Visual Models Transformation in MetaLanguage System

Alexander O. Sukhov, Lyudmila N. Lyadova

***Abstract* —** At the process of creation and maintenance of information systems the model-based approach to the software development is increasingly used. This approach allows to move the focus from writing of the program code with using general purpose language to the models development with automatic generation of data structures and source code of applications. However at usage of this approach it is necessary to transform models constructed by various categories of users at different stages of system creation with usage of various modeling languages. An approach to models transformation in DSM platform MetaLanguage is considered. This approach allows fulfilling vertical and horizontal transformations of the designed models. The Metalanguage system support "model-text" and "model-model" types of transformations. The component of transformations is based on graph grammars described by production rules. Transformations of model in Entity-Relationship notation are presented as example.

***Keywords* —** Domain-specific languages, visual language, DSM-platform, language workbench, model-based approach, model transformation, vertical transformation, horizontal transformation.

I. Introduction

Development of information systems with usage of the modern tools is based on the design of the various models describing the domain of the information system, defining data structures and algorithms of system functioning. The main idea of such model-driven approach is the systematic usage of models at various stages of software development that allows to shift the focus from writing code in general purpose programming language to building models and automatic generation of the source code and other necessary artifacts. At modeling developer abstracts from concrete technologies of implementations. It facilitates the creation, understanding and maintenance of models. This approach is intended to increase productivity and to reduce development time.

There are implementations of model-driven approach which use general purpose modeling languages for describing of information systems. So, the modeling language UML with the standard MOF (Meta-Object Facility) forms a basis of the concept MDA (Model-Driven Architecture) [1]. Other implementations of the model-driven approach are based on use of the visual *domain-specific modeling languages* (DSMLs, DSLs), intended to solve a particular class of problems in the specific domain. Unlike general purpose modeling languages, DSMLs are more expressive, simple in applying and easy to understand for different categories of users as they operate with domain terms. To support the process of development and maintenance of DSMLs the special type of software – *language workbench* (*DSM-platform*) – is used.

The various categories of specialists (programmers, system analysts, database designers, domain experts, business analysts, etc.) are involved in the process of information systems creation and maintenance. Often they need modification of modeling language description to customize and adapt DSML to new conditions, requests of business and possibilities of users. The transformations of models constructed by various users at different stages of information system creation with usage of various DSMLs are necessary for the models adjustment and integration [2].

For implementation of these possibilities it is necessary, that the language workbench allowed to build the whole hierarchy of models: model, metamodel, meta-metamodel, etc., where *model* is an abstract description on some formal language of system characteristics that are important from the point of view of the modeling purpose, a *metamodel* is a model of the language, which is used for models development, and a *meta-metamodel (metalanguage)* is a language for the metamodels description. Furthermore, the language workbench should contains the tools allowing to fulfill conversion of models between various levels of hierarchy (*vertical* transformations) and in one hierarchy level (*horizontal* transformations).

The *MetaLanguage* system is a language workbench for creating of visual dynamic adaptable domain-specific modeling languages. This system allows to fulfill multilevel and multi-language modeling of domain [3]. The basic elements of the metalanguage are *entity*, *relationship* and *constraint*.

Usage of domain-specific languages and tools for the system development also affects a transformation problem as there is a need of export of the models created with DSML to external systems which, as a rule, use one of the standard modeling languages that is different from used DSL. That is why one of the main components of the MetaLanguage system is the *transformer*. This component uses graph grammars for models transformations description. Implementation of graph grammars in the MetaLanguage system is defined by appointment of this language workbench.

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II. Basic Concepts

The basic concept of transformation definition is a *production rule* which looks like $p: L \to R$, where p is a rule *name*, L is a *left-hand side* of the rule, also called the *pattern*, and R is a *right-hand side* of the rule, which is called the *replacement graph*. Rules are applied to the starting graph named the *host-graph*.

Let's suppose that four labeled graphs G, H, L, R are given, and graph L is a subgraph of graph G. Applying of the rule $p: L \to R$ to the starting graph G is called the replacement in graph G of subgraph L on graph R, which is a subgraph of graph H. The graph H is the result of this replacement [4].

Graph grammar is a pair $GG = (P, G_0)$, where P is a set of production rules, G_0 is a starting graph of grammar.

Graph transformation is a sequenced applying to the starting labeled graph G_0 of finite set of rules $P = (p_1, p_2 \dots p_n)$: $G_0 \overset{p_1}{\to} G_1 \overset{p_2}{\to} \dots \overset{p_n}{\to} G_n$.

Transformations can be classified as horizontal and vertical according to direction. The *horizontal transformation* is the conversion, in which the source and target models belong to one hierarchy level. An example of a horizontal transformation is a conversion of model description from one notation to another (see Fig. 1). The *vertical transformation* converts the models which belong to various hierarchy levels, for example, at mapping of the metamodel objects to domain model objects.

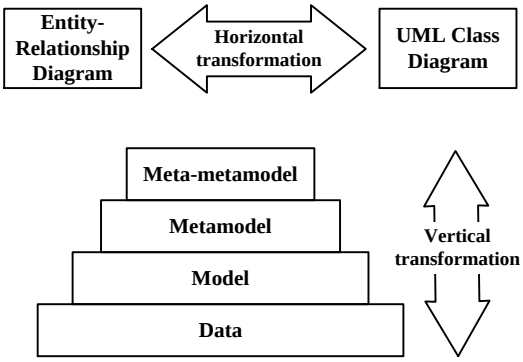


Fig. 1. Horizontal and vertical model transformations

The models are described with some modeling languages. Depending on the language on which source and target models are described, horizontal transformations can be divided into two types: endogenous and exogenous. An *endogenous transformation* is the transformation of the models, which are described on the same modeling language. An *exogenous transformation* is the transformation of models, which are described on various modeling languages [5].

Graph grammars are often used to describe any transformations performed on graphs: definition of the models operational semantics [6], the analysis of program systems with dynamic evolving structures [7], etc.

The right-hand side of the rule may be not only a labeled graph, but the code on any programming language, and also a fragment of a visual model described in some notation. That is why the graph grammar can be used for generation syntactic correct models and for refactoring of existing models, code generation and model transformation from one modeling language to another [8].

Considering singularities and designation of MetaLanguage system, it is necessary to make the following requirements to its transformation component:

- To be obvious and easy to use for providing the opportunity of involving to transformation description not only programmers, but also experts, specialists in domains. It can be achieved through the usage of visual notation of transformations description language.
- To allow using the created transformations directly in the system, i.e. to produce the models transformations in the same user interface, in which they were designed.
- To perform both horizontal and vertical transformations, and possibility to fulfill the horizontal transformations from one notation to another, including a "model-text" type.
- To allow specifying the transformations of entities and relationships attributes and constraints imposed on metamodel elements.

III. Related Works

There are various approaches to model transformations. Some of them have the formal basis, so the systems AGG, GReAT, VIATRA use graph rewriting rules to perform transformations, and others apply technologies from other areas of software engineering, for example the technique of programming by example.

Various modifications of the algebraic approach [9] are implemented in systems AGG, GReAT, VIATRA. In AGG (Attributed Graph Grammar) [10], [11] the left- and right-hand sides of the production rule are the typed attribute graphs, both sides of a rule should be described in one notation, i.e. this system allows to fulfill only endogenous transformations that does impossible its usage in MetaLanguage system. Besides, this tool does not allow to make transformation of a "model-text" type. However the usage as the formal basis of the algebraic approach to graph transformations allows to produce graph parsing, to verify graph models, and the extension of graphs of Java possibilities makes transformations more powerful.

The GReAT (Graph REwriting And Transformation) system [12], [13] is based on the algebraic approach with double-pushout, therefore for transformation description it is necessary to create the domain that contains both the left- and right-hand sides of the production rule simultaneously with instructions of what element it is necessary to add, and what to remove. This form of rule is unusual for the user and a bit tangled. However it provides a possibility of execution the transformation of several source metamodels at once, which is significant advantage in comparison with other approaches. For metamodels definition the GReAT uses UML and OCL, it does not allow the user to choose the language of metamodels specification or to change its description. It makes this

approach unsuitable for usage in MetaLanguage.

The QVT (Query/View/Transformation) is the proposed by OMG approach to models transformation, which provides the user with declarative and imperative languages [14], [15]. Conversion is defined at the level of metamodels, which is described on MOF. The advantage of this approach is the existence of standard of its description, and also usage of standard languages OCL and MOF at the models transformation definition. But usage of MOF as a meta-metamodeling language, does not allow the user to choose a metalanguage convenient for him, or to change description of the metalanguage which is integrated in the QVT.

VIATRA (VIsual Automated model TRAnsformations) [16], [17] is a transformation language, based on rules and patterns, which combines two approaches into a single specification paradigm: the algebraic approach for models description and the abstract state machines intended for exposition of control flow. Thanks to constructions of state machines the developers significantly raised the semantics of standard languages of patterns definition and graph transformation. Besides, powerful metalanguage constructions allow to make multilevel modeling of domains. One of shortcomings of the VIATRA is an inexpressive textual language of metamodels description. VIATRA is not intended for execution of horizontal model transformations. Its main purpose is a verification and validation of the constructed models by their transformation.

The ATL (ATLAS Transformation Language) is the language, allowing to describe transformations of any source model to a target model [18], [19]. Transformation is performed at the level of the metamodels. The disadvantage of this language is high requirements to the developer of transformation. Since ATL in most cases uses only textual definition of transformation, then in addition to knowledge of source and target metamodels the developer needs to know language of transformation definition. The ATL is a dialect of QVT language and therefore inherits all its shortcomings.

MTBE (Model Transformation By-Example) approach [20], [21] is quite non-standard and unusual. The main purpose of MTBE is automatic generation of transformation rules on a basis of an initial set of learning examples. However implementations of this approach do not guarantee that the generation of model transformation rules is correct and complete. Moreover, the generated transformation rules strongly depend on an initial set of learning examples. Current implementations of MTBE approach allow to fulfill only full equivalent mappings of attributes, disregarding the complex conversions.

In summary, it is possible to say that all considered systems have some disadvantages which restrict their applicability for transformation definitions in the MetaLanguage system. But the most appropriate and perspective, from the author's point of view, is the algebraic approach.

IV. Model Transformations

Horizontal transformation is the conversion, in which the source and target models belong to one hierarchy level.

All horizontal transformations in MetaLanguage system are described at level of metamodels that allows to specify conversions which can be applied to all models created on basis of this metamodels. For a transformation definition it is necessary to select a source and target metamodels and to define production rules that are describing conversion.

To define the rule it is necessary to select objects (entities and relationships) in a source metamodel, to set constraints on pattern occurrence and to define the right-hand side of the rule. Depending on a type of transformation a right-hand side will be a text template for code generation, or a fragment of a target visual metamodel.

Transformation rules are applied according to their order. At first all occurrences of a first rule pattern will be found, for each of them the system will replace it by the right-hand side of the production rule, then the system will pass to the second rule and will begin to execute it, etc.

Let's assume that the system has selected next production rule of transformation and trying to execute it. For implementation of rule application it is necessary to describe two algorithms: the algorithm of the pattern search in the source host-graph and the algorithm of replacement of the left-hand side of the rule by the right-hand side.

There are various algorithms of search of subgraph isomorphic to the given pattern: Ullmann algorithm [22], Schmidt and Druffel algorithm [23], Vento and Foggia algorithm [24], Nauty-algorithm [25], etc. These algorithms are the most elaborated and often used in practice.

However difference of the proposed approach from the classical task of graph matching is that in this case it is necessary to find a pattern in the metamodel graph, i.e. it is required to lead matching of graphs which belong to various hierarchy levels, thus it is necessary to consider type of nodes and arcs, as between two nodes of the metamodel graph the several arcs of various type can be led.

The offered algorithm for finding a pattern in the graph model is a kind of backtracking algorithm that takes exponential time.

Since the amount of arcs in the model graph is less than amount of the nodes usually, each arc uniquely identifies nodes, that are incident to it, and the degree of node can be more than two, that does not allow to select the following node of the model graph, entering into a pattern. It was decided to start search of subgraph in a model graph on the basis of search of particular type arcs.

At the first step of algorithm all instances of some arbitrary relationship of the pattern will be found, i.e. search of an initial arc with which execution of the second step of algorithm will begin is carried out. At the second stage it is necessary to find one of possible occurrence of all relationships instances of the pattern-graph G_P in the source model graph G_S. At the third step necessary nodes will be add to target graph G_T and

replace the left-hand side of the rule by the right-hand side.

Then it is necessary to replace the left-hand side of the production rule by the right-hand side after the subgraph of left-hand side has been found in the source graph. The algorithm of replacement will depend on a type of transformation: whether transformation is “model-text” or “model-model”.

Transformation “model-text”. The transformation of this type allows to generate the source code on any target programming language on the basis of the constructed models as well as any other textual representation of model, for example, its description on XML. In this case the right-hand side of production rule contains some template consisting of as static elements, which are independent of the found pattern, and dynamic parts, i.e. elements which vary depending of the found fragment of model.

For transformation fulfillment it is necessary to find all occurrences of a pattern in a source graph and to produce an insertion of an appropriate text fragment with a replacement of a dynamic part by appropriate names of entities, relationships, values of their attributes, etc.

The template is described on the target language. For selection of a dynamic part of a template the special metasymbols are used: “<<” (double opening angle brackets) to indicate the beginning of a dynamic part, “>>” (double closing angle brackets) to indicate the end of a dynamic part. As entities and relationships can have the same name, then for entity describing before its name the prefix “E.” is specified, and for relationship describing before its name the prefix “R.” is specified.

At the transformation specifying it is possible to set constraints on pattern occurrence. These constraints allow to define the context of the rule. They contain conditions with which found fragment of model should satisfy.

Let’s consider an example: define the transformation that allows on the basis of Entity-Relationship Diagrams (ERD) to generate a SQL-query, building the schema of a corresponding database.

At the first step it is necessary to choose the metamodel of Entity-Relationship Diagrams (see Fig. 2) and to set the transformation rules.

The metamodel contains the entities “Abstract”, “Attribute”, “Entity”, “Relationship”. Attributes of the entity “Abstract” are “Name” that identifies an entity instance, and “Description”, containing the additional information about the entity. The entity “Abstract” is abstract, i.e. it is impossible to create instances of this entity in the model. “Abstract” acts as a parent for entities “Entity” and “Relationship” (in the figure it is shown by an arrow with a triangular end). Both child entities inherit all parent attributes, relationships, constraints. “Entity” does not have own attributes and constraints. “Relationship” has the own attribute “Multiplicity”. The entity “Attribute” has following attributes: “Name”, “Type” and “Description”.

The bidirectional association “Linked_Links” connects entities “Relationship” and “Entity”. It means that it is possible to draw equivalent relationship between these entity instances in ERD-models. The second unidirectional association “SuperClass_SubClass” binds entity “Entity” with itself, it allows any instance of “Entity” to have parent (another instance of “Entity”) in ERD-models. In ERD metamodel between entities “Attribute” and “Abstract” the aggregation “Belongs” is set (in figure this relationship is presented by an arc with a diamond end), therefore in ERD-models instances of entities “Relationship” and “Entity” can be connected by aggregation with the instances of entity “Attribute”.

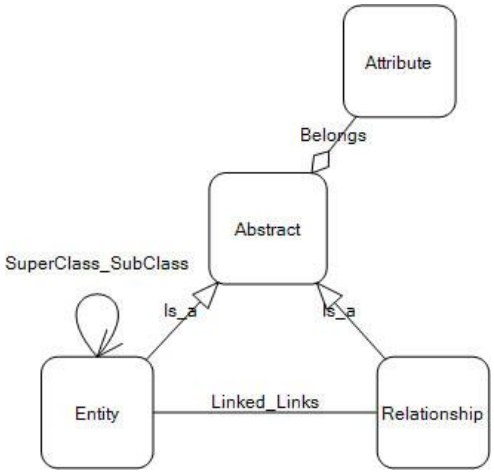
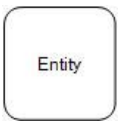


Fig. 2. Metamodel of Entity-Relationship Diagrams

For correct transformation execution the additional attributes in the source metamodel should be added. To determine what entity is a parent, and what entity is a child it is necessary to add the mandatory attributes of a reference type (“Child” and “Parent”) to relationship “SuperClass_SubClass”. The entity “Relationship” should be transformed to the reference between relational tables, therefore we will add to “Relationship” additional mandatory attributes-references of “LeftEntity” and “RightEntity” and attribute of logical type “Has_Attribute”, which will facilitate the replacement of the left-hand side of the production rule by the right-hand side.

For transformation definition we will use the traditional rules of conversion of the ERD notation to a relational model, for this purpose we will define the following rules.

The rule “Entity” which transforms the instance of entity “Entity” to the single table looks like:



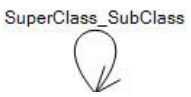
→

```
CREATE TABLE <<E.Entity.Name>>
(id INTEGER primary key)
```

Here `<<E.Entity.Name>>` is a dynamic part of the template which allows to get a name of corresponding entity.

As there is not inheritance relationship in a relational model, it is necessary to specify the rule “Inheritance”, which for each instance of the relationship “SuperClass_SubClass” in the “SubClass” table creates foreign key for connection with the “SuperClass” table.

This rule looks like:




```
ALTER TABLE
<<R.SuperClass_SubClass.Child>>
ADD <<R.SuperClass_SubClass.Parent>>
ID INTEGER
ALTER TABLE
<<R.SuperClass_SubClass.Child>>
ADD FOREIGN KEY
(<<R.SuperClass_SubClass.Parent>>ID)
REFERENCES
<<R.SuperClass_SubClass.Parent>> (id)
```

The rule "Relationship_1M" allows to transform instance of entity "Relationship", which does not have attributes and its multiplicity is "1:M", to the reference between tables.

The rule has the following appearance:


```
ALTER TABLE <<E.Relationship.LeftEntity>>
ADD <<E.Relationship.RightEntity>>
ID INTEGER
ALTER TABLE <<E.Relationship.LeftEntity>>
ADD FOREIGN KEY
(<<E.Relationship.RightEntity>>ID)
REFERENCES <<E.Relationship.RightEntity>>
(id)
```

In this rule at first in the table corresponding to the left entity the additional column with the name `<<E.Relationship.RightEntity>>ID` is added, and then the foreign key (correspondence between this additional column and a column containing the identifiers of right table rows) is created. This rule contains the constraint on the pattern occurrence:

```
E.Relationship.Multiplicity = 1:M AND
E.Relationship.Has_Attribute = False
```

The rule "Relationship_M1" allows to transform instance of entity "Relationship", which does not have attributes and its multiplicity is "M:1", to the reference between tables.

The rule looks like:


```
ALTER TABLE <<E.Relationship.RightEntity>>
ADD <<E.Relationship.LeftEntity>>
ID INTEGER
ALTER TABLE
<<E.Entity.Relationship.RightEntity>>
ADD FOREIGN KEY
(<<E.Relationship.LeftEntity>>ID)
REFERENCES
<<E.Relationship.LeftEntity>>(id)
```

The content of this rule is similar to the content of the rule "Relationship_1M". This rule contains the constraint on the pattern occurrence:

```
E.Relationship.Multiplicity = M:1 AND
E.Relationship.Has_Attribute = False
```

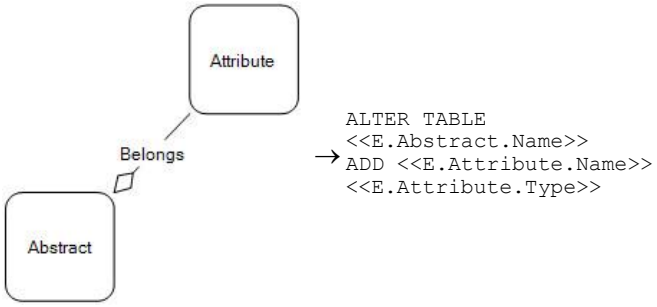
For each instance of entity "Relationship", which has the attributes, or has the multiplicity "1:1" or "M:M", it is necessary to create the single table that contains the key columns of each entity involved in relationship. We call this rule "Relationship_MM", it has the following appearance:


```
CREATE TABLE <<E.Relationship.Name>>
(id INTEGER primary key,
<<E.Relationship.LeftEntity>>ID INTEGER,
<<E.Relationship.RightEntity>>ID INTEGER)
ALTER TABLE <<E.Relationship.Name>> ADD
FOREIGN KEY
(<<E.Relationship.LeftEntity>>ID)
REFERENCES <<E.Relationship.LeftEntity>>
(id)
ALTER TABLE <<E.Relationship.Name>> ADD
FOREIGN KEY
(<<E.Relationship.RightEntity>>ID)
REFERENCES <<E.Relationship.RightEntity>>
(id)
```

This rule contains the constraint on the pattern occurrence:

```
E.Relationship.Multiplicity = M:M OR
E.Relationship.Multiplicity = 1:1 OR
E.Relationship.Has_Attribute = True
```

The rule "Attribute" adds the columns corresponding to attributes of instances of entities and relationships to the created tables:



Let's consider an example, apply the described transformation to the model "University" presented in Fig. 3.

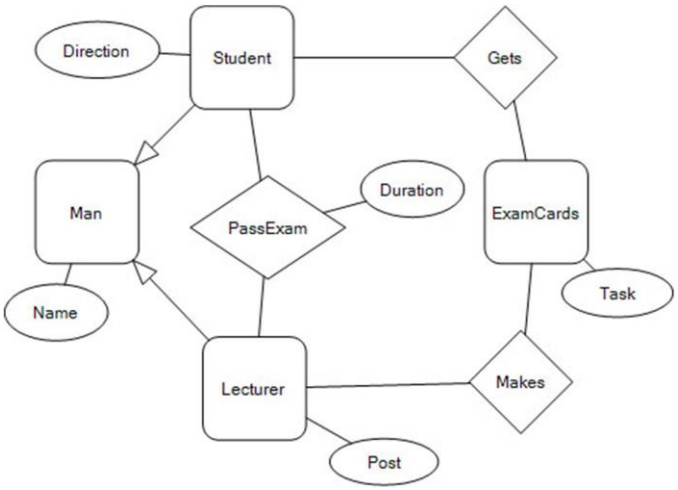


Fig. 3. Simplified model "University" on the ERD notation

As the result the following text has been generated by the MetaLanguage system:

```
CREATE TABLE Man (id INTEGER primary key)
CREATE TABLE Student (id INTEGER primary key)
CREATE TABLE Lecturer (id INTEGER primary key)
CREATE TABLE ExamCards (id INTEGER primary key)
ALTER TABLE Lecturer ADD ExamCardsID INTEGER
ALTER TABLE Lecturer ADD FOREIGN KEY
(ExamCardsID) REFERENCES ExamCards (id)
ALTER TABLE ExamCards ADD StudentID INTEGER
ALTER TABLE ExamCards ADD FOREIGN KEY (StudentID)
REFERENCES Student (id)
CREATE TABLE PassExam (id INTEGER primary key,
StudentID INTEGER, LecturerID INTEGER)
ALTER TABLE PassExam ADD FOREIGN KEY (StudentID)
REFERENCES Student (id)
ALTER TABLE PassExam ADD FOREIGN KEY (LecturerID)
REFERENCES Lecturer (id)
ALTER TABLE Student ADD ManID INTEGER
ALTER TABLE Student ADD FOREIGN KEY (ManID)
REFERENCES Man (id)
ALTER TABLE Lecturer ADD ManID INTEGER
ALTER TABLE Lecturer ADD FOREIGN KEY (ManID)
REFERENCES Man (id)
ALTER TABLE Man ADD Name nvarchar(MAX)
ALTER TABLE PassExam ADD Duration nvarchar(50)
ALTER TABLE Lecturer ADD Post nvarchar(50)
ALTER TABLE Student ADD Direction nvarchar(MAX)
```

It should be noted that this transformation does not take into account complex conversions the ERD notation to the database schema, for example, those which would allow to create single dictionary table on the base of attribute, because it requires a special description language of templates and it is one of the areas for further research. Although such conversion could be done by adding to the entity "Attribute" the attribute "Is_a_Dictionary" and setting the constraints on pattern occurrence.

Transformation "model-model". Transformation of this type allows to produce conversion of model from one notation to another or to perform any operations over model (creation of new elements, reduction, etc.). Such transformation will allow to export model to external systems, and to provide the ability to convert the domain-specific language that was created by the user in one of most common modeling language, for example, UML, ERD, IDEF0, etc.

The left-hand side of a production rule of this type transformation is some fragment of the source metamodel, and the right-hand side of the rule is some fragment of the target metamodel. At the production rule definition also it is necessary to describe the rules for converting the attributes of entities and relationships. The created model should not contain dangling pointers, therefore the process of the transformation executions begins with the creation of entity instances and only then instances of relationships are created. If in the process of model building the dangling pointers are still found the system will delete them.

At transformation execution it is necessary to consider the following elementary conversions:

- conversion "entity → entity";
- conversion "relationship → relationship";
- conversion "entity → relationship";
- conversion "relationship → entity".

Let's suppose that in the source model the instances of entities and relationships of pattern are already found.

For fulfillment of the conversion $ee: Ent_L \to Ent_R$ it is necessary to create in the new model the instance $EntI_R$ of the appropriate entity from a rule right-hand side and to perform transformation of attributes. The created instance of entity will have the same name, as the name of source entity instance.

For execution the conversion $rr: Rel_L \to Rel_R$ at first it is necessary to found in the source model the instances of entities $RelI_L.SEI$ and $RelI_L.TEI$, which are connected by the relationship instance $RelI_L$, then the images of these instances should be found in the new model, and an instance of the relationship from a rule right-hand side should be lead between them. After that it is necessary to fulfill transformation of attributes.

For fulfillment of the conversion $er: Ent_L \to Rel_R$ it is necessary to find in source model the nodes $EntI_S$, $EntI_T$ which are adjacent to entity instance $EntI_L$. Let's denote their images in the target model as *Source* and *Target*. In the target model the relationship instance $RelI_R$ between nodes *Source* and *Target* should be lead. Further it is necessary to execute defined transformation of attributes.

Conversion $re: Rel_L \to Ent_R$ transforms the instance of relationship $RelI_L$ found in the source model to the entity instance $EntI_R$ of target model. For conversion execution it is necessary to create the entity instance $EntI_R$, to perform the specified transformation rules of attributes. The name of $EntI_R$ will be the same as the name of the relationship instance $RelI_L$. At the next step it is necessary to find entities instances $RelI_L.SEI$, $RelI_L.TEI$, which are connected by relationship instance $RelI_L$.

Further the instances of relationships that connect an entity instance $EntI_R$ with nodes *Source* and *Target*, which are images of the nodes $RelI_L.SEI$ and $RelI_L.TEI$, accordingly, are created with keeping of orientation of relationship instance.

It is possible to present the rest conversions of "model-model" type by a combination of these elementary operations.

Let's consider an example, perform the transformation of the model on ERD notation to UML Class Diagrams.

Since the transformation is done at the metamodel level, then at the first step it is necessary to create/open source and target metamodels. The ERD metamodel was presented in the Fig. 2. Metamodel of UML Class Diagrams is shown in the Fig. 4. It contains the following elements: the entity "Class" and three relationships "Inheritance", "Association", "Aggregation". Let's define the production rules that determine the transformation.

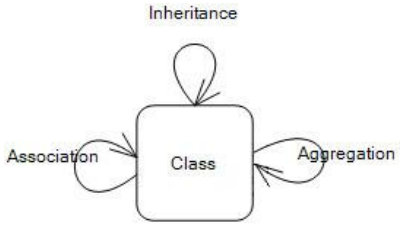
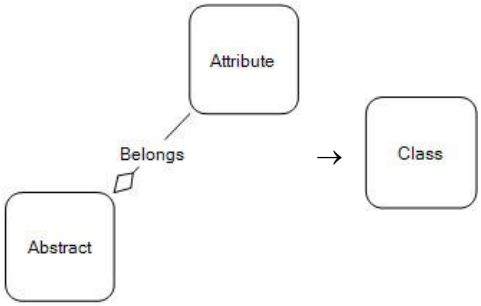


Fig. 4. Metamodel of UML Class Diagrams

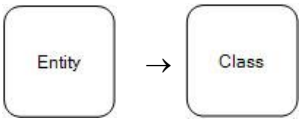
The rule "Abstract-Class" allows to convert the instances of entities "Entity" and "Relationship", which are connected at least with one instance of entity "Attribute", to the instance of entity "Class".

This rule has the following appearance:



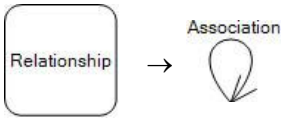
The rule “Entity-Class” allows to convert the instance of entity “Entity”, which is not associated with any instance of the entity “Attribute”, to the instance of an entity “Class”.

The rule has the following form:

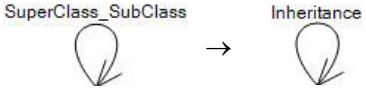


The rule “Relationship-Association” converts instances of the entity “Relationship” of the source model to instances of the relationship “Association” of the target model.

This rule looks like:



The rule “Inheritance” puts in correspondence to each instance of the relationship “SuperClass_SubClass” of source model a particular instance of the relationship “Inheritance” of target model. This rule has the following form:



After definition of all rules, which are included in the transformation, it is possible to execute conversion on a specific model. Let’s perform this transformation on the considered earlier model “University” (see Fig. 3). The result of the transformation execution is presented in Fig. 5.

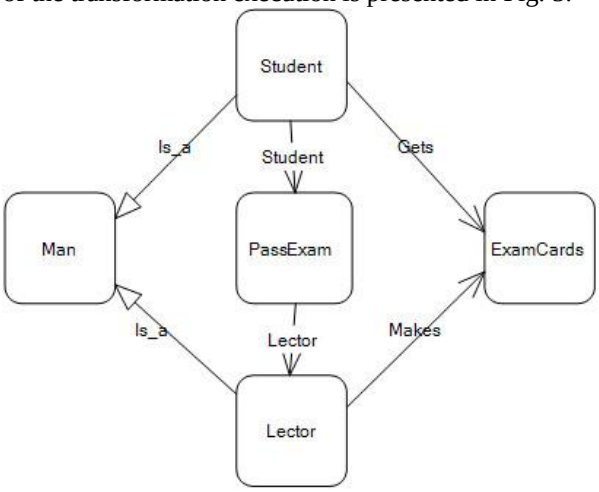


Fig. 5. Simplified model “University” in the Class Diagrams notation, generated by MetaLanguage system

Vertical transformation is a conversion of model, described at one level of hierarchy, to model presented at other level. Transformation of model allocated at higher level of hierarchy to model of subordinate level corresponds to operation of creation of model allocated at subordinate level. Inverse transformation allows to make interpretation of subordinate level model, to define types of its elements, to fulfil various operations over this model.

This mapping allows to support metamodels and created on their basis models in a consistent state. At metamodel modification the MetaLanguage system automatically makes all necessary changes in appropriate models.

Let’s consider the process of vertical models transformations in more details.

If the model “University” is loaded in the MetaLanguage system as a metamodel, it will play the role of the domain-specific language and the models can be created on its basis. Let’s construct on the basis of the domain-specific metamodel “University” the model “Exam”. This model contains the following elements (see Fig. 6):

- “Test”, “Essay” are instances of the entity “ExamCards”;
- “Full-time student”, “Extramural student” are instances of the entity “Student”;
- “Professor”, “Senior lecturer” are instances of the entity “Lecturer”;
- “Name” is instance of the entity “Name”;
- “Writes”, “Solves” are instances of the relationship “Gets”;
- “Checks”, “Prepares” are instances of the relationship “Makes”.

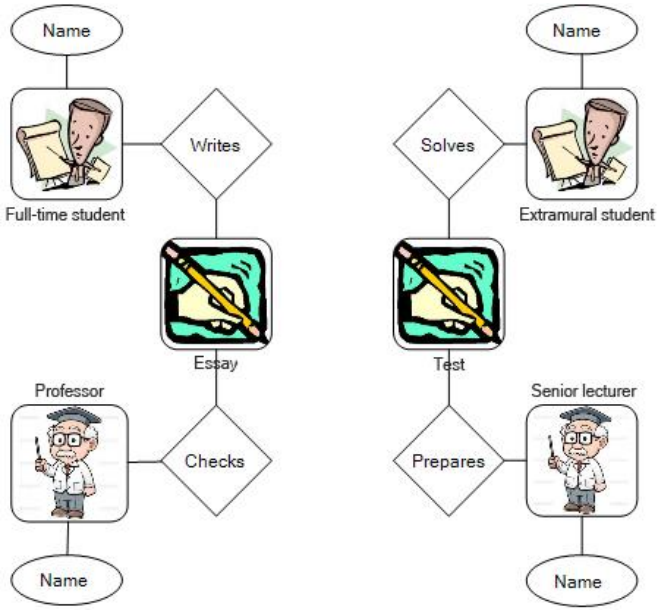


Fig. 6. Simplified model “Exam”

Thus, at creation of metamodel “ERD” the mapping of metalanguage constructions in metamodel entities and relationships is fulfilled. So the metalanguage construction “Entity” is mapped in the entities “Abstract”, “Attribute”, “Entity”, “Relationship”.

Then at construction of the domain-specific metamodel “University” the elements of metamodel “ERD” are mapped in instances of entities and relationships of the metamodel “University”. For example, on the basis of entity “Attribute” its instances “Direction”, “Duration”, “Name”, “Post”, “Task” are built.

At the creation of model “Exam” the entities and relationships of the domain-specific metamodel “University” are mapped in elements of the model “Exam”. So on the basis of entity “Lecturer” the elements “Professor”, “Senior lecturer” are created.

At the stage of models validation and transformation the MetaLanguage system fulfills interpretation of models elements at various hierarchy levels. So at transformation of the domain-specific metamodel "University" in the SQL-query the language workbench should determine with what entities and relationships the elements of metamodel "University" are created, since transformation rules are described at level of metamodels. For example, at fulfillment of the previously described transformation "model-text" the MetaLanguage system will determine that elements "Man", "Student", "Lecturer", "ExamCards" are instances of the entity "Entity" and will apply to them the transformation rule "Entity".

V. Conclusion

Models transformations are a central part of the model-based approach to system development, because an existence in one system of models, which are fulfilled from the different points of view, with a different level of details and with use of different modeling languages, requires of existence of model transformation tools, which allow to convert models both between various levels of hierarchy, and within one level (at transition from one modeling language to another).

The presented approach has been implemented in a transformer of MetaLanguage system. This component allows to convert models described on visual domain-specific languages to text or other graphical models. The component has a convenient and simple user interface, therefore not only professional developers, but also domain specialists, for example business analysts, can work with it.

With the usage of this approach some languages and models have been developed. As example, the domain specific languages for the queuing system simulation have been designed and rules for transformation of visual simulation models into code in GPSS language have been described [26]. Generated model has been used for simulation running.

References

[1] A. Kleppe, J. Warmer, W. Bast, *MDA explained. The model-driven architecture: practice and promise*. Reading: Addison-Wesley, 2003, 170 p.

[2] S. Sendall, W. Kozaczynski, "Model transformation: the heart and soul of model-driven software development", *IEEE Software*, vol. 20, pp. 42–45, 2003.

[3] A. O. Sukhov, "The language workbench for visual domain-specific modeling languages creation", *Fundamental Researches*, vol. 4, pp. 848-852, 2013.

[4] E. Grabska, B. Strug, "Applying cooperating distributed graph grammars in computer aided design", *Parallel Processing and Applied Mathematics*, vol. 3911/2006, pp. 567–574, 2006.

[5] T. Mens, K. Czarnecki, P. V. Gorp, "A taxonomy of model transformations", *Electronic Notes in Theoretical Computer Science*, vol. 152, pp. 125–142, 2006.

[6] U. Montanari, F. Rossi, "Graph rewriting, constraint solving and tiles for coordinating distributed systems", *Applied Categorical Structures*, pp. 333–370, 1999.

[7] B. Konig, "Analysis and verification of systems with dynamically evolving structure", habilitation thesis [Online]. Available: http://jordan.inf.uni-due.de/publications/koenig/habilschrift.pdf.

[8] J. Rekers, A. Schuerr "A graph grammar approach to graphical parsing", in *Proc. of the 11th IEEE International Symposium*, Washington, 1995, pp. 195–202.

[9] H. Ehrig, K. Ehrig, U. Prange, G. Taentzer, *Fundamentals of algebraic graph transformation*. New York: Springer-Verlag, 2006, 388 p.

[10] A. Corradini, U. Montanari, F. Rossi, H. Ehrig, R. Heckel, M. Loewe, "Algebraic approaches to graph transformation. Part I: basic concepts and double pushout approach", *Handbook of Graph Grammars and Computing by Graph transformation*, vol. 1, pp. 163–246, 1997.

[11] H. Ehrig, R. Heckel, M. Korff, M. Loewe, L. Ribeiro, A. Wagner, A. Corradini, "Algebraic approaches to graph transformation. Part II: single pushout approach and comparison with double pushout approach", *Handbook of Graph Grammars and Computing by Graph Transformation*, vol. 1, pp. 247–312, 1997.

[12] A. Agrawal, G. Karsai, S. Neema, F. Shi, A. Vizhanyo, "The design of a language for model transformations", *Journal on Software and Systems Modeling*, vol. 5, pp. 261–288, 2006.

[13] D. Balasubramanian, A. Narayanan, C. P. Buskirk, G. Karsai, "The graph rewriting and transformation language: GReAT", *Electronic Communications of the EASST*, vol. 1, pp. 1–8, 2006.

[14] T. Gardner, C. Griffin, J. Koehler, R. Hauser, "A review of OMG MOF 2.0 Query/Views/Transformations submissions and recommendations towards the final standard", in *Proc. of the 1st International Workshop on Metamodeling for MDA*, York, 2003, pp. 1–20.

[15] P. Stevens, "Bidirectional model transformations in QVT: semantic issues and open questions", *Model Driven Engineering Languages and Systems*, vol. 4735/2007, pp. 1–15, 2007.

[16] G. Csertan, G. Huszerl, I. Majzik, Z. Pap, A. Pataricza, D. Varro, "VIATRA – visual automated transformations for formal verification and validation of UML models", in *Proc. of the 17th IEEE International Conference on Automated Software Engineering*, Washington, 2002, pp. 267–270.

[17] A. Balogh, D. Varro, "Advanced model transformation language constructs in the VIATRA2 framework", in *Proc. of the ACM Symposium on Applied Computing*, New York, 2006, pp. 1280–1287.

[18] V. Chiprianov, Y. Kermarrec, P. D. Alff, "An approach for constructing a domain definition metamodel with ATL", in *Proc. of the 1st International Workshop on Model Transformation with ATL*, Nantes, 2009, pp. 18–33.

[19] F. Jouault, F. Allilaire, J. Bezivin, I. Kurtev, "ATL: a model transformation tool", *Science of Computer Programming*, vol. 72, pp. 31–39, 2008.

[20] D. Varro, Z. Balogh, "Automating model transformation by example using inductive logic programming", in *Proc. of the ACM Symposium on Applied Computing*, New York, 2007, pp. 978–984.

[21] M. Wimmer, M. Strommer, H. Kargl, G. Kramler, "Towards model transformation generation by-example", in *Proc. of the 40th Annual Hawaii International Conference on System Sciences*, Washington, 2007, pp. 1–10.

[22] J. R. Ullmann, "An algorithm for subgraph isomorphism", *Journal of the Association for Computing Machinery*, no. 23, pp. 31–42, 1976.

[23] D. Schmidt, L. Druffel, "A fast backtracking algorithm to test directed graphs for isomorphism using distance matrices", *Journal of the Association for Computing Machinery*, no. 23, pp. 433–445, 1976.

[24] L. P. Cordella, P. Foggia, C. Sansone, M. Vento, "An improved algorithm for matching large graphs", in *Proc. of the 3rd Workshop on Graphbased Representations in Pattern Recognition*, Ischia, 2001, pp. 149–159.

[25] B. D. McKay, "Practical graph isomorphism", *Congressus Numerantium*, vol. 30, pp. 45–87, 1981.

[26] E. B. Zamyatina, L. N. Lyadova, A. O. Sukhov, "An approach to integration of modeling systems and information systems on the basis of DSM-platform MetaLanguage", in *Proc. of the 4th International Conference Information Systems Development Technologies*, Gelendzhik, 2013, pp. 61–70.