Three Way Merge for Feature Model Evolution Planning

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Abstract

[[TODO: write abstract]]

Feature Model Evolution Plans is intended to help ease the development of software product lines (SPLs). Feature Models allow software engineers to explicitly encode the similarities and differences of an SPL. However, due to the changing nature of an SPL, Evolution Plans allows for representing the *evolution* of a feature model, not just the feature model as a single point in time.

Evolution planning of an SPL is often a dynamic, changing process, due to changing demands of the focus of development. The evolution planning is often not just done by a single engineer, but multiple engineers, working separately and independent of each other. Due to these factors, the need to unify and synchronize the changes the evolution plan emerges.

In this thesis, we develop a merge tool for Feature Model Evolution Plans. The core of the tool is a three-way merge algorithm. Given two different versions of an evolution plan, together with the common evolution plan they were derived from, the merge algorithm will attempt to merge all the different changes from both versions. If the merges are unifiable, the algorithm will succeed and yield the merged result containing the changes from both versions. However, if the changes are conflicting in any way, breaking the structure or semantics of evolution plans, the algorithm will stop, telling the user the reason of failure.

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Preface

[[TODO: write better and more]] something about the LTEP project

something about summer project?

Chapter 1

Introduction

A *Software Product Line (SPL)* is a collection of closely-related software products. The different software products in the SPL have several things in common, as well aspects that separate them. As an software development paradigm, SPLs allows the developers to leverage the softwares commonalities and variabilities in order to improve a variety of factors.

This variability and commonalities can be captured by *feature models (FM)*, which uses *features* to capture the different aspects of an SPL. Each feature in the feature model corresponds to a certain increment in program functionality. The particular *variant* of the software product line is defined by a unique combination of features [1]. The feature model organizes the features in a tree structure to capture the variability of the SPL.

Since SPLs undergo continuous evolution, planning for the long-term evolution of a software product line is often crucial. The evolution of the SPL is mostly handled as an informal procedure relying on the intuition and experience of individual engineers. Without formal tools, long-term goals might not be addressed properly, increasing the risk of significantly increased development costs.

We address the lack of tools for long-term evolution planning with *feature model evolution plans*, or just *evolution plans*, which not only models the current feature model, but all intended future feature models. This allows engineers as well as non-technical stakeholders to have a concrete tool for planning the long-term development of the software product line. The evolution plan makes it possible to plan when certain features are introduced or removed, or simply changing the way the features are related to each other.

Planning the evolution of the software product line often involves multiple engineers changing and evolving the plan. Therefore, creating tools for evolution planning requires synchronization techniques for allowing collaborators to work independently. Naively integrating each persons changes to the evolution plan may yield inconsistencies and conflicts, so we investigate different merging strategies to ensure a sound, well-formed evolution plan is produced after the merge.

[[TODO: scope: her modellerer jeg bare planlegging.]] [[TODO: hvordan min oppgave skal leses.]]

1.1 Motivation

Evolution plans are designed to help engineers cope with the long-term evolution of software. Designing the software is an iterative and dynamic process, which is subject to change. Having several engineers working in parallel on the same evolution plan can be beneficial in handling the dynamic nature of evolution planning. This requires good synchronization tools for handling several engineers working and changing the evolution plan.

1.2 Objective

The objective of my thesis is to design and implement a three-way merge algorithm for evolution plans. To achieve an effective and accurate algorithm, good data structures and representations for evolution plans has to be chosen. The three-way merge algorithm will consider a base evolution plan, and two derived evolution plans, all following the formally defined structure and semantics. The algorithm will then try to merge the two derived plans, with the base model as a reference to what changes were made. Any conflict that occur when merging will be dealt with by consulting the user and providing options for what to do. When all conflicts are dealt with, a new merged evolution plan is produced, where the algorithm ensures that the merged plan follows the strict structure and semantics defined. This task is not trivial, and the algorithm should follow some specified heuristics to ensure a plan that follows the users intent as closely as possible, without creating an unnecessary amount of conflicts and warnings. The algorithm should also find a good balance between complexity and usability.

1.3 About the Project

ltep stuff blabla

1.4 Research Questions

As the goal of the thesis is to provide tools aiding developers and engineers cooperate in planning the evolution of a software product line, we propose some research questions (RQ). The research questions are concrete questions that we want to answer as a result of this thesis:

- **RQ1**: In what way should we represent an evolution plan in order to do an effective merge?
- **RQ2**: How should we design the three-way merge algorithm in order to produce a sound evolution plan?
- **RQ3**: How do we create a merge tool that produces predictable, transparent results?

1.5 Contributions

The main contribution of this thesis is a three-way merge algorithm for feature model evolution plans that ensures a well-formed, sound plan upon a successful merge. In order to achieve this, we have created a new representation of evolution plans more suitable for merging. With such a representation of evolution plans, the algorithm will include alterations from both derived versions, combining them into a single evolution plan, which are then checked to ensure a sound, well-formed evolution plan.

The three-way merge algorithm is implemented in the strongly-typed, functional programming language Haskell. The Haskell program is created as an *command line interface (CLI)*, to handle reading and writing from file, logging the output of the algorithm, checking for correct behaviour, etc. The CLI allows a variety of different input formats for the evolution plans, as well as the option for generating some predefined examples, both sound and unsound. Since feature models and evolution plans often are very hard to read in textual format, a frontend visualization tool has also been created using a language similar to Haskell, namely Elm. The Elm application is a web application that can display the evolution plans as visual tree structures, and lets users explore what the merge algorithm produces. Several examples and test cases have also been implemented, checking that the expected behaviour of the program matches the actual output.

To summarize, the contributions include:

- Created a formal definition of evolution plans suitable for merging
- Constructed a three-way merge algorithm producing sound, well-formed evolution plans
- Implemented the algorithm as part of a command line interface in Haskell
- Created a visualization tools for exploring the results of the merge in Elm
- Provided test cases and examples that results in both sound evolution plans and merge conflicts

1.6 Chapter Overview

Chapter 2 something about background

Chapter 4 something about the bigboy algo

[[TODO: WRITE]]

1.7 Project Source Code

All the source code from the master thesis can be found on Github[1].

[1] https://github.com/eirikhalvard/master-thesis

Chapter 2

Background

bakgrunn er ting vi vet i dag om spl. ikke blande inn min contribution i bakgrunn. tydelig skille. i bakgrunnseksjon: diskutere litt hvordan forskjellige merge teknikker har fordeler/ulemper.

2.1 Software product lines

A software product line (SPL) is a family of closely related software systems. These systems will often have several features in common, as well as variations that makes each piece of software unique. SPLs are used to make highly configurable systems, where each product in the SPL, called a *variant*, is defined by the combination of features chosen. Several large scale companies such as Hewlett-Packard and Nokia are finding remarkable quantitative improvements in product quality, customer satisfaction, and more by using a software product line approach [5].

Software product line engineering is a discipline for efficiently developing such families of software systems. Instead of maintaining potentially hundreds of different software artifacts, these engineering methods have ways of capitalizing on the similarities and differences between each variant. The number of variants are subject to combinatorial explosion, with additions of new features may double the amount of variants. Developing software product lines can be very time efficient, because you can maintain one code base, instead of one code base per variant. This simplifies additions of features or bug fixes greatly.

2.2 Feature Models

All possible variants of a software product line can be defined in terms of a *feature model*. A feature model is a tree structure of features and groups. Features can be mandatory or optional, and will contain zero or more groups. Each group has a set of features. A group (of features) can have different types. For example, in an `AND` group, all the features has to be chosen.

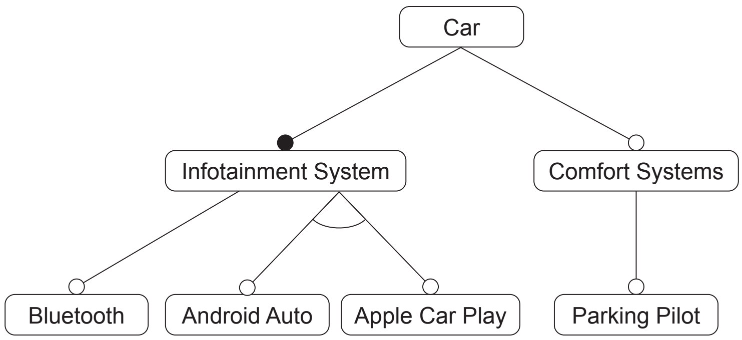


Figure 2.1: Example feature model

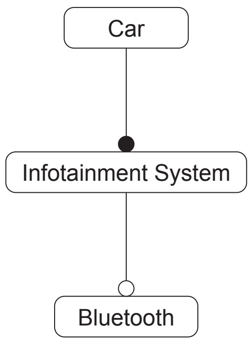
A visual representation of a feature model can be seen in Figure 2.1. The small dot above `Infotainment System` indicates that the feature is mandatory, where as the white dot above `Comfort Systems` represents an optional feature. Each feature (except the root) is in a group. The `Infotainment System` feature is in a singleton group below `Car`. The features `Android Auto` and `Apple Car Play` are in a `XOR` group, indicated by the arch between the features. This represents that each valid variant has to choose between one of the two (but not both).

2.3 Evolution planning

Feature models let engineers capture all variants of the current software product line, but sometimes it can be beneficial to model future or past versions as well. Planning for the long term evolution of the product line can be important in managing the complexity that comes with large software systems. Developing these kinds of systems typically involves many engineers, managers or other stakeholders, and managing when certain changes, additions or deprecations are implemented can be complex and confusing without suitable tools. Changing the SPL potentially influences many configurations, which might conflict with the stakeholders requirements.

SPL evolution is a major challenge in SPL engineering as many stakeholders are involved, many requirements exist, and changing the SPL potentially influences many configurations. Thus, it is paramount to thoroughly plan SPL evolution in advance, e.g., to perform analyses and to have enough time for implementing new or adapted features.

Evolution plans lets us model a sequence of feature models, which represents the current and all planned future versions of the feature model. Each feature model represents the product line in a point in time, which could have varying validity, from a week from now to a year. Since the next feature model is derived from the previous one, we can represent the evolution plan as an initial feature model, as well as a sequence of *points*, where each point is a set of operations to perform on the previous feature model to achieve the current one. The operations vary from changing, adding or deleting features or groups from the feature model.



At time 1:

add an XOR group to Infotainment System.
add feature Android Auto to the Infotainment System XOR group
add feature Car Play to the Infotainment System XOR group

At time 2:

add feature Comfort Systems to the Car AND group
add an AND group to Comfort Systems
add feature Parking Pilot to the Comfort Systems AND group

Figure 2.2: An example evolution plan

An example of an evolution plan can be seen in Figure 2.2. The initial feature model contains three features, and two time points are added. At time 1, a group and two features are added, and at time 2, another group and two features are added. The evolution plan can derive three feature models, the initial, and the two at time 1 and 2. Performing all the operations results in a feature model that is equal to the one in Figure 2.1 on page 6

2.4 Version Control Systems

Software configuration mechanisms is the discipline of managing the evolution of large and complex software systems [8]. *Version control mechanisms* are used to deal with the evolution of software products. These mechanisms include ways to deal with having multiple, parallel versions of the software simultaneously. Techniques like *software merging* are used to keep consistency and unify different versions by automatically or semi-automatically deriving merged versions of the different parallel versions.

Mens [4] categorizes and describes different aspect of version control systems and software merging techniques. Two-way and three-way merging differentiates between how many versions of the artifact you are comparing. Different representations of the merge artifact can be categorized in textual, syntactic, semantic or structural merging. State-based merge techniques uses delta algorithms to compute differences between revisions while change-based techniques keeps track of the exact operations that were performed between the revisions.

2.4.1 Two-way vs three-way merging

When merging different versions of a piece of software, we differentiate between *two-way* and *three-way* merging. Two-way merging merges the two versions without taking a common ancestor into account. Three-way merging on the other hand, uses a common ancestor as a reference point, to know how the different versions were changed. The latter technique is more powerful and produces more accurate merges, because the merge will know extra information from the common ancestor.

To illustrate the difference, consider the following program: `print(a); print(b); print(a + b)`, and two different versions derived from the base program, (1) `print(a); print(b); print(a+b); print("new line")`, (2) `print(b); print(a + b)`. Since a three-way merger uses the base program as a reference point, it will notice that derived version 1 added one statement, while version two deleted one. The three-way merger will then merge successfully without conflict with the following result: `print(b); print(a + b); print("new line")`. However, a two-way merger does not use the base program the different versions were derived from, and can not deduce whether `print(a)` were added in version 1 or deleted in version 2, thus raising a conflict. The same ambiguity occurs with the added statement `print("new line")`.

2.4.2 Textual merging

Textual merging views the software artifacts as unstructured text files. There exist several granularities of what is considered one unit, but *line-based merging* is probably the most common textual merge. Line-based merging techniques computes the difference between files by comparing equality over the lines. This has several implications, like adding a single space after a line is considered a deletion of the old line and addition of the new. This coarse granularity often leads to unnecessary and confusing conflicts. Changing the indentation or other formatting differences often lead to unnecessary conflicts.

To exemplify this, consider the two versions of a Python program, Listing 1 and Listing 2 on the following page. The second version simply wrapped the content of the function in an if-statement that checks for input sanity. Using a standard textual, line-based differencing tool like the Unix' *diff*-tool [3], we are able to calculate the difference between the two files by calculating the longest common subsequence. As seen in the result (Listing 3 on the next page), difference between the two are confusing and inaccurate. Conceptually, the difference is that the second version wrapped the block in a if-statement. Due to the coarse grained line-based differencing and the disregard of structure and semantics, the algorithm reports that the whole block is deleted, and the same block wrapped in an if is inserted.

```python
def some_function(n):
  sum = 0
  for i in range(0, n):
    sum += i
  print(sum)
some_function(5)
```

Listing 1: Code diff 1

As discussed, text-based merge techniques often provide inferior results, however, they have several advantages in terms of efficiency and generality. The algorithm is general enough to work well for different programming languages, documentation, markup files, configuration files, etc. Some measurements performed on three-way, textual, line-based merge

```
def some_function(n):
  if isinstance(n, int):
    sum = 0
    for i in range(0, n):
      sum += i
    print(sum)
some_function(5)
```

Listing 2: Code diff 2

```
<   sum = 0
<   for i in range(0, n):
<     sum += i
<   print(sum)
---
>   if isinstance(n, int):
>     sum = 0
>     for i in range(0, n):
>       sum += i
>     print(sum)
```

Listing 3: Resulting code diff

techniques in industrial case studies showed that about 90 percent of the changed files could be merged automatically [6]. Other tools can complement the merge algorithm in avoiding or resolving conflicts. Formatters can make sure things like indentation and whitespace are uniformly handled, to avoid unnecessary conflicts. Compilers can help in resolving conflicts arising from things like renaming, where one version renames a variables, while another version introduces new lines referencing the old variable.

2.4.3 Syntactic Merging

Syntactic merging [2] differs from textual merging in that it considers the syntax of the artifact it is merging. This makes it more powerful, because depending on the syntactic structure of the artifact, the merger can ignore certain aspects, like whitespace or code comments. Syntactic merge techniques can represent the software artifacts in a better data structure than just flat text files, like a tree or a graph. In example, representing the Python program from Listing 1 on the preceding page and Listing 2 as a parse tree or abstract syntax tree, we can avoid merge conflicts.

The granularity of the merger is still relevant, because we sometimes want to report a conflict even though the versions can be automatically merged.

Consider the following example. $n < x$ is changed to $n \leq x$ in one version, and to $n < x + 1$ in another. Too fine grained granularity may cause this to be merged conflict free as $n \leq x + 1$. The merge can be done automatically and conflict free, but here we want to report a warning or conflict, because the merge might lead to logical errors.

2.4.4 Semantic Merging

While syntactic merging is more powerful than its textual counterpart, there are still conflicts that go unnoticed. The syntactical mergers can detect conflicts explicitly encoded in the tree structure of the software artifact, however, there often exist implicit, cross-tree constraints in the software. An example of such a constraint is references to a variable. The variable references in the code are often semantically tied to the definition of the variable, where the name and scope implicitly notes the cross tree reference to the definition.

Consider the following simple program: `var i; i = 10;`. If one version changes the name of the variable: `var num; num = 10;`, and another version adds a statement referencing the variable: `var i; i = 10; print(i)`. Syntactic or textual mergers would not notice the conflict arising due to the implicit cross-tree constraints regarding the variable references, and merge the versions conflict-free with the following, syntactically valid result: `var num; num = 10; print(i)`.

Semantic mergers takes these kinds of conflicts into consideration while merging. Using *Graph-based* or *context-sensitive* merge techniques, we can model such cross tree constraints, by linking definitions and invocations with edges in the graph. However, in some cases, such *static semantic* merge techniques are not sufficient. Some changes cannot generally be detected statically, and may need to rely on the runtime semantics.

2.5 Haskell and Algebraic Data Types

[[TODO: write about type synonyms, data types including records and sum types. show polymorphic data types. maybe something about deriving, maybe lens generation? etc. something about maybe? expressive and strict type system]]

2.6 Problem Definition

Chapter 3

Formal Semantics of Feature Model Evolution Plans

As stated in **RQ2** in section 1.4 on page 3, we want design the merger in a way that guarantees a sound merge result. In order to do so, we need to have a clear, formal definition of the software artifact at hand, namely feature model evolution plans.

The formal structure and semantics of evolution plans are defined in a paper published in the Software Product Line Conference (SPLC)[1], which I was fortunate enough to contribute to [7]. The paper defines the evolution plan as an initial feature model, together with an ordered list of planning sections containing all edit operations that are scheduled for the same time point. The edit operations include addition and deletion of features and groups, as well as modifications to their fields, such as names or types. For every operation, we defined what makes an operation valid or invalid according to the formal definitions of feature models.

In the work in this thesis, I will build upon, alter and extend the definitions and semantics of evolution plans defined in the other work I have contributed to. The semantics of editing operations were defined to create a soundness checker for evolution plans, which is used as a tool aiding replanning of evolution plans. However, since the focus of this thesis is to harmonize different alterations to evolution plan, we will need to adapt the evolution plan representation to fit this task.

[1] https://splc.net/

3.1 Issues with using a list-based approach

In our work on creating a soundness checker for evolution plans, we used a representation where the ordering of the operations for a single point in time mattered. This list-based approach of grouping operations had several advantages regarding the formal definition of sound evolution plans as well as implementation-specific concerns. In defining what was considered a well-defined operation, we considered only the current feature model and the operation at hand. What order the user applied the operations did not really matter, as long as applying each operation resulted in a sound evolution plan.

However, when we design an approach to merging two evolution plans, the exact way each feature model in the evolution plan was derived is besides the point. The only thing the user sees are a list of feature models associated with time points. Exactly how the evolution plan was manipulated, and in what order each editing operation took place is not relevant for the user, so it should also not be relevant for the merge algorithm. As described in **RQ3** in section 1.4, we want to produce merge results that are predictable and transparent. Having a list-based approach might make it hard to differentiate equal plans. Since there often is more than one way of going from one feature model to another, seemingly equal evolution plans might be represented differently.

Since part of the goal is to produce a sound result, we cannot simply rearrange the ordering of operations without complications. Some operations might be dependent on other operations, and rearranging the operations might result in an unsound plan.

To counter these issues, one might naïvely find an standardized ordering of operations so one could sort the operations, or simply just store them as a set of operations instead of a list. However, as we will see, the order of the operations still matter, and changing the ordering can have varying effects. We observe three different ordering related scenarios for operations; non-dependent operations, dependent operations, and shadowed operations. By swapping the operations in a plan, you might achieve one of these scenarios. In the following sections, We investigate the scenarios in the following sections, which is also illustrated in Figure 3.1.

Non-dependent Operations

In some cases, swapping the order of the operations in a time point has no effect on the resulting feature model. To exemplify this, take a simple feature model with two features and a group, organized in the following way: `Root` → `G1` → `F1`. In the following time point, there is scheduled a removal of feature `F1` as well as a name change for the root feature `Root` to `F0`. Applying both operations should yield the following feature model: `F0` → `G1`. Since there is no structural or semantic relation between the operations, the order of when they are applied makes no difference. With the current list-based representation of a plan for a single time point, there are two ways of representing the changes. You could either schedule the removal of the `F1` feature first, or the name change of the root feature first.

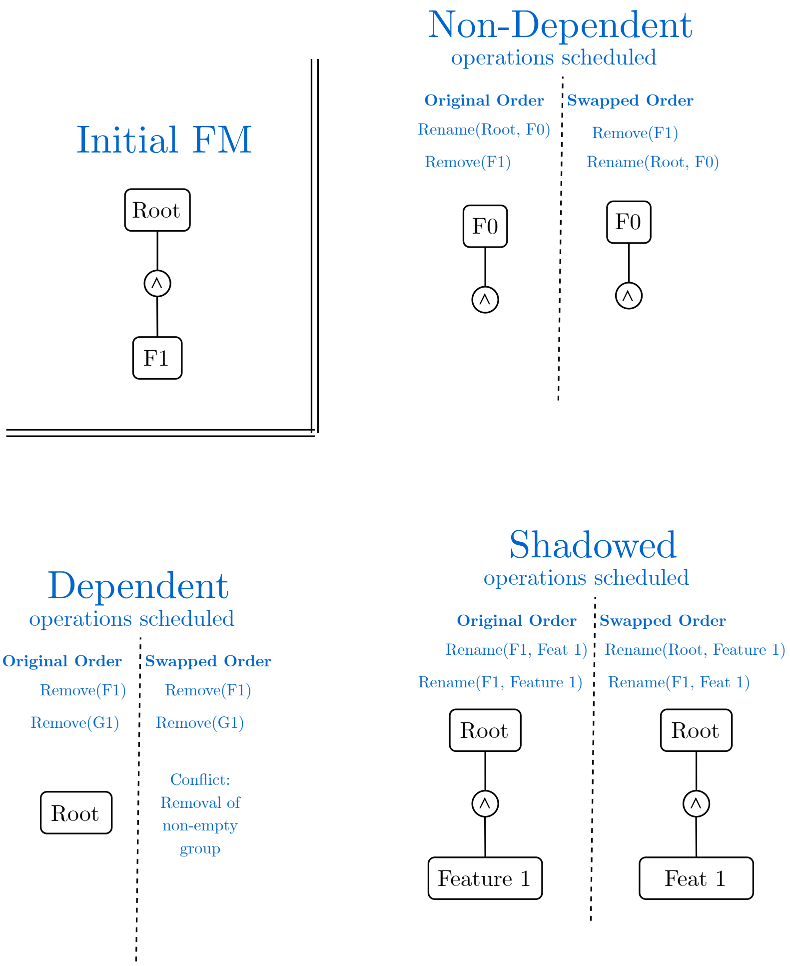


Figure 3.1: The various effects of swapping the ordering of operations

Dependent Operations

To showcase the problem, we start with the same feature model used previously, with two features and a group: `Root` → `G1` → `F1`. In the next planned time point, the changes to the feature model include the removal of both group G1 and feature F1. However, there is only one legal ordering, namely removing the feature first, then removing the group. Applying the operation in this order yields a sound feature model; Root. Trying to remove the group first will as we defined sound evolution plans yield an inconsistency, because we are trying to remove a non-empty group.

Operation Shadowing

Another issue with the list-based approach is *operation shadowing*, which is the phenomenon where an operation is rendered useless because of another operation later in the list. This issue would also have to be considered, because rearranging the operation could lead to unwanted results. In addition to rearrangement resulting in unsound plans, moving a shadowed operation might result in a different, yet sound evolution plan.

We exemplify operation shadowing, we consider the same initial feature model as before: Root $\rightarrow$ G1 $\rightarrow$ F1. The list of operations for the next point in time include first changing the name of F1 to Feat 1, then later to Feature 1. The operation shadowing occurs because of the second renaming makes the first renaming completely useless. The resulting feature model, Root $\rightarrow$ G1 $\rightarrow$ Feature 1, are identical to the one we would have if we excluded the shadowed operation. However, if we were to swap the ordering of the rename operations, the resulting feature model would still be sound, but differ from the original ordering: Root $\rightarrow$ G1 $\rightarrow$ Feat 1.

3.2 Constructing a Normal Form for Evolution Plans

In order to avoid the problems stated above, we construct a new representation for evolution plans. This representation is more aligned with what the user interacts with, so equal plans are also represented equally. In this representation, called TreeUserEvolutionPlan, the evolution plan is represented as a list of feature models together with a time point. Instead of storing the operations necessary to go from the previous time point to the next, each feature model is explicitly encoded. Each feature model is represented as a mutually recursive tree structure of features and groups. This representation is the normal form of evolution plans, and the closest representation to what the user actually interacts with.

The exact representation of `TreeUserEvolutionPlan` are defined formally in the Haskell code. Haskell's powerful type system with records and algebraic data types allows for a pretty precise formalization. When presented here in the thesis, the types are somewhat simplified, leaving out unnecessary noise, such as automatically derived instances for JSON serialization, equality checking, etc.

3.2.1 Feature Model Definition - Tree Representation

First, we will look at the tree representation for feature models, formalized as `TreeFeatureModel`.

```haskell
data TreeFeatureModel = TreeFeatureModel
  { rootFeature :: TreeFeature
  }

data TreeFeature = TreeFeature
  { id :: FeatureId
  , featureType :: FeatureType
  , name :: String
  , groups :: Set TreeGroup
  }

data TreeGroup = TreeGroup
  { id :: GroupId
  , groupType :: GroupType
  , features :: Set TreeFeature
  }

data FeatureType
  = Optional
  | Mandatory

data GroupType
  = And
  | Or
  | Alternative

type FeatureId = String

type GroupId = String
```

There is a few important things to note in this representation. Each feature and groups id is unique across the entire feature model, which we will leverage when merging. Each feature and group can have an arbitrary number of children. The children is organized in a `Set`, not a `List`, noting that the ordering is irrelevant. In order for the feature model to be sound, some combination of parent group type and child feature types are prohibited. If a group is of type `Alternative` or `Or`, every child feature has to be of type `Optional`.

3.2.2 Evolution Plan Definition - User Level, Tree Representation

Polymorphic User Level Evolution Plan

Now that we have a suitable definition feature models, we define evolution plans. In this representation, we want the evolution plans to mirror what the user interacts with, so we define the evolution plan as a list of feature models. In later stages of the merge algorithm, we will reuse this *user level* definition of evolution plans, only with a different definition of feature models. This allows us to leverage Haskell's polymorphic type system, which spares us from defining it twice.

```
data UserEvolutionPlan featureModel = UserEvolutionPlan
  { timePoints :: [TimePoint featureModel]
  }

type Time = Int

data TimePoint featureModel = TimePoint
  { time :: Time
  , featureModel :: featureModel
  }
```

Instantiated User Level Evolution Plan (Tree Feature Model)

Now that a generalized representation for evolution plans are defined, using a representation with a list of feature models, we can instantiate the polymorphic evolution plan to create our normal form, `TreeUserEvolutionPlan`. This is relatively straight forward, the only thing we have to do is replace the `featureModel` argument with our concrete feature model, namely `TreeFeatureModel`.

```
type TreeUserEvolutionPlan = UserEvolutionPlan TreeFeatureModel
```

3.2.3 Example Representation

Now that we have defined the normal form for evolution plans formally, we will give a concrete example and how it is represented in this formalization. The example we will showcase is a small example containing three time points. The initial feature model at time 0 is simply just the root feature. The next time point at time 1 adds a new group and two features belonging to this group. The last time point removes one of the features and alters the name of the root and type of the group. A visualization of this simple evolution plan can be seen in Figure 3.2 on the next page. Below is the Haskell code necessary for encoding this example.

```haskell
simpleExample :: TreeUserEvolutionPlan
simpleExample =
  UserEvolutionPlan
    [ TimePoint 0 fm0
    , TimePoint 1 fm1
    , TimePoint 2 fm2
    ]
  where
    fm0 =
      TreeFeatureModel
        ( TreeFeature
            "rootFeature"
            Mandatory
            "Feature 1"
            []
        )
    fm1 =
      TreeFeatureModel
        ( TreeFeature
            "rootFeature"
            Mandatory
            "Feature 1"
            [ TreeGroup
                "group"
                And
                [ TreeFeature
                    "feature2"
                    Optional
                    "Feature 2"
                    []
                , TreeFeature
                    "feature3"
                    Mandatory
```

```
                  "Feature 3"
                  []
              ]
          ]
      )
fm2 =
  TreeFeatureModel
    ( TreeFeature
        "rootFeature"
        Mandatory
        "Root Feature"
        [ TreeGroup
            "group"
            Or
            [ TreeFeature
                "feature2"
                Optional
                "Feature 2"
                []
            ]
        ]
    )
```

Note that each feature and groups `Set` of children are constructed using list syntax. This is to make it a bit easier to read, not having too much visual clutter. This is possible using the language extension `OverloadedLists` [2], where we allow Haskell's type system to figure out that the list is actually a `Set` based on the context.

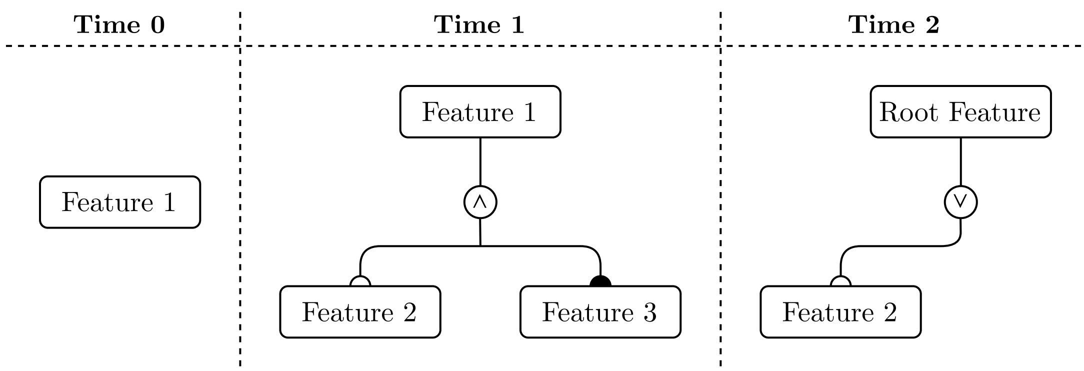


Figure 3.2: A Simple Evolution Plan Example

[2]https://ghc.gitlab.haskell.org/ghc/doc/users_guide/exts/overloaded_lists.html

3.3 A Suitable Representation of Evolution

The evolution plan formalization defined above, `TreeUserEvolutionPlan`, works well for capturing the essence of evolution plans. It represents evolution plans in terms of what the user actually deals with. However, in order to do an effective merge of two evolution plans, we need to represent the evolution plan a bit differently.

Refactoring the evolution plan doesn't just involve modifying the last time point, but replanning the other time points earlier in the plan. When users are replanning such time points, the additions, deletions and modifications has an effect not just on the time point at hand, but all subsequent time points. When a user adds a new feature in the middle of the plan, the feature would appear on the specified time points as well as all the time points beyond. When calculating the changes made, we don't want to look at this like a feature was added in all the time points, but rather just the specified time. In order to capture the essence of the changes made to each evolution plan, we would need to find a representation capturing the actual changes more explicitly.

In order to to capture the explicit modifications between each time point in the evolution plan, we would need to figure out an approach to calculating the difference between two subsequent feature models. However, with our current tree-based feature model, `TreeFeatureModel`, this can be a bit cumbersome, requiring us to traverse the two trees simultaneously. In some cases this is not very straight forward, i.e. handling `Move`-operations that relocates entire subtrees.

3.3.1 Feature Model Definition - Flat Representation

We define a new representation for feature models, `FlatFeatureModel`, in order to have a structure better suited for detecting and applying changes to the tree-structure. This is achievable due to our features and groups having unique ids. This allows for a simple mapping-structure, where we each feature and group can be looked up by its id. The edges and relations in the tree are modeled as node-id references instead of a recursive structure. Every node only stores its parent relation, not its child relations as well. This makes moving entire subtrees straight forward, requiring changing only the parent-field of the node to move.

```
data FlatFeatureModel = FlatFeatureModel
  { rootId :: FeatureId
  , features :: Map FeatureId FlatFeature
  , groups :: Map GroupId FlatGroup
  }
```

```
data FlatFeature = FlatFeature
  { parentGroupId :: Maybe GroupId
  , featureType :: FeatureType
  , name :: String
  }

data FlatGroup = FlatGroup
  { parentFeatureId :: FeatureId
  , groupType :: GroupType
  }
```

The definitions of `FeatureType`, `FeatureId`, `GroupType` and `GroupId` is still the same as defined in Section 3.2.1 on page 16.

3.3.2 Evolution Plan Definition - User Level, Flat Representation

With our new, flat representation for feature models, we can use this to create a new user level representation, with our flat structure instead of the tree-based. Since we created a generalized data type, `UserEvolutionPlan`, we can instantiate it in the following way.

```
type FlatUserEvolutionPlan = UserEvolutionPlan FlatFeatureModel
```

With this new representation for evolution plans, the example from Figure 3.2 on page 19 can be encoded in the following way:

```
simpleExampleFlat :: FlatUserEvolutionPlan
simpleExampleFlat =
  UserEvolutionPlan
    [ TimePoint 0 fm0
    , TimePoint 1 fm1
    , TimePoint 2 fm2
    ]
  where
    fm0 =
      FlatFeatureModel
        "rootFeature"
        [
          ( "rootFeature"
          , FlatFeature Nothing Mandatory "Feature 1"
          )
        ]
        []
```

```haskell
fm1 =
  FlatFeatureModel
    "rootFeature"
    [
      ( "feature2"
      , FlatFeature (Just "group") Optional "Feature 2"
      )
    ,
      ( "feature3"
      , FlatFeature (Just "group") Mandatory "Feature 3"
      )
    ,
      ( "rootFeature"
      , FlatFeature Nothing Mandatory "Feature 1"
      )
    ]
    [("group", FlatGroup "rootFeature" And)]
fm2 =
  FlatFeatureModel
    "rootFeature"
    [
      ( "feature2"
      , FlatFeature (Just "group") Optional "Feature 2"
      )
    ,
      ( "rootFeature"
      , FlatFeature Nothing Mandatory "Root Feature"
      )
    ]
    [("group", FlatGroup "rootFeature" Or)]
```

Each feature model in the evolution plan consists of a reference to the root feature id, as well as two `Maps`. Using the `OverloadedLists` extension, each Map is noted by a list of tuples, where the first part of the tuple is the id of the feature or group, and the second part is the fields of the feature or group.

Advantages over the tree structured evolution plan

The new definition of feature models has advantages we will make deriving and integrating modifications between two subsequent feature models easier.

Since we have a flat structure, deriving or integrating modifications on a feature or group saves us from traversing the tree structure. The flat structure leverages the unique ids in order to allow lookup based on id. Changing a feature or group requires a lookup based on the id, then changing the fields of the mapping entry. Removing or adding a node is similarly simple, requiring only adding or removing an entry in the mapping. Since the edges in the tree are modeled as references to the parent id, we don't need to modify the parent node when removing a node.

The flexible flat structure allows for temporarily damaging the tree-structure, which allows for applying modifications in an arbitrary order. We recall some of the issues related to the list-based operations in Section 3.1, where some dependent operations had to be applied in a specific order, i.e. adding the parent feature before adding the child group. Since the tree-structure of our `FlatUserEvolutionPlan` is implicit through the node-id references, we could simply add the child feature first, with a reference to the parent id, then directly after add the parent id. We just have to ensure that all the operations we apply will result in a sound feature model.

3.3.3 Evolution Plan Definition - Modification Level, Flat Representation

As discussed in Section 3.1, the list-based operation approach is problematic in order to achieve a desired merge result. What the user perceived as equal plans had several representations. In order to combat this we created a normal form for evolution plans, `TreeUserEvolutionPlan`, more aligned with the users perspective of evolution plans. Since tree-based structure of its feature models had some disadvantages in terms of detecting and applying modifications, we created a new representation for feature models, which we used in our intermediate representation for evolution plans, `FlatUserEvolutionPlan`.

However, the user level evolution plan representation with the list of feature models for each time point didn't model the replanning aspect of evolution plans as we wanted. When users have to go back to intermediate time points in the evolution plan and make changes, the changes will appear in the subsequent time points as well. This requires modeling the evolution plan similar to the list-based operation approach discussed previously, while still avoiding the issues regarding operation ordering, operation shadowing, etc.

We present the final evolution plan representation, `FlatModificationEvolutionPlan`, modeling the evolution plan as an initial model along with an ordered list of time points associated with *modifications*. The modifications model the changes necessary to go from the previous feature model to the one in the specified time point. The modifications consists of two mappings, one for features and one for groups. Each mappings map ids to a *modification*. A modification can be one of three things, an addition, deletion or a change to one or more fields.

The Haskell representation of our `FlatModificationEvolutionPlan` can be seen below.

```
data TransformationEvolutionPlan transformation featureModel =
  TransformationEvolutionPlan
    { initialTime :: Time
    , initialFM :: featureModel
    , plans :: [Plan transformation]
    }

data Plan transformation = Plan
  { timePoint :: Time
  , transformation :: transformation
  }

type ModificationEvolutionPlan featureModel =
  TransformationEvolutionPlan Modifications featureModel

type FlatModificationEvolutionPlan =
  ModificationEvolutionPlan FlatFeatureModel
```

Notice that the actual types are generalized in two ways. As with our user level representation, we have made the evolution plan polymorphic over the feature model. In addition, we have generalized the actual transformation type necessary to go from one feature model to the next. This is useful for the actual merge algorithm, which will reuse the evolution plan with another transformation type. With the evolution plan structure in place and our newly defined `ModificationEvolutionPlan`, we can define `Modifications` in the following way:

```
data Modifications = Modifications
  { features :: M.Map FeatureId FeatureModification
  , groups :: M.Map GroupId GroupModification
  }

data FeatureModification
  = FeatureAdd GroupId FeatureType String
  | FeatureRemove
  | FeatureModification
      (Maybe FeatureParentModification)
      (Maybe FeatureTypeModification)
```

```haskell
      (Maybe FeatureNameModification)

data FeatureParentModification
  = FeatureParentModification GroupId

data FeatureNameModification
  = FeatureNameModification String

data FeatureTypeModification
  = FeatureTypeModification FeatureType

data GroupModification
  = GroupAdd FeatureId GroupType
  | GroupRemove
  | GroupModification
      (Maybe GroupParentModification)
      (Maybe GroupTypeModification)

data GroupParentModification
  = GroupParentModification FeatureId

data GroupTypeModification
  = GroupTypeModification GroupType
```

Example representation

With our final, merge ready representation of evolution plans, we can encode the simple example in the defined data types. A visual representation of the example can be seen in Figure 3.3

```haskell
simpleExampleMod :: FlatModificationEvolutionPlan
simpleExampleMod =
  TransformationEvolutionPlan
    0
    initial
    [Plan 1 modifications1, Plan 2 modifications2]
  where
    initial =
      FlatFeatureModel
        "rootFeature"
        [
          ( "rootFeature"
          , FlatFeature Nothing Mandatory "Feature 1"
          )
```

```
    ]
    []
modifications1 =
  Modifications
    [
      ( "feature2"
      , FeatureAdd "group" Optional "Feature 2"
      )
    ,
      ( "feature3"
      , FeatureAdd "group" Mandatory "Feature 3"
      )
    ]
    [("group", GroupAdd "rootFeature" And)]
modifications2 =
  Modifications
    [ ("feature3", FeatureRemove)
    ,
      ( "rootFeature"
      , FeatureModification
          Nothing
          Nothing
          (Just (FeatureNameModification "Root Feature"))
      )
    ]
    [
      ( "group"
      , GroupModification
          Nothing
          (Just (GroupTypeModification Or))
      )
    ]
```

[[TODO: kan snakke om operasjonene, hva de betyr på høynivå. referere til artikkel for detaljer.]] [[TODO: arbeid er basert på sunn plan.]]

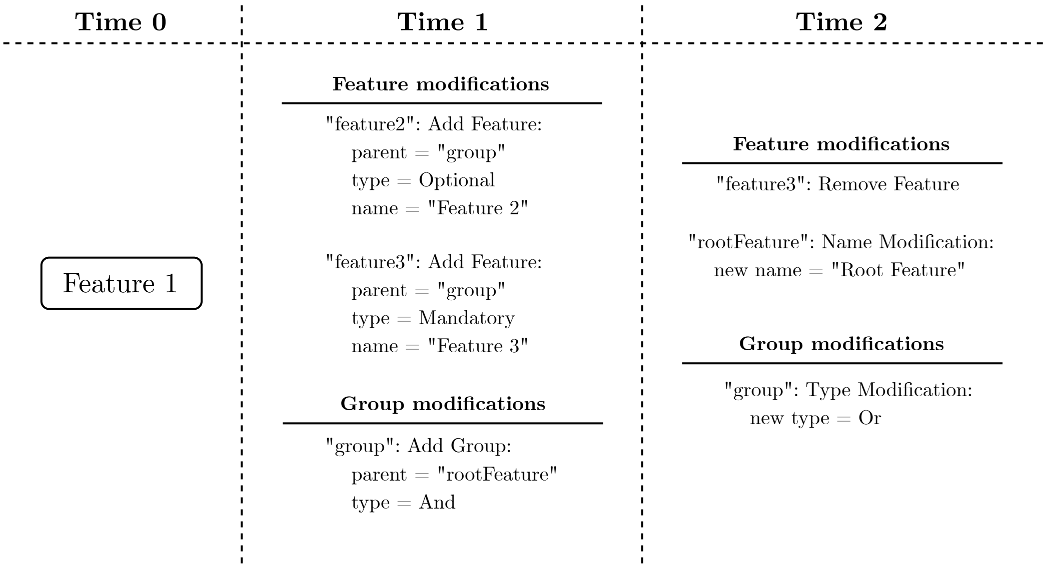


Figure 3.3: A Simple Evolution Plan Example

Chapter 4

Three Way Merge Algorithm

4.1 Algorithm Overview

4.1.1 Three-Way Merging of Evolution Plans

The three-way merge algorithm for feature model evolution plans will take two different versions of an evolution plan, *version 1* and *version 2*, and attempt to merge the evolution plans into a single plan. In order to do so, a third evolution plan has to be provided, which is the common evolution plan they were derived from. The common evolution plan, called *base*, will implicitly provide information about what things were added, removed and changed in each of the derived evolution plans.

4.1.2 Soundness Assumption

The three-way merge algorithm will assume that the three evolution plans provided are sound. By assuming the soundness of the plans, the algorithm can leverage this to create a better merge result. But more importantly, the assumption is based around the fact that there is no point in merging an evolution plan you know violates soundness in some way.

4.1.3 Algorithm Phases

In order to merge the different versions of the evolution plan, the algorithm is separated into several distinct phases. The different steps and phases of the algorithm can be seen in Figure 4.1.

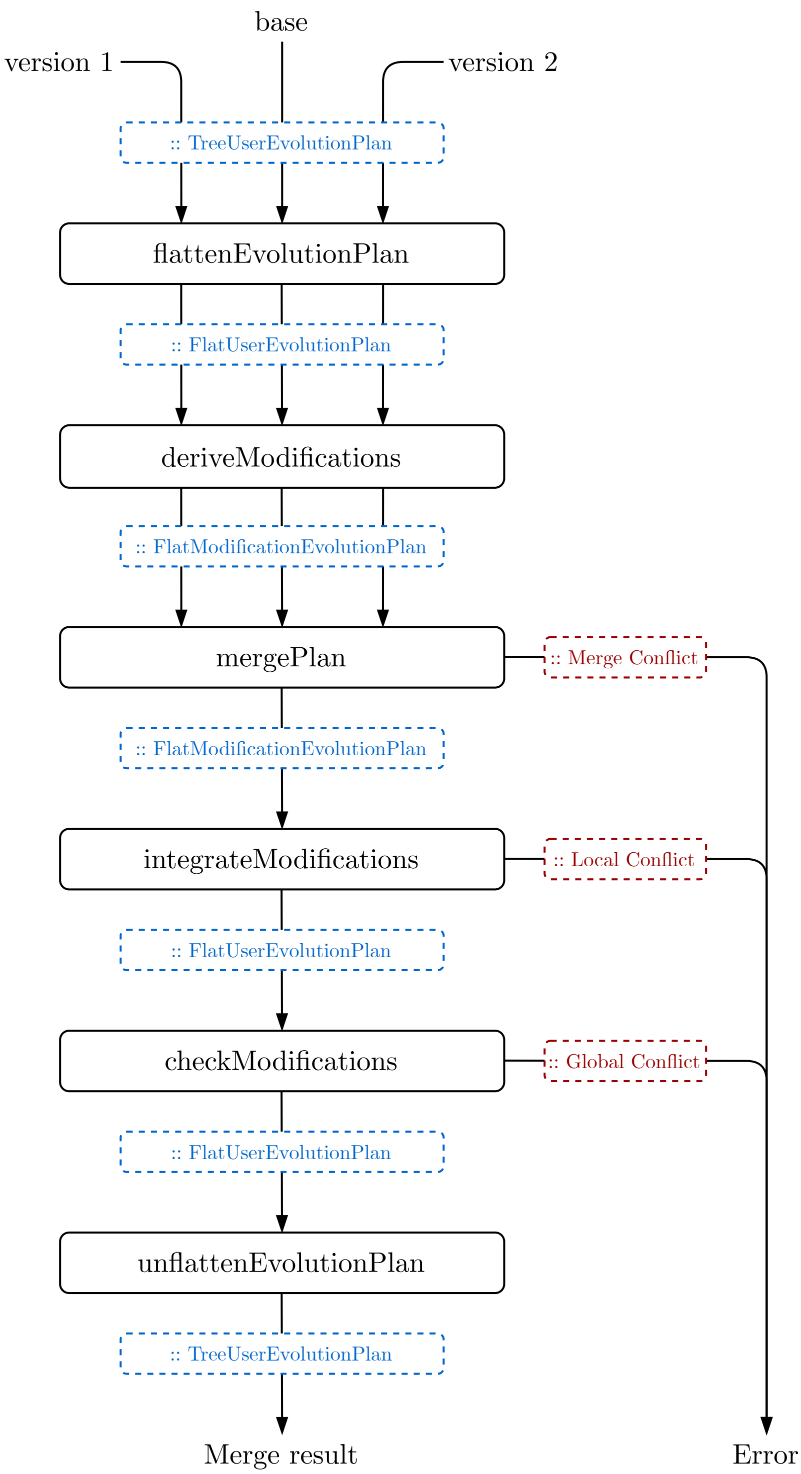


Figure 4.1: Outline of the three-way merge algorithm

The first phase is transforming the three different evolution plans into representations that is more suitable for merging. This includes converting both the way feature models are represented as well as the way the entire evolution plan is represented. This phase includes the `flattenEvolutionPlan` and `deriveModifications`, which is described in further detail in 4.2 on the following page

After changing the way evolution plans are represented, the second phase of the algorithm will calculate the differences between the *base* evolution plan and both derived evolution plans, *version 1*, and *version 2*. This will let us know what were added, changed and removed in each of the derived evolution plans. This phase is part of the `mergePlan` function, which is described in further detail in 4.3 on page 36

The information from the previous phase will be used to create a single merged evolution plan. This evolution plan is simply just the *base* evolution plan integrated with all the changes from *version 1* and *version 2*. This phase is part of the `mergePlan` function, which is described in further detail in 4.4 on page 36

Now that a single merged evolution plan is provided, the last step is to ensure that the plan is following the structural and semantic requirements of an evolution plan. Merging all changes from both versions might yield various inconsistencies. This includes structural conflicts such as orphan features, entire subtrees forming cycles, removing non-empty features, etc. The last phase includes converting back to the original representation, as well as ensuring soundness while doing so. This phase is part of the `integrateModifications`, `checkModifications` and `unflattenEvolutionPlan` functions, which is explained further in 4.5 on page 36

4.1.4 Conflicts

During the different phases of the merge algorithm, different kind of conflicts or errors could occur. Depending on what part of the algorithm a conflict occurred, the conflicts might be either a *merge*, *local* or *global* conflict. At what phase each conflict could occur can also be seen in Figure 4.1 on the preceding page, but a short description of the different conflicts are described below.

Merge Conflicts occur because of conflicting operations on a single feature or group. This could happen if one version tries to remove a feature, while the other tries to change the type of a feature. This could also happen if there originally existed a modification in the *base* version, and one of the derived versions try to change the modification, while the other tries to remove the modification.

Local Conflicts occur when a modification is not possible to be applied because of the existence or non-existence of a feature or group. For example, if we try to add a feature with an id that already exist, or try to change the type of a group that does not exist.

Global Conflicts is the last kind of error that could occur. When all the modifications has been integrated into the evolution plan, each feature model is checked for certain structural or semantical errors. At this point, each change *local* to a feature or group is valid, so we check for potential errors that occur because of dependencies between the features and groups, *global* to the entire feature model. The structural errors is typically modifications that lead to anomalies in the tree structure. These violations of the structure could happen if you add features to parents that don't exist, remove groups that has children, or move features in such a way that cycles are formed. Other violations to the semantics are also checked. This could for example be violations of well-formedness, that could happen if we change the type of a feature to something incompatible with its group.

4.2 Converting To a Suitable Representation

As discussed in Chapter 3, we needed to create a suitable representation for evolution plans before attempting to merge the different versions.

The input of the three-way merge algorithm is three evolution plans in our evolution plan normal form, `TreeUserEvolutionPlan`. Each of the three evolution plans will be transformed into our merge-ready representation of evolution plan in two steps. First we will use `flattenEvolutionPlan` in order to flatten the evolution plan and represent it as our intermediate representation `FlatUserEvolutionPlan`. After this transformation, the evolution plans will be transformed into the merge-ready representation, `FlatModificationEvolutionPlan`.

4.2.1 Transformation to the Intermediate Representation

The first step in the merge algorithm is using `flattenEvolutionPlan` to transform the tree-based evolution plan into the flattened structure. Note that in the code we call this `flattenSoundEvolutionPlan`, since we assume that the three plans in the algorithm is sound. In order to do this transformation, we would need to go through every feature model in the plan and transform it using `flattenSoundFeatureModel`

```haskell
flattenSoundEvolutionPlan ::
  TreeUserEvolutionPlan ->
  FlatUserEvolutionPlan
flattenSoundEvolutionPlan =
  L.timePoints
    . traversed
    . L.featureModel
    %~ flattenSoundFeatureModel
```

Flattening a feature model is relatively straight forward, requiring traversing the tree structure, and creating a list of features and a list of groups as we traverse. In order to do so, we create a tuple of lists, where the left side contains a list of flat features and the right side a list of flat groups. When traversing the tree, we create a new flat feature or group, and concatinate it with the result from the recursive call with `<>` and `foldMap`.

```haskell
flattenSoundFeatureModel ::
  TreeFeatureModel ->
  FlatFeatureModel
flattenSoundFeatureModel fm =
  FlatFeatureModel
    (fm ^. L.rootFeature . L.id)
    (M.fromList features)
    (M.fromList groups)
  where
    (features, groups) =
      flattenFeature Nothing (fm ^. L.rootFeature)
    flattenFeature parent (TreeFeature id fType name gs) =
      ([(id, FlatFeature parent fType name)], [])
        <> foldMap (flattenGroup id) gs
    flattenGroup parent (TreeGroup id gType fs) =
      ([], [(id, FlatGroup parent gType)])
        <> foldMap (flattenFeature (Just id)) fs
```

4.2.2 The Final, Merge Ready Representation

After transforming to our intermediate representation, we begin the process of deriving the modifications between each pair of subsequent feature models. As before, we have assumed soundness for our plans, which is why the actual function in the code is called `deriveSoundModifications` and not `deriveModifications` as in Figure 4.1.

The function will use the first time point in the evolution plan as the initial time point, and create a list of subsequent feature model pairs which is then passed to the `timePointsToPlan` function. The function will use the two subsequent feature models, previous and current, to calculate the differences between them.

```
deriveSoundModifications ::
  FlatUserEvolutionPlan ->
  FlatModificationEvolutionPlan
deriveSoundModifications (UserEvolutionPlan timePoints) =
  case timePoints of
    [] -> error $ "evolution plan has to have "
               ++ "at least one time point!"
    ((TimePoint initialTime initialFM) : restTimePoints) ->
      TransformationEvolutionPlan
        initialTime
        initialFM
        (zipWith timePointsToPlan timePoints restTimePoints)

timePointsToPlan ::
  TimePoint FlatFeatureModel ->
  TimePoint FlatFeatureModel ->
  Plan Modifications
timePointsToPlan
  (TimePoint _ prevFM)
  (TimePoint currTime currFM) =
    Plan currTime $ diffFeatureModels prevFM currFM
```

The main part of the algorithm is actually detecting the changes between the two feature models and representing them in the `Modifications` data type. The function defined below, `diffFeatureModels`, handles this process. Since the flat representation of feature models includes two maps, one for features and one for groups, we calculate the modifications for both separately using the functions `calculateFeatureModifications` and `calculateGroupModifications`.

```
diffFeatureModels ::
  FlatFeatureModel ->
  FlatFeatureModel ->
  Modifications
diffFeatureModels prevFM currFM =
  Modifications
    ( calculateFeatureModifications
        (prevFM ^. L.features)
        (currFM ^. L.features)
    )
    ( calculateGroupModifications
        (prevFM ^. L.groups)
```

```
        (currFM ^. L.groups)
    )
```

[[TODO: maybe not just features, but groups as well]] In order to calculate the differences between two Maps, we rely on the Haskell module Data.Map.Merge from the containers module[1]. This module provides ways of merging maps with keys of the same type. In our case, we have two mappings from FeatureId to FlatFeature, which we will attempt to merge into a mapping from FeatureId to FeatureModification. The merging will be done using the merge function from Data.Map.Merge, which will compare the keys, the feature ids, in both maps. Based on the result of the comparison, one of three different merge tactics will be used to produce the desired result. The merge tactics will rely on the three functions that we pass to the merge function. Given a feature id, the following three cases describes can appear:

- **The id exists only in the previous feature model**: This will produce a FeatureRemove modification for the id.
- **The id exists only in the next feature model**: Since the feature did not exist in the previous feature model, but appeared in this, we will get a FeatureAdd modification for the id.
- **The id exists in both the previous and next feature models**: If the two features are equal, no modification should be generated. However, if any of the fields has changed, a FeatureModification would be generated. The modification will include all the fields that were changed, and skip the ones that remained unchanged.

[[TODO: diagram from merging]]

```
calculateFeatureModifications ::
  M.Map FeatureId FlatFeature ->
  M.Map FeatureId FlatFeature ->
  M.Map FeatureId FeatureModification
calculateFeatureModifications =
  Merge.merge
    (Merge.mapMissing (const inPrevMissingNew))
    (Merge.mapMissing (const missingPrevInNew))
    (Merge.zipWithMaybeMatched (const inPrevInNew))
  where
    inPrevMissingNew _ = FeatureRemove
    missingPrevInNew (FlatFeature mParent featureType name) =
      case mParent of
        Nothing -> error "cannot add a new root"
        Just parent -> FeatureAdd parent featureType name
```

[1] https://hackage.haskell.org/package/containers-0.6.2.1

```
    inPrevInNew prev new =
      let FlatFeature prevParent prevType prevName = prev
          FlatFeature newParent newType newName = new
       in if prev == new
            then Nothing
            else Just $
              FeatureModification
                ( case (prevParent, newParent) of
                    (Just prev, Just new)
                      | prev /= new ->
                        Just (FeatureParentModification new)
                    -- NOTE: since the root is assumed to
                     ↪ never change, we only record changes
                     ↪ of non-root features
                    _ -> Nothing
                )
                ( if prevType == newType
                    then Nothing
                    else Just (FeatureTypeModification newType)
                )
                ( if prevName == newName
                    then Nothing
                    else Just (FeatureNameModification newName)
                )
```

The calculations for groups follow a very similar approach:

```
calculateGroupModifications ::
  M.Map GroupId FlatGroup ->
  M.Map GroupId FlatGroup ->
  M.Map GroupId GroupModification
calculateGroupModifications =
  Merge.merge
    (Merge.mapMissing (const inPrevMissingNew))
    (Merge.mapMissing (const missingPrevInNew))
    (Merge.zipWithMaybeMatched (const inPrevInNew))
  where
    inPrevMissingNew _ = GroupRemove
    missingPrevInNew (FlatGroup parent groupType) =
      GroupAdd parent groupType
    inPrevInNew prev new =
      let FlatGroup prevParent prevType = prev
          FlatGroup newParent newType = new
       in if prev == new
            then Nothing
            else Just $
```

```
GroupModification
  ( if prevParent == newParent
      then Nothing
      else Just (GroupParentModification
       ↪  newParent)
  )
  ( if prevType == newType
      then Nothing
      else Just (GroupTypeModification newType)
  )
```

4.3 Detecting the Changes Between Versions

4.4 Merging Intended Changes

4.5 Ensuring structural and semantic soundness of the merge result

Chapter 5

Example Merge – Vending Machine

write about the vending machine example. Write about how the entire example is done. from cli parsing, converting to right representation, merging, checking, converting back, writing to file. Then how the frontend visualization tool parses the result and displays the tree as an interactive thing.

sound vs unsound examples

Chapter 6

Conclusion and Future Work

konklusjon bør si hvordan det jeg har gjort addresserer forskningsspørsmålene forskningsspørsmålene kan være større en bidraget how to ensure sound plan and merge of sound plans

future work kan være flere ting å se på for å belyse forskningsspm

Bibliography

[1] Don S. Batory. "Feature Models, Grammars, and Propositional Formulas". In: *Software Product Lines, 9th International Conference, SPLC 2005, Rennes, France, September 26-29, 2005, Proceedings*. Ed. by J. Henk Obbink and Klaus Pohl. Vol. 3714. Lecture Notes in Computer Science. Springer, 2005, pp. 7–20. DOI: 10.1007/11554844_3. URL: https://doi.org/10.1007/11554844%5C_3.

[2] Jim Buffenbarger. "Syntactic Software Merging". In: *Software Configuration Management, ICSE SCM-4 and SCM-5 Workshops, Selected Papers*. Ed. by Jacky Estublier. Vol. 1005. Lecture Notes in Computer Science. Springer, 1995, pp. 153–172. DOI: 10.1007/3-540-60578-9_14. URL: https://doi.org/10.1007/3-540-60578-9%5C_14.

[3] James W. Hunt and Thomas G. Szymanski. "A Fast Algorithm for Computing Longest Subsequences". In: *Commun. ACM* 20.5 (1977), pp. 350–353. DOI: 10.1145/359581.359603. URL: https://doi.org/10.1145/359581.359603.

[4] Tom Mens. "A State-of-the-Art Survey on Software Merging". In: *IEEE Trans. Software Eng.* 28.5 (2002), pp. 449–462. DOI: 10.1109/TSE.2002.1000449. URL: https://doi.org/10.1109/TSE.2002.1000449.

[5] Linda M. Northrop. "SEI's Software Product Line Tenets". In: *IEEE Softw.* 19.4 (2002), pp. 32–40. DOI: 10.1109/MS.2002.1020285. URL: https://doi.org/10.1109/MS.2002.1020285.

[6] Dewayne E. Perry, Harvey P. Siy, and Lawrence G. Votta. "Parallel changes in large-scale software development: an observational case study". In: *ACM Trans. Softw. Eng. Methodol.* 10.3 (2001), pp. 308–337. DOI: 10.1145/383876.383878. URL: https://doi.org/10.1145/383876.383878.

[7] Eirik Halvard Sæther et al. "Consistency-preserving evolution planning on feature models". In: *SPLC '20: 24th ACM International Systems and Software Product Line Conference, Montreal, Quebec, Canada, October 19-23, 2020, Volume A*. Ed. by Roberto Erick Lopez-Herrejon. ACM, 2020, 8:1–8:12. DOI: 10.1145/3382025.3414964. URL: https://doi.org/10.1145/3382025.3414964.

[8] Walter F. Tichy. "Tools for Software Configuration Management". In: *Proceedings of the International Workshop on Software Version and*

Configuration Control, January 27-29, 1988, Grassau, Germany. Ed. by Jürgen F. H. Winkler. Vol. 30. Berichte des German Chapter of the ACM. Teubner, 1988, pp. 1–20.