METRICS FOR A MODEL DRIVEN DEVELOPMENT CONTEXT

Motoshi Saeki
Tokyo Institute of Technology, Ookayama 2-12-1-W8-83, Meguro, Tokyo 152-8552, Japan

Haruhiko Kaiya
Shinshu University, Wakasato 4-17-1, Nagano 380-8553, Japan

Keywords: Metrics, Model Transformation, Graph Rewriting, Model Driven Development.

Abstract: In a Model Driven Development context, in addition to the metrics of models themselves, the metrics of model transformation should be considered in order to measure its various characteristics such as quality. In this paper, we propose the technique to define the metrics of model transformation using a meta-modeling technique and a graph rewriting techniques. The meta-modeling technique is used for defining model-specific metrics, while graph rewriting rules formalize transformation. The values of model-specific metrics to be calculated are attached to graph rewriting rules, and can be evaluated and propagated between the models during the transformation. The evaluation and propagation methods can be defined within the graph rewriting rules, and their evaluation and propagation result in the metric values of the transformation. Furthermore the paper includes the example of transforming object models into relational database models in order to show the usefulness of our approach.

1 INTRODUCTION

The techniques of metrics are to quantify characteristics of software products and development processes, e.g. quality, complexity, stability, development efforts, etc., and are significant to predict these characteristics at earlier steps of the development processes, as well as to know the current status of the products and the processes.

Model Driven Development (MDD) is one of the promising approaches to develop software of high quality with less developers' efforts. There are wide varieties of models such as object-oriented models, data flow models, activity models etc. that can be produced in the MDD processes. For example, object oriented modeling mainly adopts class diagrams consisting of classes and their associations, while in data flow modeling data flow diagrams having processes (data transformation), data flows and data stores, etc. are used. In this situation, according to models, we should use different metrics to quantify their characteristics, and it is necessary to define the metrics according to the models. For example, in the object-oriented models, we can use the CK metrics (Chidamber and Kemerer, 1994) to quantify the structural complexity of a produced class diagram, while we use another metrics such as Cyclomatic number (McCabe and Butler, 1989) for an activity diagram of UML (Unified Modeling Language). These examples show that effective metrics vary on a model, and first of all, we need a technique to define model-specific metrics in MDD context.

In MDD, model transformation is one of the key technologies (OMG, 2003; Kleppe et al., 2003; Mellor and Balcer, 2003) for development processes, and the techniques of quantifying the characteristics of model transformation and its processes are necessary to measure the development processes based on MDD. Although we have several metrics for quantifying traditional and conventional software development processes such as staff-hours, function points, defect density during software testing etc., they are not sufficient to apply to model transformation processes of MDD. In other words, we need the metrics specific to model transformation in addition to model-specific metrics. Suppose that a metric value can express the complexity of a model, like CK metrics, a change or difference between the metric values

Saeki M. and Kaiya H. (2008).
METRICS FOR A MODEL DRIVEN DEVELOPMENT CONTEXT.
In *Proceedings of the Third International Conference on Evaluation of Novel Approaches to Software Engineering*, pages 13-22
DOI: 10.5220/0001759000130022
Copyright © SciTePress

before and after a model transformation can be considered as the improvement or declination of model complexity. For example, the model transformation where the resulting model becomes more complex is not better and has lower quality from the viewpoint of model complexity. This example suggests that we can define a metric of a model transformation with a degree of changing the values of model-specific metrics by it. Following this idea, the formal definition of a transformation should include the definition of model-specific metrics so that the metrics can be calculated during the transformation.

Although we could find excellent techniques to formalize model transformation of MDD until now, there are quite few arguments on the significance of clarifying and defining the metrics of model transformation (Saeki and Kaiya, 2006). In (Merilinna, 2005), the relations between model transformation and quality attributes was discussed. However, the goal of this work is the usage of model transformation in order to generate a new model from the older model when quality requirements were changed.

In this paper, we propose a technique to solve the problem on how to define metrics of model transformation together with model-specific metrics. To realize this technique, as mentioned before, we take the following existing techniques;

1. Using a meta modeling technique to specify model-specific metrics
   Since a meta model defines the logical structure of models, we specify the definition of metrics, including its calculation technique, as a part of the meta model. Thus we can define model-specific metrics formally. We use Class Diagram plus Object Constraint Language (OCL) to represent meta models with metrics definitions.

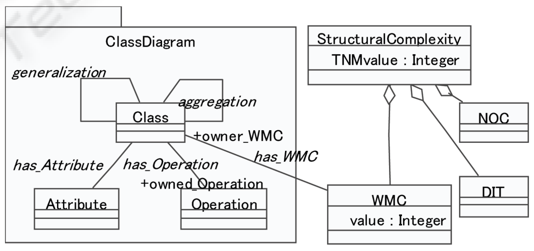
2. Using a graph rewriting system to formalize model transformation
   Since we adopt Class Diagram to represent a meta model, a model following the meta model is mathematically considered as a graph. Model transformation rules can be defined as graph rewriting rules and the rewriting system can execute the transformation automatically in some cases.

The metric values to be calculated are attached to graph rewriting rules, and can be evaluated and propagated between the models during the transformation. This evaluation and propagation mechanism is similar to Attribute Grammar, and the evaluation and propagation methods can be defined within the graph rewriting rules. We define the metrics of a model transformation using the model-specific metric values of the models, which are attached to the rules.

The usages of the meta modeling technique for defining model-specific metrics (Saeki, 2003) and of graph rewriting for formalizing model transformation (Czarnecki and Helsen, 2003; Karsai and Agrawal, 2003; Saeki, 2002) are not new. In fact, OMG is currently developing a meta model that can specify software metrics (OMG, 2006) and the workshop (Bézivin et al., 2006) to evaluate practical usability of model transformation techniques including graph rewriting systems was held. However, but the contribution of this paper is the integrated application technique of meta modeling and graph rewriting to solve the new problem, i.e. how to formalize the metrics of model transformation, with unified framework.

The rest of the paper is organized as follows. In the next section, we introduce our meta modeling technique so as to define model-specific metrics. In section 3, we briefly introduce graph rewriting technique to formalize model transformation. Section 4 presents the technique to define the metrics of model transformation and includes the examples of the metrics of model transformations. Section 5 is a concluding remark and discusses the future research agenda.

2 META MODELING AND DEFINING METRICS



(a) Meta Model of Class Diagram (b) Meta Model of Structural Complexity Metrics

Figure 1: Meta Model with Metrics Definitions.

A meta model specifies the structure or data type of the models and in this sense, it can be considered as an abstract syntax of the models. In addition to meta models, we should consider constraints on the models. Suppose that we define the meta model of the models which are described with class diagrams, i.e. object-oriented models. In any class diagram, we cannot have different classes having the same name, and we should specify this constraint to keep consistency of the models on their meta model.

In our technique, we adopt a class diagram of UML for specifying meta models and OCL for constraints on models. The example of the meta model of the simplified version of class diagrams is shown in Figure 1 (a). As shown in the figure, it has the concepts “Class”, “Operation” and “Attribute” and all of them are defined as classes and these concepts have associations representing logical relationships among them. For instance, the concept “Class” has “Attribute”, so the association “has_Attribute” between “Class” and “Attribute” denotes this relationship.

We can embed metrics and their calculation methods into a meta model in the same way. More concretely, metrics such as WMC (Weighted Methods per Class), DIT (Depth of an Inheritance Tree) and NOC (Number of Children) of CK metrics are defined as classes having the attribute “value” in the meta model as shown in the Figure 1 (b). The “value” has the metric value and its calculation is defined as a constraint written with OCL. For example, WMC is associated with each class of a class diagram through the association “has_WMC” and the role names “owner_WMC” and “owned_Operation” are employed to define the value of WMC with OCL. Intuitively speaking, the value of WMC is the number of the methods in a class when we make weighted factors 1 and we take this simple case. It can be defined as follows.

context WMC::value : Integer

derive: owner_WMC.owned_Operation -> size()

WMC and the other CK metrics are for a class not for a class diagram. Thus we can use the maximum number of WMCs in the class diagram or the average value to represent the WMC for the whole of the class diagram. In this example, which is used throughout the paper, we take the sum total of WMCs for the class diagram, and the attribute TNMvalue of StructuralComplexity holds it as shown in Figure 1 (b). The techniques of using OCL on a meta model to specify metrics were also discussed in (Abreu, 2001; Saeki, 2003), and the various metrics for UML class diagrams can be found in (Genero et al., 2005).

3 GRAPH REWRITING SYSTEM

In Model Driven Development, one of the technically essential points is model transformation. Since we use a class diagram to represent a meta model, a model, i.e. an instance of the meta model can be considered as a graph, whose nodes have types and attributes, and whose edges have types, so called attributed typed graph. Thus in this paper, model transformation is defined as a graph rewriting system, and graph rewriting rules dominate allowable transformations. In this section, we introduce a graph rewriting system.

A graph rewriting system converts a graph into another graph or a set of graphs following pre-defined rewriting rules. There are several graph rewriting systems such as PROGRESS (Schurr, 1997) and AGG (Taentzer et al., 2001). Since we should deal with the attribute values attached to nodes in a graph, we adopt the definition of the AGG system in this paper. A graph consists of nodes and edges, and type names can be associated with them. Nodes can have attribute values depending on their type. The upper part of Figure 2 is a simple example of rewriting rules. A rule consists of a left-hand and a right-hand side which are separated with “::=”. The attribute values should be able to be propagated in any direction, i.e. from the left-hand side of “::=” to the right-hand side, the opposite direction, as well as within the same side, and this mechanism is similar to synthesized and inherited attributes of Attribute Grammar. In this sense, the graph rewriting system that we use is an extended version of AGG.

In figure 2, a rectangle box stands for a node of a graph and it is separated into two parts with a horizontal bar. Type name of a node appears in the upper part of the horizontal bar, while the lower part contains its attribute values. In the figure, the node of “TypeA” in the left-hand graph has the attribute “val” and its value is represented with the variable “x”. A graph labeled with NAC (Negative Application Condition) appearing in the left-hand controls the application of the rule. If a graph includes the NAC graph, the rule cannot be applied to it. In addition, we add the conditions that are to be satisfied when the rule is applied. In this example, we have two conditions, one of which says that “val” of the node “1:TypeA” has to be greater than 4 to apply this rewriting rule.

The lower part of Figure 2 illustrates graph rewriting. The part encircled with a dotted rectangular box in the left-hand is replaced with the sub graph that is derived from the right-hand of the rule. The attribute values 5 and 2 are assigned to x and y respectively, and those of the two instance nodes of “TypeD” result in 7 (x+y) and 3 (x-y). The attribute “val” of “TypeD” node looks like an inherited attribute of Attribute Grammar because its value is calculated from the attribute values of the left-hand side of the rule, while “sval” of “TypeC” can be considered as a synthesized attribute. The value of “sval” of the node “TypeC” in the left-hand side is calculated from the values in the right-hand side, and we get 8 (TypeD_val + x = 3+5). Note that the value of “val” of “TypeA” is 5, greater than 4, the value of “sval” is less than 10, and none of nodes typed with “TypeD” appear, so the rule is applicable. The other parts of the left-hand side graph are not changed in this rewriting process.

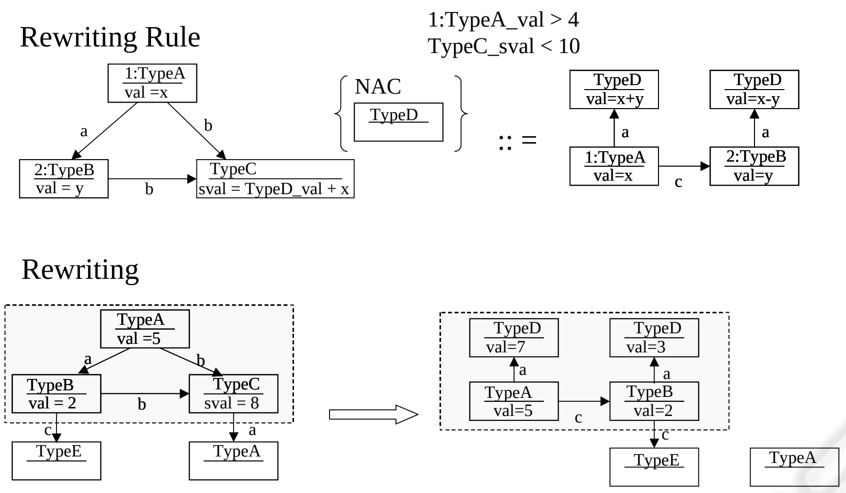


Figure 2: Graph Rewriting Rules and Rewriting Process.

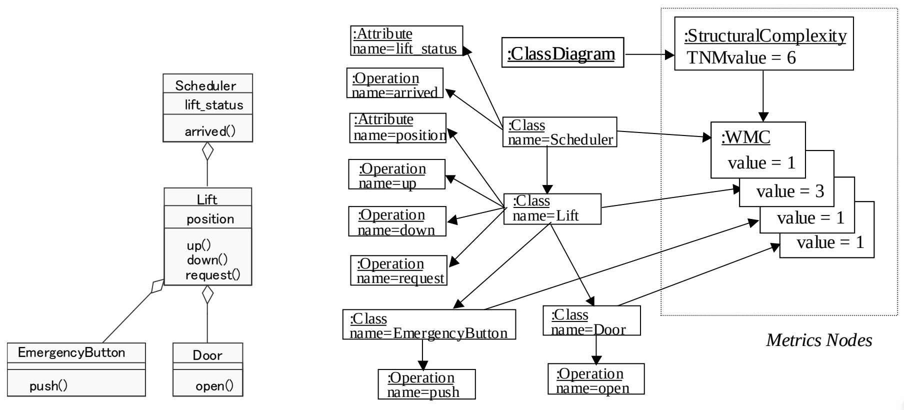
4 METRICS ON MODEL TRANSFORMATION

4.1 Using Model-Specific Metrics

The model following its meta model is represented with an attributed typed graph and it can be transformed by applying the rewriting rules. We call this graph instance graph in the sense that the graph is an instance of the meta model. Figure 3 shows the example of a class diagram of Lift Control System and its instance graph following the meta model of Figure 1. The types of nodes result from the elements of the meta model such as Class, Attribute and Operation, while the names of classes, attributes and operations are specified as the values of the attribute “name”. In the figure, the class Lift in the class diagram corresponds to the node typed with Class and whose attribute “name” is Lift. Some nodes in the instance graph have metric values as their attribute values. For example, a node typed with WMC has the attribute “value” and its value is the number of the operations of the class, which is automatically calculated using the formula (1). The WMC value of class Lift is 3 as shown in the figure.

We can design graph rewriting rules considering the nodes of the metrics and their values. See an example of a transformation rule shown in Figure 4. Two conditions $x2 > a$ and $x3 < y3$ are attached to the rule for rewriting the graph G1 with G2 and these conditions should be satisfied before the rule is applied. This transformation rule includes two nodes named “metrics for G1” and “metrics for G2”, each of which holds the metric values of the model. The first condition $x2 > a$ expresses that the rule cannot be applied until the value of the metric m2 before the rewriting is greater than a certain value, i.e. “a”. It means that this model transformation is possible when the model has a metric value higher than a certain standard. The second condition $x3 < y3$ specifies monotonic increasing of the metric m3 in this transformation. This formula has both metric values before and after the transformation as parameters and it can specify the characteristics of the transformation, e.g. a specific metric value is increasing by the transformation. As shown in the figure, the calculation of the metric n2 uses the metric m1 of the model before the transformation, and this calculation formula of n2 shows that the metric value of G1 is propagated to G2. The metrics of a transformation can be formally specified by using this approach. In Figure 4, we can calculate how much a metric value could be improved with the transformation by using the metric values of the model before the transformation and those after the transformation. The function g in the figure calculates the improvement degree of the metric value. This is a basic idea of the metrics of model transformation.

Let’s consider the example of a model transformation using graph rewriting rules. The model of Lift Control System in Figure 3 (a) can be considered as a platform independent model (PIM) because of no consideration of implementation situation, and we illustrate its transformation into a platform dependent model (PSM). We have a scheduler to decide which lift should be made to come to the passengers by the information of the current status of the lifts (the position and the moving direction of the lift), but we don’t explicitly specify the concrete technique to im-



(a) Class Diagram (b) Instance Graph with Metrics Nodes

Figure 3: Class Diagram and Its Instance Graph.

plement the function of getting the status information from the lifts. If the platform that we will use has an interrupt-handling mechanism to detect the arrival of a lift at a floor, we put a new operation "notify" to catch the interruption signal in the Lift module. The notify operation calls the operation "arrived" of Scheduler and the "arrived" updates the lift_status attribute according to the data carried by the interrupt signal. As a result, we can get a PSM that can operate under the platform having interrupt-handling functions. In Figure 5, Rule #1 is for this transformation and PSM#1 is the result of applying this rule to the PIM of Lift Control System.

Another alternative is for the platform without any interrupt-handling mechanism, and in this platform, we use multiple instances of a polling routine to get the current lift status from each lift. The class Thread is an implementation of the polling routine and its instances are concurrently executed so as to monitor the status of the assigned lift. To execute a thread object, we add the operations "start" for starting the execution of the thread and "run" for defining the body of the thread. The operation "attach" in Scheduler is for combining a scheduler object to the thread objects. Rule #2 and PSM#2 in the figure specifies this transformation and its result respectively. The TNMvalue, the total sum of the operations, can be calculated following the definition of Figure 1 for PIM, PSM#1 and PSM#2. It can be considered that the TNM value expresses the efforts to implement the PSM because it reflects the volume of the source codes to be implemented. Thus the difference of the TNMvalues ($\Delta TNMvalue$) between the PIM to the PSM represents the increase of implementation efforts. In this example, PSM#1 is easier to implement because $\Delta TNMvalue$ of PSM#1 is smaller than that of PSM#2, as shown in Figure 5. So we

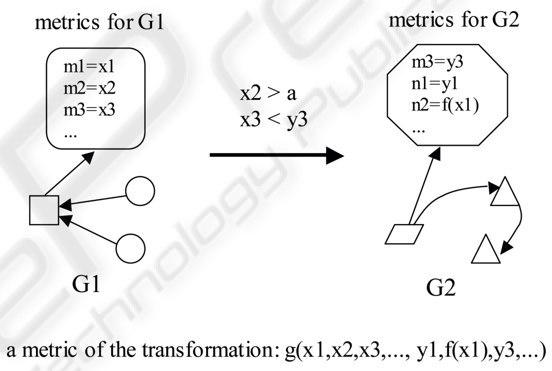


Figure 4: Metrics and Model Transformation.

can conclude that the transformation Rule #1 is better rather than Rule #2, only from the viewpoint of less implementation efforts. This example suggests that our framework can specify formally the metrics of model transformations by using the metric values before and after the transformations.

4.2 Example: Transforming a Class Model to Relational Tables

In the previous section, we showed the example where the model metrics before and after the transformation were used to calculate the metrics of the transformation. On the other hand, in this section, we pick up more complicated example of metrics of transformation that are defined using the values of the model metrics before or during the transformation. Our example is based on the mandatory example of Workshop on Model Transformations in Practice jointly held in MoDELS/UML2005 Conference (Bézivin et al., 2006) and it is the transformation of

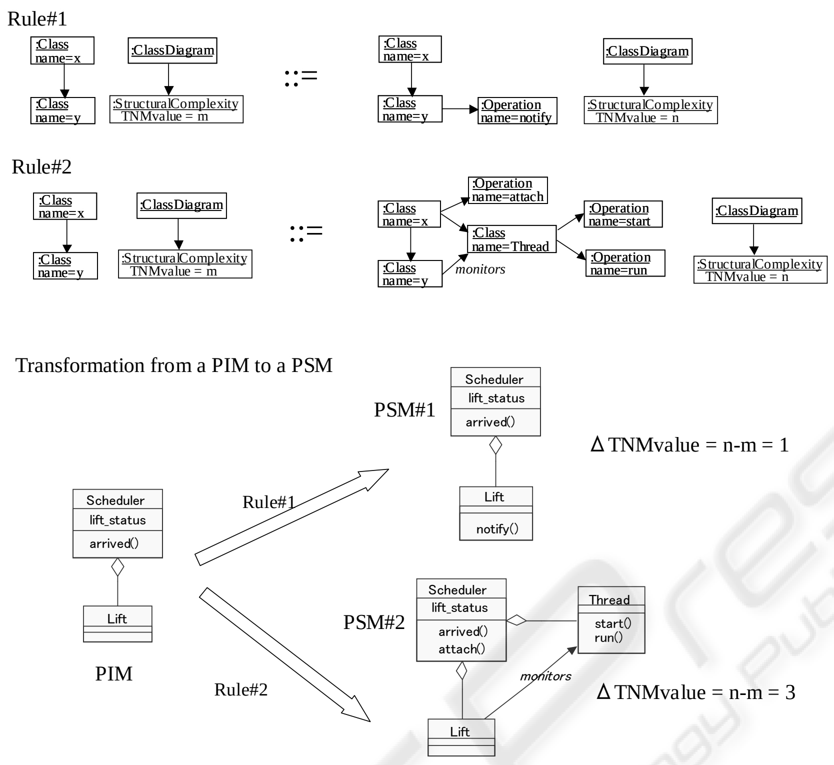


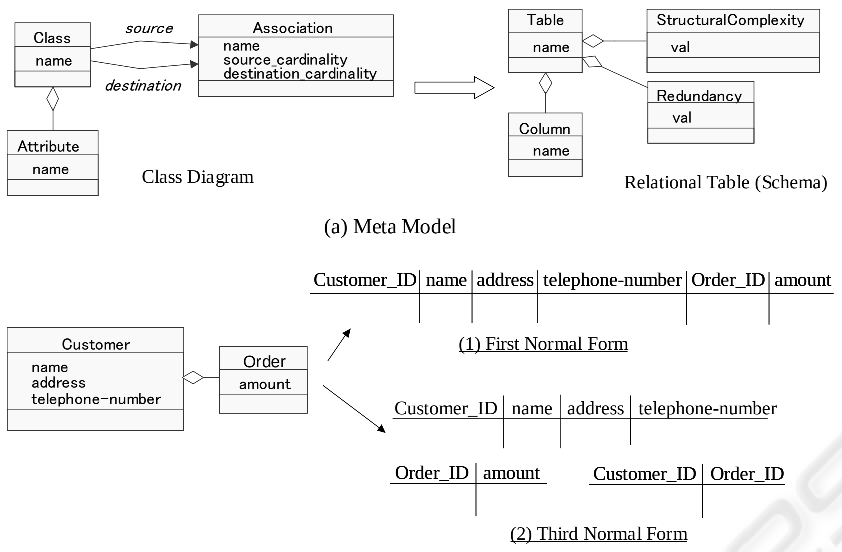
Figure 5: Model Transformation Example.

a class model into a relational database. More concretely, a set of tables for a relational database, i.e. schema is generated from a class model. Figure 6 shows the overview of this example. The meta models of class diagrams and of relational tables (shortly tables) are shown in the figure (a). An association in the meta model of class diagrams has cardinalities as its attributes and the value of cardinality consists of a pair of integers; minimal and maximal cardinalities. As shown in the meta model of tables, a table consists of one or more columns. Note that two elements StructuralComplexity and Redundancy are associated to Table and will be used for the calculation of metrics.

We can have two alternatives of transformation as shown in Figure 6 (b). The first alternative is simpler and it produces a single and flat table from a class diagram, while a set of tables with less redundant data entries is generated in the second alternative. Let us explain the example of Customer-Order class diagram shown in the left-hand side of Figure 6 (b). In the first alternative of transformation, we generate a table where all of the classes and their attributes are included and formed in a line of columns. More concretely, all of object identifiers and attributes are collected into a single table. For Customer class, the identifier Customer_ID, "name", "address" and "telephone-number" are extracted and put as columns of a table. As for Order class, the transformation adds its identifier and attributes. The resulting table has the columns Customer_ID, name, address, telephone-number, Order_ID and amount, as shown in the figure (b) (1). It may have redundant data entries. For example, suppose that a customer has more than one order, say 100 orders. The table has the 100 entries but they include the 100 occurrences of the same data of Customer_ID, name, address and telephone-number. This type of the table is so called first normal form. On the other hand, the second alternative is the transformation for reducing redundant data entries. As shown in Figure 6 (b) (2), for each class and association, a table is generated. In this example, we have three tables Customer, Order and Customer-Order, and they are in third normal form [1].

A part of the rules for these two transformations is shown in Figures 7 and 8 respectively. For simplicity,

[1]If the attributes that are not so dependent on a class exist, the tables may not be in third normal form but second one. For example, if Customer class has the attribute "mayor's name in the home address" in addition to "(home) address", its transformation result is in second normal form, because a mayor essentially depends not on a customer but on his address.



(a) Meta Model

(b) Transformation from a Class Diagram to Tables

Figure 6: A Class Model and Relational Tables.

we omit NAC parts from the rules. The rules in Figure 7 is for performing the transformation shown in Figure 6 (b) (1). By Rule #1, a table having an object identifier (class name + _ID, e.g. Customer_ID) and an attribute y as columns is initially created. Rule #2 is iteratively applied according to the occurrences of the attributes in the class x and this rule adds them to a table as its columns. This iterative application continues until all attributes of class x have been added to the table. To deal with the occurrences of associations between classes, Rule #3 is iteratively applied so that the object identifiers of the other classes, e.g. y, are newly added to the table. The attributes of the newly added class are also added in the same way using Rule #2. Note that i and j of a source_cardinality express the range of the cardinality, i.e. minimal and maximal cardinalities of the class that is the source of the association. In this transformation, we adopt the metrics expressing the structural complexity of the table and it is the sum of the number of the columns plus 1. “Plus 1” means that we include the number of the tables in the structural complexity. The calculation is being performed during the transformation, and its result is in the attribute “val” of the node StructuralComplexity, which is connected to the generated table.

The rules shown in Figure 8 are for performing the transformation in Figure 6 (b) (2) and for getting tables in third normal form. Rules #1 and #2 are quite similar to the rules of the previous example, except that the Table nodes have their names as represented with “name=x” in the figure. These two rules generate a table for each class, and the generated table includes as columns all attributes of the class. For example, their applications generate Customer and Order tables. To generate a table for each association between two classes, e.g. x and y, Rule #3 is applied. The generated table consists of two columns, each of which is an object identifier of the class participating in the association. For example, from an association between Customer and Order, as shown in Figure 6 (2) (b), we can get a table having the two columns Customer_ID and Order_ID. To quantify a characteristic of transformation, we pick up structural complexity of the resulting tables, which is calculated with a total number of the tables and columns.

From structural complexity view, the transformation (1) generating a table of first normal form is better than (2), because it generates only one table and fewer columns. However, the table of first normal form may have redundant data entries as mentioned before. Lower cardinality the associations have, the fewer redundant data entries can be included in the table. For example, all associations appearing in a class model have the cardinality 1, i.e. they are one-to-one associations, the table of first normal form, which has been generated by Figure 7, cannot have any redundant data entries. So, it is better that we add to our metrics the degree of the possibility of including redundant data entries in the resulting tables. To complete our metrics, using the maximal cardinality values j and k in Figures 7 and 8, we calculate how many redundant data entries can appear in the tables. Figure 9 shows the transformation rules to calculate the

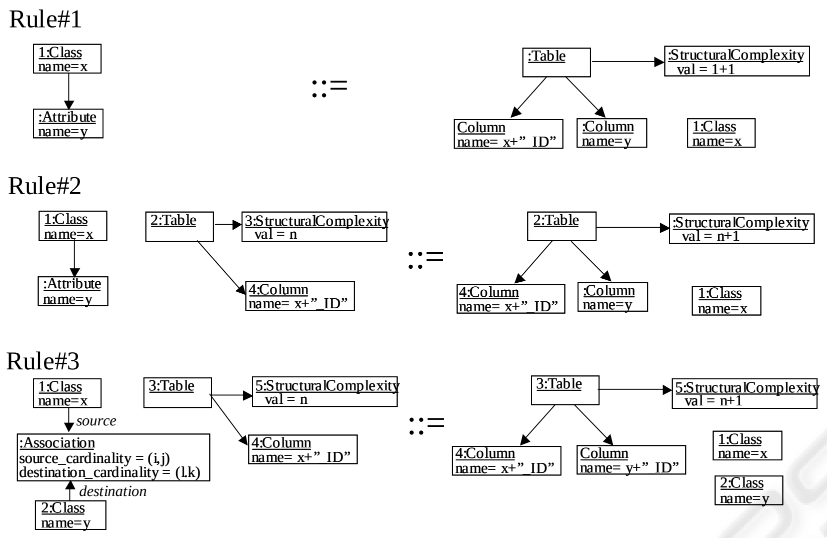


Figure 7: Rules for Transformation (1): to First Normal Form.

metric of Redundancy, and we can use as a metric of these transformations the weighted linear combination of StructuralComplexity and Redundancy. To calculate it, we add the node having the value of the Redundancy metric to the Rule #3 in both of the transformations (1) and (2). In the transformation (1), the number of redundant data entries depends on the maximal cardinalities of an association, and so we use the multiplication of the cardinalities of source and destination classes in the association. If the both cardinalities are 1, there are no possibilities of occurring redundant data entries, i.e. the redundancy value is 0. The redundancy value of the resulting table is the total sum of the redundancy values of all associations appearing in the class model. In the transformation (2), the transformation of any association does not cause this type of redundancy, and so our calculation does not change the value of the node Redundancy, i.e. m, as shown in Rule #3 for (2) in Figure 9.

This example uses not only the model metrics after the transformation, but also the model metrics before the transformation or of the intermediate artifacts during the transformation. Note that we used two specific metrics StructuralComplexity and Redundancy for the explanation of our technique. Readers can find more useful and practical metrics for relational databases, e.g. the number of foreign keys and the depth of a referential tree in (Calero et al., 2001), and our approach can be applied to them.

5 CONCLUSIONS AND FUTURE WORK

In this paper, we propose the technique to specify the metrics of model transformations based on graph rewriting systems, and show the applicability of our technique using the examples of model transformation. Our final goal of this research project is to develop the techniques of measuring the quality of model transformations in addition to of models. Although the metrics that we picked up in this paper were for quantifying complexity and could not express the quality directly, they surely affect the quality. Exploiting the metrics related to quality in a MDD context is the next step of this project.

In addition, the future research agenda can be listed up as follows.

1) Metrics on Graph Rewriting. The metrics mentioned in the previous section was based on model-specific metrics and value changes during model transformations. We can consider another type of metrics based on characteristics of graph rewriting rules. For example, the fewer graph rewriting rules that implement the model transformation may lead the more understandable transformation, and the complexity of the rules can be used as the measure of understandability of the transformation. This kind of complexity such as the number of rules and the number of nodes and edges included in the rules can be calculated directly from the rules. Another example is related to the process of executing graph rewriting. During a transformation process, we can calculate the number of the application of rules to get a final model,

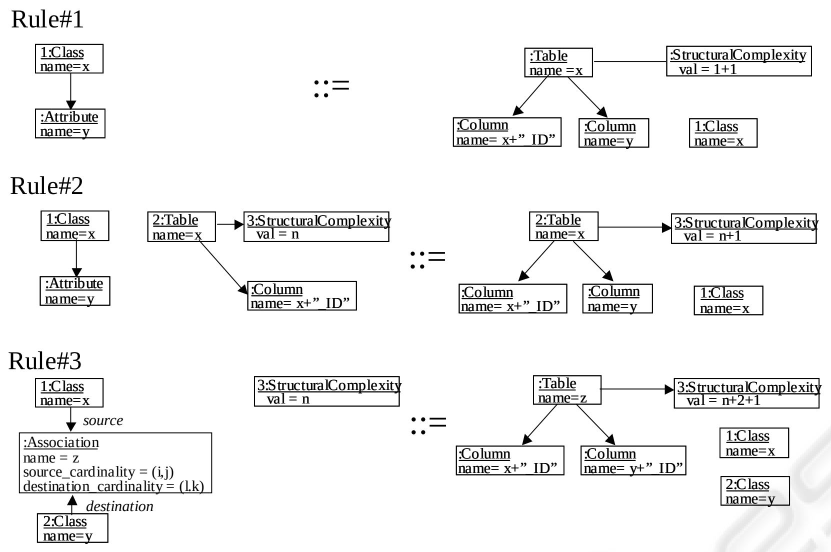


Figure 8: Rules for Transformation (2): to Third Normal Form.

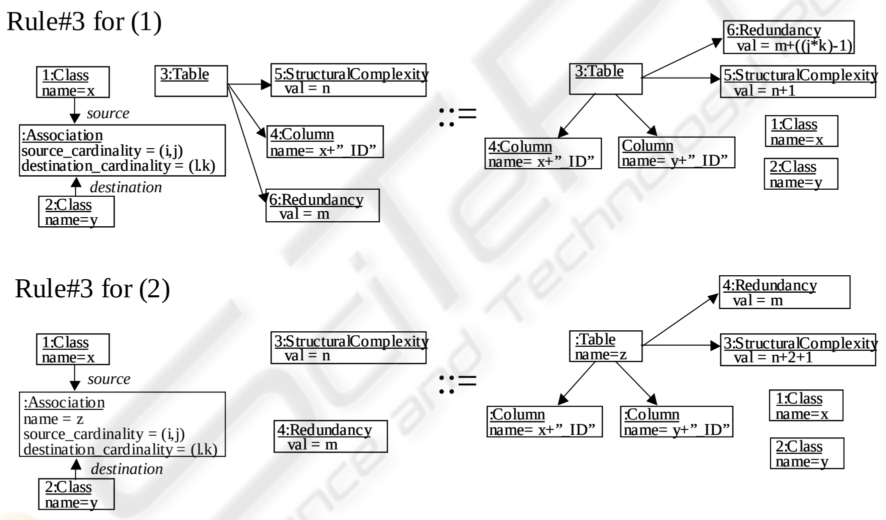


Figure 9: Metric for Redundancy.

and this measure can express efficiency of the model transformation. The smaller the number is the more efficient. This type of metrics is apparently different from the above metrics on the complexity of rules, in the sense that it is the metrics related to the actual execution processes of transformation. We call the former type of the metrics static metrics and the latter dynamic one. As mentioned above, our approach has potentials for defining wide varieties of model transformation metrics.

2) Development of Supporting Tools. We consider the extension of the existing AGG system, but to support the calculation of the metrics of transformations and the selection of suitable transformations, we need more powerful evaluation mechanisms of attribute values. The mechanisms for version control of models and re-doing transformations are also necessary to make the tool practical.

3) Usage of Standards. For simplicity, we used class diagrams to represent meta models and OCL to define metrics. To increase the portability of meta models and metrics definitions, we will adapt our technique to standard techniques that OMG proposed or is proposing, i.e. MOF, XMI, QVT and Software Metrics Metamodel (OMG, 2006).

4) Collecting Useful Definitions of Metrics. In the paper, we illustrated very simple metrics for explanation of our approach. Although the aim of this research project is not to find and collect useful and effective metrics, making a kind of catalogue of metric definitions and specifications like (Ebert et al., 2005; Lorenz and Kidd, 1994) is important in the next step of the supporting tool. The assessment of the collected metrics is also a research agenda.

REFERENCES

Abreu, F. B. (2001). Using OCL to Formalize Object Oriented Metrics Definitions. In *Tutorial in 5th International ECOOP Workshop on Quantitative Approaches in Object-Oriented Software Engineering (QAOOSE 2001)*.

Bézivin, J., Rumpe, B., Schur, A., and Tratt, L. (2006). Model Transformations in Practice Workshop. In *Lecture Notes in Computer Science*, volume 3844, pages 120–127.

Calero, C., Piattini, M., and Genero, M. (2001). Empirical Validation of Referential Integrity Metrics. *Information & Software Technology*, 43(15):949–957.

Chidamber, S. and Kemerer, C. (1994). A Metrics Suite for Object-Oriented Design. *IEEE Trans. on Software Engineering*, 20(6):476–492.

Czarnecki, K. and Helsen, S. (2003). Classification of Model Transformation Approaches. In *OOPSLA2003 Workshop on Generative Techniques in the context of Model Driven Architecture*.

Ebert, C., Dumke, R., Bundschuh, M., and Schmietendorf, A. (2005). *Best Practices in Software Measurement*. Springer.

Genero, M., Piattini, M., and Calero, C. (2005). A Survey of Metrics for UML Class Diagrams. *Journal of Object Technology*, 4(9):59–92.

Karsai, G. and Agrawal, A. (2003). Graph Transformations in OMG's Model-Driven Architecture: (Invited Talk). In *AGTIVE*, pages 243–259.

Kleppe, A., Warmer, J., and Bast, W. (2003). *MDA Explained*. Addison-Wesley.

Lorenz, M. and Kidd, J. (1994). *Object-Oriented Software Metrics*. Prentice-Hall.

McCabe, T. and Butler, C. (1989). Design Complexity Measurement and Testing. *CACM*, 32(12):1415–1425.

Mellor, S. and Balcer, M. (2003). *Executable UML*. Addison-Wesley.

Merilinna, J. (2005). A Tool for Quality-Driven Architecture Model Transformation. http://virtual.vtt.fi/inf/pdf/publications/2005/P561.pdf.

OMG (2003). MDA Guide Version 1.0.1. http://www.omg.org/mda/.

OMG (2006). ADM Software Metrics Metamodel RFP. http://www.omg.org/docs/admtf/06-09-03.doc.

Saeki, M. (2002). Role of Model Transformation in Method Engineering. In *Lecture Notes in Computer Science (Proc. of CAiSE'2002)*, volume 2348, pages 626–642.

Saeki, M. (2003). Embedding Metrics into Information Systems Development Methods: An Application of Method Engineering Technique. In *Lecture Notes in Computer Science (Proc. of CAiSE 2003)*, volume 2681, pages 374–389.

Saeki, M. and Kaiya, H. (2006). Model Metrics and Metrics of Model Transformation: *Materials of 1st Workshop on Quality in Modeling: MoDELS2006 Conference*. http://www.ituniv.se/ miroslaw/QiM.htm.

Schurr, A. (1997). Developing Graphical (Software Engineering) Tools with PROGRES. In *Proc. of 19th International Conference on Software Engineering (ICSE' 97)*, pages 618–619.

Taentzer, G., Runge, O., Melamed, B., Rudorf, M., Schultzke, T., and Gruner, S. (2001). AGG : The Attributed Graph Grammar System. *http://tfs.cs.tu-berlin.de/agg/*.