Model-Driven Software Refactoring

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Abstract
In this chapter, we explore the emerging research domain of model-driven software refactoring. Program refactoring is a proven technique that aims at improving the quality of source code. Applying refactoring in a model-driven software engineering context raises many new challenges such as how to define, detect and improve model quality, how to preserve model behavior, and so on. Based on a concrete case study with a state-of-the-art model-driven software development tool, AndroMDA, we will explore some of these challenges in more detail. We propose to resolve some of the encountered problems by relying on well-understood techniques of meta-modeling, model transformation and graph transformation.

1. Introduction
In the current research and practice on software engineering, there are two very important lines of research for which tool support is becoming widely available. The first line of research is program refactoring, the second one is model-driven software engineering. To this date, however, the links and potential synergies between these two lines of research have not been sufficiently explored. This will be the main contribution of this chapter.
Model-driven software engineering.

In the realm of software engineering, we are witnessing an increasing momentum towards the use of models for developing software systems. This trend commonly referred to as model-driven software engineering, emphasizes on models as the primary artifacts in all phases of software development, from requirements analysis over system design to implementation, deployment, verification and validation. This uniform use of models promises to cope with the intrinsic complexity of software-intensive systems by raising the level of abstraction, and by hiding the accidental complexity of the underlying technology as much as possible (Brooks, 1995). The use of models thus opens up new possibilities for creating, analyzing, manipulating and formally reasoning about systems at a high level of abstraction.

To reap all the benefits of model-driven engineering, it is essential to install a sophisticated mechanism of model transformation, that enables a wide range of different automated activities such as translation of models (expressed in different modeling languages), generating code from models, model refinement, model synthesis or model extraction, model restructuring etc. To achieve this, languages, formalisms, techniques and tools that support model transformation are needed. More importantly, their impact on the quality and semantics of models needs to be better understood.

Program refactoring.

Refactoring is a well-known technique to improve the quality of software. Martin Fowler (1999) defines it as “A change made to the internal structure of software to make it easier to understand and cheaper to modify without changing its observable behavior”.

The research topic of refactoring has been studied extensively at the level of programs (i.e., source code). As a result, all major integrated software development environments provide some kind of automated support for program refactoring.

As a simple example of a program refactoring, consider the refactoring Extract Method, one of the more than 60 refactorings proposed by Fowler. Essentially, it is applied to a method in which part of the method body needs to be extracted into a new method that will be called by the original one. The situation before this program refactoring on a piece of
Java source code is shown in Figure 1, the situation after is shown in Figure 2. The code lines that differ between both versions are marked with an asterisk.

```
protected LectureVO[] handleFindLecture
    (java.lang.String title, domain.Weekday day, domain.Time time)
    throws java.lang.Exception
*  { SearchCriteria c = new SearchCriteria();
*    c.setDay(day);
*    c.setTitle(title);
*    c.setTime(time);
    Collection coll =
        getLectureDao().findLecture(LectureDao.TRANSFORM_LECTUREVO,c);
LectureVO[] lectures = new LectureVO[coll.size()];
    return (LectureVO[])coll.toArray(lectures); }
```

**Figure 1:** Java source code example before applying the *Extract Method* program refactoring.

```
protected LectureVO[] handleFindLecture
    (java.lang.String title, domain.Weekday day, domain.Time time)
    throws java.lang.Exception
*  { SearchCriteria c = this.initialise(title,day,time);
    Collection coll =
        getLectureDao().findLecture(LectureDao.TRANSFORM_LECTUREVO,c);
LectureVO[] lectures = new LectureVO[coll.size()];
    return (LectureVO[])coll.toArray(lectures); }
* protected SearchCriteria initialise
*  { java.lang.String title, domain.Weekday day, domain.Time time)
*    throws java.lang.Exception
*  { SearchCriteria c = new SearchCriteria();
*    c.setDay(day);
*    c.setTitle(title);
*    c.setTime(time);
*    return c; }
```

**Figure 2:** Java example after applying the *Extract Method* refactoring.

For program refactoring, a wide variety of formalisms has been proposed to gain a deeper understanding, and to allow formal analysis. One of
these formalisms is graph transformation theory (Mens et al., 2005). We mention it here explicitly, as we will show later in this chapter how this formalism can be applied to support model refactoring as well. It is, however, not our goal to provide a detailed overview of existing work on program refactoring here. For the interested reader, we refer to a detailed survey of the state-of-the-art in this domain (Mens and Tourwé, 2004).

Model-driven software refactoring.

A natural next step seems to explore how the idea of refactoring may be applied in a model-driven software development context. We will refer to this combination as model-driven software refactoring and we will explore the ramifications of this synergy in the current chapter. One of the straightforward ways to address refactoring in a model-driven context is by raising refactorings to the level of models, thereby introducing the notion of model refactoring, which is a specific kind of model transformation that allows us to improve the structure of the model while preserving its quality characteristics. To the best of our knowledge, Sunyé et al. (2001) were the first to apply the idea of refactoring to models expressed in the Unified Modeling Language (UML).

A simple yet illustrative example of a UML model refactoring is shown in Figure 3. It depicts a class model in which two classes having attributes of the same type have been identified. The model refactoring consists of removing the redundancy by introducing an abstract super class of both classes, and moving up the attribute to this new super class.

Figure 3: Example of a model refactoring on UML class diagrams.

The above example may look simple, but it should be seen in a more general context, which makes dealing with model refactorings considerable less trivial. Consider the scenario depicted in It clearly
illustrates the potentially high impact a simple refactoring may have on the software system. We assume that a model is built up from many different views, typically using a variety of different diagrammatic notations (e.g., class diagrams, state diagrams, use case diagrams, interaction diagrams, activity diagrams, and many more). We also assume that the model is used to generate code, while certain fragments of the code still need to be implemented manually. Whenever we make a change (in this case, a refactoring) to a single view or diagram in the model (step 1 in Figure 4), it is likely that we need to synchronize all related views, in order to avoid them becoming inconsistent (step 2 in Figure 4) (Grundy et al., 1998). Next, since the model has been changed, part of the code will need to be regenerated (step 3 in Figure 4). Finally, the manually written code that depends on this generated code will need to be adapted as well (step 4 in Figure 4).

Figure 4: A scenario for model-driven software refactoring.
2. State-of-the-art in Model Refactoring

At the level of models, research on refactoring is still in its infancy. Little research has been performed on model refactoring, and many open questions remain that are worthy of further investigation. For example, the relation between model refactoring and its effect on the model quality remains a largely unanswered question. From a practical point of view, only very few tools provide integrated support for model refactoring. Also, the types of models for which refactoring is supported is very limited.

In research literature, mainly UML models are considered as suitable candidates for model refactoring (Suryè et al., 2001) (Astels, 2002) (Boger et al., 2002). In particular, refactoring of class models (e.g., UML class diagrams) has been investigated by various researchers. The advantage of such models is that they provide a representation that is relatively close to the way object-oriented programs are structured. As such, many of the refactorings known from object-oriented programming (Fowler, 1999) can be ported to UML class diagrams as well. For example, the refactoring shown in Figure 1 can also be considered as a class diagram refactoring, since a new method is created that will be visible in a class diagram. Of course, additional techniques are needed in order to ensure traceability and consistency between class diagrams and their corresponding source code when applying class diagram refactorings (Bouden, 2006).

When it comes to reasoning about the behavior preservation properties of class diagram refactorings, however, things become more difficult for various reasons. The main problem is that class diagrams provide an essentially structural description of the software architecture. Hence, behavioral information has to be expressed in a different way, either by resorting to OCL constraints, behavioral models (e.g., state diagrams or interaction diagrams), or by program code.

With respect to refactoring of behavioral models, not much work is available. We are only aware of a few approaches that address the problem of refactoring state diagrams, and try to prove their behavior preservation properties in a formal way. Van Kempen et al. (2005) use a formalism based on CSP to describe statechart refactorings, and show how this formalism can be used to verify that a refactoring effectively preserves behavior. Pretschner and Prenninger (2006) provide a formal
approach for refactoring state machines based on logical predicates and
tables. Integrating these ideas into tool support is left for future work.
Apart from some limitations imposed by the formalisms used, a more
general problem is that there is still no generally accepted formal
semantics for (UML) state diagrams. Many different interpretations exist
and, obviously, this has an important effect on how the behavior is
formally defined.

Though research on model refactoring is still in its infancy, a number of
formalisms have already been proposed to understand and explore model
refactoring. Most of these approaches suggest expressing model
refactoring in a declarative way. Van Der Straeten et al. (2004) propose
to use description logics; Van Der Straeten & D’Hondt (2006) suggest
the use of a forward-chaining logic reasoning engine to support
composite model refactorings. Gheyi et al. (2005) specify model
refactorings using Alloy, a formal object-oriented modeling language.
They use its formal verification system to specify and prove the
soundness of the transformations. Biermann et al. (2006) and Mens et al.
(2007) use graph transformation theory as an underlying foundation for
specifying model refactoring, and rely on the formal properties to reason
about and analyze these refactorings.

An important aspect of refactoring in a model-driven software
development context that is typically neglected in research literature is
how it interferes with code generation. Most contemporary tools for
model-driven software development allow generating a substantial part
of the source code automatically from the model, while other parts still
need to be specified manually (see Figure 4). This introduces the need to
synchronize between models and source code when either one of them
changes. How such synchronization can be achieved in presence of an
automated refactoring support is a question that has not been addressed
in detail in research literature. If a model is being refactored, how should
the corresponding source code be modified accordingly? Vice versa, if
source code is being refactored, how will the models be affected? These
are the kind of questions that will be addressed in this chapter. To this
extent, we will report on our experience with AndroMDA, a state-of-the-
art tool for model-driven software development based on UML.
3. Motivating example: Model-driven development with AndroMDA

This section presents the model-driven development of a small web application for a simple university calendar. We will develop this calendar in two iteration steps using AndroMDA. First the underlying data model is designed and a web application with a default web presentation is generated. Second, application-specific services and the web presentation are developed with AndroMDA. This means that use cases are defined and refined by activity diagrams that can use controllers and services. The development is not hundred percent model-driven, since service and controller bodies have to be coded by hand.

For both iteration steps, we first present the UML model using the AndroMDA profile and then discuss a refactoring step useful in that context.

3.1 Getting started with developing a university calendar using AndroMDA

One of the main tools for model-driven software development is AndroMDA. Its transformation engine is structured by cartridges. A number of pre-defined cartridges is already available realizing the generation of web applications from UML models. We illustrate model-driven software development based on AndroMDA by the example of a very simple university calendar.

In principle, the model-driven development process of AndroMDA is based on use cases. But in this initial example, we start with an even simpler way of using AndroMDA. We just design the underlying data model and AndroMDA generates a complete web application with a default web presentation from that.

A web application generated by AndroMDA has a three-tier architecture consisting of a service layer building up on a database, controllers using the services defined, and a web presentation. The underlying data model, services and controllers are defined by an UML class diagram. Additionally, visual object classes are modeled, which are used for presenting data to the user, decoupled from the internal data model.

\[^1\text{http://galaxy.andromda.org}\]
FIGURE 5: Data model for a simple university calendar

An example of an AndroMDA class diagram is shown in Figure 5. It depicts a simple data model for a university calendar. We can observe that the basic entities are Rooms that can be occupied for giving a Lecture or a Seminar. Based on this class diagram, AndroMDA can generate a default web interface for managing lectures, seminars and rooms. Users can add and delete instances, change attribute values and perform searches. The webpage for managing lectures is shown in Figure 6.

The UML profiles used in connection with AndroMDA can be considered as a domain-specific language, dedicated to the generation of web applications. This is achieved by giving a specific semantics to UML models by relying on that dedicated UML profiles. They extend the semantics of the UML by introducing specific stereotypes, to which additional constraints and tagged values are attached. For example, the stereotype «Entity» attached to a class is used to represent a data entity to be stored in a database. If, additionally, the «Manageable» stereotype is used, it causes AndroMDA to generate a default web presentation for managing the corresponding entities. The use of such manageable entities has been illustrated in Figure 5.
3.2 First refactoring of the university calendar

Due to their compactness, large parts of AndroMDA UML models are used for generating user interfaces. Thus, model refactorings in this context are likely to cause changes in user interfaces as well. Following Fowler (1999) in a strict sense, refactorings should not change the user interface of software, since they are supposed to “preserve the observable behavior”. This strict interpretation of refactoring, however, makes little sense if applied in a model-driven software development context, due to the side-effects that model refactorings may cause on the generated code, especially user interfaces. Thus, Fowler’s definition of refactoring should be interpreted in a more liberal way, in the sense that it should not change the functionality offered by software. Modifications to the usability of the software or to other non-functional properties (such as interoperability, portability, reusability, adaptability and the like) should be allowed, if the goal of these modifications is to improve the software quality.

In the remainder of this section we will show a concrete refactoring on our university calendar case study to clarify what refactoring can mean in the context of model-driven development.
Since «Entity» classes Lecture and Seminar contain several attributes in common (see Figure 5), it would make sense to refactor this data model by adding a new abstract superclass, called Course, and pulling up all common attributes to this new class. The result of this refactoring is shown in Figure 7.

Figure 7: Data model for a simple university calendar after having applied the Pull Up Attribute refactoring
Figure 8: Webpage for managing courses

Note that tagged value \( @\text{andromda.hibernate.inheritance} \) has to be set to \texttt{interface} for restricting the management facilities for courses to searching functionalities only.

When regenerating a web application from the refactored data model in Figure 7, most of the web interface remains unaltered. But a new webpage will appear for managing courses, as shown in Figure 8. Because of the tagged value attached to \texttt{Course}, this webpage only offers search functionality, but does not allow the addition or deletion of course instances.

In the example explained in section 3.1, all application code is generated from the model. Thus, refactoring the model alone appears to be sufficient to refactor the whole software application. However, it should be noted that, due to the refactoring applied to the model, the behavior has been changed slightly, since AndroMDA has generated a new kind of webpage.
3.3 Developing application-specific use cases with AndroMDA

In this section, we will consider additional stereotypes and tagged values in the AndroMDA UML profile, but only as far as we need them to develop our example. For a complete overview of all available stereotypes and how to use them we refer to the AndroMDA website.

«Service» is a class stereotype used to specify application-specific services. These services typically use one or more entities that store the data used by the services. For the model-driven development of a web presentation, we extend the model by use cases that are refined by activity diagrams. This model part describes the web presentation and its usage of controllers based on services. The development is not hundred percent model-driven, since service and controller bodies have to be coded by hand.

To illustrate the development of specific web applications we reconsider the university calendar and develop a specific use case diagram for lectures (see Figure 9). Use case Search lectures has two stereotypes being «FrontEndUseCase», which determines the use case to be visible to the user in form of a webpage, and «FrontEndApplication», which defines this use case to be the starting one.

![Figure 9: Example of a use case model in AndroMDA](image)

Use case Search lectures is refined by an activity diagram that supports a search activity and the presentation of filtered lectures (see Figure 10). Activity Search lectures is an internal activity that calls the controller method showLectures(). Activity Present lectures has stereotype «FrontEndView» implying that this activity models a webpage. Both activities are connected by two transitions arranged in a
cyclic way. After calling method `showLectures()` the result is transferred to the webpage by signal `show`, which has the resulting value object array as parameter. Signal `search` and its parameters are used to model the web form for filtering the lectures.

**Figure 10:** Example of an activity diagram specifying the *Search lectures* use case

The class model in Figure 5 is again used as data model. To show lectures, a special value object class for lectures is used, which is specified by stereotype «ValueObject» (see Figure 11). This makes sense in terms of encapsulation (think of security, extensibility, etc.) and corresponds to the layered model-view-controller approach. Necessary information of the business layer is packaged into so-called "value objects", which are used for the transfer to the presentation layer. Passing real entity objects to the client may pose a security risk. Do you want the client application to have access to the salary information inside the Lecturer entity?

An attribute `room` of type `String` was added to `LectureVO` in order to allow a connection to the unique number of the `Room` class. Since value objects are used at the presentation layer, the types used are primitive ones; entity types are not used in that layer. A dependency relation between an entity and a value object is used to generate translation methods from the entity to its corresponding value object. Moreover, search criteria can be defined by a class of stereotype «Criteria».
Method `showLectures()` that is called from activity `Search lectures` in Figure 10, is defined in `LectureController`, a class that relies on class `LectureService`. This class is stereotyped as `<<Service>>` and relies on entities `Lecture` and `Room` (see Figure 12). However, the bodies of service and controller methods cannot be modeled, but have to be coded directly by hand. For example, the implementation of service method `findLecture()` is shown in Figure 1. Because of special naming conventions of AndroMDA it has to be named `handleFindLecture()`.

The web application generated by AndroMDA from the complete model given in the previous figures (together with manually written code parts) produces the webpage shown in Figure 13. Please note that the names used as page title, in the search form and for the buttons are generated from the model.
Figure 12: Service and controller classes

Figure 13: Webpage for searching lectures
3.4 Further refactoring of the university calendar

As a second model refactoring\(^2\), we will discuss the renaming of attribute \texttt{time} to \texttt{starttime} based on the model given in Section 3.3. We will argue that this refactoring affects the usability of the generated software. The refactoring is primarily performed on entity class \texttt{Lecture}, but since there is a value object class \texttt{LectureVO} for that entity, the corresponding value class attribute \texttt{time} has to be renamed into \texttt{starttime}, too (see Figure 14). The same is true in \texttt{SearchCriteria}. Thus, the standard refactoring method \texttt{Rename Attribute} becomes domain-specific and affects several classes in this domain-specific context.

![Figure 14: Value Object and Entity classes after renaming](image)

Since the value object attribute is not used directly in other parts of the model, the model does not have to be updated any further. But the handwritten code (given in Figure 1) is affected, since accessor method \texttt{setTime()} is no longer available after regenerating the code. Thus, it has to be renamed as well, by calling method \texttt{setStarttime()} instead. After

\(^2\) This model refactoring is actually domain-specific, as will be discussed later in this chapter.
Mens et al., Model-Driven Software Refactoring

having performed this refactoring, the webpage for searching lectures has been changed slightly. As a result, the usability is affected, though not dramatically, since the column named “Time” of the presented table presented has changed into “Starttime” (see Figure 15).

Figure 15: Webpage for searching lectures after renaming

Based on the analysis of both model refactorings carried out in this section, we can derive the following important preliminary conclusions:

- Generic model refactorings need to be adapted and refined in order to work properly in a domain-specific modeling language.
- Model refactorings may also affect, and require changes to the handwritten source code.
- Model refactorings may change external qualities as perceived by the user, such as usability aspects.


In this section, we will discuss some important challenges in model refactoring that have to do with the relation between model refactoring and model quality. It is not our ambition to solve all these challenges in
the current chapter. In Sections 5 and 6 we will therefore only focus on those challenges that we consider being most urgent and most important and we will exemplify our proposed solution using the case study introduced in the previous section.

Model quality.

A first challenge is to provide a precise definition of model quality. A model can have many different non-functional properties or quality characteristics that may be desirable (some examples are: usability, readability, performance and adaptability). It remains an open challenge to identify which qualities are necessary and sufficient for which type of stakeholder, as well as how to specify these qualities formally, and how to relate them to one another.

Since the main goal of refactoring is to improve certain aspects of the software quality, we need means to assess this quality at the model level in an objective way. On the one hand, this will allow software modelers to identify which parts of the model contain symptoms of poor quality, and are hence potential candidates for model refactoring. On the other hand, quality assessment techniques can be used to verify to which extent model refactorings actually improve the model quality.

One of the ways to assess model quality is by resorting to what we will call model smells. These are the model-level equivalent of bad smells, a term originally coined by Kent Beck in (Fowler, 1999) to refer to structures in the code that suggest opportunities for refactoring. Typical model smells have to do with redundancies, ambiguities, inconsistencies, incompleteness, non-adherence to design conventions or standards, abuse of the modeling notation, and so on. A challenge here is to come up with a comprehensive and commonly accepted list of model smells, as well as tool support to detect such smells in an automated way. What is also needed is a good understanding of the relation between model smells and model refactoring, in order to be able to suggest, for any given model smell, appropriate model refactorings that can remove this smell.

A second way to assess and control model quality is by resorting to model metrics. In analogy with software metrics (Fenton and Pfleeger, 1997) they are used to measure and quantify desirable aspects of models. It remains an open question, however, how to define model metrics in such a way that they correlate well with external model quality.
characteristics. Another important issue is to explore the relation between model metrics and model refactoring, and in particular to assess to which extent model refactorings affect metric values. These issues have been addressed by (Demeyer et al., 2000) (Du Bois, 2006) (Tahvildari & Kontogiannis, 2004) though mainly at code level.

A final way to improve model quality is by introducing design patterns, which are proven solutions to recurring problems (Gamma et al., 1994). At code level, Kerievsky (2004) explored the relation between refactorings and design patterns. It remains to be seen how similar results may be achieved at the level of models.

Kamthan (2004) provided a quality framework for UML models. It systematically studies the quality goals, how to assess them, as well as techniques for improving the quality, similar to the ones discussed above.

**Model synchronization.**

With respect to model refactoring, one of the key questions is how it actually differs from program refactoring. Can the same ideas, techniques and even tools used for program refactoring be ported to the level of models? If not, what is it precisely that makes them different?

One answer to this question is that models are typically built up from different views, using different types of diagrams, that all need to be kept consistent. This in contrast to programs, that are often (though not always) expressed within a single programming language.³

Perhaps a more important difference is that models are abstract artifacts whose main purpose is to facilitate software development by generating a large portion of the source code that would otherwise need to be written manually. However, 100% full code generation is unfeasible in practice for most application domains. The additional challenge therefore consists in the need to synchronize and maintain consistency between models and their corresponding program code, especially when part of this program code has been specified or modified manually. In the context of model

³ Of course, programs also need to be synchronised with related software artefacts such as databases, user interfaces, test suites and so on. Each of these kinds of artefacts may have been expressed using a different language.
transformation, this implies that automated model refactorings (or other transformations) may need to be supplemented with code-level transformations in order to ensure overall consistency. Vice versa, program refactorings may need to be supplemented with model-level transformations to ensure their consistency.

Though no general solutions exist yet, the problem of model synchronization and model consistency maintenance is well known in literature. For example, (Van Gorp et al., 2003) discuss the problem of keeping the UML models consistent with its corresponding program code. (Correa & Werner, 2004) explain how OCL constraints need to be kept in sync when the class diagrams are refactored and vice versa. Egyed (2006) proposes an incremental approach to model consistency checking that scales up to large industrial models. Liu et al. (2002) and Van Der Straeten & D’Hondt (2006) rely on a rule-based approach for detecting and resolving UML model inconsistencies, respectively. Van Der Straeten et al. (2003) bear on the formalism of description logics to achieve the same goal. Mens et al. (2006) propose to resolve inconsistencies in an incremental fashion by relying on the formalism of graph transformation. Grundy et al. (1998) report on how tool support can be provided for managing inconsistencies in a software system composed of multiple views. Goedicke et al. (1999) address the same problem by relying on the formalism of distributed graph transformation.

**Behavior preservation.**

Another important challenge of model refactoring has to do with behavior preservation. By definition, a model refactoring is supposed to preserve the observable behavior of the model it is transforming. In order to achieve this, we need a precise definition of “behavior” in general, and for models in particular. In addition, we need formalisms that allow us to specify behavioral invariants, i.e., properties that need to be preserved by the refactoring. The formalism should then verify which of these invariants are preserved by the model refactoring. Although formal research on behavior preservation is still in its infancy, in Section 2 we already pointed to a few approaches that carried out initial research in this direction. Another approach that is worthwhile mentioning is the work by Gheyi et al. (2005). They suggest specifying model refactorings in Alloy, an object-oriented modeling language used for formal
specification. It can be used to prove semantics-preserving properties of model refactorings.

A more pragmatic way to ensure that the behavior remains preserved by a refactoring is by resorting to testing techniques. Many researchers have looked at how to combine the ideas of testing with model-driven engineering (Brottier et al., 2006) (Mottu et al., 2006). Test-driven development is suggested by the agile methods community as good practice for writing high-quality software. In combination with refactoring, it implies that before and after each refactoring step, tests are executed to ensure that the behavior remains unaltered.

**Domain-specific modeling.**

A final challenge is the need to define model refactorings in domain-specific extensions of the UML (such as AndroMDA), or even in dedicated domain-specific modeling languages. These refactorings should be expressible in a generic yet customizable way. Indeed, given the large number of very diverse domain-specific languages, it is not feasible, nor desirable, to develop dedicated tools for all of them from scratch.

Zhang et al. (2004) therefore proposed a generic model transformation engine and used it to specify refactorings for domain-specific models. Their tool is implemented in the Generic Modeling Environment (GME), a UML-based meta-modeling environment. A model refactoring browser has been implemented as a GME plug-in. Their tool enables the automation and user-defined customization of model refactorings using ECL (Embedded Constraint Language), an extension of the declarative OCL language with imperative constructs to support model transformation. As an example of the expressiveness of their approach, they illustrated how it can be applied to class diagrams, state diagrams and Petri nets. The solution that we will explore later in this chapter is related, in the sense that we will propose a generic approach for UML-based model refactoring based on graph transformation concepts.

In general, the main challenge remains to determine, for a given domain-specific modeling language, which transformations can be considered as meaningful refactorings. On the one hand, they will need to preserve some notion of “behavior” and, on the other hand, they need to improve some quality aspect. These notions of behavior and quality can differ
widely depending on the domain under study. For domains that do not refer to software (e.g., business domains, technical domains, etc.) it is much harder to come to a meaningful definition of behavior, implying that the notion of refactoring would become much harder to define in that context.

Analyzing model refactorings.
Even more advanced support for model refactorings can be envisaged if we have a precise means to analyze and understand the relationships between refactorings. This will enable us to build up complex refactorings from simpler ones; to detect whether refactorings are mutually exclusive, in the sense that they are not jointly applicable and to analyze causal dependencies between refactorings. These techniques have been explored in detail by Mens et al. (2007), and promise to offer more guidance to the developer on what is the most appropriate refactoring to apply in which context. A short introduction to this line of research will be given in Section 6.

5. Motivating example revisited
In Section 3 two concrete model refactorings have been applied to AndroMDA models: pulling up an attribute into a new superclass and renaming an entity. In this section, we explore some more refactorings for AndroMDA models.\(^4\) We start by considering a set of “standard” model refactorings widely used to restructure class diagrams. As it will turn out, most of these refactorings have side-effects due to constraints imposed by AndroMDA’s code generator. Therefore, these model refactorings need to be customized to take into account more domain-specific information. Next to these “standard” refactorings, we will also discuss entirely new “domain-specific” refactorings for AndroMDA models.

In the following, we will take a slightly broader view, and we discuss three categories of model transformations as follows:
(1) model refactorings that do not affect the user interface at all;

\(^4\) It is not our goal to be complete here.
(2) model refactorings that do affect the user interface with respect to the usability, but that do not affect what the user can do with the application; and
(3) model transformations that also affect the actual behavior/functionality of the application.

The latter category does not contain refactorings in the strict sense of the word, but it is nevertheless useful and necessary to deal with them. For example, it could be the case that what is perceived as a normal refactoring will actually extend the behavior as a side effect of the code generation process.

**Pull up Attribute.**

When pulling up an attribute to a super class, as explained in Section 3.2, the code generator will automatically generate a new webpage corresponding to this super class, with search functionality for each manageable entity. Thus, this model transformation belongs to category (3).

**Rename.**

The refactoring example in Section 3.4 is concerned with renaming an attribute of an entity class. This refactoring affects the user interface, if the entity is manageable. In this case, one of the columns in the table of the webpage has been renamed. Furthermore, in case that the entity class comes along with a value object class that is derived from the entity class, a renaming of an entity attribute has to be accompanied by a renaming of the corresponding attribute in its value object class. If, in addition, this value object attribute is used in some activity diagram, the name has to be adapted there as well. Furthermore, this value object attribute can occur in hand-written code, which implies that renaming has to be performed also in that part of the code.

A similar situation would arise if we renamed the entity class itself, as it would be reflected by a change in the title of the corresponding webpage for manageable entities. In case that the renamed entity class comes along with a value object class whose name is derived from the entity class name (e.g., in Figure 14, “LectureVO” is derived from “Lecture” by suffixing “VO”), renaming has to be accompanied by a renaming of its corresponding value object class. Furthermore, the renaming has to be
propagated as discussed for attributes. In all cases presented, although the user interface changes slightly, the functionality of the application is not affected. Hence, these refactorings belong to category (2).

Similar to entities, use cases can be renamed as well. This might have an effect on activity diagrams, since AndroMDA supports the connection of several activity diagrams via use case names. For example, an end activity of one activity diagram may be named as a use case, which means that the control flow would continue at the start activity of the corresponding activity diagram. In the generated web applications, use cases are listed on the right-hand side of each webpage. Again, a renamed use case would change the usability of the web application, but not its functionality, so the refactoring belongs to category (2).

In summary, we see that renaming in AndroMDA may have a high impact. Due to the fact that the code generator automatically produces new types of elements based on the names of existing elements, a seemingly simple change (in casu renaming) will propagate to many different places. A tool that would implement this model refactoring would therefore need to take these issues into account to ensure that the renaming does not lead to an inconsistent model or code. Furthermore, because the changes affect hand-written code, the refactoring may require a certain amount of user interaction.

**Create Value Object.**

A domain-specific refactoring for AndroMDA models is the creation of value objects for entities. An example is visually represented in Figure 16. Given a class with stereotype «Entity» (for example, class Lecture), a new class with stereotype «Value Object» is created and the entity class becomes dependent on this new class. The value object class is named after its entity class followed by suffix “VO” (for example, value object class LectureVO). The entity attributes are copied to the value object class, keeping names and types, by default. If internal information should be hidden from the client, the corresponding attribute would not be copied. This refactoring belongs to category (1) and does not affect any other part of the model, since the value object class is only created without being used yet.
Another domain-specific model refactoring is **Merge Services.** It takes two «Service» classes and merges them as well as all their incoming and outgoing dependencies. Consider the following example where both a `LectureService` and `RoomService` exist (see Figure 17). If we do not consider remote services and have only one controller class, it does not make sense to have two service classes. Therefore, both should be merged into `LectureService`. After refactoring, the controller class will have only one outgoing dependency. As a result, the hand-written code for the controller method will be affected. Nevertheless, this restructuring will not modify the external behavior, so users of the generated web application will not notice any change. Hence, this refactoring falls into category (1).

**Figure 16:** Example of the domain-specific model refactoring `CreateValueObject`.

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**Mens et al., Model-Driven Software Refactoring**
Split Activity.

The front-end of a web application is modeled by use cases and activity diagrams. A refactoring like the splitting of activities into two consecutive ones, linked by a transition, can directly affect the web presentation. If the original activity was a «FrontEndView», the corresponding webpage is split into two pages. If an internal activity was split, this refactoring has to be accompanied by a splitting of the corresponding controller method called. In the first case, the refactoring belongs to category (2), in the second case it belongs to category (1).

Extract Method.

Extract Method is a refactoring from the standard catalogue established by Fowler. In the context of model-driven development, and AndroMDA in particular, it can have new effects. Consider the scenario in Figure 19. First, we perform the extract method refactoring to the hand-written code, as illustrated in Figure 2 where a method, called initialise(), is extracted from a given service method handleFindLecture. To reflect this change at model level, we modify the class diagram by adding the extracted method to the class LectureService as well (see Figure 18).
Consequently, the code generator will generate extra code for this method, which requires the manually written code to be adapted to make it consistent again. In particular, method initialise() needs to be renamed into handleInitialise(), because this is the convention used by the code generator: all service methods need to be prefixed with "handle" at source code level. We can use this knowledge to constrain the Extract Method refactoring to make it domain-specific: When extracting a method, the name that the user needs to provide for the extracted method needs to follow the naming conventions imposed by the code generator. Not doing so will cause the precondition of the refactoring to fail.

![Diagram](image)

**Figure 18:** Changes to the class diagram as a result of applying the Extract Method program refactoring (see Figure 2).

The above scenario is generalized and visualized in Figure 19. It shows how a refactoring at source code level (step 1) may require synchronization of the corresponding model (step 2) which, after regenerating the code (step 3) involves another modification to the handwritten part of the code (step 4). The last step is not needed, if the user obeys the naming convention for the new method as discussed above.
Figure 19: Another scenario of model-driven software refactoring, initiated by a refactoring of the hand-written source code.

6. Specifying and analyzing model refactorings
In Section 5, the important challenge of domain-independent support for model refactoring was discussed. A possible formalism that can be used to specify and also analyze refactorings is the theory of graph transformation (Ehrig et al. 2006). Compared to other approaches it has a number of advantages: it allows one to specify program refactorings and model refactorings for various languages in a uniform and generic way, by representing the software artifact under consideration as a graph, and by specifying the refactorings as graph transformation rules. In addition, one can benefit from the formal properties of graph transformation theory to reason about refactoring in a formal way. For example, properties such as termination, composition, parallel dependencies, and sequential dependencies can be analyzed.

Since the Eclipse Modeling Framework (EMF) has become a key reference for model specification in the world of model-driven development, we rely our approach to model refactoring on EMF model transformation. This approach is presented in Section 6.1. To perform a formal analysis of EMF transformations we translate them to graph
transformations, which is possible under certain circumstances. In Section 6.2, a conflict and dependency analysis of model refactorings is presented, assuming that the model refactorings are defined by graph transformation rules.

6.1 Technical solution

From a technical point of view, we will discuss how to implement and execute model refactorings. In particular, we will consider how to realize model refactoring within the Eclipse Modeling Framework (EMF). As a prerequisite, a specification of the underlying modeling language is needed, which will be given by a meta-model. Figure 20 shows an EMF model that represents a simplified extract of the AndroMDA meta-model. Figure 21 shows an instance of this EMF model for the entity class Lecture of the simple university calendar.

Figure 20: Extract of AndroMDA meta-model as EMF model.
Biermann et al. (2006) explain in detail how EMF model refactoring can be expressed by EMF model transformation. This kind of model transformation is specified by rules and is performed in-place, i.e., the current model is directly changed and not copied. Each transformation rule consists of a left-hand side (LHS), indicating the preconditions of the transformation, a right-hand side (RHS), formulating the post conditions of the transformations, and optional negative application conditions (NAC), defining forbidden structures that prevent application of the transformation rule. Objects that are checked as precondition preserved during a transformation are indicated by colors. Object nodes of the same color present one and the same object in different parts of a rule. While attributes in the LHS may have constant values or rule variables only, they are allowed to carry Java expressions in the RHS, too. The same variable at different places in the rules means the same value at all places. In the following, we use this approach to EMF model transformation for specifying UML model refactorings.

In Figure 22 and Figure 23, two model transformation rules are shown, which both are needed to perform refactoring Create Value Object explained in Figure 16 of Section 5. Rule CreateValueObjectClass is applied once, creating a new value object class and a dependency of the entity class on this new class. A class model with an entity class is needed to create a value object class and a dependency in between. The name of this new value object class is constructed by taking the entity

**Figure 21:** Entity class Lecture with attributes in abstract syntax as EMF model instance.
class name e and adding suffix "VO". This rule is applied only if a value object class of this name has not already been created.

Figure 22: EMF model transformation rule *CreateValueObjectClass* for refactoring method *Create Value Object*.

Thereafter, rule *CreateValueObjectAttribute* is applied for each of the attributes of the entity class that should occur also in the value object class. Each time it is applied, it copies an attribute that has not yet been copied into the value object.

Figure 23: EMF model transformation rule *CreateValueObjectAttribute* for refactoring method *Create Value Object*.

Applying rule *CreateValueObjectClass* once and rule *CreateValueObjectAttribute* as often as entity class *Lecture* has attributes (i.e., four
times in this case) to the EMF model instance in Figure 21, we obtain the EMF model instance in Figure 24.

![Figure 24: Entity class Lecture with value object class LectureVO in abstract syntax as EMF model instance.](image)

To open up the possibility for analyzing EMF model refactorings, we translate them to graph transformations. In this way, the formal analysis for graph transformation becomes available for EMF model refactoring. Although EMF models show a graph-like structure and can be transformed similarly to graphs, there is an important difference between both. In contrast to graphs, EMF models have a distinguished tree structure that is defined by the containment relation between their classes. Each class can be contained in at most one other class. Since an EMF model may have non-containment references in addition, the following question arises: What if a class, which is transitively contained in a root class, has non-containment references to other classes not transitively contained in some root class? In this case we consider the EMF model to be inconsistent.

A transformation can invalidate an EMF model, if its rule deletes one or more objects. To ensure consistent transformations only, rules that delete objects or containment links or redirect them, have to be equipped with additional NACs.
6.2 Formal solution

As an illustration of how refactoring dependency analysis may increase the understanding of refactoring, consider the following scenario. Assume that a software developer wants to know which refactoring rules need to be applied in order to restructure a software system. Typically, many different refactoring rules may be applicable, and it is not easy to find out what would be the most optimal way to apply these rules. Joint application of some refactoring rules may not be possible due to parallel dependencies between them, and some refactoring rules may sequentially depend on other ones. Graph transformation theory allows us to compute such dependencies by relying on the idea of critical pair analysis. The general-purpose graph transformation tool AGG5 provides an algorithm implementing this analysis.

Figure 25: Sequential dependencies computed by AGG for a representative set of refactorings implemented as graph transformations.

Figure 25 gives an example of all sequential dependencies that have been computed between a representative, yet simplified, subset of refactorings expressed as graph transformation rules. For example, we see that there is a sequential dependency between the CreateSuperclass refactoring and the PullUpVariable refactoring. CreateSuperclass inserts a new intermediate superclass (identified by node number 2) in between a class (node 1) and its old superclass (node 3). PullUpVariable moves a

5 http://tfs.cs.tu-berlin.de/agg
variable contained in a class up to its superclass. The dependency between both transformation rules, as computed by AGG, is visualized in Figure 26. The effect of applying \textit{CreateSuperclass} before \textit{PullUpVariable} will be that the variable will be pulled up to the newly introduced intermediate superclass instead of the old one. As such, there is a sequential dependency between both refactoring rules. It is even the case, in this example, that the application of both refactorings in a different order will produce a different result.

\textbf{Figure 26:} Example of a sequential dependency between the \textit{CreateSuperclass} and the \textit{PullUpVariable} refactoring.

For a more detailed discussion of how critical pair analysis can be used to reason about refactoring dependencies, we refer to (Mens \textit{et al.}, 2007) that provides a detailed account on these issues.

\section*{6.3 Related Work}

Various authors have proposed to use some kind of rule-based approach to specify model refactorings, so it appears to be a natural choice:

Grunskie \textit{et al.} (2005) show an example in Fujaba$^6$ of how model refactoring may be achieved using graph transformation based on story-driven modeling. Bottoni \textit{et al.} (2005) use distributed graph transformation concepts to specify coherent refactorings of several software artifacts, especially UML models and Java programs. Both kinds of artifacts are represented by their abstract syntax structures.

\footnote{http://www.fujaba.de}
Synchronized rules are defined to specify not only refactoring on models and programs separately, but to update also the correlation between different model parts and program. Synchronized rules are applied in parallel to keep coherence between model and program. Considering the special case where exactly two parts (one model diagram and the program or two model diagrams) are related, the triple graph grammar (TGG) approach by Schürr et al. (Schürr 1994, Königs & Schürr 2006) could also be used. Originally formulated for graphs, TGGs are also defined and performed on the basis of MOF models by the modeling environment MOFLON7.

(Porres, 2003) uses the transformation language SMW to specify model refactorings. This script language is also rule-based and resembles the Object Constraint Language (OCL). SMW is oriented at OCL for querying patterns, but also provides basic operations to realize transformations. A prototypical refactoring tool for UML models has been implemented based on SMW.

Van Der Straeten and D’Hondt (2006) suggest using a rule-based approach to apply model refactorings, based on an underlying inconsistency detection and resolution mechanism implemented in the description logics engine RACER8.

We decided to specify model refactorings based on EMF model transformation, since EMF is developing to a standard format for models and to be compatible with upcoming UML CASE tools based on EMF. Moreover, our approach opens up the possibility for analyzing model refactorings, since EMF model transformations can be translated to algebraic graph transformations.

7. Summary

Software complexity is constantly increasing, and can only be tamed by raising the level of abstraction from code to models. With the model-driven software engineering paradigm, automated code generation techniques can be used to hide the accidental complexity of the

7 http://www.moflon.org
8 http://www.racer-systems.com
underlying technology (Brooks, 1995). This enables one to deal with complex software in a systematic way.

To guarantee high-quality software, it is also important to address concerns such as readability, extensibility, reusability and usability of software. Software refactoring is a proven technique to reach these goals in a structured, semi-automated manner.

By integrating the process of refactoring into model-driven software development, we arrive at what we call model-driven software refactoring. Analogously to program refactoring, the first phase is to determine potential candidates for model refactorings, which can be obtained using “model smells” and “model metrics”. The second phase consists of applying the selected refactorings. This would be a relatively straightforward issue, if hundred-percent code generation were achievable. In practice, for large and complex software systems, this is not the case. Full code generation is not even desirable in many situations since – at least for describing algorithms or data conversions – source code seems to be more adequate than behavioral models. An additional difficulty is the lack of a general accepted semantics of UML. This makes it very difficult to determine whether a given model transformation is behavior preserving, which is the main criterion to decide whether something can be called refactoring or not, according to Fowler (1999).

As a feasibility study, we have chosen AndroMDA to illustrate the model-driven development of web applications. We illustrated and discussed a number of standard and domain-specific restructurings. Since they often change the observable behavior of the software in some sense, we explored to what extent they can be considered as refactorings. All restructurings were categorized into three groups, ordered by the fulfillment degree of Fowler’s criterion. The obtained results show that we should address the notion of model refactoring with care, and may serve as suggestions for better tool support:

- We may want to support refactorings that do not fully preserve behavior, as long as they improve other important software quality aspects. This also implies that we need techniques to assess the effect of a model transformation on the software quality.
• We need to find a balance between, and provide user support for the ability to specify generic model refactorings, and the ability to adapt and refine these refactorings to work properly in a domain-specific modeling language;
• We need to provide an interactive round-trip engineering approach to refactoring. When performing model refactorings, it turns out that manual intervention is frequently required in order to keep the abstraction levels of source code and model consistent. Model refactorings may also affect and require changes to the hand-written source code.

From a theoretical point of view, we have suggested to use graph transformation to provide a formal specification of model refactorings. It has the advantage of defining refactorings in a generic way, while still being able to provide tool support in commonly accepted modeling environments such as EMF. In addition, the theory of graph transformation allows us to formally reason about dependencies between different types of refactorings. Such a static analysis of potential conflicts and dependencies between refactorings can be helpful for the user during the interactive process of trying to improve the software quality by means of disciplined model transformations.

8. Future Research Directions
In Section 4, we identified many important challenges in model-driven software refactoring. We only worked out some of these challenges in more detail: the need for a formal specification of model refactorings, the need to reason about behavior preservation, the need to synchronize models and source code whilst applying refactorings, the need to relate and integrate the aspects of model refactoring and model quality. There are still many other challenges that remain largely unaddressed:
When developing large software systems in a model-driven manner, several development teams might be involved. In this case, it would be advantageous if the model could be subdivided into several parts that could be developed in a distributed way. Considering refactoring in this setting, model elements from different submodels might be involved. Thus, several distributed refactoring steps have to be performed and potentially synchronized if they involve common model parts.
Distributed refactoring steps could be considered as distributed model transformations (Goedicke et al., 1999) (Bottoni et al., 2005).

The usual way to test refactorings is by testing the code before and after refactoring steps. Clearly, the code has to satisfy the same test cases before and after refactoring it. Considering refactoring within model-driven development, the same testing procedure should be possible, i.e., test cases for the generated code before and after refactoring should produce the same results. As we discussed within this chapter, model-driven software refactoring often does not fulfill Fowler’s criterion in a stringent way. Future investigations should clarify the impact of this kind of restructuring on test suites (Van Deursen et al., 2002).

An important pragmatic challenge that has not been addressed in this chapter has to do with performance and scalability. Is it possible to come up with solutions that scale up to industrial software? Egyed (2006) provided initial evidence that this is actually the case, by providing an instant model synchronization approach that scales up to large industrial software models.

Another interesting research direction is to apply refactorings at the meta-model level. This raises the additional difficulty of needing to convert all models that conform to this meta-model accordingly, preferably in an automated way.

References


Knowledge, Information, and Data: Theory and Applications (pp. 95-125), Idea Group Publishing


Gamma, E., Helm, R., Johnson, R., & Vlissides, J. (1994). Design Patterns: Elements of Reusable Object-Oriented Languages and Systems. Addison-Wesley.


Additional Reading

General and up-to-date information about graph transformation can be obtained via the website http://www.gratra.org/. For those readers wishing to get more in-depth information about what graph transformation is all about, we refer to the 3-volume “bible” of graph transformation research. Volume 1 focuses on its theoretical foundations; Volume 2 addresses applications, languages and tools; and Volume 3 deals with concurrency, parallelism and distribution.


Background information about model-driven software engineering can be obtained via the website http://www.planetmde.org/. This includes tool support and events devoted to this very active research domain. Many books on this topic have been published. In particular, we found the following ones to be very useful and relevant:


With respect to software evolution research, we suggest to consult the website http://www.planet-evolution.org/. Many books on this topic have been published. In particular, we found the following ones to be very useful and relevant:

Regarding software refactoring in particular, we would like to point to some of the early work on refactoring, which has been published in the following PhD dissertations:


There are many useful standards that have been published for software maintenance and software evolution. As is frequently the case, some of these standards may be somewhat outdated compared to the current state-of-the-art in research:

- The ISO/IEC 14764 standard on ``Software Maintenance'' (1999)
- The IEEE 1219 standard on ``Software Maintenance'' (1999)
- The ANSI/IEEE 1042 standard on ``Software Configuration Management'' (1987)

Finally, without pretending to be complete, we mention some useful websites with open source tools related to the themes of this chapter:

- The Eclipse Modeling Framework (EMF)
  http://www.eclipse.org/emf
• The AndroMDA open source initiative
  http://www.andromda.org
• The Tiger EMF Model Transformation Framework:
  http://tfs.cs.tu-berlin.de/emftrans
• The graph transformation environment AGG:
  http://tfs.cs.tu-berlin.de/agg
• The round-trip software engineering tool Fujaba relying on graph transformation technology:
  http://www.fujaba.de
• The graph-based model-driven engineering tool MOFLON relying on graph transformation technology:
  http://www.moflon.org