Generating UML diagrams using feature diagrams for software product line

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Generating UML Diagrams using Feature Diagrams for Software Product Line

Master Thesis
Master of Computer Science and Engineering

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Foreword

There had never been a project like FeatureUML that gave me so much concentration, so much stress, and so much pleasure at the same time. The reason that I could think of is that product line system development is still a pretty young topic, and there are still no many existing methods which support this kind of development. This attracts me as I was really curious about if we could find a way to solve the problem.

Well, after seven months work we have got something – FeatureUML. It is only an idea and a prototype, but could be the start of a possible solution. For this I am really happy because it gives me a good feeling that I haven't wasted my time on doing something just for trying to graduate for my study.

During these seven months, very often I was lost or I just thought that I could not do it. I was afraid that I could not work out something at the end; I was afraid that I could not make the prototype… It was my supervisor Michel Chaudron which continually guided me, pushed me to reach the end. I am really thankful for all the efforts he has put into helping me finishing my project.

Probably many people would think having a little baby and working at the same time would be a disaster, but I have a different experience. My just eleven month old lovely daughter Gina has helped me a great deal to go through the project. For many tiring nights I was wondering if I still could go on, then I walked into Gina's room to see her cute little sleeping face, all my tiredness was simply gone, and I could continue again. She is truly my angel.

I have to say "thank you" from my heart to my husband Christian. He has been supportive during my whole master study. Whenever I think that I am just crap and I can do nothing good, he can always calm me down and bring my confidence back. During my project period he has been taking care of Gina really a lot, and I hope he can get his whole week long sleep after my graduation.

At last I give my thanks to professor dr. Mark van den Brand and professor Johan Lukkien for taking place in my examination board.

Abstraction

Software development is going through rapid change all the time. Unlike a few decades ago we had to create an individual system from scratch when we had a new customer, the modern development tends to reuse the existing code, components, or products and do some modification on these existing software assets for each new customer. But how to make the modification as simple as possible and how to make this software reuse as effortless as possible is still an unsolved problem.

A product line is a set of software systems that shares a common software architecture and a set of reusable components. The main characteristic of a product line is that it holds commonalities for all the members of the family, but also contains variabilities for each single member of the family. It seems that product line is a candidate solution for the problem of quick software creation.

Even though the product line concept is not new in other industries, it is still not a widely accepted concept in software industry. The product line software system development guideline has been defined only on an abstract level, there are until now still no solid methods which truly support the process symmetrically and automatically. To find a good method for this process will still be a research topic for some years.

In this master thesis we give introductions to the concepts of product line and the system development process. One existing method, PLUS, will also be introduced in this thesis. PLUS supports part of the product line development process and it does have its weakness, but it also has its strong points which we can learn from.

We will also propose a new method – FeatureUML which supports part of the product line software development. This new method uses feature diagrams to hold the features in the feature model, and the UML model is slightly modified to hold mapping information between UML elements and features. The feature model can be configured for a single member of the product line; with this configuration we can also process a domain UML model to yield a specialized UML model for a single member. A prototype has been made to show the idea of FeatureUML and in this thesis we will also use a few examples to show how FeatureUML works.

Contents

1 Introduction

The software development process has been changing rapidly in the last few decades. The industry and business market have put their hope in the productivity, quality, and maintainability in the software systems in order to prove their service. The traditional way of developing an individual system from scratch cannot satisfy these demands any longer.

Software industry has gone through a few major changes trying to fulfill the requirements from software systems. The fist attempt made was to create an individual system rapidly, and then to create variations for different customs when the new requirements came in. This process did improve the speed of the software development process at the beginning. But the more variations are made, the more difficult we can guarantee the quality of the software, and the more difficult we can keep a good maintenance. The reason for this is creating variations on individual systems takes continual investment in understanding new requirements, and in redesign, recoding and retesting. Currently the software industry is going through the second change, and that is to create product lines and families of systems. In this new approach we invest in understanding new requirements and rapidly creating new family members with little or no redesign and recoding and with reduced retesting.

Product line software engineering involves two types of activities. First the common aspects and the predicted variability of a product line are carefully pre-analyzed and well documented in a systematic way with the goal of maximizing the reuse potential. This process is often called domain engineering. Secondly individual systems are built by using the common aspects and some variation features from the domain model for different customers with different requirements for these individual systems. This process is often called application engineering.

In the product line software process one of the most challenging aspects is variability management. Variability management requires methods not only to record the variability in a systematic way, but also to enable the configuring of the variability of the product line in order to create individual systems. There are already several methods proposed for recording the variations of the product line. With these methods the system common aspects and variabilities can be documented systematically, but when creating a single product, a lot of handwork is still required to configure the assets in the domain model. So in general the methods proposed vary often fail to ease the configuration of the product line.

In this thesis we propose a product line software design variability enabling method by using feature diagram. With this method it is also possible to configure the product line design UML model to generate new UML models for individual systems. A prototype *FeatureUML* has been built and tested using a case study of Navigation System. The initial case study has shown us that this method can reduce more than 80% of the time and effort which is spent on creating individual systems. As the UML model for each

single member of the product line is generated and we can hardly make any mistakes in the generating process, so the quality of the generated UML model is also improved.

This Thesis is structured as follows. Chapter 2 gives an introduction to product line software systems, the feature diagram, UML diagrams and the usage of feature diagram and UML diagrams in product line software design. Chapter 3 introduces the FeatureUML method. Chapter 4 explains how FeatureUML tool realizes the method. Chapter 5 focuses on the implementation of the FeatureUML tool. In chapter 6 we give a small case study of Navigation System to show how this method can be used in the real life. Chapter 7 concludes the study of this method. There are quite a lot of further research studies which can be done on this method, and these future works are listed in chapter 8.

2 Product Line Software Systems

2.1 Introduction

A software product line consists of a family of software systems that have some common functionality and some variable functionality. To take advantage of the common functionality, reusable assets (such as requirements, designs, components, and so on) are developed, which can be reused by different members of the family [Gomaa 2004].

The idea of a product line is not new. A modern example of product line comes from the airline industry, with the European Airbus A-318, A-319, A-320, and A-321 airplane, which share common product feature, including jet engines, navigation equipment and communication equipment [Clements and Northrop 2002].

The traditional process of software development is to develop single systems – that is, to develop each system individually. For software product lines, the development approach is broadened to consider a family of software systems. This approach involves analyzing what features (functional requirements) of the software family are common, what features are optional, and what features are alternatives. After the feature analysis, the goal is to design a software architecture for the product line, which has common components, (required by all members of the family), optional components (required by only some members of the family), and variant components (different versions of which are required by different members of the family). To model and design families of systems, the analysis and design concepts for single product systems need to be extended to support software product lines.

2.2 Process

In the product line software development process the software engineer's role is split into two parts: the domain engineer, who defines a family and creates the production facilities for the family, and the application engineer, who uses the production facilities to create new family members. Correspondingly, the two parts of the approach are known as domain engineering and application engineering. One of the well known process method is Family-Oriented Abstraction, Specification, and Translation (FAST), and this process is depicted in Figure 1 [Weiss, D., Lai, C. 1999].

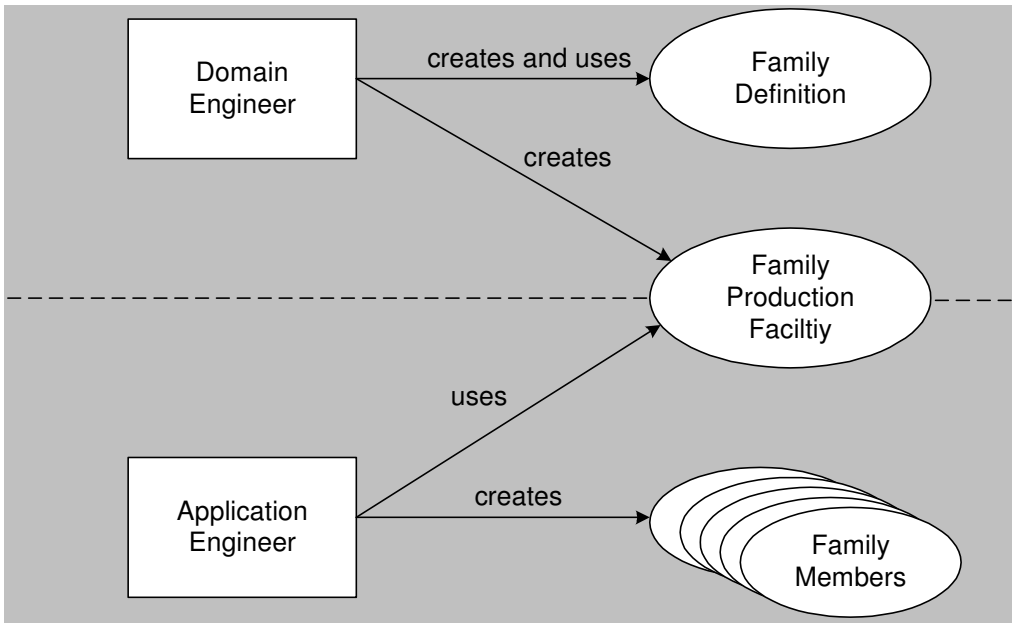


Figure 1 Family-Based Software Development Process

In this process the purpose of domain engineering is to make it possible to generate members of a family. The activities involved in the domain engineering are:

1. Define the family (also known as the domain)
2. Develop a language for specifying family members (the application modeling language).
3. Develop an environment for generating family members from their specifications (the application engineering environment).
4. Define a process for producing family members using the environment (the application engineering process).

The purpose of application engineering is to explore very quickly the space of requirements for an application and to generate the application. Application engineers use the production facilities from the family to produce new family members that satisfy the customer's requirements. The activities involved in the application engineering are:

1. The customer identifies or refines the requirements for the application.
2. The application engineer represents the requirements for the application as an application model.
3. The application engineer analyzes and refines the model until he or she is satisfied that it meets the customer's requirements. The application engineer can then generate a deliverable set of code and documentation from the model.
4. The customer inspects the application as the application engineer has modeled it, either by viewing the results of analyses or by testing the application as generated from the model.
5. The customer either accepts the generated application or returns to step 1.

The process described above is also depicted in Figure 2 [Czarnecki and Eisenecker, 2002].

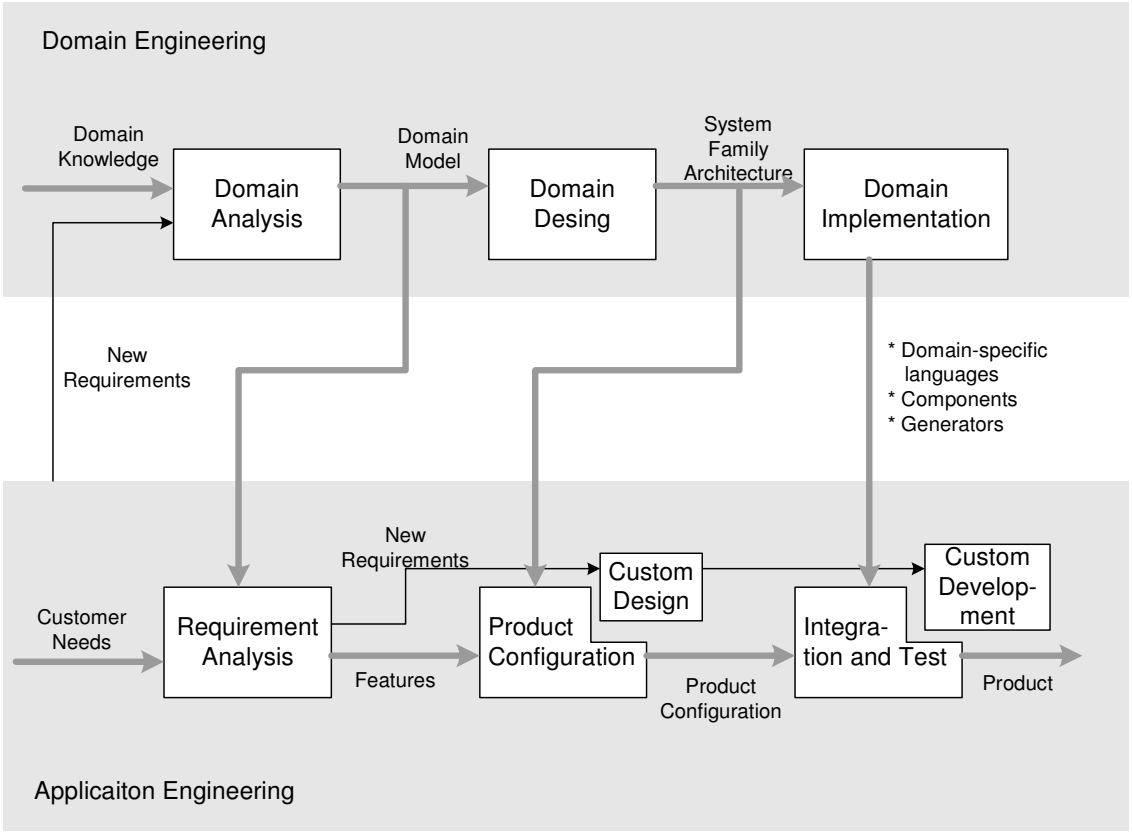


Figure 2 Software product line development process in details

2.3 Modeling Requirements – Feature Modeling

Features are an important concept in software product lines because they represent reusable requirements or characteristics of a product line. In software product lines, a feature is a requirement or characteristic that is provided by one or more members of the product line. In particular, features are characteristics that are used to differentiate among members of the product line and hence to determine and define the common and variable functionality of software product line. Feature analysis is an important aspect of product line analysis and has been used widely for the requirement analysis of software product lines in methods such as FODA (feature-oriented domain analysis) [Cohen and Northrop 1998; Kang et al. 1990] and other feature-based methods.

Feature modeling is the activity of modeling the common and the variable properties of concepts and their interdependencies and organizing them into a coherent model referred to as a feature model. The concepts here can be any elements and structures in the domain of interest.

A feature model consist of a feature diagram and some additional information, such as short semantic descriptions of each feature, rationales for each feature, stakeholders and client programs interested in each feature, examples of systems with a given feature, constraints, default dependency rules, availability sites, binding modes, and priorities.

2.3.1 Feature Diagram

2.3.1.1 Features

In a feature diagram the root node represents a concept; all other nodes represent the common and variable properties of this concept. The features in a feature diagram can be divided into three categories: mandatory, alternative and optional features. The rules concerning the features are as following:

- Mandatory feature: a mandatory feature is included in the description of a concept instance if and only if its parent is included in the description of the instance. For example, if the parent of a mandatory feature is optional and not included in the instance description, the mandatory feature cannot be part of the description.
- Optional feature: an optional feature may be included in the description of a concept instance if and only its parent is included in the description. In other words, if the parent is included, the optional feature may be included or not, and if the parent is not included, the optional feature cannot be included.
- Alternative feature: if the parent of a set of alternative features is included in the description of a concept instance, then exactly one feature from this set of alternative feature is included in the descriptions.

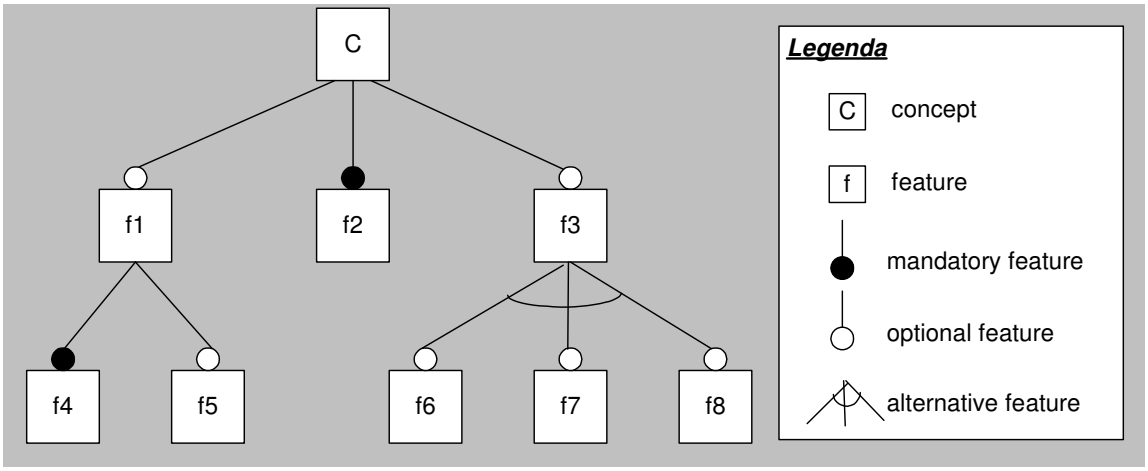


Figure 3 an example of feature diagram.

Figure 3 shows an example of a feature diagram. The root node C is a concept node, which is always included in the description of a concept instance. Concept C contains a mandatory feature f2, an optional feature f1, and an optional alternative feature f3. Furthermore f1 contains another two sub-features: mandatory feature f4 and optional f5. Even though f4 is a mandatory feature, it may not be included in the description of a

concept instance when its parent f1 is not included. Alternative feature f3 contains another three features: f6, f7 and f8. If f3 is included in the description of a concept instance, then only one of the feature f6, f7 and f8 will be included.

2.3.1.2 Feature Cardinality

We extend the features with cardinalities in the feature diagrams. In [Czarnecki, 2004] the feature cardinalities are divided into two types:

1. Feature cardinalities
   Features can be annotated with cardinalities, such as [1..*] or [3..3]. Mandatory and optional features can be considered special cases of features with the cardinalities [1...1] and [0...1], respectively.

2. Group and groups cardinalities
   Alternative features in the FODA annotation can be viewed as a grouping mechanism. The concept of groups was further generalized in [Riebisch, 2002] as a set of features annotated with a cardinality specifying an interval of how many features can be selected from that set.

2.3.1.3 Feature Dependency

In a feature diagram we can also define the relationships between features from this feature diagram. These relationships between features are called feature dependencies. The most common types of feature dependencies are:

1. Require
   If a require relation is defined between two features A and B as “A requires B”, then whenever A is present in the configuration of a feature diagram, B must also be present in the configuration. But vice versa does the presence of feature B say nothing about the presence of feature A.

2. Exclude
   If an exclude relation is defined between two features A and B as “A excludes B”, then whenever A is present in the configuration of a feature diagram, B must not be present in the configuration. Vice versa is also valid, so “A excludes B” means also “B excludes A”.

2.3.2 Expressing Commonality in Feature Diagrams

The mandatory features presented in a feature diagrams can be further categorized into two types: common features and common sub-features.

A common feature of a concept is a feature present in all instances of a concept. All mandatory features which are direct children of concept are common features. Also each

mandatory feature, whose parent is a common feature, is a common feature. Thus we can conclude that a common feature is always present in the description of a concept instance.

A common sub-feature f1 is a child feature of another feature f, which is present in all instances of a concept where f itself is also present. All direct mandatory sub-features of f1 are also common sub-features of f. A sub-feature of f is common if it is mandatory and there is a path of mandatory features connecting the sub-feature and f.

2.3.3 Expressing Variability in Feature Diagrams

Variability in feature diagrams is expressed using optional, alternative and optional alternative features. These features are also called variable features. The nodes to which variable features are attached are referred to as variation points. A variation point is where a product family member might differ from other members.

2.4 Modeling Design Variability

Techniques for modeling variability in design include modeling variability using parameterization, modeling variability using information hiding, and modeling variability using inheritance. [Gomaa and Webber 2004]. Each of these techniques has some strength and weakness. In most product lines, a combination of all three approaches is needed. The object-oriented approach to software development helps by supporting all three of these approaches to modeling variability. With the proliferation of annotations and methods for the object-oriented analysis and design of software applications, the Unified Modeling Language (UML) was developed to provide a standardized annotation for describing object-oriented models.

2.5 UML

Modern object-oriented analysis and design methods are model-based and use a combination of use case modeling, static modeling, state machine modeling, and object interaction modeling. Almost all modern object-oriented methods use the UML annotation for describing software requirements, analysis and design models [Booch et al. 2005; Fowler 2004; Rumbaugh et al. 2005].

In use case modeling, the functional requirements of the system are defined in terms of use cases and actors. Static modeling provides a structural view of the system. Classes are defined in terms of their attributes, as well as their relationships with other classes. Dynamic modeling provides a behavioral view of the system. The use cases are realized to show the interaction among participating object. Object interaction diagrams are developed to show how objects communicate with each other to realize the use case. The state-dependent aspects of the system are defined with statecharts.

An object-oriented analysis and design method for software product lines needs to extend single-system analysis and design concepts to model product lines, in particular to model

the commonality and variability in the product line, and to extend the UML annotation to describe this commonality and variability.

2.5.1 UML in Product Line Software Design - PLUS

PLUS (Product Line UML-Based Software Engineering) [Gomaa 2004] is a UML-based software design method that extends the UML-based modeling methods for single systems to address software product lines.

In the PLUS method the activities of modeling a product line system are divided into three phases: requirements modeling, analysis modeling, and design modeling.

In requirements modeling phase, the following activities are involved:

1. Product line scoping
   At a high level, the following aspects of the product line are determined: its functionality, the degree of commonality and variability, and the likely number of product line members.
2. Use case modeling
   Actors and use cases are defined, and the functional requirements of the product line are specified in terms of those use cases of actors. Product line commonality is determined by the development of kernel use cases. Product line variability is determined by the development of optional and alternative use cases, and by the identification of variation points within use cases.
3. Feature modeling
   Software product line commonality is characterized by kernel features; product line variability is characterized by optional an alternative features. Features can be identified from the use cases determined during use case modeling.

In the analysis modeling phase the following activities are involved:

1. Static modeling

   A problem-specific static model is defined. The emphasis of static modeling is on the information modeling of real world classes in the problem domain – in particular, entity classes and external classes.

2. Object structuring

   The objects – Kernel, optional, and alternative – that participate in each use case are determined. Object structuring criteria are provided to help determine the objects, which can be entity objects, interface objects, control objects, and application logic objects.

3. Dynamic modeling

The use cases from the use case model are realized to show the interaction among the objects participating in each kernel, optional and alternative use case. Communication diagrams or sequence diagrams are developed to show how objects interact to execute the use case.

4. Finite state machine modeling

   The state-dependent aspects of the product line are defined by means of hierarchical statecharts. Each state-dependent control object is defined in terms of its constituent statechart. For state dependent object interactions, the interactions among the state-dependent control objects and the statecharts they execute need to be modeled explicitly.

5. Feature/class dependency analysis

   This step is used to determine what classes from the analysis model are needed to realize the features from the feature model.

   For every feature in the software product line, certain classes realize the functionality specified by the feature. A common feature is provided by every member of the product line, the classes that support or realize a common feature are always kernel classes. Because common features are provided by every member of the product line, it follows that kernel classes are always present in all product line member. If an optional or alternative feature is selected for a given member of the product line, then the optional or variant classes that realize this feature are also selected.

In the design modeling phase the solution domain is considered. The goal is to develop a component-based software architecture for the product line. To create the product line architecture, developers consider what software architectural patterns should provide its foundation.

2.5.2 Extended UML Annotation in PLUS

In these sections we will use a few examples to show how features are represented in PLUS UML models.

Figure 4 depicts a use case example in PLUS. In this use case there is a kernel use case “Validate PIN” which correspond to a mandatory feature in a bank product line, and the mandatory character of this feature is indicated by the stereo type <<kernel>> annotation. “Validate PIN” includes another three kernel use cases “Withdraw Funds”, “Query Account”, “Transfer Funds”, and another two optional use cases “Deposit Funds” and “Print Statement”. The optional features are notated using <<optional>> stereo type. Whether these two optional use cases are present in one of the Bank system member is determined by the evaluation expression marked on the arcs with annotation [deposit option], [ministatement option] respectively.

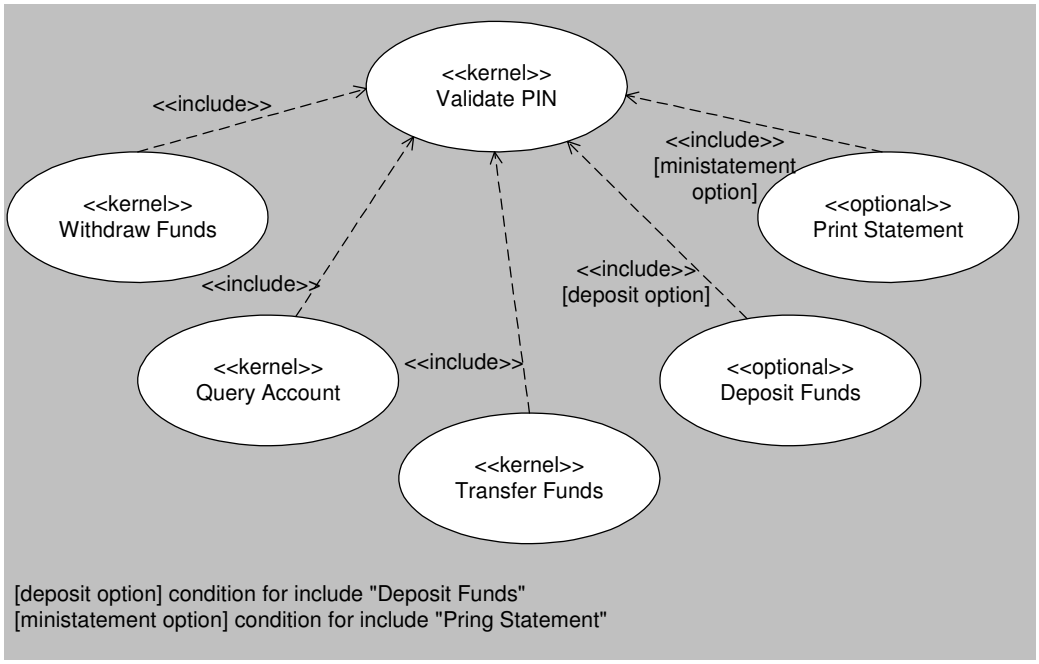


Figure 4 an use case example in PLUS

In PLUS the features are modeled by class diagrams. Figure 5 depicts a class diagram representing a set of features with feature dependencies.

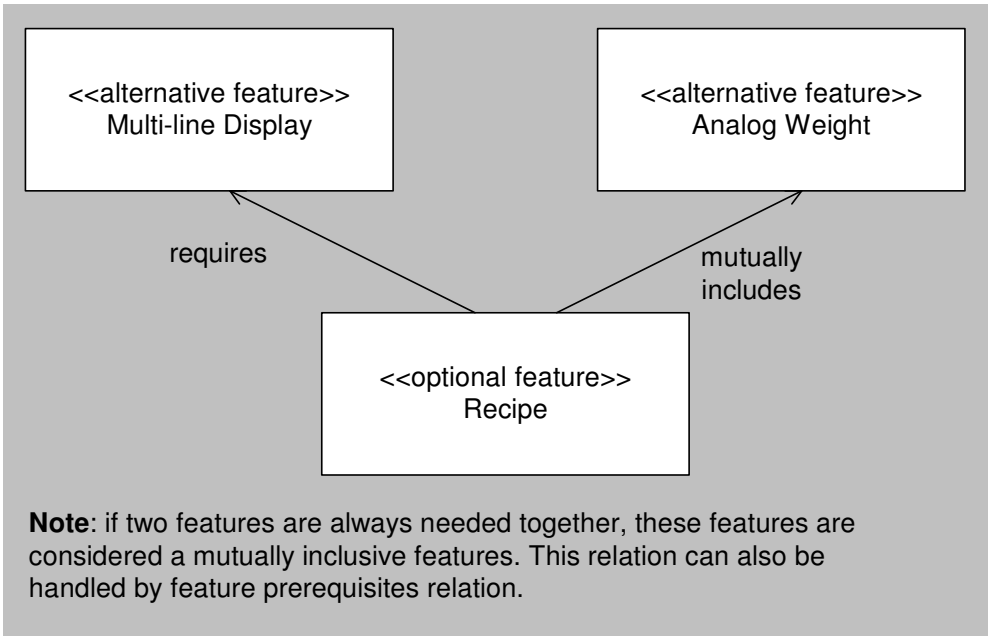


Figure 5 an example of features with dependencies in PLUS

In this class diagram there is an optional feature Recipe, which has a "requires" relationship with an "alternative feature – Multi-line Display" and a "mutually includes"

relationship with an "alternative feature – Analog Weight". The relationships are represented as associations in this diagram. A require relation means whenever optional feature "Recipe" is present in the description of an instance of this product line, the alternative feature "Multi-line Display" has to be present in this instance description as well. "Mutually includes" is basically redundant as it can also be handled with a "Requires" relation.

The relationship between features and use cases is a many to many relationship, and this relationship is recorded in a table. Table 1 shows the relationships between features and use cases in a microwave oven software product line example.

Table 1 *Tabular representation of feature/use case relationships: microwave oven software product line.*

Feature Name	**Feature Category**	**Use Case Name**	**Use Case Category/Variation Point (vp)**	**Variation Point Name**
Microwave Oven Kernel	common	Cook Food	Kernel	
Light	optional	Cook Food	vp	Light
Turntable	optional	Cook Food	vp	Turntable
Beeper	optional	Cook Food	vp	Beeper
…	…	…	…	…

2.5.3 The Strength and Weakness of PLUS Method

The major strength of PLUS method is that feature modeling is successfully integrated into the requirement and analysis modeling process of product line software development. The product line software development process has been clearly defined, which includes activities of feature modeling. The features represented in the feature model are related to classical UML model, such as use case models, static models, dynamic models, etc.

The PLUS method has also a few weaknesses. The first weakness of PLUS is that features are modeled by using class diagram instead of feature diagrams. The tree structure of feature diagrams is an important characteristic of features, and the mandatory, optional, and alternative features are also very well annotated in the feature diagram. The feature diagrams make it much easier to understand the structures of the features, the characteristics of the features, and the relationships between features. Another advantage of feature diagrams is that it is very compact, a small feature diagram can contain quite big mount of data.

The second weakness of PLUS is that the feature characteristics (mandatory, alternative, optional) are also annotated in other UML diagrams, such as use case diagrams and class diagrams. If a UML model itself is already complex, then extra feature annotation added into the UML model makes it even more complex. With feature diagram those information can be easily separated from the UML model.

The third weakness of PLUS is that this method only considers how features in a product line can be modeled into UML models, as how to generate the UML models for a product line member is not considered.

As so far we haven't seen a method which both satisfies the requirements and eases the process of product line development, so we propose a new method – FeatureUML – for this purpose. The FeatureUML will use the strength of PLUS method, and try to remove the weakness of the method. The FeatureUML method is described in details in Chapter 3.

3 FeatureUML Method

3.1 Problems FeatureUML Addresses

The FeatureUML method aims to define a systematic way of developing product software product line. The current focus of this method is the domain analysis phase and part of the application engineering phase. The modeling techniques used in this method include feature diagrams and UML models. The method should satisfy the following goals at the end:

- There should be a clear process defined for product line software system development.
- The annotation for features should be defined in such way that the method should keep the complexity of system analysis as simple as possible.
- The method should also provide a way to generate models for a member of the product line.

3.2 Product Line Process in FeatureUML

We have modified the product line development process described in section 2.2. The new situation is depicted in Figure 6.

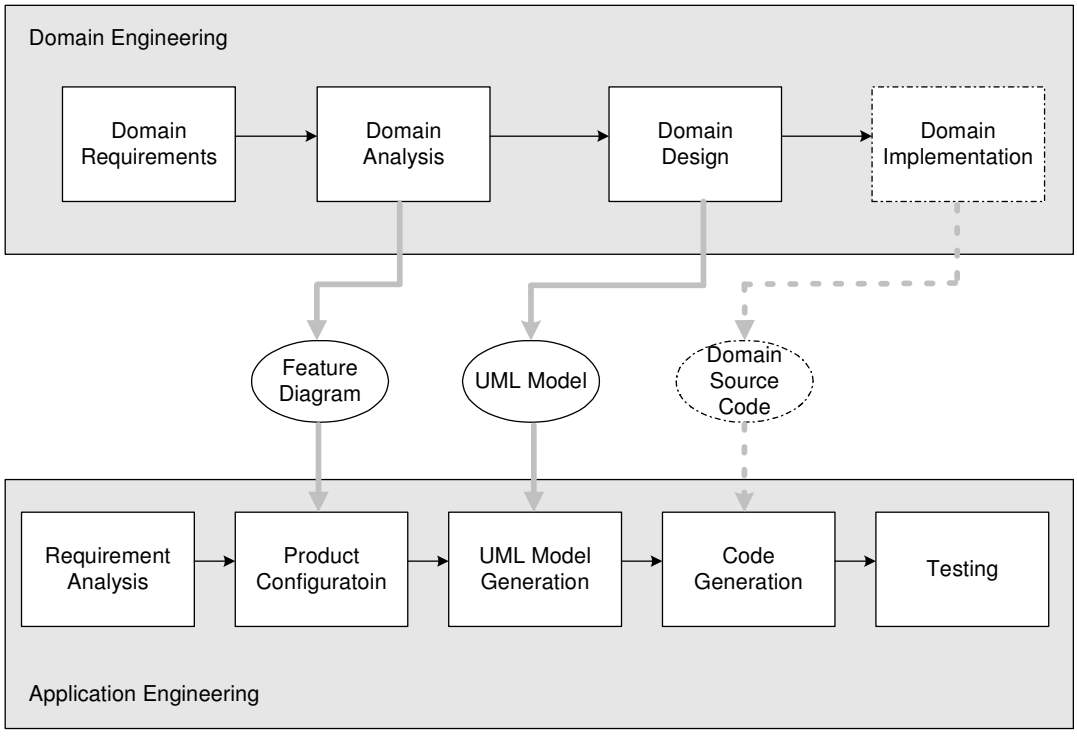


Figure 6 Product line system development process from FeatureUML.

3.2.1 Domain Engineering

Domain engineering is divided into the following phases:

1. Domain Requirements

   The purpose of domain requirements is to define the scope of the domain, collect the relevant domain information. The activities described in the PLUS method for domain requirements are also used here. So the major activities involved in domain requirements phase are:

   - Product line scoping
   - Use case modeling
   - Feature modeling

   At the end of the domain requirements we should gain a use case model, a feature model and other relevant information about a domain.

2. Domain Analysis

   The purpose of domain analysis is to identify the problem domain objects and the information passed between them. We have modified the activities in the PLUS method and the new set of the activities are as following:

   - Static modeling
     A problem-specific static model is defined. In this phase the mandatory, optional, and alternative features are also mapped into the class elements – namely class, attributes and options in the classes.
   - Dynamic modeling
     When the sequence diagrams are developed to show how objects interact to execute the use case, the features in the feature model are also mapped into the sequence diagrams.
   - Finite state machine modeling
     The state machine modeling is not considered in FeatureUML method at the moment, it can be added into this method in the future.
   - Feature model/UML model map validating
     This step is to validate the UML model again the feature model. Validating includes if all the features mapped in the UML model also exist in the feature model, and the features in the feature model has been mapped into a set of UML elements in the UML model.

3. Domain Design and Domain Implementation

   The purpose of domain design is to develop an architecture for the family of systems in the domain and to devise a production plan. The domain implementation can be done in three approaches:

1. Approach one – the traditional approach

    a. The domain code is written and the matrix to indicate the connection between the code unit and the features is setup.
    b. At the application engineering phase the UML model for a single member, the feature model and the code/feature matrix is taken as input to generate the code unit for this single member.

2. Approach two – component assembly

    In this approach a set of components are implemented and the features are mapped into the subset of the components. During the application engineering phase the right subset of the components are selected according to the configuration of the feature model, and these components are assembled into the final system.

3. Approach three – the modern and future approach

    As one of the current research trends on software development is Modern Driven Architecture (MDA). In MDA the UML model is then divided into two types: PIM (platform independent model) and PSM (platform specific model). The PSM model is very close to the final source code, so it can be used to generate source code. The UML models we develop here are PIM. After the PIM is transformed into PSM the source code can be generated from the PSM model. If this approach becomes reality, then the domain development will be not required any more in the product line process.

Our current focus of the method is not on the domain development, so we will not discuss this issue any further in this thesis.

3.2.2 Application Engineering

Application engineering is divided into the following phases:

1. Requirement analysis

    During the requirements analysis for a new concrete application, we take advantage of the existing domain model and describe customer needs using the features from domain model. If new customer requirements are not found in the domain model, then the domain engineering has to be refined and extended to fulfill the new customer requirements.

2. Product configuration

The purpose of this phase is to use the custom requirements gathered in the requirement analysis phase to configure the feature diagrams in the feature model. The required optional features are selected, and decisions are made as which of the feature options in the alternative feature should be chosen. At the end the features present in the feature configuration should fulfill the requirements from a single customer.

3. UML model generation

   In the UML model generation phase the UML models created in the Domain Engineering are used as input, and these UML models are processed automatically against the feature configurations from the product configuration phases. The output of this process is a UML model which is dedicated to a single customer.

4. Code generation

   In this phase the feature model, specific UML model and the domain source code are used to generate the source code for a single customer. Currently this phase is out of the scope of this project.

5. Test

   The source code generated in code generation phase is compiled, tested and packed in a desired format. The final package of the program is delivered to the customer to go through the acceptance test.

4 Feature and UML Modeling in FeatureUML Tool

In this chapter we give a detailed introduction of the main activities in FeatureUML, which are the feature modeling, the UML modeling, and the UML model processing in our prototype tool.

4.1 Feature Modeling

During feature modeling we extract features out of the use case model and organize them into feature diagrams.

4.1.1 Feature Types

The feature types, which can be illustrated in feature diagram, include mandatory, optional and alternative types. An alternative type has to be combined with either a mandatory or an optional type to derive two new types: mandatory alternative and optional alternative. Thus in total we have the following four types of features in FeatureUML:

- Mandatory feature
- Optional feature
- Mandatory alternative feature
- Optional alternative feature

Figure 7 shows an example of a feature diagram which contains all these four feature types.

Feature “student” is a mandatory feature which contains another two mandatory features – namely, “first_name” and “last_name”. It also contains two optional features – namely, “middle_name” and “login_info”.

Feature “remove_student” is an optional alternative feature. It contains anther two features – namely “markStudentRemoved” and “removeStudentRecordFromDatabase”. This means that each application can only choose one of these two policies when removing student is concerned.

Feature “Language” is a mandatory alternative and it contains the optional features: “Dutch” and “English”.

Note the icons for each type of features are also different.

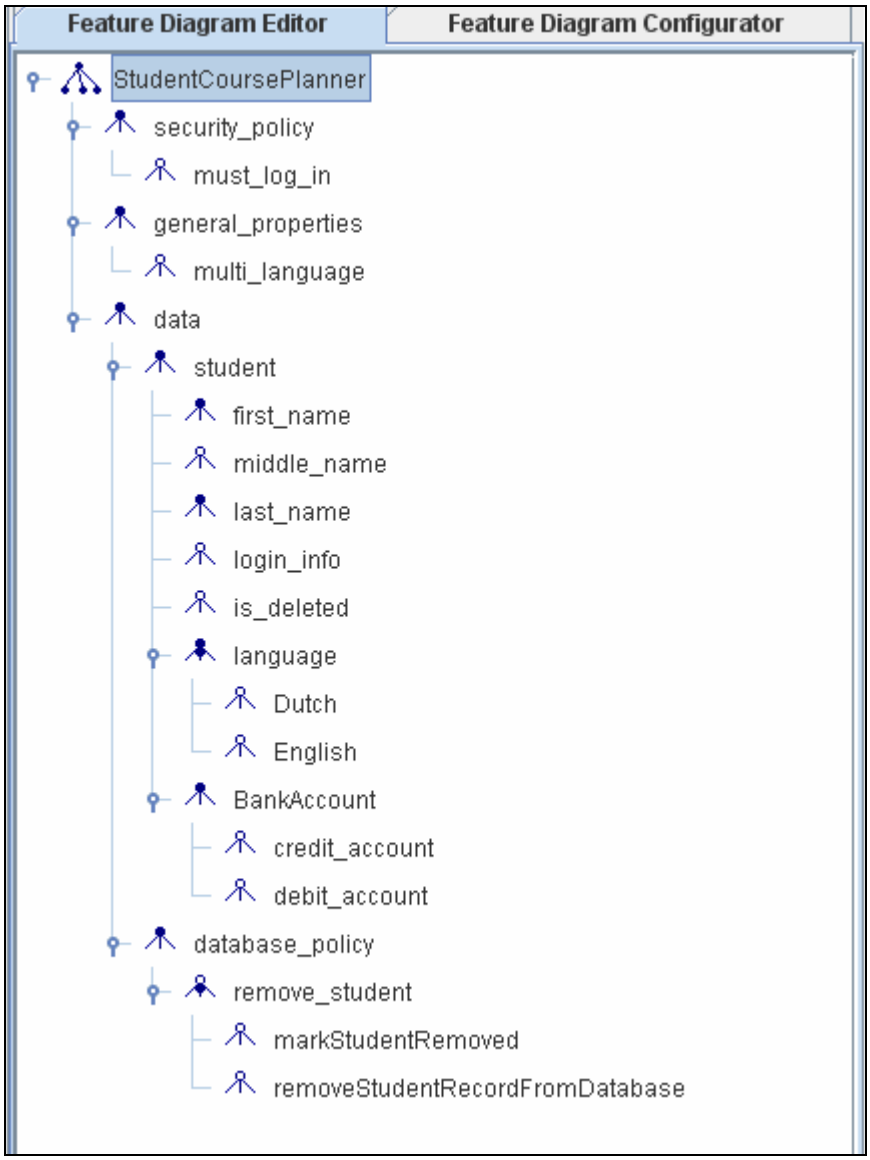


Figure 7 four feature types in a feature diagram example.

4.1.2 Feature Cardinality

In FeatureUML we use a modified version of the feature cardinality described in section 2.3.1.2. The cardinalities of the mandatory and optional features are set to [1…*] and [0…*] respectively. Our consideration for this change is that a mandatory feature or an optional feature can be selected multiple times in a configuration of the feature models. The second change was made to the feature cardinality is the alternative group feature cardinality. In FeatureUML the feature options in an alternative feature are exclusive, which means whenever we configure an alternative feature, we can only select one feature option from this alternative feature.

The feature-cardinalities in FeatureUML are based on the concept described above and are divided into two types:

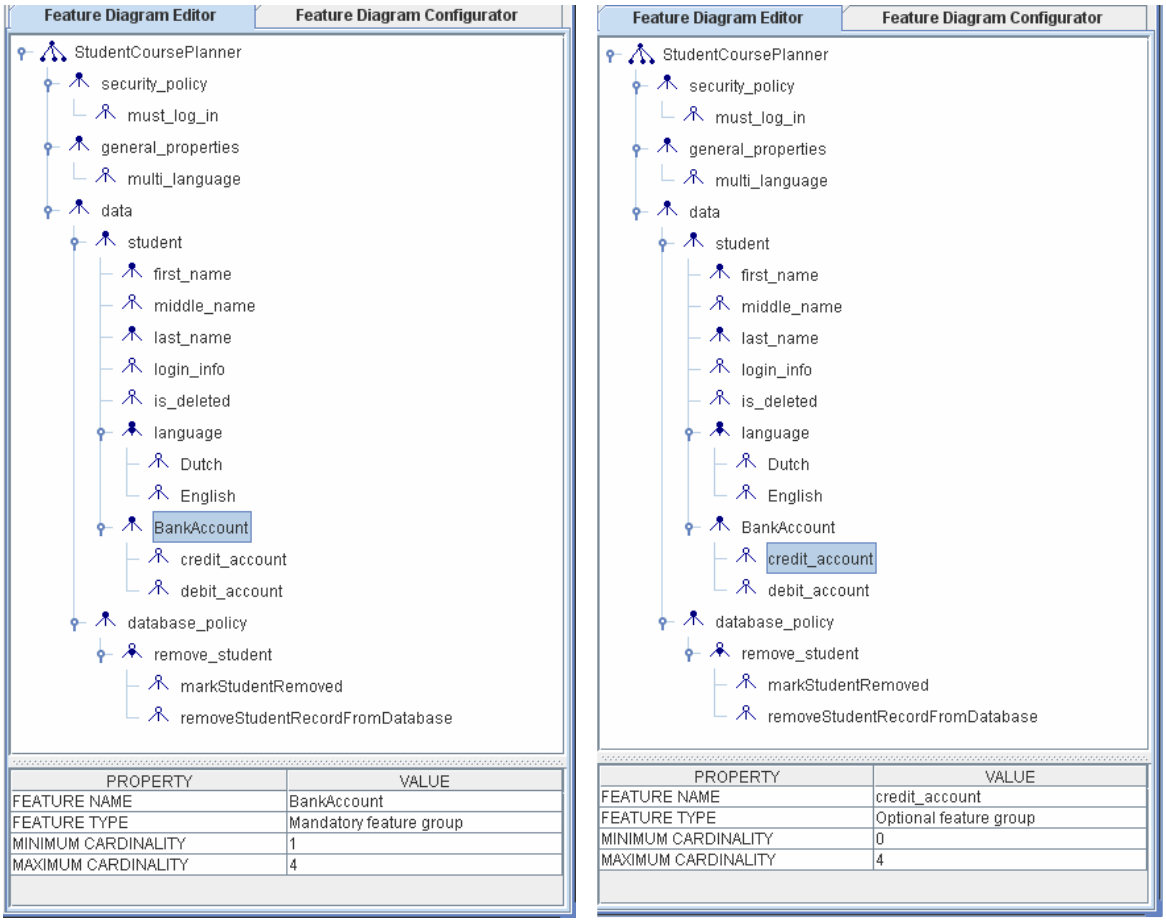


Figure 8 feature cardinalities in an example of feature diagram

Figure 8 shows the same example from Figure 7 with cardinalities. The mandatory feature "Bank Account" has a feature cardinality [1…4], which means that each student should has at least one bank account, and can have up to maximal four account information stored in the system.

Feature "Credit Account" has a cardinality of [0…4] which means each student can have from 0 up to 4 credit account information stored in the system. This is also logic as a student can only have up to 4 bank accounts.

Even though this concept is currently built into the tool, but it is not used in the UML model mapping, and this can be extended in the future.

4.1.3 Feature Dependency

We have built both of the two types of the feature dependency into the tool. Figure 9 shows a feature diagram with one require dependency and one exclude dependency.

Feature “must_log_in” require “login_info” means whenever we select optional feature “must_log_in” in a configuration, then feature “login_info” also has to be selected.

Feature “removeStudentRecordFromDatabase” has an exclude relationship with feature “is_deleted”, which means if “removeStudentRecordFromDatabase” is selected, then we can never select feature “is_deleted” in the same configuration. Vice versa is also valid.

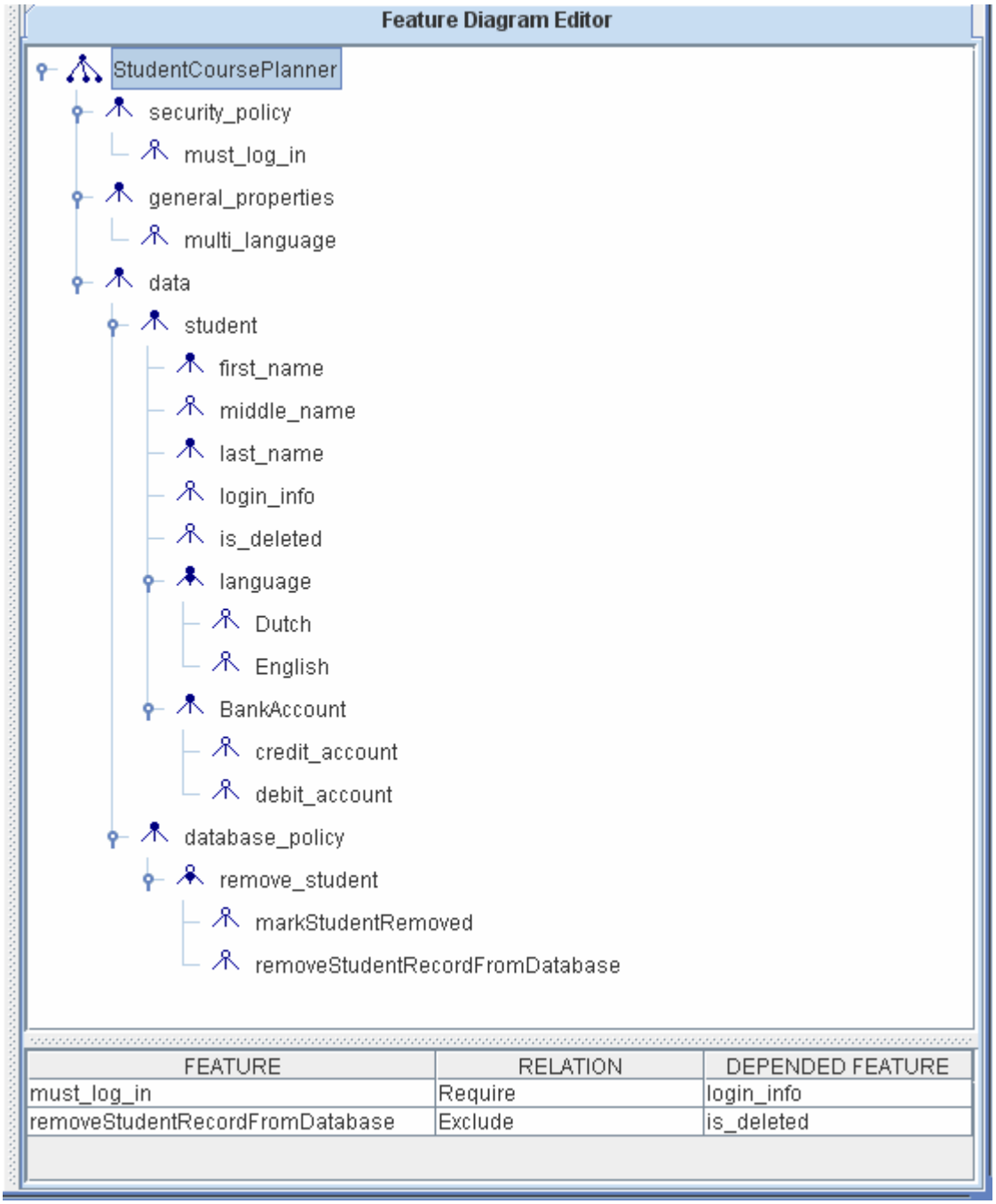


Figure 9 feature dependencies between features in a feature diagram example.

4.2 UML Modeling

4.2.1 UML Diagram Feature Annotation

In the UML diagrams a single annotation is used to indicate that a feature is mapped into a UML element, which is:

[FEATURE *feature_name*]

where "*feature_name*" is the name of the feature which is mapped into this UML element. This annotation is used in both class diagrams and sequence diagrams. Figure 10 gives a few examples of UML element/feature mappings.

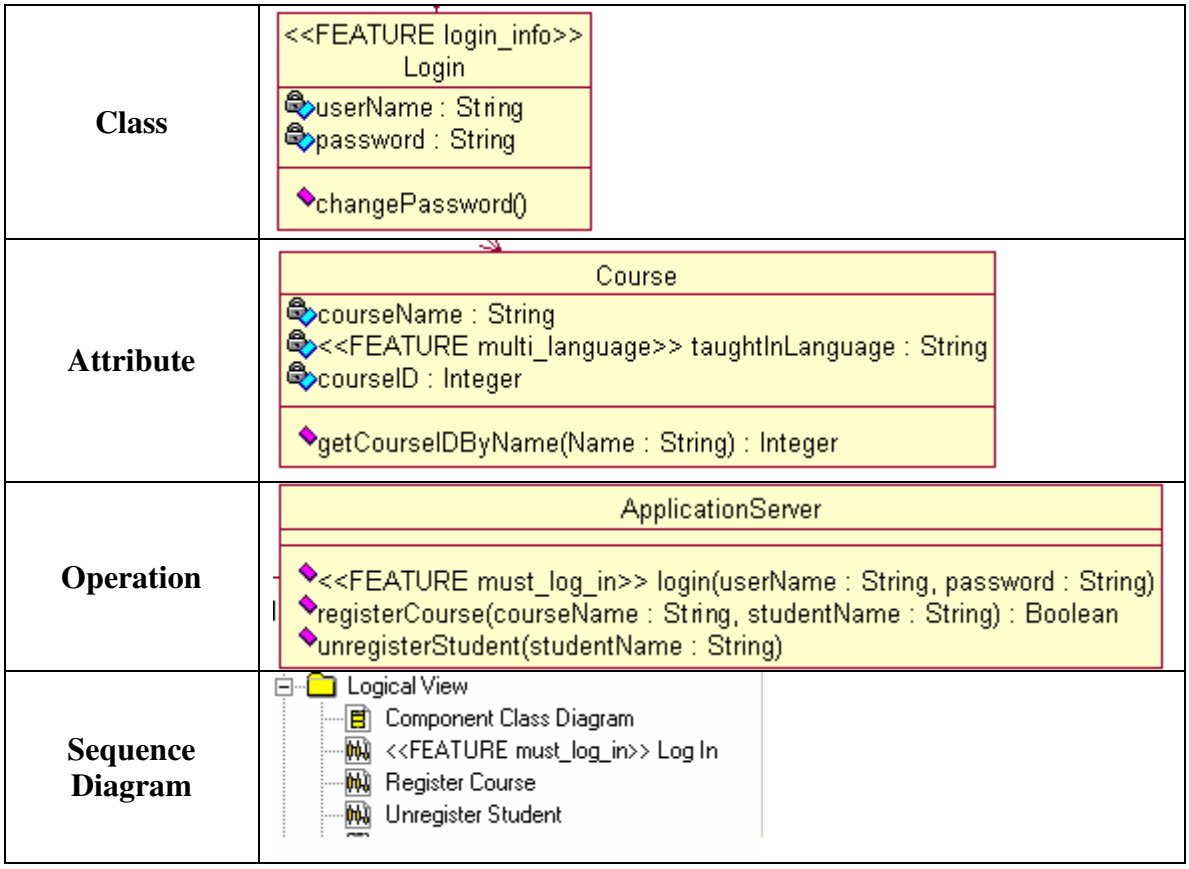


Figure 10: a few examples of the UML element/feature mappings.

In the examples the following mappings are shown:

- The feature "login_info" is mapped into the class "Login";
- The feature "multi_language" is mapped into the attribute "taughtInLanguage" in the class "Course";
- The feature "must_log_in" is mapped into the operation "login" in the class "ApplicationServer";
- The feature "must_log_in" is mapped into the sequence diagram "Log In".

4.2.2 UML Element Types

Currently we have only mapped the feature in the feature model into class diagrams and sequence diagrams. Figure 11 shows the relationship between features and UML elements.

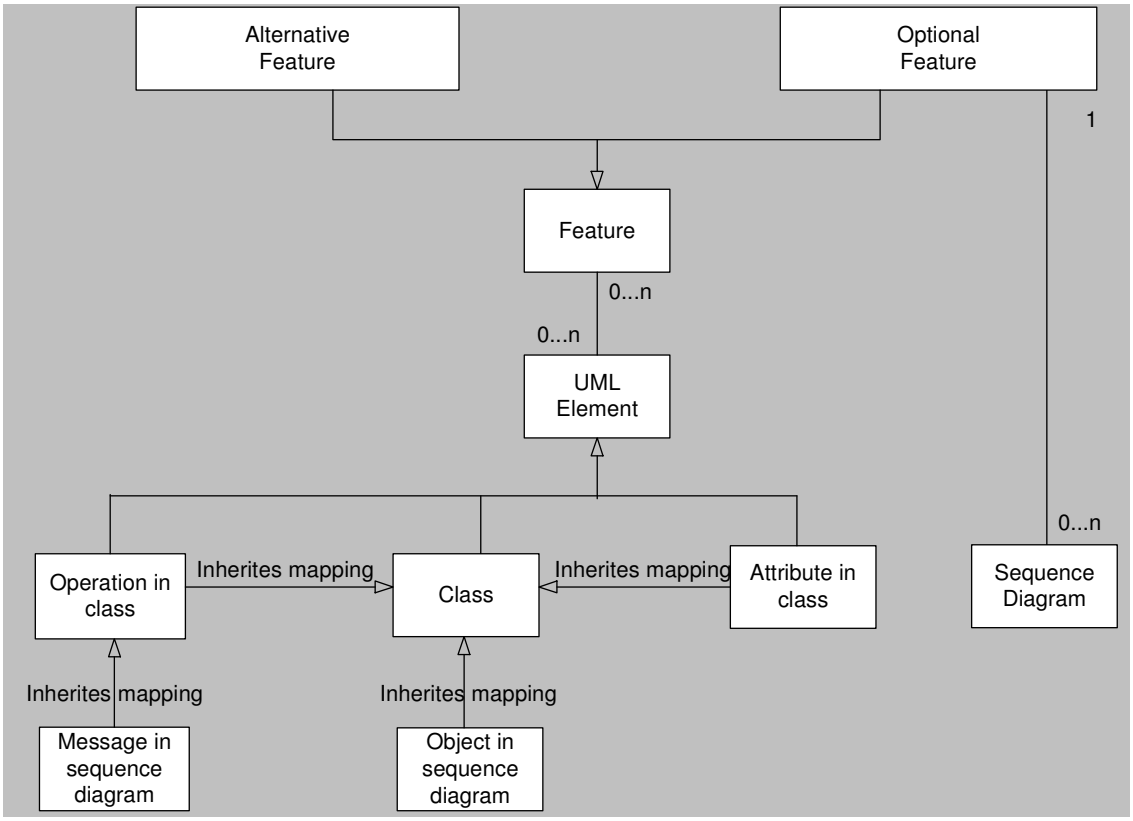


Figure 11 Mapping relationships between features and UML elements.

There are two types of mapping: direct mapping and indirect mapping. In class diagrams and sequence diagrams there are following elements which we can directly map features into:

- Class
  Both alternative features and optional features can be mapped into a class directly.
- Attribute in a class
  Same as a class, both alternative features and optional features can be mapped into an attribute of a class directly.
- Operation in a class
  Same as a class, both alternative features and optional features can be mapped into an operation of a class directly.
- Sequence Diagram
  A sequence diagram is special type of UML Element which we can only map optional features to. The reason for this is if an alternative feature needs to be mapped into sequence diagrams, then for each option in this alternative feature we

need to make a sequence diagram. Instead of mapping an alternative feature to a sequence diagram, we map each feature option in the alternative feature to a sequence diagram.

In class diagrams we have mapped the features directly into the following two types of UML elements:

- Attributes in class
  When a feature is mapped into a class, then all the attributes in the class get this mapping automatically.

- Operations in class
  When a feature is mapped into a class, then all the operations in the class get this mapping automatically.

In sequence diagrams the features are mapped into the following two types elements indirectly:

- Objects in a sequence diagram
  For a correct sequence diagram, each object in the sequence diagram should have a base class. Consequently if a feature is mapped into a base class, then all the object instances of this class get this mapping automatically.

- Messages in sequence diagram
  For the same reason as objects in a sequence diagram, each message should be an operation of the receiver object's base class. If a feature is mapped into an operation in a class, then all the corresponding messages of this operation get this mapping automatically.

With the current implementation of the FeatureUML tool we only map optional and alternative features into UML elements, as only these two features will need to be configured during the product configuration phase, the mandatory features should always be present in all the members of a product line.

Figure 12 and 13 show a class diagram and a sequence diagram respectively which we have mapped features into the UML elements directly in the diagrams.

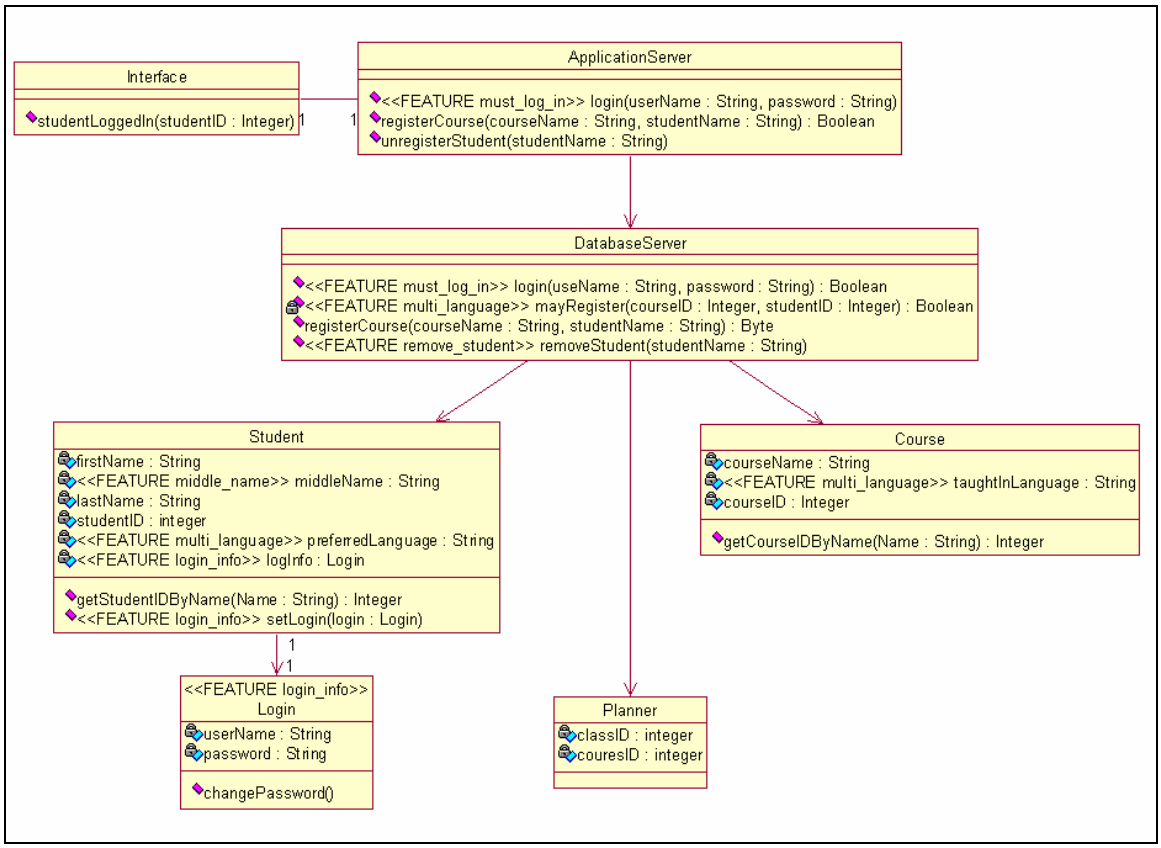


Figure 12: an example of UML model mapping into features.

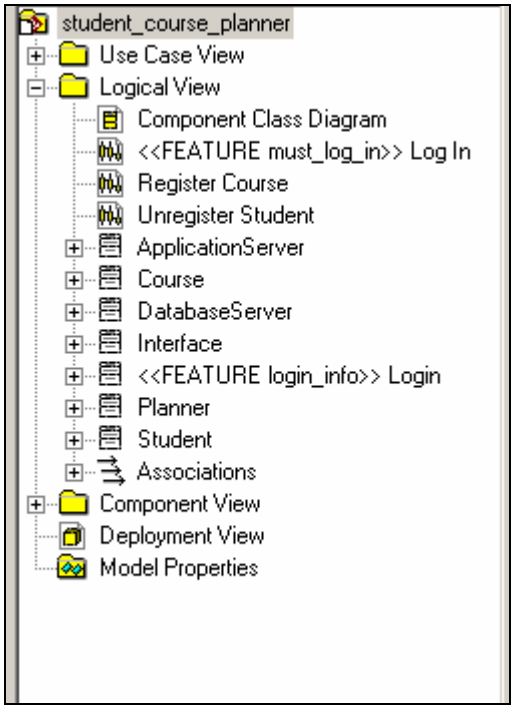


Figure 13: an example of UML feature diagram mapping into features.

4.3 Feature Diagram Configuration

In the product configuration phase we have to configure feature diagrams which are created during the feature modeling. For this process we can take any feature diagrams from the feature models as input and perform a select/unselect action on each optional features and features in the alternative features.

Figure 14 shows a feature diagram which needs to be configured. All the optional features and the features in an alternative features are marked red. There is an exception case here; with each feature marked in red (except the exception case) we can do one of the three actions:

- Select: this feature will be marked as selected in the final configuration.
- Unselect: this feature will be marked as unselected in the final configuration.
- Undecide: the feature can be configured in a later stage.

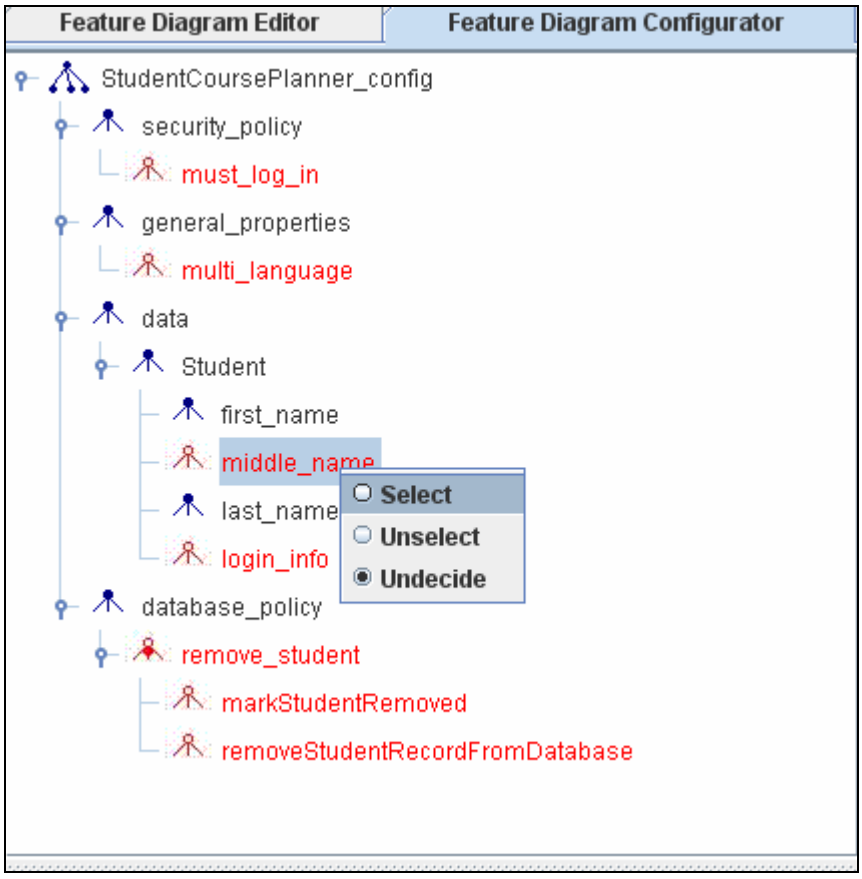


Figure 14: configuration of a feature diagram.

FeatureUML also supports staged configuration. This concept is first introduced in [Czarnecki, 2004]. Staged configuration means that the process of specifying a family member may be performed in stages, where each stage eliminates some configuration choice. The need for staged configuration arises in the context of *software supply chains*

[Greenfield and Short, 2004]. In general, supply chains require staged configuration of platforms, components, and services. However, staged configuration may be required even within one organization. For example, security policies could be configured in stages for an entire enterprise, its divisions, and the individual computers. The enterprise level configuration would determine the choices available to the divisions, and the divisions would determine the choices available to the individual computers.

In FeatureUML a configuration may have features which are not configured (marked as "Undecided"). It is valid to use a not completely configured feature diagram to process UML models. Those UML elements which have mappings with those features which are not configured yet will be untouched in the process. This configuration file can be configured further at a later stage. Figure 15 shows a configuration on a feature diagram, the selected features are marked green, and the unselected features are marked gray. There are still a few features in the diagram marked in red, which means they are not configured yet and can be configured at a later stage.

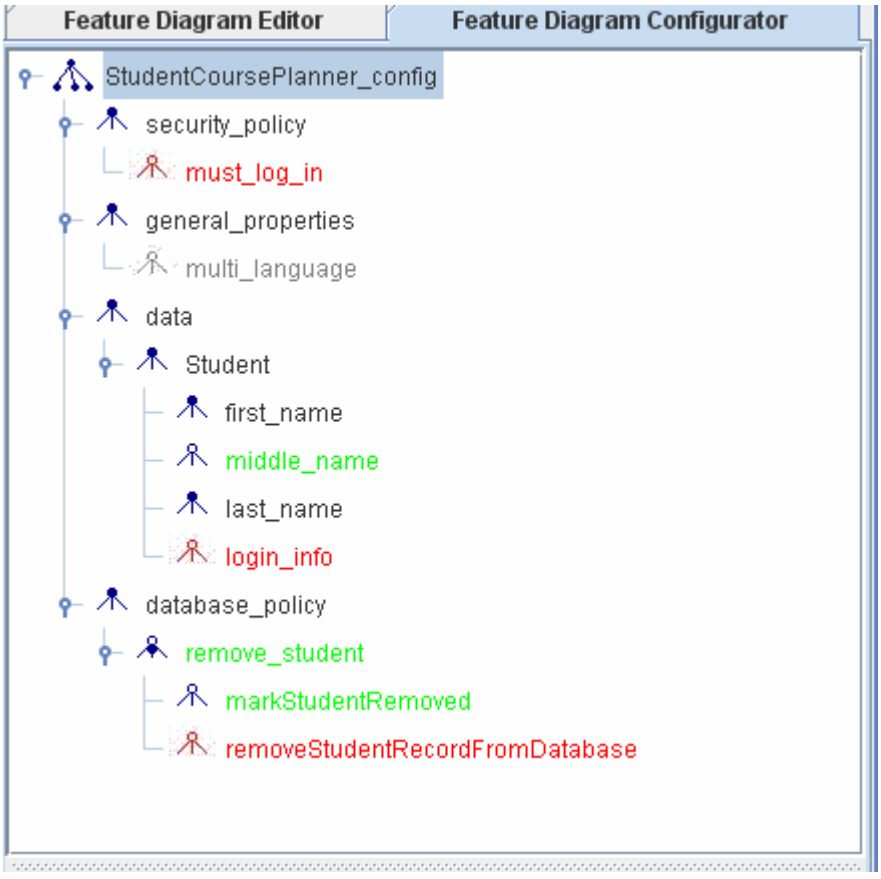


Figure 15: an example of staged configuration on a feature diagram.

4.4 UML Model Processing

4.4.1 Rules

UML model processing takes a configuration file and a UML model as input and checks the UML elements in the UML model which have mappings with the features from the configuration files. After the processing, the UML model should not contain any feature mapping annotations any more for those features which have been configured in the configuration file.

There are basically three types of operations which can be performed on a UML element which a feature is mapped into:

- Feature marking elimination
  If a UML element is marked to a feature which is selected in the configuration, then the feature marking will be removed from this UML element. For example, if a feature is mapped into a class as following:

  ```
  [FEATURE login_info] Login
  ```

  then after the processing the feature marking is gone, and the element looks like:

  ```
  Login
  ```

- UML element elimination
  If a UML element is marked to a feature which is unselected in the configuration, then the UML element is simply removed from the UML model after the process. For example a feature is mapped into an attribute in class “Student” as following:

  ```
  [FEATURE login_info] login: Login;
  ```

  After the processing this attribute is simply removed from the class “Student”.

- UML element substitution: if a mandatory or selected optional alternative feature is mapped into a UML element, and there is an option from the alternative feature which has been chosen, then this UML element’s name will be substituted with the name of the selected option from the alternative feature. For example the feature “removeStudent” is mapped into an operation in a class as following:

  ```
  [FEATURE removeStudent] removeStudent();
  ```

  The alternative feature “removeStudent” has two options: “markStudentRemoved” and “removeStudentRecordFromDatabase”. If the option “removeStudentRecordFromDatabase” is chosen from this alternative feature, then after processing the operation will look like this:

```
removeStudentRecordFromDatabase();
```

So the feature marking is gone and the name of the operation is substituted with the name of the selected option from the alternative feature.

4.4.2 Processes

The details of processing each type of UML elements are described below:

1. Feature marking elimination
   When this action is applied on a UML element, except the feature marking is removed from the UML element, no further action is performed.
2. UML element elimination
   A. Sequence diagram: the sequence diagram is removed from the UML model, and no further action is taken.
   B. Attribute in a class: the attribute is removed from the class, and no further action is taken.
   C. Operation in a class: the operation is removed from the class, all the messages corresponding to this operation are removed from sequence diagrams, and no further action is taken.
   D. Class
      a) All the attributes in this class are removed; the process of removing each attribute follows the process described in 2.B.
      b) All the operations in this class are removed; the process of removing each operation follows the process described in 2.C.
      c) All the objects derived from this class are removed from all the sequence diagrams
      d) This class is removed.
3. UML element substitution
   When this action is applied on a UML element, the name of the UML element is substituted and the feature marking annotation is removed from the UML element. No further action is performed.

5 FeatureUML Tool

For the FeatureUML method we have built a prototype to demonstrate the ideas. In this section we will describe issues related to the tool.

5.1 General Goal

The general goal of this tool is to create an environment which supports the FeatureUML method. The major activities defined in the FeatureUML method should be realized in this tool, and these major activities include: feature modeling, feature configuration, and UML model processing. UML model are made in Rational Rose (Release version: 2002.05.00).

5.2 Tool Requirements

The major functionalities in the FeatureUML tool are divided into four groups, and these major functionalities are explained in the following sections.

5.2.1 Environment Description

The environment of the tool is shown in Figure 16. Feature models are made in the FeatureUML tool, and these feature models should be saved into the hard disk in XML format. The FeatureUML tool should be able to load the existing feature models back when they are needed.

The feature configuration is also done in the FeatureUML tool. The configured feature models for a single member of the product line should be saved into the hard disc in XML format. The FeatureUML tool should also be able to load the existing configured feature models back when they are needed.

The UML models are made in Ration Rose, and they are exported from the Rational Rose into XML files by using XMI (XML metadata Interchange format). The FeatureUML should be able to load these UML models and process them against a special configured feature model. After model processing the output of the UML model should be saved back to disk in XML format again. This processed UML model should comply with the original UML model format so it can be imported back to Rational Rose for viewing.

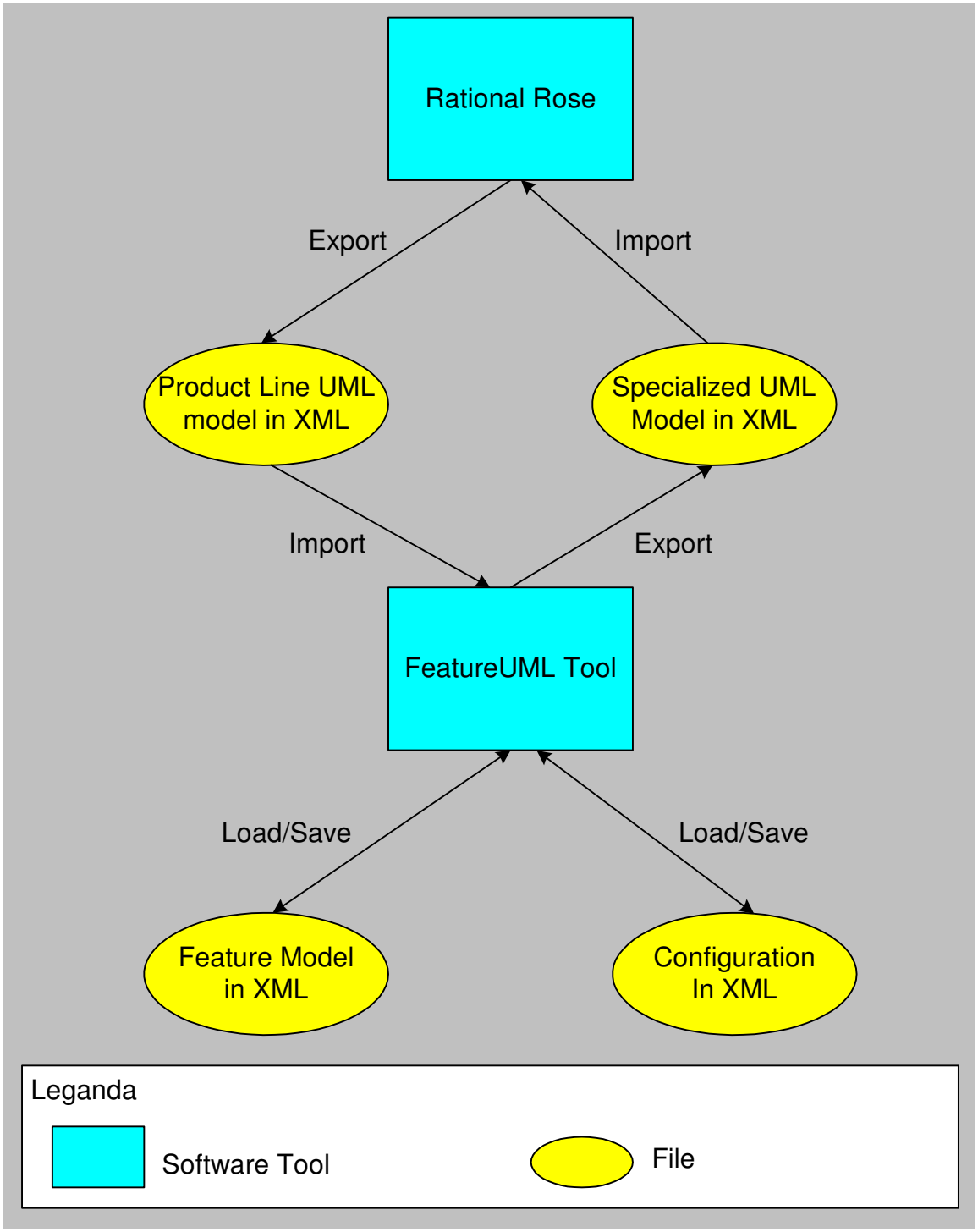


Figure 16: the environment of the FeatureUML tool.

5.2.2 Required Functionalities

The functionalities of the tool are divided into three main groups: feature modeling, feature model configuring, and UML model processing.

1. Feature Modeling

   The users should be able to create feature models. Each feature model contains multiple feature diagrams. Each feature diagram consists of mandatory features, optional features, mandatory alternative features, and optional alternative features. Thus the users should be able to create new feature diagrams in a feature model, and the users should also be able to create all these four types of features in each feature diagram.

   Each feature model should be saved into hard disk in XML format, and the tool should be able to load the existing feature models. The users should be able to modify the feature diagrams in the feature model, and the features in each feature diagram. The users should also be able to remove feature diagrams from a feature model and features from a feature diagram.

2. Feature Model Configuring

   The tool has to allow uses to configure an existing feature models for a product line. So after a feature model is loaded into the tool, the user can decide which optional features should be selected or deselected; which feature options in the alternative features should be selected. The users don't have to configure the mandatory features, as they are always present for all the members of the product line.

   The configuration can be preformed in stages, which means that users don't have to configure all the optional and alternative features at one go. The users should be able to save the configured feature model onto hard disk in XML format at any stage as they wish. These configurations can be loaded back into the program again at a later stage for further configuration.

3. UML Model Processing

   The tool should be able to load an UML model in XML format for a product line which is made in Rational Rose. The users should be able to process this UML model against a special configuration of a feature model. This configuration doesn't have to be completed, which means it is possible to have not configured optional and alternative features in the configuration. Those UML elements which have mappings with those not configured features should not be processed during the UML model processing. The output UML model after the processing should be saved back into the hard disk in XML format again, and the file should comply with the original UML model file format so it can be imported back to Rational Rose for viewing.

5.3 Tool Design

In this section we give an introduction to the design issues of the FeatureUML tool.

5.3.1 Data Structure Analysis

The FeatureUML tool has to handle three different kinds of data, feature diagrams, configuration of the feature diagram, and UML models, and all these three kinds of data exist for the purpose of a product line. So we organize data in the program in a project. Project is the container for a product line software system, and a project contains the following elements:

- Feature model of a product line: each feature model contains multiple feature diagrams;
- UML model of a product line: each product line can contain multiple UML models;
- Specialization for a member of the product line.

Each specialization contains the following two types of data again:

- Configuration of the feature model for a member of the product line
- Processed UML model for a member of the product line

5.3.2 Use Cases

Based on the required functionalities and the data structure analysis from the tool, we have divided the use cases of the tool into the following four categories.

1. Project

    a. **New project** – to create a new project.
    b. **Load project** – to load an existing project.
    c. **Save project** – to save a project and all the contents in this project into files.

2. Feature Diagram

    a. **New feature diagram** – to create a new feature diagram
    b. **Remove feature diagram** – to remove an existing feature diagram
    c. **New Mandatory Feature** – to create a mandatory feature in a feature diagram
    d. **New Optional Feature** – to create an optional feature in a feature diagram
    e. **New Mandatory Alternative Feature** – to create a mandatory alternative feature in a feature diagram
    f. **New Optional Alternative Feature** – to create an optional alternative feature in a feature diagram
    g. **Remove feature** – to remove an existing feature from a feature diagram
    h. **Define dependency** – to define dependencies between the features in a feature diagram

3. Specialization

a. **New specialization** – to create a new specialization; each specialization represents a single member of the product line.
b. **Delete specialization** – to delete an existing specialization.
c. **New configuration** – to create a new configuration for a specialization. For each specialization multiple configurations can be created. Each configuration takes a feature diagram from the project as input, and users can perform configuration actions on the features from this feature diagram.
d. **Update configuration** – it is possible to update a configuration if the input feature diagram is changed for convenience. After updating, the configuration contains the same features again as in the input feature diagram.
e. **Delete configuration** – to delete a configuration from a specialization.

4. UML models

a. **Load UML model** – to load an existing UML model. The UML models are made in Rational Rose (version: 7.6.0109.2314; release version: 2002.05.00) and the file format of the UML models is XML file. For each project multiple UML models can be loaded.
b. **Delete UML model** – to delete a loaded UML model from the project.
c. **Process UML model** – this function can only be performed in a specialization after at least one feature diagram has been configured for this specialization. The process takes a configuration from the specialization and a UML model from the project as input, and process the UML model against the configuration. After processing the output UML model is part of the specialization where the configuration is taken from.
d. Reprocessing UML model –FeatureUML supports staged configuration. If a configuration is further configured, we can process the UML models which have been processed against this configuration again.

5.3.3 Architecture

FeatureUML uses a layered architecture which is shown in Figure 17. There are three layers in the architecture:

1. Data Layer
   This is the bottom layer of the architecture and it holds all the data in the program, such as features, feature diagrams, configuration, UML models, etc.
2. GUI Layer
   GUI layer contains two sub-layers. The bottom sub-layer holds all GUI data models which hold the data part for all the GUI components. The top sub-layer is the GUI representation which contains all the visual components from the program.
3. Top Layer
   The top layer is the container which holds all the GUI layer components together, and organizes all the GUI components to react on the user commands.

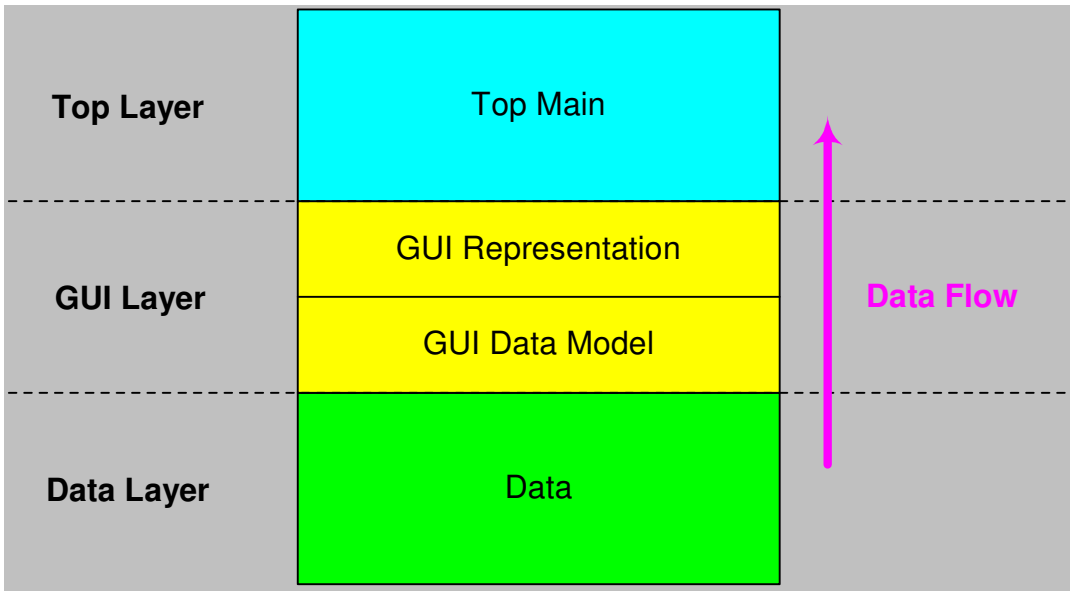


Figure 17: the layered architecture of FeatureUML.

The data flow in FeatureUML also follows the guideline from layered architecture, which is that data can only go upwards, but not downwards. So in this program data can only go from Data Layer to GUI Layer and to Top Layer, but not another way around.

5.3.4 Static Model – Packages and Classes

All the classes in FeatureUML tool are grouped into the following three packages by following the architectures, and the packages are shown in Figure 18.

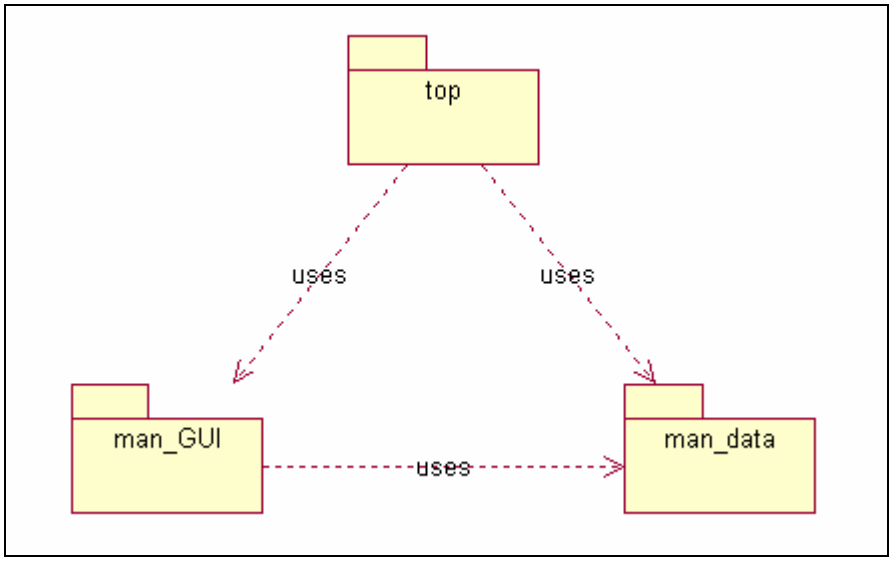


Figure 18: the packages in FeatureUML.

The details of each package are explained in the following a few sections.

5.3.4.1 Package man_data

This package contains classes for three different purposes:

1. Feature – there are a set of classes which hold information related to a feature;
2. UML Element - there are a set of classes which hold information related to a UML element from a UML model;
3. Container – there are a set of classes which act as data container, which means that an object instance from this type of class can multiple object instances from other type of classes.

5.3.4.1.1 Feature Data Class Hierarchy

The hierarchy of the feature data classes is shown in Figure 19.

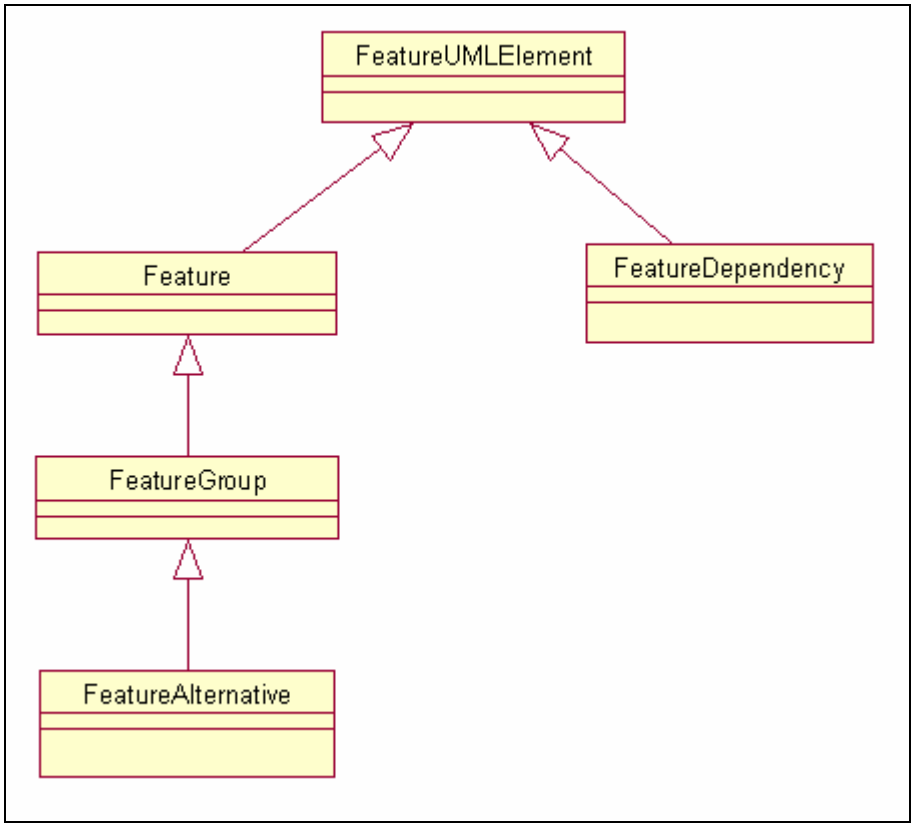


Figure 19: feature data class hierarchy in FeatureUML.

1. FeatureUMLElement

   This is the base class for both features and containers categories. This class holds three attributes:

   a. parent: type of FeatureUMLElement, to indicate the parent element of this element;

b. elementName: type of String, to indicate the name of this element;
c. changed: type of Boolean, to indication if this element's attributes have been changed.

This class contains operations related to retrieving and changing the values of each attribute, and the basic structure of saving functionalities is also built in this class.

2. Feature

This class extends FeatureUMLElement and it is the base class for all types of features. This class contains four attributes:

a. minCardinality – to indicate the minimum cardinality of this feature;
b. maxCardinality – to indicate the maximum cardinality of this feature;
c. configState – to indicate the configuration state of this feature. The configuration state can be one of the following three: selected, deselected, or undecided;
d. previousConfigState – to hold the previous config state. This field is used during the configuration process. When a use tries to select or unselect a feature from the feature diagram, the previous configuration state is held in this field. If the select or deselect action is not successful, then the configuration state of this element is set back to the previous configuration state.

This class contains operations related to retrieving and changing the values of each attribute, and it also contains special procedures for saving this feature into a XML file.

3. FeatureGroup

This class extends Feature and contains a child feature list. Each feature from feature diagram in FeatureUML is represented by an object of the class FeatureGroup. If a feature contains other features, then those features are held in the child feature list of this object as references. If a feature is a leaf feature, then the child feature list of this object is simply empty.

This class also holds the functionalities of manipulating a feature or the features in the child feature list.

4. FeatureAlternative

This class extends FeatureGroup and it is to represent an alternative feature. An alternative feature is a special type of feature-group as only one of the child features from this group can be selected for each member of the product line.

5. FeatureDependency

   This class is to describe the "exclude" or "required" relationship between two features.

5.3.4.2 UML Element Data Class Hierarchy

This set of classes is designed to hold the UML elements from a UML model. The hierarchy of this set of classes is shown in Figure 20 and the class composition relations are shown in Figure 21.

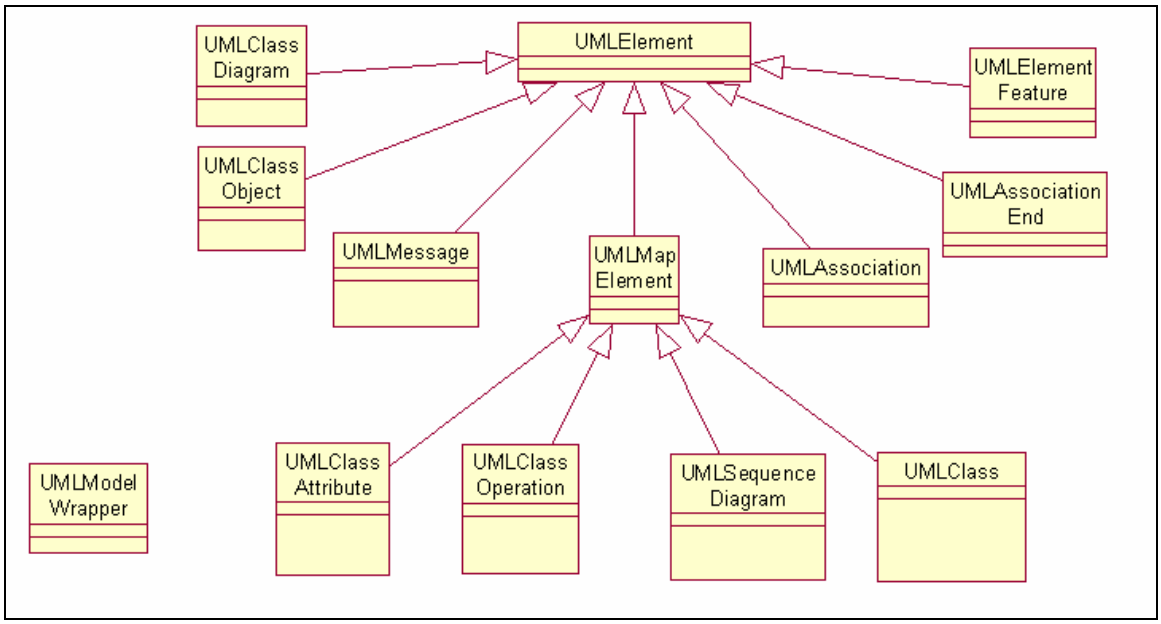


Figure 20: UML element data class hierarchy in FeatureUML.

1. UMLModelWrapper

   This is the top container which holds a list of class diagrams, a list of sequence diagram, and a list of feature mappings between the UML elements from this UML model and the features from the feature model. It also contains functionalities of loading and saving the UML models.

2. UMLElement

   This is the base class for all the UML elements. It contains the following attributes which are required for all of the UML elements:

   - xmiid: the XMI id from this UML element in the export XML file of the UML model;
   - name: the name of this UML element;
   - parent: the parent UMLElement of this UML element.

This class also contains operations related to retrieving the values of the attributes.

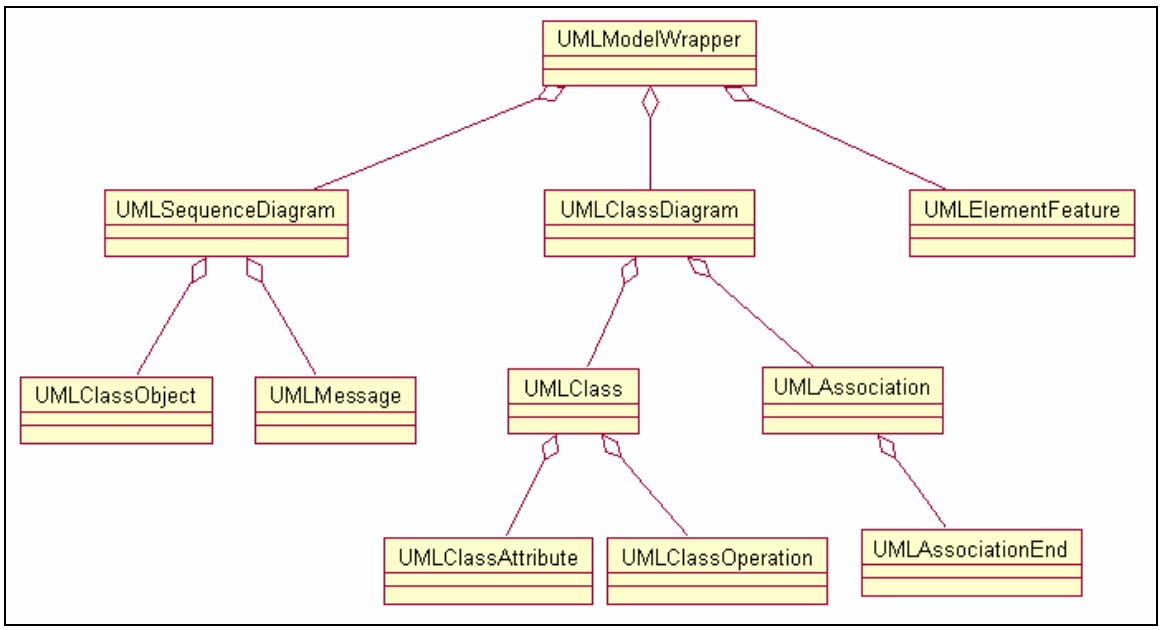


Figure 21: UML element data class composition relations in FeatureUML.

3. UMLClassDiagram

   This presents a class diagram in the UML model; it contains a list of UMLClasses, a list of UMLAssociations, and relevant functions.

4. UMLClassObject

   This class represents the objects in the sequence diagram which are derived from the classes in the class diagrams.

5. UMLAssociation

   This class represents the association relation between two classes in a UML model. Each UMLAssociation contains two UMLAssciationEnds.

6. UMLAssociationEnd

   This class represents a participant class in an UMLAssociation.

7. UMLMessage

   This class represents a message in a sequence diagram.

8. UMLMapElement

This class extends UMLElement and is the base class of all UML elements which can have a direct mapping with a feature. The mapped UML elements include UMLClassAttribute, UMLClassOperation, UMLClass, and UMLSequenceDiagram.

9. UMLClassAttribute

   This class extends UMLMapElement and represents an attribute in a class.

10. UMLClassOperation

    This class extends UMLMapElement and represents an operation in a class.

11. UMLSequenceDiagram

    This class extends UMLMapElement and represents a sequence diagram in a UML model. It contains of a list of UMLObjects, a list of UMLMessages, and relevant functions.

12. UMLClass

    This class extends UMLMapElement and represents a class in a class diagram from a UML model. It contains a list of UMLClassAttributes, a list of UMLClassOperations, and relevant functions.

13. UMLElementFeature

    This class doesn't represent a feature in the feature diagram. It is used to hold the feature marking information in a UML model.

5.3.4.2.1 Container Data Class Hierarchy

This set of classes act as containers in FeatureUML; they hold other data in the memory. The hierarchy of the structure is shown in Figure 22.

1. Project

   This is the top container which holds a list of FeatureDiagram instances, a list of Specialization instances, and a list of UML models.

2. FeatureDiagram

   This container holds all the features from this feature diagram.

3. Configuration

This container is specialized FeatureDiagram, which holds except the features from this feature diagram, but also the configuration information, such as if an optional feature is selected, unselected, or undecided yet.

4. Specialization

   This container holds a list of configurations and a list of processed UML models.

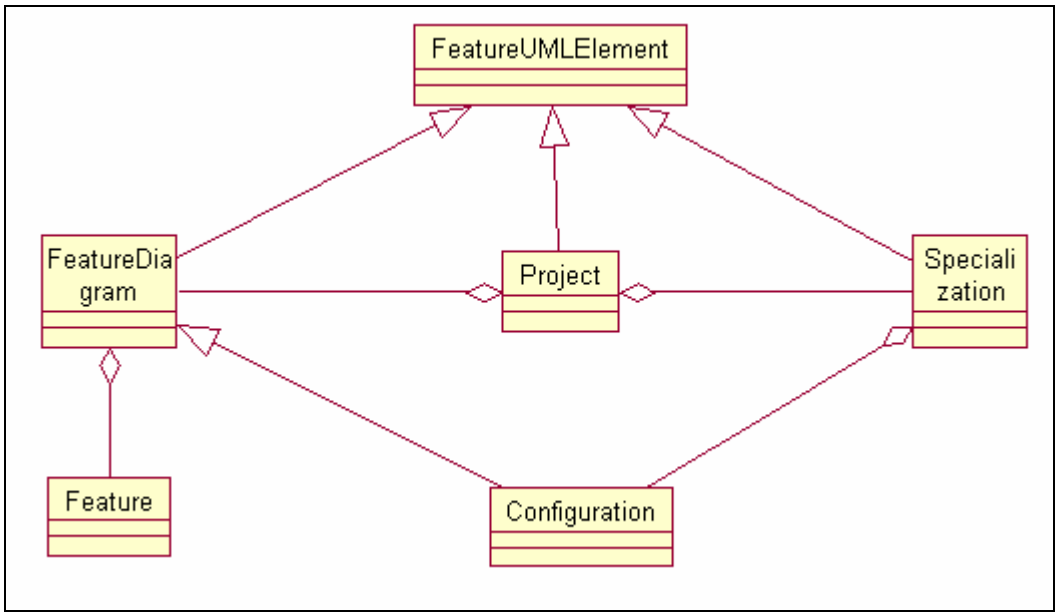


Figure 22: container data structure in FeatureUML.

5.3.4.3 Package man_GUI

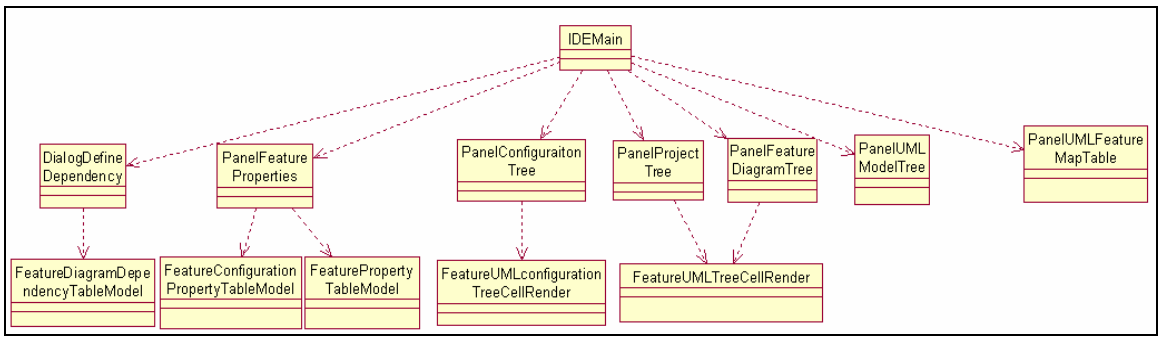


Figure 23: the GUI classes and dependencies in the FeatureUML.

The GUI classes are shown in Figure 23. This set of classes is divided into three levels:

1. Bottom Level – data models and visual component renders

   These classes are designed to hold the data for the middle level visual components or to hold the information how the visual components look like. There are five classes on this level which are:

a. FeatureDiagramDependencyTableModel
b. FeatureConfigurationPropertyTableModel
c. FeaturePropertyTableModel
d. FeatureUMLConfigurationTreeCellRender
e. FeatureUMLTreeCellRender

2. Middle Level – visual components

   These classes are the forms which users can see and interact with. These classes depend on the classes in the bottom level. There are seven classes in this level:

   a. DialogDefineDependency – to define the dependencies in a feature diagram;
   b. PanelFeatureProperty – to show the properties of a selected feature in a table;
   c. PanelConfigurationTree – to display a feature diagram tree with which users can perform configuration actions;
   d. PanelProjectTree – to display the project structure and the components in this project;
   e. PanelFeatureDiagramTree – to display a feature diagram tree;
   f. PanelUMLModelTree – to display an UML model in a tree structure;
   g. PanelUMLFeatureMapTable – to display the summary of feature-UML element mappings in a table.

3. Top Level – IDEMain

   This class holds all the visual classes in the middle level together.

5.3.4.4 Package Top

This package is the default package of the tool, and it only contains one class FeatureUML. When the tool starts, this class is loaded and run.

5.3.5 Dynamic Model – Sequence Diagrams

In this section we will show a few sequence diagrams which realize the major use cases described in section 5.3.2.

5.3.5.1 Load Project

The sequence diagram “Load Project” is shown in Figure 24. The steps involved in this sequence diagram to load a project are as following:

1. A user selects the menu item “Load Project” from the main form of the tool.
2. The main form opens a file selector to let the user to select a file from the hard disk.
3. After the use selects a project file, the tool starts to load the project XML file into memory.

4. An object of class Project is created to hold all the information from the project file.
5. The main form informs PanelProjectTree to display the loaded project in a tree structure.

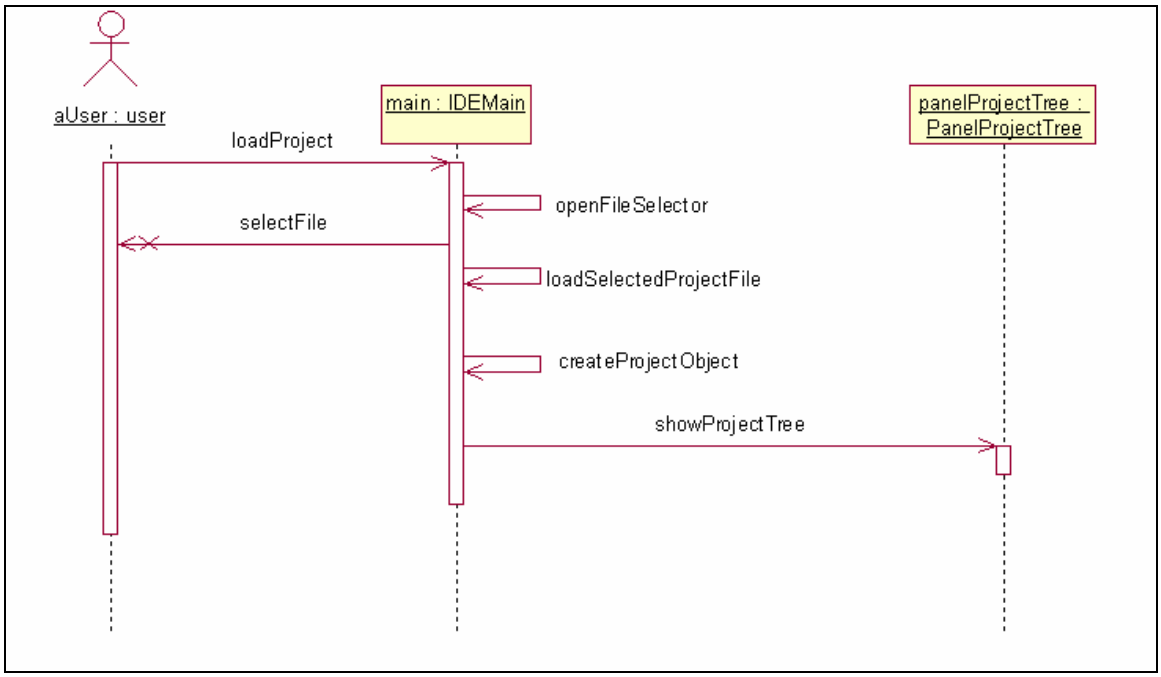


Figure 24: sequence diagram "Load Project" from FeatureUML tool.

5.3.5.2 New Mandatory Feature

The sequence diagram "New Mandatory Feature" is shown in Figure 25. The steps involved in this sequence diagram to create a new mandatory feature are as following:

1. A user selects the menu item "New Mandatory Feature" from the main form of the tool.
2. The main form checks with PanelFeatureDiagramTree if a feature in the feature diagram is selected as the parent of the new feature. If yes, continue.
3. The main form prompts the user to enter a name for the new feature.
4. The main checks if the new name is duplicated in the project. If no, continue.
5. The main form creates a new object of FeatureGroup, and sets the mandatory cardinality to this new object.
6. The main form informs the FeatureDiagram object to add this new feature.
7. The main form informs the PanelFeatureDiagramTree object to add this new feature.
8. The main form informs the PanelFeatureDiagramTree object to repaint.

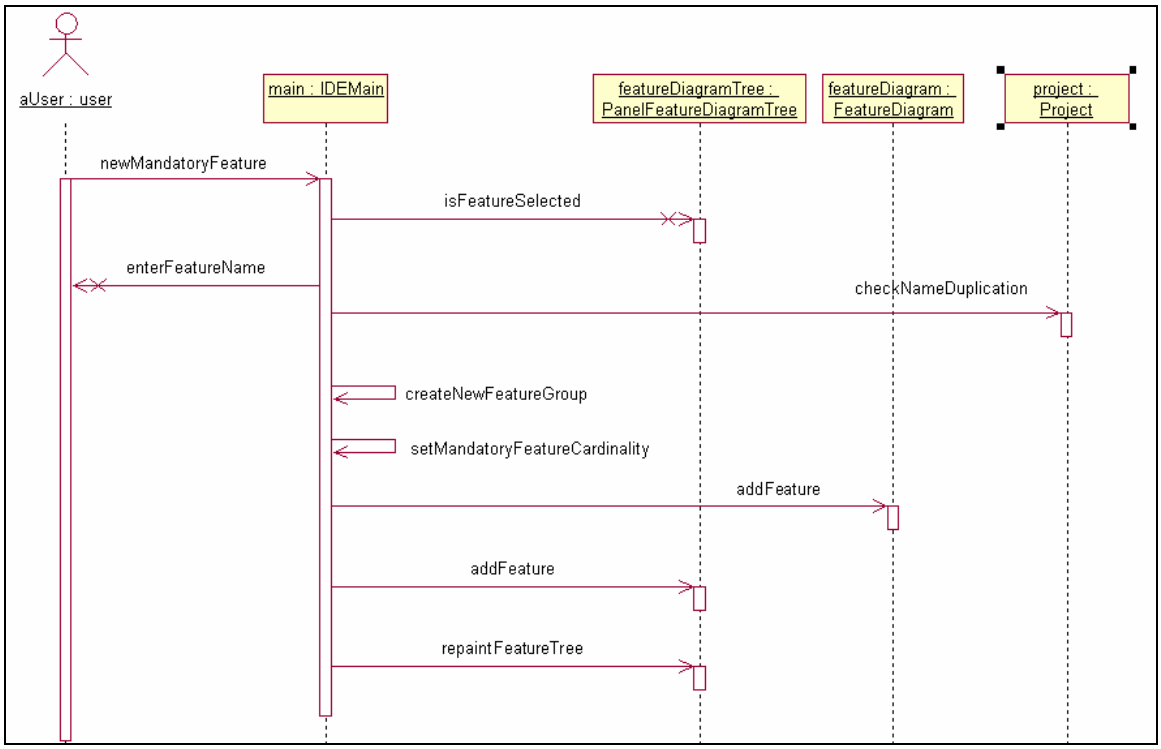


Figure 25: sequence diagram "New Mandatory Feature" in FeatureUML.

5.3.5.3 Configure Feature Diagram

The sequence diagram "Configure Feature Diagram" is shown in Figure 26. The steps involved in this sequence diagram to configure a feature diagram are as following:

1. A user set a feature on focus from the feature diagram shown in PanelConfigurationTree object.
2. The user gives command to set the configuration status of this feature to selected.
3. The PanelConfigurationTree object informs the Configuration object to select a feature.
4. The Configuration object makes a few checking and tries to select this feature (the detailed rules of this step are explained later).
5. After the feature is selected, the Configuration object informs the PanelConfigurationTree object to update the configuration tree.

There are some automated consistency mechanisms and checking which have been built into the configuration process.

When a feature is selected, the following process is carried out:

1. Check if there are any other features which have an exclude relation with this feature. If yes and one of those features is already selected, then this selection is rejected.
2. This feature is selected.

3. If this feature requires other features, we try to select those features as well. If the selection of other features is not successful, we roll back.
4. If the parent of this feature is not selected, we try to select the parent automatically. If the selection of the parent is not successful, we roll back.

When a feature is deselected, the following process is carried out:

1. Deselect this feature;
2. If there are other features which require this feature and they are also selected, then deselect those features as well.

This auto-selecting/deselecting helps the configuration go faster, and the checking guarantees that outcome from the configuration is correct.

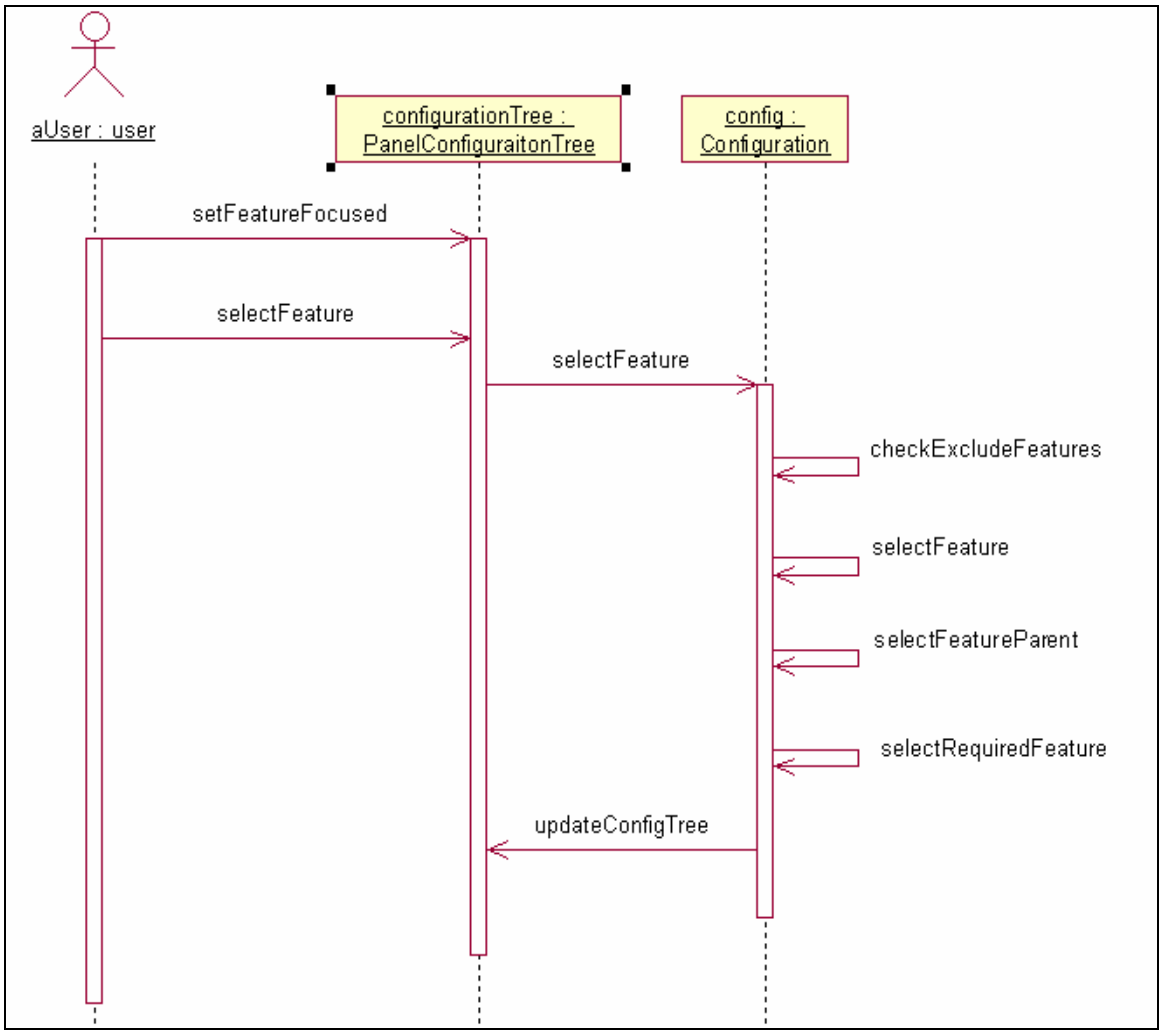


Figure 26: sequence diagram "Configure Feature Diagram" in FeatureUML.

5.3.5.4 Process UML Model

The sequence diagram "Process UML Model" is shown in Figure 2u. The steps involved in this sequence diagram to process a UML model for a member of the product line are as following:

1. A user selects the option "Process UML Model" from the main menu the main form.
2. The main form prompts the user to select a configuration.
3. The main form prompts the use to select a UML model for the product line.
4. The main informs the UMLModelWrapper object to process the selected UML model against the selected configuration.
5. The UMLModelWrapper makes a copy of the selected UML model.
6. The UMLModelWrapper processed the copy the selected UML model.
7. After the UML model is process, the UMLModelWrapper object sends the process UML model to the main form.
8. The main form informs the PanelUMLModelTree object to display the processed the UML model in a tree structure.

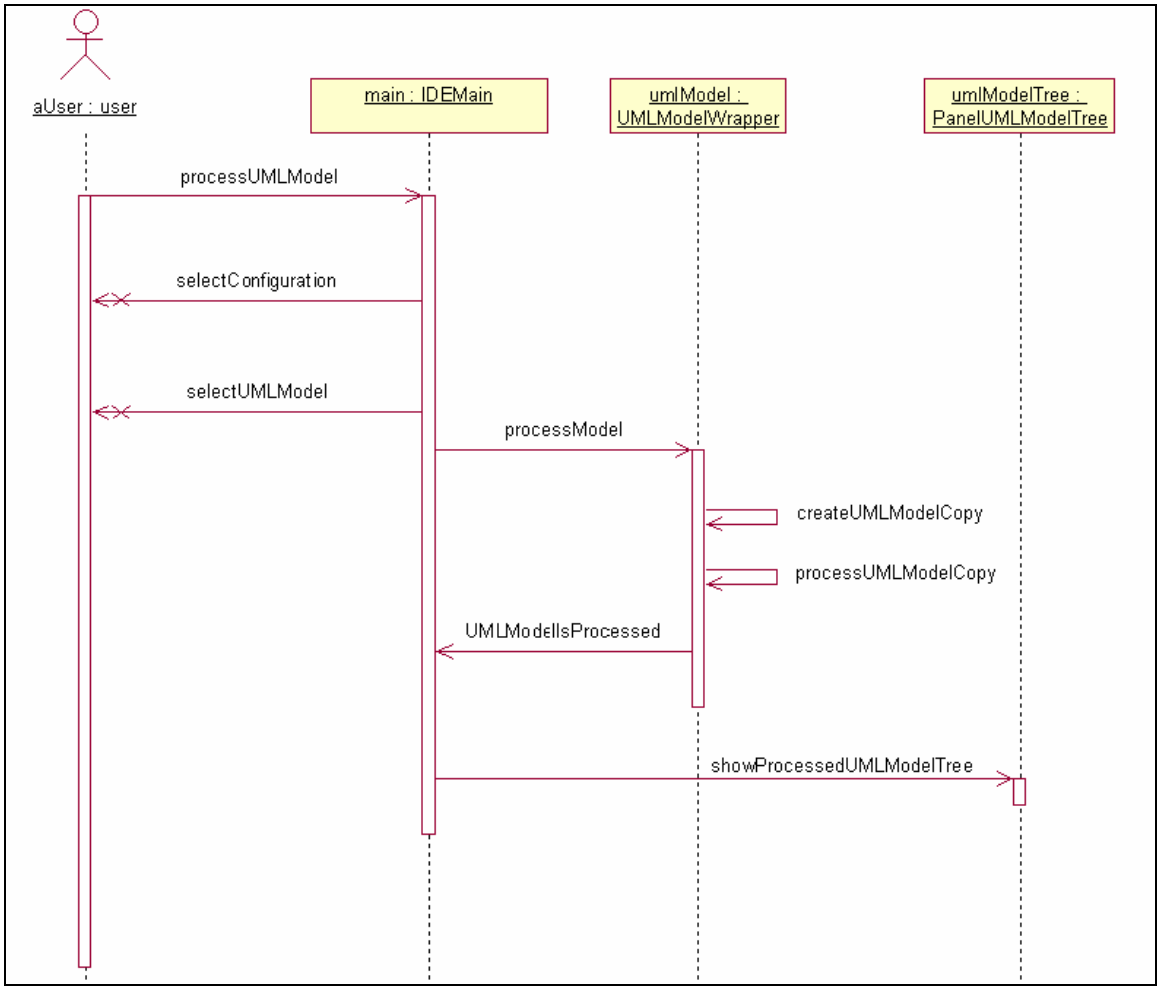


Figure 27: sequence diagram "Process UML model" in FeatureUML.

5.4 Tool Implementation

5.4.1 Source Code

The program is written in Java and can be run on the J2SE platform (Java 2 Standard Edition 6). Apart from the core API functions from the J2SE platform we have used the following external packages to implement this tool:

- xml-apis.jar
- xercesImpl.jar
- xercesSamples.jar
- javax.xml package from the J2EE (Java 2 Enterprise Edition 5) platform.

These packages are mainly used for loading UML models and saving the internal data structure into a file in XML format.

5.4.2 File Structure

The file structures from FeatureUML are exactly the same as shown in the main interface. Figure 28 shows an example of the file structure. The root directory is the project name, under project root there are three directories:

- Feature Diagrams
- Specializations
- UML models

The contents of each directory are the same as internal project structure. Only differences are:

- Project file – under project root a project file is made, and this file stores the locations of other content files of this project.
- Specialization file – under each specialization directory a specialization file is made, and this file stores the locations of all the configurations files and processed UML models from this specialization.

All the files saved in FeatureUML are in XML format. There are following file extensions which are created in FeatureUML:

- **F**eatureUML **P**roject **X**ML file (.fpx): project file extension
- **F**eatureUML Feature **D**iagram **X**ML file (.fdx): feature diagram file extension
- **F**eatureUML **S**pecialization **X**ML file(.fsx): specialization file extension
- **F**eatureUML **C**onfiguration **X**ML file (.fcx): configuration file extension

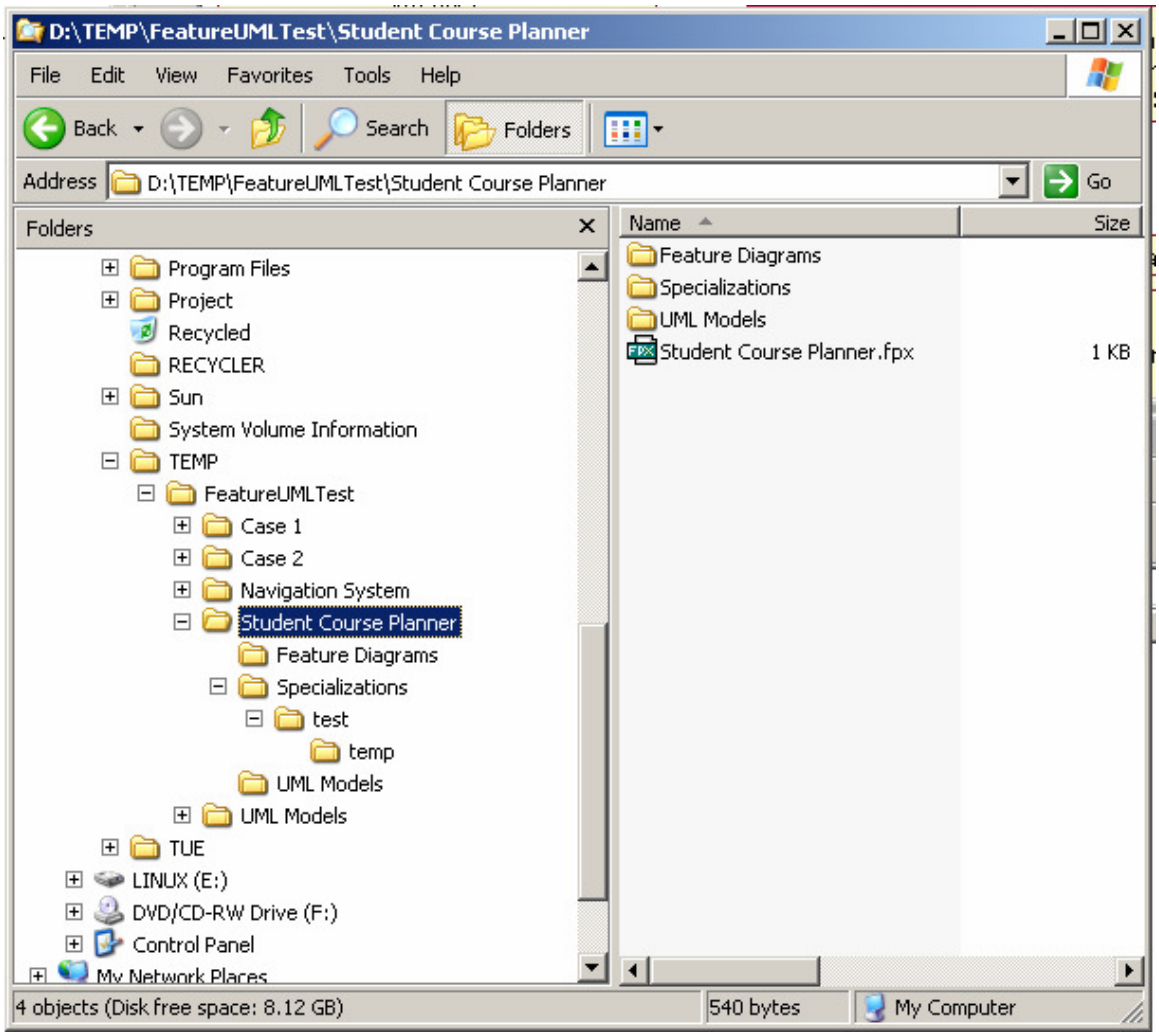


Figure 28: FeatureUML file structure.

6 Case Study – Navigation System

In this chapter we are going to show a case study of navigation system. We won't show the whole feature models and UML models of the navigation system, but only a portion of the system to demonstrate our ideas.

6.1 Variation Points of Navigation System

1. Map Media

   First we will show two variation points in a navigation system. Navigation systems can be used in different kind of hardware, such as mobile telephones, PDAs, or CD players. For each different type of hardware where a navigation system is run, it is very likely that we will use different map media to store the map information. For example, for CD players we will use CDs to store the map; for PDAs we will use flash cards to store the map. This is the first variation point in our navigation system and we call this variation point as "Map Media".

2. Voice Guide

   Very often a navigation system has a voice guide function, but this is not always necessary. For some cheap versions we can only show the route on a map without a voice guide. So with or without voice guide represents the second variation point in our navigation system and we call this variation point as "Voice Guide".

3. Route Selection

   These days a navigation system is not only used by car drivers, but also by the people who cycle or simply walk. The route that the navigation system calculates is definitely different for a car user or a bicycle user. Even for car user along there might also be different route types, such as with highway or without, with toll way or without, etc. All these different types of route for a different purpose present the third variation point in out navigation system and we call this variation point as "Route Selection".

4. Map Zoom

   When a map is viewed, the users might want to zoom in the map to see the details or they might want to zoom out to get an overall picture of the whole area. This zoom in and out function becomes our fourth variation point and we call this variation point "Map Zoom".

5. Multilingual

   To make software multilingual is very common these days; especially in Europe we also have the needs to make software multilingual. Thus we also add this variation point to our navigation system and we call this navigation point as "Multilingual".

6.2 Feature Diagram of Navigation System

The variation points described above are represented as optional features and alternative features in the feature diagram in Figure 29.

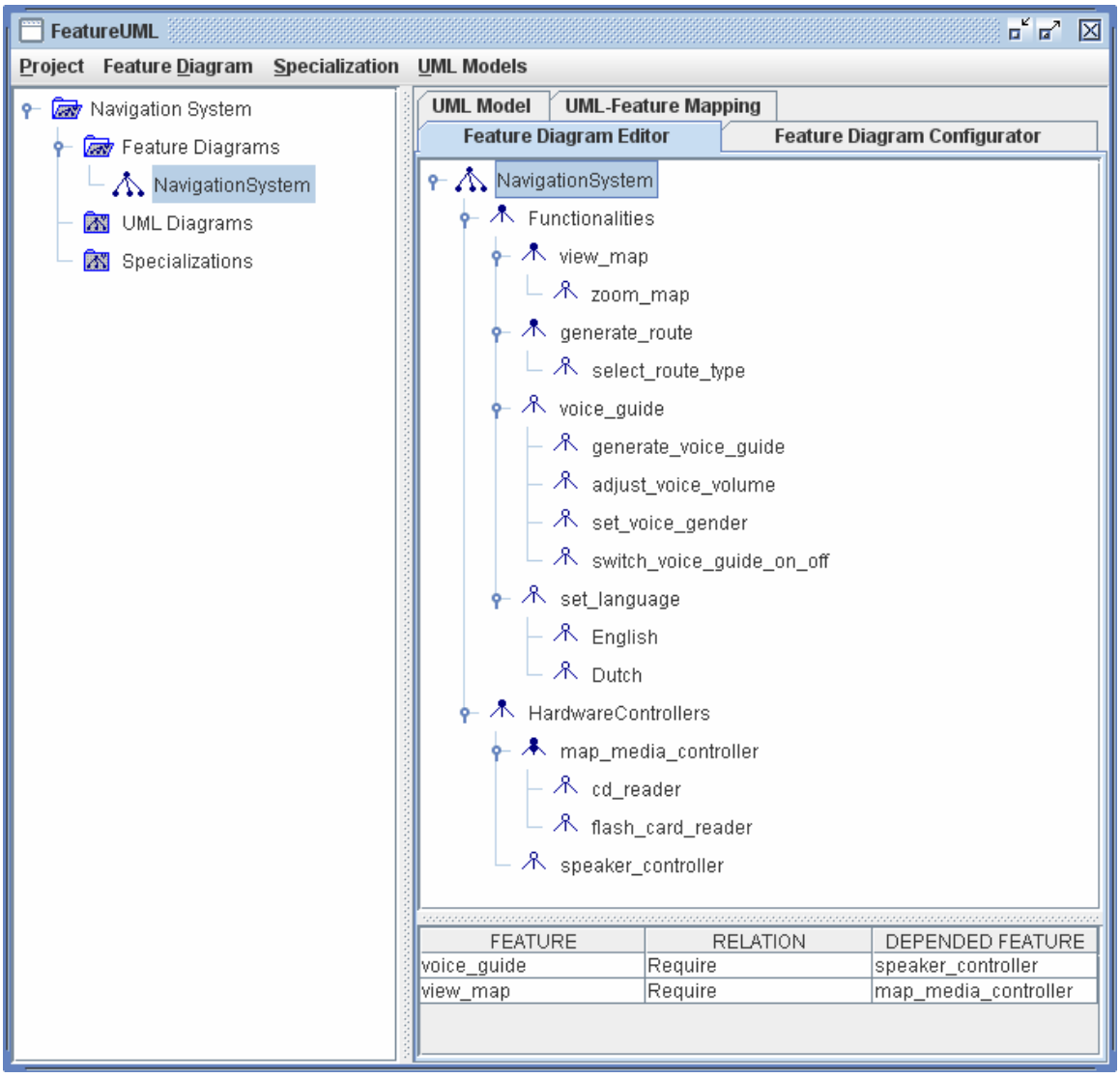


Figure 29: the feature diagram of the Navigation System.

1. Map Media

   In the feature diagram “NavigationSystem” there is a section “HardwareControllers” which contains the hardware controllers required for the system. In this section there is one mandatory alternative feature called “map_media_controller”; it has two optional features “cd_reader” and “flash_card_reader”. These features correspond to the “Map Media” variation point. When we use a CD player to run the navigation system, then the feature “cd_reader” should be selected. If the navigation system is run on a PDA, then the “flash_card_reader” feature should be selected.

2. Voice Guide

   In the section “Functionalities” there is an optional feature called “voice_guide” which corresponds to the variation point “Voice Guide”. When this optional feature is selected, then the final product should contain voice guide function. Logically the function “generate_voice_guide” will required speaker controllers, so we have also add an optional feature “speaker_controller” in section “HardwareControllers”. We also made a require relationship that “generate_voice_guide” requires the feature “speaker_controller”, and this is shown on the bottom part of the right hand side window in Figure 29. These two features together implement the variation point “Voice Guide”.

3. Route Selection

   In the section “Functionalities” an optional feature “select_route_type” is added under the mandatory feature “generate_route”. This feature means when a route is calculated, we have to take the route type that a use has selected into account.

4. Map Zoom

   In the section “Functionalities” an optional feature “zoom_map” is added under the mandatory feature “view_map”. This feature means when a map is viewed by a user, the system should allow the user to zoom in or out the map.

5. Multilingual

   In the section “Functionalities” there is an optional feature called “set_language”. We have only added two optional features under this alternative feature, which are “set_language_to_English” and “set_language_to_Dutch” respectively. This two language settings represent the multilingual environment in our navigation system.

6.3 UML Model of Navigation System

In the "Navigation System" UML model we have made one class diagram and two sequence diagrams.

6.3.1 Class Diagram

The class diagram is shown in Figure 30. There are eight classes which are defined in this class diagram. We will go through these classes to see how the features in the feature diagram described in section 6.2 are mapped into the UML elements.

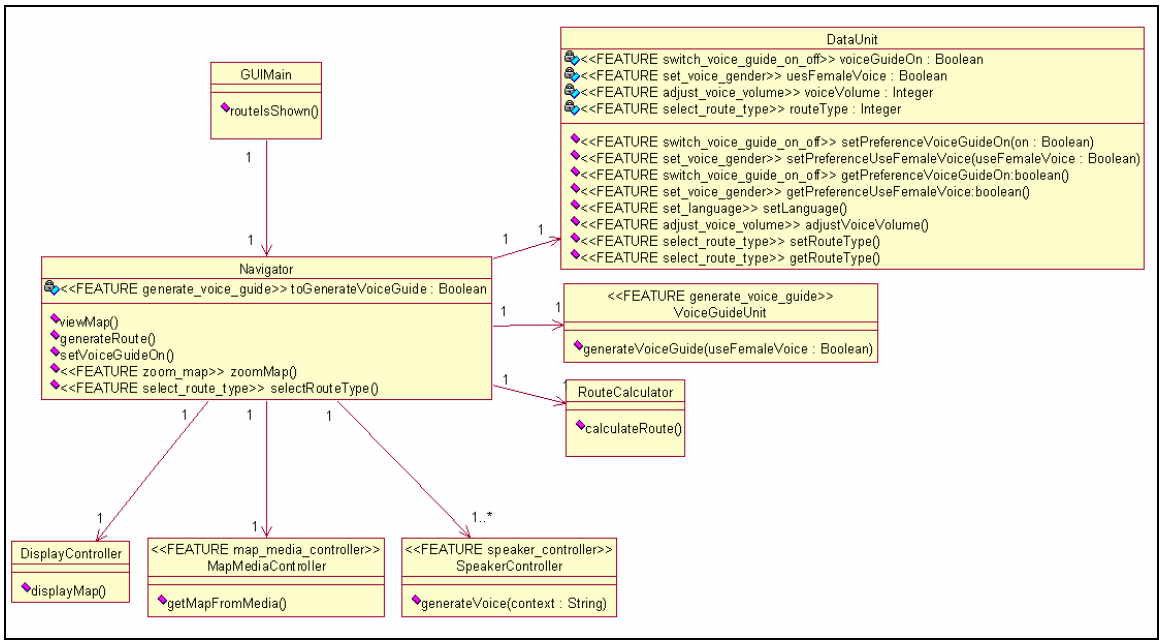


Figure 30: the class diagram of the Navigation System.

1. Navigator

   This class handles all the commands from user interface. It contains an attribute "toGenerateVoiceGuide". The attribute is marked with feature mapping annotation "<<FEATURE generate_voice_guide>>, which means the feature "generate_voice_guide" is mapped into this attribute. It also has an operation "viewMap" and this operation corresponds to the feature "view_map" in the feature diagram. As "view_map" is a mandatory feature, so the operation is not marked with feature mapping annotation. Another two operations from this class have mappings with the features from the feature diagram, which are "zoomMap" and "selectRouteType".

2. GUIMain

   This is where the users interact with the navigation system.

3. DataUnit

   This class is used to store all the preferences setting from a user. There are diverse attributes and operations which have mappings with the features “switch_voice_guide_on_off”, “set_voice_gender”, “adjust_voice_volume” and “select_route_type” in the feature diagram. These features are all related to “Voice Guide” variation point.

4. VoiceGuideUnit

   This class is to generate voice guide data and the feature “generate_voice_guide” is mapped into this class.

5. Route Calculator

   This class is responsible of calculating the route when a destination is chosen. During the calculation the selected route type has to be taken into considerations.

6. DisplayController

   This class controls the display unit from a navigation system.

7. MapMediaController

   The alternative feature “map_media_controller” is mapped into this class and this class has one operation “getMapFromMedia”. So no matter which of two options from alternative feature “map_media_controller” is selected, this class has to be able to load the map from the selected map media.

8. SpeakerController

   This class controls the speakers from the navigation system, and the feature “speaker_controller” is mapped into this class.

6.3.2 Sequence Diagram “Set Voice Guide”

This sequence diagram (Figure 31) is to set the voice guide on or off. The feature “generate_voice_guide” is mapped into the diagram itself.

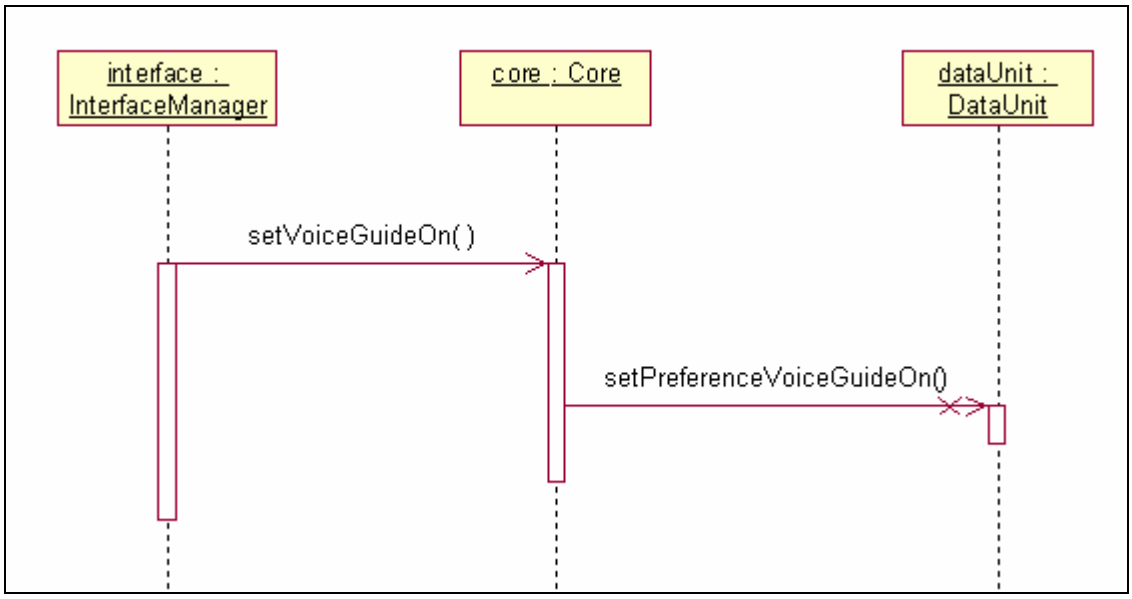


Figure 31: the sequence diagram "Set Voice Guide" from the Navigation System.

6.3.3 Sequence Diagram "View Map"

This sequence diagram (Figure 32) corresponds to the mandatory feature "view_map" in the feature diagram. In this sequence diagram there are two elements which have indirect mappings with the feature "map_media_controller"- namely class object "map" as the class "MapMediaController" has a mapping with the feature "map_media_controller" and the message "getMapFromMedia()" as the operation "getMapFromMedia()" from the class "MapMediaController" has a mapping with the feature "map_media_controller" indirectly.

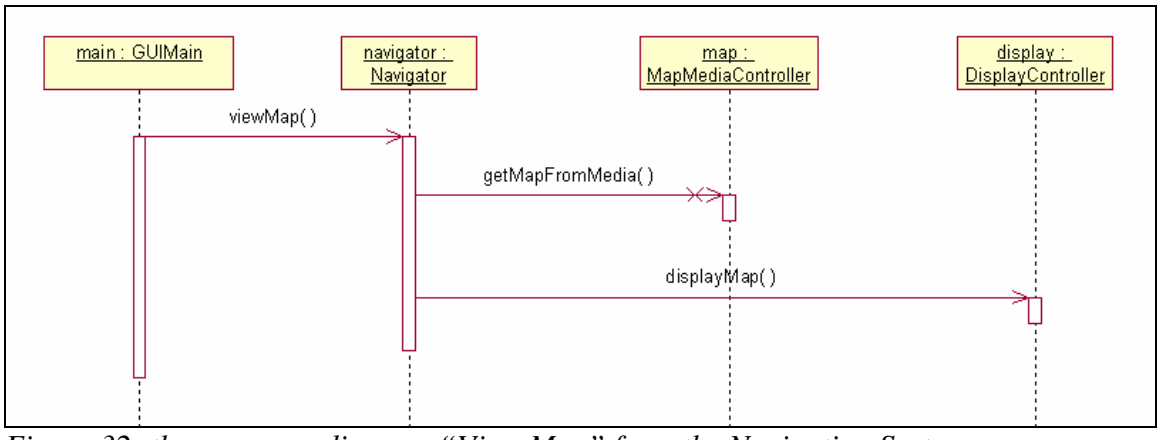


Figure 32: the sequence diagram "View Map" from the Navigation System.

6.3.4 Sequence Diagram "Generate Route"

This sequence diagram (Figure 33) corresponds to the feature "calculate_route" in the feature diagram.

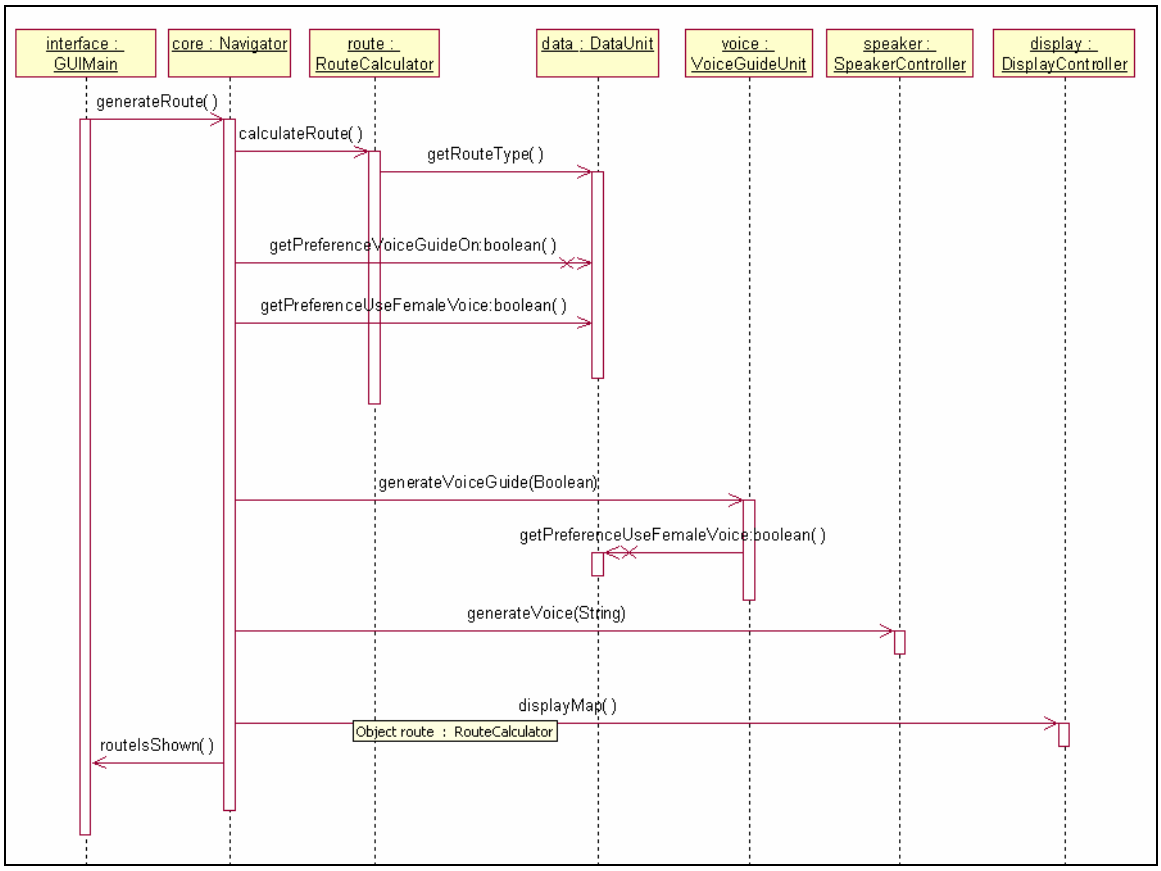


Figure 33: the sequence diagram "Generate Route" from the Navigation System.

In this sequence diagram the following elements have indirect mappings with the features in the feature diagram:

- Message "getRouteType" – as the operation "getRouteType" in the class "DataUnit" has a mapping with the feature "select_route_type";
- Message "getPreferenceVoiceGuideOn" – as the operation "getPreferenceVoiceGuideOn" in the class "DataUnit" has a mapping with the feature "generate_voice_guide";
- Message "getPreferenceUseFemaleVoice" – as the operation "getPreferenceUseFemaleVoice" in the class "DataUnit" has a mapping with the feature "generate_voice_guide"
- Message "generateVoiceGuide" and Object "voice" – as the class "VoiceGuideUnit" has a mapping with the feature "generate_voice_guide".
- Message "generateVoice" and Object "speaker" – as class "SpeakerController" has a mapping with the feature "generate_voice_guide".

6.3.5 Mapping List

The UML model of the Navigation System can be loaded into FeatureUML. In FeatureUML the UML model is shown as a tree (Figure 34) and all the UML elements that have mappings with a feature are marked red. All the directly mapping elements from this model are also summarized in a table (Figure 35).

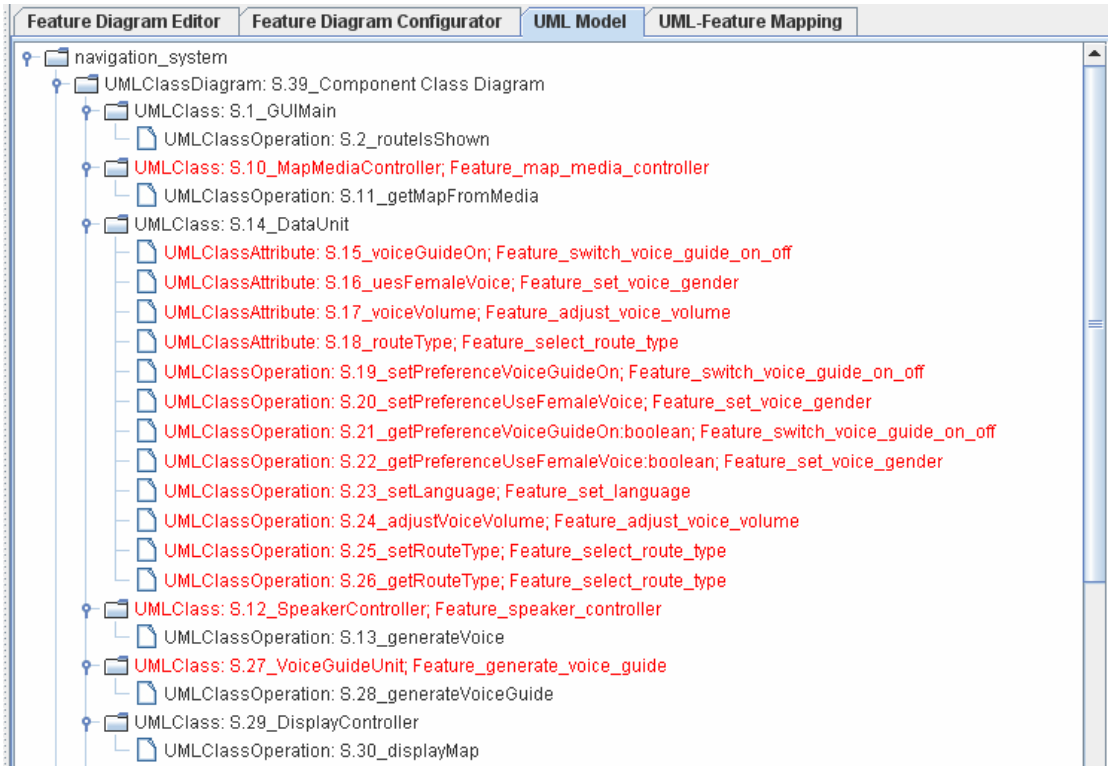
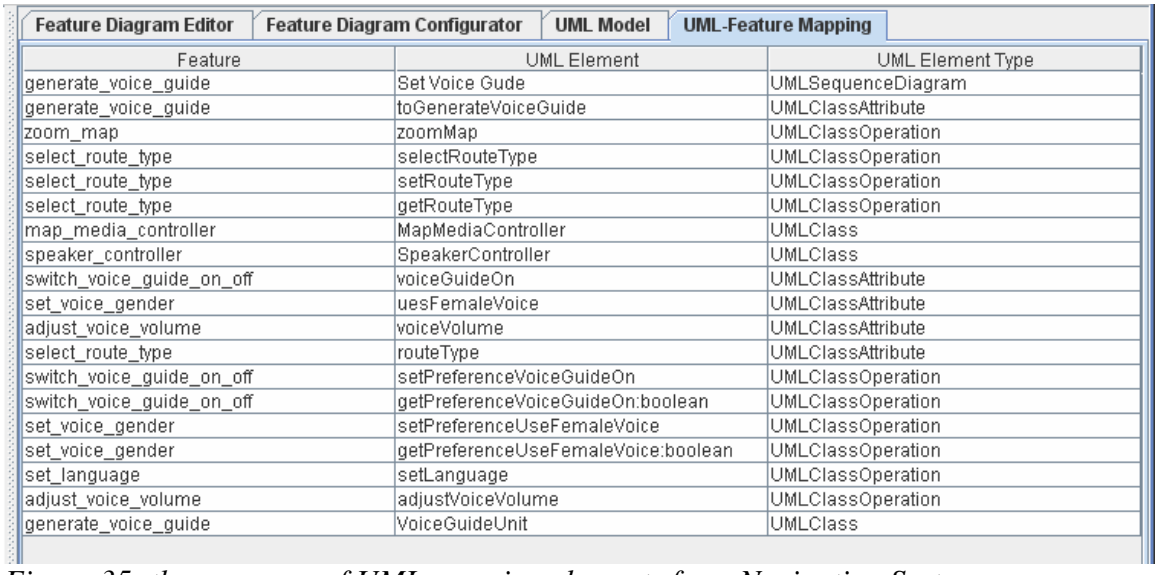


Figure 34: the UML model of navigation system is loaded into FeatureUML.



Feature	UML Element	UML Element Type
generate_voice_guide	Set Voice Gude	UMLSequenceDiagram
generate_voice_guide	toGenerateVoiceGuide	UMLClassAttribute
zoom_map	zoomMap	UMLClassOperation
select_route_type	selectRouteType	UMLClassOperation
select_route_type	setRouteType	UMLClassOperation
select_route_type	getRouteType	UMLClassOperation
map_media_controller	MapMediaController	UMLClass
speaker_controller	SpeakerController	UMLClass
switch_voice_guide_on_off	voiceGuideOn	UMLClassAttribute
set_voice_gender	uesFemaleVoice	UMLClassAttribute
adjust_voice_volume	voiceVolume	UMLClassAttribute
select_route_type	routeType	UMLClassAttribute
switch_voice_guide_on_off	setPreferenceVoiceGuideOn	UMLClassOperation
switch_voice_guide_on_off	getPreferenceVoiceGuideOn:boolean	UMLClassOperation
set_voice_gender	setPreferenceUseFemaleVoice	UMLClassOperation
set_voice_gender	getPreferenceUseFemaleVoice:boolean	UMLClassOperation
set_language	setLanguage	UMLClassOperation
adjust_voice_volume	adjustVoiceVolume	UMLClassOperation
generate_voice_guide	VoiceGuideUnit	UMLClass

Figure 35: the summary of UML mapping elements from Navigation System.

6.4 Configurations and UML Model Processing

In this section we will show two different configurations from the feature diagram for the Navigation System, and we will use each of these configurations to process the UML model and show the result of the processing.

6.4.1 Configuration 1

In this configuration we unselect the feature “zoom_map”, so the final product with this configuration doesn’t have zoom in or out function. We allow the user to select a route type, so the feature “select_route_type” is selected. We select the “generate_voice_guide” feature in this configuration, which means the final product of the Navigation System which complies with this configuration should have the “Voice Guide” function. But we haven’t selected all the optional features in “voice_guide”. For example the feature “adjust_voice_volume” and the feature “set_voice_gender” are left undecided, and these two features can be configured in a later stage. We deselect the feature “switch_voice_guide_on_off”, which means the voice guide will be always on. As “generate_voice_guide” requires feature “speaker_controller”, so “speaker_controller” is also automatically selected. In this configuration we don’t offer multilingual environment, so the feature “set_language” is deselected. For the map media we choose “cd_reader”. Figure 36 shows the configuration result.

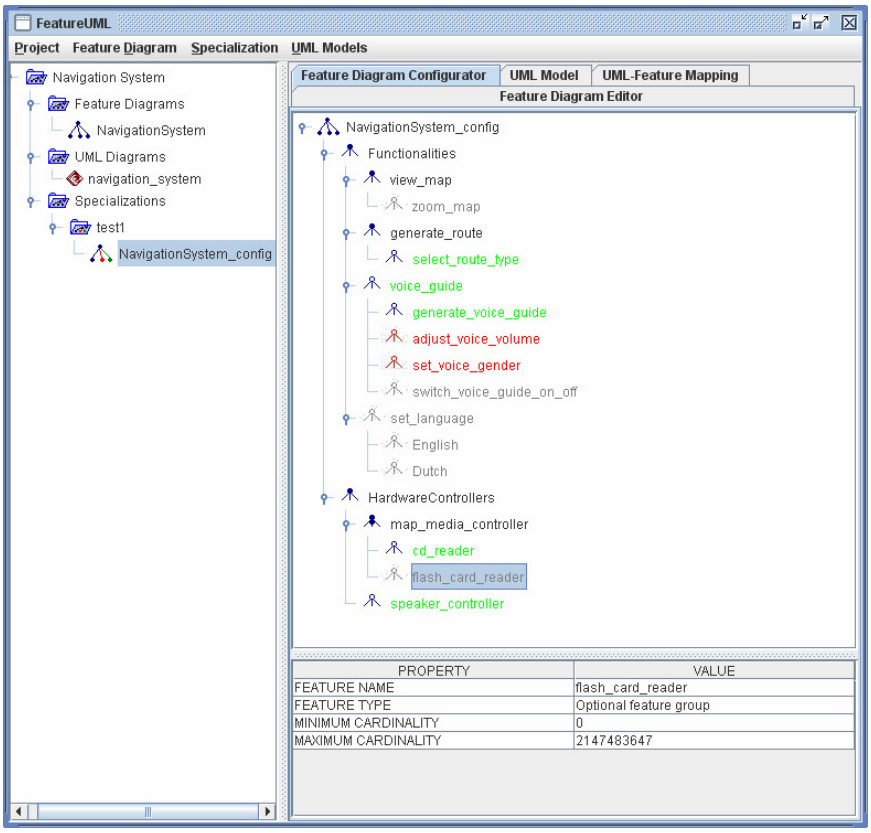


Figure 36: configuration 1 of the feature diagram in Navigation System.

Next we use this configuration to process the UML model of the Navigation System and the processed the UML model is imported into Rational Rose again. Figures 37 shows the UML model after processing.

There are two types of operations which have been performed on the original UML model:

1. UML element elimination: for all the UML elements which have direct mappings with the features “zoom_map”, “switch_voice_guide_on_off” and “set_language” are removed from the UML model.

2. Feature marking elimination: for all the UML elements which have direct mappings with the features “select_route_type”, “generate_voice_guide” and “speaker_controller”, the feature marking annotations are eliminated from those UML elements. In the class diagram (Figure 29) we don’t see any feature marking annotations for these features anymore.

3. UML element substitution: for the UML elements which have direct mappings with the alternative feature “map_media_controller”, the name of the UML element is replaced with “cd_reader”. In this case only the original class “MapMediaController” name is changed into “cd_reader”.

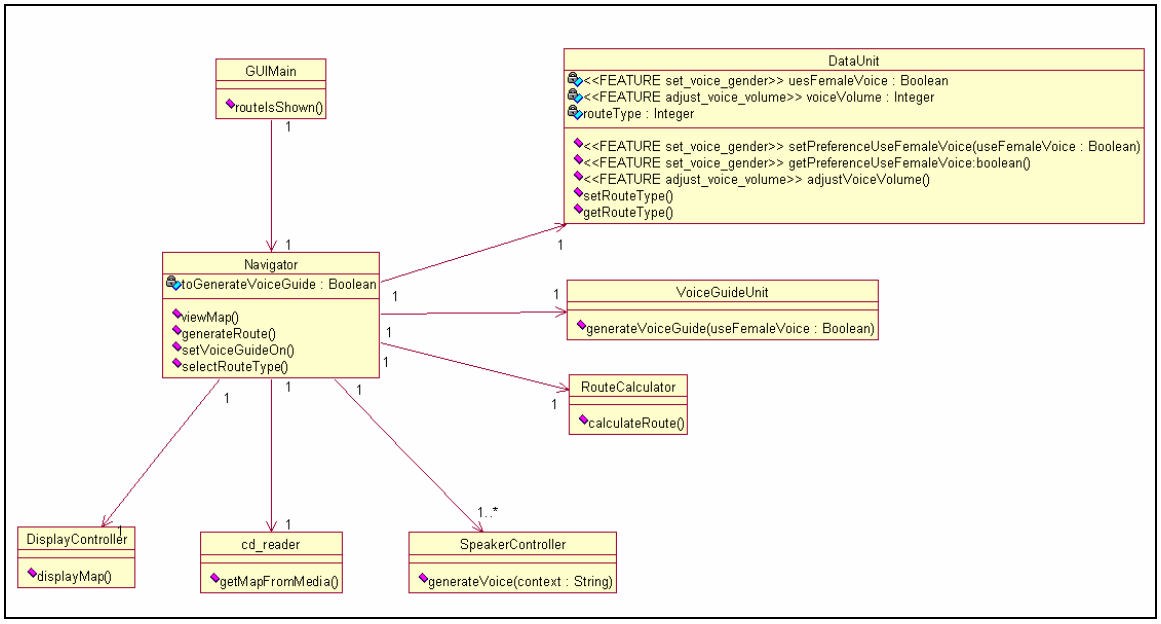


Figure 37: the output class diagram after processing using configuration 1.

From Figure 37 we also notice that some of the attributes and operations in the class “DataUnit” still have the feature marking annotations. This is because two features “set_voice_gender” and “adjust_voice_volume” in the feature diagram are not configured at this stage, so the UML elements which have mappings to these two features are not processed.

6.4.2 Configuration 2

In this configuration we have selected all the optional features except the feature "voice_guide". As the feature "voice_guide" is deselected, so all the child features from this feature are also deselected. The "speaker_controller" feature can be selected or deselected, and we have chosen to deselect it. For the map media we have chosen "flash_card_reader". Figure 38 shows the configuration result.

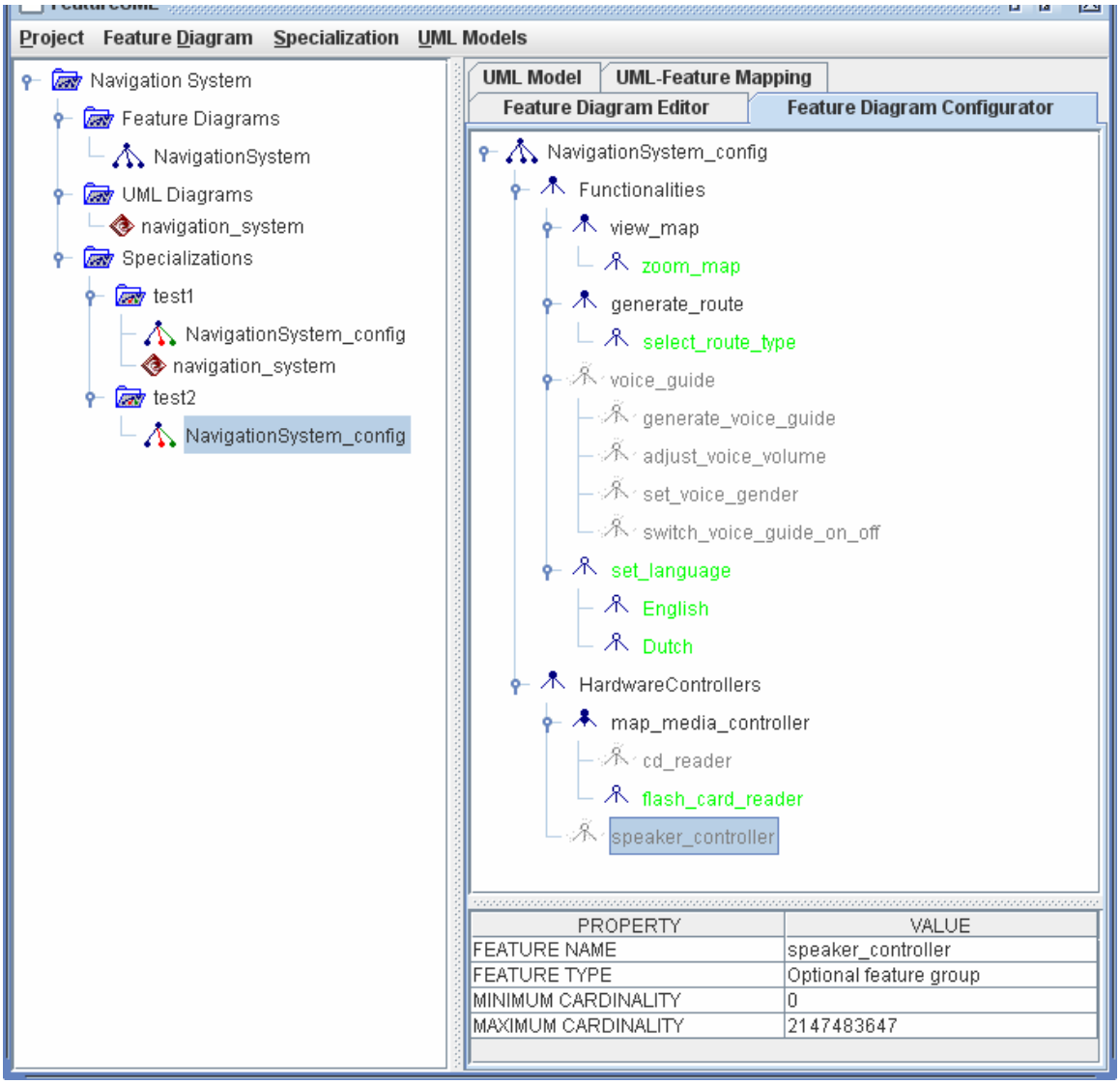


Figure 38: configuration 2 of the feature diagram in the Navigation System.

Next we use this configuration to process the UML model of the Navigation System and the processed the UML model is imported into Rational Rose again. Figures 39-1, 39-2, and 39-3 shows the UML model after processing.

There are two types of operations which have been performed on the original UML model:

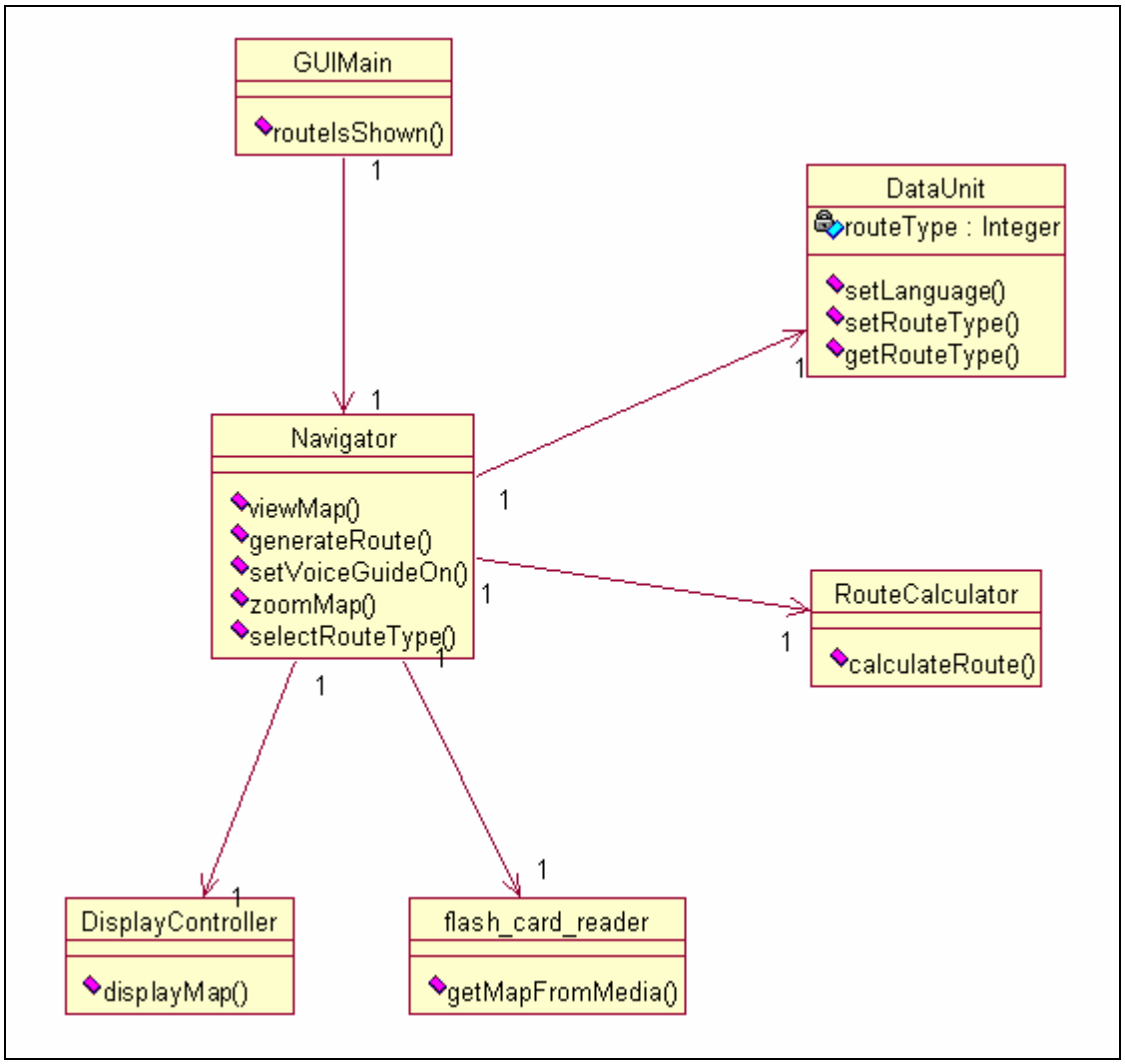


Figure 39_1: the output class diagram of the UML model after the UML model processing using configuration 2.

1. UML element elimination: for this operation there are two types of mapping elements which are affected – namely directly mapping elements and indirectly mapping elements.

    a. Directly mapping elements: all the UML elements which have direct mappings with the features "generate_voice_guide" (including the child features of this feature) and "speaker_controller" are simply eliminated from the original UML model. In the class diagram (Figure 39-1) all the original classes, attributes, and operations which have mapping with these two features are eliminated from the diagram.

    b. Indirectly mapping elements: Figure 39-2 shows a comparison of sequence diagram "Generate Route" before and after the processing. From this comparison we can see that all those elements (objects and messages)

which have indirect mappings with the features “generate_voice_guide” and “speaker_controller” are also eliminated.

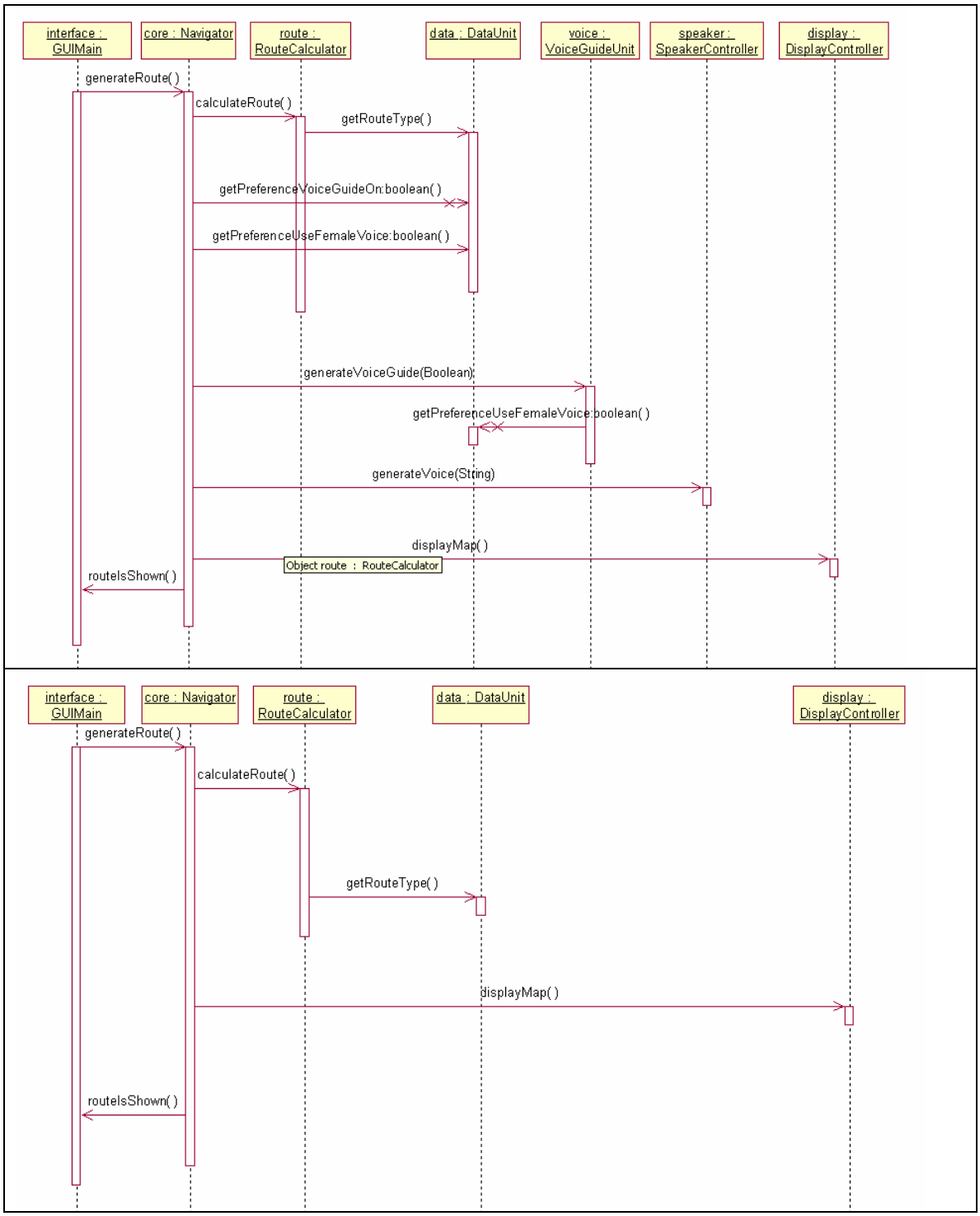


Figure 39_2: the comparison of sequence diagram “Generate Route” before and after processing using configuration 2.

2. UML element substitution: for the UML elements which have direct mappings with the alternative feature “map_media_controller”, the name of the UML element is replaced with “flash_card_reader”. In this case the original class “MapMediaController” name is changed into “flash_card_reader” (Figure 39_1). Indirecty UML mapping element object “map: MapMediaController” in sequence diagram “View Map” (Figure 39-3) is also changed into “map: flash_card_reader”.

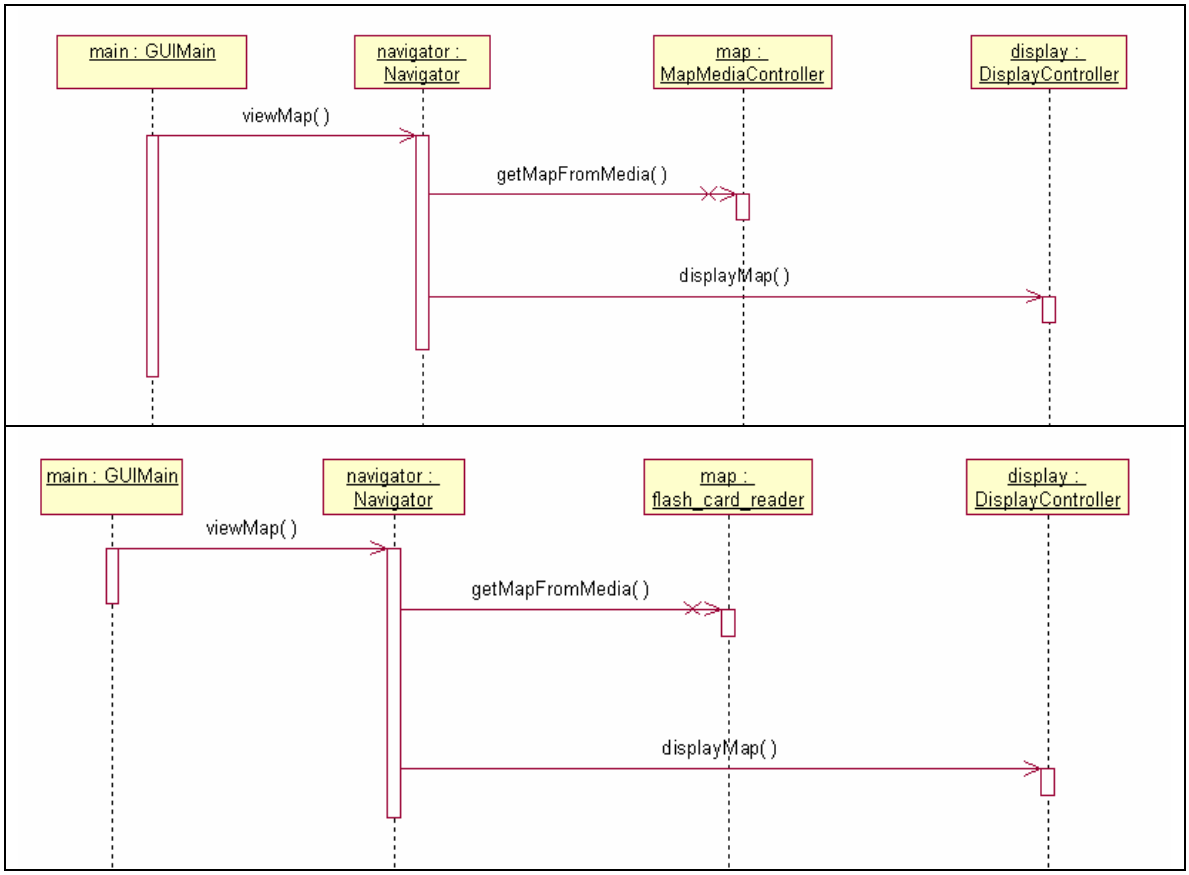


Figure 39_3: the comparison of sequence diagram “View Map” before and after processing using configuration 2.

7 Conclusion

The concept of product line software system development has been around for a few years. Until now there are still no right methods which support this development process. The method PLUS supports part of the processing by using feature concepts. In PLUS the feature model is represented in UML elements; thus the feature model is simply mixed into the UML model of the system design. This approach has increased the complexity of the UML model greatly. As modern software development pursuits concern separation, it would be better to separate feature models from UML models and then make some kind of connection between these models. This is our initial idea for our method FeatureUML.

Feature diagrams have been the widely accepted candidate to hold features in a feature model, so we have deployed the feature diagram to hold the features in our feature model. We have extended the feature ideas with dependency relationships between features and feature cardinalities. All these techniques help to hold the commonalities and variations of a product line. The feature diagram can also be configured for a special member of the product line in stages.

But a feature model will be only a set of symbols if they are no any connections between the feature model and UML models, and the existence of the feature model has also no meaning anymore. In order to setup a connection between the feature model and UML model, we have used the stereo tags in the UML model to make a mapping annotation between a feature and a UML element. With this mapping information, we can process a UML model for a special member of the product line. The processing takes a configuration as input, and checks on the status of each feature in the configuration. Depending on whether a feature is selected or deselected; we eliminate or substitute the UML elements which have mapping with this feature. At the end we derive a UML model which only contains the functionalities which are required for this member of the product line. The newly derived UML model can be further used for communication between different stake-holders, code modifications and generations, etc.

Following this idea we have built our first prototype to support this process. The prototype program can create and hold feature models of a product line, make configurations for a special member of the product line, load and process UML models. After experiments with a few examples, we have successfully generated specialized UML models for single members of the product line. This initial case study has shown us that this method can reduce the effort and time which is spent on creating individual systems. The quality of the generated UML models for single member of the product line is also improved, as with generation techniques we rarely make mistakes by removing the UML elements from the original UML models.

The current state of FeatureUML only supports part of the product line development process, namely the requirements gathering, system analysis and design. It would be interesting to extend the method to support the code generation as well, and then FeatureUML would support the whole product line development process automatically.

8 Future Works

There are quite some future works which can be done to the FeatureUML method; here I will list the future work items.

8.1 Feature Diagram

1. **Two dimensional alternative feature**: the current implementation support one dimensional alternative features, which means an alternative feature in our program cannot contain another alternative feature immediately. But in real situations it is possible to have two dimensional alternative features, which means under an alternative feature there is immediately anther alternative feature. This can be built in the FeatureUML in the feature. But extra care has to be taken in configuration and processing UML models as two dimensional alternative features do make the feature diagram more complex.
2. **Feature Dependency**: in the current prototype it is possible to have a compound "and" required (or exclude) relation, which mean A requires (or excludes) B and C. But it is not possible to have a compound "or" require (or exclude) relation, for example A requires (or excludes) B or C.
3. **Feature diagram correctness checking**: when the dependencies relations in a feature model get more complex, the correctness of the feature model is also difficult to be guaranteed. It is hard to know if feature diagram contains at least one combination of selecting/deselecting feature choice so we can make a valid configuration out of it. So we have to think of a way to check if a feature diagram contains the right dependencies such that we can make a configuration out of it.

8.2 Feature-UML Element Mapping/Processing

1. **Map into more diagrams**: the current tool can only map features into class diagrams and sequence diagrams. It would be nice to map features to other types of UML diagrams as well.
2. **Map cardinality to UML model**: even though the concept of feature cardinality is built in the current prototype, it is not mapped into the UML model and it is also not used in the UML model processing.
3. **Map feature to operation input/output**: during the experiment with our tool, we have found out it would be useful to map features to the operation input and output parameters as well. Very often an input parameter has to be one option from an alternative feature.
4. **Improve mapping quality**: the current mapping is done by hand. Thus when the UML model is made, whenever an UML element is supposed to map into a feature, the author has to add this feature mapping annotation to the UML element. The process is error-prone, especially when we have a big feature model and a

few big UML models in the product line. This process can be proved by using some automatically mechanisms, such as when a UML element is created and needs a mapping, it should be able to select an existing feature to map to. This may require the tool eventually to create UML diagrams as well.

8.3 Product Line Software System Process

The current method only supports part of the process; it would be nice to extend the method to support domain implementation and application code generation as well. This would require further research on both the method and the tool.

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