Feature Model Composition Assisted by Formal Concept Analysis

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Keywords: Software Product Line, Feature Model, Feature Model Composition, Formal Concept Analysis.

Abstract: In the domain of software product lines, Feature Models (FM) play a central role in variability modeling, completed by configuration collections (from concrete software product lines), logical representations, constraint programming or conceptual structures, coming from the field of Formal Concept Analysis (FCA). The development of feature models may take several forms, including their synthesis from configuration collections or their design in several steps (by several teams or with different concerns). FM composition (merge) operators are part of that design activity as they assist their iterative building. In this paper, we describe an approach, based on two main merging semantics (intersection and union), which assists designers in merging several FMs. This approach benefits from the help of FCA to represent all the FMs with the same configuration set through a canonical form. We describe the implementation of our approach and present a set of concrete examples.

1 INTRODUCTION

Software Product Lines have been introduced to reduce the cost and the time needed for producing software systems, while increasing their quality and diversity (Pohl et al., 2005). The design of a software product line can be achieved in different ways, depending on the context. It has two main phases, *domain engineering*, where commonality and variability are captured and *application engineering*, which focuses on the software product derivation. In domain engineering, requirement models are defined, including more specifically *feature models* that are widely used (Kang et al., 1990). *Feature models* (FM) describe the commonalities and the variability of a software product line based on a hierarchical decomposition of the system features, provided with annotations and logical formulas. An FM defines the acceptable set of configurations, a configuration being a set of features. As any design process, defining an FM is not straightforward, as several concerns have to be taken into account, several actors can participate and different sources of information can be used, depending if the FM is defined using real-word product lines (a set of concrete products already exists and the FM has to synthesize their configurations) or is defined during requirement analysis (Krueger, 2002).

Merging several FMs or simply analyzing their differences takes part in this design activity and has been studied thoroughly in the literature (Acher et al., 2010). These activities require in particular to compute intersection and union of FMs. However, there is an inherent divergence between structural intersection/union and the intersection/union of the configuration sets. Indeed, one main semantics of a feature model is its *configuration-semantics* (She et al., 2011), given by the set of configurations defined by the feature model. An issue which has to be addressed is the fact that FMs are not canonical forms, in the sense that a set of configurations (sets of features) often can be represented by several FMs (Czarnecki and Wasowski, 2007). This is the same for alternative representations as propositional formulas and constraints (in Constraint Problem solving approaches). The originality of our approach is to base the merging of feature models on a canonical structure obtained through the application of Formal Concept Analysis, using the *configuration-semantics* of feature models.

In the domain of software product lines, when the configuration set of a product collection was the primary artifact, other approaches have been tried, that rely on Formal Concept Analysis and several of its associated representations. The conceptual structures mix features and configurations. They have limits related to the need of enumerating the configurations and to the loss of ontological knowledge (as propositional formulas). As a counterpart, they are canonical and have graphical representations, that show re-

Carbonnel, J., Huchard, M., Miralles, A. and Nebut, C.
Feature Model Composition Assisted by Formal Concept Analysis.
DOI: 10.5220/0006276600270037
In *Proceedings of the 12th International Conference on Evaluation of Novel Approaches to Software Engineering (ENASE 2017)*, pages 27-37
ISBN: 978-989-758-250-9

lations between configurations, between features, and between features and configurations.

In this paper, we propose an approach, based on FCA, for understanding and assisting the feature model composition (intersection and union), also known as feature model merging, and provide assistance to designers during this activity. This work can also be used to extract a representation (with or without a feature model) for aligning two sets of product configurations, as in the case of two organisms (or vendors) that would propose or analyze a unified representation of their products.

Section 2 explains how the FCA framework allows us to build canonical forms for variability in a configuration set, in the sense that they encode all the feature models that have the same configuration set. Section 3 recalls the definition of main merge operators by (Acher et al., 2010) and describes the way conceptual structures may be used to understand and to guide the merge operations (intersection and union). Section 4 describes a process that implements the approach, gives some illustrations of its application and investigates the scope of applicability. Section 5 details the related work. Section 6 concludes the document with some perspectives.

2 FCA FOR VARIABILITY REPRESENTATION

There are several means for representing feature-based variability, from configuration set, propositional logic, set of constraints (in Constraint Satisfaction Problem paradigm), to graph-based, or Feature Models (FMs) that can be considered a standard representation. Here we consider the FODA model (Kang et al., 1990), that is the most widely-used in the litterature.

2.1 Running Example

To illustrate the rest of the paper, we use the example of grid-based medical imaging services proposed in (Acher et al., 2010). The original feature model is denoted FM1 and we also introduce a variation of this feature model denoted FM1v, both feature models are presented in Figure 1.

Let us consider the FM1. It represents a service for medical imaging. The set of features is organized in a tree where the features are the nodes and the edges indicate various dependencies between features. The medical imaging service (MI) requires a modality (Mo) and a format (F). This mandatory relation is indicated through an edge ending with a black disk. The format (F) optionally needs a header (H), indicated by an edge ending with a white circle. The children of a feature may also be grouped into *xor groups* (if the parent feature belongs to a configuration, exactly one child feature of the group is also present) or into *or groups* (if the parent feature belongs to a configuration, one or more child features of the group are also present). An *xor group* is indicated by a black line connecting the edges going from the parent to the children. An *or group* (not present in this example) is indicated by a black filled zone connecting the edges going from the parent to the children. In this FM, the modality (Mo) imposes to choose exactly one image acquisition technique (*xor group*) among magnetic resonance imaging (MRI) or X-ray computed tomography (CT).

In another FM that appears later in the paper, another image acquisition technique, namely positron emission tomography (PET), will be proposed. The format (F) requires the anonymizing service and optionally a service for header addition (H). The header may be written using exactly one (*xor group*) of the medical image exchange standards: Digital Imaging and Communication in Medicine (DICOM) or Neuroimaging Informatics Technology Initiative (Nifti).

2.2 Applying Formal Concept Analysis

The two feature models of Figure 1 admit the same set of configurations, which is denoted by $[\![FM1]\!]=[\![FM1v]\!]$. This configuration set is shown in Table 1 in which we have a column per feature and a line per configuration and in which a cross for column c and line l means that configuration l owns the feature c. In the FCA framework, such a table is called a Formal Context.

Table 1: Formal context of the configuration set associated with FM1 and FM1v.

MI1	A	CT	D	F	H	MI	MRI	Mo	N
MI1c0	×	×	×	×	×	×		×	
MI1c1	×		×	×	×	×	×	×	
MI1c2	×	×		×		×		×	
MI1c3	×			×		×	×	×	
MI1c4	×	×		×	×	×		×	×
MI1c5	×			×	×	×	×	×	×

Definition 1 (Formal Context). *A formal context K is a 3-tuple (G,M,I), where G is an object (configuration) set, M an attribute (feature) set, and $I \subseteq G \times M$ is a binary relation which associates objects (configurations) with attributes (features) they own. For a context $K=(G,M,I)$, for $g \in G$ we will denote by $I(g)$ the set of features of g, i.e. the set $\{m \in M | (g,m) \in I\}$.*

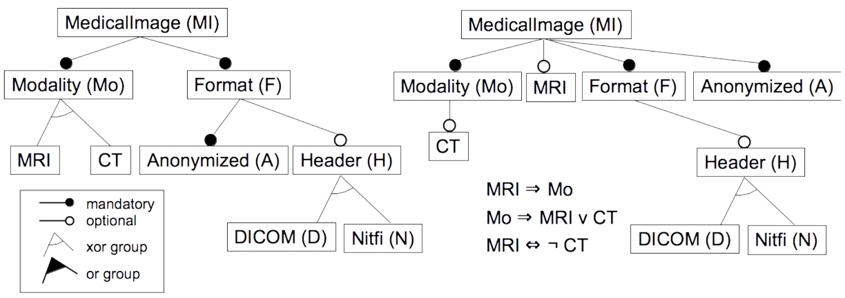


Figure 1: Left-hand-side: Feature Model FM1 from (Acher et al., 2010) (for a medical imaging service); Right-hand-side: one equivalent variation FM1v (with same set of configurations).

From the formal context, specialized algorithms from FCA framework extract *formal concepts*. A formal concept is a maximal group of objects associated with the maximal group of attributes they share. It can be read in the table of the context as a maximal rectangle of crosses (modulo permutations of rows and columns).

Definition 2 (Formal Concept). *Given a formal context $K = (G,M,I)$, a formal concept associates a maximal set of objects with the maximal set of attributes they share, yielding a set pair $C = (Extent(C), Intent(C))$ such that:*

- $Extent(C) = \{g \in G | \forall m \in Intent(C), (g,m) \in I\}$ *is the extent of the concept (objects covered by the concept).*
- $Intent(C) = \{m \in M | \forall g \in Extent(C), (g,m) \in I\}$ *is the intent of the concept (shared attributes).*

For example, $(\{MI1c1, MI1c5\}, \{MI, Mo, F, A, MRI, H\})$ is the concept that groups configurations MI1c1 and MI1c5 (concept extent) that share the features MI, Mo, F, A, MRI and H (concept intent).

The formal concepts are ordered using inclusing of their extent. Given two formal concepts $C_1 = (E_1,I_1)$ and $C_2 = (E_2,I_2)$ of K, the concept specialization/generalization order $\preceq_C$ is defined by $C_2 \preceq_C C_1$ if and only if $E_2 \subseteq E_1$ (and equivalently $I_1 \subseteq I_2$). C_2 is a specialization (a subconcept) of C_1. C_1 is a generalization (a superconcept) of C_2. Due to these definitions, C_2 intent inherits (contains) the attributes from C_1 intent, while C_1 extent inherits the objects from C_2 extent.

Definition 3 (Concept Lattice). *If we denote by $\mathcal{C}_K$ the set of all concepts of K, $\mathcal{L}_K$=($\mathcal{C}_K$, $\preceq_C$), is the concept lattice associated with K.*

The graphical representation of the concept lattice exploits the inclusion property (see Figure 2) to avoid representing in the concepts the top-down inherited features and the bottom-up inherited configurations. A concept is represented in this document in a three-part box. The top part contains the concept identifier (e.g. `Concept_MI1_10`), the middle part contains the features of the intent that are introduced by this concept (e.g. `CT`), the bottom part contains the configurations of the extent that are introduced by this concept (e.g. `MI1c2`). With inherited features, and configurations the whole concept is $Concept\_MI1\_10 = (\{MI1c2, MI1c0, MI1c4\}, \{MI, Mo, F, A, CT\})$.

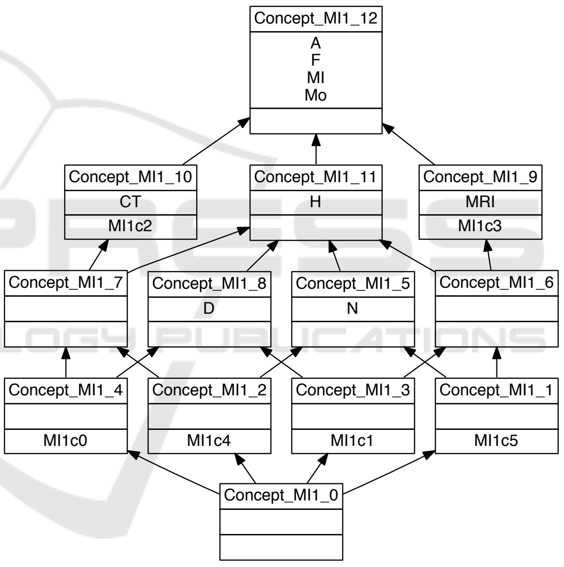
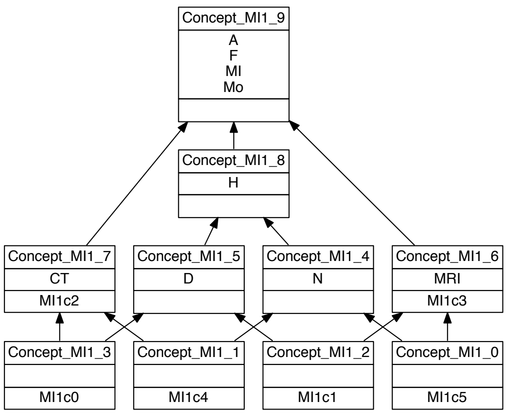


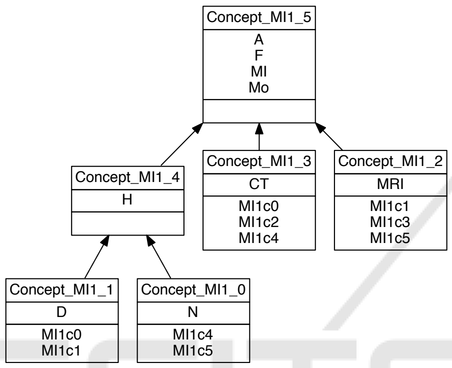
Figure 2: Concept lattice associated with Table 1.

Specific suborders can be isolated in the concept lattice, as the AOC-poset which contains only the concepts introducing at least one object (configuration), or at least one attribute (feature) (or both, see Figure 3 (a)), or the AC-poset which contains only the concepts introducing at least one attribute (feature) (see Figure 3 (b)). In the AOC-poset (as in the concept lattice) a configuration (resp. a feature) appears only once, thus we have a maximal factorization of configurations and features. In the AC-poset, one configuration (e.g. `MI1c4`) may appear several times, but features remain maximally factorized revealing a simplified structure.

Furthermore, if the formal context is exactly the set of valid configurations of an FM, conceptual struc-



(a) AOC-poset



(b) AC-poset presented with leaves labeled by the configurations

Figure 3: AOC-poset and AC-poset associated with formal context of Table 1.

tures represent, in a unique way, this configuration set: there is a unique concept lattice, a unique AOC-poset, a unique AC-poset representing the FM. Therefore, any FM with the same configuration set has the same associated conceptual structures. Thus if we consider the AOC-poset (which is a good compromise in size and in information presentation (no redundancy)) corresponding to FM1, FM1v and any other feature model with the same configuration set, all these FMs *conform* to it. This means that each dependency expressed in these feature models matches a dependency expressed in the corresponding AOC-poset. For instance, if there is a child-parent (f_c, f_p) in a FM, it belongs to the AOC-poset in this way: let C_c the concept introducing f_c and C_p the concept introducing f_p, $C_c \preceq_C C_p$.

2.3 Equivalence Class Feature Diagram

However, the posets are hardly readable and far from feature models. That is why we introduce another equivalent structure (the equivalence class feature diagram —ECFD), which is graphically closer to the feature models. An example of ECFD is shown in Figure 4, and the constructs and the semantics of the ECFD are given in Table 2. Firstly, part of the information of the ECFD comes from the concepts that introduce the features. In our example, MI, Mo, F and A are always together in configurations, thus a FM can contain any relation set between these without changing the semantics. MRI, CT and H can be connected to any feature among MI, Mo, F or A (edges going to

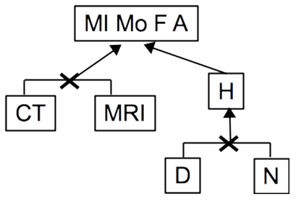
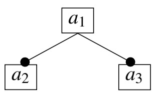
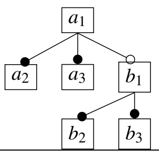
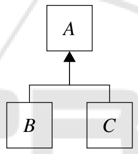
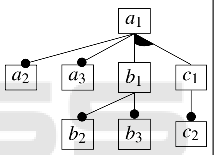
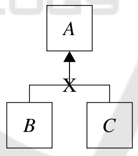
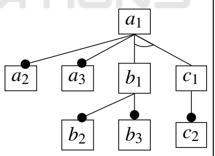
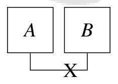
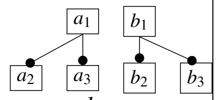


Figure 4: Equivalence class feature diagram (ECFD), alternative representation of the posets of Figure 3.

Table 2: Equivalence class feature diagram (ECFD): constructs and semantics. The third column gives an example of conform feature model with $n_A = n_B = 3$ and $n_C = 2$.

construct	semantics	ex. of conform FM
$A = \{a_1, \cdots, a_{n_A}\}$	features a_i are always present together (or absent)	
$A = \{a_1, \cdots, a_{n_A}\}$ $\uparrow$ $B = \{b_1, \cdots, b_{n_B}\}$	When b_i features are present, all a_i features are present as well	
	or-group: when a_i features are present, either the b_i are present, or the c_i are present, or the b_i and the c_i are present	
	xor-group: when a_i features are present, either the b_i are present, or the c_i are present (not both)	
	mutex: features a_i and features b_i are nether present together	 $a_1 \rightarrow \neg b_1$ $b_1 \rightarrow \neg a_1$

the entire box). D (resp. N) can be a child of H. Secondly, other information comes from the concepts that introduce the configurations and their subconcepts, as highlighted in (Ryssel et al., 2011). As the introducers of MRI and CT (resp. D and N) have no lower bound in the AOC-poset (or their lower bound is the bottom in the lattice), we deduce the mutual exclusion between them. We also observe in valid configurations (concepts introducing at least one configuration) the fact that one of both has to be present. Thus (MRI, CT) and (D, N) are *xor groups* in the ECFD.

Both FM1 and FM1v are conform to the ECFD of Figure 4 in the sense that their dependencies match the information extracted from it. Note that for FM1v, three constraints have to be added to the graphical representation in order to express the *xor* information.

The ECFD describes the equivalence class of FMs that have the same set of configurations, provides a graphical view and is pretty interesting to guide an expert from a configuration set to a satisfying FM. To assist the expert, a process should be developped so as to ease the derivation of a feature model, such a process is not described in this paper.

3 CONCEPTUAL STRUCTURES AND MERGE OPERATIONS

In this section, we detail how FCA can be used to assist merge (composition) operations on FMs.

3.1 Overview of Merge Operations

Several design situations may require FM composition, for example when several experts work on designing variability and independently develop their FMs with different concerns, or when several products have to be merged. Another reason comes from the need for product line decomposition. Indeed, for large product lines, it is hardly possible to describe the variability in a single, complex, feature model. To manage the complexity, the usually-adopted solution is apply the separation-of-concerns principle, decomposing the feature model at design time, each sub-feature model focusing on a given concern. Then the sub-feature models are to be composed back into a global feature model. For that, merge operations are needed. To focus the study, we consider the two merge operations that are defined in (Acher et al., 2010): merge-intersection and merge-union. In this work, the semantics of the merge operations is given using the configuration semantics.

Definition 4 (Merge Operations(Acher et al., 2010)).

- *The merge intersection operation, denoted by* $\cap$, *builds a feature model* FM_3 *from two feature models* FM_1 *and* FM_2 *such that* $[\![FM_3]\!]=[\![FM_1]\!]\cap[\![FM_2]\!]$.
- *The merge union operation, denoted by* $\cup$, *builds a feature model* FM_3 *from two feature models* FM_1 *and* FM_2 *such that* $[\![FM_3]\!]=[\![FM_1]\!]\cup[\![FM_2]\!]$.

Figure 5 illustrates these two merge operations on the medical imaging services presented in (Acher et al., 2010). We consider again the service whose variability is described by FM1v (Figure 1). The variability of another service of medical imaging is described by FM2 (on the right-hand-side of Figure 5). The set of configurations of FM2 is given in Table 3.

Table 3: FM2 configuration set (and formal context).

MI2	A	CT	D	F	H	MI	MRI	Mo	PET
MI2c0	×		×	×	×	×		×	×
MI2c1		×	×	×	×	×		×	
MI2c2				×		×		×	×
MI2c3	×	×	×	×	×	×		×	
MI2c4	×		×	×	×	×	×	×	
MI2c5	×			×		×		×	×
MI2c6			×	×	×	×	×	×	
MI2c7		×		×		×		×	
MI2c8	×	×		×		×		×	
MI2c9	×			×		×	×	×	
MI2c10				×		×	×	×	
MI2c11			×	×	×	×		×	×

Such operations are complex to perform based on the structure of FM since two feature models representing two close sets of configurations can be very different, as shown in Figure 5.

3.2 Definition of Merge Operations based on Conceptual Structures

Based on the definitions, our approach for building the intersection (resp. the union) of two feature models can be decomposed in three steps: 1) building the table representing the configurations that appear in the two initial feature models (resp. in at least one), 2) building the AC-poset associated with the obtained table, which describes the equivalence class of possible intersection (resp. union) feature models, and 3) extracting the ECFD from the AC-poset. The ECFD will be presented to the expert to guide him/her in choosing a FM representation. This approach absorbs,

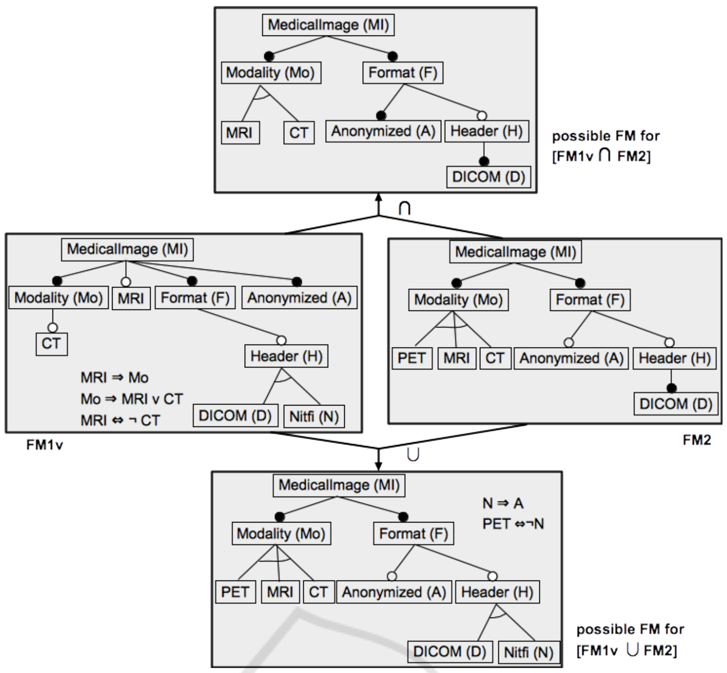


Figure 5: FM1v and FM2, with possible intersection and union Feature models. Figure adapted from (Acher et al., 2010).

during the merge operation, the differences in the structure and the representation choices of the feature models and their cross-tree constraints. We consider in the definitions of the rest of this section two formal contexts $K_1 = (G_1, M_1, I_1)$ and $K_2 = (G_2, M_2, I_2)$. K_1 and K_2 are supposed to be cleaned so that there do not exist two identical configurations (rows) in them.

3.2.1 Intersection Formal Context (Merge-intersection)

We first introduce the notion of equality of objects (configurations), denoted $\triangleq$, as objects having the same set of attributes.

Definition 5 (Equality of objects, $\triangleq$).

$$g_1 \triangleq g_2 \Leftrightarrow g_1 \in G_1, g2 \in G_2 \text{ and } I_1(g_1) = I_2(g_2)$$

In tables and figures, which are generated by tools, $MI1c0 \triangleq MI2c3$ is denoted by "MI1c0=MI2c3".

We then define the formal context associated with merge-intersection as the rows that are present in the two initial formal contexts. A labeling of rows is added to indicate their origin.

Definition 6 (Merge-intersection Formal Context). *The formal context of merge intersection* $Inter(K_1, K_2)$ *is* $K_{Inter(K_1,K_2)} = (G_{Inter(K_1,K_2)}, M_{Inter(K_1,K_2)}, I_{Inter(K_1,K_2)})$ *such that:*

- $G_{Inter(K_1,K_2)} = \{g_{g_1 \triangleq g_2} \mid \exists (g_1, g_2) \in G_1 \times G_2, g_1 \triangleq g_2\}$
- $M_{Inter(K_1,K_2)} = M_1 \cap M_2$
- $I_{Inter(K_1,K_2)} = \{(g_{g1 \triangleq g2}, m) \mid m \in M_{Inter(K_1,K_2)}, g_{g1 \triangleq g2} \in G_{Inter(K_1,K_2)}, (g1, m) \in I_1 (\text{or equiv. } (g2, m) \in I_2)\}$

Table 4 shows the merge-intersection formal context for the example. The corresponding AC-poset is presented in Figure 6. The extracted ECFD is presented in the l.h.s of Figure 7. From this ECFD, an expert can extract several FMs representing the intersection. In fact, to guide the designer in his/her choices, decorations can be added on the ECFD, like ontological relation of the initial feature models, or similar groups from the same parent or mandatory information. By choosing an ontological semantics to the ECFD, one derives a feature model description which conforms with this ECFD. Such a derivation is shown in the r.h.s of Figure 7, and the corresponding FM is represented in Figure 5 (top).

Table 4: Merge-intersection formal context.

Int12	A	CT	D	F	H	MI	MRI	Mo
MI1c0=MI2c3	×	×	×	×	×	×		×
MI1c1=MI2c4	×		×	×	×	×	×	×
MI1c2=MI2c8	×	×		×		×		×
MI1c3=MI2c9	×			×		×	×	×

3.2.2 Union Formal Context (Merge-union)

Let us now define the formal context associated with merge-union.

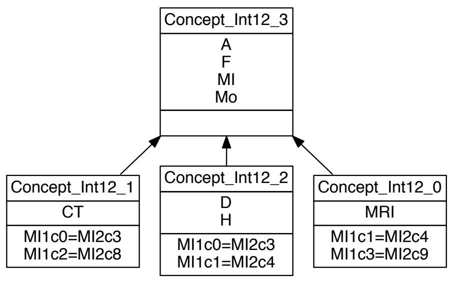


Figure 6: AC-poset associated with merge-intersection formal context of Table 4.

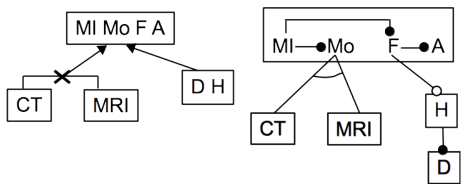


Figure 7: ECFD of AC-poset from Figure 6, and derivation of intersection FM from Figure 5 on ECFD.

Definition 7 (Merge-union Formal Context). *Let us consider:*

- *the set of common configurations (from Def. 6) $G_{Inter(K_1,K_2)}$ and the corresponding relation $I_{Inter(K_1,K_2)}$*
- *the set of configurations specific to G_1: $SPE(G_1) = \{g1 \mid g1 \in G_1 \text{ and } \nexists g2 \in G_2, with\ g_{g1 \triangleq g2} \in G_{Inter(K_1,K_2)}\}$*
- *the set of configurations specific to G_2: $SPE(G_2) = \{g2 \mid g2 \in G_2 \text{ and } \nexists g1 \in G_1, with\ g_{g1 \triangleq g2} \in G_{Inter(K_1,K_2)}\}$*

The formal context of merge-union $Union(K_1,K_2)$ is: $K_{Union(K_1,K_2)} = (G_{Union(K_1,K_2)}, M_{Union(K_1,K_2)}, I_{Union(K_1,K_2)})$ such that:

- $G_{Union(K_1,K_2)} = G_{Inter(K_1,K_2)} \cup SPE(G_1) \cup SPE(G_2)$
- $M_{Union(K_1,K_2)} = M_1 \cup M_2$
- $I_{Union(K_1,K_2)} = I_{Inter(K_1,K_2)}$
  $\cup \{(g,m) \mid g \in SPE(G_1), m \in M_{Union(K_1,K_2)}, (g,m) \in I_1\}$
  $\cup \{(g,m) \mid g \in SPE(G_2), m \in M_{Union(K_1,K_2)}, (g,m) \in I_2\}$

Table 5 shows the merge-union formal context for the example. The corresponding AC-poset is presented in Figure 8. The ECFD associated with the AC-poset is presented in the l.h.s of Figure 9. An expert can choose the union FM of Figure 5 (bottom) that can be derived from the ECFD as shown in the r.h.s of Figure 9.

4 IMPLEMENTATION AND VALIDATION

The approach has been implemented and validated with several feature models or variations of them,

Table 5: Merge-union formal context.

Union12	A	CT	D	F	H	MI	MRI	Mo	N	PET
MI1c0=MI2c3	×	×	×	×	×	×		×		
MI1c1=MI2c4	×		×	×	×	×	×	×		
MI1c2=MI2c8	×	×		×		×		×		
MI1c3=MI2c9	×			×		×	×	×		
MI1c4	×	×		×	×	×		×	×	
MI1c5	×			×	×	×	×	×	×	
MI2c0	×		×	×	×	×		×		×
MI2c1		×	×	×	×	×		×		
MI2c2				×		×		×		×
MI2c5	×			×		×		×		×
MI2c6			×	×	×	×	×	×		
MI2c7		×		×		×		×		
MI2c10				×		×	×	×		
MI2c11			×	×	×	×		×		×

taken from the SPLOT repository[1], from the Familiar [2] website, or from the literature. The process is presented in Figure 10 and uses Familiar for building the configuration set of an FM and rcaexplore[3] to build the AC-poset from which the ECFD structure (nodes and edges) is extracted. We also developed additional tools specific to this project: a first tool (`ConfigSet2FormalContext`) builds a formal context (within input format of rcaexplore) from a configuration set extracted from Familiar, a second tool (`ComputeInterAndUnion`) builds the intersection and union formal contexts, and a third tool (`ComputeGroupsAndMutex`) computes the groups `Xor`, `Or` and the `mutex` of the ECFD.

The goal of the experiments described in this section is to assess that the built structure, namely the ECFD, has humanely-tractable dimensions. Indeed, raw structures stemming from Formal Concept Analysis can hardly be handled by experts, due to their size. Here we measure the main characteristics of the obtained ECFD on a small benchmark and show that the numbers of groups of features and relations between the groups remain low, and thus that the ECFD can be used by an expert.

Table 6 shows the feature models on which we have tested our approach. For each feature model, we give the number of features, configurations, Xor groups, Or groups and constraints. We also compute the ECFD and indicate the number of Xor groups, Or groups, mutex and situations where a box in the ECFD has several direct parents (*multi-par.*). The number of groups, e.g. Xor groups, may vary be-

[1]http://www.splot-research.org/
[2]http://familiar.variability.io/
[3]http://dolques.free.fr/rcaexplore/

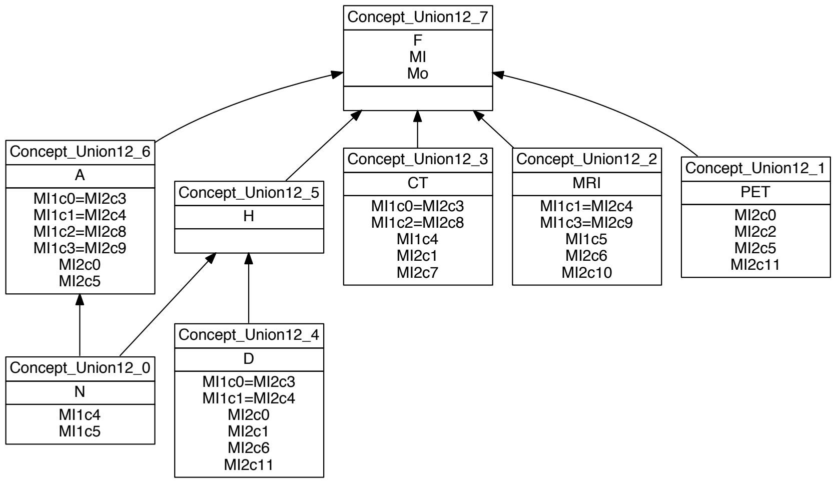


Figure 8: AC-poset associated with merge-union formal context of Table 5.

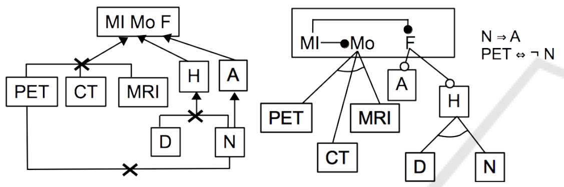


Figure 9: ECFD for AC-poset from Figure 8, and derivation of union FM from Figure 5 on ECFD.

tween the FM and the ECFD. For example, one Xor group of the ECFD may combine several Xor groups of the FM when there are additional constraints, or the ECFD may reveal more possible Xor groups than initially indicated in the FM.

Table 7 shows the information about ECFDs of the intersection (when it is not empty) and the union of the initial FMs that we obtain with our approach. As these ECFDs are intended to guide a designer towards a FM, it is important to notice that their size remains reasonable compared to the input FMs. The number of groups is not very high, and the number of mutex, except in three cases is also low. Multi-parent situations mainly offer two representation choices: implication or child-parent edge in the FM and they are very few.

Concept lattices, and thus, a fortiori, AOC-posets and AC-posets can be built for large datasets, e.g. in (Wray et al., 2016), the authors mention a large dataset, the Rijksmuseum collection which contains 100,000 objects and 1,716 attributes, giving 994,967 concepts computed in 68ms in average with FCbO update algorithm. The computation of the groups can be a hard task, as pointed out in (Ryssel et al., 2011). Many FMs have a very large configuration set, as Video player FM from SPLOT, with 71 features and more than 1 billion configurations. We do not address these cases, as we more specifically address the contexts where the FMs have a reasonable number of configurations, which corresponds in particular to FMs coming from real-world product lines. Concerning product lines inducing a number of configurations not tractable by FCA, our approach could benefit from product line decomposition: dividing a feature model according to scopes, concerns or teams into less complex interdependent feature models.

Product comparison matrices (PCMs) studied in (Bécan et al., 2014) give an overview of this type of dataset where many datasets could be investigated using our method: 75 PCMs, corresponding to 211 matrices that have 2 to 241 rows, and 3 to 51 possibly valued columns, with about 43% of the cells have boolean value (and the others should be translated into boolean features via FCA scaling (Ganter and Wille, 1999)).

5 RELATED WORK

Previous research work has used FCA for Software Product Line Engineering (SPLE), mainly in the context of reengineering concrete product lines. Feature model analysis or synthesis have been done in (Loesch and Ploedereder, 2007), (Ryssel et al., 2011), (Al-Msie'deen et al., 2014), (Shatnawi et al., 2015). In (Niu and Easterbrook, 2009), the authors present an approach based on aspect-oriented SPLE where they classify scenarios by functional requirements. Using FCA for feature location has been studied by (Xue et al., 2012), (Salman et al., 2013), and (Al-Msie'deen et al., 2013). Traceability links between features and code have been established by (Salman et al., 2013). Another available tool in the framework of FCA is the notion of implicative systems, already used in (Ryssel

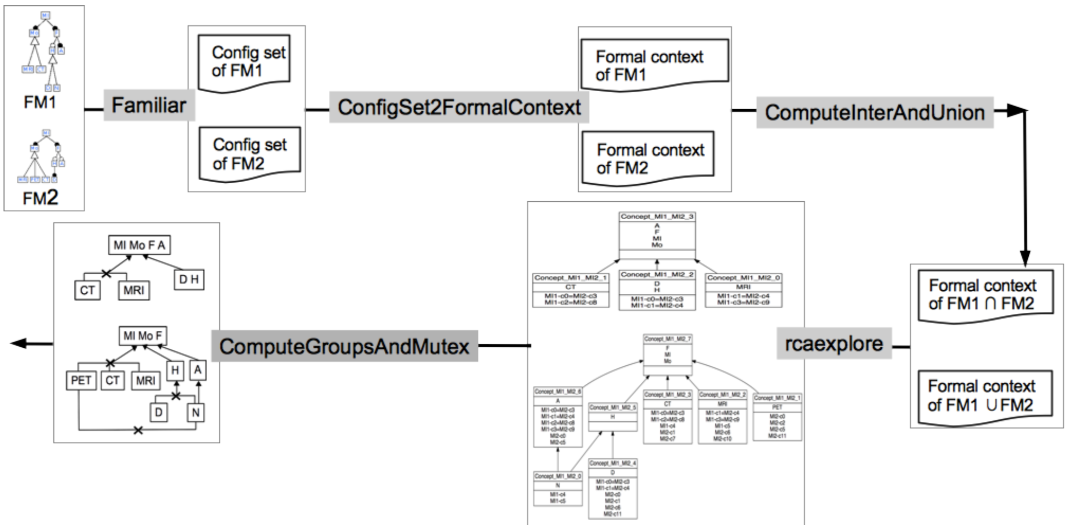


Figure 10: The implemented process.

Table 6: Features models (and the corresponding ECFD) used for testing the approach. *var.* stands for *variant*. *Cst* stands for *Constraint*.

FM	Feature Model					ECFD			
	#feat	#conf.	#Xor	#Or	# Cst	#Xor	#Or	#mutex	#multi-par.
MI1 (Acher et al.)	9	6	2	0	0	2	0	0	0
MI2 (Acher et al.)	9	12	1	0	0	1	0	0	0
Martini Eshop (SPLOT)	11	8	1	1	1	1	2	1	1
Tang Eshop (SPLOT)	10	13	1	1	2	1	2	1	1
Toacy Eshop (SPLOT)	12	48	1	2	0	1	2	0	0
Wiki V1 (Familiar example)	14	10	4	0	4	3	2	5	2
Wiki V2 (Wiki V1 var.)	17	50	4	1	4	6	13	1	1
Wiki V3 (Wiki V1 var.)	18	120	3	2	6	2	2	1	0
Bicycle1 (Mendonca SPLOT var.)	19	64	2	0	2	1	0	0	0
Bicycle2 (Mendonca SPLOT var.)	22	192	5	0	1	6	1	6	0
Bicycle3 (Mendonca SPLOT var.)	25	576	4	0	2	5	1	8	0
Bicycle4 (Mendonca SPLOT var.)	26	864	5	0	2	6	1	8	0

et al., 2011). This is another logical encoding of the formula underlying in (and equivalent to) a concept lattice (or a feature model), which can be rather compact. The paper (Carbonnel et al., 2016) gives a procedure to derive (in a polynomial time) an implicative system directly from a feature model, thus without using the configuration set which may be an obstacle in some cases as noticed by (Ryssel et al., 2011).

Acher et al. compare various approaches for FM model merging in (Acher et al., 2010) and (Acher et al., 2013). Some approaches, such as (Schobbens et al., 2007) and (Heymans et al., 2008) maintain separately the input feature models and establish links between them through constraints. The approach of (Acher et al., 2009) establishes, in a first phase, the matching between similar elements, then an algorithm recursively merges the feature models. Catalogs of local transformation rules are proposed in (Segura et al., 2007), (Alves et al., 2006). Other approaches encode the FMs into propositional formula (Batory, 2005), then compute the formula representing the intersection (resp. the union), then synthesize a FM from the boolean formula (Czarnecki and Wasowski, 2007). Logical formulas are equivalent to the conceptual structures we build, however, the introduced structure, namely the ECFD, has a graphical form closer to feature models, it is thus easier to derive a feature model from an ECFD than from logical formulas.

Our proposal can be analyzed with the criteria of (Acher et al., 2010). Concerning *quality of the result*: The configuration-semantics is preserved. The non-contradictory ontological child-parent edges are preserved. We do not reduce the set of features, except if some of them are not used, they will appear in the bottom concept and they can be eliminated. The result is not final in our case, an FM has to be chosen based on the ECFD. About criterion *Error handling*:

Table 7: Intersection and union ECFDs.

FM	Formal context		ECFD			
	#feat	#conf.	#Xor	#Or	#mutex	#multi-par.
MI1∩MI2	8	4	1	0	0	0
MI1∪MI2	10	14	2	0	1	1
Martini∪Tang	12	21	1	2	3	1
Martini∪Toacy	14	56	1	1	4	0
Tang∩Toacy	8	5	1	2	0	0
Tang∪Toacy	13	56	1	1	4	1
WikiV1∪WikiV2	20	60	5	9	26	0
WikiV1∪WikiV3	23	130	3	4	42	0
WikiV2∩WikiV3	14	50	0	6	0	0
WikiV2∪WikiV3	21	120	0	16	8	1
Bicycle1∩Bicycle2	14	8	1	0	0	0
Bicycle1∪Bicycle2	26	248	6	1	32	2
Bicycle3∩Bicycle4	23	288	5	1	8	0
Bicycle3∪Bicycle4	27	1152	6	1	8	0

errors like empty intersection are detected. When intersection is empty, the designer should conclude to an error or an incompatibility that he/she may want to fix. But in spite of empty intersection, feature models may have common parts in their structure, leading to incomplete configurations. The union, in this case, can be read to highlight such common parts. We do not make *Assumption on input FMs*: There is no specific assumption in our method. Cross-tree constraints are taken into account in the conceptual structures (implicitly, thanks to the position of the features or to the position of the configurations in subconcepts). When there are hierarchy mismatches, the AC-poset manages this information (see FM1 and its variant) but the vocabulary (feature names) has to be the same (it can be aligned before the merge operations). Then about *Aspects of the implementation*: The approach needs to know the list of configurations, thus as such, the proposed solution is restricted to some contexts: FMs that have limited number of configurations; real-world product lines given with configuration sets. There is no "testing" effort since the logical semantics is guaranteed by the FCA theory. The computational complexity is polynomial for AC-posets, in the size of the number of configurations and the number of features. As detailed by (Ryssel et al., 2011), group and *mutex* computation might be exponential in the number of configurations or features but remains reasonable in typical situations, with an optimized implementation.

6 CONCLUSION

In some design situations, combining various real-word product lines, or various FMs, given through their configuration set is a useful step in the design of a variability model. In this paper, we propose an approach, based on Formal Concept Analysis (FCA), that aims to assist a designer during this task. We exploit the properties of the AC-poset to build a canonical structure, the ECFD, which represents all the FMs with the same configuration semantics. The merge-intersection and merge-union operators are encoded in the framework of FCA, that allows us to compute the ECFD for intersection and union. These ECFDs may be used to guide the expert in deriving a representative feature model conform to the ECFD.

As a current work, we are designing the process for guiding the expert while building the feature model, in choosing the child-parent edges, the groups and the constraints among those that are included in the ECFD. Besides, the approach is currently based on a configuration set, but FCA offers other structures, such as the implicative systems. We are currently investigating the transformation of an FM into such an implicative system (without computing the configuration set), then the computation of the AC-poset and the groups and mutex of the ECFD from the implicative system. This will enlarge the scope of applicability of the approach to cases where the configuration set can hardly be computed. As a future work, we also would like to apply our method to other FMs, and to PCMs, which involves a substantial work to translates the many-valued cells into FCA framework and to synthesize associated FMs.

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