OCL and Graph-Transformations – A Symbiotic Alliance to Alleviate the Frame Problem*

Thomas Baar

École Polytechnique Fédérale de Lausanne (EPFL)
School of Computer and Communication Sciences
CH-1015 Lausanne, Switzerland
thomas.baar@epfl.ch

Abstract. Many popular methodologies are influenced by Design by Contract. They recommend to specify the intended behavior of operations in an early phase of the software development life cycle. In practice, software developers use most often natural language to describe how the state of the system is supposed to change when the operation is executed. Formal contract specification languages are still rarely used because their semantics often mismatch the needs of software developers. Restrictive specification languages usually suffer from the "frame problem": It is hard to express which parts of the system state should remain unaffected when the specified operation is executed. Constructive specification languages, instead, suffer from the tendency to make specifications deterministic.
This paper investigates how a combination of OCL and graph transformations can overcome the frame problem and can make constructive specifications less deterministic. Our new contract specification language is considerably more expressive than both pure OCL and pure graph transformations.

Keywords: Design by Contract, Behavior Specification, Graph Grammars, OCL, QVT

1 Motivation

Design by Contract (DbC) [1, 2] encourages software developers to specify the behavior of class operations in an early phase of the software development life cycle. Precise descriptions of the intended behavior of operations can be of great help to grasp design decisions and to understand the responsibilities of classes identified in the design.

The specification of behavior is given in form of a *contract* consisting of a pre- and a post-condition, which clarify two things: The pre-condition explicates all conditions that are expected to hold whenever the operation is invoked. The post-condition describes how the system state looks like upon termination of the operation's execution. Basically, contracts can be formulated in an informal way

* This work was supported by Hasler-Foundation, project DICS-1850.

or using a formal language such as OCL. Formally specified contracts have the advantage to be a non-ambiguous criterium for the correctness of a given implementation. Furthermore, contracts written in a formal language are machine readable and can be automatically processed in later stages of the software development life cycle, e.g. for the purpose of test case generation [3].

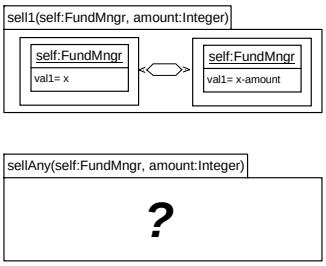
There are many specification languages available to define contracts formally. Despite their differences at the surface level, all languages can be divided into only two classes. The classification is based on the technique to specify the post-condition of a contract. *Restrictive specification languages* formulate the post-condition in form of a predicate, i.e. a Boolean expression, which restricts the allowed values for properties in the post-state. Well-known examples for restrictive languages are OCL, JML, Z, and Eiffel. *Constructive specification languages* interpret post-conditions not as restrictions on the post-state but – conceptually completely different – as updates, which transform the pre-state into the post-state. Well-known examples for constructive languages are B, ASM, graph transformations, and UML's Action Language.

The main disadvantage of using restrictive languages is the well-known frame problem [4]: The predicate for the post-condition can hardly express which parts of the system should not change.

```
context FundMngr::sell1(amount)
    post: val1 = val1@pre-amount

context FundMngr::sellAny(amount)
    post: val1+val2 = val1@pre+
                      val2@pre-amount
```

(a) Restrictive specifications using OCL



(b) Constructive specifications using graph transformations

Fig. 1. Specification of 'simple' operations

Suppose, a (simplified) class `FundMngr` has two attributes `val1`, `val2` representing the value of two stock depots. The intended behavior of operation `sell1(amount)` is to sell shares of value `amount` from the first depot. Typically, the operation `sell1()` would be specified in OCL as shown in the upper part of Fig. 1 (a). This specification, however, does not capture the intended semantics because also implementations of `sell1()` conform to the OCL specification that not only decrease `val1` by `amount` but in addition change the value of `val2`.

Constructive specification languages do not suffer from the frame problem but from a severe, complementary problem. Since a constructive specification describes how to 'construct' the post-state out of the pre-state, it prescribes

the implementation of the operation completely. Consequently, all decisions on the operation's behavior have to be taken in time of writing the specification and cannot be deferred to the implementation phase. Hence, the constructive specification and the implementation of an operation coincide.

The pros and cons of constructive specification languages are illustrated in Fig. 1 (b). Here, the behavior specification is given in form of a graph transformation rule, which consists of two graph patterns called left-hand side (LHS) and right-hand side (RHS). They define *how* to 'construct' a post-state out of a given pre-state: The pre-state is assumed to be represented as an object diagram. In a first step, all subgraphs of the object diagram are searched that matches with LHS. In a second step, each matching subgraph is rewritten with a new subgraph that can be uniquely computed based on RHS (see Sect. 3.2 for details).

The specification of operation `sell1()` in Fig. 1 (b) is read as follows. Whenever in the pre-state a subgraph can be found consisting of object `self` whose value for attribute `val1` matches with a (fresh) variable `x` then this subgraph is rewritten by the same object `self` whose attribute `val1` has now the value `x-amount`. Note that object `self` is passed as a parameter to the rule which lets LHS match with only one subgraph of the pre-state. All objects and links of the pre-state that are not part of the matching subgraph remain unchanged. The same holds for the values of all attributes of object `self` that are not mentioned in RHS. Consequently, if an implementation of `sell1()` would change for object `self` the value of attribute `val2` then this implementation would not conform to the constructive specification.

In order to illustrate the disadvantages of constructive specification languages we consider a second operation `sellAny(amount)` whose intended behavior is to sell shares of value `amount` but it is not important whether shares from the first or from the second depot are sold. The final implementation of `sellAny()`, of course, had to realize an algorithm that determines for each depot the number of shares to be sold, but the decision, which algorithm should be taken, is intentionally deferred to the implementation phase.

A contract for `sellAny()` can easily be given using a restrictive language. Figure 1 (a) shows an OCL contract where the post-state is *underspecified*: if a concrete pre-state is given, the post-state properties `val1`, `val2` can have more than one solution. In other words, the post-state is not (always) determined by the pre-state and the contract. We call such contracts *non-deterministic*. Non-deterministic contracts cannot be expressed by purely constructive languages (see Fig. 1 (b)) because there is no unique update that could by applied to the pre-state in order to construct the post-state (if there were such an update, the contract would be deterministic).

This paper investigates how the expressive power of constructive languages – as an example we consider graph transformations – can be improved to master non-deterministic contracts. In Sect. 3, graph transformations are extended with restrictive specification elements (OCL clauses). In its extended version, graph transformations are more powerful but still not powerful enough to formalize all

contracts that are relevant in practice. Thus, a second extension is discussed in Sect. 4, which allows to simulate the loose semantics of restrictive languages. To summarize, the proposed extensions of graph transformations enable software developers to write formal contracts that (1) do not suffer from the frame problem, (2) are non-deterministic, and (3) allow to change a state freely.

Related work. The idea to use graph transformations to formalize contracts is not novel. There are even already tools for this purpose available [5, 6]. The examples we found in the literature, however, are always deterministic contracts, which do not require to extend graph transformations with restrictive specification elements.

The idea to extend graph transformations with OCL clauses has been adopted from the Query/Views/Transformations proposal (QVT) [7], which is a response on a corresponding request for proposals by the OMG. In Sect. 3, the QVT approach is, however, put into a broader context by providing the link from model transformation (the original application domain of QVT) to formal contract specification.

Another attempt in the literature to make graph transformations less deterministic is by Heckel et al. in [8]. Having the same goal as our approach of Sect. 4, they first introduce graph transformations based on a loose semantics and make this notation, in a second step, more constructive by specifying explicit frame conditions on selected types.

Combining OCL with object diagrams has been explored in the literature also for a different target than contract formalization. The language VOCL (Visual OCL) uses collaborations to represent OCL constraints in a visual format for better readability [9]. Similarly, the proposal made by Schürr in [10] is inspired by Spider diagrams and aims at a more readable, graphical depiction of OCL constraints. The approaches described in [9, 10] cannot be compared with the approach presented in this paper because they have a fundamentally different goal. Firstly, [9, 10] do not use OCL in order to improve the expressive power of a graphical formalism. Instead, the graphical formalism is merely used as an alternative to OCL's textual standard syntax. Secondly, our approach targets only operation contracts whereas [9, 10] aim at a visualization of any kind of OCL constraints including invariants.

2 Restrictive Languages and the Frame Problem

In this section, we analyze why restrictive languages can hardly avoid the frame problem. The frame problem is much more complex than the trivial example in Sect. 1 was able to illustrate. This complexity makes naive approaches to tackle the frame problem, as for instance by adding frame axioms to the post-condition, very questionable. Some restrictive languages try to alleviate the frame problem by inventing a new clause for contracts. The new clause describes which parts of the system state must remain unchanged when executing the operation.

2.1 Example: CD-player

A formal specification of that are provided by CD-players will illustrate well the complexity of the frame problem. In Section 3, this example will be used again to point out limitations of constructive languages.

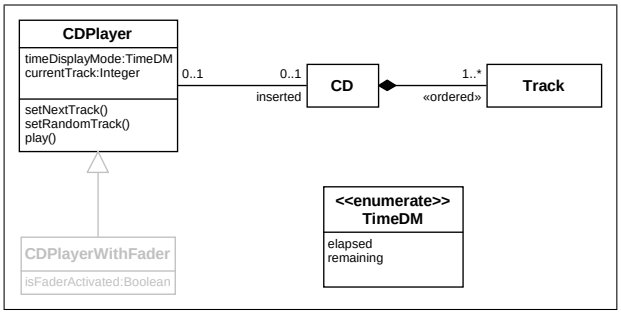


Fig. 2. Static model of CD-player scenario

The main purpose of CD-players is to entertain people and to play the content of compact discs (CDs). The content of a CD is organized by tracks that are burned in a certain order on the CD. We want to assume that a CD can be played in two modes. In the normal mode, all tracks on the CD are played in the same order as they appear on the CD. In addition, the CD-player can work in a shuffle mode in which the tracks are played in a randomized order. Finally, we want to assume that a CD-player has a display on which, depending on the chosen display mode, the elapsed or remaining time for the current track is shown.

This CD-player scenario is modeled straightforwardly by the class diagram shown in Fig. 2. The subclass `CDPlayerWithFader` can be ignored for the moment; later we will come back to it when discussing how object-oriented designs can evolve (e.g. by adding new subclasses) and which consequences this has on the semantics of operation contracts.

In the next subsection, we will focus on the formal behavior specification for the operations `setNextTrack()` whose intended semantics is to determine the next track to be played if the CD-player is working in the normal mode. The operation `setRandomTrack()` will be specified in Sect. 3 and determines the next track if the CD-player works in the shuffle mode.

2.2 Complexity of the Frame Problem

The intended semantics of operation `setNextTrack()` is to move one track forward on the CD and to increase the value of attribute `currentTrack` by one. The formalization of this behavior in a restrictive language such as OCL seems to be straightforward but there are some traps one can fall into.

```
context CDPlayer::setNextTrack()
    pre: self.inserted->notEmpty()
    post: self.currentTrack = (self.currentTrack@pre mod
    self.inserted.track->size()) + 1
```

This contract has some merits since it resolves ambiguities that were hidden in the informal description of the behavior. The first important information is expressed by the pre-condition saying that the CD-player assumes to have a CD inserted whenever the operation `setNextTrack()` is invoked. Note that this assumption is indeed necessary because the post-condition navigates over the currently inserted CD. The second merit of the contract is to make explicit the behavior of `setNextTrack()` when the current track is the last one on the CD. Reasonable variants might be to set `currentTrack` to zero (and thus to stop playing) or to continue with the first track on the CD as it is stipulated by our OCL constraint.

Although the OCL contract clarifies the informally given specification in some respects, it does not capture completely the intended behavior. According to the formal semantics of OCL in [11], an implementation still fulfills the contract even if it would not only change the value of `currentTrack` but also the display mode (attribute `timeDisplayMode`). Or the implementation could create/delete other objects, or could change the state of other objects, or could change the connections (links) between objects.

2.3 Strategies to Overcome the Frame Problem

A very naive strategy to exclude unintended implementations is by adding equations (so-call *frame axioms*) to the post-condition in order to make explicit which parts of the state should remain unchanged. In case of `setNextTrack()`, one had to add equations such as `self.timeDisplayMode=self.timeDisplayMode@pre` and `CD.allInstances=CD.allInstances@pre` and .... The huge number of necessary equations, however, let the size of the post-condition explode. Another drawback of this 'solution' is the need to rewrite all contracts of the design whenever the state space of the designed system is changed, e.g. by introducing a new class `CDPlayerWithFader`.

Unfortunately, this poor strategy of adding frame axioms is currently the only possibility, how OCL users can try to tackle the frame problem. To our knowledge, there has not been any attempt yet to make the language OCL more expressive so that users can easily add to a contract some information on which parts of the system remain unchanged.

Other restrictive languages have tried to tackle the frame problem by adding syntactical constructs which makes the semantics of a contract stronger. Users of the specification language Z [12] can separate the state space of the system into one part that is not affected by the operation and one part that can change freely as long as the restrictions formulated in the post-conditions are satisfied. The language JML [13], a contract specification language for methods implemented

in Java, offers besides pre-/post-conditions an additional clause *assignable* (also known as *modifies*) where all locations that might change their value must occur.

There has been also attempts in the literature to 'compute' then changing part of the system merely based on the post-condition [14]. This, however, makes formal reasoning on formal specifications much more complicated.

3 Constructive Languages and Non-Deterministic Contracts

After the last section has pointed out the most important drawback of restrictive languages, this section discusses a corresponding problem of constructive languages, namely, the principal obstacles for keeping the operation behavior to a certain degree unspecified. This can be only achieved by non-deterministic contracts.

Graph transformations are introduced as a constructive specification language. It is discussed, why pure graph transformations can specify the operation `setNextTrack()` but fail to specify `setRandomTrack()` correctly. To overcome this problem, we finally discuss a combination of constructive and restrictive specification style.

3.1 Non-deterministic Contracts

Non-deterministic contracts are necessary when not all details of the operation behavior should be fixed in time of writing the contract.

The intended behavior of `setRandomTrack()` is a typical example for a non-deterministic contract. The operation name set*Random*Track might be misleading as it might set up the expectation that our contract will enforce a true randomized behavior of the implementation in the sense that invoking the operation twice in the same state can result in different post-states. Note that this kind of randomness cannot be expressed by a contract (neither in OCL nor in any other contract language) because it would require to describe formally the behavior of multiple invocations whereas a contract can specify only the behavior of a single invocation.

The specification of `setRandomTrack()` in OCL looks as follows:

```
context CDPlayer::setRandomTrack()
  pre: self.inserted->notEmpty()
  post: Set{1..self.inserted.track->size()}
          ->includes(self.currentTrack)
```

This contract suffers again from the frame problem but, if this is ignored for a while, the post-condition keeps intentionally the exact post-state open and thus allows many different implementations. Even, an implementation that constantly sets attribute `currentTrack` to 1 was possible and would conform to this contract.

3.2 Graph Transformations as a Constructive Language

Graph transformations have their roots in graph grammars and were originally applied to describe the syntax of graphical languages. A graph grammar is a set of rules that specifies all syntactically correct sentences of a visual language. A visual sentence is syntactically correct if it can be derived by the recursive application of grammar rules starting on an initial graph. Graph grammars mimic in many respects the traditional syntax definition of textual languages by EBNF rules. Instead of sequences of strings, a graph grammar generates sets of visual objects placed in an n-dimensional space, or – to describe the outcome more abstract – a graph grammar generates (typed) graphs. From a more abstract point of view, rule applications are nothing but graph transformations and graph grammar rules are an elegant way to specify these graph transformations.

It has also been recognized in the literature (see [6] for a survey and [5] for a concrete example) that graph transformations can be used to specify the behavior of operations. System states can easily be represented as graphs, e.g. in form of object diagrams, and system state changes can be encoded as a transformation of graphs.

A graph transformation rule consists of two graph patterns called left-hand side (LHS) and right-hand side (RHS). Graph patterns are normal graphs whose elements, i.e. nodes and links connecting some nodes, are identified by labels. It is possible to use both in LHS and RHS the same label for the same kind of elements (nodes or links). The application of a graph transformation rule on a given graph is roughly described in two steps. In the first step, it is checked whether the given graph has a subgraph that matches with LHS. If not, the rule is not applicable on this graph. If yes, the matching subgraph is substituted by a new graph derived from RHS under the matching obtained in step 1. If a label for an element occurs only in LHS but not in RHS then the matching element is removed, if it occurs in RHS but not in LHS then a new element is created, if a label occurs in both LHS and RHS then the element is remained unchanged during the application of the rule.

Besides this basic version of graph transformation rules, where LHS and RHS consist of simple nodes and links, modern graph transformation systems offer much more sophisticated elements to describe patterns such as typed nodes, multiobjects, negative application conditions (NACs), parameters, etc. In the rest of the paper, we will use the graph transformation system QVT submitted as a proposal to the OMG for the standardization of model transformations. For details on the syntax/semantics of this formalism, the interested reader is referred to [7]. A bigger example on how QVT can be used as a contract specification language is given in [15].

As a simple example for a behavioral specification using graph transformations, Fig. 3 shows a rule specifying the intended behavior of `setNextTrack()`.

The graph patterns LHS, RHS use typed nodes (e.g. `self:CDPlayer`) that must comply to the system description given in Fig. 2. The LHS of the rules serves two things. First, it imposes restrictions that must hold in order to make

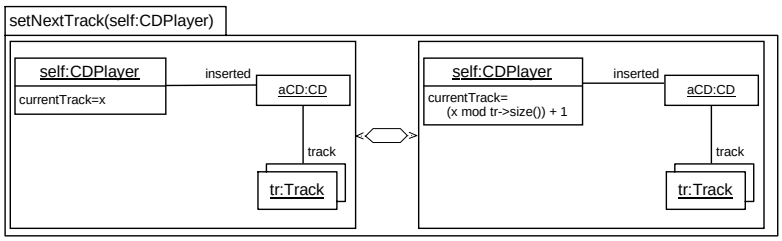


Fig. 3. Specification of `setNextTrack` with QVT

the rule applicable for the given state. For `setNextTrack()`, the effective restriction is that the CD-player `self` has a CD inserted (expressed by the link between `self` and `aCD`). The second purpose of LHS is to query the pre-state and to extract information that is important for the post-condition encoded by RHS. In our example, the variable `x` extracts the current value of attribute `currentTrack` and multiobject `tr` denotes the set of all tracks of the inserted CD. Note that the attribute `currentTrack` and the multiobject `tr` could have been omitted in LHS and the rule would still be applicable on exactly the same set of graphs as before.

The RHS of `setNextTrack()` is almost identical to LHS except for the value of attribute `currentTrack`. Consequently, applying the rule on a state will change only the value of `currentTrack` on the object `self` and nothing else. The new value of this attribute is computed based on the information queried during the first step of the rule application.

3.3 Mixing Constructive and Restrictive Languages

Graph transformation rules, as they were explained so far, can capture deterministic contracts in an elegant way whereas it seems hopeless to use them for non-deterministic contracts.

Fortunately, there is a solution and the same problem has been already tackled by other constructive languages. The language B, for example, offers, besides a pseudo-programming language for computing the post-state, the construct ANY-WHERE. This construct causes a non-deterministic split in the control flow and connects the same pre-state with possibly many post-states. The non-deterministic choices are, however, restricted by a predicate, which has to be evaluated in all control flows to true. In other words, constructive and restrictive specification style is mixed. The formal semantics of ANY-WHERE is defined in [16]. For an example-driven explanation of ANY-WHERE, the reader is referred to [17].

By integrating ANY-WHERE, the language B has lost its purely constructive semantics. The gain of expressive power is paid by loosing the executability of B specifications. This makes tool support for B more challenging but not impossible [18, 19].

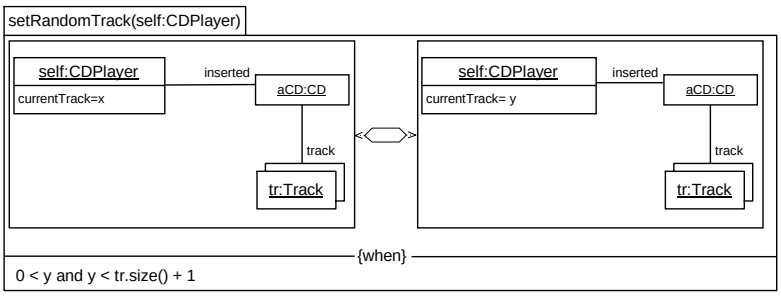


Fig. 4. Specification of `setRandomTrack` with QVT

Basically, for increasing the expressive power of graph transformations the same idea as in B can be applied. In QVT, variables can occur in RHS even if they do not occur in LHS. Consequently, the value of these fresh variables is not fixed anymore by the first step of the rule application and can be chosen non-deterministically. In order to get at least partial control over the values of these variables, QVT has added when-clauses to transformation rules. A when-clause contains constraints written in OCL. The constraint restricts the possible values not only for fresh variables used in RHS but for all elements in LHS and RHS.

The specification of `setRandomTrack()` shown in Fig. 4 takes advantage of the fresh variable `y` in RHS. The value of `y` is restricted in the when-clause what exactly captures the intended semantics.

4 Giving Graph Transformations a Loose Semantics

Although the integration of the when-clause is a necessary step to make graph transformations widely applicable and to overcome the determinism problem, this step is not sufficient. Another immanent problem of constructive languages remained unsolved. It is sometimes necessary to express in the contract that the implementations of the operation are allowed to change parts of the system state in an arbitrary way. If one puts this request to its very end, it means that in some cases the loose semantics of restrictive languages is needed.

In this section, we propose an extension of QVT that makes it possible to simulate the loose semantics of purely restrictive contracts written in OCL. These enrichments require a slight extension of QVT's notation to describe LHS and RHS.

4.1 Possible Side Effects of Restrictive Specifications

As argued in Sect. 2, the contract for `setNextTrack()` written in OCL does not exclude unintended side effects. These side effects can be classified as follows:

1. On object `self`, the values of the attributes not mentioned in the post-condition might have been changed.

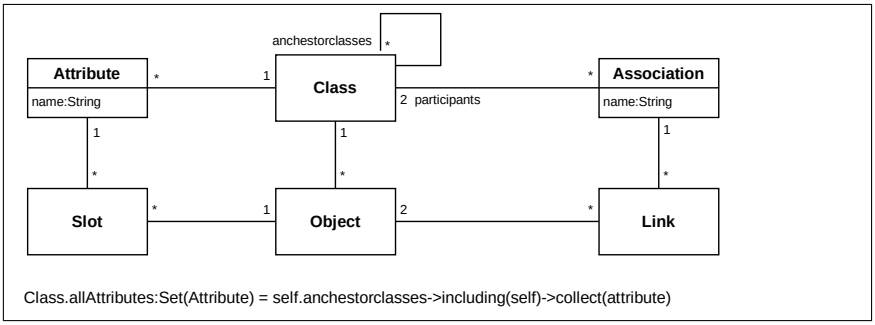


Fig. 5. Simplifed metamodel for states

2. The values of attributes of `CDPlayer`-objects different from `self` might have been changed.
3. The values of attributes of objects of other classes might have been changed.
4. An unrestricted number of objects of some classes might have been newly created.
5. An arbitrary number of existing objects except `self` might have been deleted.
6. An arbitrary number of links might have been created/deleted.

We will demonstrate in Sect. 4.3 how the contract for `setNextTrack()` shown in Fig. 3 had to be changed in order to capture each of these possible side effects. Beforehand, in the next subsection, the new constructs proposed for QVT, which are needed to simulate loose semantics, are summarized.

4.2 A Proposal for Extending QVT

Optional Creation/Deletion of Objects and Links. Graph transformation rules must be able to express that an object is optionally created or deleted. The same holds for links. So far, one can only specify that an object/link must have been created (deleted) by displaying the object/link in RHS but not LHS (in LHS but not in RHS). We propose to adorn an object/link in RHS with a question mark ('?') to mark its optional creation/deletion.

Note that it is a proven technique to adorn elements in LHS and RHS in order to modify the standard semantics of the rule. QVT and other graph transformation formalisms allow already to adorn elements with 'X' in order to express a negative application condition (NAC).

Placeholders to Denote Arbitrary Attributes/Classes. A more significant extension of graph transformations is the introduction of placeholders. Currently, QVT allows to describe the change of an attribute value only if the name of the attribute is known. One can, for example, not specify the reset of all attributes of type Integer to 0 unless all these attributes explicitly occur in the graph transformation rule.

We propose to use placeholders for attributes as a representation of arbitrary attributes. These placeholders appear in the same compartment of the object as normal attributes. In order to distinguish between normal attributes and placeholders, we start the name of the latter always with a backslash (\). This convention relies on the assumption that the name of normal attributes never starts with backslash. For example, if `\att` appears in the attribute compartment of an object, then it represents all attributes of this object (including attributes inherited from super-classes).

Sometimes, a placeholder should not represent all possible attributes but only some of them. To achieve this, we propose to use QVT's when-clause to define using OCL constraints which attributes are represented by which placeholders. Such OCL constraints, however, refer to the metamodel of UML object diagrams. To ease the understanding, we rely here on a simplified version of the official metamodel as shown in Fig. 5.

Furthermore, in order to distinguish easily OCL constraints referring to the metamodel from ordinary ones, we decided – slightly abusing OCL's official concrete syntax – to precede within OCL expressions each navigation on the metalevel with a backslash.

Besides placeholders for attributes there are also analogously defined placeholders for classes.

4.3 Realization of Possible Side Effects

We give examples on how possible side effects of OCL constraints presented in Sect. 4.1 can be simulated using our extension of QVT. In all cases, we start from the constructive specification of `setNextTrack()` shown in Fig. 3.

Other Attributes for self can change. A naive solution could be to explicitly list all attributes of object `self` in both LHS and RHS and to assign in RHS a fresh variable to the attribute.

This solution is first of all tedious to write down and in addition has the limits that were already discussed: In time of writing the contract, not all subclasses of `CDPlayer` might be known. Be aware that the QVT rule formulated in Fig. 3 is applicable even when `self` matches with an object whose actual type is not `CDPlayer` but a subclass of it. The core of the problem is, that, when writing the contract, we cannot predict which attributes the object `self` actually has.

The rule shown in Fig. 6 overcomes this principal problem. Each attribute of `self` is represented by placeholder `\attDiffCurrentTrack` as long as its name is different from 'currentTrack'. This is precisely described in the when-clause by an OCL constraint: For the actual class of `self` (which might be a subclass of `CDPlayer`) all valid declarations of attributes are collected. Note that attributes can have also been declared in one of the super-classes. The OCL constraint in the when-clause stipulates that the placeholder `\attDiffCurrentTrack` stands for any attribute as long as it is not named 'currentTrack' since this attribute cannot be changed in an arbitrary way. The value of `\attDiffCurrentTrack` in LHS is represented by variable `v`, which does not occur in the RHS. The

new value `v'` in RHS shows that the value of the attribute matching with `\attDiffCurrentTrack` might have been changed during the execution of the operation.

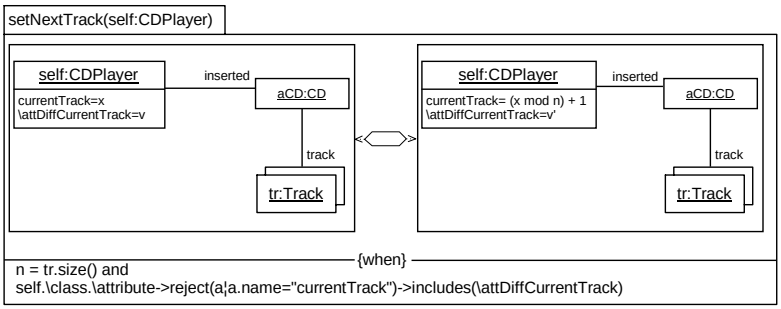


Fig. 6. Different attribute values for `self`

State of other CDPlayer-objects might change. This side effect is similar to the effect of changing the state of `self` and can be captured by applying the same technique to enrich the QVT transformation. A new object `other` is added to both LHS and RHS. In RHS, the value of the placeholder `\att` is changed to a possibly new value `v'`.

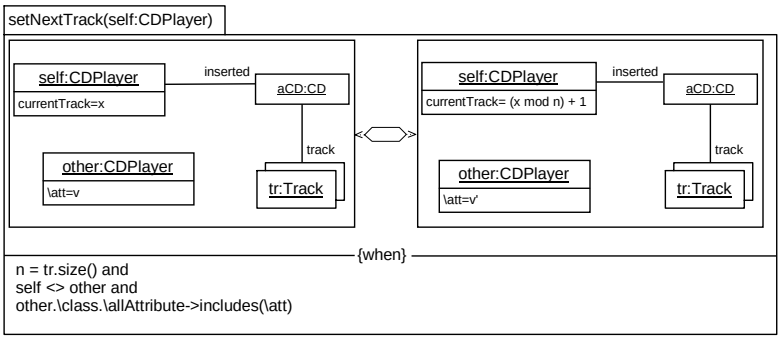


Fig. 7. Different attribute values for other objects of class `CDPlayer`

State of objects of other classes might change. In order to simulate state changes on objects of arbitrary classes different from `CDPlayer` (and its subclasses) placeholders for classes are needed. We have introduced the placeholder `\OtherClass` whose value is restricted by an appropriate constraint in the when-clause. The technique to change the state of objects of class `\OtherClass` is the same as the one exploited above to simulate the state change of `CDPlayer`-objects.

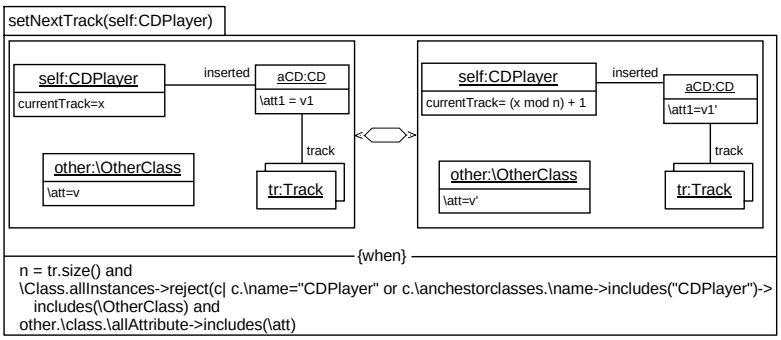


Fig. 8. Different attributes for object of other classes

Objects different from self might have been deleted. It is not enough to add the question mark to the new object `other` (that represents an arbitrary object different from `self`). Unfortunately, the question mark must also be attached on all objects different from `self` that are explicitly mentioned in RHS (without such a question mark, the QVT semantics stipulates that all objects occurring in RHS are not deleted). In addition, also the multiobject `tr` might change since some of its elements are possibly deleted. Consequently, a new multiobject `tr1` is introduced in RHS, which – according to the when-clause – must be a subset of the original multiobject `tr`.

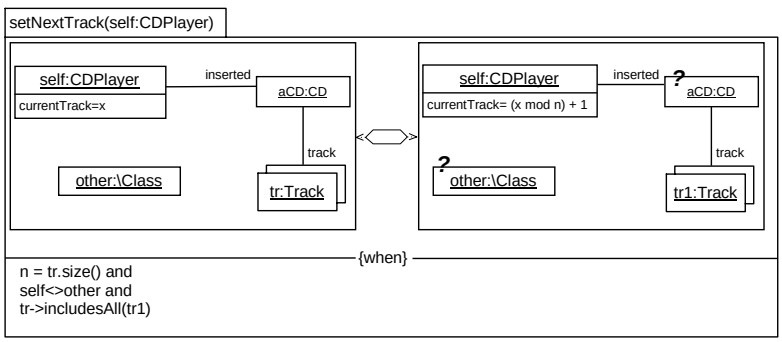


Fig. 9. Deletion of objects

Objects might have been created. Optional creation of arbitrarily many objects is expressed by adding a multiobject `other` to RHS. For each class, `other` represents the set of newly created objects. Furthermore, the multiobject `tr` might have been enlarged and became `tr1`.

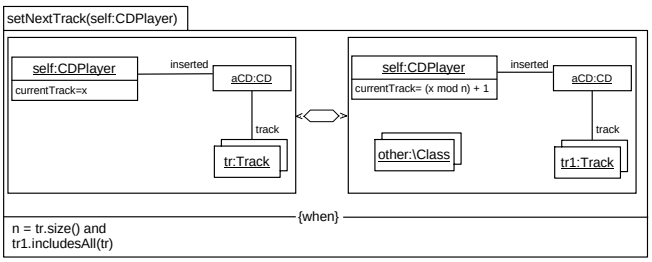


Fig. 10. Creation of objects

Links might have been created. For the optional creation of links, two arbitrary objects `o1`, `o2` are searched in LHS. The classes of `o1`, `o2` must be connected by an association with name `assoname`. RHS stipulates the optional creation of a corresponding link between both objects.

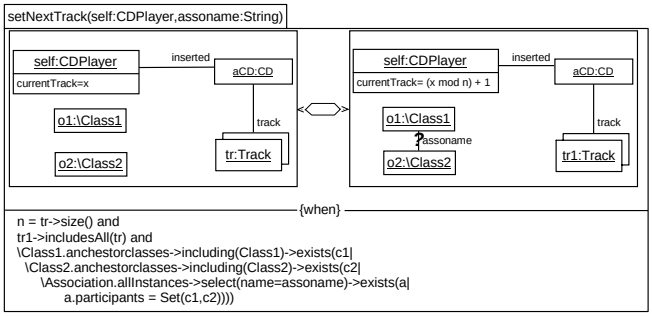


Fig. 11. Creation of links

Links might have been deleted. Analogously to the optional deletion of objects we mark also links that are deleted optionally with a question mark. Note, that the deletion of links might have be an effect on the multiobject `tr` the same way the deletion of objects has.

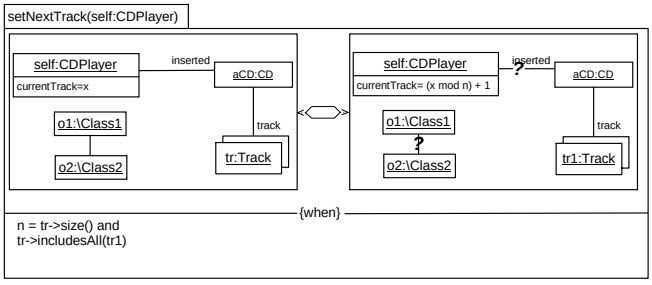


Fig. 12. Deletion of links

5 Conclusion and Future Work

In this paper, pros and cons of the two main behavior specification paradigms – constructive and restrictive style – are discussed. If restrictive languages do not provide provision for tackling the frame problem (such as OCL), then the specified contracts are comparably weak and do most often not capture the behavior intended by the user. Constructive languages suffer from the opposite problem as they sometimes prescribe too detailed the behavior and do not allow the freedom for variations among possible implementations. These two fundamental problems make it also very difficult to define a semantically preserving transformation from specifications of restrictive specification languages into specifications written in a constructive language, or vice versa.

Graph transformations can be used as a basically constructive specification language but it is sometimes also possible to pursue a restrictive specification style. Contracts given in form of a graph transformation rule have the advantage of being easily accessible by humans due to the visual format. In many cases, constructive contracts are intended and constructive contracts work well. For the case that a purely constructive semantics is not appropriate, we have given in Sect. 4 a catalog of proposals to enrich a graph transition rule so that the intended behavior is met. This approach to adapt the semantics of the rule more to the loose semantics of restrictive languages is very flexible since the user has the possibility to traverse the metamodel with OCL constraints.

A lot of work remains to be done. First of all, the proposed formalism of extended graph transformations should be implemented by a tool to resolve all the small problems that can only be recognized if a tool has to be built. In order to become confident in the formal semantics of the formalism, an evaluator needs to be implemented that can decide for any contract and any given state transition whether or not the transition conforms to the contract.

Once such a tool is available, it should be applied on bigger case studies showing or disproving the appropriateness of the proposed formalism for practical software development.

References

1. Bertrand Meyer. Applying "design by contract". *IEEE Computer*, 25(10):40–51, October 1992.
2. Bertrand Meyer. *Object-Oriented Software Construction*. Prentice-Hall, Englewood Cliffs, second edition, 1997.
3. Levi Lucio, Luis Pedro, and Didier Buchs. A methodology and a framework for model-based testing. In Nicolas Guelfi, editor, *Rapid Integration of Software Engineering Techniques, First International Workshop, RISE 2004, Luxembourg-Kirchberg, Luxembourg, November 26, 2004, Revised Selected Papers*, volume 3475 of *LNCS*, pages 57–70. Springer, 2004.
4. J. McCarthy and P. J. Hayes. Some philosophical problems from the standpoint of artificial intelligence. *Machine Intelligence*, pages 463–502, 1969.

5. Claudia Ermel and Roswitha Bardohl. Scenario animation for visual behavior models: A generic approach. *Software and Systems Modeling (SoSym)*, 3(2):164–177, 2004.
6. Lars Grunske, Leif Geiger, Albert Zündorf, Niels van Eetvelde, Pieter van Gorp, and Dániel Varró. *Model-driven Software Development - Volume II of Research and Practice in Software Engineering*, chapter Using Graph Transformation for Practical Model Driven Software Engineering. Springer, 2005.
7. OMG. Revised submission for MOF 2.0, Query/Views/Transformations, version 1.8. OMG Document ad/04-10-11, Dec 2004.
8. Reiko Heckel, Mercè LLabrés, Hartmut Ehrig, and Fernando Orejas. Concurrency and loose semantics of open graph transformation systems. *Mathematical Structures in Computer Science*, 12:349–376, 2002.
9. Paolo Bottoni, Manuel Koch, Francesco Parisi-Presicce, and Gabriele Taentzer. Consistency checking and visualization of OCL constraints. In Andy Evans, Stuart Kent, and Bran Selic, editors, *UML 2000 - The Unified Modeling Language, Advancing the Standard, Third International Conference, York, UK, October 2-6, 2000, Proceedings*, volume 1939 of *LNCS*, pages 294–308. Springer, 2000.
10. Andy Schürr. Adding graph transformation concepts to UML's constraint language OCL. *Electronic Notes in Theoretical Computer Science, Proceedings of UNIGRA 2001: Uniform Approaches to Graphical Process Specification Techniques*, 44(4), 2001.
11. OMG. UML 2.0 OCL Specification – OMG Final Adopted Specification. OMG Document ptc/03-10-14, Oct 2003.
12. J. M. Spivey. *The Z Notation: A Reference Manual*. Prentice-Hall, 1992.
13. Gary T. Leavens, Albert L. Baker, and Clyde Ruby. Preliminary design of JML: A behavioral interface specification language for java. Technical Report TR 98-06-rev28, Department of Computer Science, Iowa State University, 2005. Last revision July 2005, available from www.jmlspecs.org.
14. A. Borgida, J. Mylopolous, and R. Reiter. ...And Nothing Else Changes: The Frame Problem in Procedure Specifications. In *Proceedings of ICSE-15*, pages 303–314. IEEE Computer Society Press, 1993.
15. Slaviša Marković and Thomas Baar. Refactoring OCL annotated UML class diagrams. In Lionel Briand and Clay Williams, editors, *Proc. ACM/IEEE 8th International Conference on Model Driven Engineering Languages and Systems (MoDELS)*, volume 3713 of *LNCS*, pages 280–294. Springer, 2005.
16. Jean-Raymond Abrial. *The B Book: Assigning Programs to Meanings*. Cambridge University Press, August 1996.
17. Thomas Baar. Non-deterministic constructs in OCL – what does any() mean. In Andreas Prinz, Rick Reed, and Jeanne Reed, editors, *Proc. 12th SDL Forum, Grimstad, Norway, June 2005*, volume 3530 of *LNCS*, pages 32–46. Springer, 2005.
18. ClearSy. Atelierb homepage. http://www.atelierb.societe.com, 2005.
19. Michael Leuschel and Michael Butler. ProB: A model checker for B. In Keijiro Araki, Stefania Gnesi, and Dino Mandrioli, editors, *FME 2003: Formal Methods*, LNCS 2805, pages 855–874. Springer-Verlag, 2003.