

# Breaking the Boundaries of Meta Models and Preventing Information Loss in Model-Driven Software Product Lines

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**Keywords:** Software Product Lines, Model-Driven Development, Unconstrained Variability, Information Loss, Negative Variability, Application Engineering.

**Abstract:** Model-driven software product line engineering is an integrating discipline for which tool support has become available recently. However, existing tools are still immature and have several weaknesses. Among others, limitations in variability, caused by meta model restrictions, and unintended information loss are not addressed. In this paper, we present two conceptual extensions to model-driven product line engineering based on negative variability, being alternative mappings and surrogates. Alternative mappings allow for unconstrained variability, mitigating meta model restrictions by virtually extending the underlying multi-variant domain model. Surrogates prevent unintended information loss during product derivation based on a context-sensitive product analysis, which can be controlled by a declarative OCL-based language. Both extensions have been implemented in FAMILÉ, a model-driven product line tool that is based on EMF, provides dedicated consistency repair mechanisms, and completely automates application engineering. The added value of alternative mappings and surrogates is demonstrated by a running example.

## 1 INTRODUCTION

*Software engineering* aims at increasing the productivity of software engineers by providing powerful methods and tools for software development. Among others, model-driven software engineering and software product line engineering have emerged as complementary disciplines contributing to the achievement of this goal.

*Model-Driven Software Engineering (MDSE)* (Frankel, 2003; Völter et al., 2006) puts strong emphasis on the development of high-level models rather than on the source code. Models are not considered as documentation or as informal guidelines how to program the actual system. In contrast, models have a well-defined syntax and semantics. Moreover, model-driven software engineering aims at the development of *executable* models. Ideally, software engineers operate only on the level of models such that there is no need to inspect or edit the actual source code (if any).

*Software Product Line Engineering (SPLE)* (Clements and Northrop, 2001; Pohl et al., 2005; Weiss and Lai, 1999) deals with the systematic development of products belonging to a common system family. Rather than developing each instance of a product line from scratch, reusable software artefacts

are created such that each product may be composed from a library of components. Basically, two different approaches exist to realize variability in SPLE: (1) In approaches based upon *positive variability*, product-specific artefacts are built around a common core. *Composition* techniques are used to derive the final products. (2) In approaches based on *negative variability*, a *superimposition* of all variants is created in the form of a *multi-variant domain model*. The derivation of products is achieved by removing all fragments of artefacts implementing features *not* being contained in the specific feature configuration for the desired product.

In the past, several approaches have been taken in combining both techniques to get the best out of both worlds, resulting in the integrating discipline *Model-Driven Product Line Engineering (MDPLE)*. Both software engineering techniques consider models as primary artefacts: Feature models (Kang et al., 1990) are used in product line engineering to capture the commonalities and differences of a product line, whereas *Unified Modeling Language (UML)* (OMG, 2015) models or domain-specific models are used in model-driven software engineering to describe the software system at a higher level of abstraction. The *Eclipse Modeling Framework (EMF)*

(Steinberg et al., 2009) has been established as an extensible platform for the development of MDSE applications. It is based on the Ecore meta model which is compatible with the OMG *Meta Object Facility (MOF)* specification (OMG, 2011).

In this paper, we address two issues which have been neglected so far in MDPLE research, being *limitations in variability* and *unintended information loss*. We have identified these problems (among others) from a large case study (Buchmann et al., 2012) which had been performed using our old tool chain for model-driven product line engineering (Buchmann and Westfechtel, 2014). Furthermore, a comparison of tools available in literature has been taken into account (see Related Work in Section 5). To overcome the identified issues, we provide the contributions *alternative mappings* and *surrogates*, which have been implemented as extensions to the MDPLE tool FAMILÉ (Buchmann and Schwägerl, 2012a; Buchmann and Schwägerl, 2012b; Buchmann and Schwägerl, 2015a). The addressed issues and the presented solutions are summarized below.

**Issue: Limitations in Variability.** Since approaches which rely on negative variability use a multi-variant domain model, the respective meta model is a limiting factor for variability. In particular, single-valued structural features can only hold one value, e.g., a UML class may only have one name. Furthermore, each model element may have exactly one container.

**Contribution: Alternative Mappings.** The concept of alternative mappings allows for variability in values of single-valued features of domain model elements (e.g. UML class names). This is realized by virtual extensions to the multi-variant domain model, which are physically located in the *mapping model*.

**Issue: Unintended Information Loss.** When products are derived from the multi-variant domain model, context-sensitive information that is stored within cross-references, e.g. a transitive inheritance relationship, may get lost; state-of-the-art tools only take context-free information into account when deriving products.

**Contribution: Surrogates.** Unintended information loss is addressed by means of surrogate rules, which can be defined in a declarative way using the OCL-based language SDIRL. During product derivation, these rules are interpreted; to prevent information loss, reference targets are replaced by appropriate substitutes.

The paper is structured as follows: In Section 2, we align the MDPLE tool FAMILÉ with existing

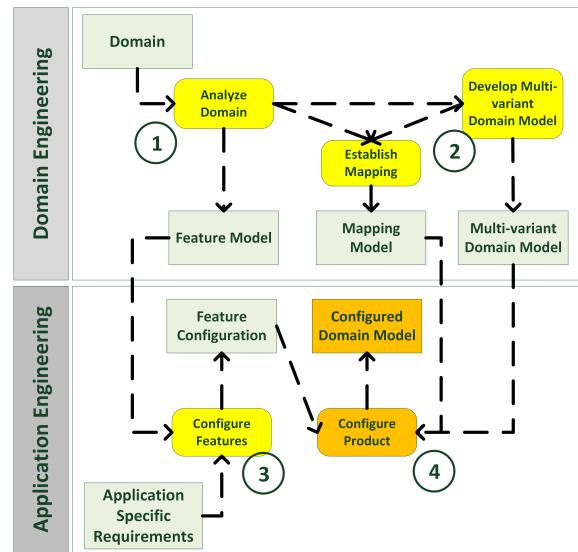


Figure 1: Model-driven product line engineering process as supported with FAMILÉ.

SPLE development processes. Section 3 describes FAMILÉ in general, before the new contributions are explained in detail in Section 4. Section 5 discusses related work, before the paper is concluded.

## 2 MODEL-DRIVEN PRODUCT LINE ENGINEERING

The contributions presented in this paper are embedded into a *model-driven product line engineering process* as shown in Figure 1. Typically, product line engineering distinguishes between *domain* and *application engineering* (Clements and Northrop, 2001; Pohl et al., 2005). *Domain engineering* is dedicated to analyzing the domain and capturing the results in a model which describes commonalities and differences thereof. Furthermore, an implementation – the so called *platform* – is provided at the end of domain engineering. The platform is then used during *application engineering* to derive application specific products, i.e., instances of the product line.

In our approach, domain and application engineering differ from each other also with respect to required processes: Domain engineering requires a full-fledged *development process*, while application engineering is reduced to a simple *configuration process*, which is realized in a preferably automated way. The activities belonging to the entire engineering process are described below:

**1. Analyze Domain.** A *feature model* describing mandatory, optional and alternative features

within the product line captures the result of the domain analysis. Typically, *Feature-Oriented Domain Analysis (FODA)* (Kang et al., 1990) or one of its descendants – like FORM (Kang et al., 1998) – is used to analyze the domain.

**2. Develop Configurable Domain Model.** Afterwards, a *multi-variant domain model* is developed, which realizes all features determined in the previous step. A link (*mapping model*) between the feature model and the domain model is established, e.g., by annotating model elements with *feature expressions*.

**3. Configure Features.** In order to build a specific system with the reusable assets provided by the product line, features of the feature model have to be selected. The selected features constitute a *feature configuration*, describing the characteristics of the product configuration to be derived.

**4. Configure Domain Model.** According to the selection of features made in the previous step, the domain model is configured automatically. This is done by selecting all domain model elements which are not excluded by feature expressions evaluating to false. The result of this step is an application-specific *configured domain model*.

Please note that the activity *Develop Multi-variant Domain Model* comprises the phases *Domain Requirements Engineering*, *Domain Design*, *Domain Implementation* and *Domain Testing*, as described in the product line process proposed by Pohl et al. (Pohl et al., 2005). In a model-driven software engineering process, the corresponding artefacts produced by these subprocesses are represented as models. FAMILIE is able to handle the respective models as long as their meta models are based upon Ecore.

### 3 THE TOOL FAMILIE

Before we give detailed descriptions of the new concepts *alternative mappings* and *surrogates*, let us briefly provide a short description of our tool *FAMILIE* by detailing its architecture and existing consistency mechanisms. More comprehensive tool descriptions can be found in (Buchmann and Schwägerl, 2012a; Buchmann and Schwägerl, 2012b; Buchmann and Schwägerl, 2015a).

#### 3.1 Architecture

*FAMILIE (Features and Models in Lucid Evolution)* is an EMF-based MDPLE tool chain that offers capabilities to capture commonalities and variabilities of

a software family using feature models and to map features to elements of arbitrary EMF-based domain models, which contain the realization of those features. FAMILIE has been developed itself in a model-driven way, being based on several meta models. The feature meta model describes the structure of feature model and feature configurations, respectively, and F2DMM (*Feature to Domain Mapping Model*) is the meta model for mappings between features and realization artefacts (elements of the multi-variant domain model).

Figure 2 shows the (meta) models involved in our tool chain. A *feature model* (Batory, 2005) consists of a tree of features. A non-leaf feature may be decomposed in two ways. In the case of an AND decomposition, all of its child features have to be selected when the parent is selected. In contrast, for an OR decomposition exactly one child has to be selected. In addition, our feature modeling tool complies with *cardinality-based feature modeling* (Czarnecki et al., 2005). *EMF Validation* is used to check corresponding feature configurations against pre-defined consistency constraints (Heidenreich, 2009).

FAMILIE’s core component is an editor for *mapping models* (F2DMM), which is used to interconnect the feature model and the Ecore-based domain model. To this end, a mapping model consists of a tree of three different kinds of mappings, which are created by the tool transparently to reflect the tree structure of the mapped domain model:

**Object Mappings** refer to an existing EObject from the multi-variant domain model and reflect its tree structure using the *Composite* design pattern (Gamma et al., 1994).

**Attribute Mappings** refer to the string representation of a concrete value of an attribute of a mapped object.

**Cross-reference Mappings** represent the applied occurrence of an object that is already mapped by an object mapping.

The connection between domain and feature model is realized by feature expressions specified with FAMILIE’s *Feature Expression Language (FEL)*. A feature expression may be assigned to each kind of mapping and consists of a propositional logical expression on the variables defined in the feature model.

Once a valid feature configuration is provided, FAMILIE may be used to derive the configured domain model by filtering all domain model elements decorated with feature expressions evaluating to false. During product derivation, *repair actions* are applied to ensure well-formedness (Buchmann and Schwägerl, 2012a). To this end, *context-free* consis-

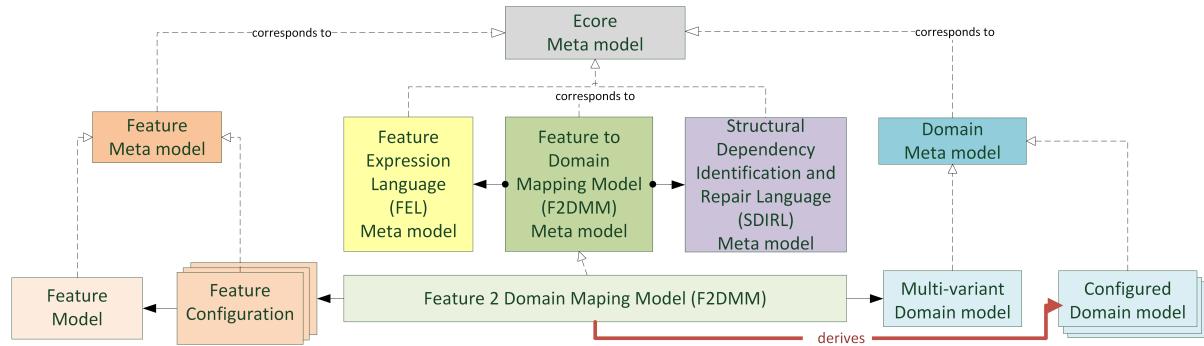


Figure 2: Architectural overview of FAMILE.

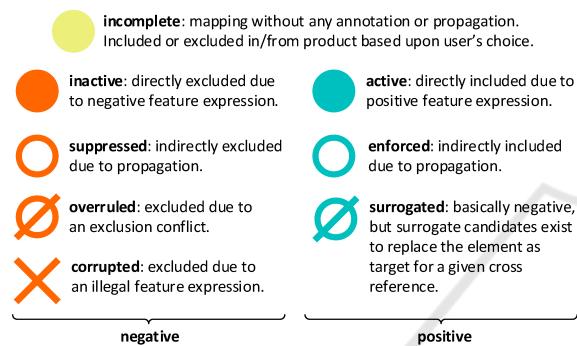


Figure 3: Possible selection states for F2DMM mappings and their graphical representation.

tency constraints are automatically derived from the used domain meta model. Furthermore, the SPL engineer may specify *context-sensitive* constraints using the textual language *SDIRL* (*Structural Dependency Identification and Repair Language*).

### 3.2 Selection States

The evaluation of a feature expression with respect to a given feature configuration results in a *selection state*. Thus, selection states determine the presence of a mapped object, cross-reference, or attribute value in the product described by a specific feature configuration. They may also indicate that automatic repair actions have been applied to ensure well-formedness or that a *surrogate* rule has been applied to prevent information loss (see Sections 3.3 and 4.1). Figure 3 depicts all eight selection states that may be assigned to a mapping in F2DMM.

Four selection states immediately result from evaluating a mapping's assigned feature expression: *active* and *inactive* denote that it evaluates to a positive or negative value, *corrupted* means that there are syntax errors in the expression. The state *incomplete* arises in case a mapping has no feature expression assigned or as long as no feature configuration has been

loaded. The four remaining selection states are motivated and explained below.

### 3.3 Propagation Strategies

When applying a feature configuration to the mapping model and calculating the respective selection states, selection states contradicting context-free or context-sensitive consistency constraints in the respective domain meta model may arise. A so called *dependency conflict* is present if a mapped element is active while a dependent element, e.g., its container, is inactive.

*Propagation strategies* have been introduced as an automatic consistency repair mechanism to resolve dependency conflicts (Buchmann and Schwägerl, 2012a). The SPL engineer may choose among two pre-defined strategies, being *forward* and *reverse* propagation. The application of propagation strategies may lead to two new selection states: Either, an *inactive* mapping can be artificially made positive, i.e. *enforced*, or an *active* mapping can be artificially made negative, i.e. *suppressed*. In order to indicate the application of a propagation strategy to the user, different symbols (empty circles instead of filled circles) are used for their representation (cf. Figure 3).

## 4 EXTENSIONS CONTRIBUTED TO FAMILE

In this section, the core contributions of this paper, *surrogates* and *alternative mappings* are explained. After motivating the respective issues, the general solutions are presented and then demonstrated by examples referring to the domain of *Home Automation Systems* (*HAS*), a prominent example in SPL literature, e.g., (Pohl et al., 2005). HAS provide a communication and controlling platform for home devices such as ovens, shutters, etc. Depending on the customers'

hardware specifications and the desired degree of automation, a variety of products may be derived from the product line.

## 4.1 Surrogates

The derivation of configured domain models in approaches based on negative variability consists in filtering of elements being mapped to a feature expression that evaluates to a negative selection state. Filtering cross-references, however, may result in unintended information loss, especially concerning context-sensitive information that is encoded transitively by a sequence of references. Let's take generalizations in a UML model as an example: Within the UML specification (OMG, 2015), a generalization is defined as a directed relationship which is owned by the more specific class. The general class, however, is referenced by means of a directed non-containment reference. As a consequence, filtering a superclass results in a dangling edge. Completely discarding the generalization results in information loss: Given the fact that the filtered class was part of an inheritance hierarchy, the user might want to replace the filtered referenced class with its closest non-filtered superclass, for example.

### 4.1.1 Surrogate Rules

To address issues like these, we have extended the language SDIRL by *surrogate rules*. Generally, SDIRL allows to phrase a set of *dependency rules* referring to the meta model(s) of the multi-variant domain model. A dependency rule states that an element, referred to by its class, has a context sensitive dependency to a set of elements described by an OCL expression in the *requires* part. For instance, the dependency rule in Listing 1 defines that a UML Generalization depends on the referenced general class.

Using the *surrogates* extension, a dependency rule may include an arbitrary number of surrogate statements, where OCL expressions that must conform to the type of the *requires* variable can be phrased. The expression may refer to the objects bound to the *element* and *requires* variables. Objects that result from evaluating any of the attached surrogate expressions are recorded as *surrogate candidates* for the given cross-reference. Surrogate candidates may replace the element(s) bound to the *requires* variable as cross-reference target(s). In our generalization example (see Listing 1), these are all superclasses of the required class (returned after evaluating *cls.allParents()*).

Listing 1: SDIRL rule for generalizations.

```
dependency GeneralizationTarget {
  element gen : uml.Generalization
  requires cls : uml.Classifier = {
    gen.general
  }
  surrogate {
    cls.allParents()
  }
}
```

### 4.1.2 Rule Application

Both dependency and surrogate rules are pre-calculated during domain engineering. In Subsection 3.2, the selection state *surrogated* has been introduced for cross-reference mappings being basically *inactive* or *suppressed*, but for which at least one surrogate candidate having a positive selection state exists. A surrogate rule can revoke the effect of a previously applied propagation strategy (see Section 3.3).

During product derivation, one of the determined surrogate candidates must be chosen by the user to replace the applied occurrence of the mapped object. FAMIL supports three different methods for choosing one of the matching surrogate candidates: In a fully automatic mode, the first surrogate candidate is selected whereas in an interactive mode the user can select among the set of all candidates. Furthermore, the user can choose not to use surrogates at all. In this case, the information loss is intentionally ignored.

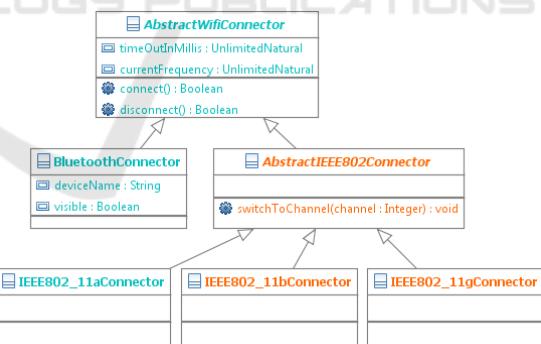


Figure 4: UML2 class diagram showing the realization of wireless connections in the multi-variant domain model.

### 4.1.3 Example

The class diagram in Figure 4 shows the realization of remote connections for wireless connections between HAS components, including Bluetooth. It comprises a three-layered inheritance hierarchy. The four concrete connector classes each correspond to one feature. Figure 5 shows the initial mapping of the package wifi in our running example.

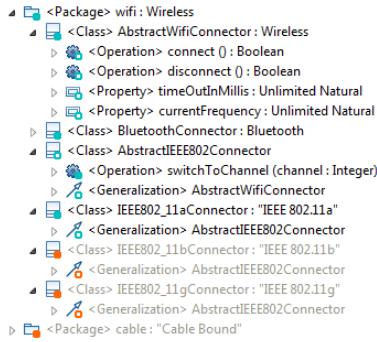


Figure 5: Initial mapping for the inheritance hierarchy.

Surrogates come into play as soon as elements with a negative selection state are cross-referenced by another, positively annotated, element. We simulate such a situation by assigning the feature expression `false` to the class `AbstractIEEE802Connector` (see Figure 6). Due to the SDIRL rule `GeneralizationTarget` defined in Listing 1, the generalization owned by `IEEE802_11aConnector` requires the class `AbstractIEEEConnector`. For the target of the reference general, a *surrogate candidate* has been pre-calculated by evaluating the surrogate statement within the SDIRL rule: the class `AbstractWifiConnector`, which is located at the top of the inheritance hierarchy. As a consequence, the selection state of the reference becomes *surrogated*.

The result of the surrogate rule application is depicted in Figure 7. The class `AbstractIEEEConnector` has been excluded from the product. The generalization owned by `IEEE802_11aConnector` has been re-targeted to `AbstractWifiConnector`. This way, transitive inheritance information has been maintained.

## 4.2 Alternative Mappings

In our approach based on negative variability, a multi-variant domain model constitutes the superimposition of all products. Nevertheless, it is an ordinary model instance which must satisfy the structural constraints imposed by its meta model. Unfortunately, there are at least two structural constraints which impede the use of a standard EMF model instance as the multi-variant domain model without being affected by the issue of *limitations in variability* (see introduction):

**Value Variability.** EMF distinguishes between single-valued structural features with an upper bound of 1 and multi-valued structural features with an upper bound greater than 1 or  $-1$  (unbounded multiplicity). In a valid EMF instance, at most one value may exist for a single-valued structural feature, and the multi-variant domain model cannot intrinsically represent alternative

feature values for different product variants.

**Container Variability.** In EMF, an object must either be the root of a resource, or be contained by exactly one container object. Thus, the location of an object in the containment tree must be fixed in the multi-variant domain model. This restriction prevents different FAMILÉ products from containing a specific object at different locations without creating redundant copies of objects.

### 4.2.1 Definition of Alternative Mappings

The FAMILÉ extension *alternative mappings* mitigates the restrictions described above. Alternative mappings are supplementary domain model elements defined in the mapping model that may be virtually inserted into the configured domain model at arbitrary locations. For each of the three kinds of mappings (see Section 3.1), FAMILÉ introduces different possibilities to specify alternative mappings in the F2DMM editor. These will not influence the multi-variant domain model, but refer to the mapping model only (and of course, affect derived products).

**Alternative Object Mappings** allow to virtually extend the multi-variant domain model with (sub-trees of) objects. FAMILÉ provides two possibilities: Either, the root of the inserted fragment is located in a separate EMF resource, or objects are defined *in-place* in the mapping model.

**Alternative Cross-reference Mappings** allow for the modification of applied occurrences of objects in configured domain models. F2DMM supports internal as well as external cross-reference mappings, which refer either to an existing, mapped element inside the F2DMM model, or to an ordinary EMF object in a different, non-mapped EMF resource.

**Alternative Attribute Mappings.** Besides references, the state of an EMF object is encoded in the values of its attributes. For a given (single- or multi-valued) attribute of a mapped object, an additional value may be specified by means of the string representation which is defined by the respective EDataType. The string is converted into its object representation as soon as product derivation includes the alternative attribute due to a positive selection state.

### 4.2.2 Mutex Conflicts and Selection Strategies

The introduction of alternative mappings leads to more flexible mapping models: For single-valued features, several values may be defined. As soon as a

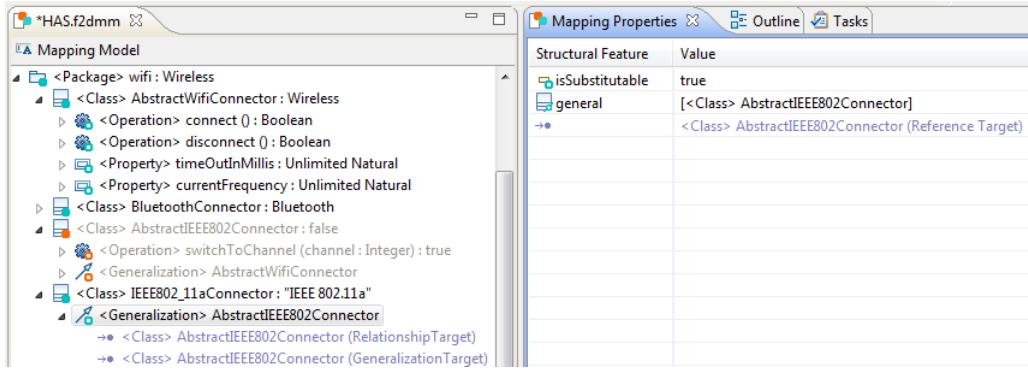


Figure 6: The disconnected inheritance hierarchy is repaired by means of a surrogate rule defined in SDIRL.

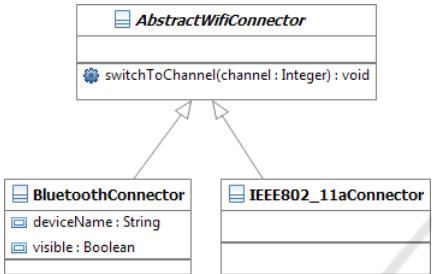


Figure 7: Result after product derivation, including surrogate selection, in class diagram representation.

configured domain model is derived from a mapping with multiple values competing for a single-valued feature, the result is not guaranteed to be unique as the values are mutually exclusive. In analogy to dependency conflicts (cf. Section 3.3), a *mutex conflict* occurs between a set of domain model elements  $\{e_1, \dots, e_n\}$  whenever the following conditions hold:

- The mappings of all elements  $\{e_1, \dots, e_n\}$  are contained in the same object mapping.
- All elements  $\{e_1, \dots, e_n\}$  are values of the same single-valued structural feature.
- The selection state of more than one element in  $\{e_1, \dots, e_n\}$  is *active* or *enforced*.

When applying *selection strategies*, the following rules are applied in FAMILÉ:

1. Since the multi-variant domain model is a valid EMF instance, there may be at most one non-alternative mapping involved in a mutex conflict. If such a mapping exists with a positive selection state, it is preferred over competing alternative mappings, i.e. they are all assigned the selection state *overruled* if they remained in a positive selection state.
2. If only alternative mappings are involved in a mutex conflict, this is resolved by the order in which the alternative mappings have been inserted, i.e.

the first alternative with a positive selection state is preferred. Again, the selection state *overruled* is assigned to all other mappings which had a positive selection state previously.

3. In both cases, the user may override the default behavior by assigning a suitable feature expression to the elements that have a higher priority than the desired candidate element.

#### 4.2.3 Example

We conclude this section by an example that demonstrates the definition of an *alternative attribute mapping* which causes a *mutex conflict*, and the resolution of this conflict. Figure 8 depicts a state diagram describing the dynamic behavior of microwave ovens in the HAS product line.

It is intended to rename the transition `stopOven` (c.f., Figure 8) to “`emergencyStop`” in case the feature “`Cooldown Mode`” is selected. Due to restrictions in the UML meta model (upper bound of 1), the name of a transition may have at most one value and we cannot introduce the second name as a part of the multi-variant domain model. As a replacement, we introduce an alternative attribute mapping below the transition `stopOven`, specifying the alternative value “`emergencyStop`” for the structural feature name. Next, we annotate the alternative mapping with “`Cooldown Mode`”.

As shown in Figure 9, this causes a *mutex conflict*: In the current feature configuration, the feature “`Cooldown Mode`” is *selected* and both names, “`stopOven`” and “`emergencyStop`” basically have a positive selection state assigned. According to the selection strategy introduced above, the alternative value “`emergencyStop`” is artificially excluded (selection state *overruled*).

In addition, the default name “`stopOven`” shall only be applied for products which deselect the feature “`Cooldown Mode`”. A corresponding feature ex-

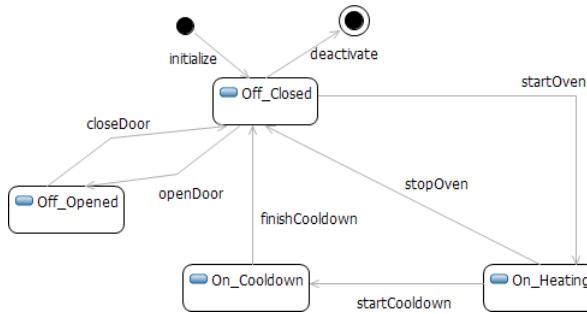
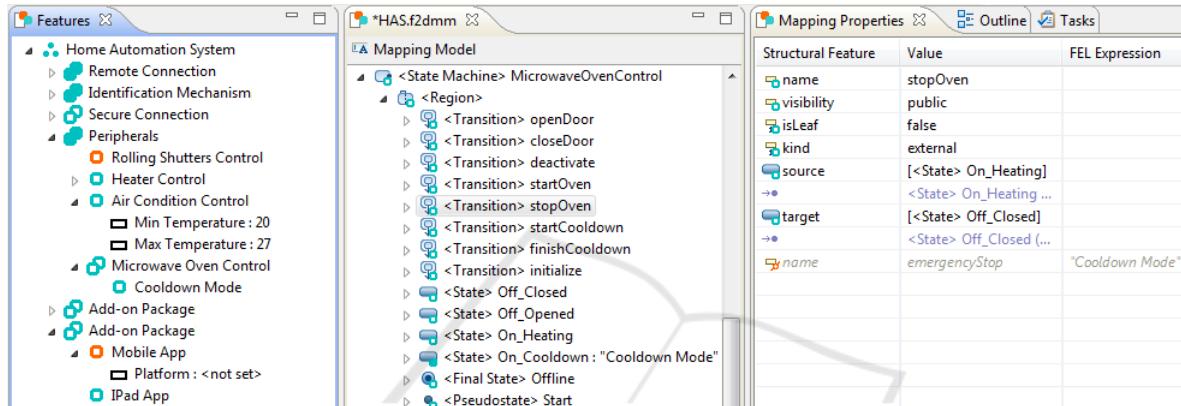


Figure 8: Superimposed statechart realizing feature “Microwave Oven” in concrete graphical syntax.

Figure 9: The alternative attribute mapping for the feature name of the transition stopOven causes a *mutex conflict*.

Structural Feature	Value	FEL Expression
<code>name</code>	<code>stopOven</code>	<code>not "Cooldown Mode"</code>
<code>visibility</code>	<code>public</code>	
<code>isLeaf</code>	<code>false</code>	
<code>kind</code>	<code>external</code>	
<code>source</code>	<code>[&lt;State&gt; On_Heating]</code>	
<code>target</code>	<code>[&lt;State&gt; Off_Closed]</code>	
<code>name</code>	<code>emergencyStop</code>	<code>"Cooldown Mode"</code>

Figure 10: The mutex conflict is resolved manually in order to obtain the desired result.

pression is added to the attribute mapping in Figure 10: `not "Cooldown Mode"`. Due to the mutual exclusion of the feature expressions attached to both names, the mutex conflict is now avoided, giving the priority to the alternative value “`emergencyStop`”. If we derived the product using the active feature configuration, the transition `stopOven` would be renamed to “`emergencyStop`”.

## 5 RELATED WORK

Lots of approaches and corresponding tools referring to model-driven product line engineering have been published in the past. In (Buchmann and Schwägerl,

2012a), a comparison of FAMILÉ with related work focused on *consistency control* is given. The comparison provided in (Buchmann and Schwägerl, 2015a) aligns FAMILÉ with related approaches to *heterogeneous* SPLE approaches. Here, after a general overview, we compare our contributions *alternative mappings* and *surrogates* to related work.

### 5.1 General Comparison

MDPLE Approaches based on *positive variability* require the use of special development tools in order to specify implementation fragments and to *compose* the variable parts with the common core (Whittle et al., 2009; Apel et al., 2009). The language VML\* (Zschaler et al., 2010) supports both positive and negative variability, since every feature is realized by a sequence of small transformations on the core model. MATA (Whittle et al., 2009) allows to develop model-driven product lines based on UML. It relies on positive variability, which means that around a common core specified in UML, variant models described in the MATA language are composed to a product specific UML model. Graph transformations based on AGG (Taentzer, 2004), which are used to compose the common core with the single MATA specifications.

An essential requirement in tools based on *negative variability* is the mapping between features and their corresponding implementation fragments. On the one hand, the mapping information may be either stored within the implementation, e.g. by using preprocessor directives in source code based approaches (Kästner et al., 2009), or annotations in model-based approaches (Ziadi and Jézéquel, 2006; Gomaa, 2004). The tool *fmp2rsm*<sup>1</sup> combines Feature-Plugin (Antkiewicz and Czarnecki, 2004) with IBM’s Rational Software Modeler, a UML-based modeling tool using specific UML stereotypes for features. *MODPL* (Buchmann and Westfechtel, 2014) also uses stereotypes to annotate Fujaba<sup>2</sup> models. On the other hand, the mapping information can be made explicit by using a distinct mapping model. Like FAMILÉ, FeatureMapper (Heidenreich et al., 2008) allows to add variability information to arbitrary Ecore-based domain models.

## 5.2 Approaches Allowing for Unconstrained Variability

In this paper, we have presented *alternative mappings* as a technique to overcome meta model restrictions in multi-variant models, e.g., the representation of multiple alternative values for single-valued structural features. To the best of our knowledge, when considering negative variability, there exists no approach in the literature that corresponds to *alternative mappings* described here, which explicitly stores alternative model elements in separate resources in order to virtually extend multi-variant domain models.

In approaches based on positive variability (Whittle et al., 2009; Apel et al., 2009; Zschaler et al., 2010), alternative values may be dynamically added to the platform using separate transformation specifications. However, during the product derivation process, the order in which the single model transformations are carried out is crucial, since “the last update wins”. Thus, a conflict detection and resolution mechanisms corresponding to *mutex constraints* and *selection strategies* presented here cannot be realized upon positive variability.

SuperMod (Schwägerl et al., 2015) applies a *filtered editing* approach to MDPL, realizing the *update/modify/commit* workflow known from version control systems. The SPL engineer always operates in a single-version view of the model, which is persisted in an *extrinsic*, multi-variant representation transparently, allowing for unconstrained variability behind

<sup>1</sup><http://gsd.uwaterloo.ca/fmp2rsm>

<sup>2</sup><http://www.fujaba.de/>

the curtains. However, in the local workspace, developers are intentionally restricted to single-version editing.

## 5.3 Approaches to Preventing Information Loss

*Surrogate rules*, as discussed in this paper, prevent the loss of information stored in context-sensitive way, e.g., in a sequence of cross references. The concept of *surrogate rules*, which are used to calculate target candidates beforehand, one of which is chosen as replacement reference target during product derivation, is unique in the field of MDPL. As a replacement, we outline one representative belonging to approaches performing context-sensitive analyses *after* product derivation.

The source-code based tool CIDE (Kästner et al., 2009) provides the SPL engineer with a product specific view on the source code, where all source code fragments not part of the chosen configuration are omitted in the source code editor. As opposed to *#ifdef*-preprocessors, CIDE abstracts from plain text files and works on the abstract syntax tree of the target language instead. The tool is based on a product-line aware type system which helps to detect typing errors resulting from applying negative variability to the multi-variant model. Since a general type system for arbitrary languages is still subject to research, a general solution is missing. Thus, for each language, a new grammar and a new product-line aware type system must be supplied by the SPL engineer. Furthermore, detected errors are not repaired automatically, which is in contrast to FAMILÉ.

## 6 CONCLUSION

In this paper, we have addressed two issues in SPLE tooling having been neglected in the past, namely limitations in *domain model variability* and *unintended information loss*.

Our contributions assume *negative variability*, where a multi-variant domain model is annotated with feature expressions. Products may be derived by configuring the feature model and by applying the configuration to the mapping. As a result, all elements which are annotated with feature expressions evaluating to false are filtered from the resulting configured domain model. However, filtering can easily result in syntactically ill-formed target models. Since the multi-variant domain model must be instance of the domain meta model, variability is constrained.

To address these issues, the following contributions have been presented in this paper as extensions to the MDPLE tool FAMILÉ:

**Alternative Mappings.** Since the multi-variant domain model has to be a valid instance of the domain meta model, several constraints must hold. In particular, single-valued features may contain at most one value. Thus, it is not possible to express variability for those features directly. This restriction is mitigated by our concept of *alternative mappings*. These in turn may cause several values competing for a single-valued feature. To resolve this, we have realized the detection of *mutex conflicts* as well as their resolution by means of *selection strategies*.

**Surrogates.** In case an element is filtered, it cannot occur as the target of another cross-reference. This way, context-sensitive information may get lost. Using the mechanism of *surrogates*, it is possible to filtered reference targets non-filtered targets of the same type. Corresponding replacement rules may be specified declaratively in SDIRL.

Future research addresses evolution of software product line artefacts, round-trip between domain and application engineering, and improved support for maintaining the consistency between model and generated source code (Buchmann and Schwägerl, 2015b) in both domain and application engineering.

## RESOURCES

The tool FAMILÉ, including the extensions presented in this paper, may be obtained by using the Eclipse update site provided at:<sup>3</sup>

We recommend a clean Eclipse Modeling installation. Screencasts demonstrating the usage of the tool can be found here:<sup>4</sup>

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<sup>4</sup><http://btn1x4.inf.uni-bayreuth.de/famile/screencasts/>

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