

A Pattern based model driven approach to model transformations

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Abstract

The OMG's Model Driven Architecture (MDA) initiative has been the focus of much attention in both academia and industry, due to its promise of more rapid and consistent software development through the increased use of models. In order for MDA to reach its full potential, the ability to manipulate and transform models – most obviously from the Platform Independent Model (PIM) to the Platform Specific Models (PSM) – is vital. Recognizing this need, the OMG issued a Request For Proposals (RFP) largely concerned with finding a suitable mechanism for transforming models. This paper outlines the relevant background material, summarizes the approach taken by the QVT-Partners (to whom the authors belong), presents a non-trivial example using the QVT-Partners approach, and finally sketches out what the future holds for model transformations.

1 Introduction - Transformations and MDA

The OMG Queries/Views/Transformations (QVT) RFP [1] defines the MDA vision thus:

MDA defines an approach to IT system specification that separates the specification of system functionality from the specification of the implementation of that functionality on a specific technology platform, and provides a set of guidelines for structuring specifications expressed as models.

The MDA approach and the standards that support it allow the same model specifying system functionality to be realized on multiple platforms through auxiliary mapping

standards... and allows different applications to be integrated by explicitly relating their models.

In less technical terms, MDA aims to allow developers to create systems entirely with models¹. Furthermore, MDA envisages systems being comprised of many small, manageable models rather than one gigantic monolithic model. Finally, MDA allows systems to be designed independently of the eventual technologies they will be deployed on; a PIM can then be transformed into a PSM in order to run on a specific platform.

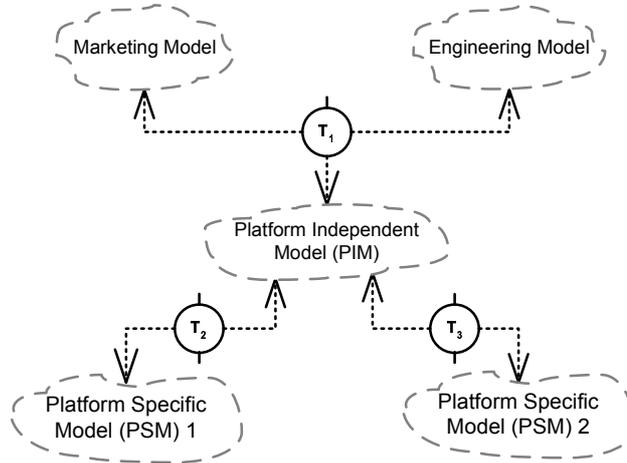


Fig. 1. Transformations and MDA

Figure 1 – based partly on a D’Souza example [2] – shows an overview of a typical usage of MDA. It shows a company horizontally split into multiple departments, each of which has a model of its system. These models can be considered to be views on an overall system PIM. The PIM can be converted into a PSM. In order to realize this vision, there has to be some way to specify the changes that models such as that in figure 1 undergo. The enabling technology is *transformations*. In figure 1 a transformation T_1 integrates the company’s horizontal definitions into an overall PIM, and a transformation T_2 converts the overall PIM into PSMs, one for each deployment platform.

The following are some representative MDA related uses where transformations are, or could be, involved:

- Converting a model ‘left to right’ and/or ‘right to left’. This is a very common operation in tools, for example saving a UML model to XML and reading it back in again.
- Abstracting a model. Abstracting away unimportant details, and presenting to the user only the salient points of the model, is a vital part of MDA.
- Reverse engineering. For example, a tool which recovers Java source code from class files.
- Technology migration. This is similar to reverse engineering, but whereas reverse engineering is simply trying to recover lost information, technology migration is effectively trying to convert outdated systems into current systems. For example, a tool which migrates legacy COBOL code to Java.

Transformations are undoubtedly the key technology in the realization of the MDA vision. They are present explicitly – as in the transformation of a PIM to a PSM – and implicitly – the integration of different system views – throughout MDA.

¹ This does not mean that *everything* must be specified fully or even semi-graphically – the definition of model allows one to drill down right to source code level.

2 QVT

In order for MDA to reach its full potential, the ability to manipulate and transform models is vital. Although there has been much discussion [3,4] of the problem area, as well as attempts at filling this gap in the past [5–8], little practical progress has been made. Recognizing the need for a practical solution for transformations, the OMG issued a Request For Proposals (RFP) [1] largely concerned with finding a suitable mechanism for transforming models. This paper is based on the QVT-Partners² initial submission [9] to the QVT RFP. An updated version of this paper based on the revised QVT partners submission is being worked on at the moment.

3 Fundamental concepts

It is our view that to provide a complete solution to the problem of a practical definition of transformations, the following complimentary parts are necessary:

- (1) The ability to express both specifications and implementations of transformations.
- (2) A mechanism for composing transformations.
- (3) Standard pattern matching languages which can be used with declarative and imperative transformations.
- (4) A complete semantics, which are defined in terms of existing OMG standards.

The solution outlined in this paper can be seen to be chiefly concerned with solving two overarching problems: the need to provide a framework into which different uses of transformations can be accommodated, and the need to provide a standard set of languages for expressing transformations. In solving these needs, the solutions to other fundamental requirements as mentioned earlier in this section follow fairly automatically.

4 A definition of transformations

This section outlines the points of our definition of transformations that are most relevant to this paper. See also section 7.

4.1 Framework

We define an overall framework for transformations that allows one to use a variety of different transformation styles. This framework also transparently allows transformations to change style throughout the lifetime of a system. Such transparency is enabled by identification of two distinct sub-types of transformations: relations and mappings.

Relations are multi-directional transformation specifications. Relations are not executable in the sense that they are unable to create or alter a model. They can however check two or more models for consistency against one another

Typically relations are used in the specification stages of system development, or for checking the validity of a mapping.

² <http://qvtp.org/>

Mappings are transformation implementations. Unlike relations, mappings are potentially uni-directional. Mappings can refine any number of relations, in which case the mapping must be consistent with the relations it refines.

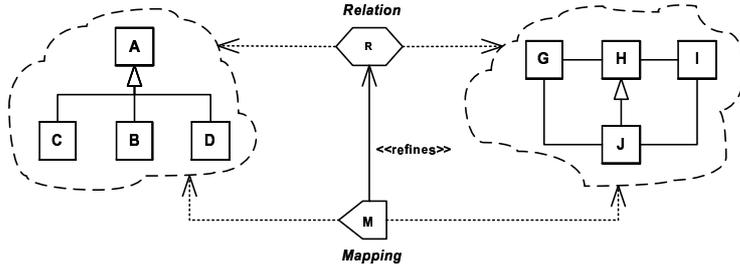


Fig. 2. A high level relation being refined by a directed mapping

Figure 2 shows a relation R relating two domains. There is also a mapping M which refines relation R; since M is directed, it transforms model elements from the right hand domain into the left hand domain.

As far as possible, the standard languages for relations and mappings share the same syntax and semantics. But by virtue of the fact that they are different concepts, there are differences between the two. The most obvious difference is that whilst a relation simple consists of a number of domains and an overall constraint, mappings also have an "action body".



Fig. 3. Transformations, relations and mappings in the MOF hierarchy

Figure 3 shows how transformations, relations and mappings are placed within the MOF [10] hierarchy. As **Transformation** is a super-type of **Relation** and **Mapping**, when we talk about a transformation we effectively mean either a relation or a mapping, we don't mind which one. When we talk about a mapping, we specifically mean a mapping and only a mapping and similarly for relations. The differentiation between specification and implementation is vital. In many complex applications of transformation technology it is often unfeasible to express a transformation in operational terms. For example, during the initial stages of system development, various choices, which will affect an implementation, may not have been made, and thus it may be undesirable to write an implementation at that stage. Another more general reason for the presence of specifications is that transformation implementations often carry around large amounts of baggage, which whilst vital to the transformations execution, obscure the important aspects of a transformation – by using specifications, these important aspects can be easily highlighted. Nevertheless, implementations are vital for the final delivered system. We also propose a standard operational transformation language to prevent the need to drop to low level technologies such as the XML transformation system XSLT (XSL Transformations) [11] – in order for transformations to be a successful and integral part of MDA, it is essential that they be modelled. Our proposal allows transformations to seamlessly and transparently evolve from specifications to implementations at any point during the development life cycle.

4.2 Pattern Languages

Pattern languages are widely used in real world transformation technologies such as Perl-esque textual regular expressions and XSL (note that the former is a declarative transfor-

mational language, whereas the latter is imperative). Clearly, any solution needs to have pattern languages, as they are a very natural way of expressing many – though not all – transformations. Our solution provides standard pattern matching languages for both relations and mappings; a pattern replacement language is also defined for relations, allowing many specifications utilizing the pattern language to be executable. Furthermore, we also provide graphical syntax to express patterns, as well as the more conventional textual representation.

5 Transformations

Our definition of transformations comes in two distinct layers. Reusing terminology familiar from the UML2 process, we name these layers *infrastructure* and *superstructure*.

5.1 Infrastructure

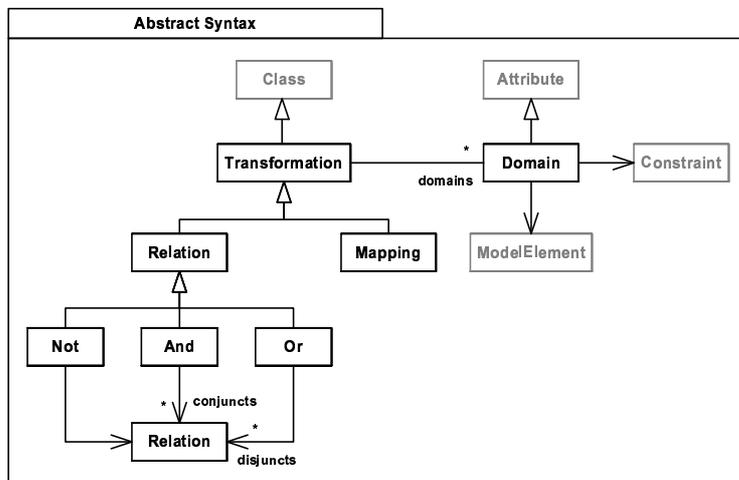


Fig. 4. Infrastructure meta model

Figure 4 shows the infrastructure abstract syntax package. This package can be merged with the standard MOF definition to produce an extended version of MOF. Original MOF elements are shown in grey; our new elements are in black. The infrastructure contains what we consider to be a sensible minimum of machinery necessary to support all types of transformations. The infrastructure is necessarily low-level and not of particular importance to end users of transformations. Its use is a simple semantic core [12].

5.2 Superstructure

Compared to the infrastructure, the superstructure contains a much higher-level set of transformation types and is suitable for end users. Figure 5 shows a transformation meta-model that extends the transformations meta-model given in Infrastructure. The elements Transformation, Relation, Domain, And, Or and Mapping inherit from and extend the corresponding elements in the infrastructure. Elements from MOF core are shown in grey.

The heart of the model is the element Relation. It specifies a relationship that holds between instance models of two or more Domains. Each Domain is a view of the meta-model, and

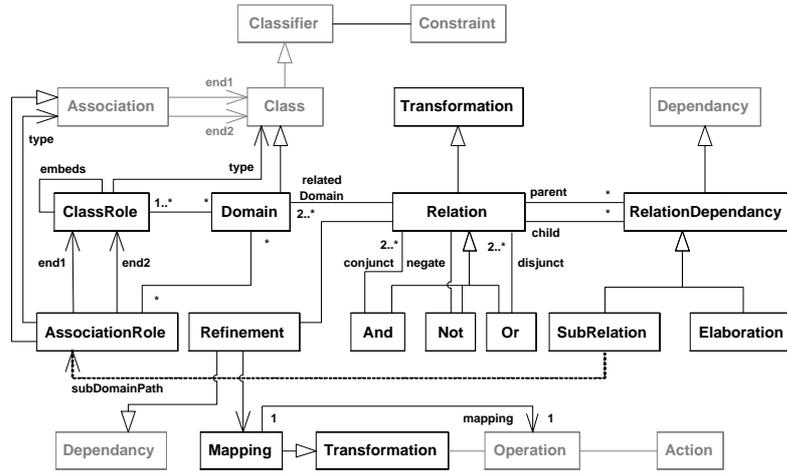


Fig. 5. Superstructure meta model

is constituted of Class and association roles. A Role has a corresponding type that the elements bound to it must satisfy. A Domain may also have an associated query to further constrain the model specified by it. The query may be specified as an OCL expression. A Relation also may have an associated OCL specification. This may be used to specify the relationship that holds between the different attribute values of the participating domains. A binary directed-relation is a special case with a source Domain and a target Domain.

5.3 Concrete syntax

Our solution defines a graphical concrete syntax for transformations. Figure 6 lists the most important notations.

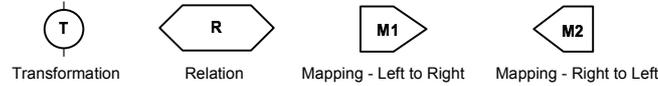


Fig. 6. Concrete Syntax for transformations

6 An example

In order to illustrate the salient features of our approach, we present an example of transformations between simplified UML models and XML.

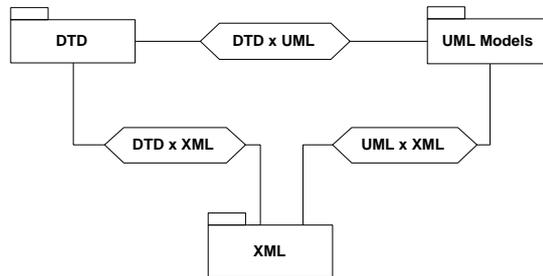


Fig. 7. The overall Transformation framework

Figure 7 shows the overall view of this transformation example. We divide the example into three parts:-

- (1) The actual transformation of the UML Models to XML represented by *UML x XML*.
- (2) Verification of the generated XML against the DTD represented by *DTD x XML*.
- (3) We attempt to capture the relationship between UML Diagrams and DTDs. This is represented by *DTD x UML*.

6.1 The example model

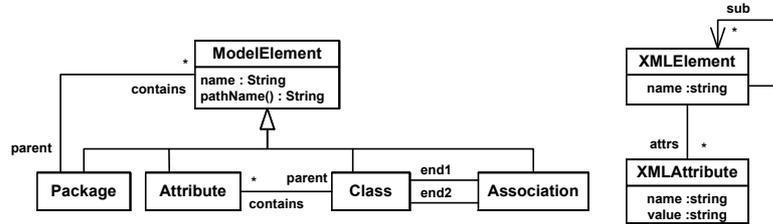


Fig. 8. The example meta-model

Figure 8 shows a simplified model of UML class diagrams. Each ModelElement has a name; the pathName operation returns a string representing the element's full pathname. The operation is defined thus:

```

context ModelElement::pathName(): String
  if not self.parent then
    self.name
  else
    self.parent.pathName() + "." + self.name
  endif

```

We assume that all elements have a unique pathname. This can be trivially enforced by placing constraints on Package and Class to ensure that none of their contents share the same name.

Figure 8 (right hand side) shows a simplified model of XML. We prefix both elements in the model by XML to avoid having to qualify references via a package name. The model captures the notion of XML elements having a number of attributes, and containing XML elements.

In the rest of this section, we gradually build up a relation from our UML model to XML, from a number of small pieces.

6.2 Building up the transformation

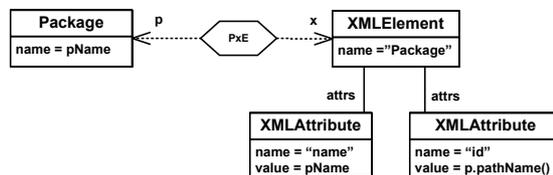


Fig. 9. A UML package to XML relation

Figure 9 shows a relation between the UML Package and XML using a pattern language. Although at first glance figure 9 may look like a standard UML class diagram, it should rather be thought of as something in between a class diagram and an object diagram. Notice

how some attributes in the transformation have constant values given to them, whilst others have variables – each variable name must have the same value across the diagram.

Thus to examine figure 9 in detail, each `Package` instance is related to an `XMLElement` with the name `Package`. The XML element has two `XMLAttribute`. The first is the name of the package which has a value of `pName`, thus forcing it to be the same literal name as the UML package. To allow us to reference elements (which is necessary for association ends), we also force each XML element to have a unique identifier – the properties of the `pathName` operation mean we can use it to produce unique identifiers.

When written in more conventional form, the UML package would be related to the following chunk of XML:

```
<Package name=pName id=p.pathName() ></Package>
```

The relations `CxE` and `AxE` for `Classes` and `Attributes` respectively are much the same as for `PxE` for `Package`.

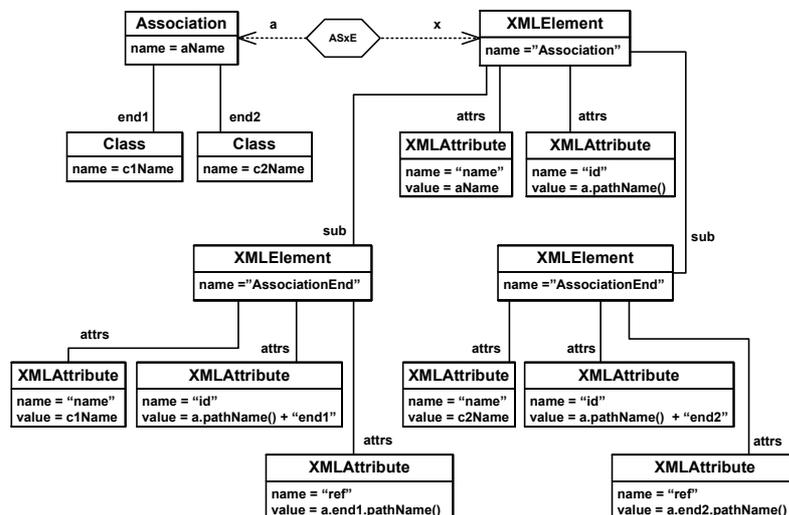


Fig. 10. Transformation of Association

Figure 10 shows the relation `ASxE` for `Association`. This is more involved than the previous relations as an association is comprised of two association ends which also need to be related to XML. Note that it is not the model elements the association ends reference that are related, but rather the references themselves. This is where the unique `id` we have forced onto XML elements comes into play. The UML association is thus related to the following chunk of XML:

```
<Association name=aName id=asc.pathName() >
  <AssociationEnd name=c1Name id=asc.pathName()+"end1"
    ref=asc.end1.pathName() />
  <AssociationEnd name=c1Name id=asc.pathName()+"end2"
    ref=asc.end2.pathName() />
</Association>
```

6.3 Putting it all together

In this section, we slot the individual relations in the previous sub-section together to form one overall transformation. This creates several new issues that are not present when the relations exist in isolation.

In general, additional constraints will be needed to ensure a relation is completely modelled. For example, a common issue is the need to ensure that all of the contents of an element (e.g. a UML package) are related to a corresponding element (e.g. an XML element). Figure 11 shows how the individual relations in the previous section slot together. Note the inheritance relationships in this figure. The transformation of the abstract ModelElement is captured by the abstract transformation MxE. The information inherited from the abstract ModelElement play a key role in the transformation of the individual elements. Similarly, the individual transformations are derived from the abstract transformation MxE defined on the ModelElement.

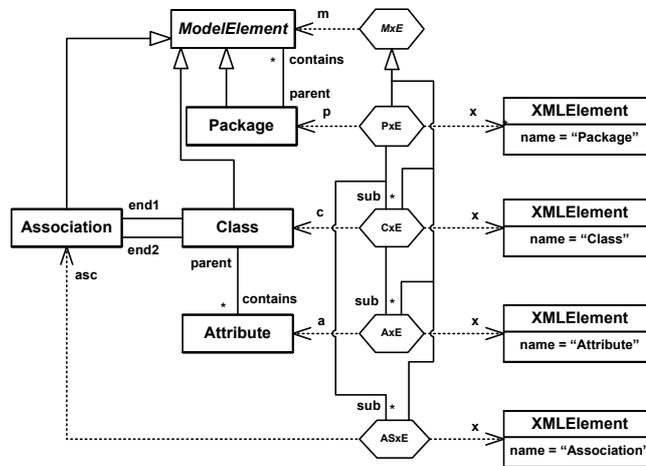


Fig. 11. Transformation composition

In order to ensure that all of the contents of an element `Package` are related to a corresponding `XMLElement` the following ‘round trip’ constraint is needed:

```
context PxE:
  self.p.contains->size() = self.sub->size() and
  self.p.contains->forall(m |
    self.sub->exists(cxe |
      cxe.m = m))
```

There are various ways that this constraint can be phrased to achieve the same end result. This particular method makes use of the fact that if the number of contents in `p.contains` is the same as `sub` and every element in `p.contains` has a transformation which is also a member of `sub` then the round trip is enforced. At the moment the user needs to explicitly enforce this constraint via OCL; we anticipate in the future adding a way to allow the user to specify that the round trip needs to be enforced, without forcing them to write out the entire constraint. The relevant constraint could be trivially generated from a boiler-plate – at the time of writing, unfortunately no OCL equivalent to macros or template programming such as found in [13] exists. We expect this shortcoming to be remedied in the relatively near future.

We now use the example object model in figure 12 to illustrate a complete transformation. This model consists of a package `pkg1` which contains two classes `cls1` and `cls2` and an association `assoc1` between these two classes. Furthermore, `cls1` contains an attribute `attr1`.

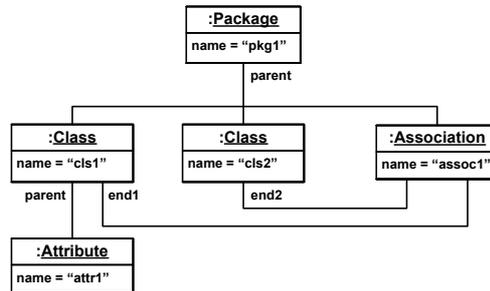


Fig. 12. Object model example to illustrate transformations

Figure 13 shows the complete relations, which combines several of the preceding relations, such as figure 9 and 11, and a few other similar relations which we do not have space for.

The end result of this transformation is the following XML output:

```

<Package name="pkg1" id="pkg1">
  <Class name="cls1" id="pkg1.cls1">
    <Attribute name="attr1" id="pkg1.cls1.attr1" />
  </Class>
  <Class name="cls2" id="pkg1.cls2">
  </Class>
  <Association name="assoc1" id="pkg1.assoc1">
    <AssociationEnd name="cls1" id="pkg1.assoc1.end1" ref="pkg1.cls1" />
    <AssociationEnd name="cls2" id="pkg1.assoc1.end2" ref="pkg1.cls2" />
  </Association>
</Package>

```

6.4 Validation of the generated XML against the DTD

A simplified DTD for the Class Diagram in the standard format is shown below:

```

<!DOCTYPE ClassModel [
<!ELEMENT Package
(Package|Class|Association)*>
  <!ATTLIST Package
    Name CDATA #REQUIRED
    id ID #REQUIRED>
<!ELEMENT Class (Attribute)*>
  <!ATTLIST Class
    Name CDATA #REQUIRED
    id ID #REQUIRED>
<!ELEMENT Attribute>
  <!ATTLIST Attribute
    Name CDATA #REQUIRED
    id ID #REQUIRED>
<!ELEMENT Association (AssociationEnd AssociationEnd)>

```

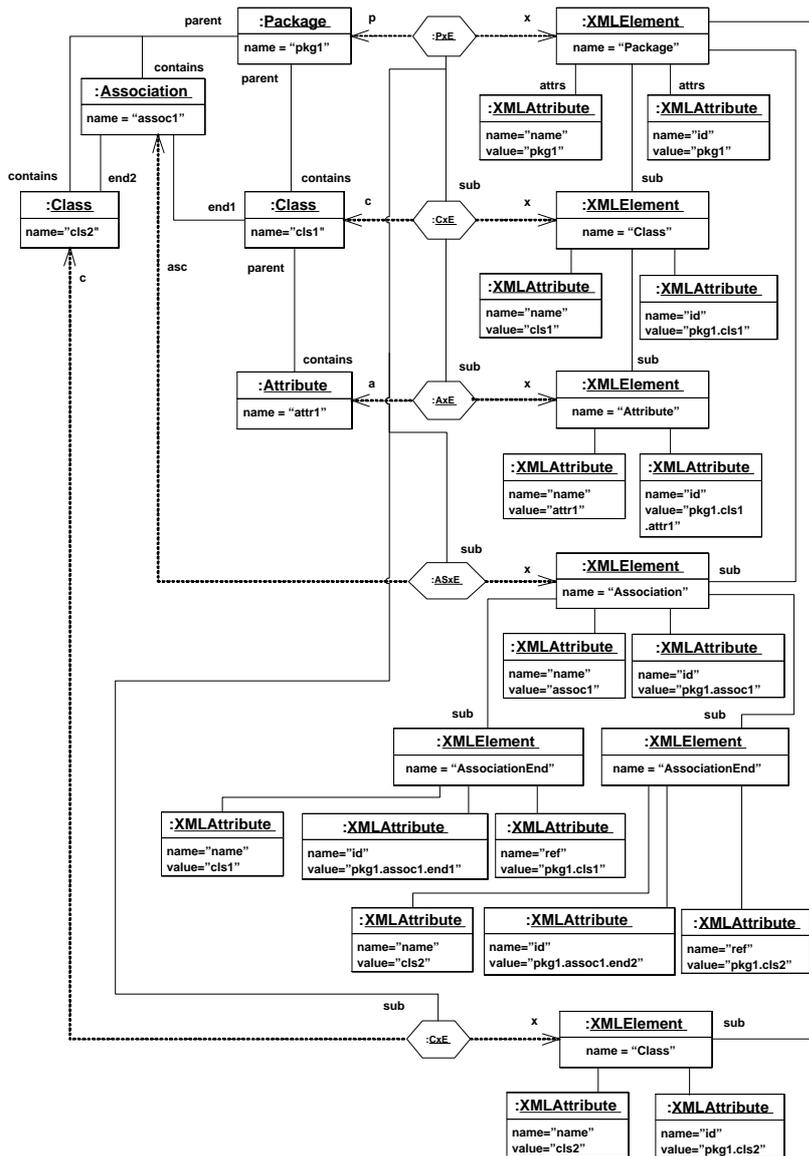


Fig. 13. Complete transformation of the example in figure 12

```

<!ATTLIST Association
  Name CDATA #REQUIRED
  id ID #REQUIRED>
<!ELEMENT AssociationEnd>
<!ATTLIST AssociationEnd
  Name CDATA #REQUIRED
  id ID #REQUIRED
  ref IDREF #REQUIRED>
] >

```

The DTD (Document Type Definition) represents the skeletal structure of the output generated for an XML representation of the class diagram. Thus, the DTD can be used for type checking of the output XML document to ensure that the generated XML is conforming to the Class Diagram's DTD. This is done by the means of Validation scripts. The scripts can be written in OCL or any other OCL like language.

6.5 Relationship between DTDs and the UML Diagrams

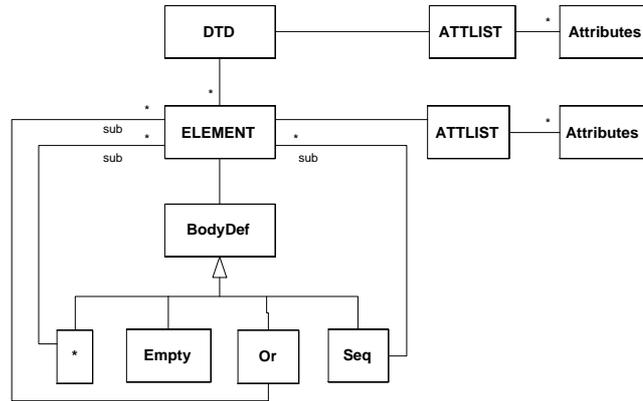


Fig. 14. A Simplified Meta Model for DTDs

Figure 14 shows a simplified meta model for DTDs. For simplicity, we ignore some attributes which are non relevant with this example.

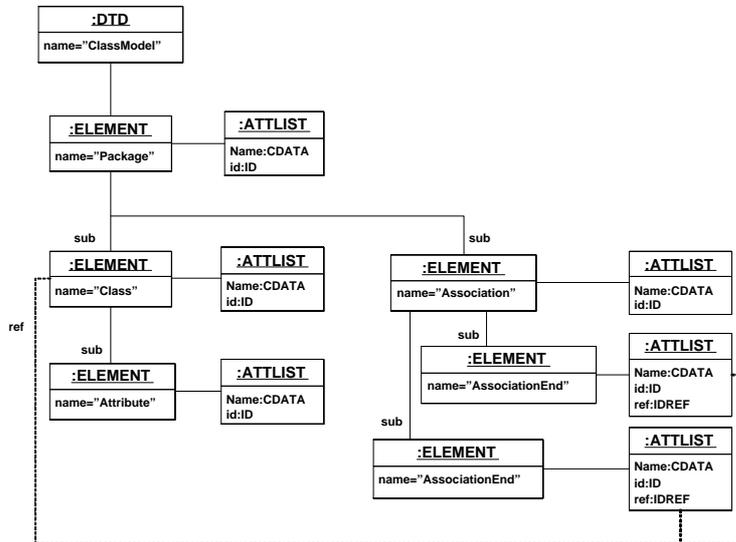


Fig. 15. DTD for Class Diagrams

Figure 15 shows an instance of the DTD Meta Model shown in figure 14. This is the model representation of the Class Diagram DTD shown in the previous subsection. Herein we define an XML Document named ClassModel having the *ELEMENTS* Package, Class, Attribute, Association and AssociationEnd. Package can contain any number of Elements of type Package, Class and Association. Each Element has two attributes (defined by the *!ATTLIST* keyword) *Name* and *ID* respectively. The Element AssociationEnd has an additional Attribute *ref* which is used to reference the class which forms the AssociationEnd as shown by the dotted association named *ref*.

On close observation of the Class Diagram Models in figure 8 and DTD meta model in figure 14, one comes across a set of relationship between the two models as shown in figure 16. Basically, each Meta object in the class diagram gets transformed into a corresponding ELEMENT in the DTD. The *contains* relation in the Class Diagram becomes the *sub* relation in the DTD. Note the transformation of Associations in figure 16(c). In this case,

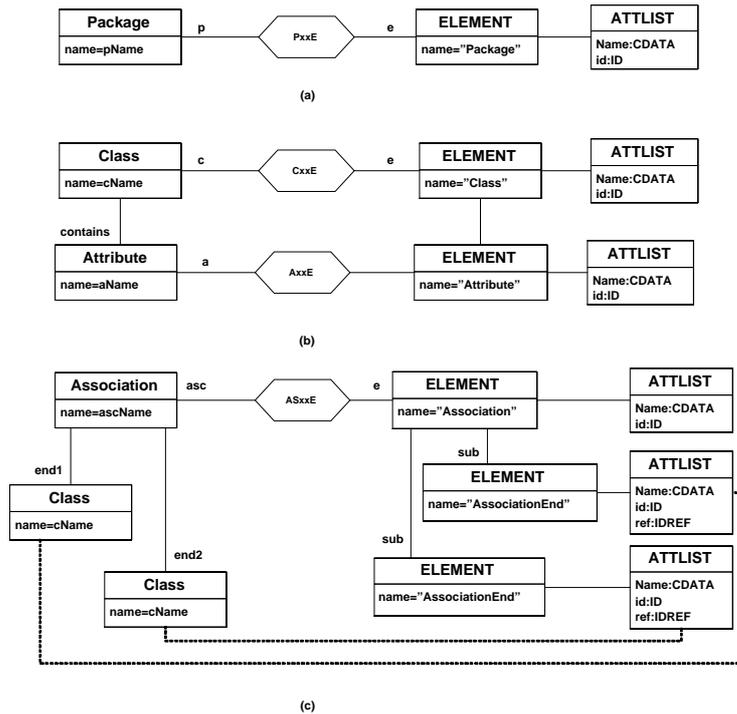


Fig. 16. Transformations of Class Diagrams to DTD

on transformation, the ATTLIST of AssociationEnds has an additional attribute *ref* which refers to the classes which the association links to.

This gives us a specification which can be used to generate DTDs from Class Diagrams or for that matter, from any UML Model.

6.6 Mapping

The example defined thus far is a relation – thus, being declarative, it is not necessarily executable. In our definition mappings, which are operational and potentially directed, transformations can be created which refine relations. Although we do not have sufficient space to write out a complete mapping which refines the relation we have created up until this point, we hope it is fairly trivial to imagine pseudo-code along the following lines which would take in UML and export XML:

```
function uml_to_xml(model:ModelElement):
  if type(model) == Package:
    xml = XMLElement("Package", id=model.pathName())
    for e in model.contains:
      xml.append(uml_to_xml(e))
  ...
```

Of course, this operational definition can be given in any programming language e.g. Java, Python or C++.

Another point of advantage is that, since the specification has been defined in terms of relations, it is possible to seek many alternative approaches to implementing this while

satisfying the relationship specification. Thus there can be several mapping choices for a given relation spec.

7 Other features

In this section we outline some other useful features of our definition of transformations.

7.1 Transformation Reuse

In order for transformations to scale up, it is essential to encompass features for reusing existing transformations and composing further transformations from existing ones. Our proposal caters to this requirement in two different ways – transformations can be reused either through the specialization mechanism or by using a more powerful composition mechanism. A composite transformation is formed of a parent transformation and a number of component transformations which are linked to the parent via logical connectives such as and, etc. The example described in this paper reuses transformations by specializing the MxE transformation defined on the ModelElement (figure 11).

7.2 Inter Transformability

Applying the conclusions drawn in subsection 6.5 to the figure 7, it becomes possible that - given any two of the DTD, XML or Class Diagrams, one can verify its correctness with respect to the third. For example, given the Class Diagram and the DTD, it is possible to verify that the XML is representative of the Class Diagram and conforms to the DTD specifications. Or, given the DTD and the XML document, one can verify that the Class Diagram is representative of the XML document.

There is also the possibility of generating the third given any two of them. for example, given the DTD and the XML Document, one can generate the Class diagram using a set of transformation specifications.

8 Conclusions

We originally motivated the need for a practical definition of transformations to allow models to be manipulated; this need is enshrined in the OMG QVT RFP. We then outlined our approach to transformations, and presented a non-trivial example. To summarize, our solution provides: the ability to express transformations as both relations and mappings; standard pattern languages for both relations and mappings; powerful mechanisms for reusing transformations and for composing transformations; a succinct definition in two parts utilizing an infrastructure – the simple semantic core, and a superstructure – where the rich end-user constructs exist.

The future for model transformations is hard to precisely predict since it is undoubtedly the case that we are still in the early stages of model transformation technology. We expect approaches such as the one we outline in this paper to be further enhanced and, as real world experience in the area develops, to evolve in different directions. We also expect that in the future specific transformation language variants will be created to handle particular

problem domains; nevertheless we feel that most of the fundamental concepts, as outlined in this paper, will hold true no matter the type of transformation involved.

This research was funded by a grant from Tata Consultancy Services. The authors would also like to thank Dr James Willans and Paul Sammut of University of York and Mr Girish Maskeri of Tata Consultancy Services for their invaluable help with this paper.

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