A Framework for Projectional Multi-variant Model Editors

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Abstract: Model-driven software product line engineering (MDSPLE) combines the productivity gains achieved by model-driven software engineering and software product line engineering. In MDSPLE, multi-variant models are created in domain engineering which are configured into single-variant models that are adapted further (if required) in application engineering. Since multi-variant models are inherently complex, tools are urgently needed which provide specific support for editing multi-variant models. In this paper, we present a framework for projectional multi-variant editors which do not hide complexity but make it manageable by a user-friendly representation. At all times, a domain engineer is aware of editing a multi-variant model which is necessary to assess the impact of changes on all model variants. Projectional multi-variant editors provide a novel approach to representing variability information which is displayed non-intrusively and supports a clear separation of the product space (the domain model) from the variant space (variability annotations). Furthermore, the domain engineer may employ a projectional multi-variant editor to adapt the representation of the multi-variant domain model in a flexible way, according to the current focus of interest.

1 INTRODUCTION

After having explained the context of our research (Section 1.1), we summarize the contribution of this paper (Section 1.2). Finally, we provide an overview of the rest of this paper (Section 1.3).

1.1 Context

In *model-driven software engineering* (MDSE) (Völter et al., 2006), software systems are developed by creating high-level models which are analyzed, simulated, executed, or transformed into code. In this context, *models* are structured artifacts which are instantiated from metamodels. A *metamodel* defines the types of elements from which models are composed and the rules for their composition. For metamodels, the Object Management Group (OMG) has defined the *MOF* standard (*Meta Object Facility*), a subset of which is implemented as *Ecore* in the *Eclipse Modeling Framework* (*EMF*) (Steinberg et al., 2009).

Models may be represented in a variety of different ways, including diagrams, trees, tables, or human-readable text. Different kinds of editors may be employed to create and modify models. In the case of a textual representation, a *syntax-based editor* may be used which persists the text and derives the underlying model by an incremental parsing process. In the EMF ecosystem, the Xtext[1] framework is frequently used to generate syntax-based editors from language descriptions.

In contrast, *projectional editors* provide for commands operating directly on the model and project the model onto a suitable representation (Völter et al., 2014). A projectional editor may ensure syntactic correctness of models and enjoys further advantages concerning tool integration. In particular, since models are stored as instances of metamodels, unique identifiers may be assigned to model elements such that they may be referenced in a reliable way.

Software product line engineering (SPLE) (Pohl et al., 2005) is a discipline which is concerned with the systematic development of families of software systems from reusable assets. To this end, common and discriminating features of family members are captured in a variability model, e.g., a *feature model* (Kang et al., 1990). In *domain engineering*, a variability model is developed along with a set of reusable assets. In *application engineering*, product variants are developed from reusable assets.

Product variants may be constructed in different

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[1] https://www.eclipse.org/Xtext

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ways. In case of *positive variability*, they are composed from reusable modules. In case of *transformational variability*, product variants are constructed by applying a sequence of transformations. In case of *negative variability*, *multi-variant artifacts* are represented as superimpositions of annotated elements. An *annotation* constitutes a presence condition over features. A product variant is defined by a *feature configuration*, stating which features have to be included and excluded, respectively. To construct a *single-variant artifact*, all elements are removed from a multi-variant artifact whose annotations evaluate to false.

Model-driven software product line engineering (MDSPLE) combines MDSE with SPLE. Thus, SPLE is applied to models. While most SPLE approaches focus on source code rather than models, a number of MDSPLE tools have been developed, e.g., FeatureMapper (Heidenreich et al., 2008), FAMILE (Buchmann and Schwägerl, 2012), and SuperMod (Schwägerl and Westfechtel, 2019) all of which are based on EMF.

1.2 Contribution

This paper presents a *framework* for generating *projectional multi-variant model editors*. This framework is based on our previous work on projectional single-variant editors for models in the technological space of EMF. As described in (Schröpfer et al., 2020), a projectional editor may be generated from a metamodel for domain models (an Ecore model defining classes, attributes, and references) and a syntax definition which maps model elements to a human-readable textual representation. In the work presented in this paper, we have extended the framework for single-variant model editors into a framework for building multi-variant editors. This extension is generic, i.e., it depends neither on the underlying metamodel nor on the syntax definition. Thus, no additional development effort is required to turn a single-variant editor into a multi-variant editor.

A projectional multi-variant editor which has been built with the help of our framework is characterized by the following properties:

1. So far, our projectional editors support *human-readable text* as the external representation of EMF models. In MDSE, human-readable text is becoming increasingly popular which is substantiated, e.g., by the definition of UML-based textual languages such as the Action Language for Foundational UML (ALF) (OMG, 2017). The editor's design is extensible; further representations such as diagrams may be added in the future.
2. Projectional multi-variant editors are based on *negative variability* (probably the main-stream SPLE approach). Thus, engineers do not have to learn new languages. Rather, domain models are augmented with *annotations*.
3. For modeling variability, *feature models* (the most widespread notation in SPLE) are used. All annotations refer to features and attributes from a feature model for the software product line.
4. Projectional multi-variant editors are designed to support *domain engineering*. Since multi-variant models are the artifacts of domain engineering, a projectional multi-variant editor *directly operates* on a *multi-variant model*. Thus, all variants may be considered by the domain engineer during editing. Furthermore, each command has a uniquely determined semantics. These properties distinguish our approach from variation control systems which are faced with view-update problems and limited awareness in filtered views.
5. Internally, annotations of model elements are stored in a separate *mapping model*. Thus, existing domain metamodels may be reused. Furthermore, the relationships between features in the feature model and elements of domain models are captured in one single central data structure. This approach facilitates traceability and propagation of changes from the feature model to annotated domain models.
6. The mapping model is shielded from the user. Rather, annotations are displayed intuitively along with the model elements in a *single representation*. Therefore, the user does not have to deal with the internal concepts and structure of the mapping model. In contrast to approaches based on preprocessor directives, annotations are *separated clearly* from domain model elements in the representation of a multi-variant model.
7. Projectional multi-variant editors include commands for *projectional editing* of *annotations*. Thus, annotations are handled as structured objects rather than as text strings. Context-free correctness of annotations is guaranteed by the projectional editor.
8. To cope with complexity, projectional multi-variant editors provide several commands for *adapting the representation* of an annotated model to the current *focus of interest*. For example, annotations may be hidden completely or selectively. In this way, the representation of the model may be simplified. It should be noted, however, that all editing commands still refer to the underlying multi-variant model.

1.3 Overview

The rest of this paper is structured as follows: Section 2 explains the background of our research and related work. Section 3 describes the functionality and the user interface of projectional multi-variant editors. Section 4 outlines the model-based internal architecture underlying these editors. Section 5 details a specific aspect of the realization: the mapping between domain models and feature models. Finally, Section 6 concludes the paper.

2 BACKGROUND AND RELATED WORK

As stated above, software product line engineering fosters organized reuse to create a set of software artifacts from which single applications sharing common features may be (automatically) derived. In order to be successful, a special development process is required which contains two phases: (1) *domain engineering* (*DE*) and (2) *application engineering* (*AE*) (Pohl et al., 2005). Domain engineering covers capturing and implementing common and variable aspects of the software system, e.g., in a variability model and implementation artifacts. The variability model and the corresponding implementation artifacts form the *platform* of the software product line. Throughout the years, *feature models* (Kang et al., 1990) have become a de facto standard for models capturing the variability of a software product line.

A feature model uses features as boolean properties of a software system which can be either present or absent in a specific product. Features are arranged in an and/or tree. Each feature is either mandatory or optional. If a child feature is selected, the respective parent feature has to be selected, as well. Additionally, groups of alternative features are provided, exactly one member of which has to be selected, respectively. Depending on the respective variant of feature models, refining modeling constructs are provided, such as *requires* and *excludes* relationships (Schobbens et al., 2006).

Application engineering deals with the construction of product variants from the reusable assets developed in domain engineering. Basically, three different approaches exist to construct products: (1) In approaches based upon *positive variability*, product-specific artifacts are built around a common core. *Composition* techniques (Apel et al., 2009) are used to finally derive products. (2) In case of *transformational variability* (Schaefer, 2018), a sequence of transformations is performed to construct products, while (3) in approaches based on *negative variability* (Apel and Kästner, 2009; Buchmann and Schwägerl, 2012), a *superimposition* of all variants is created in the form of a *multi-variant product*. The derivation of products is realized by removing all fragments of artifacts implementing features *not* contained in the desired product.

In all three cases, the application engineer binds the variability by creating a *feature configuration*. In a feature configuration, a selection state (selected or deselected) is assigned to each feature variable. A feature configuration is *consistent* if the provided selections conform to the constraints defined in the feature model.

Negative variability extends single- to multi-variant artifacts by annotating artifact elements. In contrast to positive and transformational variability, the languages for single-variant artifacts may be reused. Thus, SPLE engineers do not have to learn new languages. However, editing multi-variant artifacts poses a significant cognitive challenge. For example, editing source code written in the programming language C turns out to be difficult because preprocessor directives realizing annotations are intermingled with ordinary C code.

Therefore, dedicated *multi-variant editors* are required for making the complexity manageable. To date, quite a number of rather different approaches have been proposed and implemented. All of these approaches suffer from different shortcomings:

- Virtual separation of concerns (Apel and Kästner, 2009) applies C-like preprocessor directives to Java code; separation of concerns is supported in a syntax-based editor by assigning colors to features and by eliding deselected program fragments. Coloring works only for a small set of features; furthermore, preprocessor directives are still intermingled with ordinary code, i.e., two different aspects of the software product line are mixed in one physical resource. In addition, as soon as a product is derived, the traceability links between features and code are lost.
- Model-driven tools such as FeatureMapper (Heidenreich et al., 2008) and FAMILE (Buchmann and Schwägerl, 2012) follow a different approach: Annotations are stored and visualized in a dedicated mapping model. While annotations are separated from models, the SPLE engineer is exposed to an internal data structure which should be hidden from the user. Furthermore, it is hard to understand the relationships between model elements and annotations. Eventually, the mentioned tools support domain engineering only. As soon as a product is derived, the connection to the plat-

form of the product line is lost.

- In contrast to the approaches having been discussed above, *variation control systems* reduce complexity by *filtered editing* (Linsbauer et al., 2021). From a multi-variant artifact called *source*, a *view* is materialized in which variability has been resolved completely or partially. After editing of the view has been finished, the performed changes are propagated back to the source. Variation control systems are faced with two problems: Limited awareness of the context in which editing is performed and delineation of the scope of the change in the variant space. While the other tools mentioned above primarily display and edit artifacts of domain engineering, and provide (filtered) views of the multi-variant domain model, variation control systems operate on (partially configured) products. Thus, the software product line engineer works on specific variants (as in application engineering) and domain engineering is performed implicitly when a commit into the version repository is executed.

In contrast to the approaches mentioned above, our approach completely hides the mapping model from the user. The SPL engineer is empowered to use feature annotations in the concrete syntax in an intuitive way. Furthermore, the annotations may be hidden in the editor at any time. Sophisticated visualizations allow for different views of the multi-variant domain model ranging from fine-grained views showing single features only, over partial feature configurations to a view on the complete multi-variant domain model.

In our approach, application engineering is a fully automated process where the final products are derived from the multi-variant domain model using a feature configuration. The derived artifacts comprise traceability links to the multi-variant domain model to support evolution.

In (Mukelabai et al., 2018) the authors present a multi-view projectional editor for software product lines based on JetBrains MPS[2]. In contrast to our approach which is generic and allows for reusing existing EMF technology (modeling languages, model transformations, code generators), the PEoPL solution focuses on combining annotative and compositional editing of software product lines for a specific modeling language.

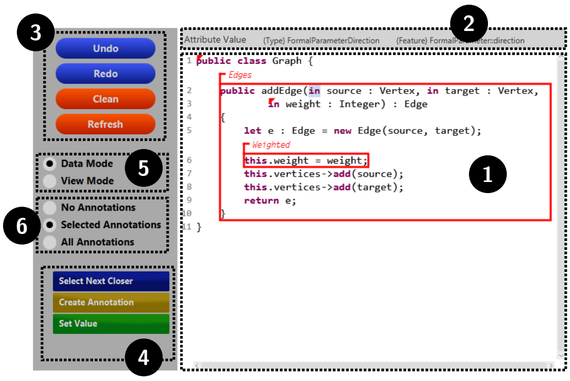
3 FUNCTIONALITY AND USER INTERFACE

This section describes the functionality of the projectional editor framework by outlining an example use case. In general, the multi-variant editor may be generated for an arbitrary domain model (or an appropriate subtree) that is an instance of an arbitrary metamodel. For the example scenario, a projectional editor for the textual modeling language ALF has been generated; the language *ALF* (*Action Language for Foundational UML*) (OMG, 2017) provides a concise textual syntax for *Foundational UML* (*fUML*) (OMG, 2020), a subset of *UML* enriched with precise execution semantics. In the editor, a *graph library* product line is modeled which constitutes a common example in SPL literature (Lopez-Herrejon and Batory, 2001; Schwägerl et al., 2015).

3.1 The Framework in General

Figure 1 shows a screenshot of the full editor. The main pane constitutes the major part of the user interface (cf. part 1); it presents the representation of the underlying abstract syntax (sub-)tree as well as the corresponding annotations. Above the main pane, brief information regarding selected elements is displayed (cf. part 2). The editor provides several modes. Besides buttons for mode-independent commands (cf. part 3), e.g., the common editor operations Undo and Redo, mode-specific buttons (cf. part 4), e.g, commands for inserting elements into the domain model, can be executed.

With respect to the range of commands, the editor differentiates two modes (cf. part 5). The *data mode* offers commands for editing the domain model. Data commands perform modifications of the abstract syntax tree which are propagated to the representation model. The *view mode* supports view-specific repre-



```
public class Graph {
    public addEdge(in source : Vertex, in target : Vertex,
            in weight : Integer) : Edge
    {
        let e : Edge = new Edge(source, target);
        this.weight = weight;
        this.vertices->add(source);
        this.vertices->add(target);
        return e;
    }
}
```

Figure 1: The editor user interface for an example use case.

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[2] https://www.jetbrains.com/mps/

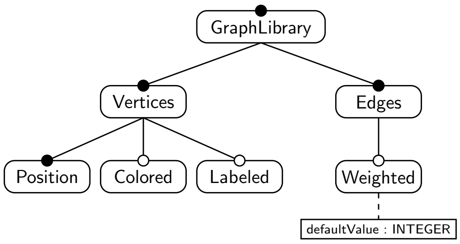


Figure 2: Feature model for the use case in graphical notation. Rectangles with rounded corners represent features while ordinary rectangles stand for feature attributes. Mandatory features are tagged by means of filled circles.

sentation commands as adding line breaks or whitespaces. View commands only affect the representation model. Since the editor framework not only persists the domain model but also the representation, custom layout information is stored after the editor has been closed.

In addition, three modes are present that refer to the visibility of annotations (cf. part 6). The domain engineer may choose whether *no annotations* are visible – without any annotation commands at all –, whether *all annotations* are visible, or whether only a subset of all annotations (*selected annotations*) are visualized, e.g., annotations that are relevant for a certain feature configuration. In the latter case, annotations can be individually visualized and hidden; hidden ones are marked by means of a corner triangle which can be clicked in order to display the respective annotation again. These three modes are orthogonal to the two modes described before; therefore, six combinations of modes are provided.

The feature model itself is not visualized by the editor. Currently, the generic EMF tree editor is used. Future work will provide for a specific projectional feature model editor with a human-readable textual syntax. To this end, we will apply our framework to a metamodel for feature models. By means of this bootstrapping strategy, we minimize the number of dependencies to other tools. For the example scenario used in this paper, we assume the feature model graphically shown in Figure 2. The root feature GraphLibrary contains the mandatory features Vertices and Edges. The feature Vertices has the mandatory child feature Position and the optional features Colored and Labeled. The feature Edges exhibits the optional child feature Weighted that possesses an integer attribute named defaultValue.

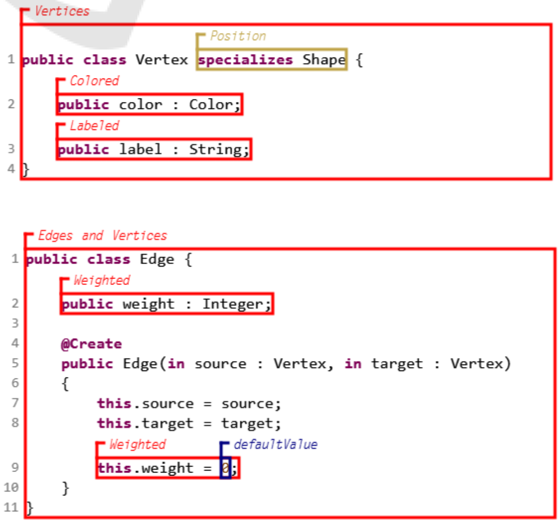
3.2 Support for Domain Engineering

In general, each representation visualized by the editor shows exactly one subtree of a domain model. Furthermore, for one domain model, several representation models may be present each of which refers to another subtree. Finally, a product line may comprise several domain models. Therefore, the editors provide different views of a range of domain models. For the illustrated use case, there is exactly one domain model. The model contains an ALF package with several classes, associations, and a data type. Each representation model shows an ALF class. Therefore, for each class, an own editor view is present – analogously to Java classes, for instance.

The editor depicted in Figure 1 shows the representation of the ALF class Graph with selected annotations two of which are completely visible and two are hidden – the annotation binding the whole class to the feature GraphLibrary and the one for the third operation parameter referring to the feature Weighted. For the sake of readability, annotations are depicted as labels which have specific colors and are located between the physical lines of the actual domain model representation. The representation area of the respectively annotated elements is marked by a border line.

Annotations can contain links to features and their attributes as atoms within boolean expressions providing common logical operators (conjunction, exand inclusive disjunction, negation). Elements are modified by projectional commands for adding and removing objects, restructuring expressions, and setting links. One physical line may also comprise more than one annotation; their representations are ordered by employing a layout mechanism that avoids overlapping (by moving the labels).

The editor supports several kinds of annotations depending on the domain model element that is annotated. All kinds of annotations are visible in Figure 3;



```
public class Vertex specializes Shape {
    public color : Color;
    public label : String;
}
```

```
public class Edge {
    public weight : Integer;

    @Create
    public Edge(in source : Vertex, in target : Vertex)
    {
        this.source = source;
        this.target = target;
        this.weight = 0;
    }
}
```

Figure 3: Further multi-variant model elements of the example use case.

for different kinds of annotations, different colors are used. The framework employs the following classification of domain artifacts that can be annotated:

- *Visibilities of Objects or Values.* The respective object or value is annotated with a boolean expression that indicates whether for a given feature configuration, the respective domain model element is present in the derived product. In the graph library example, the class Vertex as well as the contained properties color and label (cf. lines 2 f.) are annotated this way.
- *Visibilities of Optional Elements.* Optional model elements – that may comprise numerous different model artifacts as objects, links, values, or keywords – are annotated with a boolean expression that indicates whether for a given feature configuration, the respective optional part of the model is present in the derived product. The ALF class Vertex inherits from the class Shape – providing properties for the position coordinates of shapes within a diagram (not shown in the figure). This relationship is bound to the annotation Position by annotating the optional structural feature for generalizations of classifiers (cf. line 1).
- *Elementary Values of Attributes.* In addition to visibilities, values can be annotated with annotations employing feature attributes (from the feature model). In the multi-variant model, the default value is stored depending on the concrete attribute type (e.g., 0 for integer attributes). When a certain product is derived, the values for the feature attributes are specified within the course of the feature configuration. In the graph library example, the initial value for the property weight in the class Edge is derived from the feature attribute defaultValue (cf. line 9).

In case of visibility annotations, the principle of top-down propagation of annotations is applied. Therefore, an annotated element is visible if and only if its annotation evaluates to true and all transitive container elements are visible, as well.

4 ARCHITECTURE

This section outlines the underlying architecture of the framework and describes the involved system of models for an example use case. We state the assumption that each product line bases upon one global feature model. The product line comprises a set of models which are instances of arbitrary, possibly different metamodels based on EMF. Furthermore, the connections between domain model elements and annotations are persisted within one global mapping model. Analogously, one global correspondence model captures the internal editor structure.

4.1 Overview

Figure 4 shows the architecture that illustrates editors and models as well as their dependencies. As the tool context is the Eclipse Modeling Framework, all models are based on the ECORE metamodel. The editor including product line support (PL-EDITOR) is an extension of the projectional editor without product line context (EDITOR) (Schröpfer et al., 2020). An editor instance refers to exactly one abstract syntax tree (AST) and visualizes either the complete model or a subtree. The framework does not state any assumptions about the metamodel of the abstract syntax tree (AST^M).

The mappings from domain model elements to annotations are stored in the (product line) mapping model PL-MAPP. The mapping model comprises mapping elements for domain model elements of several abstract syntax trees. For each annotation, the mapping element for the respective domain model element contains a subtree that constitutes the respective logical expression referencing the feature model (FEAT); see Section 5 for details about feature model and mappings. The metamodels FEAT^M and $\mathsf{PL\text{-}MAPP}^\mathsf{M}$ are generic and fixed for arbitrary domain metamodels. The feature model is modified by using an extra editor (FEAT-EDITOR). Currently, the default tree editor provided by EMF is used; future work will deal with a more comfortable and powerful editor including consistency and satisfiability checking.

The correspondence model (CORR) serves as the central data structure of the editor. It connects the abstract syntax trees, the representation models (REPR), and the concrete syntax definition model (CSYN). Furthermore, in case of the extended editor, each editor correspondence model is linked to a specific product line mapping model and vice versa; therefore, internal editor correspondences and product line mappings are conceptually and physically separated. The correspondence metamodel CORR^M, the representation metamodel REPR^M, as well as the metamodel for the syntax definition models CSYN^M are fixed. In case of the extended editor including product line support, the representation model also contains elements for annotations and their contents and the correspondence model provides respective mappings for expressions within annotations.

Each editor instance corresponds to one representation model. The representation model consists of model elements for blocks, lines, and cells. For

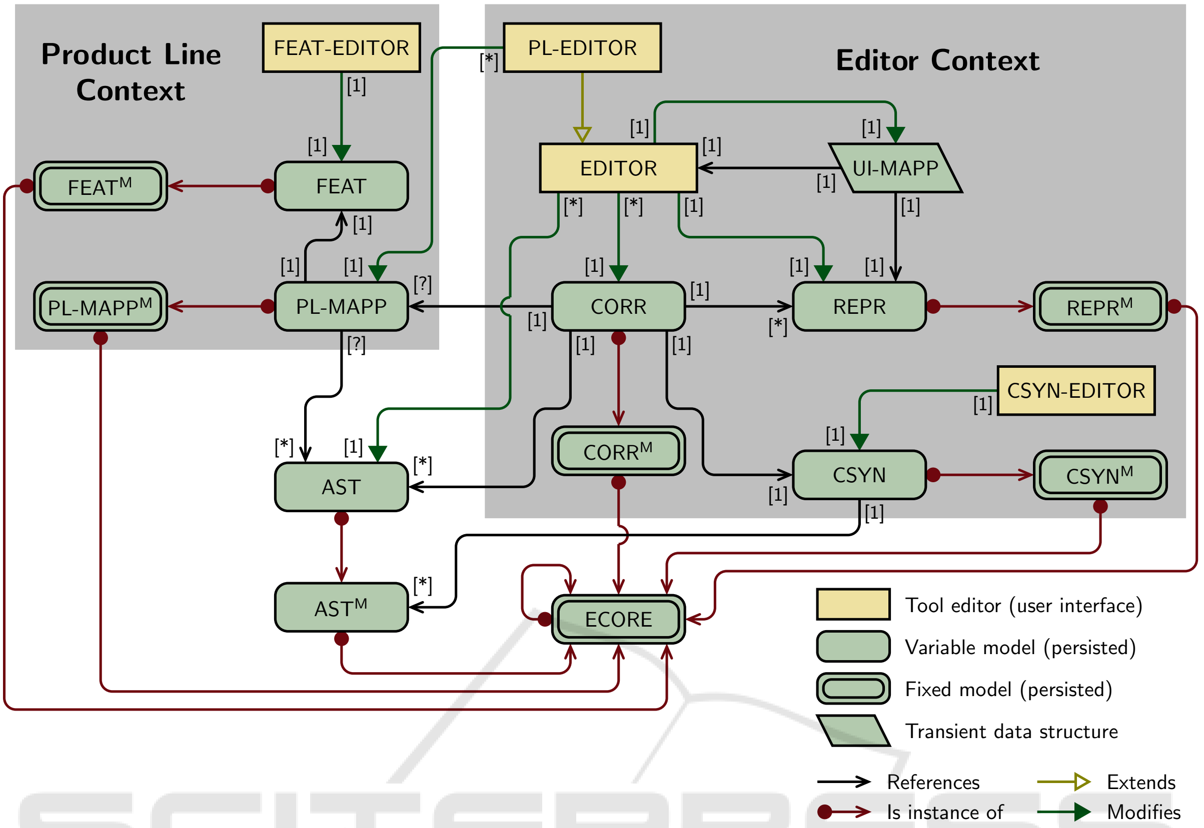


Figure 4: Megamodel describing the architecture elements within one product line and their relations. For References and Modifies dependencies, the UML multiplicities [1] (exactly one element) and [*] (arbitrarily many elements) are used; the multiplicity [?] describes optional single elements (in UML 0..1) depending on the fact whether the extended editor is used (with product line context) or not.

the abstract model elements, the editor pane visualizes concrete geometrical shapes (rectangles and labels). The traces between representation (REPR model) and presentation elements (EDITOR user interface) are captured by an internal, transient data structure (UI-MAPP) which is not persisted when the editor is closed. The concrete syntax definition model CSYN is built from projection rules which are specified by the DSL developer using an extra editor (CSYN-EDITOR).

All in all, this architecture facilitates a flexible information exchange between the involved models. For a given representation element, the editor detects the respective internal correspondence element in order to access the represented domain model element, the respective product line mapping element (if any) as well as the applied projection rule. The interconnected system of models establishes the basis for the functionality of the different editor commands.

4.2 Exemplary Model System

As example use case, we refer to the graph library example of Section 3. Figure 5 shows the involved system of models for a cutout of the domain model containing the ALF classes Graph (cf. Figure 1) and Vertex (cf. Figure 3, above) and several child elements; for the sake of readability, only inter-model dependencies and no cross references between model elements are visualized. For each ALF class within the domain model (AST), one representation model is present (REPR 1 and REPR 2). Both representation models have root blocks that refer to the respective class.

For each object that is represented by the editor, an object correspondence (within the CORR model) stores this representation relation together with the respective projection rule (contained in the syntax definition model CSYN) as well as the product line mapping element (in the PL-MAPP model). In this example, the correspondence model contains an object correspondence (1) for the root block (2) that represents

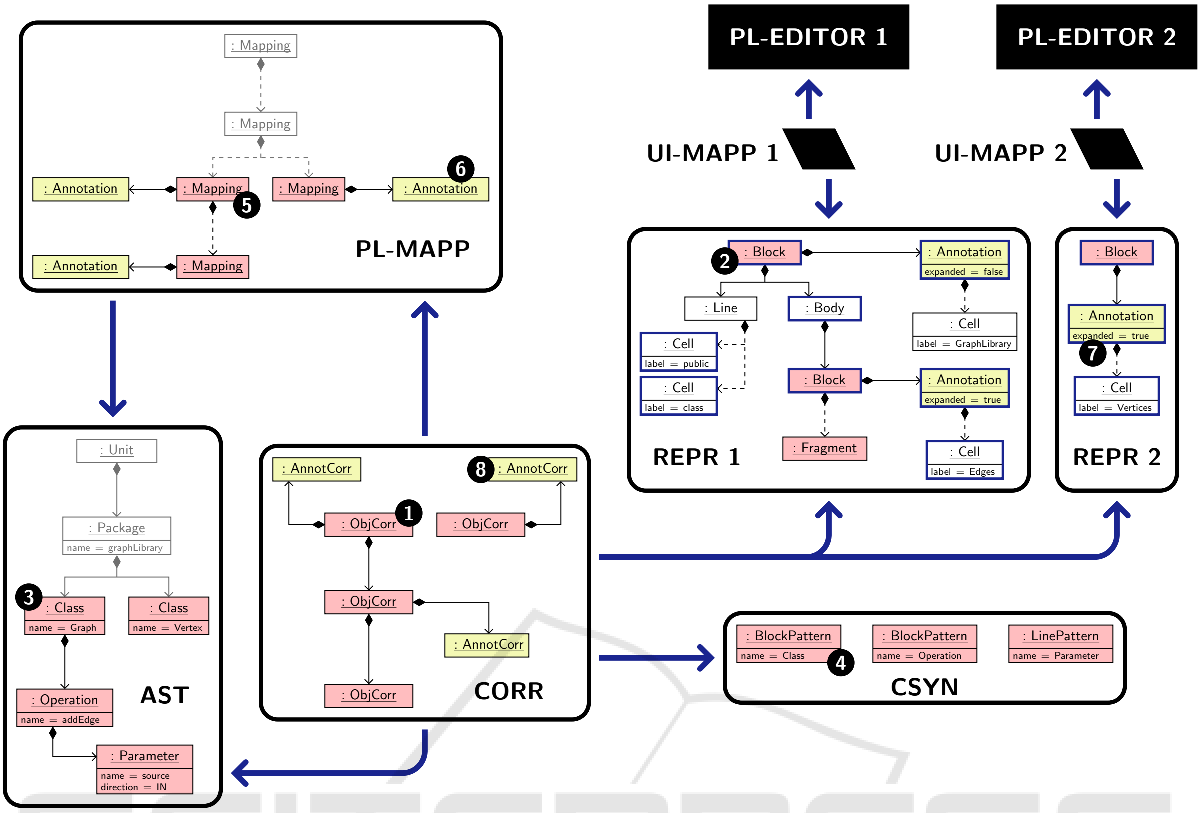


Figure 5: Example system of models for the graph library example (cutout). AST objects which are visible within the editors, their representation elements, and related elements have a red filling while annotations and their corresponding elements are marked by a yellow filling. Blue arrows symbolize cross references between components of the system. Elements of the representation models that exhibit analogous elements within the editors are marked through a blue border. AST objects and the respective mappings which are not visualized by the editors are grayed out. Diamond arrows stand for direct containment relations and dashed ones for transitive containment relations between model elements.

the ALF class Graph (3). This element is connected with the respective projection rule (4) and the product line mapping element (5). As the editors only show the representations of the ALF classes, the container elements (and their product line mappings) do neither have any representation elements nor any correspondence elements.

In general, the containment hierarchy of the abstract syntax tree is also applied for the correspondence model and the representation models. Thus, in case of the class Graph that contains the ALF operation addEdge, the representation element for the operation is contained in the representation element for the class and the correspondence element for the operation is contained in the correspondence element for the class. The product line mapping elements also possess this structure; more details about the mapping models are provided by Section 5.

While the referenced features are contained in the feature model, the annotation expressions are persisted as children of mappings within the product line mapping model. Besides the representation elements of the domain model, the representation model also comprises elements for the annotations (and their cells). For instance, the annotation Vertices (6) is represented by a REPR annotation (7) with an annotation correspondence element (8). The representation model also stores the information that the annotation for the whole class Graph is hidden.

Each representation model (REPR) is visualized by a specific editor (EDITOR) where the traces are persisted by a specific transient data structure (UI-MAPP). The editor contains corresponding graphical elements for blocks, bodies, cells, and annotations. Note that for hidden annotations – for which the attribute expanded is set to false –, their cells are not part of the editor presentation.

5 MAPPING DOMAIN MODEL AND ANNOTATIONS

After a brief overview of the metamodel for feature models, this section outlines structure and concepts of the product line mapping models that persist the annotations of domain model elements. Finally, for an example use case, the internal structure of the concrete feature model and the mapping model is depicted.

5.1 Feature Model

Figure 6 shows the metamodel for feature models. One feature constitutes the unique root feature. Each feature has a name and a boolean value whether it is mandatory. Features may be groups – which can contain arbitrarily many child features – or atomic features – that do not have any child features. Furthermore, features may have named attributes for boolean, integer, real, and string values.

A group is linked to a selection range that indicates how many child features must be selected at least (minimum number) and may be selected at most (maximum number). The minimum number must be less than or equal to the maximum number; furthermore, the minimum number may not be less than the number of mandatory child features; the maximum number has to be less than or equal to the number of child features. For instance, the semantics of OR- and XOR-groups which are commonly supported by feature models can be easily expressed by appropriate selection ranges.

In addition to the feature model tree, cross-tree constraints, i.e., dependencies between features, can be specified. To this end, an expression language is provided that supports common logical operators. By means of this expression language as well as the concept of selection ranges, arbitrary dependencies between features can be specified precisely.

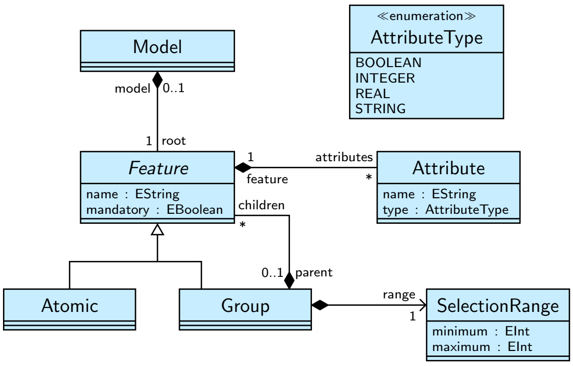


Figure 6: The metamodel for feature models.

5.2 Mapping Model

This section covers the metamodel for mapping models, i.e., models connecting domain model elements and annotations. As stated in Section 4, this model is conceptually separated from the correspondence model, i.e., the internal mapping model of the editor core. The domain engineer is not exposed to the internal structure of the product line mapping model directly; rather, annotations are visualized with the domain model elements by the editor within an integrated, user-friendly view.

Figure 7 shows the metamodel of the product line mapping metamodel. The mapping model consists of Mapping instances referring to the domain model. In order to provide the different kinds of annotations introduced in Section 3, three kinds of mappings are distinguished; concrete examples are depicted by Figure 3.

- All ObjectMapping instances refer to objects within the domain model, i.e., EObject instances. Object mappings are annotated if a domain model object is annotated, e.g., the whole class Vertex.
- All PropertyMapping instances correspond to structural features (attributes or references), i.e., EStructuralFeature instances, in the context of an object. Annotations contained in property mappings refer to annotated options, e.g., the declaration fragment of supertypes of the ALF class Ver-

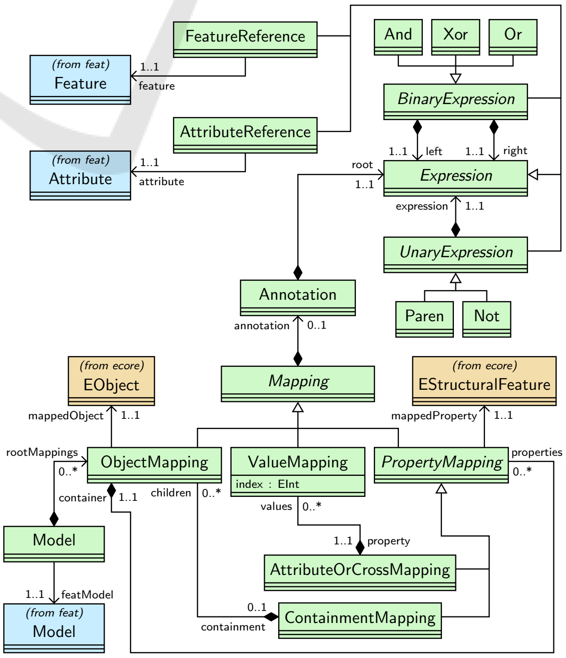


Figure 7: The metamodel for (product line) mapping models.

tex.

- All ValueMapping instances represent attribute values or cross links within the domain model. Value mappings are used for annotations referring to values, e.g., the natural literal for the initial weight value in the class Edge.

The structure of the mapping model reflects the containment hierarchy of the domain model elements. Direct child mappings of object mappings are always property mappings – corresponding to their structural features. Direct child mappings of property mappings are either object mappings – in case the property mapping refers to a containment reference – or value mappings – otherwise. Different value mappings contained in the same property mapping – which occurs in case of multi-valued structural features – can be identified by their index values. The index value of a value mapping describes the index of the element within the respective collection in the domain model; note that EMF always provides ordered collections for multi-valued structural features. The root mappings, i.e., the mappings referring to domain model root objects, build a flat collection in the root Model instance.

As a consequence of this analogous structure, mapping elements can be located very easily by employing their location in the domain model. The editor framework applies the principle of *lazy creation and deletion*: When a new annotation is created, only mapping elements are created which are necessary for this annotation; these elements comprise the mapping element that contains the annotation as well as all container mappings up to the object mapping for the domain model root. Furthermore, when an annotation is deleted, the mapping elements are not removed; mapping elements are deleted if and only if the respective domain model elements are deleted.

Annotations are stored as subtrees within the respective mapping element. The root Expression instance is directly referenced by the Annotation object. The child expressions are arbitrarily nested according to the respective logical operator precedence. Atomic expressions pose references to features or feature attributes.

5.3 Example Annotation Mapping

Figure 8 depicts the internal structure of the feature model as well as the mapping model for a cutout of the multi-variant domain model presented in Figure 3. Besides other artifacts that are comprised by the graph product line, the given ALF package contains the classes Vertex and Edge. The ALF class Vertex contains the properties color and label and inherits from the class Shape. The ALF class Edge provides the operation addEdge which transitively contains a natural literal expression. The property weight within the class Edge as well as other children of the operation addEdge are not considered here.

The feature model (cf. Figure 2) comprises the features Position, Colored, Labeled, and Weighted as atomic features. All other features are groups with default selection ranges, e.g., the group Vertices has a selection range (1) with minimum value 1 – since it has one mandatory child feature – and maximum value 3 – since it has three child features.

The unique global mapping model is linked (2) to the unique global feature model. As exactly one abstract syntax tree – with different views of it – is present, the mapping model has one root mapping (3) that references the domain model root. The containment hierarchy of the abstract syntax tree leads to an alternating sequence of ObjectMapping and ContainmentMapping instances. Since both properties color and label are contained in the same class Vertex and refer to the same containment reference, the respective object mappings are children of the same containment mapping (4); analogously for the two ALF classes within one package. The attribute for the natural literal is represented by an AttributeOrCrossMapping instance (5) with a single ValueMapping object (6). Due to the lazy creation principle, the mapping model exhibits no mapping element which neither contains an annotation nor another mapping (as the mapping element would be useless).

Annotations are stored as subtrees within the respective mappings. The annotations for the classes and the properties are internally represented as child objects of the respective object mappings, e.g., the annotation Vertices (i.e., a feature reference) within the mapping (7) for the class Vertex. The annotation for the superclass of the class Vertex comprises the whole optional structural feature; thus, the respective annotation constitutes a child element of the ContainmentMapping instance (8) for the generalization objects. The annotation for the natural literal value is a child element of the single value mapping (6). Mappings that do not directly contain annotations only serve as members within the structure of the complete containment hierarchy.

In this use case, the annotations contain both feature references – referring to groups or atomic features – and attribute references. The AND-conjunction within the annotation of the class Edge is represented by a binary tree (9) with the two operands as its leaf elements.

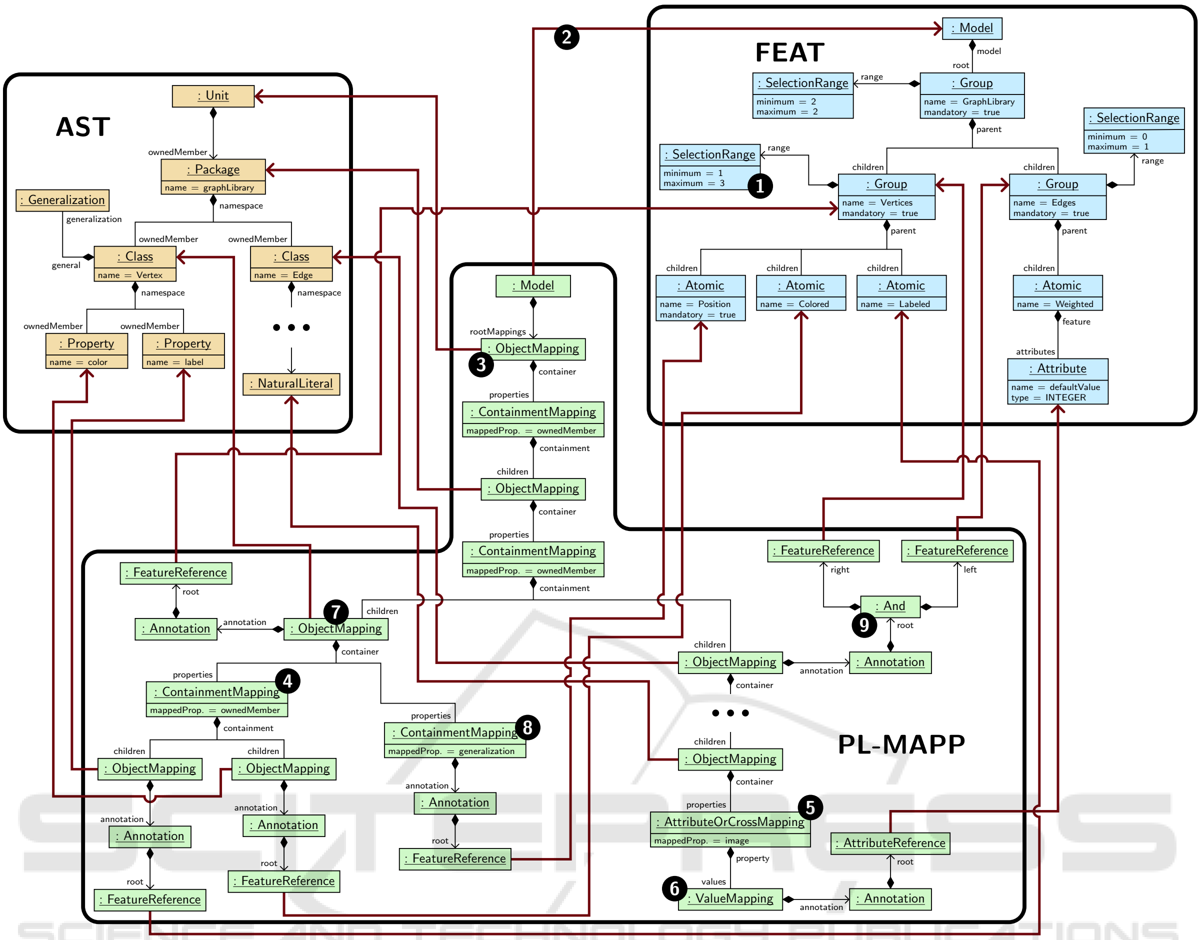


Figure 8: The internal representation of an example mapping model (PL-MAPP) with cross links to one feature model (FEAT) and one domain model (AST) that constitutes a cutout of the model in Figure 3. Inter-model cross references are visualized by red, bold arrows.

6 CONCLUSION

We presented a generic framework for building projectional multi-variant editors which are based on feature models for defining variability and support negative variability by annotating domain model elements with feature expressions. Human-readable textual notation is employed at the user interface. In particular, the notation provides for a clear separation between domain model elements and annotations, and offers a variety of commands for flexible filtering of variability information (Section 3).

Projectional multi-variant editors have not only been designed for model-driven engineering; they have also been realized with model-driven engineering. Thus, projectional multi-variant editors constitute a complex use case for the application of model-driven engineering. As described in Section 4, we devised a notation for megamodeling which we applied to describe the internal architecture of projectional multi-variant editors. Furthermore, Section 5 illustrates the complexity of the models employed internally by means of the mapping between domain models and feature models.

The work presented in this paper is still ongoing. Future work will include support for defining partial or total feature configurations and configuring multi-variant domain models accordingly. Here, ensuring well-formedness of configured domain models constitutes an important challenge which may be addressed along the lines of our previous work on FAMILE (Buchmann and Schwägerl, 2012). Please note that configuration of feature models and domain models is essential not only for application engineering but should be supported in domain engineering, as well. In domain engineering, configuration support enables previews of configured domain models which may be visualized by coloring and eliding. In addition, such previews will be editable. In this way, the projectional multi-variant editor will support automated management of annotations in a similar way as variation control systems (avoiding their view-update problems since each editing command always refers to the underlying multi-variant model).

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