

# An Approach for Validating Semantic Consistency of Model Transformation Based on Pattern

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**Abstract.** The correctness of model transformation is an important research field in model-driven architecture. Syntactic correctness and semantic consistency are hot topics in the field of model transformation. Syntactic correctness has many mature solutions. However the validation of semantic consistency has some problems. Therefore, how to validate semantic consistency of model transformation is a major problem in model-driven development. In this paper, we propose a validation approach for semantic consistency of model transformation, which is based on pattern. We analyze some patterns in models and make these patterns as transformation pattern. We define transformation rule with transformation pattern and analyze three parts of semantic transformation. We present two theorems to validate semantic consistency of model transformation. Finally, we give a case to illustrate the effectiveness of our approach.

**Keywords:** Model transformation, Transformation rule, Transformation pattern

## 1 Introduction

The correctness of model transformation is an important research field in model-driven architecture (MDA) [1-2]. The research mainly focuses on syntactic correctness and semantic consistency [3]. Syntactic correctness has some mature solutions [4], e.g. planning algorithm [5]. However the validation of semantic consistency has some problems, e.g. effective theory. Therefore, how to validate semantic consistency of model transformation is a major problem in model-driven development of software systems.

Model transformation consists of transformation rules which describe how a set of elements of the source model are transformed into a set of elements of the target model through transformation relationships [6]. Semantic consistency of model transformation is for maintaining consistency between source model and target model in the semantics. So, the validation problem for semantic consistency of model transformation is equivalent to the formalization proof of semantic consistency in the process of model transformation.

Many methods to solve semantic consistency of model transformation have emerged from industrial and academic research. Varró [7] defined and validated the model constraints to preserve semantic consistency of model transformation. Jinkui Hou [8] proposed a semantic description framework, and promoted category theory to describe and validate semantics of model transformation. Caplat [9] extended formal language to describe and validate model semantics. Engles [10] provided the relationships of semantic objects of UML-RT to describe the consistency required among models, and proved these relationships through static analysis. XiaoHe [11] extended QVT Relations with three new concepts and discussed the semantics of the mapping pattern and creating model.

Different model transformation methods may need different methods to preserve semantic consistency of model transformation. The paper proposes a validation approach for semantic consistency of model transformation based on pattern. We make some patterns, e.g. sequence pattern, branching pattern and loop pattern, in models as transformation patterns and use these transformation patterns to define transformation rule. There are three parts of the validation process of semantic consistency: (1) the semantic mapping from source model to source transformation pattern; (2) the semantic mapping from source transformation pattern to target transformation pattern; (3) the semantic mapping from target transformation pattern to target model. Then, the validation problem for semantic consistency of model transformation is equivalent to the problem about the three semantic mappings.

The rest of this paper is structured as follows. In Sect. 2, we propose the motivating example which will be used throughout the paper. Section 3 provides the core concepts. Section 4 presents the validation theory of semantic consistency of model transformation. Section 5 illustrates the validation theory. Sect. 6 concludes the paper and further work.

## 2 Motivation Example

There are some basic patterns in models, e.g. sequence pattern, branching pattern, and loop pattern, which belong to business process model. The three patterns are shown in Fig.1 (a). We use the model transformation from UML Activity Diagram Model (UADM) to Java Business Process Model (JBPM) to describe how to preserve model semantics during model transformation. The UADM and JBPM are shown in Fig.1(b). The UADM describes a business process of submitting sale order. The process is: firstly query sale data, secondly fill these data into a sale order, thirdly audit the sale order, and finally submit the sale order. The activity about auditing the sale order has a judging condition, i.e. if the sale data is less than 1000, the sale order should be submitted directly. Otherwise the manager should audit the sale order. If the manager agrees the sale order, he submits the sale order. Otherwise the sale data will be queried again.

The UADM contains these three patterns above. For example, the operations of querying sale data and filling the sale order correspond to the sequence pattern; the operation of checking the sale data corresponds to the branching pattern; the operation

of auditing the sale order corresponds to the loop pattern, and the auditing loop pattern contains the sequence pattern.

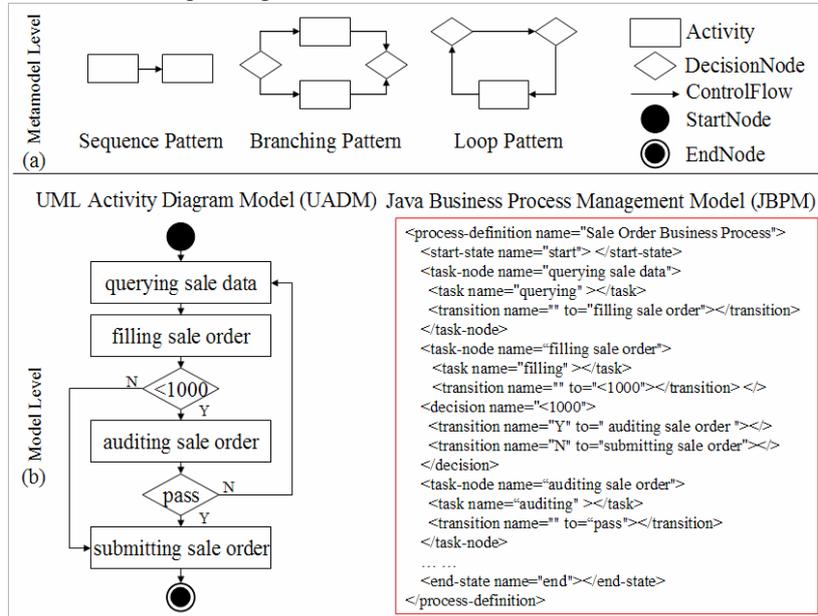


Fig. 1. Motivation example

The approaches of model transformation define transformation rules with the patterns. A pattern is either basic pattern or user-defined pattern. The user-defined pattern is generally defined according to domain business requirements. The patterns are called transformation patterns in transformation rules. These transformation patterns can simplify transformation definition, raise transformation efficiency, and improve transformation quality.

### 3 Transformation Pattern and Transformation Rule

Transformation rule, which is defined in model transformation based on pattern, contains two patterns: left pattern and right pattern. The two patterns also consist of some basic patterns and user-defined patterns. These basic patterns and user-defined patterns are called transformation pattern in the paper. Transformation patterns must be formed in pairs transformation rule, namely if left pattern contains a transformation pattern  $TP_s$ , right pattern should contain another transformation pattern  $TP_t$ . The semantics of  $TP_s$  and  $TP_t$  must be equivalence. The metamodel of transformation rule is shown in Fig.2.

The class *TransformationRule* consists of *LeftPattern*, *RightPattern* and *Constraint*. *LeftPattern* and *RightPattern* are composed of *Element* and *TransformationPattern*. *Element* has three subclasses, and they are *TransformationPattern*, *NodeElement*, and *RelationElement*. *TransformationPattern* is composed of *NodeElement*,

*RelationElement*, and *Constraint*. *Constraint* has two subclasses: *interConstraint* and *exterConstraint*. *interConstraint* describes the internal relationships of *LeftPattern* and *RightPattern*, and *exterConstraint* describes the external relationships of *LeftPattern* and *RightPattern*. *interConstraint* can be described by OCL, while *exterConstraint* is described according to the constraint relationships of *NodeElement*, *RelationElement* and *TransformationPattern*. We focus on the semantic information of *exterConstraint* in the paper. We firstly analyze the external relationships of transformation pattern, which are illustrated in Fig. 3.

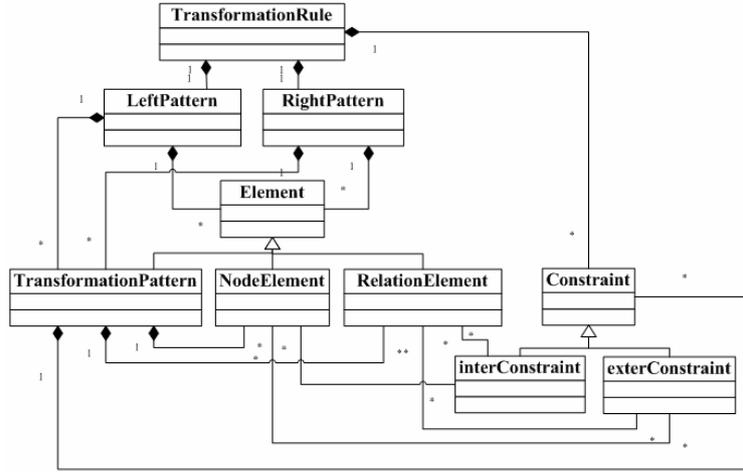


Fig. 2. Metamodel of transformation rule

In Fig. 3, there are two kinds of constraint relationships: Element-Pattern and Pattern-Pattern. In the first constraint relationship, there is a relationship  $r_1$  between the element  $n_1$  and the transformation pattern  $TP_1$ . The end element of  $r_1$  is one of elements of  $TP_1$ . Because  $TP_1$  contains two elements ( $n_2$  and  $n_3$ ), there are three conditions of the mapping between  $n_1$  and  $TP_1$ : (1) from  $n_1$  to  $n_2$ ; (2) from  $n_1$  to  $n_3$ ; (3) from  $n_1$  to  $n_2$  and  $n_3$ . There needs an external constraint relationship to accurately describe the mapping condition between  $n_1$  and  $TP_1$ . In the second constraint relationship, the identifier  $r_2$  is a relationship between the transformation patterns  $TP_1$  and  $TP_2$ . Because the start element of  $r_2$  comes from  $TP_3$  and the end element of  $r_2$  comes from  $TP_2$ , we divide the constraint relationship (Pattern-Pattern) into two constraint relationships (Element-Pattern): the relationship between  $r_2$  and  $TP_2$ , and the relationship between  $r_2$  and  $TP_3$ . The two relationships are similar to the relationship between  $r_1$  and  $TP_1$ .

We firstly propose the model definition, the definition of transformation pattern with the external constraint relationship, and the definition of transformation rule.

**Definition 3.1 (Model):** A model is defined as

$$M = \langle E, L, rel, meta \rangle \quad (1)$$

Where

- $E = \{e_1, e_2, \dots, e_s\}$  denotes a finite set of model elements,

- $L=\{l_1, l_2, \dots, l_t\}$  denotes a finite set of the relationships among model elements,
- $rel(l_k)=[e_i, e_j]$  denotes a relational function between model elements, and describes that  $e_i$  is a start element of  $l_k$  and  $e_j$  is an end element of  $l_k$ ,  $e_i, e_j \in E$ ,  $1 \leq i, j \leq s$ ,  $l_k \in L$ ,  $1 \leq k \leq t$ ,
- $meta(e_u)$  denotes an instance function, and it describes the metamodel of  $e_u$ ,  $1 \leq u \leq s$ .

Note that we use " " to describe the element of model, e.g.  $M.E$  describes the element set of  $M$ , and  $M.L$  denotes the relationship set of  $M$ .

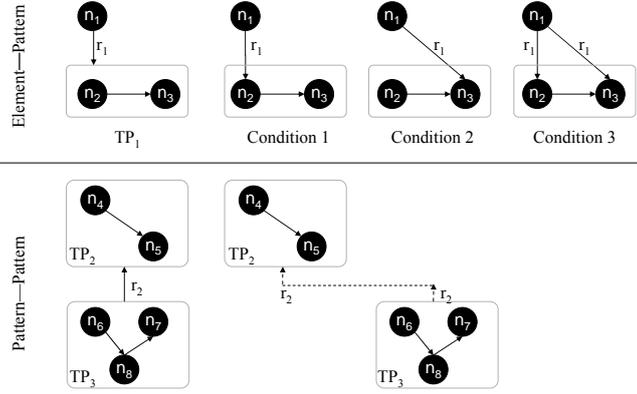


Fig. 3. The external relationship of transformation pattern

**Definition 3.2 (Transformation Pattern):** A transformation pattern is defined as

$$TP = \langle N, R, rel, interC, exterC \rangle \quad (2)$$

Where

- $N = \{n_1, n_2, \dots, n_p\}$  denotes a finite set of nodes, and its instance element set is  $M.E$ ;
- $R = \{r_1, r_2, \dots, r_q\}$  denotes a finite set of relationships, and its instance element set is  $M.L$ ;
- $rel(r_k) = [n_i, n_j]$  denotes an element-relationship function, and describes that  $n_i$  is a start element of  $r_k$  and  $n_j$  is an end element of  $r_k$ ,  $n_i, n_j \in N$ ,  $1 \leq i, j \leq p$ ,  $r_k \in R$ ,  $1 \leq k \leq q$ ,
- $interC = \{iC_1, iC_2, \dots, iC_m\}$  denotes a finite set of the internal constraint relationships;
- $exterC = \{eC_1, eC_2, \dots, eC_n\}$  denotes a finite set of the external constraint relationships,  $eC_x = \langle r, TP, \{n_x, n_{x+1}, \dots, n_l\} \rangle$  denotes the constraint relationship between  $r$  and  $TP$ ,  $r \notin R$ ,  $1 \leq x, l \leq p$ . Every element  $n_k$  is either a start element or an end element of  $r$ ,  $n_k \in N$ ,  $1 \leq k \leq p$ .

In Fig. 3, the three mapping condition of the constraint relationship between  $n_1$  and  $TP_1$  can be defined as the following:

$$eC_1 = \langle r, TP, \{n_2\} \rangle, eC_2 = \langle r, TP, \{n_3\} \rangle, eC_3 = \langle r, TP, \{n_2, n_3\} \rangle.$$

When a transformation rule contains an element, we make the element as a transformation pattern. Therefore, the left and right pattern of transformation rule can contain one or more transformation patterns.

**Definition 3.3 (Transformation Rule):** A transformation rule is defined as

$$TR = \langle LP, RP, C \rangle \quad (3)$$

Where

- $LP = \{tp_{s1}, tp_{s2}, \dots, tp_{su}\}$  denotes left pattern, and it contains a finite set of source transformation patterns,
- $RP = \{tp_{t1}, tp_{t2}, \dots, tp_{tv}\}$  denotes right pattern, and it contains a finite set of target transformation patterns;
- $C$  denotes constraint relationship of  $LP$  and  $RP$ .

The left and right pattern are formed pairs in transformation rule, i.e. if left pattern contain the transformation pattern  $tp_{si}$ , right pattern should contain another transformation pattern  $tp_{tj}$ . The semantics  $tp_{si}$ , is similar to the semantics of  $tp_{tj}$ ,  $1 \leq i \leq u$ ,  $1 \leq j \leq v$ .

## 4 The Validating of Semantic Consistency of Model Transformation

The goal of preserving semantic consistency of model transformation is that the semantics of source and target model is equivalence. During a process of model transformation based on pattern, the semantic transformation process from source model to target model is an implementation process of transformation rules. The processes contain three parts of model semantic mappings: the semantic mapping from left pattern to source model, the semantic mapping from left pattern to right pattern, and the semantic mapping from right pattern to target model. Because the left and right patterns have the equivalent semantics, the problem of preserving model semantic consistency is similar to two the semantic mapping problem: the mapping from left pattern to source model, and the mapping from right pattern to target model. We will propose the theorems to solve the problem.

### 4.1 Semantic Mapping from source transformation pattern to source model

According to the definition 3.3, the left pattern of transformation rule is a set of source transformation patterns. Every element of source transformation pattern is either automatic element or another transformation pattern. So we describe the semantic mapping from left pattern to source model according to two mapping conditions. The identifiers  $M$  and  $TP$  denote a model and a transformation. If the semantics of  $M$  and  $TP$  is equivalence, we called the equivalence relationship as  $TP \cong M$ . We provide a theorem to validate the semantic consistency of the mapping between transformation pattern and model.

**Theorem 4.1** Let  $M$  be a Model, the node set of  $M$  is  $M.E = \{e_1, e_2, \dots, e_s\}$ ,  $TP$  is a transformation pattern, the node set of  $TP$  is  $TP.N = \{n_1, n_2, \dots, n_p\}$ .  $TP \cong M$  if and only if Satisfying the following three conditions:

- (1) every node  $n_i \in TP.N$ , then  $n_i \in \cup \text{meta}(M.E)$ ;
- (2) every relationship  $r_j \in TP.R$ , then  $r_j \in \cup \text{meta}(M.L)$ ;
- (3) every external constraint relationship  $eC \in TP.\text{exter}C$  preserves the semantics.

**Proof.**

- (1) Every node of transformation pattern is a certain metamodel element of model element.  $n_i$  is an element of  $TP$ ,  $1 \leq i \leq p$ ,
  - <i> if  $n_i$  is an automatic element, there exists a node  $e_k \in M.E$  which satisfies  $n_i = \text{meta}(e_k)$ . So  $n_i \in \cup \text{meta}(M.E)$ ; ①
  - <ii> if  $n_i$  is a transformation pattern, it should semantic map with a submodel  $M_i'$  of  $M$ . The node set of  $M_i'$  is a sub set of  $M$  nodes, i.e.  $M_i'.E \subseteq M.E$ . Every element  $n_l$  of  $n_i$ , there exists a node  $e_o \in M_i'.E$  and it satisfies  $n_l = \text{meta}(e_o)$ . So  $n_i \in \cup \text{meta}(M.E)$ ; ②
- (2) Every relationship of transformation pattern is a certain metamodel relationship of model element.  $r_j$  is a relationship of  $TP$ ,  $1 \leq j \leq q$ . According to the definition 3.2,  $\text{rel}(r_j) = [n_{j1}, n_{j2}]$ ,  $n_{j1}$  and  $n_{j2}$  are the elements of  $TP$ , i.e.  $n_{j1}, n_{j2} \in TP.N$ . And according to ①②, because  $n_{j1}, n_{j2} \in \cup \text{meta}(M.E)$ , there exists two elements  $e_u, e_v \in M.E$ . They satisfy  $n_{j1} = \text{meta}(e_u)$  and  $n_{j2} = \text{meta}(e_v)$ . To the relationship  $l_w$  between  $e_u$  and  $e_v$ , there exists  $\text{rel}(l_w) = [e_u, e_v]$ . So  $r_j \in \cup \text{meta}(M.L)$ ; ③
- (3) The constraint relationship of transformation pattern satisfies semantic consistency. There are two parts of the constraint relationship: the internal constraint relationship and the external constraint relationship. Preserving the internal constraint relationship can be validated by OCL, while preserving the external constraint relationship is validated according to the definition of the external constraint relationship. There is an external relationship  $r$  between the element  $n_i$  and the transformation patten  $TP$ :
  - <i> if  $n_i$  is an automatic element, there exists an instance element  $l_k (l_k \in M.L)$  of  $r$  and  $\text{rel}(l_k) = [e_i, e_j]$  ( $e_i, e_j \in M.E$ ). According to ①②,  $n_i$  satisfies either  $n_i = \text{meta}(e_i)$  or  $n_i = \text{meta}(e_j)$ , then the external constraint relationship  $eC = \langle r, TP, \{n_i\} \rangle$  preserves the semantics of  $r$  and  $TP$ ; ④
  - <ii> if  $n_i$  is a transformation pattern  $TP_i$ , according to ②, there exists a sub model  $M_j'$  of  $M$ , and  $n_i \cong M_j'$ , then a certain element  $n_k$  of  $TP_i$  may be the start or end element of  $r$ ,  $n_k \in TP_i.N$ . According to ④, the external constraint relationship  $eC = \langle r, TP_i, \{n_k\} \rangle$  preserves the semantics of  $r$  and  $TP$ . ⑤

## 4.2 Semantic Mapping from target transformation pattern to target model

In the session, we will propose the construction process from target transformation pattern to target model, and provide a theorem to validate whether the process preserve the semantics.

$TP_s$  and  $TP_t$  are the source and target transformation patterns, and their corresponding mapping models are  $M_s$  and  $M_t$ . The construction process from  $TP_t$  to  $M_t$  is the following:

- (1) Constructing element.  $n_i$  is an element of  $TP_t$ ,  $n_i \in TP_t.N$ ,
  - <i> if  $n_i$  is an automatic element, according to the instance relationship of the metamodel and model, constructing a new model element  $e_i$  and make  $n_i = meta(e_i)$ ; ⑥
  - <ii> if  $n_i$  is a transformation pattern, according to the corresponding element  $n_s$  of  $TP_s$ :
    - a) if  $n_s$  is an automatic element, constructing a new element  $e_i$ , and make  $n_i = meta(e_i)$ ; ⑦
    - b) if  $n_s$  is a transformation pattern, constructing a sub model  $M_i'$ , and make  $n_i.N = meta(M_i'.E)$ ; ⑧
- (2) Constructing relationship.  $r_k$  is a relationship of  $TP_t$ ,  $r_k \in TP_t.R$ . There exists two elements ( $n_i, n_j$ ) and they satisfy  $rel(r_k) = [n_i, n_j]$ ,  $n_i, n_j \in TP_t.N$ ,
  - <i> if  $n_i$  and  $n_j$  are two automatic elements, according to ①, their instance elements ( $e_{ii}, e_{ij}$ ) are the automatic elements of  $M_t$ .  $n_i$  and  $n_j$  satisfy  $n_i = meta(e_{ii})$  and  $n_j = meta(e_{ij})$ . Then, constructing a relationship  $l_k$  from  $e_{ii}$  to  $e_{ij}$ , and make  $rel(l_k) = [e_{ii}, e_{ij}]$ ,  $l_k \in M_t.L$ ; ⑨
  - <ii> if  $n_i$  is a transformation pattern and  $n_j$  is an automatic element. According to ②,  $n_i$  corresponds to a sub model  $M_{ii}'$  of  $M_t$ ,  $M_{ii}'.E = \{e_{ii1}, e_{ii2}, \dots, e_{iim}\}$ . If there exists an external constraint relationship  $eC = \langle r, n_i, \{e_{ij}\} \rangle$ , the model element  $e_{ik}$  will be found in  $M_{ii}'.E$ . Then constructing a relationship  $l_k$  from  $e_{ik}$  to  $e_{ij}$ , and make  $rel(l_k) = [e_{ik}, e_{ij}]$ . In the same way, if  $n_i$  is an automatic element and  $n_j$  is a transformation pattern, there exists  $M_{ij}'.E = \{e_{ij1}, e_{ij2}, \dots, e_{ijn}\}$ . According to the external constraints relationship  $eC = \langle r, n_j, \{n_i\} \rangle$ , there exists an element  $e_{ik}'$  in  $M_{ij}'.E$ , constructing a relationship  $l_k'$  from  $e_{ii}$  to  $e_{ik}'$ , make  $rel(l_k') = [e_{ii}, e_{ik}']$ ; ⑩
  - <iii> if  $n_i$  and  $n_j$  are two transformation patterns, according to ②,  $n_i$  and  $n_j$  are corresponds to the sub model  $M_{ii}'$  and  $M_{ij}'$ , and these sub models satisfy  $M_{ii}'.E = \{e_{ii1}, e_{ii2}, \dots, e_{iim}\}$  and  $M_{ij}'.E = \{e_{ij1}, e_{ij2}, \dots, e_{ijn}\}$ . According to the external relationships  $eC_1 = \langle r, n_i, \{e_{ij1}, e_{ij2}, \dots, e_{ijn}\} \rangle$  and  $eC_2 = \langle r, n_j, \{e_{ii1}, e_{ii2}, \dots, e_{iim}\} \rangle$ , if there exists two elements  $e_{ik}$  and  $e_{ik}'$  in  $M_{ii}'.E$  and  $M_{ij}'.E$ , constructing a relationship  $l_k$  from  $e_{ik}$  to  $e_{ik}'$ , and make  $rel(l_k) = [e_{ik}, e_{ik}']$ . ⑪

**Theorem 4.2.** Let  $TP_s$  and  $TP_t$  be two transformation patterns, if they correspond to the source  $M_s$  and target model  $M_t$ , the semantics of  $M_s$  and  $M_t$  is equivalence.

**Proof.**

There are three parts of the semantic transformation of source model: the semantic mapping from  $M_s$  to  $TP_s$ , the semantic mapping from  $TP_s$  to  $TP_t$ , and the semantic mapping from  $TP_t$  to  $M_t$ . According to definition 3.3, the semantics of  $TP_s$  and  $TP_t$  is equivalence. According to the theorem 4.1, the semantics of  $M_s$  and  $TP_s$  is equivalence. So the preserving semantic problem of  $M_s$  and  $M_t$  is equivalent to the preserving semantic problem of  $TP_t$  and  $M_t$ . Because  $M_t$  is constructed by  $TP_t$ , the preserving semantic problem only validates the semantic equivalence of element and relationship of  $M_t$ . The validation of preserving the semantic equivalence of element and relationship are the following:

- (1) Element equivalence.  $n_i$  is an element of  $TP_t$ ,  $n_i \in TP_t.N$ ,
- <i> if  $n_i$  is an automatic element, according to ⑦, the instance element  $e_i$  of  $n_i$  satisfies  $n_i = \text{meta}(e_i)$ , then  $TP_t.N \cong M_t.E$ ;
- <ii> if  $n_i$  is a transformation pattern, according to ⑧, the instance sub model  $M_t'$  of  $n_i$  satisfies  $n_i.N = \text{meta}(M_t'.E)$ , then  $TP_t.N \cong M_t.E$ ;
- (2) Relationship equivalence.  $r_k$  is a relationship of  $TP_t$ ,  $r_k \in TP_t.R$ . There exists two elements ( $n_i, n_j$ ) and they satisfy  $\text{rel}(r_k) = [n_i, n_j]$ ,  $n_i, n_j \in TP_t.N$ ,
- <i> if  $n_i$  and  $n_j$  are two automatic elements, according to ③⑥, their instance elements are  $e_{i_i}$  and  $e_{j_j}$  which are two elements of  $M_t$ . According to ⑨, there exists the instance relationship  $l_k$  of  $r_k$ , and  $\text{rel}(l_k) = [e_{i_i}, e_{j_j}]$ , So  $TP_t.R \cong M_t.L$ ;
- <ii> if  $n_i$  is a transformation pattern and  $n_j$  is an automatic element. According to ③⑩, there exists an element  $e_{i_k}$  in the instance model  $M_{i_i}'$  of  $n_i$ , and a relationship  $l_k$  from  $e_{i_k}$  to  $e_{j_j}$ . The relationship satisfies  $\text{rel}(l_k) = [e_{i_k}, e_{j_j}]$ , so  $r_k \cong M_{i_i}'$ ;
- In the same way, if  $n_i$  is an automatic element and  $n_j$  is a transformation pattern, there exists a relationship  $l_k'$ , so  $TP_t.R \cong M_t.L$ ;
- <iii> if  $n_i$  and  $n_j$  are two transformation patterns, according to ③⑩, if there exists  $e_{i_k}$  and  $e_{j_k}'$ , the relationship  $l_k$  between  $e_{i_k}$  and  $e_{j_k}'$ , and  $\text{rel}(l_k) = [e_{i_k}, e_{j_k}']$ , so  $TP_t.R \cong M_t.L$ .

## 5 Experiment

We validate the semantic equivalence of UADM and JBPM. There are three parts of the validation process: (1) preserving semantic equivalence of UADM and  $TP_s$ ; (2) preserving semantic equivalence of  $TP_s$  and  $TP_t$ ; (3) preserving semantic equivalence of  $TP_t$  and JBPM. The validation process is the following:

(1) Preserving semantic equivalence of UADM and  $TP_s$

The metamodel of UADM contains *Activity*, *Decision*, *ControlFlow*, *Start* and *End*. There are three basic patterns in UADM: sequence pattern, branching pattern and loop pattern. We firstly define three transformation patterns according to these basic patterns.

(a) A source sequence pattern is composed of *querying sale data*, *filling sale order* and their relationship in UADM. It is defined as  $TP_{SS} = \langle N_{SS}, R_{SS}, \text{rel}_{SS}, \text{inter}C_{SS}, \text{exter}C_{SS} \rangle$ , where  $N_{SS} = \{\text{Activity}, \text{ControlFlow}\}$ ,  $R_{SS} = \{r_1, r_2\}$ ,  $\text{rel}_{SS}(r_1) = [\text{Activity}, \text{ControlFlow}]$ ,  $\text{rel}_{SS}(r_2) = [\text{ControlFlow}, \text{Activity}]$ ,  $\text{exter}C_{SS} = \{eC_1\}$ ,  $eC_1 = \langle r_{s1}, TP_{SS}, \{\text{Activity}\} \rangle$ .

Note that  $r_{s1}$  is an external relationship,  $r_{s1} \notin \text{rel}_{SS}$ .

(b) A source branching pattern is composed of *auditing sale order*, *pass*, and  $TP_{SS}$ . It is defined as  $TP_{SB} = \langle N_{SB}, R_{SB}, \text{rel}_{SB}, \text{inter}C_{SB}, \text{exter}C_{SB} \rangle$ , where  $N_{SB} = \{\text{Activity}, \text{Decision}, \text{ControlFlow}, TP_{SS}\}$ ,  $R_{SB} = \{r_3, r_4, r_5, r_6\}$ ,  $\text{rel}_{SB}(r_3) = [\text{Decision}, \text{ControlFlow}]$ ,  $\text{rel}_{SB}(r_4) = [\text{ControlFlow}, \text{Activity}]$ ,  $\text{rel}_{SB}(r_5) = [\text{Activity}, \text{ControlFlow}]$ ,  $\text{rel}_{SB}(r_6) = [\text{ControlFlow}, \text{Decision}]$ ,  $\text{exter}C_{SB} = \{eC_2\}$ ,  $eC_2 = \langle r_{s2}, TP_{SB}, \{\text{Decision}\} \rangle$

Note that  $r_{s2}$  is an external relationship,  $r_{s2} \notin \text{rel}_{SB}$ .

(c) A source loop pattern is composed of less 1000, *auditing sale order*, *pass*, and  $TP_{SS}$ . It is defined as  $TP_{SL}=\langle N_{SL}, R_{SL}, rel_{SL}, interC_{SL}, exterC_{SL} \rangle$ , where  $N_{SL}=\{Activity, Decision, ControlFlow, TP_{SS}\}$ ,  $R_{SL}=\{r_7, r_8, r_9, r_{s1}\}$ ,  $rel_{SL}(r_7)=[Decision, ControlFlow]$ ,  $rel_{SL}(r_8)=[ControlFlow, TP_{SS}]$ ,  $rel_{SL}(r_{s1})=[TP_{SS}, ControlFlow]$ ,  $rel_{SL}(r_9)=[ControlFlow, Decision]$ ,  $exterC_{SL}=\{eC_3\}$ ,  $eC_3=\langle r_6, TP_{SL}, \{Activity\} \rangle$ .

According to the theorem 4.1, we validate the semantic equivalence of source transformation patterns and UADM. The instance model of  $TP_{SS}$  contains the elements *querying sale data* and *filling sale order*. When the auditing order is error, the sale data should be queried again. So there is a relationship between  $TP_{SS}$  and  $r_{s1}$ .  $TP_{SS}$  contains an external relationship  $eC_1=\langle r_{s1}, TP_{SS}, \{Activity\} \rangle$  to describe the relationship. When the auditing order is ok, there exists a relationship between  $TP_{SL}$  and  $TP_{SB}$ . Then there is a relationship  $r_6$  between  $TP_{SL}$  and  $TP_{SB}$ .  $TP_{SL}$  contains an external relationship  $eC_3=\langle r_6, TP_{SL}, \{Activity\} \rangle$  to describe the relationship. So the transformation patterns ( $TP_{SS}, TP_{SB}, TP_{SL}$ ) preserve the semantic equivalence of  $M_s$ .

(2) Preserving semantic equivalence of  $TP_s$  and  $TP_t$

We firstly define three target transformation patterns. JBPM contains *TaskNode*, *DecisionNode*, and *Transition*.

(d) Target sequence pattern contain two *TaskNodes* and a *Transition*. Target sequence pattern  $TP_{TS}=\langle N_{TS}, R_{TS}, rel_{TS}, interC_{TS}, exterC_{TS} \rangle$ , where  $N_{TS}=\{TaskNode, Transition\}$ ,  $R_{TS}=\{r_{10}, r_{11}\}$ ,  $rel_{TS}(r_{10})=[TaskNode, Transition]$ ,  $rel_{TS}(r_{11})=[Transition, TaskNode]$ ,  $exterC_{TS}=\{eC_4\}$ ,  $eC_4=\langle r_{11}, TP_{TS}, \{TaskNode\} \rangle$

(e) Target branching pattern contain a *TaskNode*, a *DecisionNode*, a *Transition* and a  $TP_{TS}$ . It is defined as  $TP_{TB}=\langle N_{TB}, R_{TB}, rel_{TB}, interC_{TB}, exterC_{TB} \rangle$ , where  $N_{TB}=\{TaskNode, DecisionNode, Transition, TP_{TS}\}$ ,  $R_{TB}=\{r_{12}, r_{13}, r_{14}, r_{11}\}$ ,  $rel_{TB}(r_{12})=[DecisionNode, Transition]$ ,  $rel_{TB}(r_{13})=[TaskNode, Transition]$ ,  $rel_{TB}(r_{14})=[TaskNode, DecisionNode]$ ,  $rel_{TB}(r_{11})=[DecisionNode, TP_{TS}]$ ,  $exterC_{TB}=\{eC_5\}$ ,  $eC_5=\langle r_{12}, TP_{TS}, \{TaskNode\} \rangle$

(f) Target loop pattern contain two *DecisionNodes*, a  $TP_{TS}$ , and a *TaskNode*. It is defined as  $TP_{TL}=\langle N_{TL}, R_{TL}, rel_{TL}, interC_{TL}, exterC_{TL} \rangle$ , where  $N_{TL}=\{TaskNode, DecisionNode, Transition, TP_{TS}\}$ ,  $R_{TL}=\{r_{15}, r_{16}, r_{17}, r_{18}, r_{11}\}$ ,  $rel_{TL}(r_{15})=[DecisionNode, TP_{TS}]$ ,  $rel_{TL}(r_{16})=[TP_{TS}, TaskNode]$ ,  $rel_{TL}(r_{17})=[DecisionNode, TaskNode]$ ,  $rel_{TL}(r_{18})=[TaskNode, DecisionNode]$ ,  $exterC_{TL}=\{eC_6\}$ ,  $eC_6=\langle r_{13}, TP_{TL}, \{TaskNode\} \rangle$

The semantics of  $TP_s$  and  $TP_t$  is equivalence. This is not the focus of this paper, and therefore, we will not describe it here.

(3) Preserving semantic equivalence of  $TP_t$  and JBPM

$M_t$  is constructed by  $TP_t$ . According to the theorem 4.2, the semantics of the constructed elements and relationships is equivalence is equivalent to the semantics of  $M_s$ . So the mapping between  $TP_t$  and  $M_t$  preserves the semantic equivalence.

As noted above, the semantics of UADM to JBPM is equivalence.

## 6 Conclusions and Future Work

In this paper we propose an approach for validating semantic consistency of model transformation. We analyze some basic patterns in models, e.g. sequence pattern, branching pattern, and loop pattern, and use these basic patterns to define

transformation rules. Therefore, the semantic transformation of source model has been divided three parts: (1) the semantic mapping from source transformation pattern to source model; (2) the semantic mapping from source transformation pattern to target transformation pattern; (3) the semantic mapping from target transformation pattern to target model. The validation problem for semantic consistency of model transformation is equivalent to the problem about the three semantic mappings. The motivation example illustrates the effectiveness of our approach.

Future work is to optimize transformation rules constructed through our approach transformation. For this reason, we plan to analyze the typical business patterns in models and compose some transformation rules using these patterns to improve the efficiency of model transformation.

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