

# A Comparison of Rule Inheritance in Model-to-Model Transformation Languages\*

M. Wimmer<sup>1</sup>, G. Kappel<sup>1</sup>, A. Kusel<sup>2</sup>,  
W. Retschitzegger<sup>2</sup>, J. Schönböck<sup>1</sup>, W. Schwinger<sup>2</sup>,  
D. Kolovos<sup>3</sup>, R. Paige<sup>3</sup>, M. Lauder<sup>4</sup>, A. Schürr<sup>4</sup>, and D. Wagelaar<sup>5†</sup>

<sup>1</sup> Vienna University of Technology, Austria

<sup>2</sup> Johannes Kepler University Linz, Austria

<sup>3</sup> University of York, United Kingdom

<sup>4</sup> Darmstadt University of Technology, Germany

<sup>5</sup> AtlanMod (INRIA & École des Mines de Nantes), France

**Abstract.** Although model transformations presumably play a major role in Model-Driven Engineering, reuse mechanisms such as inheritance have received little attention so far. In this paper, we propose a comparison framework for rule inheritance in declarative model-to-model transformation languages, and provide an in-depth evaluation of three prominent representatives thereof, namely ATL, ETL (declarative subsets thereof), and TGGs. The framework provides criteria for comparison along orthogonal dimensions, covering *static aspects*, which indicate whether a set of inheriting transformation rules is well-formed at compile-time, and *dynamic aspects*, which describe how inheriting rules behave at run-time. The application of this framework to dedicated transformation languages shows that, while providing similar syntactical inheritance concepts, they exhibit different dynamic inheritance semantics and offer basic support for checking static inheritance semantics, only.

**Key words:** Rule Inheritance, Model Transformations, Comparison

## 1 Introduction

Model-Driven Engineering (MDE) defines models as first-class artifacts throughout the software lifecycle, which leads to a shift from the “everything is an object” paradigm to the “everything is a model” paradigm [5]. In this context, model transformations are crucial for the success of MDE, being comparable in role and importance to compilers for high-level programming languages. Support for large transformation scenarios is still in its infancy, since reuse mechanisms such as inheritance have received little attention so far [10], although the concept of inheritance plays a major role in metamodels, as revealed, e.g., by the evolution of the UML standard [13]. As inheritance is employed in metamodels to reuse

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feature definitions from previously defined classes, inheritance between transformation rules is indispensable in order to avoid code duplication and consequently maintenance problems. Although this need has been recognized by developers of transformation languages, the design rationales underlying individual transformation languages are not comparable at first sight. This makes it difficult to understand how these constructs are to be used.

Therefore, we propose a comparison framework for rule inheritance in declarative model-to-model transformation languages that makes explicit the hidden design rationales. The proposed framework categorizes the comparison criteria along three orthogonal dimensions analogous to the three primary building blocks of programming languages [2]. The first two dimensions comprise *static criteria*: (i) the *syntax* a transformation language defines with respect to inheritance and (ii) *static semantics*, which indicates whether a set of inheriting transformation rules is well-formed at compile-time. The third dimension of the comparison framework describes how inheriting rules interact at run-time, i.e., *dynamic semantics*. On the basis of this framework, inheritance mechanisms in dedicated transformation languages (ATL [9], ETL [11], TGGs (MOFLON) [10]) are compared. The results show that the inheritance semantics of these languages differ, which has profound consequences for the design of transformation rules.

**Outline.** Section 2 provides the rationale of this work, and Section 3 presents the comparison framework with its three dimensions. In Section 4, we compare the inheritance mechanisms of ATL, ETL and TGGs and present lessons learned. Finally, Section 5 gives an overview on related work, and Section 6 concludes.

## 2 Motivation

When developing a framework for comparing rule inheritance in transformation languages, one starting point is to look at the well-known model transformation pattern (cf. Fig. 1) and to examine where the introduction of inheritance would play a role. Obviously, a transformation language must define syntactic concepts (cf. question 1 in Fig. 1), which leads to the first dimension of our comparison framework, namely *syntax*. In this respect, the following questions are of interest:

- *Which types of inheritance are supported?* Does the transformation language support only single or multiple inheritance?
- *Are abstract rules supported?* Is it possible to specify transformation behavior that is purely inherited?

In addition to syntax, further well-formedness constraints on the transformation rules must hold (cf. question 2 in Fig. 1), which represents the second dimension, namely *static semantics*. Thereby, the following questions may arise:

- *In which way may a subrule modify a superrule?* For instance, how may the types of input and output elements be changed in subrules such that they may be interpreted in a meaningful way?
- *When is a set of inheriting rules defined unambiguously?* Are there sets of rule definitions that do not allow selecting a single rule?

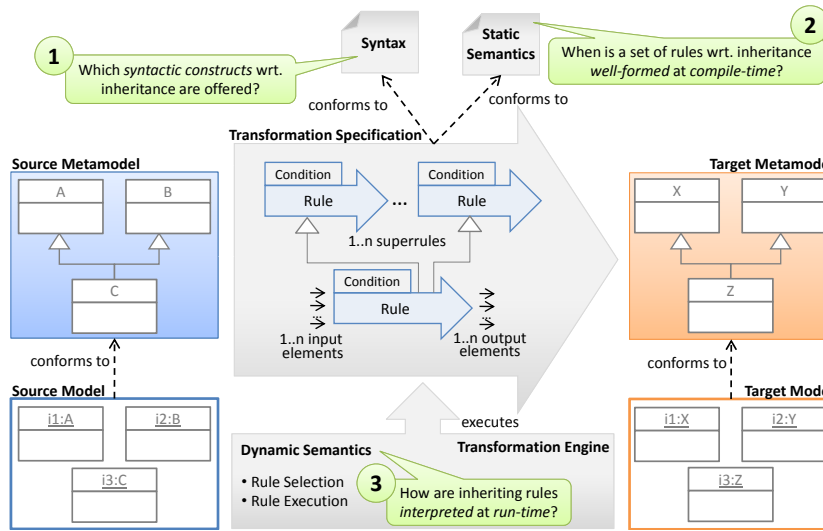


Fig. 1. Model-to-Model Transformation Pattern

A transformation specification is usually compiled into executable code, which is interpreted by a transformation engine that takes a source model and tries to select and execute rules in order to generate a target model. Again several questions concerning the interpretation of inheritance at run-time arise (cf. question 3 in Fig. 1), which leads to the third dimension, namely *dynamic semantics*:

- Which instances are matched by which rule? If a rule is defined for a super-type, are the instances of the subtype also affected by this rule?
- How are inheriting rules executed? Either top down or bottom up in the rule inheritance hierarchy?

### 3 Comparison Framework

This section presents our framework for comparing inheritance support in declarative transformation languages which are used to describe transformations between object-oriented metamodels, conforming to, e.g., Ecore or MOF2. Although metamodeling languages such as MOF2 support refinements between associations, e.g., **subsets** or **redefines**, these are out of scope of this paper. As shown in Fig. 2, the comparison criteria can be divided into the three dimensions of (i) *syntax*, (ii) *static semantics*, and (iii) *dynamic semantics*. These dimensions and the corresponding sub-criteria are described in the following.

#### 3.1 Syntax

This subsection provides criteria for comparing transformation languages in terms of syntactic concepts that they support. We consider both general criteria (e.g., the numbers of input and output elements of a rule) and inheritance-related criteria (e.g., whether single or multiple inheritance is supported).

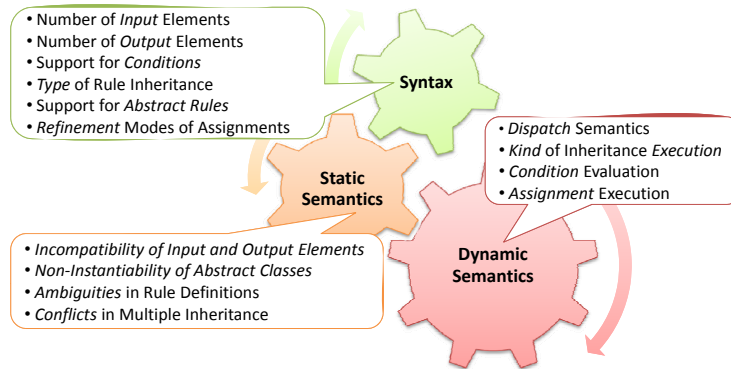


Fig. 2. Overview on the Comparison Framework

To identify the criteria for comparison, we analyzed (i) the features of transformation languages and (ii) the classification of model transformation approaches presented in [7]. The identified features are expressed in a metamodel (MM), shown in Fig. 3 illustrating the core concepts of transformation languages. A **Transformation** typically consists of several **TransformationRules**, including an **InPattern**, referring to **InputElements** of the source MM, and an **OutPattern**, referring to **OutputElements** of the target MM. Please note that programmed graph transformations and TGGs distinguish between (i) rule parameters and (ii) input/output elements, whereby we consider only the latter. A general distinguishing criterion is the *allowed number of input and output elements*. Furthermore, transformation languages typically support the definition of a **Condition**, which may be interpreted in different ways (cf. Section 3.3). Finally, they provide the possibility of setting the values for target features by means of **Assignments**.

In the context of inheritance-related aspects, three criteria are relevant. First, a **TransformationRule** may inherit from either one or multiple other transformation rules, depending on whether *single or multiple inheritance* is supported. Second, the concept of **abstract rules** may be supported in order to specify that a certain rule is not executable per se but provides core behavior that can be reused in subrules. Finally, one can distinguish between different *refinement modes* by which inherited parts are incorporated into inheriting rules (cf. enumeration **RefinementMode** in Fig. 3). First, *override* implies that when a subrule refines an assignment of a superrule, the assignment of the subrule is executed

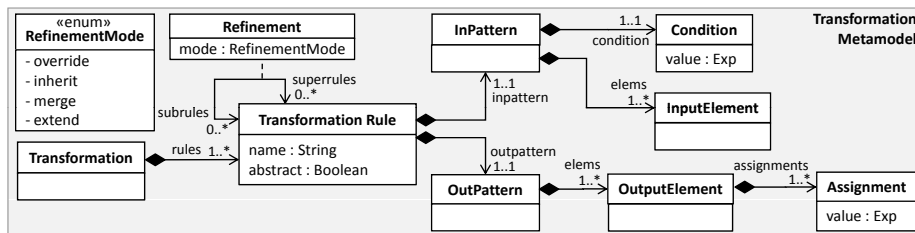


Fig. 3. Inheritance-Related Concepts of Transformation Languages

together with those assignments in the superrule which are not overridden. In the refinement mode *inherit* first the overridden assignments are executed, and then the overriding assignment may alter the resulting intermediate result (such as by initializing some state by a supercall and then altering this intermediate result). Third, *merge* means that again both assignments are executed, but first the assignments of the subrule and then the overridden assignments of the superrule are executed. Finally, the refinement mode *extend* induces that inherited assignments may not be changed at all. For consistency reasons, all assignments in a single rule should follow the same refinement mode (cf. class `Refinement`).

### 3.2 Static Semantics

In the previous subsection, we identified criteria targeting the comparison of syntactic concepts. Here we elaborate on criteria relevant for checking the static semantics of inheritance. These criteria reflect the following semantic constraints: (i) incompatibility of input and output elements of subrules and superrules in terms of type and number, (ii) non-instantiability of abstract classes, (iii) ambiguities in rule definitions, and (iv) conflicts in multiple inheritance.

**Incompatibility of Input and Output Elements.** In the context of transformation rules, both feature assignments and conditions should be inheritable to subrules. Thus, it has to be ensured that the *types* of the input and output elements of subrules have at least the features of the types of the elements of the superrule. Thus, types of the input and output elements of a subrule might become more specific than those of the overridden rule. The inheritance hierarchy of the transformation rules must therefore have the same structure as the inheritance hierarchy of the MMs. This means that co-variance for input and output elements is demanded, conforming to the principle of *specialization inheritance* in object-oriented programming. This is in contrast to popular design rules for object-oriented programming languages, where a contra-variant refinement of input parameters and a co-variant refinement of output parameters of methods is required to yield type substitutability, also known as *specification inheritance* [12]. Additionally, the *number* of input and output elements should be extensible. Therefore, four cases of potential variations of input elements in type and number can be distinguished:

- **Same number, different types (a).** As an example, Fig. 4(a) shows two rules A2X and B2Y that are bound to the source base classes A and B and to the target base classes X and Y, where both rules simply copy the contained features. Since source class C inherits from both classes A and B and the target class Z from the classes X and Y, the rule C2Z may inherit from the rules A2X and B2Y. Thus, the feature assignments of the superrules are reused (cf. grey assignments in Fig. 4(a)).
- **Same number, equal (source or target) types (b).** This case (cf. Fig. 4(b)) may be counterintuitive, since inheritance is usually used to specialize some core behavior for subsets of instances, and subtypes are typically used to construct these subsets. In this case – at first sight – no subsets (according to *specialization inheritance*) are built, and it is unclear which rule

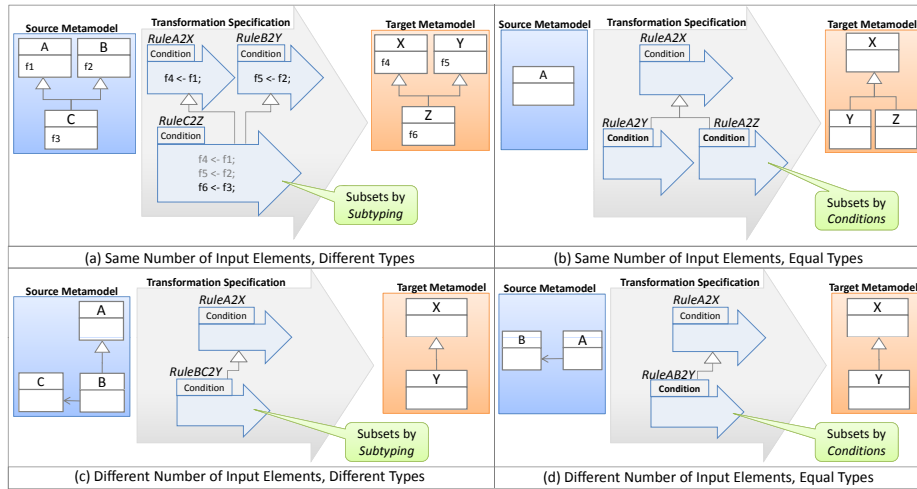


Fig. 4. Rule Compatibility

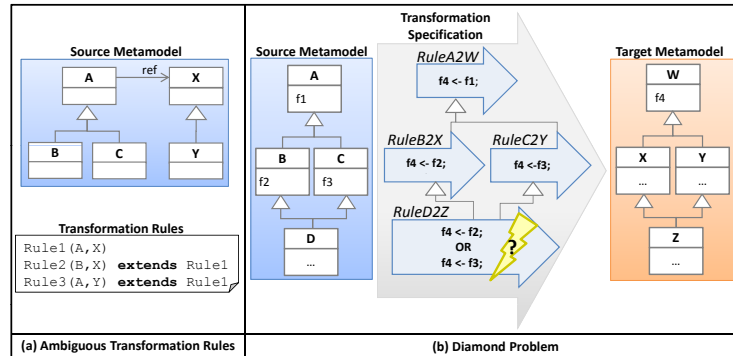
should be executed for a combination of instances. Therefore, the subsets needed must be built by applying corresponding disjoint conditions to the subrules in case of equal source types. In case the target type remains equal, feature assignments refer to target elements of the superrule. These scenarios occur if either the source or the target metamodel makes use of inheritance.

- **Different number, different types (c).** Here, the subsets needed are built through the specialization of at least one input element (cf. Fig. 4(c)).
- **Different number, equal types (d).** In this case, only the number of input or output elements is extended, but the types of elements bound in subrules remain the same. Thereby, the same problem as in case (b) arises, where the subsets must be realized by means of conditions which may require certain relationships between the matched input elements (cf. Fig. 4(d)).

One interesting question in the context of cases (b) and (d) is whether the instances that do not fulfill any of the conditions of the subrules are matched by the superrule (provided that the superrule is concrete). Since this question is closely related to dynamic semantics, we further discuss it in Section 3.3.

**Non-Instantiability of Abstract Classes.** Since abstract classes cannot be instantiated, it must be ensured statically that no concrete rule tries to create instances of an abstract target class as output. Only abstract rules are allowed in this case, since they are not themselves executed but must be refined by a subrule. The situation is different for abstract source classes: although an abstract source class cannot have any direct instances, indirect instances may be affected by the transformation rule.

**Ambiguities in Rule Definitions.** An ambiguity between inheriting transformation rules may arise if a rule requires multiple input elements, and if there is no single rule for which the match in run-time types is closer than all the other rules. This is analogous to the problem that arises in multiple dispatch-



**Fig. 5.** Examples of Static Constraints: (a) Rule Ambiguity and (b) Diamond Problem

ing as needed for multi-methods (cf. [1, 6]), since choosing a method requires the run-time type not of a *single* input element, but of a *set* of input elements. Thus, the method whose run-time types most closely match the statically specified types should be dispatched at run-time. A simple example of such a problem is depicted in Fig. 5(a). Three transformation rules are specified taking two input elements of different MM types, respectively. Now, suppose that a pair of instances  $(b, y)$  of type B and Y is transformed, and let us assume that the rules might also match indirect instances. The transformation engine should now look for a rule whose arguments *most closely match* the pair  $(b, y)$ . In this case, no single rule can be determined, since Rule2 and Rule3 are equally good matches. Thus, the set of defined transformation rules is ambiguous.

**Conflicts in Multiple Inheritance.** The *diamond problem* [16], also referred to as *fork-join* inheritance [15], arises, when contradicting assignments are inherited via different inheritance paths. Consider, for instance, the common superrule A2W in Fig. 5(b), which contains an assignment for copying a feature value. This assignment is overridden within the transformation rules B2X and C2Y. Thus, it cannot be decided in the rule D2Z which assignment should be applied, unless assistance is given by the transformation designer.

### 3.3 Dynamic Semantics

Now we shift our focus from static to dynamic semantics, i.e., how transformation specifications may be interpreted at run-time. In this context, two main aspects are investigated: (i) which rules apply to which instances, i.e., *dispatch semantics* and (ii) how a set of inheriting rules gets executed, i.e., *execution semantics*.

**Dispatch Semantics.** In order to execute transformation specifications, it must be determined which rules apply to which instances, i.e., transformation rules must be dispatched for source model instances. In [7], potential strategies and scheduling variations of rules were discussed, but without any focus on inheritance. Thus, literature does not indicate, whether *type substitutability* should be considered. This principle is well-known in object-oriented programming and states that, if S is a subtype of T, objects of type T may be safely replaced

by objects of type S [12]. Type substitutability for transformation rules would, thus, mean that if a rule can be applied to all instances of class T, then this rule can also be applied to all instances of all subclasses of T. Consequently, if no specific subrule is defined for instances of a subclass, then these instances of the subclass may be transformed by the rule defined for the superclass.

Concerning the evaluation of the condition two main strategies can be followed during dispatching. First, the condition is part of the matching process, i.e., if the condition fails, the rule is not applicable, but a superrule might be applied (*rule applicability* semantics). Second, the condition is not part of the matching process, i.e., the matching takes only place on the specified types of the input elements and thus, those elements, which do not fulfill the condition, are filtered, but never matched by a superrule anymore (*filter* semantics).

**Execution Semantics.** After having determined which rules are applicable to which source model instances, the question arises how a set of inheriting rules is executed. A first distinguishing criterion is, whether the concept of inheritance is directly supported by the execution engine or whether it is first flattened to ordinary transformation code in a pre-processing step. Independent of whether the inheritance hierarchy is flattened or not, various strategies may be applied to evaluate conditions and to execute assignments. This raises questions such as “Are conditions of a superrule also evaluated?” and “Are the assignments of a superrule executed before the assignments of a subrule?”. Hence, we investigated the main characteristics of executing methods in an inheritance hierarchy in object-oriented programming [16]: (i) the *completion of the message lookup*, i.e., whether only the first matching method is executed (*asymmetric*) or all matching methods along the inheritance hierarchy are executed (*composing*), and (ii) the *direction of the message lookup*, i.e., whether a method lookup starts in the subclass (*descendant-driven*) or in the superclass (*parent-driven*).

## 4 Comparison of Transformation Languages

In this section we use the criteria introduced in the previous sections to compare inheritance support in model-to-model transformation languages. The results are based on a carefully developed test set, which includes at least one test case for each criterion. These documented test cases, including the example code, the MMs, and source models, can be downloaded from our project homepage<sup>6</sup>.

**Comparison Setup.** For the comparison we considered common model-to-model transformation languages which offer dedicated inheritance support and allow relationships between source and target models to be specified in a declarative way. We examined the declarative subsets of the hybrid transformation languages ATL (version 3.1.0) and ETL (version 0.9.0). There are different implementations of TGGs, whereby our comparison bases on the one of MOFLON. Although MOFLON’s current implementation of the execution engine of TGGs (MOFLON 1.5.1) does not yet support inheritance, TGGs were included, since specific literature concerning inheritance support exists [10]. In order to compare

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<sup>6</sup> <http://www.modeltransformation.net>



the bidirectional TGG-based model transformation approach with the unidirectional languages ATL and ETL, we considered only the unidirectional forward translation. Although the QVT standard specifies the declarative transformation language QVT Relations, it is not included in this survey, since QVT Relations support only redefinition of whole rules, i.e., they do not allow the reuse of original rule definitions, and no inheritance between rules is offered, as is the focus of our framework. Actual mapping refinement is only mentioned in the QVT Core part, which leaves the transfer to QVT Relations open. Fig. 6 shows an example of the differences between the languages when transforming UML Statemachines into Petri Nets. The rule `State2Place` transforms `State` instances that are not of the kind `initial` into corresponding `Place` instances, while inheriting from the rule `ModelElem2Element`, which specifies the `name` assignment.

#### 4.1 Comparison of Syntax

When comparing the supported language features (cf. Table 1), differences in the *number of allowed input elements* can be detected. Whereas ATL (multiple elements in `from` pattern) and TGGs (source object graph) allow several input elements to be bound to a rule, this is not possible in ETL (cf. single variable after `transform` keyword in Fig. 6). However, all of the languages evaluated support multiple *output elements* (multiple elements in `to` pattern in ATL and ETL, target object graph in TGGs). Finally, all transformation languages allow for the specification of *conditions* (OCL expressions in ATL and TGGs, and a `guard` in ETL). ETL and TGGs support multiple inheritance, whereas ATL is restricted to single inheritance (keyword `extends` in ATL and ETL, inheritance arrow on type level of TGGs). All languages provide means to define abstract rules (keyword `abstract` in ATL, annotation `@abstract` in ETL, property `abstract` in TGGs). Finally, concerning potential *refinement modes of assignments*, none of the approaches evaluated provide specific keywords for explicitly choosing the semantics to be applied. Instead, ATL and ETL implicitly assume *override* semantics, and TGGs support the refinement mode *extend* since only new assignments may be added, but existing ones must not be modified.

In summary, all of the approaches evaluated support similar syntactic concepts in terms of inheritance. The main differences lie in the type of inheritance supported and the implicitly assumed refinement modes of assignments.

**Table 1.** Comparison of Syntax

Rule Part	Values	ATL	ETL	TGGs
Input Elements	1   1..n	1..n	1	1..n
Output Elements	1   1..n	1..n	1..n	1..n
Condition	Yes   No	Yes	Yes	Yes
Type of Rule Inheritance	Single   Multiple	Single	Multiple	Multiple
Abstract Rules	Yes   No	Yes	Yes	Yes
Refinement Modes of Assignments	Override   Inherit   Merge   Extend	Override (implicit)	Override (implicit)	Extend

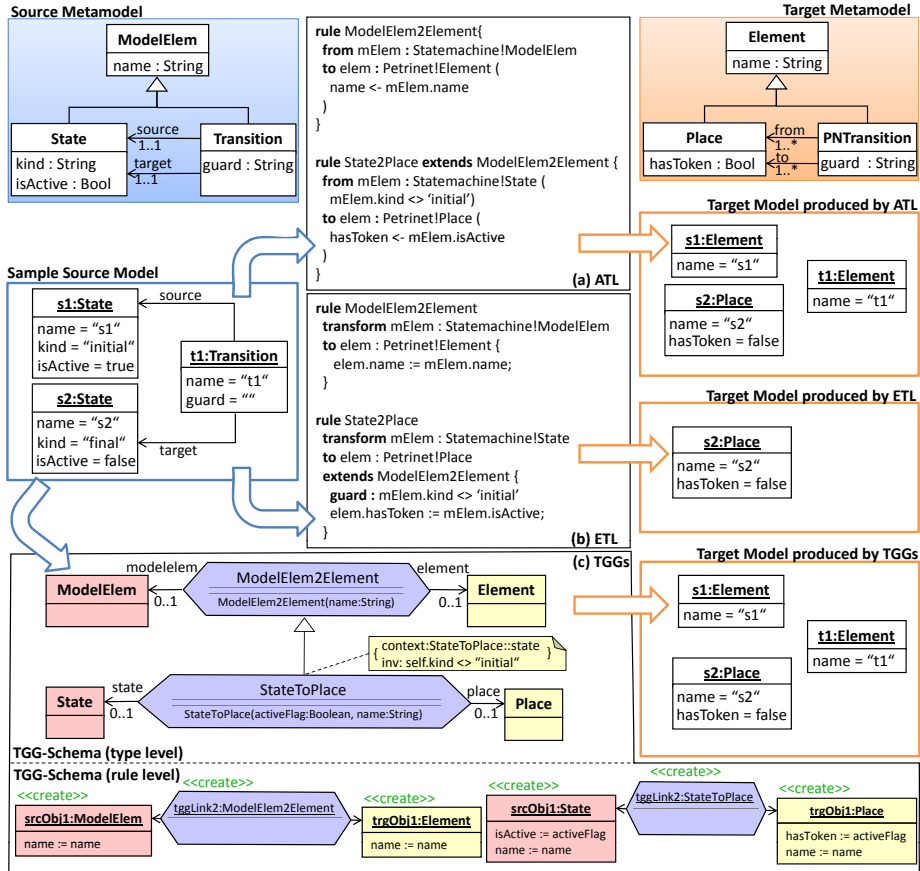


Fig. 6. Transformation example in ATL, ETL and TGGs

## 4.2 Comparison of Static Semantics

This part of the comparison evaluates to which extent the static semantics of inheritance is checked in each transformation language (cf. Table 2). Concerning *input and output elements*, in ATL a violation of co-variance is detected at run-time, since missing features result in a “feature not found” exception. In ETL no error is reported, and a target model with invalid features is created. In TGGs this results in a compile-time error in the upcoming implementation, since the main principle is that applying the subrule should guarantee the existence of the subgraph created by the superrule. Concerning the number of input elements, in ATL a run-time error also occurs, if the number is changed in any way, i.e., ATL prohibits to extend number of input elements. ATL does not raise any exception if the number of output elements is restricted, since they are produced even if they are not respecified. In ETL, the restriction of the number of input elements is not applicable, since ETL restricts the number of input elements to exactly one anyway. In ETL a run-time error (“index out of bound” exception) is raised

**Table 2.** Comparison of Static Semantics with respect to Inheritance

Verification Target	Fault	Values	ATL	ETL	TGGs
Input Elements	Non-co-variant Type Change	[Compile-Time] Run-Time No] Error	Run-Time Error	No Error (invalid target model)	Compile-Time Error
	Restriction in Number	[Compile-Time] Run-Time No] Error	Run-Time Error (also with extension)	n.a. (cf. syntax)	Compile-Time Error
Output Elements	Non-co-variant Type Change	[Compile-Time] Run-Time No] Error	Run-Time Error	No Error (invalid target model)	Compile-Time Error
	Restriction in Number	[Compile-Time] Run-Time No] Error	n.a. (output elements are still produced even if not specified again)	Run-Time Error	Compile-Time Error (except of output to input modification)
Abstract Target Classes	Concrete Rules for Abstract Target Classes	[Compile-Time] Run-Time No] Error	Run-Time Error	Run-Time Error	Run-Time Error (application fails)
Rule Ambiguity		[Compile-Time] Run-Time No] Error	No Error (first matching rule in file wins)	n.a. (cf. syntax)	Run-Time Error
Diamond Problem		[Compile-Time] Run-Time No] Error	n.a. (cf. syntax)	Compile-Time Error	Compile-Time Error

if the number of output elements is restricted. In TGGs, to conform to the main principle that applying the subrule should guarantee the existence of the subgraph created by the superrule, only an extension of the number of input and output elements is allowed, which is again ensured statically.

None of the languages evaluated detect *concrete rules referencing abstract classes* at compile-time, but run-time errors are thrown. ATL does not throw exceptions for *ambiguous rule definitions* – neither at compile-time nor at run-time. Instead, the first matching rule defined in the file is executed. In ETL, the problem of ambiguous rule definitions cannot arise, since multiple input elements are not supported. In TGGs, a run-time error is thrown. It must be noted that in the area of multi-methods, there are approaches for explicit disambiguation (e.g., [3] proposes a minimal set of method redefinitions necessary for disambiguation), which could be reused in transformation languages. The *diamond problem in multiple inheritance* does not apply to ATL, since multiple inheritance is not supported. Although the diamond problem is detected in ETL at compile-time, it is checked on a coarse-grained level, i.e., diamonds that do not include ambiguous assignments also cause errors. In TGGs, this problem is checked statically. Analogously to the explicit disambiguation of rule definitions, the transformation designer could be supported by proposals which assignments must be overridden in order to achieve unambiguous assignment definitions.

In summary, ATL and ETL provide limited support for static inheritance checks. Only the diamond problem gets statically checked by ETL. In contrast, the TGG-related publication lists a number of static checks that will be considered in the upcoming implementation of rule inheritance.

### 4.3 Comparison of Dynamic Semantics

In order to compare the dynamic semantics, the *dispatch semantics* and the *execution semantics* are investigated (cf. Table 3). Considering the *dispatch semantics*, one can see that the output models produced by ATL and TGGs (Fig. 6(a))

and (c)) include only one `Place` instance, since only the `State s2` fulfills the specified condition in the subrule. As ATL and TGGs support *type substitutability* and *rule applicability* semantics for conditions, instance `s1` is matched by the more general superrule `ModelElem2Element`, and therefore creates the target `Element s1`. Also the indirect instance `t1` is matched by the superrule, and therefore the target `Element t1` is created. In contrast, ETL does not support *type substitutability* by default. Thus, although the specifications in ETL and ATL are syntactically similar, the produced target models are quite different. ETL’s target model contains only a `Place s2` produced by the rule `State2Place`. The dispatch semantics may be modified by annotating rules with `@greedy` in ETL. Such rules also match indirect instances, but the interpretation is different to ATL and TGGs, since the superrule still regards all instances irrespective of whether the instances have already been matched by subrules or not. Adding the `@greedy` annotation to the rule `ModelElem2Element` in our example would therefore create four instances in total: three `Elements s1, s2, and t1` produced by the superrule `ModelElem2Element`, and one `Place s2` produced by the subrule `State2Place`. Even if type substitutability is enabled in ETL, the result of the condition evaluation does not influence the dispatch semantics because the superrule always matches all direct and indirect instances, disregarding subrules.

Regarding the inheritance support in the engine, in ATL inherited rules are flattened during compilation and can thus use optimization strategies, i.e., the ATL compiler inlines the assignments of a superrule. In contrast, ETL supports inheritance in the execution engine, which reduces the amount of code generated. In TGGs, this criterion is not applicable, since an inheriting TGG rule contains a copy of the superrules, which causes code duplication. Concerning the evaluation of the *conditions*, all transformation languages we compared exhibit a *composing* completion of the lookup, i.e., an instance processed by a subrule must fulfill all the specified conditions up the inheritance hierarchy. The actual evaluation is parent-driven in ATL and descendent-driven in ETL. In TGGs, this criterion is not applicable, since a subrule lists all its inherited conditions. Concerning

**Table 3.** Comparison of Dynamic Semantics of Inheritance

	Criterion	Subcriterion	Values	ATL	ETL	TGGs
Dispatch semantics		Type Substitutability	Yes   No	Yes	User-Definable	Yes
		Condition Semantics	Filter   Rule Applicability	Rule Applicability	n.a.	Rule Applicability
Execution Semantics	Inheritance Support	-	Flattened   Direct engine support	Flattened	Direct engine support	n.a. (since flattened in patterns already)
	Condition	Completion of lookup	Asymmetric   Composing	Composing	Composing	Composing (by copy)
		Direction of lookup	Parent-driven   Descendent-driven	Parent-driven	Descendent-driven	n.a.
	Assignments	Completion of lookup	Asymmetric   Composing	Optimized Composing	Composing	Composing (by copy)
Direction of lookup		Parent-driven   Descendent-driven	Descendent-driven	Parent-driven	n.a.	

*assignments* the same strategy as for conditions is applied. Thus, in ATL (i) the assignments of the superrule, which are not overridden, (ii) the overridden assignments, and (iii) new assignments specified in the subrule are executed realizing the optimization strategy. In contrast, in ETL, (i) the assignments of the superrule, and (ii) the assignments of the subrule are executed. In TGGs this is again not applicable. More specifically, TGGs enforce composition already in the syntax, which causes code duplication.

In summary, the main difference in terms of dynamic semantics lies in the application of type substitutability, which is user-definable in ETL, but interpreted in a different way than in ATL and TGGs. ETL has the disadvantage that several target instances for a single source instance are created when a superrule is annotated with `@greedy`. Moreover, all of the transformation languages implement a *composing* behavior for conditions and assignments. Thus, the lookup direction does not influence the result of the transformation.

#### 4.4 Lessons Learned

This subsection presents lessons learned from our comparison.

**Similar Syntax, Different Semantics.** As the example in Fig. 6 reveals, similar syntax (cf. ATL and ETL) does not necessarily lead to the same results, which implies different dynamic semantics. This is undesirable, since the dynamic semantics is not made explicit by any syntactical elements to the transformation designer. Thus, the transformation designer must know the design decisions taken in each transformation language in order to obtain the desired result. Therefore, the current situation concerning rule inheritance is comparable to the situation in the early stages of object-oriented programming, where no common agreements on the dynamic semantics of inheritance had been reached.

**Limited Support for Static Semantics.** Currently, support for checking the static semantics is limited. This gives rise to run-time errors or – even worse – to erroneous target instances with no error message. Thus, the tedious task of checking the static semantics is left entirely to the transformation designer.

**Fixed Dynamic Semantics.** As introduced above, different kinds of refinement modes may be desirable. The evaluation of the languages has shown, that each of them assumes a certain refinement mode, but none of them allows the transformation designer to choose between different options. Thus, the languages support only fixed dynamic semantics for rule inheritance. Since different dynamic semantics are suitable for different transformation scenarios, the transformation designer should be enabled to alter the dynamic semantics. The introduction of a **super** reference as in object-oriented programming languages would enable the transformation designer to express different refinement modes.

**Consequences for Transformation Interoperability.** The discovered differences in the interpretation of inheritance lead to profound consequences for transformation development, and thus, for transformation interoperability. Concerning ATL, the main restriction is the support for single inheritance only. Although multiple inheritance can be achieved by simulation, this leads to code duplication reducing the advantages of the concept of inheritance significantly.

In contrast, although TGGs and ETL allow for multiple inheritance, they exhibit other intricacies. In case of TGGs, assignments are duplicated in any case. ETL provides a different interpretation of type substitutability, leading to redundant instances. Thus, transformation interoperability demands for a detailed knowledge to achieve exactly the same outcome of a transformation expressed in different transformation languages.

## 5 Related Work

This section considers two threads of related work. First, we focus on inheritance support in transformation languages, and second, since inheritance is mainly a reuse mechanism, we broaden the scope to other reuse facilities.

**Inheritance Support in Transformation Languages.** Although inheritance plays a vital role in object-oriented modeling, and thus also in model transformations, no dedicated survey exists to the best of our knowledge. Only a small number of publications mention inheritance explicitly. Inheritance support in ATL is briefly described in [9], and that in ETL in [11], but rather on a syntactical level, while the actual execution semantics are left open. A detailed discussion of static semantics that must be considered in TGG rule inheritance may be found in [10]. For graph transformations in general, Bardohl et. al [4] introduced type substitutability when executing graph transformation rules, i.e., (abstract) supertypes may be used in patterns which are then applicable to subtypes at run-time. Finally, in the QVT standard [14] detailed semantics with respect to inheritance is defined only for QVT Operational.

**Reuse Facilities in Model Transformations.** General work has been done in composing transformations. Wagelaar et. al. [18] proposed a superimposition mechanism of transformations to build the union of all transformation rules. Thereby rules can be added and redefined (i.e., replacing a rule by a new one), whereby it is impossible to refer to the original rule. This is similar to the mechanism in QVT Relations, in which a transformation can extend another transformation and redefine existing rules [14]. Another reuse mechanism is to provide predefined transformations that can be adapted to specific MMs. Varró et al. [17] introduced generic transformations in VIATRA2 which in fact resembles the concept of templates in programming languages. Another approach to generic transformations was proposed in [8], where transformations are designed between generic “concepts models”. These transformations can be bound to concrete MMs, but only if they have the same structure. Finally, Wimmer et. al. [19] presented mapping operators which allow to specify model transformations by means of reusable components, similar to mappings known in data engineering.

In summary, only basic approaches for reuse are available, which confront the transformation designer with code duplication and maintenance problems.

## 6 Conclusion and Future Work

In this paper, we have presented a systematic comparison of inheritance support in the transformation languages ATL, ETL, and TGGs. We (i) identified

syntactic concepts required for inheritance, (ii) elaborated on static semantics that should be checked between inheriting rules, and (iii) investigated potential dynamic semantics of rule inheritance. Thus, the design rationales behind the realizations have been made explicit. Since we have considered declarative model-to-model transformations only, future work will comprise an investigation of inheritance support in imperative transformation languages, including also the imperative parts of hybrid transformation languages.

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