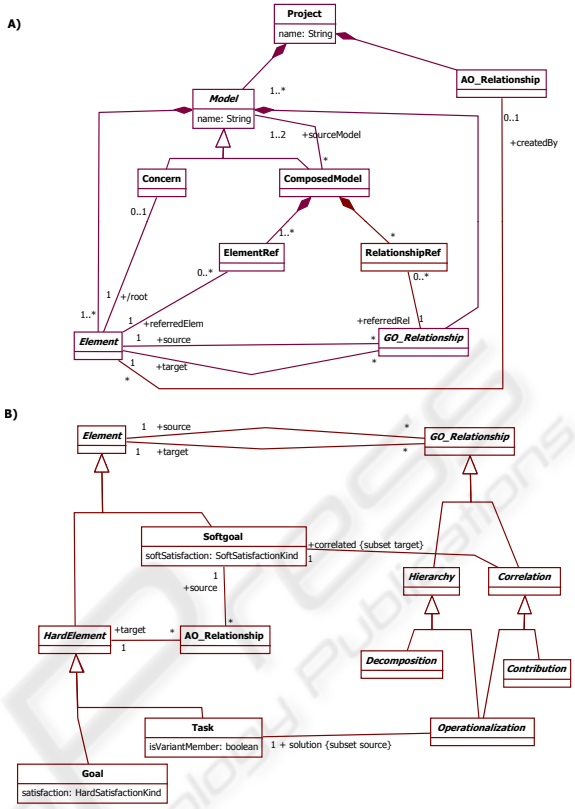


Figure 2: Meta-model classes and relationships.

Table 1: Subtypes of GO relationships.

Decomposition	And, Or and Xor
Operationalization	WeakOp and StrongOp
Contribution	Make, Help, Hurt and Break

2.1 Example

To illustrate the use of the meta-model and the composition, we apply them to an example. The cho-

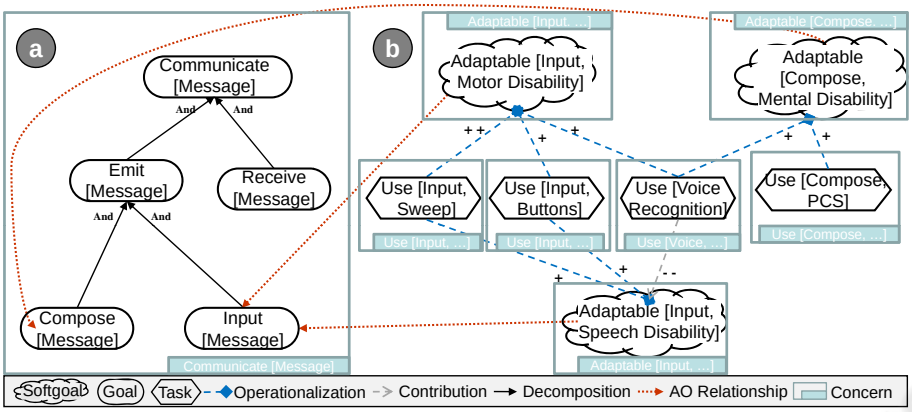


Figure 3: Concern examples for AAC domain. Each concern is in separated boxes. Part a) shows the functional one, and b) several softgoals (NFR) and their solutions.

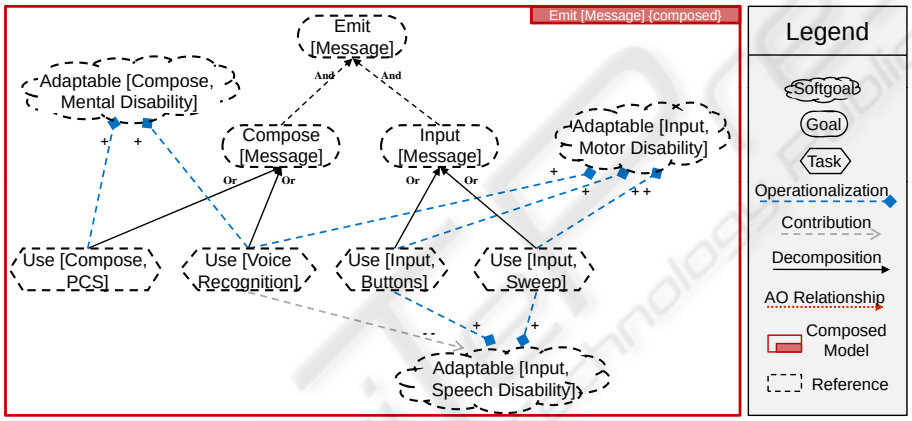


Figure 4: Partial model composed from the concerns of Fig. 3.

sen application domain is Alternative & Augmentative Communicators (AAC), i.e. tools that allow people with disabilities to communicate. Our choice of this domain is based on its high variability.

Figure 3 shows some concerns (represented as boxes) for the domain in the same figure. Part a) describes a simple functional model where the main goal is to communicate a message (*Communicate [Message]*), decomposed into several sub-goals. Figure 3b) shows some of the domain softgoals, and their solutions. The NFR analysis focuses on softgoal *Adaptability* that represents how easy the system is to use for certain disabilities. Note that tasks are usually represented as new concerns, this is because they are the solution to several softgoals, so they cannot be part of them. Finally, AO relationships (red dotted lines) describe how softgoals affect functional elements.

Figure 4 shows an example of a *ComposedModel*, resulting from the successive composition of the models in Fig. 3. This new model includes references to the elements of the concerns. Both figures are similar, but the first shows seven different models that are separated, while the second shows a single model where non-functional solutions are integrated with the functional elements (new Or decompositions), and the elements are references to the source elements.

3 APPLICATION TO TOOL GENERATION

We apply the meta-model to generate a modeling environment using the meta-modeling tool named GME (Generic Modeling Environment) (Vanderbilt University (Nashville), 2007). We use GME because it is easy to use, and freely available. But we need to make some modifications to our meta-model, because the tool M2-model is not MOF. The differences between the M2-models are mainly that GME uses some extra classes to represent graphical concepts, marked with

Table 2: Changes to meta-model in Fig. 2 to adapt to GME M2-model.

Meta-model class	GME Implementation
Models	Class with stereotype <<Model>>
Project	Model which contains the other models
Elements	Class with stereotype <<Atom>>
Associations	Classes with stereotype <<Connection>> and special elements named connectors attached to Connection and meta-classes to be connected
References	Class with stereotype <<Reference>> linked to referred metaclass

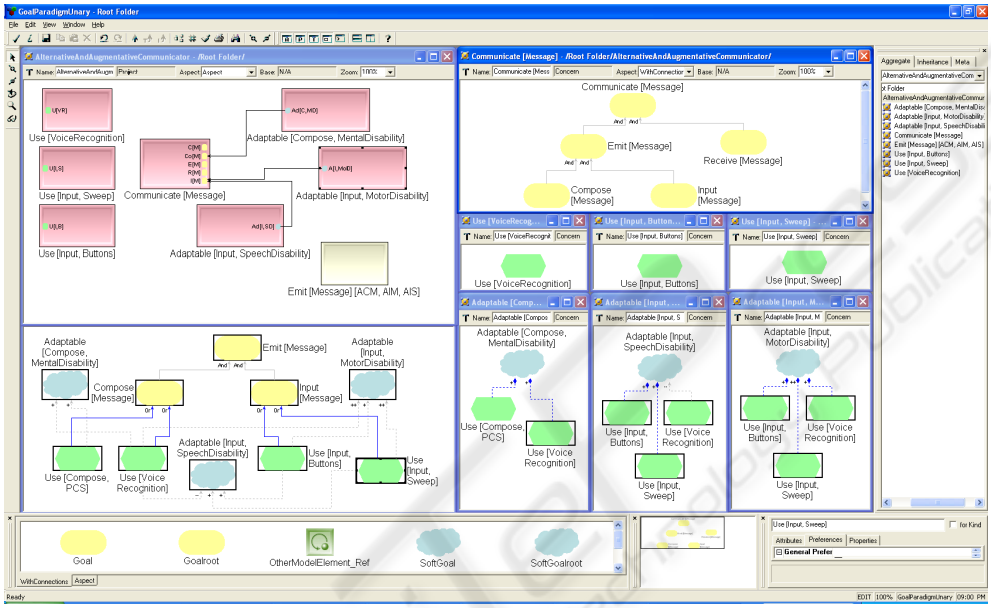


Figure 5: Screenshot of the modeling environment generated with GME.

stereotypes. These changes are indicated in Table 2

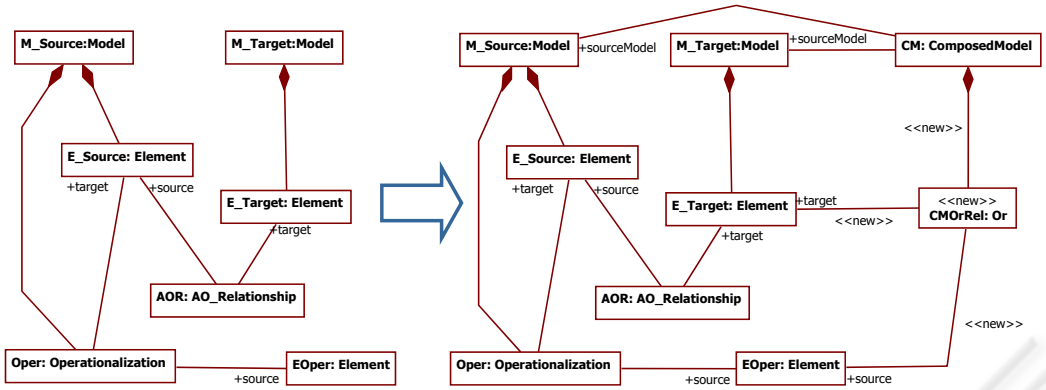
An important question is how to associate elements in different models. To relate elements of different concerns (i.e. when one concern is a sub-model of another concern, and when one element contributes to a softgoal of another concern) we use another element reference (named *OtherModelElement_Ref*) that refers to the other concern element, and is different from *ElementRef* (part of the original meta-model). As for about *AO_Relationships*, since they are owned by Project, they can use the port feature of GME models, i.e. models are represented in the Project window as boxes with the elements inside (but not the relationship) what can be linked.

GME allows the figures that represent each element to be customized. Figure 5 shows a screenshot of the resulting tool with the models in Fig. 3 and 4. Several models are in the figure: the model in the upper-left window is the project model, where the boxes are the models (red for concerns and yellow for composed models), the elements are ports on boxes, and the lines are the AO relationships. The right-hand windows are the concerns in Fig. 3, and lower-left window is the composed model in Fig. 4. The boxed elements are references, both to refer elements from other models as to represent *ElementRef*.

Another advantage of this tool is that it provides OCL constraints, and allows the project to be exported to XML. A drawback here is that exportation is done using the tool meta-model (e.g. with meta-classes *connection*), not as instances of the defined meta-model classes. This implies that the models need to be converted to apply the rules defined in the next Section.

4 APPLICATION TO COMPOSITION

A second direct application of the meta-model is the definition of model compositions. *Concerns* allow separated system parts of interest to be defined, but we



$$\neg\exists \text{relOR} : \text{OR/ORrel.owner} = \text{CM} \wedge \text{ORrel.target} = \text{E\_Target}$$

Figure 6: Composition rule example (Rule 3.1).

need to compose these parts to obtain a classical GO model where existing techniques can be used to analyze the system. We define composition rules using model transformations, which are based on instances of the meta-model elements. These rules transform a *Project* to obtain a modified *Project* with the new *ComposedModel*. Hence, the transformation source and target are defined over the same meta-model, and rules are successively applied over the result of previous rules as done in graph transformation. In our approach the composition is fairly simple:

1. A new model is created (instance of *ComposedModel*), owned by the *Project* and linked to the source models (*sourceModel* relationship).
2. References to *Elements* and *GO_Relationships* in the source models are created, and they are linked to the original ones. Note that this is done for elements/relationships, but also for references to them, but new references must refer to the original elements/relationships.
3. For each *AO_Relationship* between elements of source models, new relationships (instances of *Or* decomposition) are created. They link operationalizations of the source softgoal to the target of *AO_Relationships*.

Figure 6 shows an example of a composition rule definition. This rule corresponds to the third step: it creates a new OR relationship when an AO relationship exists between two elements of the input models (each one in a different model), and when there is no OR relationship decomposing to the target element (*E_Target*) in the new model (ensured by the constraint). In this case, one of the operationalizations of the source element (*E_Source*) is added to the new relationship. To complete the composition another rule is needed (numbered 3.5) which adds all the other softgoal operationalizations to the OR relationship. Constraint ensures the rule is only executed when there is already no OR relationship in the model. The complete definition can be found in (Gonzalez-Baixauli, 2006).

We implemented these rules using XML stylesheets (XLST), that take the project represented in XML, the models to be composed and the name of the new model, and return a new XML file with the project containing the new model. Note that to integrate this implementation with the modeling environment it is necessary to convert the model in the GME M2-model to our model, what is also done using XLST.

5 CONCLUSIONS AND FUTURE WORK

In this work, we show a meta-model that describes the elements of our proposal for requirements variability analysis based on goal models and aspects. The meta-model definition includes GO modeling elements, separation into different models, AO constructs, and variability analysis relationships.

Our approach has advantages both for variability analysis, as for a more general application of goal models, such as: improving the separation of concerns; allowing functional and non-functional models to be integrated; and improving the scalability of satisfaction analysis. Better separation of concerns also leads to a higher reuse if the concerns are general enough, for example using NFR Catalogs as proposed in the NFR Framework (Chung et al., 1999).

Concerning future work, this is a first step in our framework for variability analysis. We intend to adapt our previous work in variability selection (Gonzalez-

Baixauli et al., 2004) to this new framework and the AO paradigm. New examples will be worthy for evaluating the composition mechanism, and the modeling approach. Finally, even though the tool used allows simple models to be created, and to easily change the meta-model, that makes it very useful for prototyping, we find some drawbacks, such as the limited customization, the complex extension mechanism (e.g. to link with other tools), and the requirement of the main program (GME), only for Windows platform. Therefore, we are working on a new tool using Eclipse and the GMF project, that will give support to the complete framework.

REFERENCES

Brito, I. and Moreira, A. (2004). Integrating the NFR framework in a RE model. In *Early Aspects 2004: Aspect-Oriented Requirements Engineering and Architecture Design*, pages 27–32.

Chung, L., Nixon, B. A., Yu, E., and Mylopoulos, J. (1999). *Non-Functional Requirements in Software Engineering*, volume 5. Springer.

da Silva, L. F. (2006). *An aspect-oriented requirements modeling strategy*. PhD thesis, Departamento de Informatica, PUC-Rio. in Portuguese.

Gonzalez-Baixauli, B. (2006). Meta-modelo para el análisis de variabilidad guiado por metas. Technical report, Grupo GIRO. Universidad de Valladolid.

Gonzalez-Baixauli, B., Leite, J., and Mylopolous, J. (2004). Visual Variability Analysis for Goal Models. In *RE 2004*, pages 198–207, Kyoto, Japan. IEEE Computer Society.

Grau, G., Cares, C., Franch, X., and Navarrete, F. (2006). A comparative analysis of i* agent-oriented modelling techniques. In *SEKE 2006*, San Francisco, CA, USA.

Griss, M., Favaro, J., and d'Alessandro, M. (1998). Integrating Feature Modeling with the RSEB. In *ICSR5*, pages 76–85, Vancouver, BC, Canada.

Halmans, G. and Pohl, K. (2003). Communicating the Variability of a Software-product Family to Customers. *Journal Software and Systems Modeling*, 2(1):15–36.

Kang, K., Cohen, S., Hess, J., Novak, W., and Peterson, S. (1990). Feature-Oriented Domain Analysis (FODA) Feasibility Study. Technical Report CMU/SEI-90-TR-21.

Kiczales, G., Lamping, J., Mendhekar, A., Maeda, C., Lopes, C. V., Loingtier, J.-M., and Irwin, J. (1997). Aspect-oriented programming. In *European Conference on Object-Oriented Programming, ECOOP'97*, volume 1241 of *LNCS*, pages 220–242, Jyväskylä, Finland. Springer-Verlag.

Susi, A., Perini, A., Mylopoulos, J., and Giorgini, P. (2005). The tropos metamodel and its use. *Informatica*, 29:401–408.

Vanderbilt University (Nashville) (2007). Generic modeling environment (gme 6). http://www.isis.vanderbilt.edu/projects/gme/. Date retrieved: April 18, 2006.

Yijun, Y., Leite, J. C. S. d. P., and Mylopoulos, J. (2004). From goals to aspects: discovering aspects from requirements goal models. In *RE 2004*, pages 33–42.