Electronic Communications of the EASST
Volume 25 (2010)

Proceedings of the Workshop
Visual Formalisms for Patterns
at VL/HCC 2009

Design Pattern Modeling with Constraint Relaxation

Tamás Vajk, Tamás Mészáros and Tihamér Levendovszky

12 pages

Guest Editors: Paolo Bottoni, Esther Guerra, Juan de Lara
Managing Editors: Tiziana Margaria, Julia Padberg, Gabriele Taentzer
ECEASST Home Page: http://www.easst.org/eceasst/ ISSN 1863-2122

Design Pattern Modeling with Constraint Relaxation

Tamás Vajk, Tamás Mészáros and Tihamér Levendovszky

[tamas.vajk, mesztam, tihamer]@aut.bme.hu
Department of Automation and Applied Informatics
Budapest University of Technology and Economics, Budapest, Hungary

Abstract: Metamodeling is a widely applied technique in the field of graphical language engineering. Environments supporting metamodeling aid rapid and flexible domain-specific modeling language (DSML) definition and utilization. In software engineering, design patterns are efficient solutions for recurring problems. With the proliferation of DSMLs, there is a need for domain-specific design patterns to offer solutions to problems recurring in different domains. The aim of this paper is to illustrate a concept that integrates modeling patterns into a metamodeling environment. The introduced approach utilizes the modeling functionalities of the environment; a visual design pattern metamodel, a system architectural metamodel extended with textual constraints are introduced. Furthermore, design patterns are validated against relaxed constraints defined in the metamodel to only allow the creation of patterns that can be extended to valid instance models.

Keywords: Design pattern, DSML, VMTS, OCL constraint, relaxation

1 Introduction

Design patterns in software engineering describe a problem that recurs, and then describe the core of the solution to that problem, in a way that the solution can be used many times, without ever doing it the same way twice [GHJV94]. In general, patterns have four essential elements: a name for identification, a problem description, the solution and the consequences, meaning the achieved results and trade-offs. As an example, a pattern ensuring that a class only has one instance with a global point of access is named *Singleton* pattern. The solution (in C++) is to create a protected constructor, a private member variable that stores the globally unique instance and a static query method that instantiates the instance if it has not been already done, and returns it. And finally, as an example benefit of the use of this pattern is that it can have strict control over how and when clients access the sole instance. Together this four elements define a design pattern.

Graphical modeling languages have been applied in software engineering since the beginning of the field. One of the most successful techniques to define the rules of graphical modeling languages is metamodeling. Domain-specific modeling [KT08] can be aided by design pattern [GHJV94] utilization. Domain-specific design patterns are design patterns inserted into domain-specific instance models. In DSMLs, not only design patterns can be developed, but model patterns for many other purposes as well. Design patterns can be considered UML-like best practice structural patterns, while model patterns are general purpose submodels that can be reused several times. In this sense, design patterns are specialized model patterns.

Design patterns aid rapid development only if the tool support is flexibly solved. Defining and reusing patterns should be seamless, otherwise users would remodel the pattern instead. Also, design-time validation should be available to support validated pattern development and insertion. A pattern is only valid, if it can be extended to an instance of the metamodel, this instance should satisfy all the hierarchical restrictions defined by the metamodel and none of the textual constraints should fail on it. We have developed tool support for domain-specific model patterns for our metamodeling and model transformation environment called Visual Modeling and Transformation System (VMTS). In our solution, the four essential elements of design patterns are integrated as follows: a name should be given for identification purposes, a pattern model is created as a solution and finally, problem statement and consequences can be explained in description fields.

Visual Modeling and Transformation System [VMT09] is a general purpose metamodeling environment supporting n-level metamodeling. N-level means in this context that the instance models can be used as metamodels: they can be used to define model hierarchies such as metaclass diagram - class diagram - object diagram. The maximum depth of these hierarchies is not limited; we can construct an n-level modeling chain. VMTS uses a proprietary modeling space. Models in VMTS are represented as directed, attributed graphs. In our approach, edges are attributed as well.

The structure of this paper is as follows. Section 2 provides a brief overview of available modeling tools. Section 3 describes the design pattern development process in VMTS. Afterwards Section 4 details the hierarchical constraint relaxation in Section 4.1 and the general OCL constraint handling in Section 4.2. Finally, we draw the conclusions and describe future research options in Section 5.

2 Related work

There are several modeling and metamodeling frameworks that support domain-specific modeling. The Generic Modeling Environment (GME) [LBM$^+$01] is a highly configurable metamodeling tool supporting two layers: a metamodel, and a modeling layer. Diagram Editor Generator (DiaGen) [Min02] provides an efficient solution to create visual editors for DSLs. DiaGen is not based on metamodeling techniques, it uses its own specification language for defining the structure of diagrams. Eclipse [BBM03] is probably the most popular, highly extensible, open source modeling platform that supports metamodeling.

To the best of our knowledge, besides VMTS, only GME provides tool support for domain-specific design patterns to certain extent. However, there are several implementations and industrial applications that utilize patterns in UML environments.

Commercial applications, such as Rational Software Architect [IBM09], have the functionality to define and apply patterns in a productive environment, but these tools only support UML as modeling language, thus domain-specific patterns and models cannot be created.

The standardization of design patterns in UML diagrams is handled in [DYZ07], where detailed formalism and implementation details have been given. The main idea of the paper is that it is not enough to utilize design patterns, but information should be stored on how they have been applied. In this way, refactoring and the comprehension of the developed system can be simplified. In the given solution, an UML profile has been provided to brand diagrams with stereotype information. Based on the attached information, the applied design patterns and the role of each element played in the pattern can be retrived from the system. The authors implemented a system, named VisDP, in which the augmented information is not only stored but visualized in a legible way. The complexity of the resulting diagrams are kept to a minimum based on several aspects. The given solution could be integrated into VMTS to aid domain-specific design pattern creation, however, our approach now deals with more fundamental problems, such as how to integrate design patterns into a DSL environment, and how to force valid pattern definition. Thus, the UML related design pattern achievments given in [DYZ07] can be considered a future work for our domain-specific pattern solution.

The Design Pattern Modeling Language (DPML) [MHG02] is a high level language which is proposed to describe UML design patterns. With DPML one can model the static structure of a pattern, however, the approach also provides a solution to identify the usage of a pattern in the host model later as well. During the instantiation process, an instance model is created, that maps the elements of the pattern to the elements of the host model. Compared to DPML, our solution is not limited to UML, and we use the target domain and the concrete syntax to define patterns. Although, we do not create a reference between the pattern elements and the concrete instances of them. Furthermore, the focus of our research is to verify - at least partially - the constraints of the metamodel on the patterns, which issue is not handled by DPML.

The work presented in [ZKDZ07] provides solutions for two different problems: (i) it verifies whether a design observes the structural integrity of the pattern using spatial graph grammars. (ii) Furthermore, it offers graph transformation to evolve models by preserving the properties of the patterns: an individual graph transformation is suggested for each characteristic operations related to a design pattern. Although [ZKDZ07] is limited to UML class diagrams, the approach could be generalized to arbitrary modeling languages as well.

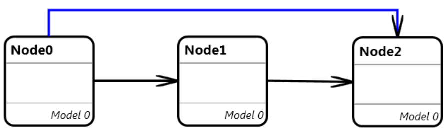
3 Design pattern modeling support in VMTS

As we are embedding design pattern support into a metamodeling environment, it is straightforward to use the modeling environment and its data repository to create and store patterns as well. The simplest solution is to define patterns as general models, thus, we have a complete solution to store default model element properties and layout information together with the patterns as well.

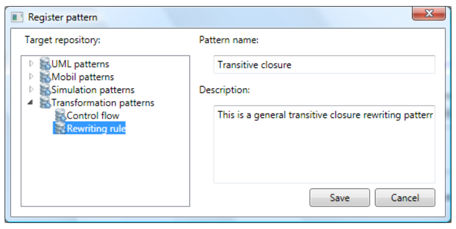
In addition to defining design patterns, there is a natural need to organize them into categories, and attach meta information to them. For this purpose, we have created a simple language that can model the hierarchy of pattern categories, and the position of design patterns in this hierarchy.

3.1 Defining design patterns in VMTS

Recall that design patterns can be created as any other models, however, the modeling environment can be less restrictive when performing editing operations compared to traditional modeling. A criterion that does not have to be verified for design patterns is the existence of dangling edges. Obviously, a model with a dangling edge cannot be valid, however, a design pattern may



(a) Transitive closure



Target repository:
- UML patterns
- Mobil patterns
- Simulation patterns
- Transformation patterns
  - Control flow
  - Rewriting rule

Pattern name: Transitive closure

Description: This is a general transitive closure rewriting patterr

(b) Registering design pattern

Figure 1: Design pattern definition in VMTS

contain edges with only one endpoint set, as the another endpoint can be set in the target model the design pattern is inserted into. Another criterion that can be checked less restrictively is the correspondence of the containment hierarchy to the one defined in the metamodel: when building a model, the container node of an element has to be exactly of the type that was defined in the metamodel. However, when a design pattern is built, each element can also be placed directly onto the diagram, and we have to check at insert time, whether the target container is correct or not.

Figure 1 illustrates a general transitive closure pattern for graph rewriting rules, and the interface to register a pattern in the central repository. When registering a design pattern, one can select among existing pattern categories for the container of the new element (or create a new category in the tree), and provide a name and description for the pattern.

3.2 Organization of design patterns

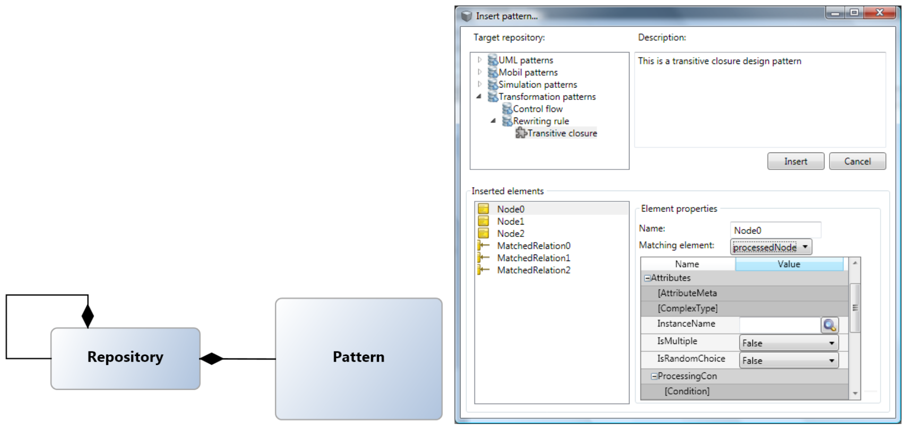
Design patterns can be organized into categories. These categories correspond to the elements of a unique model, its metamodel is depicted in Figure 2 (a).

On the diagram, the *Repository* element corresponds to the categories. Repositories can be embedded into each other, and they can contain *Pattern*s. Each pattern contains a *Description* attribute, and a *Reference* attribute pointing to a model that contains a design pattern.

3.3 Inserting patterns

Design pattern instances can be inserted into any target model, however, verifications have to be performed whether the pattern can be inserted into the selected context or not. The most important constraint is that the design pattern must have the same metamodel as the target model. Figure 2 (b) depicts the window used to insert patterns into the target model. Design patterns with non matching metamodels are not even provided for insertion. Another important criterion is that the root elements of the pattern (the elements that are placed directly onto the diagram of the pattern model) should be able to be contained by the target element in the target model according to the metamodel.

During the insertion, one can also customize the properties of the inserted elements. In addition to providing a new name for each element, the attributes that are not specified in the pattern model can also be set.



(a) (b)

Figure 2: (a) Pattern repository metamodel (b) Pattern insertion window

When a design pattern is being inserted, it is common that several elements of the pattern are already defined by the target model. These elements are the connection points between the pattern and the target model. Therefore, VMTS also provides the possibility to select a matching target model element for pattern elements. Pattern elements with matching target model elements are not inserted again, but the remaining parts are glued to the existing ones.

4 Constraint relaxation

Restrictions applied to models can be divided into two categories: (i) general restrictions that the modeling environment forces onto the models and (ii) domain-specific constraints defined in the metamodels. The former ones can be considered domain independent constraints that are given by the tool-set of the environment. Generally, these are structural constraints, such as the disallowance of dangling edges. The latter ones are developed by the metamodel creator, these constraints are restrictions that cannot be defined visually by the metamodel. A platform-independent, standardized language for this purpose is the Object Constraint Language (OCL) [WK03].

During the pattern creation, constraint validation should be performed to filter invalid patterns. A pattern can be considered invalid, if there is no possible augmentation to create a valid instance model from it. The two types of constraint require different constraint relaxation approaches, which are introduced in the following sections.

4.1 Structural constraint relaxation

In VMTS, metamodels can be extended with Object Constraint Language restrictions that are checked on the instance models during their design [VML08]. These domain-specific textual constraints that cannot be expressed with graphical notations give a fine control over our models. As mentioned before, to extend the modeling environment, it is a straightforward approach to utilize previously implemented functionalities.

4.1.1 Interface hierarchy of VMTS Models

To utilize OCL constraints for validating general structural properties, such as cardinality, edge multiplicity or whether a model contains dangling edges or not, a technique is needed to define general constraints that do not correspond to a specific domain. Extending OCL with non-domain specific features would require changing the language definition, thus, this is not considered a viable solution. As illustrated in [AALa09], VMTS translates metamodels into C# class libraries that are instantiated when instance models are created. Naturally, the generated classes implement a predefined interface hierarchy, called VMTS Domain Interface (VDI). To support domain independent constraints, this VDI has been modeled in VMTS as a standard domain-specific model, which is depicted in Figure 3. The illustrated model gives the possibility to express constraints that apply to all the domains, which implement the VDI. The modeled VDI hierarchy strictly follows the one used in the actual VDI implementation. Thus, for further reference see [AALa09].

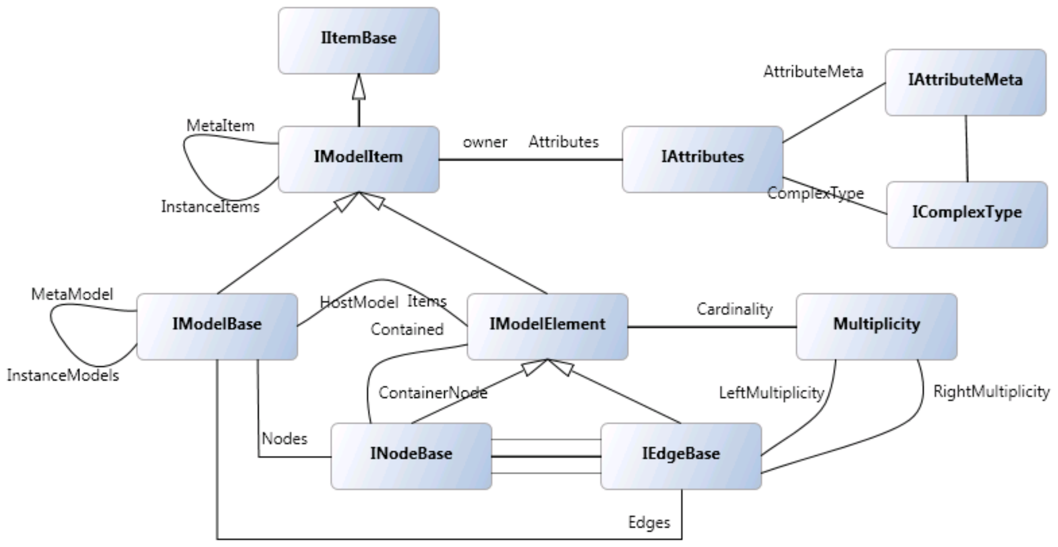


Figure 3: Modeled VMTS Domain Interface (VDI)

General model constraints that can be expressed with standard OCL are integrated into VMTS. For example, during modeling, dangling edges should not be allowed, thus a constraint illustrated in Figure 4 is defined to enforce valid edges.

4.1.2 Constraint relaxation in pattern definition

During pattern definition, general OCL constraints should be relaxed, as the defined constraints need to be valid on models and not on patterns. However, patterns that cannot be augmented to a valid model should be filtered. In most of the practical cases, partial instantiation means relaxing

```
context IEdgeBase
 inv DanglingEdge:
  not self.Left.oclIsUndefined() and not self.Right.oclIsUndefined()
```

Figure 4: Dangling edge invariant

the multiplicities on the edges, the cardinalities of the nodes in the metamodel and allowing empty attributes [LLM]. In practice, this means that some of the general constraints should be changed, such as the multiplicity checking; some should be omitted, such as the dangling edge validation; and some may be left unchanged, such as enforcing model item naming conventions.

Figure 5 illustrates the constraint that validates edge multiplicities in design patterns. Note that the minimum multiplicity verification is omitted. In Line 3, the code iterates through all the nodes in the model. Line 4 selects an edge from the *LeftEdges* navigation. In Line 5, the metaedge of the selected edge is stored in a local variable (*let* expression). In Line 6, edges of the metaedge-type are counted from the *LeftEdges*. Finally, the previously computed value is compared to the upper value of the right multiplicity. The code fragment only checks the *LeftEdges* navigation on the *node*, similarly the *RightEdges* navigation should be validated as well.

```
1 context IModelBase
2  inv RelaxedEdgeMultiplicity:
3  self.Nodes->forAll(node |
4   node.LeftEdges->forAll(edge |
5    let mEdge: IEdgeBase := edge.MetaItem.oclAsType('IEdgeBase') in
6     node.LeftEdges->select(e | e.MetaItem = mEdge)->size() <=
7     mEdge.RightMultiplicity.MaxInt)
8      and ...)
```

Figure 5: Relaxed edge multiplicity checking

Similarly, Figure 6 depicts the relaxed cardinality validation constraint. The code fragment developed collects all the metamodel elements used in the current model into a set, and then the number of the instances are compared to the maximum value of the cardinality.

```
context IModelBase
 inv RelaxedCardinality:
 self.Items->collect(element |
  element.MetaItem.oclAsType('IModelElement'))->asSet()->
   forAll( meta |
    self.Items->select(i | i.MetaItem = meta)->size() <=
    meta.Cardinality.MaxInt)
```

Figure 6: Relaxed cardinality multiplicity checking

4.2 Constraint relaxation

The structural constraint relaxation introduced above works only because the hierarchical relaxation rules in patterns do not change based on the actual domain, but only on general restrictions, such as the allowance of dangling edges. However, metamodels are augmented with domain-specific constraints that should be enforced on the instance models. Thus, a mechanism is needed to handle OCL constraint relaxation as well. If a comprehensive method is given for OCL relaxation, the development tool can force restrictions on the developed pattern to ensure that patterns that cannot be augmented to a conforming model cannot be created at all.

Figure 7 illustrates the general overview of the constraint relaxation. *MM* illustrates the metamodel, *M* the instance model, *PM* is the pattern model. PM' marks a modified pattern on which the relaxed C' constraints should be checked. PM' is an extended version of *PM*, in which each dangling edge is augmented with the appropriate end node. This is by no mean a restriction, as all the edges are typed, the types of the end nodes are well-known. Thus adding an element to the end does not cause any ambiguities. However, the constraint evaluation can be facilitated by providing the evaluator as much information as possible. Figure 7 depicts the schematic overview of the constraint relaxation.

$$\begin{tikzcd}
MM & & C \arrow[ll, dotted, "defines"] \arrow[d] \\
PM \arrow[u, "conforms"] \arrow[r] & PM' & C' \arrow[l, dotted, "validates"] \\
M \arrow[u, "augments"] \arrow[uu, bend left, "conforms"] & & C \arrow[ll, dotted, "validates"] \arrow[uu, leftrightarrow, bend right, "equals"']
\end{tikzcd}$$

Figure 7: General constraint relaxation overview

4.2.1 Relationship between OCL and relaxation

To handle OCL relaxation comprehensively, the relationship between OCL constraints and design patterns should be examined. Figure 8 depicts the basic structure of the OCL expression metalanguage.

Studying the figure reveals that the only point where an OCL code fragment interacts with the underlying model is the *CallExp*, more precisely, the *FeatureCallExp* non-terminal of the language. A *FeatureCallExp* can express attribute calls, navigations and method calls on model items.

4.2.2 Relaxation

A simple OCL constraint relaxation can be provided as follows: (i) If there is at least one *FeatureCallExp* in the currently checked constraint, the constraint is omitted, and it is reported to the user that it cannot be validated. (ii) If there is no *FeatureCallExp*, the constraint is validated on the design pattern. This is a simple and bullet-proof constraint relaxation algorithm that can

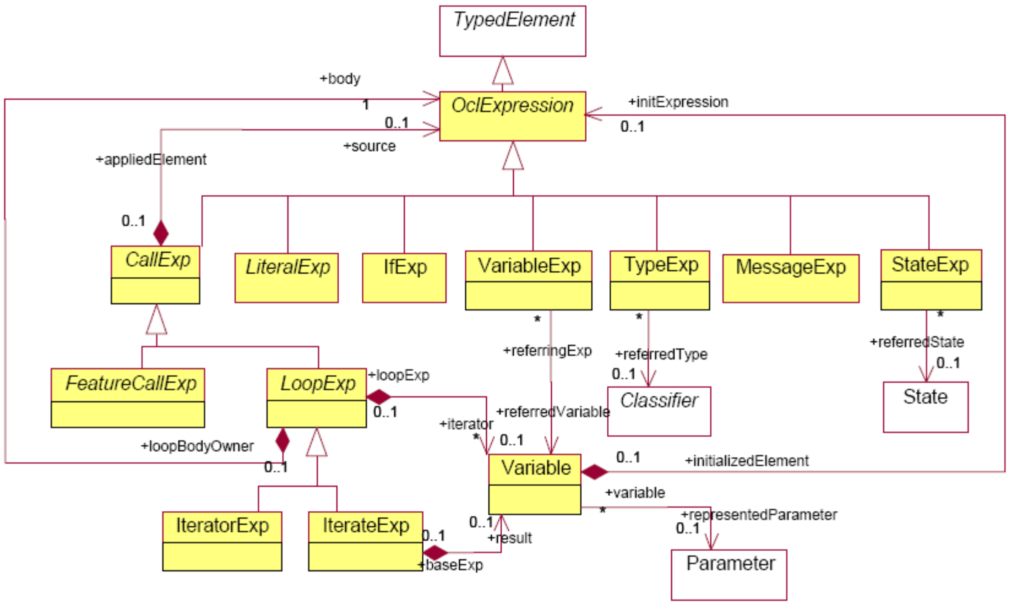


Figure 8: OCL language overview

be further refined if the constraint is separated into several independent parts, and only those subexpressions are omitted that contain *FeatureCallExp*s. The separation can be implemented alongside Boolean operations, such as *and* or *or*, and possibly, lazy evaluation may not require the evaluation of undecidable expressions. However simple this method is, it is not useful in practice, as OCL constraints rarely omit model element retrieval, since the main aim of the constraint is to restrict the models somehow.

Handling the model element access is a complex task, as different programming constructs react differently to a subpart that cannot be evaluated. For instance, in an *if* expression, if the condition is undecidable, the true and false branches should not be evaluated at all, and all the expressions that rely on this *if* have undecidable value. Unless, of course, the true and false branches contain the same evaluatable expressions. On the other hand there are cases, when there is no need to evaluate an expression on a pattern, for instance, consider the following expression: $element.navigation \rightarrow includes(expression)$. If $navigation$ is a navigation with $0..*$ multiplicity, the $expression$ does not need to be evaluated as the pattern is always amendable with a new item connected to $element$ that satisfies the $expression$. Thus in this case, we can see that $includes$ should always return $true$ on a pattern.

In general, expressions that contain a body part can hardly be evaluated without all the information. Thus $iterate$ and the iterators that needs complex program comprehension to analyze them in an off-line way can be considered undecidable. However, methods on collection types, such as $size()$, $includes()$, $count()$, etc., can be handled. Naturally, these differ from collection type to collection type. In the following, a simple *Set* is examined, more precisely a navigation, whose multiplicity is $0..*$, thus returns a set of elements. Table 1 summarizes the methods available on OCL sets, their meanings and how they should be handled during constraint relaxation.

Method name	Meaning	Handling
$size() : int$	The size of the set	Gives a lower bound
$includes(T1) : bool$	Whether the element is in the set	Omit
$excludes(T1) : bool$	Opposite of *includes*	Enforce
$count(T1) : int$	The number of occurrences of the argument	Gives a lower bound
$includesAll(Set(T1)) : bool$	Whether all the elements of the argument is in the set	Omit
$excludesAll(Set(T1)) : bool$	Opposite of *includesAll*	Enforce
$isEmpty() : bool$	Whether the set is empty	Enforce
$notEmpty() : bool$	Whether the set is not empty	Omit
$sum() : T1$	The sum of the elements if $+$ exists on $T1$	No information
$product(Coll(T2)) : T3$	The cross product of the two sets	Gives a partial result
$union(Set(T1)) : Set(T1)$	The union of the two sets	Gives a partial result
$intersect(Set(T1)) : Set(T1)$	The intersection of the two sets	Gives an augmented result
$minus(Set(T1)) : Set(T1)$	The elements of the set that are not in the argument	Gives a partial result
$symmetricDifference(Set(T1)) : Set(T1)$	The elements of the set that are in one of the sets	No information
$including(T1) : Set(T1)$	The set with the argument union added to it	Gives a partial result
$excluding(T1) : Set(T1)$	The set with the argument union subtracted from it	Gives a partial result

Table 1: OCL set methods and relaxation

In the third column of Table 1, the following options are presented:

Gives a lower bound A number is returned and the evaluated constraint would give a smaller number than it would return on the instance model.

Omit The constraint validation can be omitted on the design pattern as the instance can always be augmented to return $true$.

Enforce The constraint validation should be enforced on the design pattern, if it returns $false$, the evaluation on the instance would return $false$ as well.

No information Nothing can be stated about the result of the method.

Gives a partial result The method executed on the pattern returns a subset of the real result.

Gives an augmented result The method executed on the pattern returns a superset of the real result.

The last two can be considered undecidable as well, because in general we cannot state anything based on approximate results. *Omit* and *enforce* are straightforward. And the first option that states it gives a lower bound should be examined further. In this case, if we still consider that the set is a result of a navigation, the multiplicity of the navigation gives another restriction on the model. Thus the combination of the two multiplicity constraints should be utilized. Multiplicity relaxation states that $n1..n2$ multiplicity should be changed to $0..n2$, where $n2$ can be infinity. The lower bound restriction ($c1$) coming from the constraint modifies it to $c1..n2$. Note that if $c1 > n2$, there cannot be any instance model that satisfies all the restrictions thus the pattern is not valid.

5 Conclusions and Future Work

This paper has presented an approach to treat domain-specific design patterns in metamodeling environments. The Visual Modeling and Transformation System has been utilized as the implementation framework. We have shown a way how a modeling environment can facilitate the design pattern definition, categorization and utilization. Also, structural constraints defined in the metamodels have to be partly checked in design patterns to allow only valid pattern definition. Thus, relaxed versions of general constraints are given in the modeling environment. Also, OCL constraints added to the metamodels should be considered during pattern validation, however, comprehensive handling requires complex program analysis. The given solution for supporting domain-specific design patterns reutilizes the modeling functionalities of the environment, thus, it requires only few modifications in the system, and integrates well into the environment.

Pattern integration in VMTS could be further improved by providing automatic gluing of patterns to the already existing model elements in the instance models. This requires common subgraph matching, as the most appropriate gluing options should be returned to the user. Also with drag and drop capabilities, this automatic gluing could be improved to aid pattern gluing to a specific subpart of the model. Constraint relaxation requires further examination. It would be highly useful to support the relaxation of iterator and *iterate* expressions. However, these programming constructs require a high level of program comprehension that has not been yet studied.

Acknowledgment

This paper was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences.

Bibliography

[AALa09] L. Angyal, M. Asztalos, L. Lengyel, et al. Towards a Fast, Efficient and Customizable Domain-Specific Modeling Framework. In *Proceedings of the IASTED International Conference*. Volume 31, pp. 11–16. Innsbruck, Austria, February 2009.

[BBM03] F. Budinsky, S. A. Brodsky, E. Merks. *Eclipse Modeling Framework*. Pearson Education, 2003.

[DYZ07] J. Dong, S. Yang, K. Zhang. Visualizing Design Patterns in Their Applications and Compositions. *IEEE Trans. Softw. Eng.* 33(7):433–453, 2007.

[GHJV94] E. Gamma, R. Helm, R. Johnson, J. M. Vlissides. *Design Patterns: Elements of Reusable Object-Oriented Software (Addison-Wesley Professional Computing Series)*. Addison-Wesley Professional, illustrated edition edition, November 1994.

[IBM09] IBM. Rational Software Architect website. 2009.
http://www-01.ibm.com/software/awdtools/architect/swarchitect/

[KT08] S. Kelly, J.-P. Tolvanen. *Domain-Specific Modeling: Enabling Full Code Generation*. John Wiley & Sons, March 2008.

[LBM$^+$01] kos Ldeczi, rpd Bakay, M. Marti, P. Vlgyesi, G. Nordstrom, J. Sprinkle, G. Karsai. Composing Domain-Specific Design Environments. *Computer* 34(11):44–51, 2001.

[LLM] T. Levendovszky, L. Lengyel, T. Mészáros. Supporting domain-specific model patterns with metamodeling. *Software and Systems Modeling*. accepted.

[MHG02] D. Mapelsden, J. Hosking, J. Grundy. Design Pattern Modelling and Instantiation using DPML. In Noble and Potter (eds.), *Fortieth International Conference on Technology of Object-Oriented Languages and Systems (TOOLS Pacific 2002)*. CRPIT 10, pp. 3–11. ACS, Sydney, Australia, 2002.

[Min02] M. Minas. Specifying Graph-like Diagrams with DiaGen. In *Science of Computer Programming*. P. 2002. 2002.

[VML08] T. Vajk, G. Mezei, T. Levendovszky. OCL Compiler Support for Modeling Environments with Incremental Compilation. *Buletinul Stiintific al Universitatii "Politehnica" din Timisoara* 53(1):19–24, 2008.

[VMT09] VMTS Team. Visual Modeling and Transformation System website. 2009.
http://vmts.aut.bme.hu

[WK03] J. Warmer, A. Kleppe. *Object Constraint Language, The: Getting Your Models Ready for MDA, Second Edition*. Addison Wesley, 2003.

[ZKDZ07] C. Zhao, J. Kong, J. Dong, K. Zhang. Pattern-based design evolution using graph transformation. *Journal of Visual Languages & Computing* 18(4):378–398, 2007. Visual Interactions in Software Artifacts.