TECHNISCHE UNIVERSITÄT BERLIN
FAKULTÄT IV ELEKTROTECHNIK UND INFORMATIK
BACHELORSTUDIENGANG INFORMATIK

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Towards Synchronizing Relations Between Artifacts in the Java Technological Space

Work presented in partial fulfillment
of the requirements for the degree of
Bachelor in Computer Science

Advisor: Prof. Dr.

Berlin
January 2016

Hiermit erkläre ich, dass ich die vorliegende Arbeit selbstständig und eigenhändig sowie ohne unerlaubte fremde Hilfe und ausschließlich unter Verwendung der aufgeführten Quellen und Hilfsmittel angefertigt habe.

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Unterschrift

ACKKNOWLEDGMENTS

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ABSTRACT

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ZUSAMMENFASSUNG

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Schlagwörter: ..

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

TGG   Triple graph grammar

CONTENTS

1 INTRODUCTION

The techniques for software development has changed in the course of time since the rise of general-purpose programmable computers and specially in the second half of the 20th century with the rise of digital computers (Ceruzzi, 2003). In the beginning of digital computer programming machine code was used to describe algorithms, but as complexity and size of such algorithms got bigger this technique soon became impracticable, what evoked the need for a more sophisticated way of programming these digital machines. The assembly languages (also known as low-level programming languages) came to solve this problem, but clearly the complexity kept increasing as well as the need for new techniques and technologies for software programming. The popularization of computing, and the increasing application of computers in the practice urged the creation of high-level programming languages (e.g. Cobol, Fortran), which kept evolving mainly in regard to the needs of the software market (Ceruzzi, 2003). More sophisticated languages (e.g. C, Pascal) and new paradigms (e.g. modular and object-oriented programming) also arose in the late 20th century. But the evolution of software development does not seem to stop, evidenced by the lately increasing research on new software engineering techniques such as the Model-driven Engineering.

The newest characteristics of the information system market, like the constant evolution of the software systems, the interoperability between them and the big number of developers working in a common software artifact has required the use of software models; and the research on how to apply systematically and correctly such models in the development processes, what is called Model-driven Engineering (MDE) or Model-driven Software Development France and Rumpe (2007). This Bachelor thesis aims therefore to explore one specific realm of Model-driven Engineering research, namely the problem of synchronization of models (or artifacts) in the Java technological space. The goal here is to pick commonly used meta-models in Java systems, describe them and identify their relations, so that they can be synchronized.

TALK ABOUT THE REMAINDER OF THE DOCUMENT.

1.1 Background

According to Czarnecki and Helsen (2006, p. 21): "*Models are system abstractions that allow developers and other stakeholders to effectively address concerns, such as answering a question about the system or effecting a change*". By defining a model as a system abstraction, it becomes clear, that a software system might have several models abstracted from it,

each one representing certain aspects of the whole system. These models also have relations between them, in the sense that they all are supposed to describe the actual system consistently by not presenting logical contradictions. Here examples of models are *UML class diagram*, *Use Cases*, or even the source-code itself. The term model and artifacts will be used interchangeably throughout this document.

The constant evolving nature of current large-scale software systems causes their models to be constantly changed Diskin (2011). But in order to maintain this whole network of interconnected models consistent the changes have to be forwarded through the network, i.e. all models have to be synchronized. Suppose one have a *UML Class Diagram*, a series of *UML Sequence Diagrams* and the source-code. If a method has its name changed in the class diagram, all occurrences of this method has to have its name updated in the sequence diagrams and in the source-code. It turns out though, that neither a model synchronization tool comprising the most common meta-models used nowadays in Java information systems is known by us nor have we found clearly defined relation definitions between them on the literature.

1.2 Motivation

The lack of a functional model synchronization tool integrating a broad range of meta-models used currently in Java software engineering is the main motivation for this thesis. Although an expressive effort has been made by the academic community to create solutions for the problem of model synchronization, no study known by us presents an effective tool, that could be used extensively in practice. We believe though, that the contribution of this thesis can be useful for the creation of such a tool.

Another motivation for this thesis is the lack of relation definitions in current literature for extensively used meta-models in Java systems industry. Examples of these relations include relations between *UML Class and Sequence Diagrams* and *Java Code*, between *Use Cases* and *Requirements Diagrams*, between *OCL contracts (used in design by contract methods)* and *Unit Tests*, among others. It means, that the success of this thesis brings the contribution towards the definition of a network of interconnected meta-models useful to both research and industry community. Therefore the availability of such a network might finally allow the extensive use of Model-driven Engineering in practice − helping bridging the gap between system abstractions and their concrete form − and foster the further development of more sophisticated model synchronization methods.

It is worth to note also, that the contribution of this thesis might help enhancing the qual-

ity of current software construction and therefore lessening the number of software problems and errors, what seems to be a big problem nowadays, by fomenting the wide application of Model-Driven Software Development.

1.3 Objective

In order to help filling this gap in knowledge, this bachelor thesis aims to present a set of meta-models commonly used in current Java object oriented software systems and the respective relations between them. The goal is then to contribute to current research, by providing such relations, that later could be further extended as a benchmark case or as the basis of a synchronization tool.

The end of this document shall present all the written definitions as well as the results of the synchronization of representative examples useful in the practice. Furthermore, the report of this thesis recording the difficulties and experiences found during the work process and an analysis and discussion of future development and challenges of the realm is also a legacy.

1.4 Methodology

In order to achieve the goals, the following procedure is taken. In the first moment a collection of common meta-models used in the Java technological space is to be defined, this is done through an state-of-art research, since that some meta-models have already been defined by other authors, plus the creation of our own versions of some meta-models. So for example, in this phase the choice of the applied meta-models (i.e. *UML Class Diagram* and *Java Code*) will be done and their definitions will be written.

Later on, given the defined meta-models, the relations between them can be written. So for example, in this phase the inherent relation between the *UML Class Diagram* meta-model and the *Java Code* meta-model will be written. Analogously, the relations between *Java Code*, *JavaDoc*, *UML Sequence Diagram* and other meta-models of the Java technological space are also to be defined. All of these relations are developed during the work of this thesis.

After having this network of meta-models ready, a showcase using a synchronization method from the current academic literature is applied to illustrate the synchronization between some representative meta-models. We work therefore with the hypothesis, that the meta-models can be found or defined; that some relations between them can be written in some language;

and that some of these relations can be synchronized using a tool or technique available in the current literature.

It is out of the scope of this work a creation or implementation of a synchronization algorithm, as well as a theoretic analysis of the problem or the analysis of performance or completeness of the relations.

2 FOUNDATIONS

Before describing the development of this thesis is important to review some important definitions regarded to Model-driven Engineering. Below is a list of necessary basic concept definitions, that will be used throughout this document. Some of these definitions are rather narrower than they could be, but for the scope of this thesis they seem to be suitable.

Technological Space: According to the definition from Kurtev et al. (2002, p. 1): *"A technological space is a working context with a set of associated concepts, body of knowledge, tools, required skills, and possibilities. It is often associated to a given user community with shared know-how, educational support, common literature and even workshop and conference meetings".* By *Java Technological Space* is meant the set of commonly used models, practices, techniques and technologies in Java software development. For example, object-oriented development, unit tests, code documentation and the *Java Virtual Machine* are items of the Java technological space.

System: *"A system is the primary element of discourse when talking about MDE."* (Favre, 2004a, p. 13). One example of a system, according to this definition, is a Java program, once it can be the primary handled element in a certain software engineering context. Nevertheless, this definition is wide enough to affirm that a UML Class Diagram is a system, since it can be the primary handled element in a certain context. This fact allows an easier-to-understand definition of model.

Model: According to Favre (2004a), a model is a possible role a system can play. A system plays the role of a model, when it represents another system (system under study, or SUS), i.e. By being so, when one refers to the a model M, it is meant, a system that represents (or abstracts) another system S, i.e. $M\mu S$. Seidewitz (2003) affirms that, models can be used (1) to describe a system, in this case the model makes statements about the SUS, an example is an *UML sequence diagram* employed to help understand the behavior of a Java program. But models can also be used (2) to specify a system, in this case it is used in the validation of the system, an example is a *UML class diagram* employed as design specification of a Java system. Further examples of models, according to this definition, are a *relational database diagram* of a database, the documentation of a system in *Java Doc* or even a Java source-code.

Modeling Language: A model is expressed, using a modeling language. *"A modeling language (L) is a set of models"* (Favre, 2004a, p. 13), that contains all the models M_i expressed in that language, i.e. $L \ni M_i$. Examples of modeling languages are the *UML*,

the *diagram notation for relational database diagram* or the Java language.

Meta-model: Favre (2004b, p. 14) affirms also: *"A metamodel is a model of a modelling language."*. In other words, a meta-model specifies what can be written using a certain modeling language. One certain model M is conform to a meta-metamodel MM (i.e $M\epsilon MM$), if and only if, $M \in L$ and $MM\mu L$. Thus, examples of meta-models are *UML specification document* (OMG, 2007), the *entity-relationship meta-model* (Chen, 1976) or the Java meta-model (one example is to be found in Heidenreich et al. (2009)). Finally Seidewitz (2003, p. 29) also claims: *"Because a metamodel is a model, we express it in some modeling language"*. One example of a modeling language for meta-models is the *EMF Ecore*[1] (which is the modeling language for meta-models used in this thesis ans will be explained further below).

Meta-metamodel: Analogously to the meta-model definition, one can go forth and define meta-metamodel, which is a model that specifies a modelling language for meta-models. An example of meta-metamodel is the *MOF*(Omg, 2015), which the *EMF Ecore* is conform to. It is to note also, that such derivation can be done iteratively in the sense that a $meta^3 model$ definition is also possible, although it is not useful for the scope of this thesis. The figure 2.1 illustrate our understanding of the definitions above.

Model Relation: Model relation here is defined abstractly as every relationship or constraint possible to happen between one source model and one target model. For instance, the models *UML class diagram* and Java code have a relation, because once a new class is created in the class diagram, the correspondent class has to be created in the Java code. Moreover, a *UML class diagram* with contracts definitions (pre and post-conditions) have a relation to the *JUnit model*, once that the formers have to be tested correspondingly in the latter.

Model Transformation: Model transformation can be viewed as common data transformation – very common in computer science – with the specificity of dealing with models Czarnecki and Helsen (2006). More specifically, model transformation is defined here as a function $t : M \rightarrow N$, where $t(m) = n$ means that a target model $n \in N$ is created from a source model $m \in M$, M and N being respectively the set of all valid models of the meta-models Φ_M and Φ_N. Practical example: Creation of Java code from *UML class diagram*. Note that, model transformation is by nature deterministic, unidirectional and does not preserve the information of the target model (e.g. comments in the Java code).

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[1]https://eclipse.org/modeling/emf

Figure 2.1: On the left is a depiction of the theoretical definitions of system, model, metamodel, meta-metamodel and modeling language. Like stated before, a system is represented by models, which themselves are expressed in languages and are conform to meta-models. A more concrete and practical illustration of the definitions is on the right. This example shows a scenario very close to the implementation made in chapter 4.
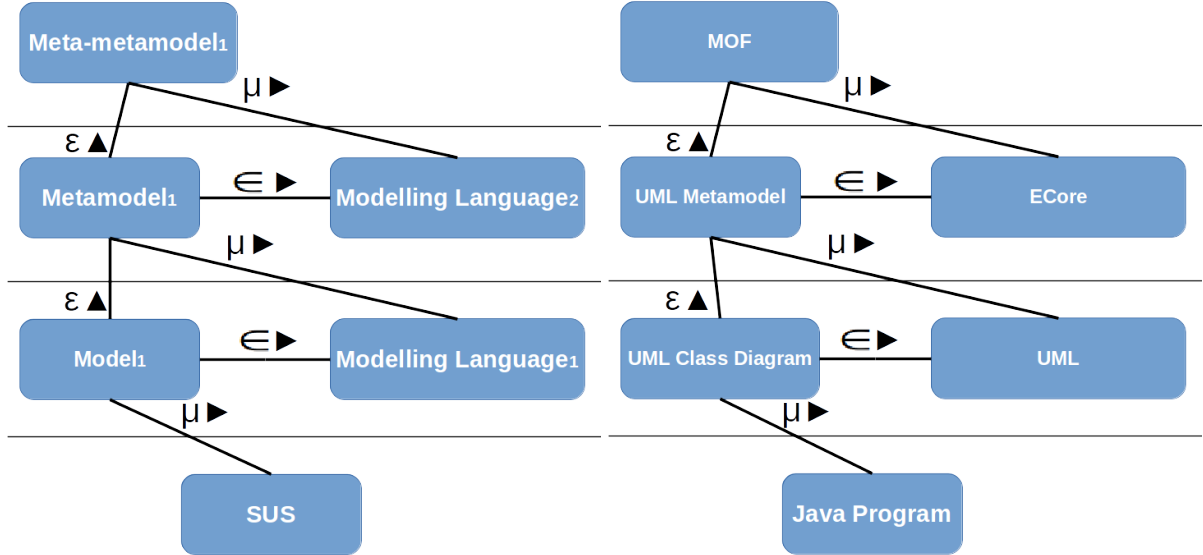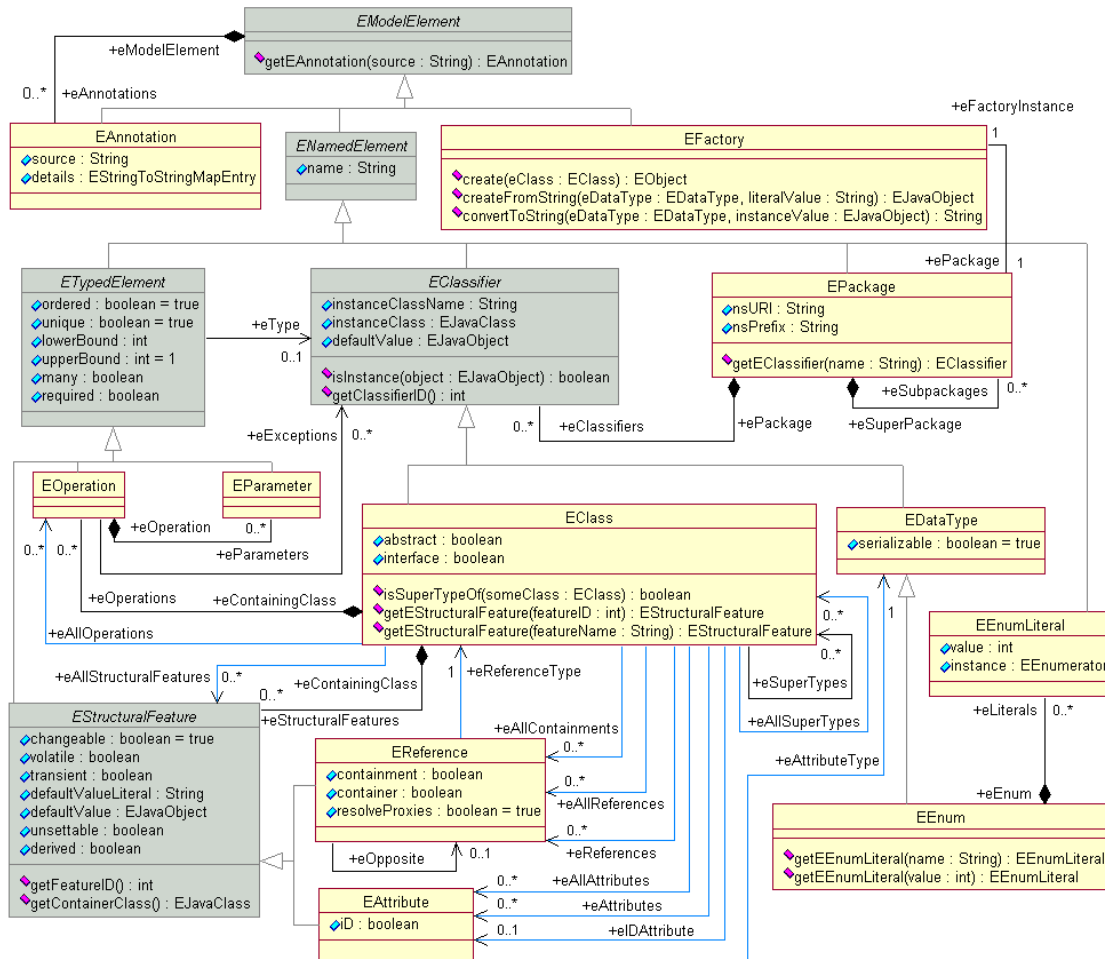

Source: The author

Model Synchronization: The goal of model synchronization is to maintain all relations between the models of a system consistent/correct as updates are performed over them Diskin (2011). More specifically, model synchronization is defined here as a function $s : MxMx\Delta_M xNxNx\Delta_M \rightarrow MxN$, where $s(m_0, m_1, \delta_m, n_0, n_1, \delta_n) = (m_2, n_2)$ means that final synchronized models m_2 and n_2 are created from the initial synchronized models m_0 and n_o and the modified non-synchronized models m_1 and n_1, considering the modifications (respectively δ_m and δ_n) performed over both. Practical example: Modification of a method name (δ_m) in the *UML class diagram*(m_0) has to be forwarded to the Java code(n_0), without losing extra information of it (e.g. comments). Note that, model synchronization is deterministic, bidirectional and preserves the informations of the both models. Other terms for model synchronization used interchangeably throughout this document are iterative or information preserving bidirectional model transformation.

Network of Models: A network of models of a system S is an undirected graph $G = (V, E)$, whereas each vertex $v_i \in V$ represents a unique model i abstracting S, and an edge (v_i, v_j) exists if, and only if there is a relation defined between both models i and j. In the figure 2.2 is an example of a network of models, illustrating the possible complexity of such network. More discussion is to find in Mens and Van Gorp (2006).

Figure 2.2: An example of a network of models very similar to the one developed in this work.

UML Class Diagram JavaDoc

UML Sequence Diagram Java Code OCL Contracts

Source: The Author

Meta Object Facility: *"The Meta Object Facility (MOF) provides an open and platform-independent metadata management framework and associated set of metadata services to enable the development and interoperability of model and metadata driven systems"* (Omg, 2015). The MOF describes therefore the MOF modeling language, which is used to model the meta-metamodel utilized in this thesis. Essentially, it inherits much from the UML and deals with the ideas of classes, properties and associations, providing and extensible but simple fashion to define meta-models. The figure 2.3 shows the part of MOF.

Figure 2.3: Part of MOF definition, which handles basically classes, properties, operations, associations, and generalization.

Source: (Omg, 2015, p. 27)

Ecore: Ecore[2] is the meta-metamodel utilized in this thesis to describe all the applied meta-models (e.g the Java meta-model). Ecore is an initiative of the EMF Project and aims to provide not only a meta-metamodel but a set of tools for criating meta-models, like an Eclipse plug-in generation feature, that enables the model developer to easily test and debug its meta-models. The Ecore meta-metamodel is at least similar to the essential MOF standard, and that is the reasons it is applied here. A proof of such compliance is not know by us though. The figure 2.4 shows the essential part of Ecore.

Figure 2.4: Ecore definition illustrating the use of classes, attributes, operations, references and super types, analogously to the figure 2.3

Source: http://download.eclipse.org/modeling/emf/emf/javadoc/2.9.0/org/eclipse/emf/ecore/package-summary.html. On the December 29th, 2015

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[2]https://eclipse.org/modeling/emf

Triple Graph: With the use of a triple graph a relation between a source model S and a target model T are abstracted into a triple (G_s, G_c, G_t) – where G_s is the graph representation of source model elements, G_t is the graph representation of target model elements, and G_c represents the correspondence between the two set of model elements – together with two mappings $s_g : G_c \rightarrow G_s$ and $t_g : G_c \rightarrow G_t$, which bind the three graphs (Hermann et al., 2011).

In this case, an addition in the triple graph $G = (G_s, G_c, G_t)$, that leads to a new triple graph $H = (H_s, H_c, H_t)$ consists in a triple graph morphism $m : G \rightarrow H$, with $m = (m_s, m_c, m_t)$. According to the figure 2.5.

Figure 2.5: The morphism $m : G \rightarrow H$ is a triple graph $m = (m_s, m_c, m_t)$.

$$
\begin{array}{ccccc}
G = (G^S & \xleftarrow{s_G} & G^C & \xrightarrow{t_G} & G^T) \\
m\downarrow \quad m^S\downarrow & & m^C\downarrow & & m^T\downarrow \\
H = (H^S & \xleftarrow[s_H]{} & H^C & \xrightarrow[t_H]{} & H^T)
\end{array}
$$

Source: (Hermann et al., 2011)

Triple Rule: A triple rule is a triple graph morphism $t_r = (s, c, t) : L \rightarrow R$, where L and R are called respectively the left-hand the right-hand sides (Ehrig et al., 2007).

Triple Axiom: A triple axiom is a triple rule $t_a = (s, c, t) : \emptyset \rightarrow R$. In order to apply such definitions in the practice, it is common to use attributed graphs and a easier to read diagram scheme depicted in the figure 2.6.
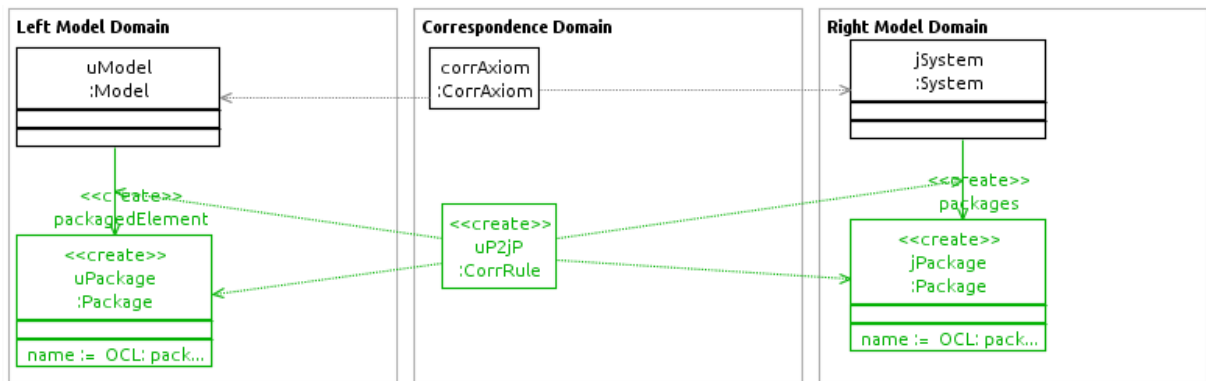
Triple Graph Grammar: A triple graph grammar $TGG = (t_a, T_{rules})$ consists of a triple axiom t_a and a set of triple rules T_{rules} (Giese et al., 2010a, p. 4). While one triple graph can be used as a description of a relation between two meta-models, one TGG describes the language of the these two related models and serves rather as description of consistency. Nevertheless, extra rules can be derived from a TGG, in order to create the operational semantic of a transformation procedure (Giese et al., 2010a). Figure 2.7 summarizes the so far defined terms.

Figure 2.6: In this kind of diagram for triple rules a triple graph is represented by three columns (left model domain, correspondence domain, and right model domain) each one representing respectively the source model elements, the correspondence between source and target and finally the target model elements. A triple rule in turn is represented by a triple graph in black (left-hand side) plus a triple graph in green(right-hand side) (see 2.6b). Because an axiom is a triple rule with empty left-hand side, only green graph occurs in an axiom (see 2.6a).

(a) Triple axiom example for the relation between UML and Java
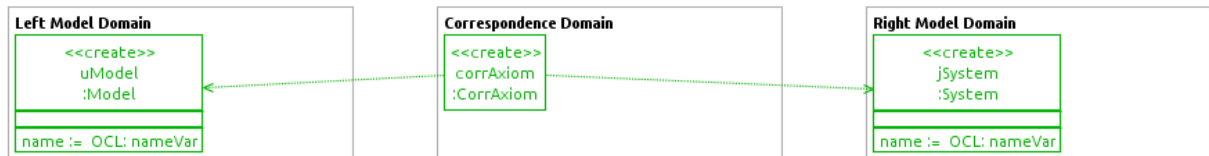
(b) Triple Rule example for the relation between UML package and Java package

Source: The author

Figure 2.7: Illustration of the definitions of model relation, transformation and synchronization as well as triple graph grammars (TGG). Relations between metamodels are coded by triple graphs; additions in the models are coded by triple rules, which are then organized in a TGG. A TGG can be used to derive operational semantic definitions. The concept of modeling language is pictured as red lines.
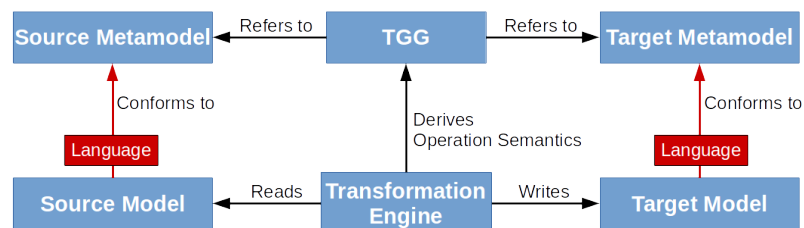
Source: Adapted from Czarnecki and Helsen (2006, p. 623)

3 STATE OF THE ART

Some endeavors have been made in order to code relations between some meta-models and mainly to develop theoretical results and synchronization methods. Heidenreich et al. present in (2009) and (2010) a Java meta-model using *Ecore*, what influenced considerably the development of our work, although it has not been used by us because of its size and unnecessary comprehensiveness for our needs. Greenyer et al. (2008) comes up with a transformation between *UML activity diagrams* and *CSP diagrams* using *TGG*. Foss et al. (2011) defined the translation between *UML* and *Simulink* using graph grammars. Blouin et al. (2014) reports about the synchronization between some specific meta-models of the automotive standards and influences our work, by using the same modeling language and transformation method as us, namely *EMF* (Steinberg et al., 2008) and *MoTE* (Giese et al., 2010a). Finally Giese et al. (2010b) introduce their approach to the synchronization of two automotive industry meta-models, lightening in the paper the *MoTE* tool and its algorithm for synchronization.

We judge that the *MoTE* transformation tool is the most adequate option for our needs, once literature about it is widely available (see also (Giese and Hildebrandt, 2009) and (Hildebrandt et al., 2012)). Nevertheless there are other attempts to build a model synchronization tool, like the *ATL Eclipse Plug-in* (Jouault et al., 2008), which uses the *Atlas Transformation Language* to code the relations between models; the Medini QVT [1], which claims to implement the *Query/View/Transformation Language* to code the relations; and the FUJABA (Nickel et al., 2000), in which relations are coded using *Triple Graph Grammars*. Hildebrandt et al. (2013) also publicized a survey on synchronization tools based on TGG. Other publications aim to solve specific problems, like the ones in Hermann et al. (2011), Xiong et al. (2007), Giese and Wagner (2006), Ivkovic and Kontogiannis (2004), or Song et al. (2011), where advanced algorithms for bidirectional synchronization have been proposed.

A research road-map for model synchronization found in France and Rumpe (2007) gives an overview on the realm, and together with Mattsson et al. (2009) show an interesting point of view about the challenges. Seidewitz (2003) writes an interesting reflection about what models mean and how to interpret them and in Mens and Van Gorp (2006) a taxonomy for model transformation is proposed, what helps to carry more precise analysis. In Czarnecki and Helsen (2006) a survey was driven and a framework for classification of model transformation approaches was presented. In Diskin et al. (2014) and (2016) a taxonomy for a network of models is presented and in Diskin (2011) a theoretical algebraic basis is proposed.

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[1]http://projects.ikv.de/qvt

Additionally, one can judge by the date of publication of these works, that the topic of model synchronization is extremely active and is actually the edge of current academic research, what motivates even more the development of this thesis.

4 META-MODEL RELATIONS IN THE JAVA TECHNOLOGICAL SPACE

With the terms and the theoretical basis clarified, the report of the main development phase of the thesis is shown below. The idea here is first to present the selected network of meta-models, by describing what each model represents and how they relate to each other. Then the developed meta-model definitions and the relations between them are exposed, as well as the justification of the choices made during the work.

4.1 The Network of Meta-models

The choice of which models are used in a certain Java program may vary considerably depending on the context of the development and the software requirements, which themselves can range from high dependability (e.g. airplane software) to continuous evolution (e.g. applications for cellphones) for example. Nevertheless we selected a few typical models and the relations between them and created a network of meta-models, shown in figure 4.1.

Figure 4.1: The created network of meta-models
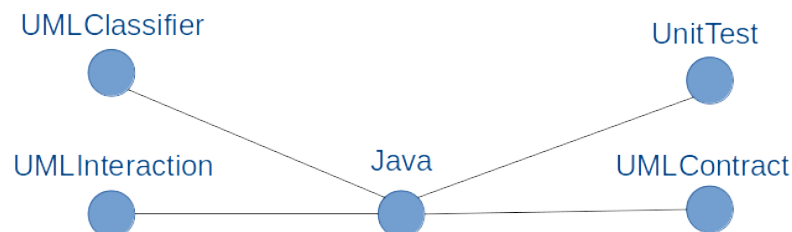
Source: The author

The central element of the network is the *Java* meta-model. A Java model (or, Java code) contains both structural and behavioral information about the system, which is represented among other elements through *classes*, *fields*, *methods* and *statements*.

Once a meta-model might be relatively big and comprise a huge number of elements, it is interesting to split it into smaller pieces for a specific set of relations. Take for example the UML, that includes a large number of different concerns (e.g. classifiers, state machines, activities, interaction, etc) and may be split into sub meta-models in order to ease the writing of the relations. For this reason we separate the UML into *UMLClassifier*, *UMLInteraction*, and *UMLContract*. The first is constructed around the concept of *classifier*, that is *"used to classify*

different kinds of values" (OMG, 2007, p. 97) and is widely used under the name *class* in the object oriented paradigm. In special, we focus on structured classifiers, thus considering elements like *class*, *property*, *operation*, *interface* and *package*. This meta-model is usually used to describe the structure of a object oriented Java program through a class diagram, representing the definition of its classes, field and methods, but leaving out behavioral aspects. The relations between *UMLClassifier* and *Java* is then given by an almost direct translation between their elements. A *class* in the former is transformed into a *class* in the latter, a *property* in a *field*, an *operation* in a *method* and so on.

To represent some behavioral aspects, *UMLInteraction* is used instead. *"Interactions [...] are used to get a better grip of an interaction situation for an individual designer or for a group that needs to achieve a common understanding of the situation"* (OMG, 2007, p. 563). The elements of this meta-model are usually reproduced with sequence diagrams, where *lifelines* and *messages* provide information about the sequence of event occurrences. In a Java program it may correspond to the sequence of calls inside a specific method. This means, the semantical information of each sequence diagram could be brought to correspondent method in the Java model.

UMLContract is based on the ideas of design-by-contract, whose main goal is to improve reliability of object oriented software (Meyer, 1992), and where operations have *pre* and *postconditions* as well as *invariants*. Its relation with *Java* is basically, that each constraint of the contracts can be tested as assertions and expressed in terms of annotations in the Java source-code. Moreover, once can have check methods, that are supposed to be updated as soon as the contracts undergo changes.

At last is the *UnitTest*, that endeavor to enhance the software quality by means of tests. It tests small units of code, by basically verifying the pre and postconditions as well as invariants of each method. Because unit tests for Java programs are usually written in Java, we use the same meta-model for the vertices *Java* and *UnitTests* of our network. Anyways, the relation between both is based on creating test cases in the latter according to the contract annotations (e.g pre and postconditions, invariants, examples, etc) present in the methods of the former.

4.2 Meta-model Definitions

The modeling language used to write these meta-models is the *EMF Ecore* and the tool used is the special version for model development of the *Eclipse Mars 4.5.1 IDE*[1], which eases

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[1]https://projects.eclipse.org/releases/mars

the creations of models ans their diagrams and the generation of plug-ins necessary for running the transformations, thus being more suitable than the alternatives of the *Netbeans IDE*[2] or the FUJABA (Nickel et al., 2000), whose support or popularity in the community are not so valuable. The *Ecore* language has been chosen not only for its extensible documentation and popularity in the community, but also for its ease to use in the *Eclipse IDE*. The meta-models are listed in the sections below.

4.2.1 UML

The meta-model utilized for UML represents the version 2.0 of the standard and is provided by the *EMF plug-in*[3] for Eclipse, which clearly integrates easily with the IDE and seems to be suitable for our needs. Alternatively we could use the meta-model provided by the OMG, but then unnecessary work of adaption could late our progress. A meta-model for the latest version of the UML (2.5) has not been found. The figures **??**, 4.3 and 4.4 address simplified views of the UML meta-model for respectively the classifiers, interactions and contracts concerns.

4.2.2 Java

For the Java a brand new meta-model was designed in regard to the necessities of this work. Other possibilities included the meta-model[4] provided by the *Eclipse IDE*, whose simplicity hindered its use, or yet the one found in Heidenreich et al. (2010), but this one happens to be so extensive that could bring unnecessary complexity. The figure 4.5 reports the created Java meta-model.

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[2]https://eclipse.org
[3]https://eclipse.org/modeling/emf
[4]http://www.eclipse.org/modeling/emf/downloads

4.3 Relations

With all the meta-models defined, the definition of the relations between their elements can be done. In order to accomplish that, TGG is used to code the relations, because it has been extensively used in current academic research; and is supported by several tools for synchronization. Other options included the *ATL* (Jouault et al., 2008), which does not seem to be enough ripe for our use; or the *Henshin* (Arendt et al., 2010), that is not widely supported for the best tools (Hildebrandt et al., 2013). A theoretical basis of TGG has been given in the chapter 2. Here the relations written by us are presented as well as some explanations over them.

### 4.3.1 UmlClass2Java

EXPLAIN FIGURE 4.6 to 4.7

4.3.2 UmlInteraction2Java

FIGURE 4.8 to 4.10

4.3.3 UmlContracts2Java

FIGURE 4.11 to 4.15

Figure 4.2: A simplified view of the UML meta-model focused on the elements used in classes diagrams. Elements in blue are abstract elements, whilst elements in yellow are concrete. Some features like operations and some relations between elements were omitted for a better visualization.
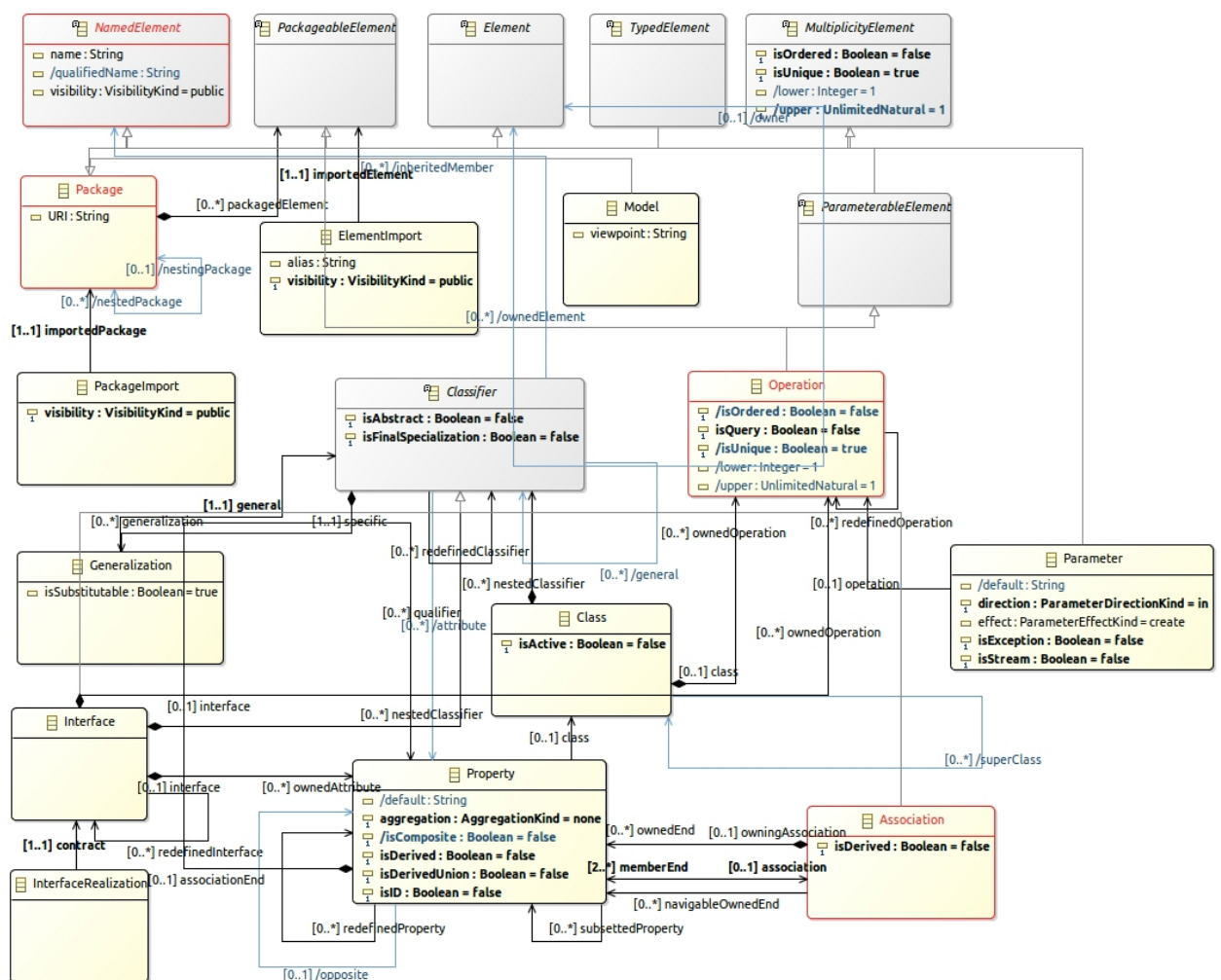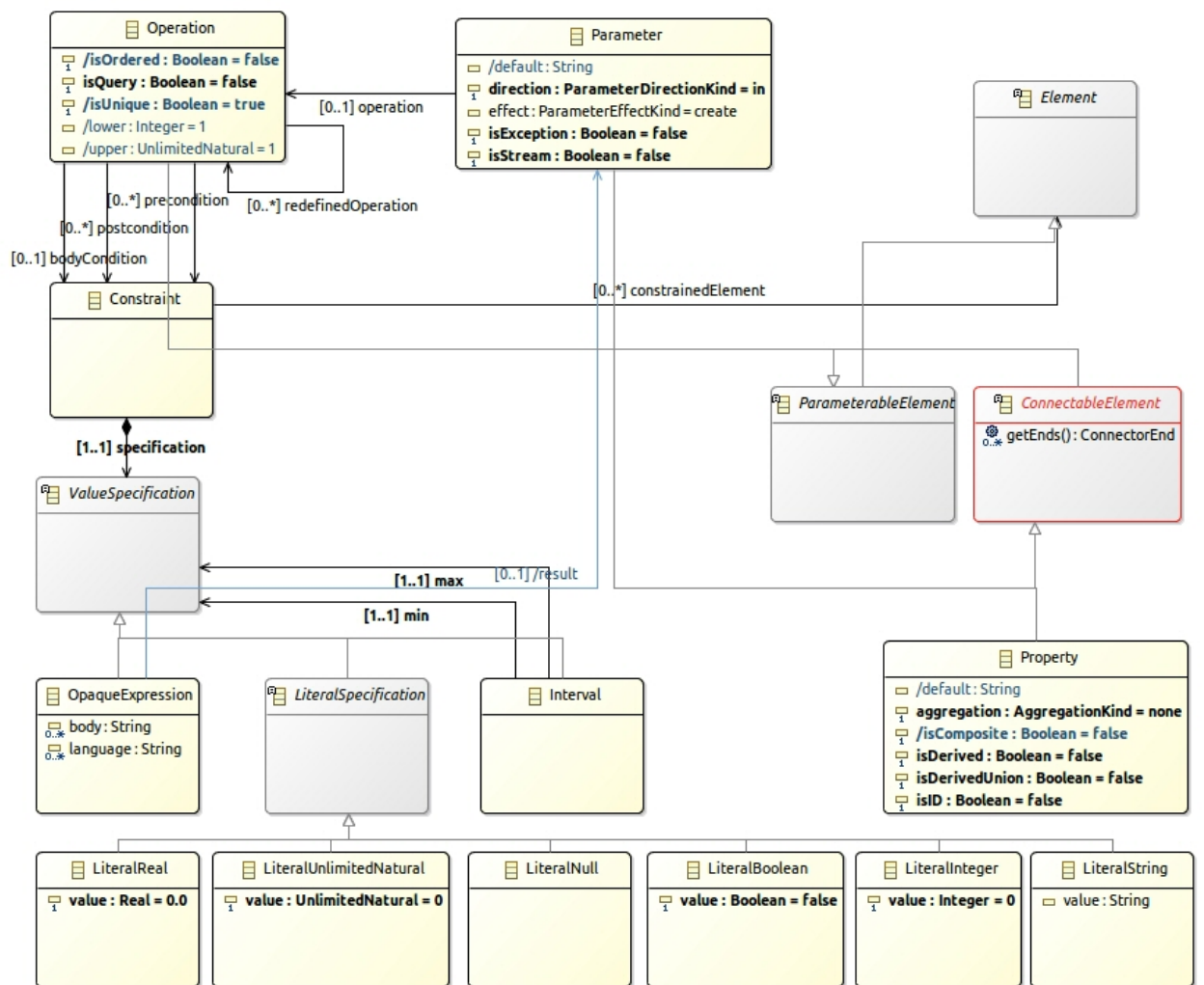

Source: Image created by the author using the *Eclipse IDE*. Meta-model from *EMF plug-in*

Figure 4.3: A simplified view of the UML meta-model focused on the elements used in sequence diagrams.
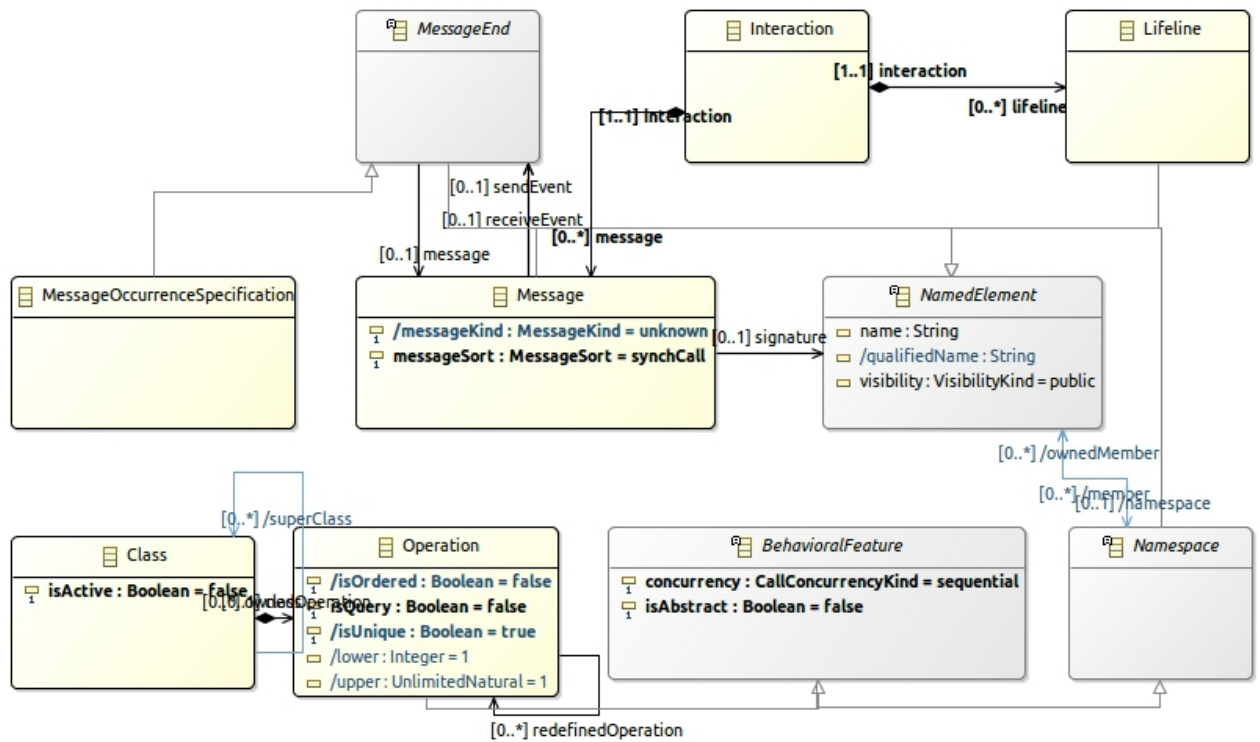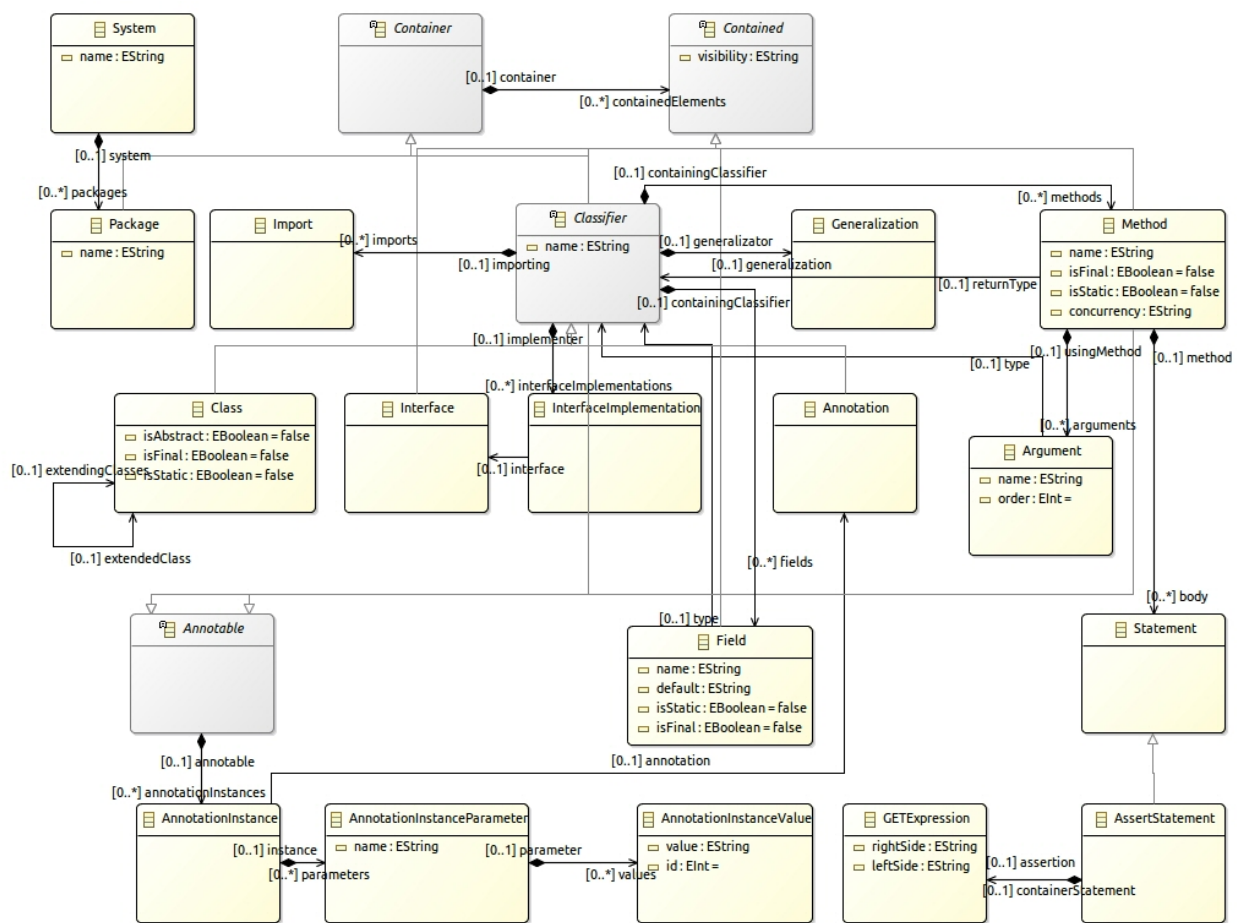

Source: Image created by the author using the *Eclipse IDE*. Meta-model from *EMF plug-in*

Figure 4.4: A simplified view of the UML meta-model focused on the elements used in contracts.
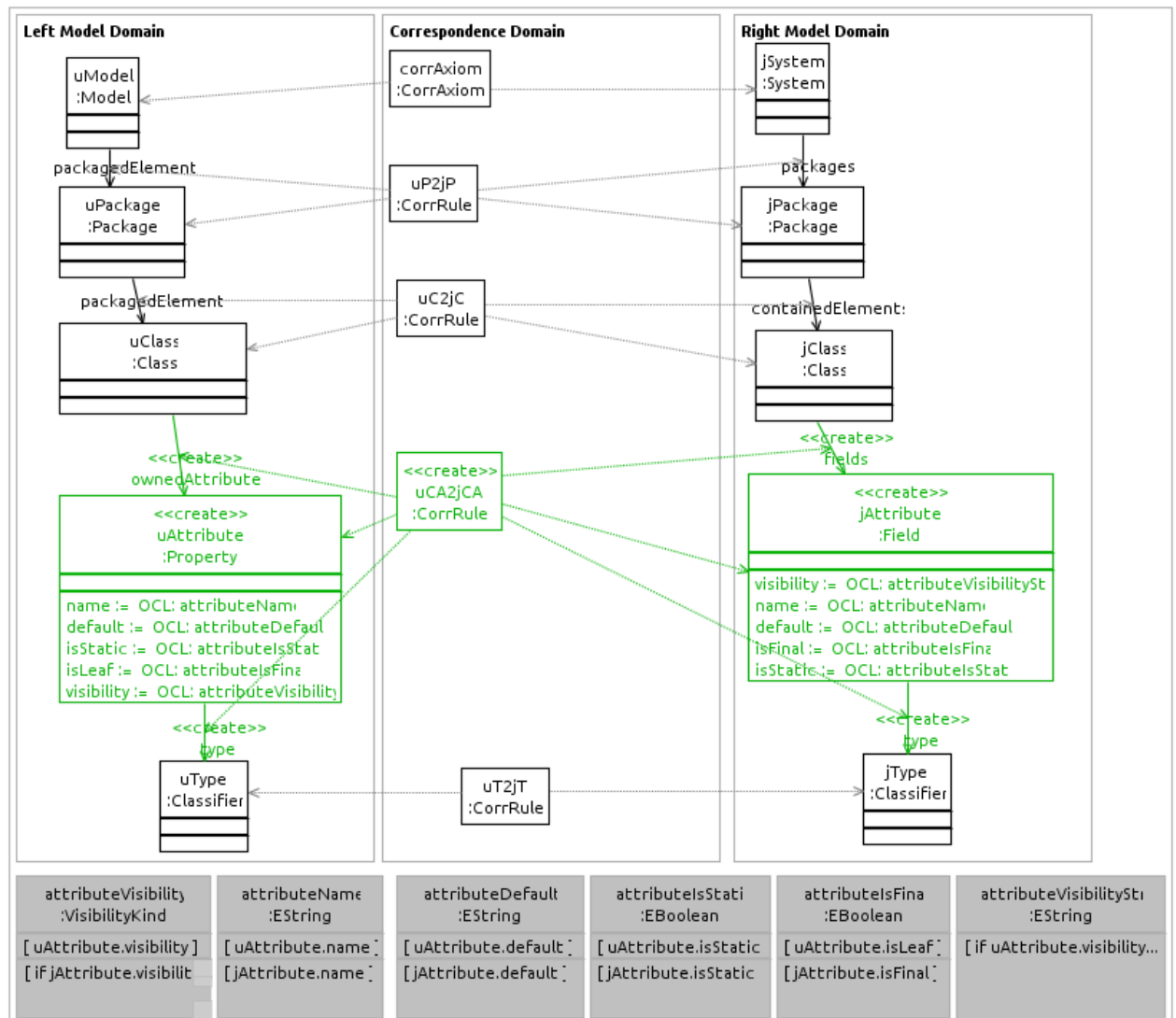

Source: Image created by the author using the *Eclipse IDE*. Meta-model from *EMF plug-in*

Figure 4.5: The Java meta-model created. It goes beyond the common classes and attributes scenario, by comprising also annotations and statements.
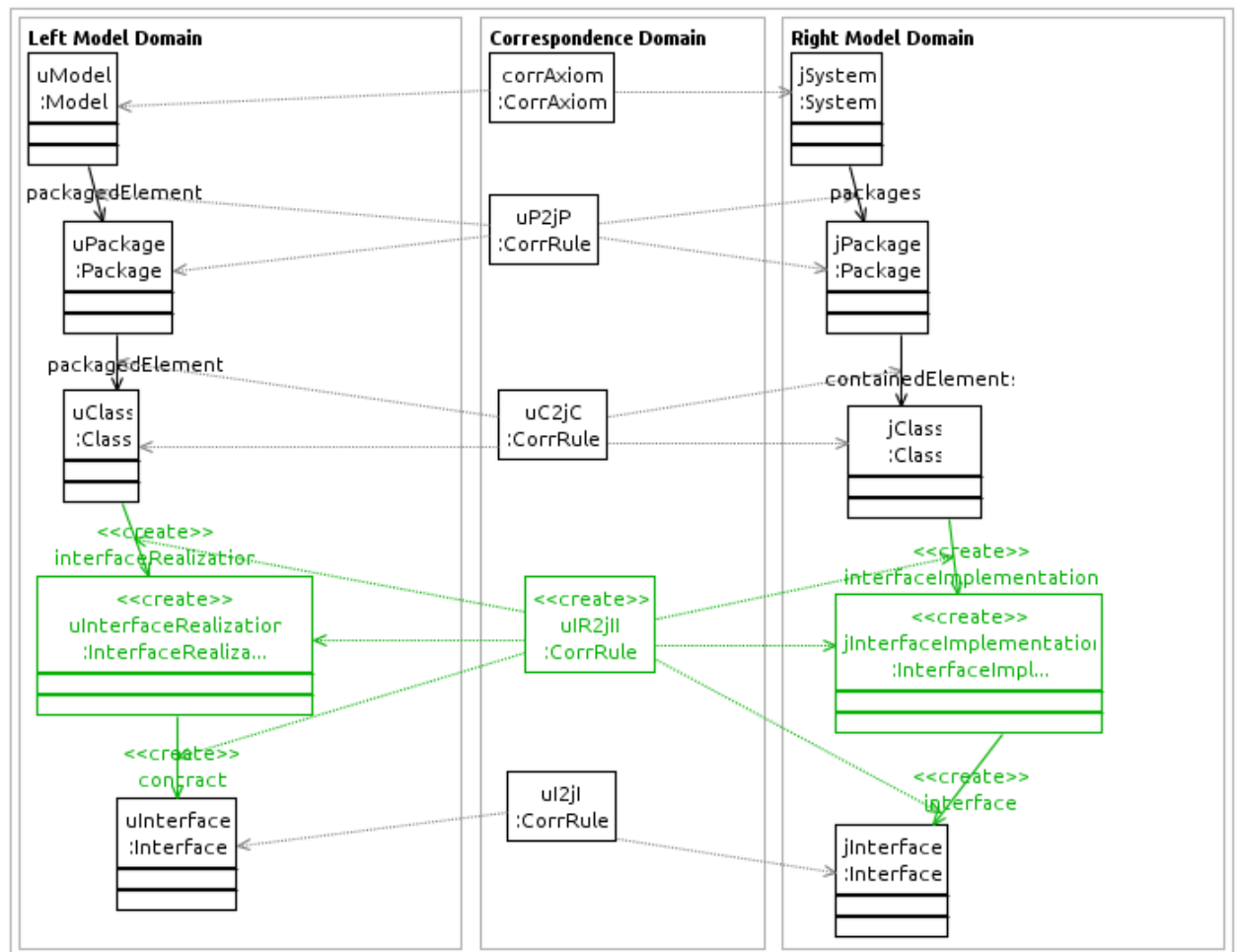

Source: Image created by the author using the *Eclipse IDE*.
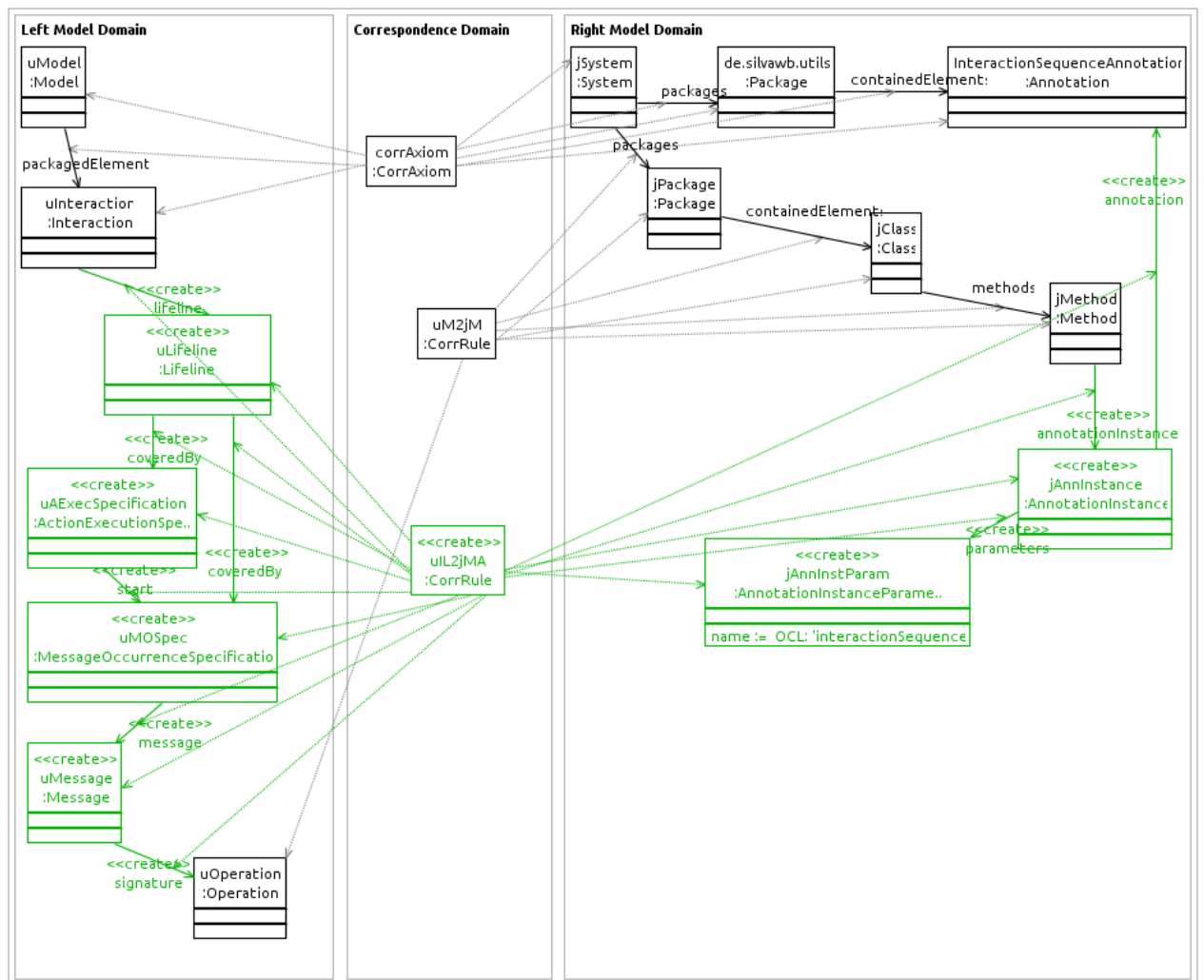
Figure 4.6

Source: Image created by the author using the *Eclipse IDE*.

Figure 4.7

Source: Image created by the author using the *Eclipse IDE*.

Figure 4.8

Source: Image created by the author using the *Eclipse IDE*.

Figure 4.9

Source: Image created by the author using the *Eclipse IDE*.

Figure 4.10

Source: Image created by the author using the *Eclipse IDE*.

Figure 4.11

Source: Image created by the author using the *Eclipse IDE*.

Figure 4.12

Source: Image created by the author using the *Eclipse IDE*.
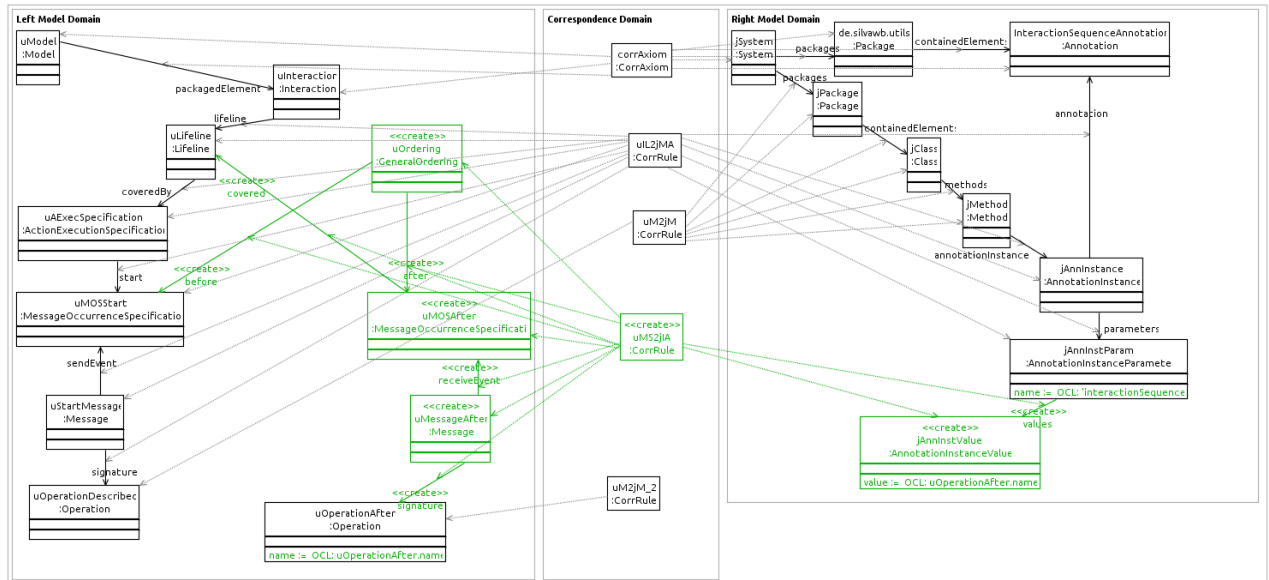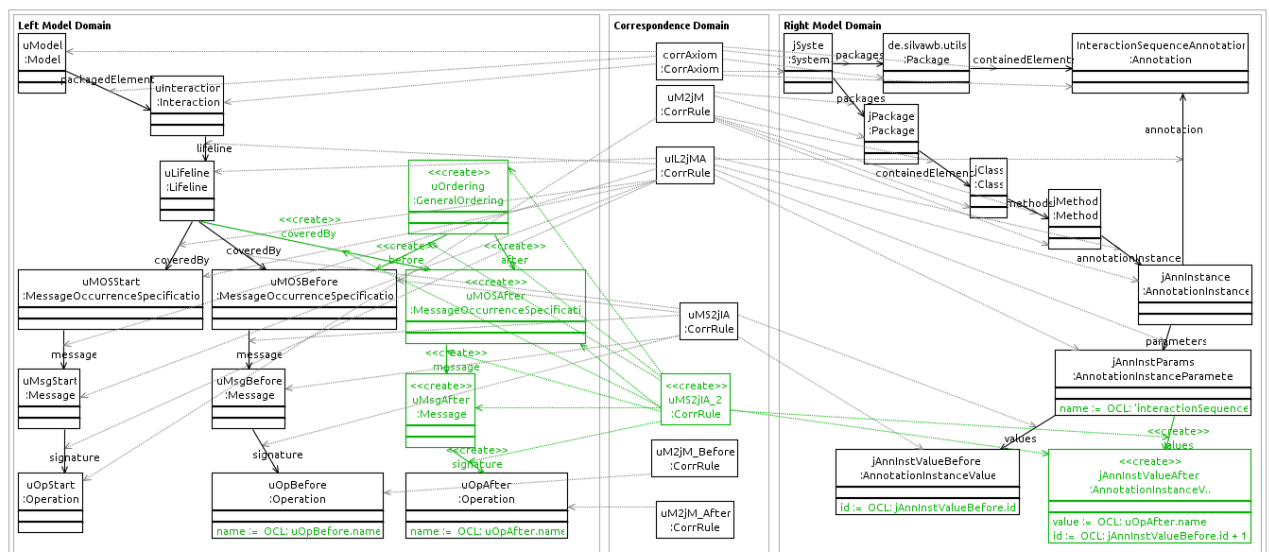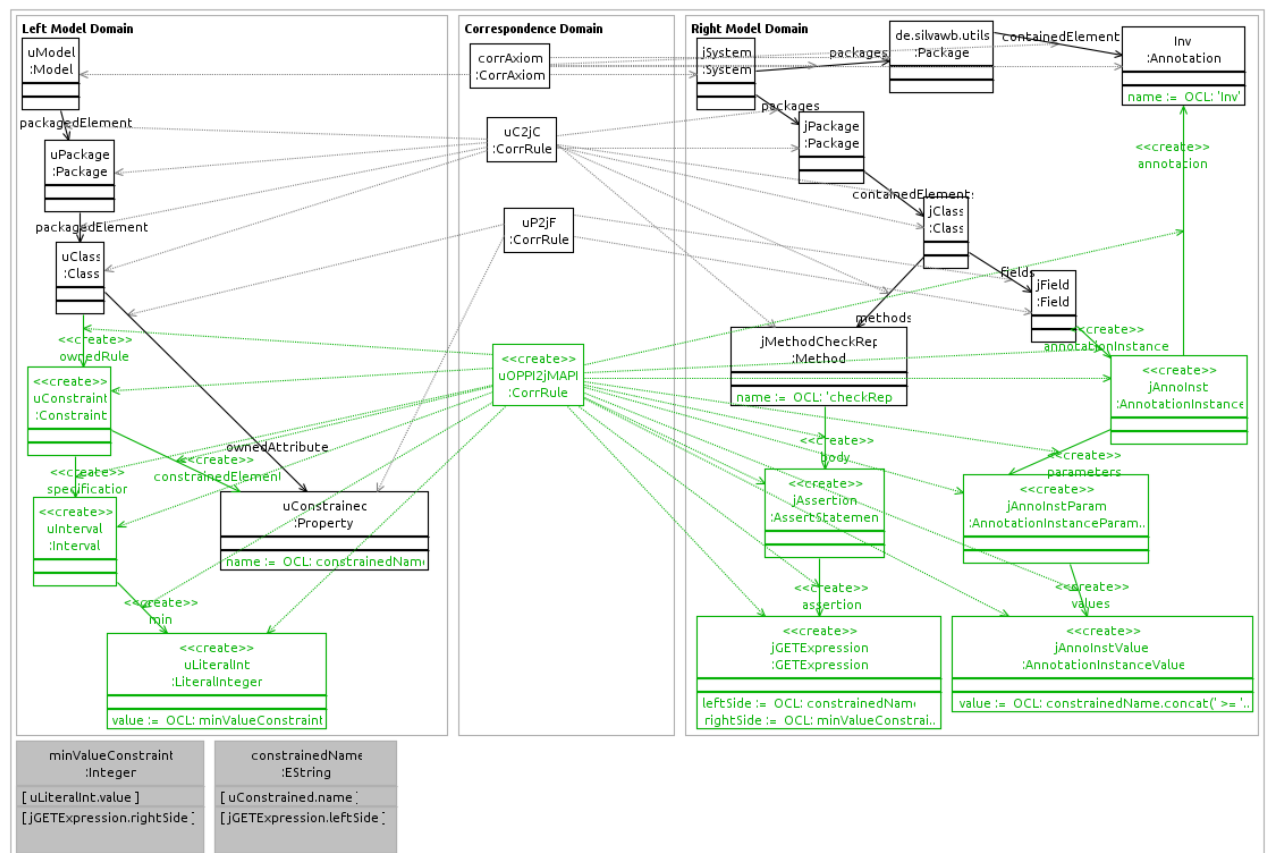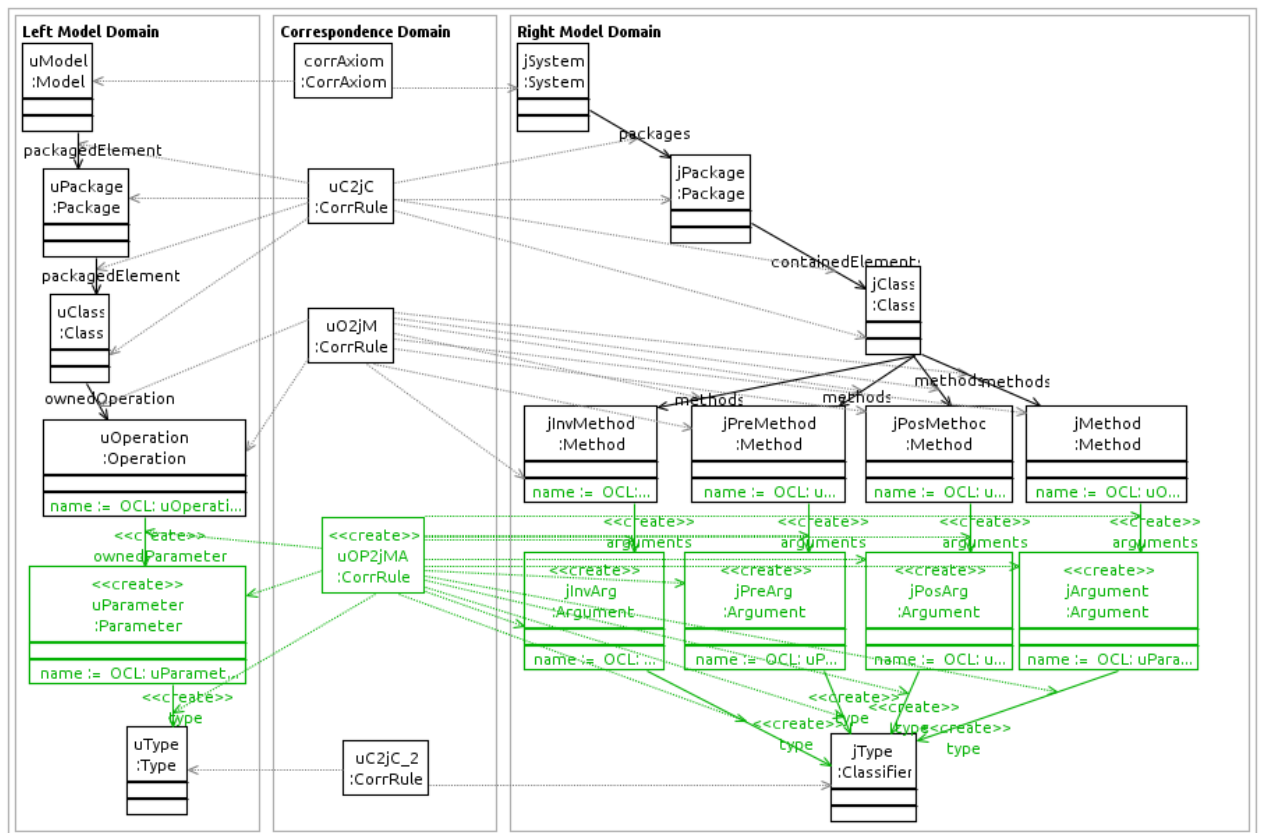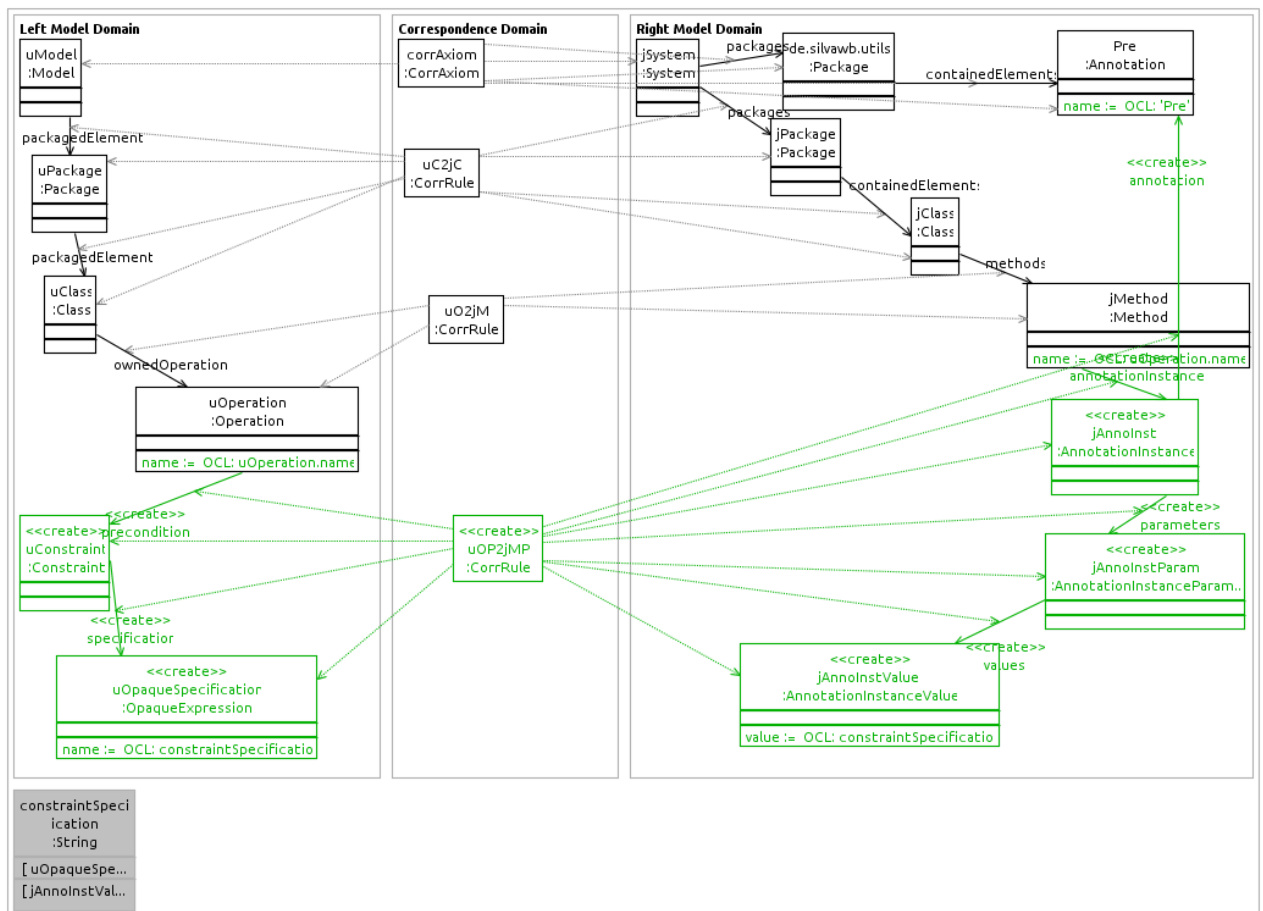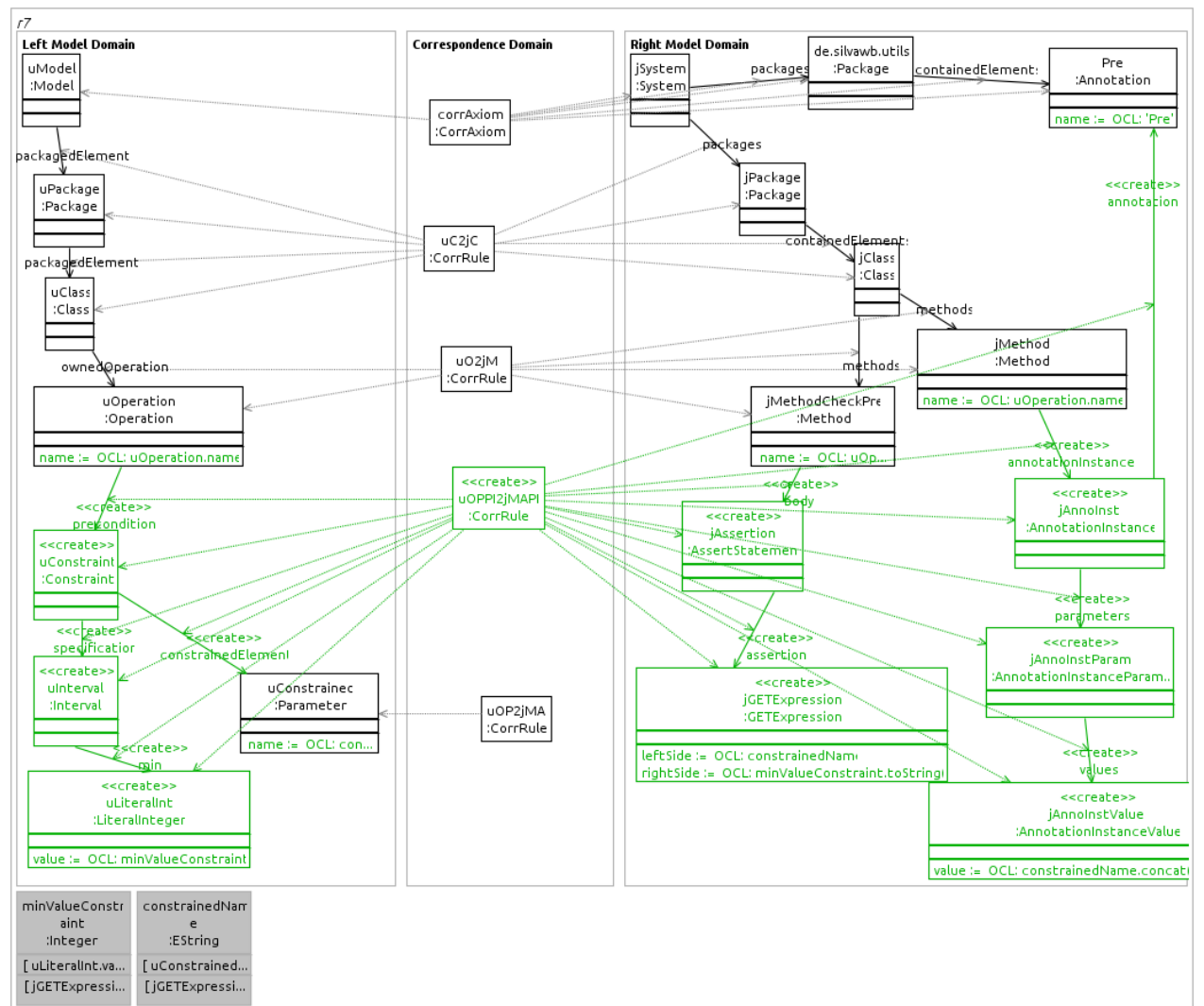
Figure 4.13

Source: Image created by the author using the *Eclipse IDE*.

Figure 4.14

Source: Image created by the author using the *Eclipse IDE*.

Figure 4.15

Source: Image created by the author using the *Eclipse IDE*.

5 SYNCHRONIZATION BETWEEN SOME MODELS IN THE JAVA TECHNOLOGICAL SPACE

6 CONCLUSION AND DISCUSSION

A network of meta-models of the Java technological space was developed, comprising a set of common meta-models used in Java software and the respective relations between them, as well as synchronization between the models was showcased, demonstrating as final result that the construction of such network and the employment of synchronization has worked and moreover seems to be promising. Despite the outcomes are not complete and not ripe enough to be put in practice, the ideas and the insights reported plus the summary of the state-of-art are valuable for current research and thus contributing.

In the first phase some meta-models were developed (e.g Java), and in the second phase the relations were coded (e.g. umlClass2java). In regard to these both steps the main legacy are the novel relations between some elements of some meta-models (e.g. the relation between UML contracts and Java assertions). The third phase serve to demonstrate briefly the application of synchronization in the practice. Most of the initially set up goals were achieved, even though the relations could rather be more extensive, likewise a more comprehensive synchronization demonstration would be desired.

Some difficulties were found along the work, but they absolutely did not obstructed the success of the final result. The first one the lack of openly available meta-models in the literature or by the vendors. For instance *Oracle* does not publicize any standard meta-model for Java, nor are them easily to find in the literature. One may find alternative versions in the source code of IDE's, but it still requires some cost. Moreover, they are sometimes because their format incompatible with the employed tool, what also hinders the progress of someone's work. The result of this thesis may be a partial solution for that, although meta-models of other technological spaces still lack a similar work. Another complication are the lack of documentation of some tools − in special the *MoTE* −, that makes both the flow of the development and eventual debug tasks sometimes troublesome. *MoTE* might have publications about it and also a good reputation in the community, but a extensive broad documentation of the plug-in for the *Eclipse IDE* is needed. At last, but not least is the performance problem of such tools. Both the *EMF* and *MoTE* need to generate Java code in order to run the synchronization procedure, and with big models this process happens to cost a considerable computation time.

Some points become therefore remarkable for future work. Firstly, an easy to find and accessible tutorial or instructions for the theoretic and practical basis of triple graph grammars is valuable in order to make the use of models synchronization popular among engineers or software developers, who sometimes are not very used to the area and thus express a big rejection

to apply such technique in their projects.

Secondly, the work of this thesis can be naturally continued and expanded, by completing the identification of relation between the meta-model or by creating meta-models that satisfy completeness. Not to mention, such relations could be expressed in other languages (e.g. *ATL*) and the same work extended to other technological spaces (e.g. COBOL, C#).

Furthermore, the implementation of a *Eclipse* plug-in should not be a big problem, since the *MoTE* already generates a plug-in for the execution of its algorithm. So the task in this case would be enhance it with a user-friendly interface plus new functionalities and naturally a slightly more practical approach (e.g. handling of actual Java code instead of quasi-theoretic scenarios like Java expressed in XML files).

And lately, a relatively big issue is the use of TGG's for non-MOF-compliant meta-models – or meta-models that are not naturally seen as MOF-compliant, e.g. the complete Java model. Because under certain conditions it could be interesting to see such models from another point of view than the MOF. A clear example is source-code, which can be treated in an easier way with abstract syntax trees. Angyal et al. (2008) suggests a method to treat this case, but anyways it still remains an open problem and certainly a future challenge.

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