

# A Model Transformation Framework for Model Driven Engineering

Xiaoping Jia, Hongming Liu, Lizhang Qin and Adam Steele

School of Computer Science, Telecommunication and Information Systems  
DePaul University, Chicago, Illinois, U.S.A.

**Abstract.** Model Driven Engineering(MDE) is a model-centric software development approach aims at improving the quality and productivity of software development processes. While some progresses in MDE have been made, there are still many obstacles in realizing the full benefits of model driven engineering. These obstacles include incompleteness in existing modeling notations, inadequate in tools support, and the lack of effective model transformation mechanism. This paper presents a new model driven engineering framework, which is based on a formal modeling notation – Z-based Object-Oriented Modeling notation (ZOOM). It includes a set of supporting tools aiming at delivering the benefits in practical applications of model driven engineering. In particular, this proposal focuses on one key aspect of MDE – model transformation. A template based model transformation framework using Hierarchical Relational Meta-model (HRM) is introduced. This framework aims to provide a simple, effective, and practical way to define model transformations. The potential benefits of the proposed model transformation framework include: 1) readability and rigorosity of meta-model definitions; 2) simplicity of transformation definition; and 3) extensibility of transformation templates. The architecture and design of the framework is discussed and comparisons with related research work are provided to show the benefits of this framework.

## 1 Introduction

Model Driven Engineering (MDE) tackles the elusive problem of system development by promoting the usage of models as the primary artifact to be constructed and maintained [1,2]. MDE shifts software development from a code-centric activity to a model-centric activity. Accomplishing this shift entails developing support for modeling concepts at different levels of abstraction and transforming abstract models to more concrete descriptions of software. In other words, MDE reduces complexity in software development through modularization and abstraction [3].

Because of MDE's potential to dramatically change the way we develop applications, companies are already working to deliver supporting technologies [4]. However, there is no universally accepted definition of the requirements for a MDE infrastructure and many requirements for MDE support are unclear or even unspecified. Notwithstanding the lack of standards, with careful reading of related researches [5], we argue

that the main issues MDE infrastructure is facing are: (1)incompleteness in existing modeling notations; (2)lack of effective model transformation mechanism.

The first issue is currently addressed specifically yet inadequately by the Object Management Group(OMG) UML 2.0 [6] standard specification. UML-2 is the *de facto* standard object modeling notation for software engineering. It allows modelers to capture a wealth of information about software system components, their behaviors, and their interactions. However, currently UML-2 is insufficient for MDE owing to its deficiencies in several critical areas including incompleteness, semi-formal and inconsistent [7, 8].

The second issue of model transformation is also an active yet premature research area [9, 10]. Model transformation is the process of converting one model to another model. Performing a model transformation requires a clear understanding of the abstract syntax and semantics of both the source and target models. To take modeling to a higher level of abstraction, it is needed to define a standard mechanism to define meta-models of modeling languages [11]. OMG addresses this issue in its MDE initiative Model Driven Architecture(MDA) [12] by creating Model Object Facility(MOF) [13]. In response to the need for a standard approach to define the functions that map between metamodels, the OMG issued the MOF (Meta Object Facility) 2.0 Query/View/Transformation (QVT) [14] Request for Proposals. Currently this initiative is undergoing finalization [15].

Considering both of above issues, we provide an alternate solution, which is a new model-driven engineering framework including a formal modeling notation and a set of supporting tools aiming at the realization of the benefits of true model-driven engineering. We have developed a new formal modeling notation called Z-based Object-Oriented Modeling notation or ZOOM, which is based on the formal specification notation Z [16–18], and several key components of UML-2. ZOOM is a simple, precise, and easy to use modeling language. It has dual representation textual and visual. The syntax of textual representation is defined precisely in EBNF grammar. The formalism of modeling notation provides a solid foundation for metamodeling which is an important factor in model transformation. With a simplified metamodeling design, we are able to develop an extensible model transformation process.

In summary, our work objective is to apply such an overall research approach in realization of MDE focusing on model transformation. The notation and metamodel design lays the foundation of my tool development and the tool development in turn demonstrates the validity and advantage of the design.

This paper is organized as follows: Section 2 provides detailed background information about model driven engineering and model transformation. Section 3 presents the ZOOM architecture and notation. Then section 4 covers the characteristics of our model transformation approach and the model transformation process. Section 6 discusses related research work and compares them with our approach and finally Section 7 concludes the paper.

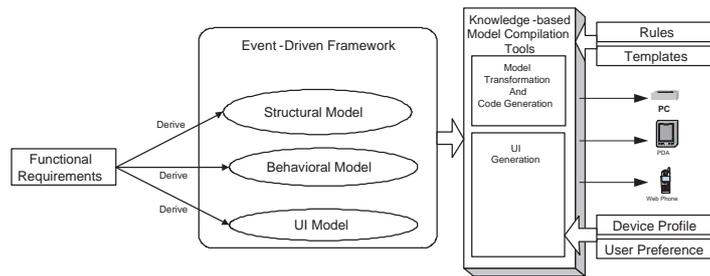


Fig. 1. ZOOM Architecture.

## 2 ZOOM Architecture and Notation

### 2.1 ZOOM Architecture

While UML-2 is widely used as a visual modeling language to support MDE, it has several weaknesses. UML-2 is not specifically designed for MDE, so its models are generally informative without providing definitive views. Also, while UML-2 provides multiple visual views to present similar aspects of a software design, it lacks an inherent mechanism to enforce consistency between these views. Additionally, UML-2 lacks user and system interface design notations. To overcome these obstacles, we propose to enhance the UML-2 models and meta-model to include support for formal syntax and semantics and to provide a new UI model. The result is a new formal notation called ZOOM. ZOOM stands for Z-based Object-Oriented Modeling. It is based on the formal specification notation Z [17–19], which is in turn based upon set theory and mathematical logic. ZOOM provides a human-readable syntax to specify the mathematical model in Z. A complete description of how ZOOM supports Z notation can be found in [20]. Although widely used to specify software systems, one deficiency of Z is that its specification is limited to mathematical logic and does not provide useful mechanisms to support OO modeling such as classes or inheritance. ZOOM extends Z to support these object-oriented concepts. Another deficiency of Z (and the other Z-Based OO extensions) is the lack of visual notations for its constructs and an absence of notations for specifying user interfaces. ZOOM provides visual representations of models that are consistent with UML-2, and extends those notations to support UI and formal action design [21].

Figure 1 shows the overall architecture of the ZOOM models for a software system. The functional requirements derive the structural, behavioral and UI models. ZOOM provides a pre-defined event model, which is processed by an event-driven framework, to bind the structural, behavioral, and UI models together [22]. The integrated ZOOM model will be processed by the Knowledge-based Model Compilation Tools resulting in different implementations of the software system based on the specific platform and knowledge base.

We partition the software design into three components: structural models, behavioral models and UI models. The separation of a system into these three parts is an

---

```
1  struct Student {
2      String name;
3  }
4
5  struct Graduate extends Student {
6      String advisor;
7      String thesis;
8  }
9  struct Undergraduate extends Student {
10     String minor;
11 }
12
13 @Association(multiplicityLeft=Multiplicity.Many,
14             multiplicityRight=Multiplicity.Many,
15             roleLeft = students, roleRight = courses)
16 Relation<Student, Course> enroll;
```

---

**Listing 1.1.** Student.zoom.

application of the well-known paradigm in software engineering - Separation of Concerns, which formally separates the system based on special purpose concerns [23]. This separation allows each aspect of the system to be specified separately, making each aspect easier to write, understand, and change with less impact on the other aspects. For example, under this separation, modelers can modify the user interface based on device profiles and user preferences without changing the structural or behavioral models. The other advantage of this separation is that we can use different formal specification languages to describe different aspects of the system. Using a specific language, which is developed and aimed at a specific need, makes the modeling process more accurate and formal.

Each ZOOM model has dual representations including a textual specification and a visual view. The visual representations are consistent with common UML-2 diagrams, such as class, use case and state machine diagrams, but also include semantics and extensions. Listing 1.1 shows an example of a ZOOM structural model. The same model is used as example in Section 3.2.2. This enables the use of popular tools to design and maintain ZOOM models. Modelers will appreciate the ability to use available tools to construct their models and to add formal specifications to those models. Unlike the models in UML-2, the ZOOM models are executable with its execution semantics. All three components in ZOOM can be independently animated, and the whole software system can be visually animated with the event-driven framework.

### 3 Our Model Transformation Approach

The primary objective of our approach is to assist a development lifecycle, from platform independent models to platform dependent models and code, with a framework that provides a simple way to define transformations, mappings, and refinements. We

accomplish this by using ZOOM as a UML extension to define platform independent model and a transformation mechanism supporting model to model transformation.

Our approach of model transformation is different from most of the existing MDE approaches that are based on MOF. We propose a simpler hierarchical meta modeling architecture than MOF. The key element in our model transformation is focus on how transformations can be specified at the metamodel level. The approach to specifying model transformations involves specializing the Hierarchical Relational Metamodel(HRM) we proposed to characterize source or target models. We will discuss the use of metamodel in transformation in following sections.

Figure 2 shows the basic structure of our model transformation framework. A transformation engine takes the HRM defined source model as input, and use a template comprise of a set of transformation rules to produce output model in a format specified by the templates. In other words, the output from the transformation engine is a transformation of the input model. We regard a model as a set of model elements that are in correspondence with a metamodel element via the instantiation relationship. Metamodel based transformations use only the elements of the metamodels, thus the transformation description is expressed in terms of the two metamodels. The rule set in the Figure 2 is the transformation template which is an extensible component. Different set of templates can be used in different transformation tasks for various target platforms. It's in this sense that we also call the template "cartridge" to reflect the exchangeability of templates. It's the core component of the transformation framework. We will discuss the characteristics of our approach in the following subsections.

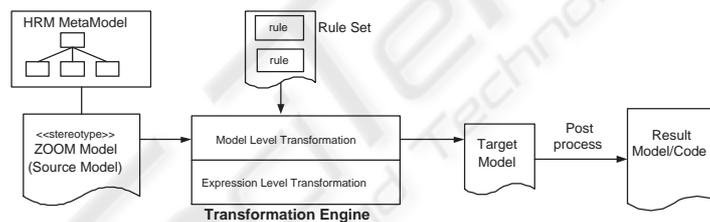


Fig. 2. Model Transformation Process Overview.

### 3.1 Source Model Representation

We use ZOOM notation to represent Platform Independent Model(PIM). ZOOM notation has a textual syntax defined by BNF, which gives us a simplified way to define and use ZOOM metamodel. Since ZOOM provides the textual syntax in a form that most programming languages have, we are able to build an internal representation of ZOOM models in a structure similar to Abstract Syntax Tree(AST), only the node in the tree will be constructs of the modeling language instead of constructs of programming language. However, to capture more complicated modeling language constructs like association. We adopt mathematical collection to depict the relationships of different constructs. Considering it's tree structure and such relationships, we name our metamodel Hierarchical Relational Metamodel(HRM).

The use of HRM provides a way for transformation to understand and make use of the abstract syntax and semantics of both the source and target models. Base on HRM, we design our template based model transformation to get the information necessary to generate target model or code from HRM-compliant models inside a model repository. A set of interchangeable templates can be provided for model transformation between different target technical platforms.

### 3.2 A Metamodeling Language

Metamodeling is a critical part of our transformation approach. It provide a mechanism to unambiguously define modeling languages - ZOOM in our case. It is the prerequisite for a model transformation tool to access and make use of the models. We will now look into the design of our Hierarchical Relational Metamodel(HRM).

**Hierachical Relational Metamodel.** The fact that ZOOM notation has a textual syntax defined by BNF gives us a simplified way to define and use ZOOM model's metamodel. From implementation point of view, metamodel defines the internal representation of models. In programming language, this internal representation often takes the form of Abstract Syntax Tree(AST) that can be processed by interpreter or compiler [24, 25]. Since ZOOM provides the textual syntax in a form that most programming languages have, we are able to build an internal representation of ZOOM models in a structure similar to Abstract Syntax Tree. The only difference is the nodes in the tree are constructs of the modeling language instead of constructs of programming language. To capture more complicated modeling language constructs like association, we also adapt mathematics collection to depict the relationships of different constructs. It is considering its tree structure and such relationships that we name this metamodel Hierarchical Relational Metamodel(HRM).

**HRM Definition.** We provide the following definition of HRM:

*Definition 5.1.* Hierarchical Relational Metamodel is a 3-tuple:  $HRM = (N, C, R)$

$N$  is a set of nodes:  $N = \{n_1, n_2, \dots, n_j\}$

$C$  is a relation on  $N \times N$ , which forms a tree structure that has one root and no un-connected nodes. Each node may have zero or more children. In other words, a node is either a *leaf*(i.e. with no children) or can be decomposed as one or more children and each child forms a subtree

$R = \{r_1, r_1 \dots r_k\}$  is a set of relations between nodes, where  $r_i$  is a relation on  $N \times N$ .

Figure 3 shows a simple class diagram that has four classes: Student, Graduate, Undergraduate and Course. The corresponding HRM diagram is also show in Figure 3 in the middle. This metamodel can be represented as  $(N, C, R)$  according to Definition 5.1.

More specifically, we can elaborate the contents of its three components as:

HRM component	content
$N$	{ ClassDiagram, Student, Graudate, enroll, x, y, Student.name, Graduate.advisor, ... }
$C$	{ (Student, Student.name),(Graduate, Graduate.advisor), (Graudate, Graduate.thesis), ... }
$R$	{ superClass, subClass, leftAssociationEnd, rightAssociationEnd }
superClass	{ (x, Student), (y, Student) }
subClass	{ (x, Graduate), (y, Undergraduate) }
leftAssociationEnd	{ (enroll, Student) }
rightAssociationEnd	{ (enroll, Course) }

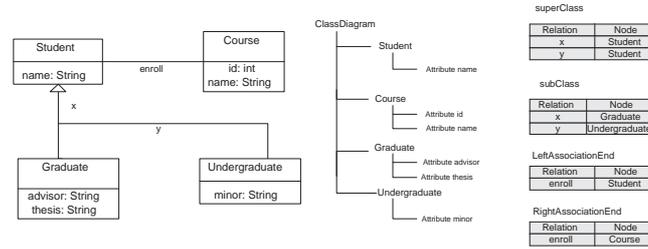


Fig. 3. HRM Example of a Class Diagram.

The components `superClass`, `subClass`, `leftAssociationEnd` and `rightAssociationEnd` are relations between classes Student, Graduate, Undergraduate, Course and relationship enroll, x, y.

### 3.3 Transformation Template

The rule set shown in Figure 2 is a collection of transformation rules. Here we provide the definition of transformation rule as followings:

*Definition 3.1:* A transformation rule  $r = P \rightarrow (T_{pre}, T_{post})$  where  $P$  defines the pattern to select the element of source model and the template pair  $(T_{pre}, T_{post})$  defines the mapping to target model. Respectively  $T_{pre}$  defines the mapping to target model before traversing children of selected element, and  $T_{post}$  defines the mapping to target model after traversing children of selected element. The rationale of this design is closely related to the transformation algorithm that we will talk about in the next sub section.

In our framework, the development of transformation is in a large part the process of constructing transformation rules. The rule set in the Figure 2 is an extensible component. Different set of templates can be used in different transformation tasks for various target platforms. That's why we also call the template "cartridge" to reflect the exchangeability of templates. Template is the core component of the transformation framework. We will show how template or rules are developed in Section 7.

### 3.4 Transformation Algorithm

Metamodel based transformation uses the elements of metamodel. Our adopting of Hierarchical Relational Metamodel(HRM) allows us to build an internal representation of ZOOM models in a structure similar to Abstract Syntax Tree(AST). Once metamodel is generated as an AST like structure, it is accessible by the transformation process through traversing the tree.

```

1 transformNode(node, ruleSet, outputModel)
2   rule <- findMatchingrule(node, ruleSet) //finding the matching rule for this node
3   targetText <- instantiate(rule.pre, node)
4   outputModel.append(targetText) //getting the output text by applying pre part of the rule
5   foreach c is a child of node
6     transformNode(c, ruleSet, outputModel)
7   endforeach //traverse all the children nodes and do transformation on each of them

```

```

8   targetText <- instantiate(rule.post, node)
9   outputModel.append(targetText) //getting the output text by applying post part of the rule

```

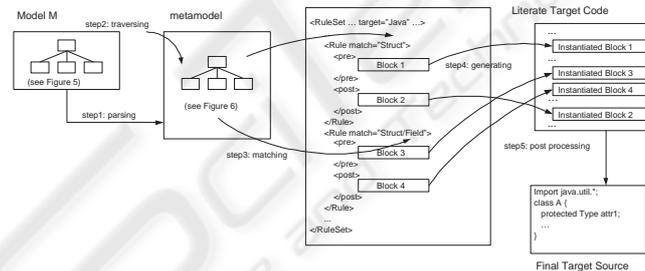
We use an algorithm of “pre-order” to traverse of the tree which means each node is visited before its children are visited and the root is visited first. The algorithm is exemplified by the pseudo code shown in the above pseudo-code.

As we can see in Definition 3.1, a transformation rule has two mapping part,  $T_{pre}$  and  $T_{post}$ . They are represented as *rule.pre* and *rule.post* in the pseudo code. Shown in the above pseudo code: *rule.pre* is the mapping before traversing children of selected element, while *rule.post* is the mapping after traversing children of selected element. And as shown in line 5-7 in the pseudo code, each node in the metamodel will be visited once and all its children node will get visited. To trigger the transformation algorithm, the root node of source metamodel need to be passed, in the form of `transformNode(root, ruleSet, outputModel)`.

## 4 Model Transformation Process

To start the MDE process we need to build a platform-independent model that comprises the essence of target software system. This is the only model that the developer will create completely “by hand.” The other models are mostly generated.

The complete transformation process is depicted in Figure 4. It is divided into 5 individual steps. Now let’s walk through the transformation process step by step.



**Fig. 4.** Model Transformation in details.

**Parsing the Source Model.** A source model is provided, in our case, student.zoom in Listing 1.1. Parsing involves reading actual source code of the model, or the textual representation of model roster and splitting it into understandable language symbols. This is made possible by ZOOM’s formally defined syntax. A parser will parse the textual representation of model roster and generates an internal abstract syntax tree (AST) representation of roster, which is an object tree.

**Traversing the Object Tree.** Once metamodel is generated as AST, which is accessible by the transformation process through traversing the tree. We use an algorithm of “pre-order” traversal of the tree which is introduced in section 4.3. It means each node

is visited before its children are visited and the root is visited first. The traversing is exemplified by pseudo code shown in section 3.4. Since the matching metamodel node with rule(step 3) and generating target text(step 4) happen during the process of traversing. The pseudo code in section 3.4 actually shows all of these 3 steps. To trigger this transformation algorithm, the root node of source metamodel need to be passed. In our case, it is passing as `transformNode(m1, ruleSet, outputModel)`, since `m1` is the root node.

As we can see in Definition 4.2, a transformation rule has two mapping part,  $T_{pre}$  and  $T_{post}$ . They are represented as *rule.pre* and *rule.post* in pseudo code in Section 3.4. Shown in the pseudo code: *rule.pre* is the mapping before traversing children of selected element, while *rule.post* is the mapping after traversing children of selected element. And as shown in line 5-7 in the pseudo code, each node in the metamode will be visit once and all its children node will get visited.

**Matching Node in Object Tree with Rule.** The key step in this transformation process is applying rules to source medels represented by their metamodels. At this point, transformation engine enters into the picture. As implied in transformation rule definition,  $r = (P \rightarrow (T_{pre}, T_{post}))$ , to apply a rule on a certain model include both matching the pattern  $P$  and implement mapping  $T_{pre}$  and  $T_{post}$ . The pattern  $P$  is specified to make sure that right node is being located and used. In the pseudo code in section 3.4, *rule.pre*(line 3) and *rule.post*(line 8) function as a template for the transformation. When implement a template, we allow both static and dynamic specification. Static specification is a verbatim mapping and dynamic specification can be in one of these two forms: macros or JSP alike syntax.

**Generating Target Text.** The generation of target text can be as simple as output the text included in the rule *pre* or *emphpost* elements as shown in pseudo code in section 3.4 line 3 and line 8. However, more complicated scenario can be involved in this step. For example, in most of the cases, expressions are in different forms in source and target model. We provide an extensible mechanism to assist the transformation, or mapping. The result of these steps is Literate Target Code. It will be used as input in the final step, post processing.

**Post Processing.** The Literate Target Code generated in Step 4 as shown in Figure 4 may or may not in a desirable order that fits to the target technical platform. Post processing is responsible to rearrange the Literate Target Code in a desirable style that fits to the target technical platform. Here we treated the Literate Target Code as pieces of segment that can be flexibly rearranged. A post process goes through all these pieces and place each of them in right places in final models or code. This frees the model transformation engine from the details of contextual requirements of target platform. This approach has a similar style as proposed in Knuth's Literate Programming [26]. Literate programming is a methodology that combines a programming language with a documentation language, hereby making programs more robust, more portable, more easily maintained, and arguably more fun to write than programs that are written only in a high-level language.

After all the above transformation steps, the results are models or source code of target platform. In our example, the results are a group of Java source code.

## 5 Related Work

A number of partial solutions to describe and implement model transformation are currently available. Some of these are applicable only in a limited domain, or provide very low-level abstractions for transformations [27].

### 5.1 AndroMDA

AndroMDA [28] is a code generation tool that takes a UML model as input and generates source code as output. It adopts a template-based transformation methodology similar to ours in a degree but differs significantly in handling of metamodel. Using a series of template files (which you can customize if you wish), AndroMDA can produce source code from a UML model in any programming language. Default templates exist to generate Java code (and in particular J2EE code). AndroMDA was designed to get the information necessary to generate code from MOF compliant models inside a MOF repository.

Both AndroMDA and our approach are template-based, metamodel-based model transformation frameworks that support code generation. Both have an extensible architecture consists of cartridges. These cartridges generate the code specific to a certain concrete technical platform. However, the fundamental difference between these two approaches are the metamodel that they base upon. AndroMDA uses MOF while we use HRM. Because of the complexity of the MOF compliant metamodel, when AndroMDA traverses its AST objects, it has to access them via a proprietary JMI interfaces, metamodel facades. Comparing to AndroMDA, our approach simplified the transformation template development by adopting a concise, tree-structure metamodel.

### 5.2 XSLT Style

Extensible Stylesheet Language Transformations (XSLT) [29] is an XML-based language used for the transformation of XML documents into other XML. The XSLT processor ordinarily takes two input files - an XML source document, and an XSLT stylesheet and produces an output document. The XSLT stylesheet contains the XSLT program text and is itself an XML document that describes a collection of template rules: instructions and other hints that guide the processor toward the production of the output document. Since XSLT must be written in terms of the concepts in the source XMI document (model), and object (or element) creation explicit, the style is highly procedural and due to its XML basis, the concrete syntax is very user unfriendly. As such, it is unsuitable for one of the major goals of a declarative transformation language - which is to communicate mapping specifications to human beings.

Comparing to XSLT, our approach provides a much more user friendly template language syntax. In most cases, transformation developer just need to fill in the syntax details of target platform when writing the specific template.

### 5.3 QVT(Queries/Views/Transformations)

In the Model-Driven Architecture(MDA), QVT (Queries/Views/Transformations) is a standard for model transformation defined by the Object Management Group. Presently

there are several products (commercial or open source) that claim compliance to the QVT standard. QVT defines a standard way to transform source models into target models. Duddy et al propose a transformation language which will meet the requirements of QVT RFP, and several others besides [30]. The language is declarative and patterns based. Transformation descriptions are explicitly reusable and modular. Rules that make up such descriptions may be aspect-driven, allowing for transformations to be written to address semantic concepts rather than structural features.

Since the abstract syntax of QVT conform to MOF 2.0 metamodel, one of the strength in our approach again is adopting a concise, tree-structure metamodel, HRM. Because of the simplified metamodel, when transformation engine traverses its AST objects, it can have direct access to the properties of the objects. This facilitates model transformer to develop transformation template in a easier and quicker way.

## 6 Conclusions

In this paper we present a template based model transformation framework using Hierarchical Relational Meta-model (HRM). By adopting Z-based Object-Oriented Modeling notation (ZOOM) as the formal modeling notation, this model transformation framework provides benefits consist of: 1) readability and rigorousness of meta-model definitions; 2) simplicity of transformation definition; and 3) extensibility of transformation templates.

The current development of this project has made substantial progress and further research effort will be mainly focusing on two things: one is to extend the capacity of current framework; the other is to further prove the validity of this research by building more sophisticate cases. With these two major parts in place, we can further compare our approach with other model transformation mechanisms to verify the advantages of our framework, which is providing a simple, effective, and practical way to define model transformations.

## References

1. Kent, S.: Model driven engineering. In: Proc. IFM 2002, Springer-Verlag (2002) LNCS Vol. 2335.
2. Balasubramanian, K., Gokhale, A., Karsai, G., Sztipanovits, J., Neema, S.: Developing applications using model-driven design environments. *Computer* 39 (2006) 33
3. Gray, J., Lin, Y., Zhang, J.: Automating change evolution in model-driven engineering. *Computer* 39 (2006) 51
4. Poole, J.: Model-driven architecture: Vision, standards, and emerging technologies. In: ECOOP'01 – Object-Oriented Programming. (2001)
5. Rouvoy, R., Merle, P.: Towards a model-driven approach to build component-based adaptable middleware. In: ARM '04: Proceedings of the 3rd workshop on Adaptive and reflective middleware, New York, NY, USA, ACM Press (2004) 195–200
6. (UML<sup>TM</sup> 2.0 Superstructure Specification) OMG Document ptc/03-08-02 (August, 2003).
7. France, R.B., Ghosh, S., Dinh-Trong, T., Solberg, A.: Model-driven development using uml 2.0: Promises and pitfalls. *Computer* 39 (2006) 59

8. Rumbaugh, J., Jacobson, I., Booch, G.: The Unified Modeling Language reference manual.(1998)
9. Sendall, S., Kozaczynski, W.: Model transformation: The heart and soul of model-driven software development. *IEEE Software* 20 (2003) 42–45
10. D'Ambrogio, A.: A model transformation framework for the automated building of performance models from uml models. In: *WOSP '05: Proceedings of the 5th international workshop on Software and performance*, New York, NY, USA, ACM Press (2005) 75–86
11. Bzivin, J., Farcet, N., Jzquel, J.M., Langlois, B., Pollet, D.: Reflective model driven engineering. In: "UML" 2003 - The Unified Modeling Language, Springer-Verlag (2003) LNCS Vol. 2863.
12. Mukerji, J., Miller, J.: (Model-Driven Architecture) [http:// www.omg.org/cgi-bin/doc?ormsc/2001-07-01](http://www.omg.org/cgi-bin/doc?ormsc/2001-07-01).
13. Group, O.M.: (Meta-Object Facility 1.4) OMG Document formal/2002-04-03.
14. (MOF 2.0 Query / Views / Transformations RFP) OMG Document ad/04-10-02.
15. (MOF QVT final adopted specification) OMG Document ad/05-11-01.
16. Spivey, J.M.: *The Z Notation: A Reference Manual*, 2nd Ed. (1992)
17. Woodcock, J., Davies, J.: *Using Z Specification, Refinement, and Proof*. Prentice Hall Europe (1996)
18. Wordsworth, J.B.: *Software Development with Z*. Addison Wesley, Boston, MA (1992)
19. Jia, X.: An approach to animating Z specifications. In: *Proc. 19th Annual IEEE Int'l Computer Software and Applications Conf. (COMPSAC 1995)*, Dallas, Texas, USA (1995) 108–113
20. Jia, X.: (The ZOOM Notation - A Reference Manual) Technical Report, DePaul University, 2004.
21. Jia, X., Steele, A.: Incorporating uids into model-driven development. In: *Proceedings of UIXML2004*, Gallipoli, Italy (2004)
22. Qin, L., Liu, H., Jones, C., Jia, X.: An Integrated Event-Driven Framework Supporting MDD. In: *Proc. of the 2004 Midwest Software Engineering Conference (MSEC'04)*, Chicago, IL USA. (2004) 32–44
23. Lopes, C., Hrsh, W.: (Separation of concerns) Technical Report, Computer Science School, Northeastern University, Boston, US, 1995.
24. Aho, A.V., Ullman, J.D.: *Theory of Parsing, Translation and Compiling*. Prentice Hall Professional Technical Reference (1973)
25. Wile, D.S.: Abstract syntax from concrete syntax. In: *ICSE '97: Proceedings of the 19th international conference on Software engineering*, New York, NY, USA, ACM Press (1997) 472–480
26. Knuth, D.E.: *Literate programming*. CSLI Lecture Notes (2003)
27. Czarnecki K., S.H.: Classification of model transformation approaches. In: *OOPSLA*. (2003)
28. (Andromda website) <http://www.andromda.org/>.
29. (W3C), T. W. W. W. C.:(XSL Transformations (XSLT) Version 1.0) [http:// www.w3c.org/TR/xslt](http://www.w3c.org/TR/xslt).
30. et al, K.D.: Model transformation: A declarative, reusable patterns approach. (In: *Proceedings of the Seventh IEEE International Enterprise Distributed Object Computing Conference (EDOC03)*)