VARIABILITY MANAGEMENT IN SOFTWARE PRODUCT LINES FOR DECISION SUPPORT SYSTEMS CONSTRUCTION

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Keywords: Software Product Lines, Decision Support Systems, Variability Management, Software Architectures.

Abstract: This paper presents software variability management in complex cases of Software Product Lines where two kinds of variabilities emerge: domain variability and application variability. We illustrate the problem by means of a case study in Decision Support Systems. We have death with the first one by using variability points that are captured using decision-tree techniques in order to select base architectures and the second one by decorating the base architectures with the features of the application domain. In order to present this variability management, we focus on the diagnostic domain, a special case of Decision Support Systems. A generic solution for the automatic construction of systems of this kind is given using our approach: Baseline Oriented Modeling (BOM).

1 INTRODUCTION

The development of Decision Support Systems is complex since the elements that form their software architecture vary. These architectural elements change in their behaviour and in their structure.

In these kinds of systems, the variability management cannot be performed through a unique Feature Model, and the variability must be treated in two phases: the first phase through different base architectures derived from a unique generic architecture; and the second phase by means of a more classic treatment using a Feature Model and decorating these base architectures with different features.

We have illustrated the variability management in the domain of Decision-Oriented Systems, and an application field: the diagnosis of educational programs using BOM (Baseline Oriented Modeling). BOM is a framework that semi-automatically generates DSS in a particular domain, based on product lines techniques.

Our work integrates different technological spaces to cope with the complexity of the problem. These are the following: a) The generic architecture of Decision Support Systems (DSS) (Turban et al., 2001) to capture the knowledge of experts and to try to imitate their reasoning processes when they solve problems in a certain domain; b) Model-Driven Architecture (MDA of OMG) (http://www.org/mda) at the abstract modelling level (PIM); c) The PRISMA Architectural Framework (Pérez, 2006) as the target software level (PSM); d) The Software Product Lines (SPL) (Clements et al., 2002) as a technique for systematic reuse in software products, and e) Feature-Oriented Modeling (FOM) (Trujillo, 2007) to capture the different variabilities of the problem.

Several methodologies and applications on SPL have produced a wide variety of research products, offering suggestions and solutions in specific domains. Our research is related to the following works:

- i) (Batory et al.,2006) express the domain features in the Feature Model.
- ii) (Trujillo, 2007) uses Feature-Oriented Programming as a technique for inserting the features.
- iii) (González-Braixauli et al.,2005) apply the MDA proposal as well as Requirements Engineering for Product Lines.
- iv) (Clements et al., 2002) use the SPL development approach, considering a division between domain engineering and application engineering phases for the reuse and the automation of the software process.
- v) (Trujillo, 2007) has developed the XAK tool for inserting features into XML documents by means of XSLT templates.

Eugenia Cabello M. and Ramos I. (2008).
VARIABILITY MANAGEMENT IN SOFTWARE PRODUCT LINES FOR DECISION SUPPORT SYSTEMS CONSTRUCTION.
In *Proceedings of the Tenth International Conference on Enterprise Information Systems - ISAS*, pages 49-56
DOI: 10.5220/0001675300490056

vi) (Santos, 2005) proposes the development of a technique based on MDA for variability management in Software Product Lines.

vii) The AMPLE project (http://www.ample-project.net) deals with variability management in different ways. This project mentions that (Bachman et al., 2005) propose to separate the variability declaration from the affected artifacts.

The structure of the paper is the following: Section 2 presents the variability management in the DSS. Section 3 introduces the variability dimensions of our domain (diagnosis). Section 4 introduces the variability in the application domain. Section 5 describes the design of the Decision Software Architecture. Section 6 presents our conclusions and provides some ideas for future work.

2 VARIABILITY MANAGEMENT IN DECISION SUPPORT SYSTEMS

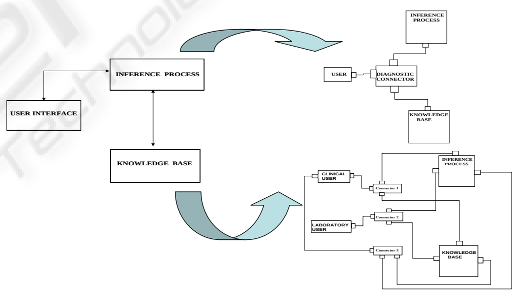
The development process of a specific application (member of the product line) starts from a unique generic architecture of the domain. The DSS domain unique generic architecture is presented in Figure 1(a). This implies the existence of additional particular features that are represented as variability points, and their choice configure the final product. However, another variability emerges, in complex application domains. This variability is represented by the existence of several base architectures for the same generic architecture (see Figure 1(b)). We use a Modular view for describing the generic architecture conforming a Modular view metamodel (MM MODULAR VIEW) and a Component-Connector view for describing the Base Architectures Skeletons conforming a Component-Connector view metamodel (MM C-C SKELETON). Figure 1 shows a unique generic architecture and two base architectures.

In these cases, there are two variability types which are orthogonal: one provided by the domain (e.g. diagnosis) and another one provided by the application domain (e.g. medical diagnosis, educational diagnosis).

Therefore, we have treated variability in two phases. The initial variability is treated through variability points in a Decision Tree (DT). This DT selects the right base architecture. The second variability is managed by decorating this base architecture with the features of the application domain.

To illustrate our approach, we have selected a case study: the diagnosis of educational programs within the diagnosis domain. Our research considers the following ontology:

- The diagnosis consists of interpreting the status of an entity through its properties.
- In the application domain of the diagnosis, the entity to be diagnosed is a postgraduate academic program, and the diagnosis result is the level of development of this program. The properties of the entities belong to the features and sub-features that are evaluated to obtain the validation of only one hypothesis (appropriate/inappropriate) as a result of the diagnosis.
- The scenario for the academic diagnosis process is as follows: the system takes data that are given as input by the final user and relates it to the features of the educational program. The system infers other properties by deduction and subsequently does the same for the hypothesis. The result is the development level of the educational program.



(a) Modular View (b) Component-Connector View

Figure 1: Visual metaphor of (a) a unique Generic Architecture, and (b) two Base Architectures.

3 THE VARIABILITY IN THE DOMAIN: V1

The first type of variability involves a family of base architectures. This SPL must be constructed and stored on the Baseline. The Baseline is then itself a SPL, formed by all the assets necessary to construct the base architectures.

Some assets are templates (or architectural element skeletons) and the configuration information for the base architectures. Thus, when we configure the base architectures, we obtain the first SPL.

This first type of variability represents the variability information of the domain (properties of the entity that participate in the diagnostic process, property levels, types of the reasoning, and hypotheses), and the variability in the final user requirements (number of use cases, actors, and use cases by actor).

The features of the first variability type are present in the Feature Model (FM) of our SPL (Figure 2). These features are represented as variability points in a DT. This DT allows the access to the assets necessary to build base architectures (i.e. the architectural elements, their feature insertion processes, the base architectural model configuration, the feature insertion main process, the Application Domain Conceptual Model (ADCM), and the Reusable Asset Specification (RAS) (http://www.omg.org/technology/documents/formal/ras.htm) model of assets. These assets are the leaves of the DT (Figure 3). The FM and the DT act as variability mechanisms that manage the variability at the artefact level.

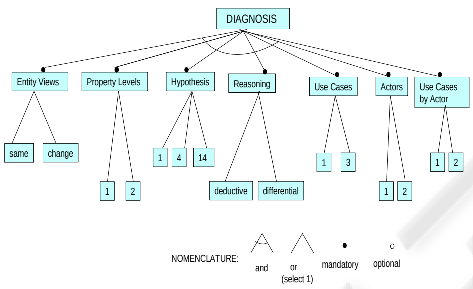


Figure 2: Diagnostic Feature Model.

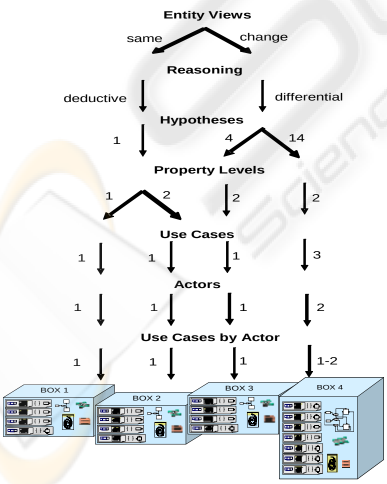


Figure 3: Diagnostic Decision Tree.

We have detected seven types of features (or variability points) that are present in the FM and the DT:

- entity views: an entity can be characterized by the same properties (the same view), or have different properties (different views) during the diagnostic process.
- property levels: the properties of the entities can have n different abstraction levels. The deduction rules relate these properties between levels.
- number of hypotheses: the goal of the diagnostic process is a single hypothesis. There can be one or several candidate hypotheses, which must all be validated in order to obtain the unique and correct hypothesis.
- reasoning types: reasoning shows the way in which the rules are applied by the inference motor in order to infer a final diagnosis. The reasoning types can be: deductive reasoning (driven by data), inductive reasoning (driven by goals), and differential reasoning (establishing the difference between two or more diagnostic possibilities).
- number of use cases: a use case indicates the division of the system based on its functionality; i.e., the different operations of the systems and how the system interacts with the environment (final users).
- number of actors: represents the number of final users of the system.
- use cases per actor: each final user can access different use cases.

An example of these features applied to our educational program diagnosis is: the entity views are the same during the diagnostic process, there are two property levels, one hypothesis, deductive reasoning, one use case, one actor, and one use case per actor. With this information, the assets that will form the base architecture of this case study are selected (Figure 3).

The variability shown in the use cases, actors, and use cases per actor is reflected in the construction of the assets of the architectural element skeletons and in the base architecture in the following way:

- there is one connector that joins all the architectural component assets for each use case,
- the number of ports of the Inference Process component is the same as the number of use cases,
- the number of ports of the Knowledge Base is the number of use cases,
- the number of User Interfaces is the number of actors of the use cases,

- the number of ports of the User Interface is the number of use cases that can be accessed by an actor.

The domain variability management could be viewed as a transformation taking as input the Domain Conceptual Model (DCM) and the Decision Tree Model, and producing as output the corresponding Base Architecture Model (we call it T1).

The structure of the architectural elements involves features on three variability points in the DT. These features are used to select assets that let to configure the base architectures.

The behaviour of the architectural elements involves the features of four variability points in the DT: entity views, property levels, number of hypotheses, and reasoning types. These features are related to the services, the protocols and the played_roles of the aspects from the PRISMA architectural elements (the information of state, process, and roles, respectively).

To optimize the feature insertion process, instead of repeating this information in each PRISMA type, we have placed it in the skeletons of the Baseline.

4 VARIABILITY IN THE APPLICATION DOMAIN: V2

The second type of variability involves the SPL of the application in a specific field. This variability allows to the base architectures to be enriched or decorated with the application domain features.

In the process of the application variability management, the variations of the specific requirements of the application domain should be selected. This selection is made by means of an ADCM. The features are inserted (by means of QVT-Transformations (http://www.omg.org/docs/formal/05-07-01.pdf) in the base skeletons in order to generate the types of the PRISMA software artifacts. These PRISMA architectural elements will be used to configure the PRISMA architectural model of the application. That model is automatically compiled into code (C#) using the PRISMA Model Compiler (Cabedo et al., 2005), and it is executable over the PRISMA NET Middleware (Costa et al., 2005).

The features that are used to fill the skeletons to obtain PRISMA types that make up the PRISMA base architectures of our SPL are:

- name and type of the entity properties, that will be diagnosed,
- name and type of the hypotheses,
- the rules that relate the entity properties.

In the following, we present an example of these features (F) in our educational program diagnosis:

- *Features of the properties of level 0 (FP.0)* = {student_population, graduation_rate, graduation_time, graduate_quality, control_school, critical_mass, academic_training, scientific_productivity, groups_lines_research, general_design, pupil_control, research_experience_students, number_courses, scheduled_duration, library, computer_equipment, laboratories, building&facilities, general_services }
- *Features of the properties of level 1 (FP.1)* = {student_body, faculty, curriculum, infrastructure&services }
- *Features of the hypotheses (FH)* = developmental_stage
- *Features of the rules of level 1 (FR.1)* = {student_population=”good” and graduation_rate=”good” and graduation_time=”good” and graduate_quality=”good” and control_school=”good” } student_body =”good”
- *Features of the rules of level 2 (FP.2)* = {student_body =” good” and faculty =” good” and curriculum =” good” and infrastructure&services=” good” } developmental_stage = “consolidated”

The features considered as constants represent the base models (in our case, the skeletons). For example, S-IP-EPD, which means the “S-IP-EPD program”. It is a constant feature. S-IP-EPD is the nomenclature used for Inference Process Skeleton of the Educational Program Diagnosis.

The skeletons selected will be filled or decorated with the features of the application domain in order to create the respective types. These types will include the features as functions, which are refinements of the base models. These models are extensions of the base model, which is taken as input. For example, F ● S-IP-EPD, wich means: “insert the F feature into the S-IP-EPD model”, where ● is the application of the F function. The successive decoration process with features will be represented as:

$S\text{-}IP\text{-}EPD_0 = FP.0 \bullet S\text{-}IP\text{-}EPD_1 = FP.0 \bullet (E\text{-}MI\text{-}\ DPE_1)$

$S\text{-}IP\text{-}EPD_1 = FP.1 \bullet S\text{-}IP\text{-}EPD_2 = FP.1 \bullet (E\text{-}MI\text{-}\ DPE_2)$

$S\text{-}IP\text{-}EPD_2 = FH \bullet\cdot S\text{-}IP\text{-}EPD_3 = FH \bullet (E\text{-}MI\text{-}\ DPE_3)$

S-IP-EPD$_3$ = FR.1 ● S-IP-EPD$_4$ =
FR.1 ● (E-MI- DPE$_4$)
S-IP-EPD$_4$ = FR.2 ● S-IP-EPD$_5$ =
FR.2 ● (E-MI- DPE$_5$)

Figure 4 represents a visual metaphor of the feature insertion process in a skeleton selected from the Baseline (S-IP-EPD0) to create its PRISMA type.

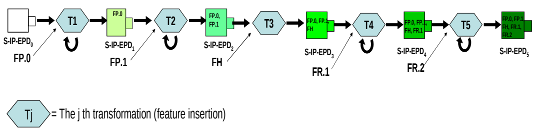


Figure 4: Feature insertion process in a skeleton to create its PRISMA type.

It is important to state that a Skeleton-Base Architecture can be instantiated to one or more PRISMA-Base Architecture types (i.e. several products of our SPL), when the decorating features are different. In two case studies performed by the authors (the diagnosis of the developmental_stage of educational programs, and the diagnosis of TV video quality), they shared the same skeleton, but each one of them has different PRISMA types. This was due to the fact that different properties of the application domain were inserted in each case.

As an example of this, we present in Table 1 the functional aspect skeleton of the Knowledge Base and the PRISMA type. Both the skeleton and the type are specified in PRISMA-ADL (Architecture Description Language).

Table 1: PRISMA-ADL of the Functional Aspect of the Knowledge Base (The different section holes are depicted in bold type.

Functional aspect of the Knowledge Base of a skeleton	Functional aspect of the Knowledge Base of a PRISMA type
Functional Aspect FBaseEPD using IDomainDPEDT Attributes Variables **<FP.0>** Derived **<FP.1>** **<FH>** ...... Derivations **<FR.1>** **<FR.2>** .... Services ...... Played_Roles .... Protocols ...... End_Functional Aspect FBaseEPD	Functional Aspect FBaseEPD using IDomainDPEDT Attributes Variables **laboratories:string,** **library:string,** **critical_mass:string,** **scientific_productivity:string;** Derived **infrastructure&services:string,** **faculty:string** **developmental_stage:string;** ...... Derivations **{laboratories="good" and library="good"}** **infrastructure&services:="good"** **{critical_mass="good" and** **scientific_productivity ="good"} faculty:=** **"good"** **{infrastructure&services="good" and faculty=** **"good"} developmental_stage:="consolidated";** ...... Services ...... Played_Roles .... Protocols ...... End_Functional Aspect FBaseEPD

5 DESIGNING DECISION SOFTWARE ARCHITECTURES: PRODUCT ENGINEERING PHASE

Figure 5 shows the transformations involved in the design of the decision software architectures. This figure illustrates how the two transformations performed at the model level are applied in the transformation process. Transformations T1 and T2 are executed at the model level (M1 in OMG-MOF (http://www.omg/org/mof) shown in Figure 5, they are defined as relations in QVT-Relational at the metamodel level (M2 in OMG-MOF).

In transformation T1, the Component-Connector (C-C) Skeleton model (c) is obtained from the DSS modular model (a) and the DCM (b). In transformation T2, the PRISMA architecture model (e) is obtained from the Skeleton C-C model generated in T1 (c) and the ADCM (d).

The relations R1 and R2 that specify the corresponding transformations T1 and T2 are:

```
R1 ⊆  MM MODULAR VIEW X MMV1  →
  def           MM C-C SKELETON ;


R2 ⊆  MM C-C SKELETON X MMV2  →
  def            MM PRISMA VIEW ;
```

Where MMV1 and MMV2 are the metamodels (MM) of the DCM and the ADCM. We use the UML metamodel (http://www.omg.org/docs/formal/05-07-04.pdf) for both.

The relations R1 and R2 have been specified using QVT-Relational. One of them is (R1 relations):

```
MODULAR VIEW  →  C-C VIEW
```

In BOM, the stakeholders only introduce the variability data by means of the Conceptual Models: In the fisrt step, the stakeholders introduce the variability of the domain by means of the DCM capturing the domain variability V1. T1 will obtain a base architecture "ad hoc" to the case study using the Generic Architecture Modular View. In the second step, the stakeholders introduce the variability of the application domain by means of the ADCM capturing the application variability V2. T2 will generate a PRISMA architecture model as a product of our SPL (application engineering), using the Skeleton C-C- model generated in the first step. The two conceptual models conform to their respective metamodels (MM): the UML metamodel.

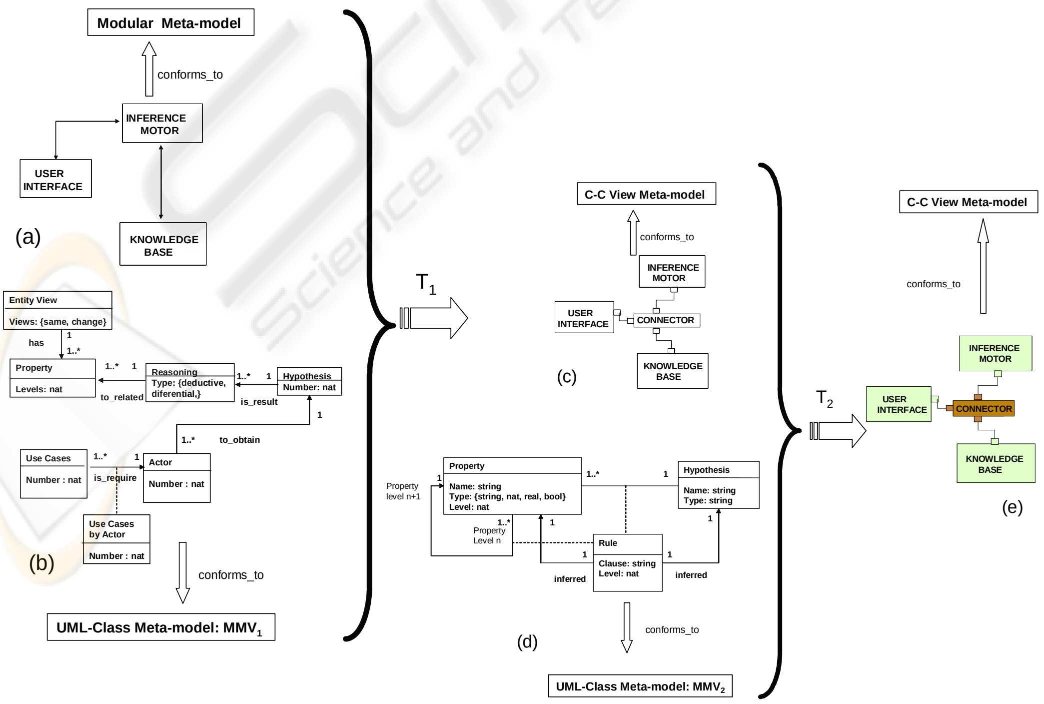


Figure 5: The transformation of models in BOM.

5.1 Specification of the Relations between the Software Views

The relations between the software views are specified by means of a MOF diagram, and the code for these relations is written in the QVT-relational. Code and diagrams are shown in (Limón et al., 2007). In order to gain clarity the prefix "skeleton" will be omitted from now, i.e "skeleton component" will be written as "component", and "skeleton connector" will be written as "connector". The relations between the software views are the following:

i) Relation moduleToComponent. This relation maps each module with a component. Relation moduleToComponent has two types of relations: the checkonly type and the enforce type. The object of the Module domain is of the checkonly type. In contrast, the object of the Component domain is of the enforce type. This creates an object of the Component class that is related to the Module class. The where clause indicates a call to the functionToService relation, which relates an object of the Module class with an object of the Component class.

ii) Relation functionToService. This relation implies that a function of the module metamodel will generate a service of the Component class. When this occurs, the type of the Function will generate a port. In the where clause, the name of the port is obtained by calling the function typePort. When the relation is executed, the classes that are in the source metamodel can only be verified and the classes that are in the target meta-model will be created (only the ServiceToPort class).

iii) Relation rUseModToConnector. The 'uses' relation is transformed from the modular meta-class to a link between a connector and two components in the C-C meta-class. The creation of objects for this relation is from 1 to n because a relation of two components is generated through a connector. In (Limón et al., 2007) is shown part of the code to illustrate how the relations are invoked in the 'where' clause to create the relations among module, component, and functionToService.

iv) Relation rCompositionModToComp. The set of modules will also generate a set of components. However, in this case when a component is created (container) a subordinate is created inside it.

6 CONCLUSIONS

The development of DSS is complex because there is variability in the architectural elements that conforms them as well as variability in their final architecture. This situation produces several base architectures in our SPL, sharing a unique generic architecture.

Futhermore, the complexity problem of these kind of systems is not solved by means of a unique Feature Model and the insertion of its features. Since the variability management is the essence of SPL, we have taken a new approach. This approach manages the variability in two stages, wich correspond to the development of two SPL:

i) the base architectures SPL that shares a generic architecture, and

ii) the application SPL in a specific domain, that shares a base architecture.

In this context, we describe how the variability is managed in our SPL by means of our BOM framework. BOM automatically generates DSS in a specific domain using SPL.

BOM captures the data that characterize the domain variability and the application variability in conceptual models. DT and FOM exploit this data in the domain engineering and product engineering phases in order to obtain a specific application by means of Model Transformation techniques. In BOM, the variability appears in the construction of the DCM (which is represented as a DT showing the different variation points). The base assets are selected by the DT to configure a base architecture. These assets are enriched by the specific application features (given in the ADCM) by a process that results in PRISMA types (a product of our LPS).

In the domain engineering phase, the user constructs the different assets and stores them in the Baseline. This Baseline is used in the application engineering phase by a production plan in order to obtain the final product. The production plan is one of the assets stored in the Baseline.

We can conclude that the main characteristics of BOM are the following:

i) Variability is managed at the model level rather than at the program level.

ii) Systems variability is modeled using conceptual models independently of their functional models. The DSLs for expressing the variability are suited for the domain, instead of adding tangled variability annotations directly to the functional models (UML, ADLs) as other approaches have proposed (AMPLE project: http://www.ample-project.net).

iii) Variability is operated by two orthogonal types: one provided by the features of the domain (e.g. diagnosis), and another one provided by the features of the application domain.

iv) Various technological spaces are integrated to cope with the complexity of the problem.They are the current trends in Software Engineering.

v) BOM implements a generic approach to SPL developement, that can be applied to different domains, application domains and systems. In this paper, the BOM framework is applied to the diagnostic domain. Other domains will be considered in the near future, e.g. interpretation, and prediction.

A prototype of the BOM framework: ProtoBOM has been implemented and will be used in real case studies. In the future, we will use benchmarks in order to compare BOM results with other approaches.

ACKNOWLEDGEMENTS

This work has been funded under the Models, Environments, Transformations, and Applications: META project TIN20006-15175-605-01.

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