

SUPPORTING DESIGN PATTERNS IN GRAPH REWRITING-BASED MODEL TRANSFORMATION

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Abstract: Model transformations appear in many, different situations in a model-based development process. A few representative examples are as follows: refining the design to implementation, aspect weaving, analysis, and verification. In object-oriented software design, design patterns describe simple and elegant solutions to specific problems. Similarly, design pattern should be identified in model transformations as well to support the frequently appearing problems. This paper introduces the design pattern support of a modelling and model transformation framework (Visual Modeling and Transformation System). Furthermore, we discuss two model-based development related design patterns.

1 INTRODUCTION

Specifying systems in a higher abstraction level helps understanding, developing and maintaining software. A higher abstraction level can be achieved by software models and their model transformation. Model compilers provide a solution for automated source code generation from software models and mechanisms for software maintenance (Sztipanovits & Karsai, 1997) (Sztipanovits & Karsai, 2002).

Modelling software systems helps conceiving and visualising the actual design, but real automation needs efficient model processing facilities, namely, model compilers.

A model compiler is a tool that automatically composes a model from a set of sub-models and an architectural description of the arrangement of sub-models (Butts et al, 2001). The output of a model compiler can be not only a model but source code as well.

Model-driven development approaches (such as Model-Integrated Computing (MIC) (Sprinkle, 2004) (Sztipanovits & Karsai, 1997) and OMG's Model-Driven Architecture (MDA) (OMG MDA, 2003)) emphasize the use of models at all stages of system development. They have placed model-based approaches to software development into focus.

Graph transformation is a widely used technique for model transformations. Especially, visual model transformations can be expressed by graph

transformations, since graphs are well-suited to describe the underlying structures of models.

Graph rewriting (Rozenberg, 1997) is a powerful tool for graph transformations with strong mathematical background. The atoms of graph transformation are rewriting rules, each rewriting rule consists of a left-hand side graph (LHS) and right-hand side graph (RHS). Applying a graph rewriting rule means finding an isomorphic occurrence (match) of the LHS in the graph the rule being applied to (host graph), and replacing this subgraph with RHS. Replacing means removing elements which are in the LHS but not in the RHS, and gluing elements which are in the RHS but not in the LHS.

In graph rewriting-based model transformation, there are several recurring problems that should be solved again and again in the context of different transformations or different environments. In (Agrawal et al, 2004), a few reusable idioms and patterns are provided in the context of graph transformation languages. A pattern is a reusable entity, which describes a frequent design or implementation problem, and gives a general but customizable solution to it. Illustrative examples are object-oriented design patterns defined by UML diagrams (Gamma et al, 1995). The current work discusses model transformation design patterns from the point of metamodel-based model transformation view. Furthermore, we introduce our tool support

that provides the application of the patterns in transformation definitions.

The presented model transformation design patterns require neither unusual transformation language features nor unusual sophisticated solutions. All can be implemented in standard graph rewriting-based transformation languages. In general, implementing patterns might take a little more work than ad hoc solutions, but the extra effort returns in increased flexibility and reusability.

The rest of the paper is organized as follows. Section 2, as background information, introduces our modelling and model transformation framework: Visual Modeling and Transformation System (VMTS). Section 3 presents the design pattern and transformation wizard tool support of VMTS. Section 4 discusses the metamodel-based model transformation design patterns. Section 5 provides the related work information. Finally, conclusions are given.

2 VISUAL MODELING AND TRANSFORMATION SYSTEM

As background information, this section introduces our implemented metamodeling and model transformation framework Visual Modeling and Transformation System (VMTS) (VMTS, 2003).

Visual Modeling and Transformation System supports editing models according to their metamodels, and allows specifying constraints written in Object Constraint Language (OCL) (OMG OCL, 2006). Models are formalized as directed, labelled graphs. VMTS uses a simplified class diagram for its root metamodel ("visual vocabulary"). Also, VMTS is a model transformation system, which transforms models using graph rewriting techniques. Moreover, the tool facilitates the verification of the constraints specified in the transformation rule during the model transformation process.

In VMTS, LHS and RHS of the transformation rules are built from metamodel elements. This means that an instantiation of LHS must be found in the input graph instead of the isomorphic subgraph of LHS.

Rewriting rules can be made more relevant to software engineering models if the metamodel-based specification of the transformations allows assigning OCL constraints to the individual transformation rules. This technique facilitates a natural representation for multiplicities, multi-objects and

assignments of OCL constraints to the rules with a syntax close to the UML notation.

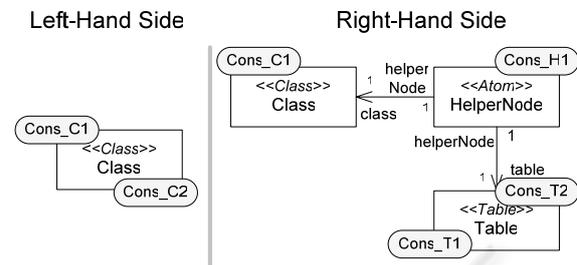


Figure 1: Example transformation rule: *ClassToTable*.

An example transformation rule that generates database tables from UML classes is depicted in Fig. 1. Constraints propagated to the transformation rule nodes are also presented: *Cons_C1*, *Cons_C2*, *Cons_H1*, *Cons_T1*, and *Cons_T2*. With the help of these constraints we can require certain properties from the transformation rule, and we can make them validated (Lengyel, 2006).

```
context Class inv Cons_C1:
not self.abstract
```

The constraint *Cons_C1* is assigned to the pattern rule node *Class* in LHS of the rule *CreateTable*. This link forms a precondition for the rule, it requires the rule to process only non-abstract classes.

```
context Table inv Cons_T1:
self.columns->exists(c | c.datatype =
'int' and c.is_primary_key)
```

The constraint *Cons_T1* is a postcondition of the rule *CreateTable*, it is assigned to the rule node *Table*. This constraint requires the rule that all created table has a primary key of *int* type.

```
context Atom inv Cons_H1:
self.class.attribute->forAll
(self.table.column->
exists(c | (c.columnName =
class.attribute.name))
```

The constraint *Cons_H1* is linked to the rule node *TableHelperNode*, it requires that each class attribute should have a created column with the same name in the resultant table.

The constraints assigned to the transformation rule guarantee our requirements. After a successful

rule execution, the conditions hold and the output is valid, which cannot be achieved without constraints.

VMTS facilitates a refined description of the transformation rules. When the transformation is performed, the changes are specified by the RHS and *internal causality* relationships defined between the LHS and the RHS elements of a transformation rule. Internal causalities can express the modification or removal of an LHS element, and the creation of an RHS element. Imperative OCL (OMG QVT, 2005) or XSLT scripts can access to the attributes of the objects matched to the LHS elements, and produce a set of attributes for the RHS element to which the causality points.

Classical graph grammars apply any production that is feasible. This technique is appropriate for generating and matching languages but model transformations often need to follow an algorithm that requires a stricter control over the execution sequence of the rules, with the additional benefit of making the implementation more efficient.

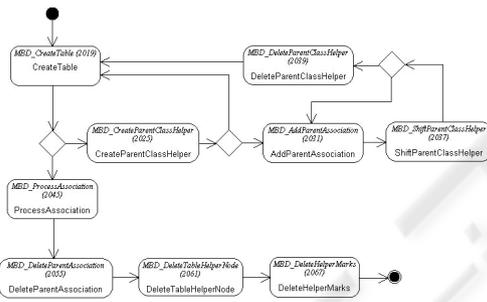


Figure 2: Example transformation (VCFL model): *ClassToRDBMS*.

The VMTS approach is a visual approach, thus, it also uses graphical notation for control flow: stereotyped UML activity diagrams. VMTS Visual Control Flow Language (VCFL) is a visual language for controlled graph rewriting and transformation, which supports the following constructs: sequencing transformation rules, branching with OCL constraints, hierarchical rules, parallel execution of the rules, and iteration. An example VMTS transformation, a VCFL model, is presented in Fig. 2.

VMTS transformation rules have two specific properties: *Exhaustive* and *MultipleMatch*. An exhaustive transformation rule is executed repeatedly, as long as LHS of the rule can be matched to the input model. The *MultipleMatch* property of a rule allows that the matching process finds not only one but all occurrences of LHS in the

input model, and the replacement is executed on all the found places.

The interface of the transformation rules allows the output of one rule to be the input of another rule (parameter passing), in a dataflow-like manner. In VCFL, this construction is referred to as *external causality*. An external causality creates a linkage between a node contained by RHS of the rule i and a node contained by LHS of the rule $i+1$. Since rule i provides partial match to rule $i+1$, this feature accelerates the matching process and reduces the complexity.

VMTS supports validated model transformation, constraint management and control flow definition. The environment has standalone algorithms and other solutions that make them efficient. Moreover, VMTS has a unique, aspect-oriented technique-based constraint management (Lengyel, 2006). The constraint-driven branching mechanism of the VMTS is unique in the sense that the decision is made not only based on the actual state of the input model but using system variables (*SystemLastRuleSucceed*) as well. If a transformation rule fails, and the next element in the control flow is a decision object, then it can provide the next branch based on these variables. Fig. 3 outlines the principles of VMTS metamodel-based model transformation.

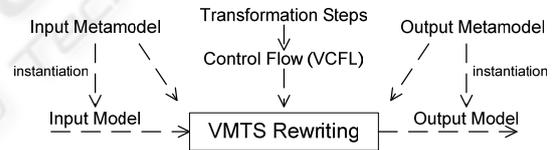


Figure 3: Principles of VMTS metamodel-based model transformation.

3 DESIGN PATTERN AND TRANSFORMATION WIZARD SUPPORT IN VMTS

This section shortly introduces domain-specific design patterns and the Visual Model Processor (VMP) wizard support of VMTS.

3.1 VMTS Design Pattern Support

Creating domain-specific model patterns and reusing them in different domain-specific models offer great perspectives for rapid application development and keep reliability at a high-level as well. VMTS

provides a tool support to create general but customizable model patterns.

Patterns are defined as general models based on their metamodels. Of course, patterns can be applied for models, which have the same metamodel as the patterns.

There was a natural need for the capability of organising them into pattern repositories and attaching some meta-information to the patterns as well. A domain-specific model has been created, whose instance model elements represent a reference to pattern models. The instance models behave as pattern repositories as they can contain numerous references to design pattern models.

The modelling framework of the VMTS facilitates to browse patterns and apply them to the actual model. Furthermore, the customization of pattern element attributes is also supported.

The VMTS Rule Editor and Control Flow plugins are implemented as domain-specific models: they are defined with their metamodels and plug-in-dependent visualisation is added to them (VMTS, 2003). Therefore, the VMTS design pattern support can be applied both for transformation rules and control flow models.

3.2 VMTS Visual Model Processor Wizard

VMTS provides a tool support for automatic Visual Model Processor (VMP) generation. The transformation generated by VMTS VMP Wizard contains a control flow (VCFL) model and rewriting rules.

VMTS VMP Wizard provides the possibility (i) to select from the “hello world transformations”: such as UML class diagram to source code (*ClassToCode*), or (ii) to customise the transformation: e.g. select the metamodels of the source and target models, or to select the option to generate source code.

The mechanisms used by the framework to generate the transformation based on the selected options are the XML-based import and the design pattern support (Section 3.1) of VMTS. The example transformations are exported as XML files and can be imported during the VMP generation. Furthermore, the import and the design pattern support is combined in certain cases: the control flow model is imported from XML, but the rewriting rules are inserted via the design pattern support mechanisms.

4 DESIGN PATTERNS IN MODEL TRANSFORMATION

Design patterns presented in this section are based on the transformation “class model to relational database management system (RDBMS) model” (also referred to as object-relational mapping). The control flow model of the transformation is presented in Fig. 2. The validated solution of the case study can be found in (Lengyel, 2006) and (Lengyel et al, 2006).

We have divided the model transformation-related design patterns into the following groups: full rewriting rules, partial rewriting rules, and control flow patterns (a pattern containing more rewriting rules).

Based on the well-established method used to define design patterns in the object-oriented world, we provide the same structure for the description of metamodel-based model transformation patterns: (i) *Motivation*: a problem, the pattern is intended to solve. (ii) *Applicability*: the general class of problems in which the design pattern can be applied. (iii) *Structure*: the abstract graphical representation of the pattern. (iv) *Consequences*: the trade-offs and results of using the pattern (advantages and disadvantages). (v) *Known uses*: examples of the pattern found in transformations. (vi) *Variations*: the known solutions of other approaches, and the important differences.

Section 4.1 is devoted to the discussion of a rewriting rule pattern, which presents a rule part. Section 4.2 presents a pattern that contains not only a single rule or rule part, but several rewriting rules and a control flow pattern as well.

4.1 The Helper Construct Pattern

Motivation. In transformation *ClassToRDBMS*, the first rule, *ClassToTable* (Fig. 1), creates database tables for all non-abstract classes. A generated table contains columns for each attribute in its origin class. At this point the tables are not complete, because not only the actual class but its parent classes should also be taken into account. In general, an input model contains several classes. Later in the transformation we need to add further columns to the tables based on the corresponding parent classes. Therefore we need the information that relates the original class and its generated table. This can be solved with helper constructs that can temporarily relate model elements, even if they are in different models (with different metamodels).

Applicability. Helper constructs support to temporarily relate model elements that cannot be related based on their metamodel. The helper construct is created by a model transformation, it can be used during the actual transformation, but it should be removed till the end of the transformation.

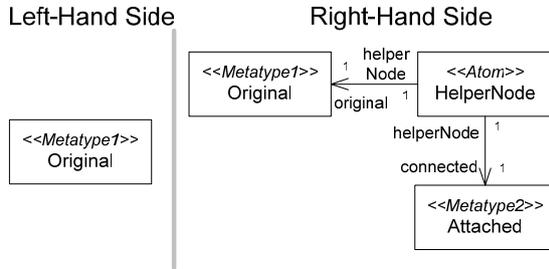


Figure 4: Structure of the *Helper Construct Pattern*.

Structure. The structure of the pattern is presented in Fig. 4. Recall that metamodel-based rewriting rules are built from metamodel elements. Often, the helper construct must connect elements from different models. In the current solution the metatypes of the helper constructs do not belong to any of the actually used metamodels. They are based on the hard-wired meta-metamodel that provides basic constructs for metamodel definitions: *Atom*, and different relations: *SystemInheritance*, *SystemContainment*, and *SystemRelationship* (VMTS, 2003). Fig. 5 presents that metamodel-based rewriting rules are on the same level as metamodels. Furthermore, the rule node *Original* has metatype from *Metamodel 1*, rule node *Attached* has metatype from *Metamodel 2*, and the metatype of the helper construct is from *Meta-metamodel*. Fig. 5 introduces the instantiation hierarchy applied in a metamodeling tool.

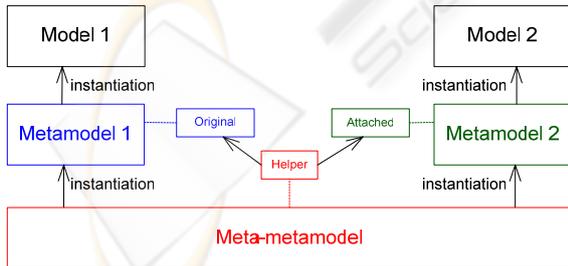


Figure 5: The the instantiation hierarchy of a metamodeling tool.

Consequences. Optional temporary relations can be supported between optional model elements, even they are from different models. Furthermore,

optional attributes can be assigned to the temporary relations that can make them more sophisticated. Helper construct elements have different metatypes than input and output model elements, therefore, it can be automatically checked not to leave helper construct in processed models.

This pattern provides the basis for the automatic trace generation during the model transformation. In VMTS, trace elements are generated based on the internal causalities using the structure of the current pattern.

Known uses. (i) In the transformation *ClassToTable* temporary relations between: (a) *Class* and *Table* elements, (b) *Class* elements, which are devoted to support the creation of the transitive closure upwards in the inheritance hierarchy, and (c) *Class* elements, which are used to create foreign key relations. (ii) In transformation *ClassToCode* between *Package* and *Namespace* elements.

Variations. The following environments have been examined how they support helper constructions: AGG (Taentzer, 2003) is an integrated development tool for typed attributed graph transformation, AToM³ (Lara et al, 2004), which supports regular graph grammars and triple graph grammars, the VIATRA (Varró and Pataricza, 2003) approach that combines the rule and pattern-based paradigm of graph transformation and abstract state machines (ASM), the GReAT (Karsai et al, 2003) framework, which is a transformation system for domain-specific languages, and FUJABA (Köhler et al, 2000) that extends UML, story driven modelling and graph transformation. All of them provides solutions that support the runtime creation of the helper constructs. In case of AGG and AToM³ helper types are added to the metamodels and then they can be used in model transformation rules (Taentzer et al, 2005).

4.2 The Optimized Transitive Closure Pattern

Motivation. Recall that in transformation *ClassToTable* the columns of the generated table should be created not only based on the actual class, but on its parent classes as well. Therefore, we should support the creation of the transitive closure upwards in the inheritance hierarchy. Furthermore, the relations between the tables should be created not only based on the relations of the actual class, but based on the relations of the parent classes as well. Furthermore, using temporary associations the actual class and the neighbours of the parent classes should be related.

The control flow pattern of the transitive closure traversing inheritance hierarchy is depicted in Fig. 6.

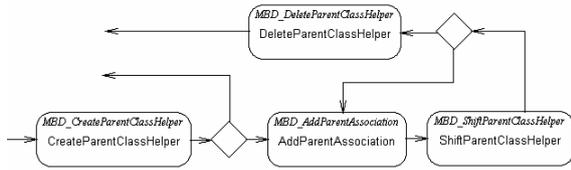


Figure 6: The control flow model of the inheritance transitive closure.

Rule *CreateParentClassHelper* inserts a helper construct between a class (provided with the help of an external causality) and its base class if any. If the rule was successful, there exists a base class, then the transformation continues with rule *AddParentAssociation* (Fig. 7). This rule creates a temporary association that links the child class to the neighbours of the parent class. These associations facilitate that the rule *ProcessAssociations* (Fig. 2.) processes not only the direct associations of a class, but the association of its parents as well.

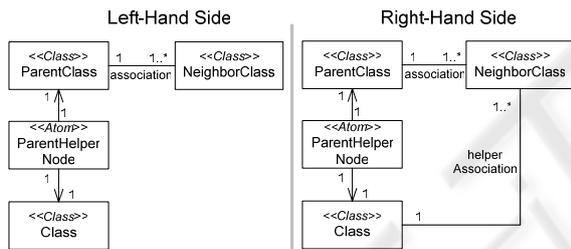


Figure 7: Rewriting rule *AddParentAssociation*.

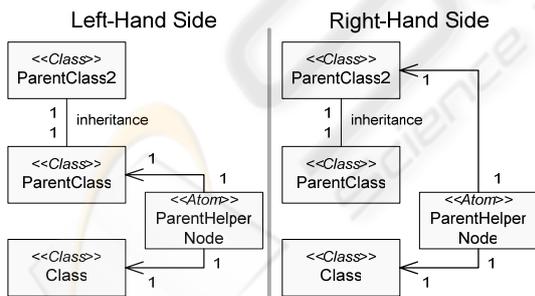


Figure 8: Rewriting rule *ShiftParentClassHelper*.

The transformation should traverse the whole inheritance hierarchy. The rule *ShiftParentClassHelper* (Fig. 8) removes the original helper construct, and adds a new one which links the child class to the parent of the parent class. If the rule *ShiftParentClassHelper* finishes successfully (there exists parent on the next inheritance level), then the transformation continues

with rule *AddParentAssociation*. These two rules form a loop that presents the core of the transitive closure pattern. The external causalities defined between the rules *ShiftParentClassHelper* and *AddParentAssociation* are depicted in Fig. 9. The key external causality is the causality *parentClass* that links the node *ParentClass2* from RHS of the rule *ShiftParentClassHelper* and *ParentClass* from the LHS of the rule *AddParentAssociation*. This external causality supports to step between the inheritance levels. Finally, rule *DeleteParentClassHelper* removes the helper construct.

Name	Start Node	Destination Node
parentClass	ParentClass2 [22620...	ParentClass [208900...
class	Class [22650000-00...	Class [20910000-00...
helperNode	ParentClassHelperN...	ParentClassHelperN...

Figure 9: External causalities between rules *ShiftParentClassHelper* and *AddParentAssociation*.

Applicability. In case of transformations where the transitive closure should be calculated.

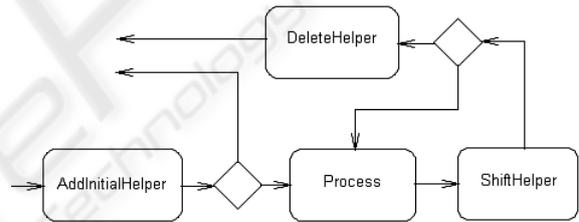


Figure 10: The control flow pattern of the transitive closure.

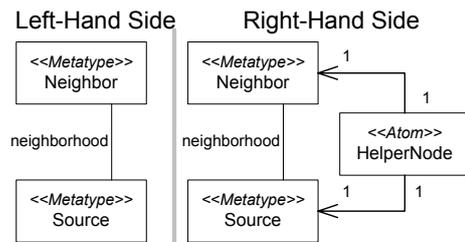


Figure 11: Rewriting rule *AddInitialHelper*.

Structure. The abstract control flow model of the optimized transitive closure is depicted in Fig. 10. The rule *AddInitialHelper* (Fig. 11) initializes the input with a helper construct: connects the rule node *Source* with its direct special type neighbour. If the rule node has the adjacent rule node of required type, the rule can be executed successfully and the next rule will be the *Process*. The rule *Process* performs the required modifications based on the rule nodes *Source* and its actual *Neighbor*, which are

connected with a helper construct. The rule *ShiftHelper* (Fig. 12) is responsible to shift the helper construct from the actual neighbour to its next neighbour. There is a key external causality in the loop formed by the rules *ShiftHelper* and *Process*, which connects the rule node *NextNeighbor* from RHS of the rule *ShiftHelper* to the rule node *ActualNeighbor* from LHS of the rule *Process*. This external causality facilitates that each loop iteration to expand the visited neighbour chain. Finally, rule *DeleteHelper* removes the helper construct.

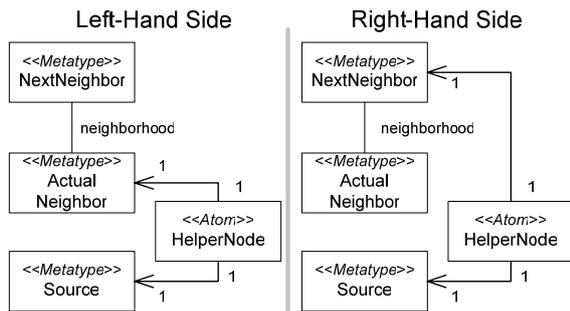


Figure 12: Rewriting rule *ShiftHelper*.

Consequences. The presented construct is not a usual transitive closure pattern, rather an optimized transitive closure pattern. Helper constructs are not left between the traversed classes, but they are moved up during the process and removed at the end.

Often, algorithms implemented by model transformations require the repetition of a process within a transformation. The presented pattern provides solution for iterative and recursive behaviour. The key concepts of these constructs are external causalities that facilitates to a rule provide part matches (input or parameters) to another rules.

Known uses. (i) In the transformations *ClassToTable* and *ClassToCode* to traverse the inheritance hierarchy. (ii) In transformations *FlattenStatechart* and *StatechartToSourceCode* to traverse the statechart hierarchy.

Variations. In AGG, transitive closure is calculated by recursive rule application. AGG do not define additional control structures for the rule execution, but coordinate them by the definition of layers. Each rule is assigned to a certain layer. Starting with layer 0, the rules of one layer are applied as long as possible, and then the next layer is executed. AToM³ and AGG use negative application conditions (NACs) to forbid the rule execution in certain cases. In AToM³, the transitive closure is calculated by iterative rule application (Taentzer et al, 2005).

The control structures in VIATRA are implemented with abstract state machine (ASM) statements. Transitive closure is calculated by the *forall* ASM control structure.

In (Agrawal et al, 2004), the transitive closure solution of GReAT is provided, which works for directed acyclic graphs. The solution is based on the iterative rule application. Comparing this solution with the currently presented optimized transitive closure pattern we can state that GReAT's solution leave the helper constructs in the processed model. Contrary to this, VMTS adds the helper construct to the model only for the execution of the useful procedure.

FUJABA uses the * operator to compute the transitive closure of a basic path expression (a dotted list of edge labels).

5 RELATED WORK

Object-oriented design patterns (Gamma et al, 1995) make it easier to reuse successful designs and architectures in source code level. Defining proven methods as design patterns makes them more accessible to developers of new systems. Design patterns help choosing design alternatives that make a system reusable. Furthermore, design patterns can improve the documentation and maintenance of existing systems by providing an explicit specification of class and object interactions and their underlying intent.

In (Agrawal et al, 2004), a graph transformations language, GReAT is presented, and it is shown how typical design problems that arise in the context of model transformations can be solved using the constructs of GReAT. The presented patterns are intended to serve as the starting point for a more complete collection. Unfortunately, the presented tool does not have direct support for patterns.

Many approaches have been introduced in the field of graph grammars and transformations to capture graph domains; for instance, GReAT (Karsai et al, 2003), PROGRES (Schürr, 1999), FUJABA (Köhler et al, 2000), VIATRA (Varró and Pataricza, 2003), AToM³ (Lara et al, 2004) and Attributed Graph Grammar (Taentzer, 2003). These approaches are specific to the particular system, and each of them has some features that others do not offer. The main features of these approaches are already discussed in the *Variations* sections of the presented design patterns.

At the time of the writing, we have no knowledge about that any of the modeling or model

transformation environments (except for VMTS) provide tool support for transformation patterns.

6 CONCLUSIONS

This paper has introduced the design pattern and transformation wizard tool support of Visual Modeling and Transformation System, and discussed two metamodel-based model transformation related design patterns.

VMTS supports rewriting rule patterns in model-based development. Patterns are available on different levels: parts of the whole transformation rules, whole transformation rules, and several transformation rules can represent a pattern as well. Patterns can contain constraints assigned to the rule nodes, and internal causalities that describe the changes that should be executed during the rule firing.

Model transformation-related design patterns and the presented transformation wizard support make the metamodel-based model transformation easier, more efficient and rapid. Furthermore, design patterns with adequate constraints attached to them can support the validated model transformation as well.

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