

fUML Refactoring with EMF

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Abstract. In this work we will present ideas and concepts for the refactoring of fUML models. The main contribution of this work is the extension of existing UML refactorings to cover not only the static aspect of UML such as class diagrams but to also include refactorings for dynamic parts such as activity diagrams. In this work we will present basic concepts for refactoring of models with EMF and show how model semantics can be preserved through the use of OCL constraints. In the remainder of the paper we then present our toolchain and the used technologies of EMF (in particular Ecore and OCL) and how we used them for refactoring of models. We also present a discussion of EMF.Refactor, which shows how such refactorings can be made available in the Eclipse GUIs such as the UML tree editor or Papyrus.

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1 Introduction

Model-based software development or model-driven software development is not only an extensive field of research but receives also more and more attention from the industry. Nowadays models are not only used as visual explanations of software concepts but as source for the development process itself. Thus models need to provide an abstraction of the represented domains in a high quality. Mohagheghi et al. [11] discussed possible quality attributes of models in their work.

To represent formal models the OMG developed UML [13] which by now advanced to an industry standard for modeling. With these common semantics enriched models can be preserved over time and even reused. Nevertheless models might have to be revised over the lifecycle of the software. With today's trend to more agile software development such as eXtreme Programming [4] or Scrum [16] changes on models have to be even more efficient which brings refactoring of models into the focus of research.

Refactoring is a technique that originates from source code development but can also be applied to model engineering. The goal is to introduce behavior preserving changes [15] that increase the quality and understandability of the models.

While refactoring source code and textual code respectively applies to a single type of representation, in UML different types of diagrams exist to represent various aspects of the models. This makes behavior preserving refactoring even harder as it needs to span over those different types of diagrams and semantics.

To prove the correctness of models before and after refactoring different approaches exist. One is the static analysis of UML models via metrics and the attempt to find model smells [2] which can be done via OCL [12]. Another way is to verify that models can be executed and to compare the execution traces of the original and refactored models. The OMG introduced a subset of UML named fUML [14] which precisely defines semantics for class and activity diagrams to make them executable. Furthermore in [9] Mayerhofer proposed a framework based on fUML that is able to execute and debug those models.

The goal of this work is to introduce refactorings for fUML models, examine the requirements for co-refactoring of the corresponding diagram types and define which co-changes have to be performed to preserve the behavior. Our approach to verify the correctness of the models after refactoring is twofold. On the one hand we use pre- and postconditions [17] to define if the specific changes can be applied and that the models are semantically correct afterwards. On the other hand the models have to stay executable as well as traceable after the changes.

The rest of the work is structured as follows. In section 3 we give an overview over fUML and provide a motivating example of a model that is used throughout the paper. Section 4 describes a selection of useful refactorings inspired by Fowler [6] and Markovic and Baar [8] and their effects on class diagrams as well as activity diagrams. In section 5 we show which pre- and postcondition are needed for the refactorings and how we refactor the models. In section 6 we describe

the toolchain that we use to define the models, implement a set of refactorings and test them. Related work is covered in section 7 and a conclusion is drawn in section 8 to summarize the paper.

2 Motivation

fUML is an extension of UML which builds on a subset of UML classes with the purpose of adding semantics to UML models such that they can be executed on the model level. The dominant concept for this is the activity diagram. If a refactoring is performed on a UML model such as a class diagram, then any activity diagram which is related to the class diagram, has to be checked and possibly changed as well. In section 4 we will present some examples of fUML activity diagrams and present the implications that result from changing class diagrams.

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Since a refactoring changes the structure of a model it is important to ensure that all changes maintain the original semantics of the model. Violating this requirement can result in models with either a different behavior, or in models which can no longer be executed. To ensure semantic preservation, two main techniques can be used. First, the refactoring can be broken down into smaller steps, each of which either guarantees to preserve the semantics of the model or makes it easier to verify that this is the case. Second, logical constraints can be used to limit refactorings on models to only those cases where semantic preservation can be ensured. For this purpose pre- and postconditions are specified with OCL constraints. A refactoring is then only applied if the original model satisfies the precondition before the refactoring is applied and the postcondition after the refactoring has been completed. Such constraints must be individually specified for each kind of refactoring that is to be performed, as such a part of this paper will discuss different OCL constraints for the refactorings that we introduce.

In this paper we will present a set of refactorings and give examples of how each refactoring can be applied to a concrete model .

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3 Refactoring Examples

This section covers some general refactorings of UML class diagrams. As the basis for these refactorings an example from the insurance domain is used. In the insurance business there are domain objects such as an insurance policy. Cars and trucks can be insured by adding them to the policy. There is an insurance company which has customers and employees where customers may purchase an insurance policy for their cars or trucks. Figure 1 shows a class diagram of such an insurance company. This class diagram would benefit from several possible refactorings such as an *extract superclass* which can be applied to both `Car` and `Truck` to extract a `Vehicle` class. A simple *extract class* can be used on `InsurancePolicy` to extract the `from` and `until` dates into their own

`InsurancePeriod` class. As part of the *extract superclass* refactoring two additional refactorings namely *pull up attribute* and *pull up method* are used to move the identical attributes and methods of both classes to the new superclass. As the attributes `weight` and `registration` are public, we can use *encapsulate field* to make them private and provide getter and setter implementations. Finally the method `addCar` can be renamed into `addVehicle` with *rename method* and the `addTruck` method can be removed with *remove method*. Finally figure 2 shows the refactored class diagram.

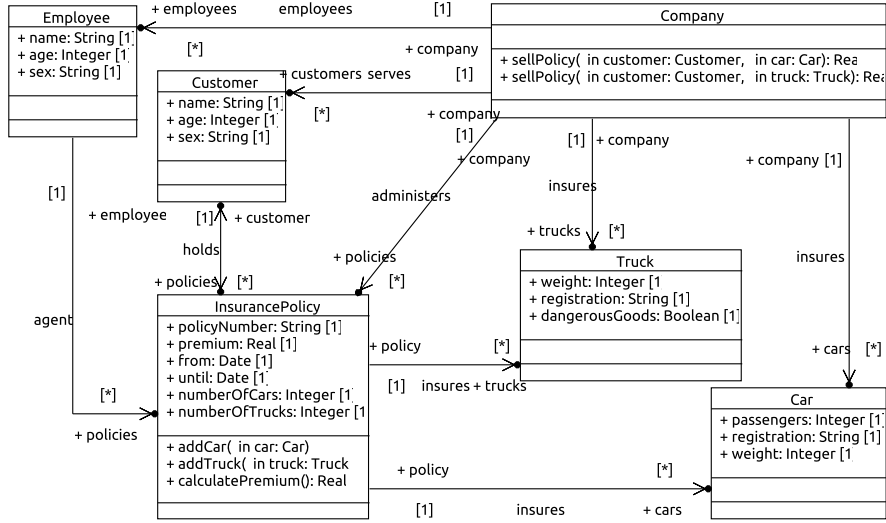


Fig. 1. Insurance class diagram without refactorings

For each of the methods in the `InsurancePolicy` class a separate activity diagram exists which defines the semantics of these methods. As some of them are quite similar we will present only the diagrams for `addCar` in figure 4 and `calculatePremium` figure 3.

The activity for the `addCar` operation works as follows. Read the policy with a `ReadSelfAction`, take the car as a parameter and use the `AddStructuralFeatureValueAction` to add the car to the insurance policy. In parallel it reads the number of cars in the policy with `ReadStructuralFeatureValueAction`, specifies the integer one with a `ValueSpecificationAction`, adds the numbers up with a `CallBehaviorAction` and writes it back to the number of cars variable with another `AddStructuralFeatureValueAction` that replaces the old value.

The `calculatePremium` activity is more complex, it calculates the insurance premium as described below:

- Read the policy with a `ReadSelfAction`.

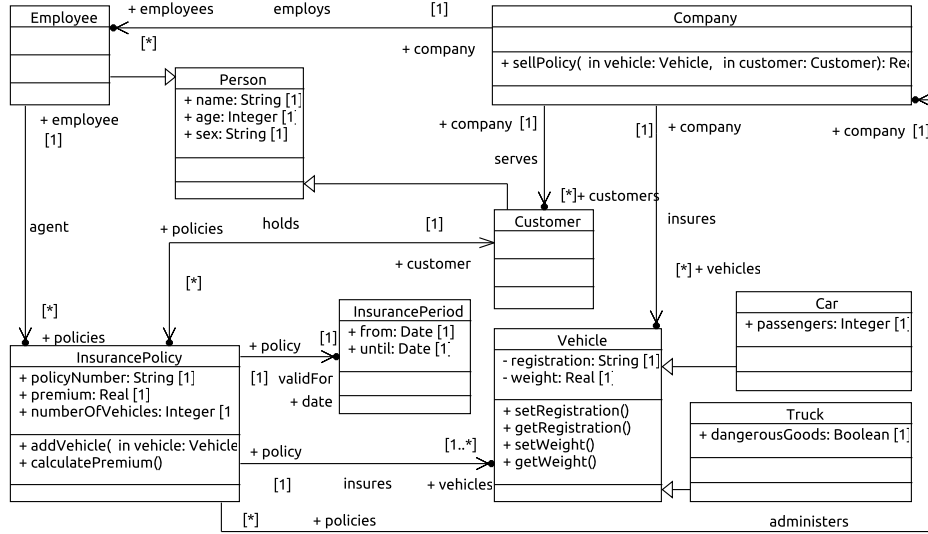


Fig. 2. Insurance class diagram with refactorings

- Read the number of cars and trucks with **ReadStructuralFeatureValueAction**.
- Add the two numbers up with a **CallBehaviorAction**.
- Multiply the result in a **CallBehaviorAction** with a base premium value specified in a **ValueSpecificationAction**.
- Read the age of customer of the policy with two actions of **ReadStructuralFeatureValueAction** in a row.
- Decide whether the age of a customer is below a certain age and define a or a base value or supplement with a **ValueSpecificationAction**.
- Multiply the value and the result of the calculation above and return it.

Figure 5 shows how the activity diagram benefit from a refactoring of the corresponding class diagram. Additionally a new activity diagram for the **addVehicle** instead of the old **addCar** and **addTruck** diagrams was created. It is rather obvious that the complexity of both diagrams decreased on the visual level as well as on the level of execution.

4 Refactoring of fUML models

In the last section we presented some models and their related activity diagrams. We also presented some of the possible refactorings such as *extract superclass* or *extract class*. This section discusses how the models actually need to be transformed in order to realize the refactoring.

Every model has two kinds of syntaxes. The concrete syntax, which defines how the model looks like, and the abstract syntax, which defines the language

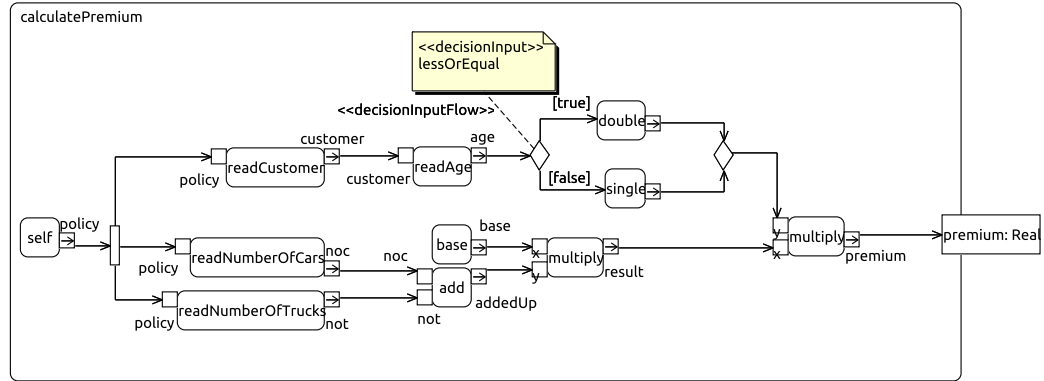


Fig. 3. Calculate premium activity diagram without refactorings

elements and the grammar of the model. In order to refactor a model, we need to look at its abstract syntax and transform it according to the refactoring rules.

A refactoring takes several parameters to configure the parts of the model that change and how they change. For example the *extract superclass* refactoring takes two parameters, the new name of the extracted superclass as well as the list of classes that participate in the refactoring and which will receive the new class as their superclass.

In terms of the abstract syntax of these models, the two classes Car and Truck are instances of type class of the meta-model a superclass named Vehicle would be an instance of type Class as well, and can be associated with these two classes through the recursive attribute *superclass* of the class *Class* to create the inheritance hierarchy. In order to guarantee that the refactoring is possible, we must ensure that each class that participates in the refactoring does not already have a superclass.

In this section we will present some general refactorings such as the “extract superclass” refactoring. A list of example refactorings is presented in figure 7.

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5 Toolchain and implementation

For our toolchain we have relied on the moliz¹ repository, mainly for the ability to execute the fUML models in a virtual machine. The models are stored in XMI format and loaded with an EMF ResourceSet. The ResourceSet can be used to retrieve a Resource object through an URI, which is then used to access the different objects in the model (see figure 8). All elements contained in the model are instances of Ecore (the implementation of the MOF meta-meta-model) and they represent classes of the UML meta-model, which is implemented with Ecore.

¹ <http://www.modelexecution.org>

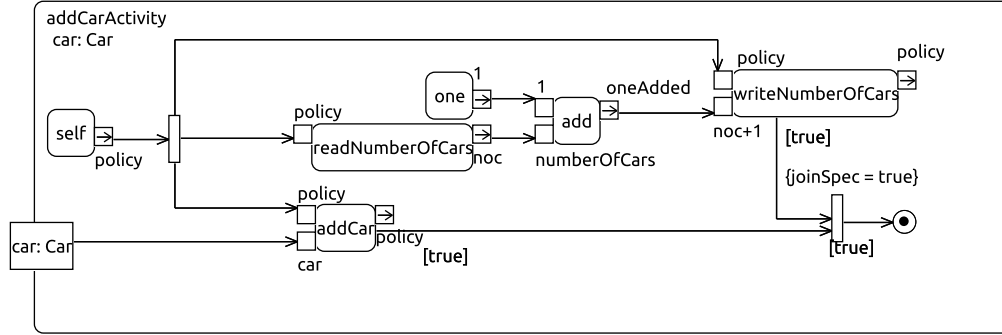


Fig. 4. Add car activity diagram without refactorings

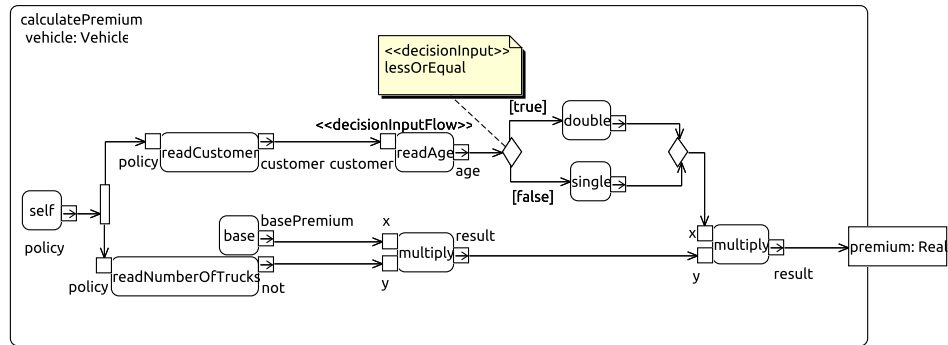


Fig. 5. Calculate premium activity diagram with refactorings

The extract superclass pre- and postconditions are shown in figure for single and multiple inheritance respectively. 9.

These ocl constraints are checked by the refactoring for each class object that participates in the refactoring. An object to type OCL from the org.eclipse.oc package is used to create and evaluate these queries as can be seen in figure 10.

5.1 Model refactoring

Describe our toolchain, how we created models, how we load them, what information of the abstract syntax we use for refactoring, etc.

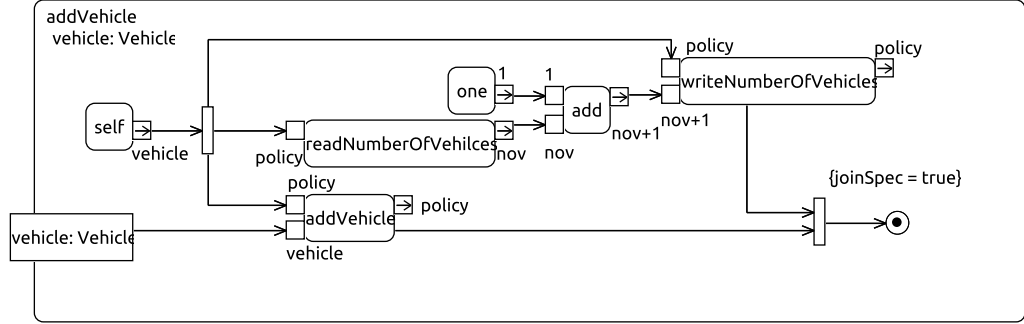


Fig. 6. Add vehicle activity diagram resulting from the refactorings

-
- Extract class
 - Extract superclass
 - Rename Class
 - Rename Method
 - Rename Variable
 - Add / Remove Parameter
 - Encapsulate Field
 - Pull up attribute
 - Pull up operation
 - Pull up association end
 - Remove unused class
-

Fig. 7. Refactoring examples

5.2 GUI Integration

At the time of this writing our GUI integration is not finished, so we cannot describe it here. The idea is to use EMF.Refactor to add

6 Current Limitations

Our work currently has several limitations. So far we have designed a set of related class and activity diagrams, which are the basis for our refactorings. We have discussed the *extract superclass* refactoring including its pre- and post conditions and shown how it can be refactored with our toolchain. Until the final version of this paper we will add several more refactorings from the list shown in figure 7, such as the *extract class*, the *rename method*, the *pullup method*, the *pullup field* and *rename variable* refactorings.

We have also briefly mentioned EMF.Refactor and we plan to extend our toolchain such that our implemented refactorings can be invoked from the Eclipse

```

1 resourceSet = new ResourceSetImpl();
2 resourceSet.getPackageRegistry().put(UMLPackage.eNS_URI,
3                                     UMLPackage.eINSTANCE);
4 resourceSet.getResourceFactoryRegistry()
5     .getExtensionToFactoryMap()
6     .put(UMLResource.FILE_EXTENSION,
7         UMLResource.Factory.INSTANCE);
8 File file = new File(umlModelFile);
9 URI uri = URI.createFileURI(file.getAbsolutePath());
10 resource = resourceSet.getResource(uri, true);

```

Fig. 8. Loading a UML model into a resource set

```

1 Single Inheritance:
2   pre: self.superClass->isEmpty() and
3       self.owner.ownedElement
4       ->select(class|class.oclIsTypeOf(Class))
5       .oclAsType(Class).name
6       ->forall(o | o<>newSuperClass.name)
7   post: self.superClass->size() = 1
8
9 Multiple Inheritance:
10  pre: self.owner.ownedElement
11      ->select(class|class.oclIsTypeOf(Class))
12      .oclAsType(Class).name
13      ->forall(o | o<>newSuperClass.name)
14  post: self.general->contains(superClass)

```

Fig. 9. OCL pre and post conditions for extract superclass

GUI. At least we want to show that this is possible with our toolchain for at least one refactoring.

7 Related Work

In this section we give an overview on the related work. Refactoring in a general way with preconditions was described by Opdyke [15] in his master thesis and stated more precisely by Roberts [17] who also introduced postconditions for refactorings. Fowler [6] generated an extensive yet simple to understand catalog of refactorings for Java and Ruby which can be adapted to model refactorings.

Suny  et. al. [18] described how several refactorings can be applied to *UML* diagrams and introduced OCL as a possibility to specify pre- and postconditions. Gorp et al. [7] extends the discussion with the usage of *OCL* for additional analysis such as code smells of models.

```

1 variable = ExpressionsFactory.eINSTANCE.createVariable();
2 variable.setName("newSuperClass");
3 variable.setType(UMLPackage.Literals.CLASSIFIER);
4 ocl.getEnvironment().addElement(variable.getName(),
5                               variable, true);
6 query = helper.createQuery(
7     "self.general->includes(newSuperClass)");
8 eval = ocl.createQuery(query);
9 eval.getEvaluationEnvironment()
10    .add("newSuperClass", superClass);
11 if (!eval.check(clazz))
12    return false;

```

Fig. 10. OCL validation in Java

Despite of the further discussion of model refactoring ([5], [3], [1]) most authors concentrate on static analysis and class diagram representations of models. Dynamic analysis of models by execution and debugging *fUML* models is discussed by Mayerhofer [9] and provides the basis for the approach discussed here. Mayerhofer et al. [10] furthermore introduce a runtime model and an implementation² that is capable to test the models and directly show impacts of refactorings.

Arendt and Taentzer [1] present a framework that is based on *Eclipse* and the *Eclipse Modelling Framework* which allows static model analysis and refactorings that are implemented in different languages (Java, OCL & Henshin) and can be directly extended in *Eclipse*.

8 Conclusion

Refactoring models is a rather difficult task and it requires a concise knowledge of the involved technologies, with the list of involved technologies being rather long. For one a reasonably well understanding of fUML is required, in particular how class diagrams and activity diagrams are constructed and how they are related. It is not enough to simply be able to draw both class and activity diagrams, as one also needs a good understanding of the meta-meta-model (MOF) and the fUML and UML meta-model implementations in Ecore in order to understand and manipulate the model on the level of its abstract syntax. Finally an understanding of EMF (in particular Ecore and OCL) is required. While MOF and OCL are both modeling concepts and languages respectively, EMF contains implementations for them in Java with a complex API. Understanding these APIs of Ecore and OCL is required to perform the refactorings and was a prerequisite to build our toolchain.

² <http://www.modelexecution.org>

With the toolchain in place another challenge was to identify the required steps to perform the actual refactoring work. In particular this meant to identify how the activity diagrams need to change if a change is made in the class diagram.

Most of our efforts in the development of this work were focused on gaining a comprehensive understanding of the technologies described above, to develop the tool chain and to draw the various diagrams presented in this paper and make them executable. We have presented a comprehensive set of diagrams as the basis for our refactoring work and demonstrated the feasibility of our tool chain. However a more comprehensive evaluation of the different refactorings including the specification of pre- and postconditions OCL in is still required and will be the focus of our ongoing efforts.

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