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A model driven approach to building implementable 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.

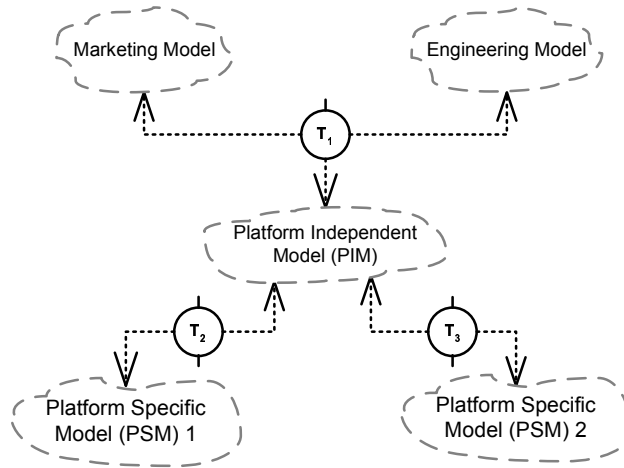


Fig. 1. Transformations and MDA

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:

- Integrating the components of a horizontal direction in a federated model. This is the example used in figure 1
- 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.

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.

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.

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 revised submission [9] to the QVT RFP.

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.

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 and can return values. Mappings can refine any number relations, in which case the mapping must be consistent with the relations it refines.

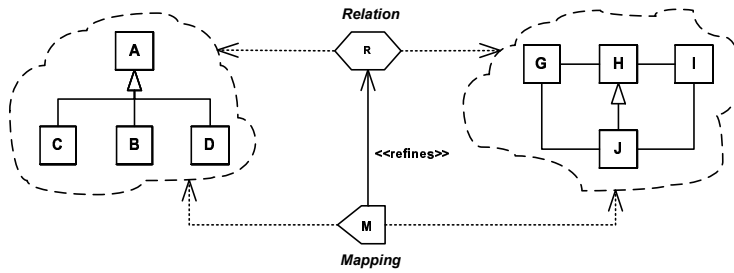


Fig. 2. A high level relation being refined by a directed mapping

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.

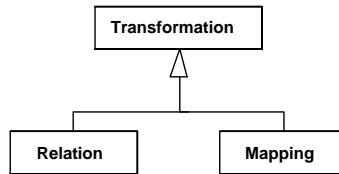


Fig. 3. Transformations, relations and mappings in the MOF hierarchy

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 identification and separation of transformation specifications and implementations, as relations and mappings respectively, gives several benefits to the modeller. These include giving the modeller the ability to:

- use relations in the initial stages of system development when implementation details may not have been fully decided upon. This allows transformations to be concretely discussed without an over-commitment to implementation details.
- write multiple mappings, possibly in completely different programming languages, which refine a single relation.
- construct a relation from a pre-existing mapping to tease out details which would otherwise be lost in the melange.

We also propose a standard language (MTL - Model Transformation Language) for relations and mappings. MTL utilizes pattern matching as one of the key factors in allowing powerful transformations to be created. Providing a single language for relations and mappings is advantageous for several reasons, but most noticeably for lowering the entry barrier to transformation use. MTL comes in both graphical and textual forms, the graphical form being most useful (as with most diagrams) when used as an abstraction of the textual form.

4.2 Pattern Languages

In order to facilitate transformations we define powerful a pattern matching language which is utilized by MTL. Pattern matching is a proven concept within transformation systems such as XSLT [W3C99] and textual regular expressions ‘a la Perl. The essential idea behind pattern matching is to allow the succinct expression of complex constraints on an input data type; data which matches the pattern is then picked out and returned to the invoker. MTL allows model fragments to be matched against meta-model patterns and used in transformations. Pattern languages are inherently a compromise between expressivity on the one hand, and brevity and legibility on the other. As is the case with most pattern languages, the pattern language we propose is not always the best way of expressing aspects of a particular transformation. To that end, domains in our standard relations and mappings languages are comprised of patterns and conditions. By utilizing conditions, arbitrarily complicated expressions can be specified to augment patterns. Furthermore, a separate condition is scoped over all domains which allows domains to be related to one another in a natural way. The general form of a relation when written in textual form is thus:

```
relation R { domain { pattern-1 when condition-1 }
  ...
  domain {pattern-n when condition-n }
  when { condition }
}
```

The final condition is effectively a global condition which scopes over all domains. A relation is called with a number of arguments corresponding to its number of domains; each argument is either a single element, or it is a choice. A choice is a data set which contains zero or more objects, each of which may be tested to see if some combination of candidates satisfies the transformation choices come in both unordered and prioritised forms. The relation is only satisfied when all domains are satisfied. This is more complex than it may initially seem as there can be constraints which hold across more than one domain. Thus an arbitrary object o may satisfy one domain but cause another to fail; the semantics of MTL ensure that all domains must be satisfied, which means that a runtime engine may have to try different combinations to ensure the relation is satisfied.

A specific example involving patterns and conditions is the following:

```
relation IncreasingWisdom {
  domain { (Person)[name = n, age = a, wisdom = w1]
    when a + 1 < 13 or a + 1 > 19 }
  domain {(Person)[name = n, age = a + 1, wisdom = w2] }
  when { w2 > w1 }
}
```

Intuitively, this example checks that a birthday brings with it increased wisdom, except during the teenaged years when this is not always the case. $(Person)[name = n, age = a, wisdom = w1]$ when $a > 18$ is an example of an object pattern, which take the general form of:

```
(Class, self)[label1 = expr1, ... , labeln = exprn]
```

Class is the class the object must be an instance of, self is a variable which is used to refer to the object and the object pattern consists of zero or more entries. An object pattern will match successfully against any object which is an instance of Class and whose fields

all match successfully against the object patterns fields note that the object pattern can specify a subset of the field which Class defines, although it cannot define more. The pattern language contains many other constructs, such as set and sequence patterns, and patterns can nest within patterns giving huge flexibility [9].

4.3 Differences between relations and mappings

Whereas a relation is a specification of a transformation which can check two models for conformance with each other with respect to the relation, a mapping is an implementation that can be run on an input data model to produce an output data model. Mappings take the general form of:

```
mapping M {
  domain { pattern-1 when condition-1 }
  ...
  domain {pattern-n when condition-n }
  when { condition }
  body { expression }
}
```

Although a mapping may have a number of domains, as do relations, there is a fundamental difference to the way multiple domains are used with mappings and relations. With mappings, all the domains are effectively input arguments to the mapping which, providing the input data satisfies the domains, executes the body of the mapping to produce output. A mapping can refine one or more relation, which essentially means that the mapping must be consistent with the relations: in other words, the relations the mapping refines are effectively pre and post conditions for the mapping. There is no implication that a mapping is the only refinement of a relation multiple different mappings may refine the same relation. Mappings which refine trivial relations often look very similar because of the intentionally close syntactic correspondence between object expressions and patterns.

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 simply consists of a number of domains and an overall constraint, mappings also have an action body. A practical example is a mapping `IncreasingWisdomMapping` which is a refinement of the relation `IncreasingWisdom` given in subsection 4.2:

```
mapping IncreasingWisdomMapping refines IncreasingWisdom {
  domain { (Person)[name = n, age = a, wisdom = w1]
           when a + 1 < 13 and a + 1 > 19 }
  body {
    p = new Person()
    p.name = n
    p.age = a + 1
    p.wisdom = w1 + 5
  }
}
```

Note how the only one of the two domains of `IncreasingWisdomMapping` has survived into the mapping: the second domain is effectively replaced by the body of the mapping.

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*.

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 [11].

Compared to the infrastructure, the superstructure [9] contains a much higher-level set of transformation types and is suitable for end users.

5.1 Concrete syntax

Our solution defines a graphical concrete syntax for transformations. Figure 4 lists the most important notations.



Fig. 4. Concrete Syntax for transformations

6 Transformation Reuse

Our proposal allows two means by which transformations can be reused. They are as follows:

6.1 Transformation Composition

The submission provides various composition operators which allow complex transformations to be built up from smaller transformations. They come in both unary and binary flavours and include operators such as *and*, *not* and *or*. To give a very simple example, an *and* composition would require all the individual components to hold for the composite relation to hold.

6.2 Sub-Transformation

This form of reuse involves one transformation calling another (sub) transformation. This usage typically occurs in *when* condition.

7 An example

In order to illustrate the salient features of our approach, in this section we present an example between simplified UML models and RDBMS models.

7.1 The example model

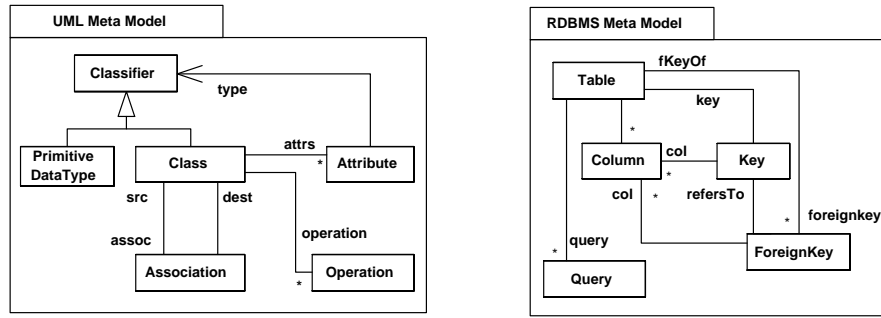


Fig. 5. The example meta-model

Figure 5 (left hand side) shows a very simplified model of UML Class diagrams which we will use to illustrate our approach. It consists of a *Class* having a set of *Attributes* and *operations*. The attributes can be of type *PrimitiveDataType* or, of type *Class*. Classes also have *Associations* with other classes. *Note: For the purposes of our current example we have assumed the attributes to be of type PrimitiveDataType only.*

Figure 5 (right hand side) shows a simplified RDBMS model. It consists of a *Table* having a set of *Columns*, a primary *Key*, *ForeignKeys* and *Queries*. The *Key* comprises columns which are of the kind *primary*. *Queries* are performed on *Tables* to either extract information from it or, to update some information.

In the rest of this section, we shall gradually build up the transformation between the UML model and the RDBMS model from a number of small pieces.

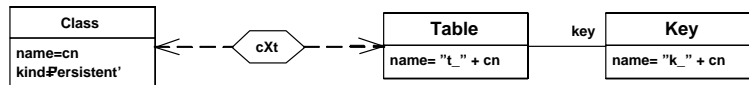


Fig. 6. A UML Class to Table relation

Figure 6 shows the relation *cXt* between Classes and Tables. Herein, each class of *kind = persistent* gets transformed to a corresponding Table and a Key (primary) element having the same name as the class, but prefixed with a "t_" and "k_" respectively (The naming may be altered to suit the local database naming conventions). This relation may be represented textually as follows:

```

relation cXt{
  domain {(Class)[ name = cn, kind = "persistent" ]}
  domain {(Table)[ name = "t_" + cn ,
                  key = (Key)[ name = "k_" + cn ]]}
}

```

Figure 7 captures the relation *atXcol* between Attributes of the class and the columns of the table. Basically, each attribute of the class gets transformed to a corresponding column of the table. The *dataType* of the column is typically set to either *Number* or *Varchar* depending on the type of the attribute. The textual representation is as follows:

```

relation atXcol{
  domain { (Attribute)[ name = attN, kind = k,

```

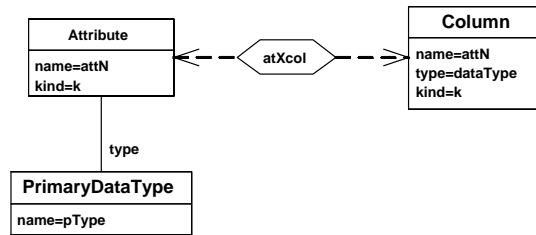


Fig. 7. Attributes to Columns relation

```

                                type = (PrimitiveDataType)[ name = pType] ]
}
domain { (Column)[ name = attN, kind = k, type = dataType ] }
when { dataType = if (pType = 'Integer') 'number' else 'varchar' }
}

```

The above relation is valid in the case of Attributes of type PrimitiveDataType only.

In the case of attributes of type Class, the type Class is broken down further into its attributes, and each individual attribute of the Type Class is added to the generated table as a column with an altered name as per the naming convention. The columns which are generated are of a type (i.e. datatype) corresponding to the type PrimaryDataType only.

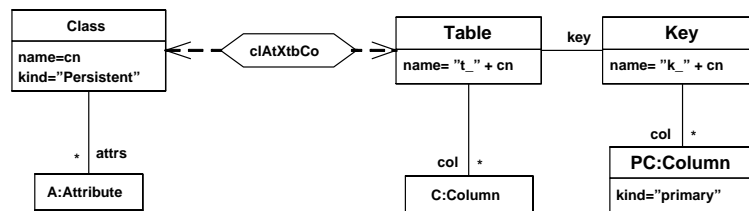


Fig. 8. Classes and Attributes relation

Figure 8 shows the combined view of the transformation of Classes and Attributes. Note that attributes of the *primary* kind, apart from being transformed into Columns, result in an association with the *Key* object of the table as well. This is textually (*clAtXtbCo*) represented as follows:

```

relation clAtXtbCo{
  domain { (Class)[ name = cn, kind = "persistent", attrs = A] }
  domain { (Table)[ name = "t_" + cn,
                    col = C,
                    key = (Key) [ name = "k_" + cn, col = PC] ] }
}
when {
  conjunct( A->forall(a | AtXcol(a, C.tochoice())),
            C->forall(c | AtXcol(A.tochoice(), c)),
            PC = C->select(c | c.kind = 'primary') )
}
}

```

Function *tochoice()* is a function that returns the member elements of the set as a choice. A *choice* is basically a container of objects - the relation will attempt to find a combination of objects from different domains which satisfy the relation.

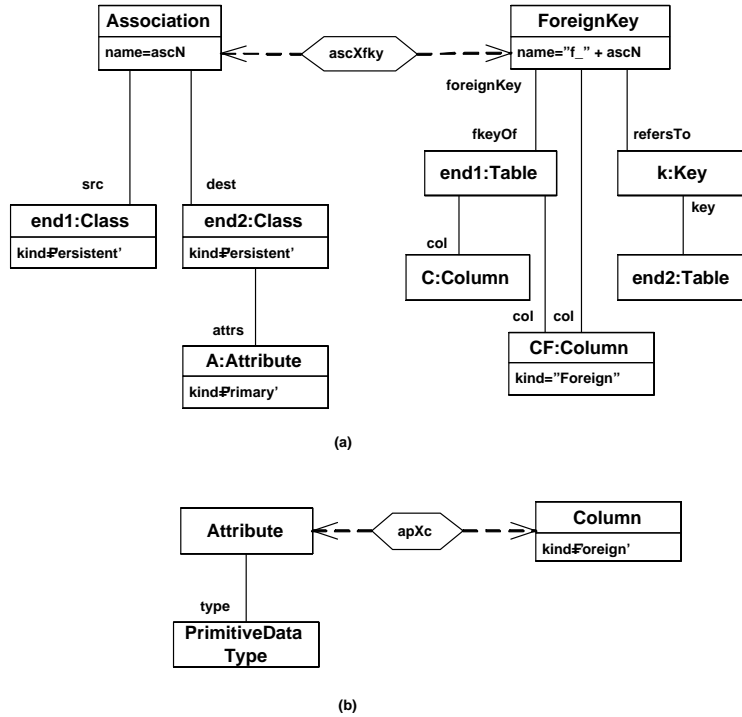


Fig. 9. Transformation of Associations

Transformation of Associations, as shown in figure 9(a) is a little less straightforward compared to the other transformations which have been covered so far. In this case, the *ForeignKey* element is introduced to relate the two tables corresponding to the two classes that the association relates. We assume *src* to represent the source of the association and *dest* to represent the destination of the association. The transformation results in a Foreign key being defined for the Table corresponding to the source class. This foreignKey refers to the key of the table corresponding to the destination Class of the association. All the primary key columns of the destination class are added to the source table with the column kind being set to *foreign* (figure 9(b)). This relation is textually represented as follows:

```

relation ascXfkey{
  domain { (Association)[ name = ascN, end1 = src,
                          end2 = (Class, dest)[ attrs=A ] ]
}
  domain { (ForeignKey)[ name = "f_" + ascN,
                        fKeyOf = (Table, srcTbl) [ col = C ],
                        refersTo = (Key, k)[ keyOf = destTbl ],
                        col = CF ]
}
  when {
    conjunct( cXt(src, srcTbl),
              cXt(dest, destTbl),
              ((A->select(a | a.kind='Primary'))->forall(at| atXcol(at,
                                                                CF.tochoice()))),
              (CF->forall(cf | atXcol((A->select(a |
                                                                a.kind='Primary').tochoice(), cf)))) )
  }
}

```

Figures 6 through to figure 9 show the building blocks based on which a UML model is transformed into a corresponding RDBMS model. Thus, the final RDBMS model will be a composition of the above mentioned basic transformations. The textual representation of the complete relation *clsAttrAscXtblColFkey* is as follows:

```

relation clsAttrAscXtblColFkey{
  domain { (Class)[ name = cn, kind = "persistent",
                   attrs = A , assoc = ASC]
  }
  domain { (Table)[ name = "t_" + cn,
                   col = C,
                   foreignKey = F,
                   key = (Key) [ name = "k_" + cn, col = PC ] ]
  }
  when {
    conjunct( A->forAll(a | AtXcol(a, C.tochoice())),
              PC = C->select(c | c.kind = 'primary'),
              C->forAll(c | AtXcol(A.tochoice(), c)),
              ASC->forAll(asc | asXf(asc, F.tochoice())),
              F->forAll(f | AtXcol(ASC.tochoice(), f)) )
  }
}

```

7.2 An example instance model

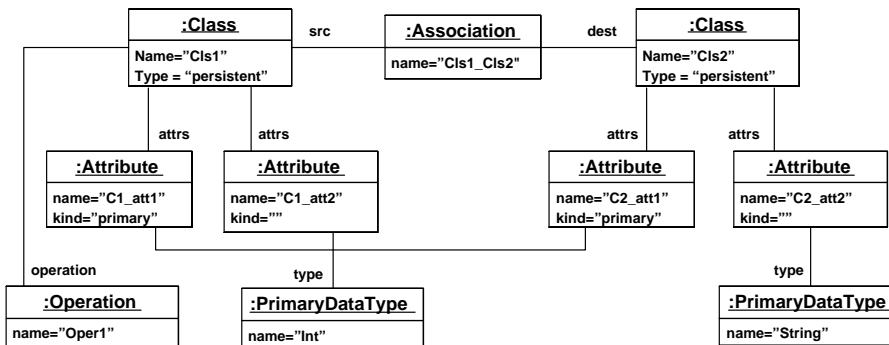


Fig. 10. An Example UML Model

We now illustrate the transformation by means of an actual example. Figure 10 represents an example UML model. It consists of two classes *Cls1* and *Cls2* having two attributes each as shown in the figure. As mentioned earlier, for the purposes of our illustration we will be specifying Attributes to be of the type *PrimaryDataType* only. The Attribute *C1_att1* of Class *Cls1* as well as Attribute *C2_att1* of Class *Cls2* have their kind set to *primary*. *Cls1* has an operation *Oper1* attached to it. *Cls1* and *Cls2* are also linked together by an *Association* as shown in the figure.

Figure 11 shows the resultant RDBMS model of the example UML model shown in figure 10. Note the foreign key relationship *f_Cls1_Cls2* which is established between the two classes to capture the association. Thus table *t_Cls1* has a foreign key relationship which refers to the Key *Cls2* of Table *t_Cls2* and the key column *C2_att1* of table *t_Cls2* gets added as a column with *kind = "foreign"* into the table *t_Cls1*.

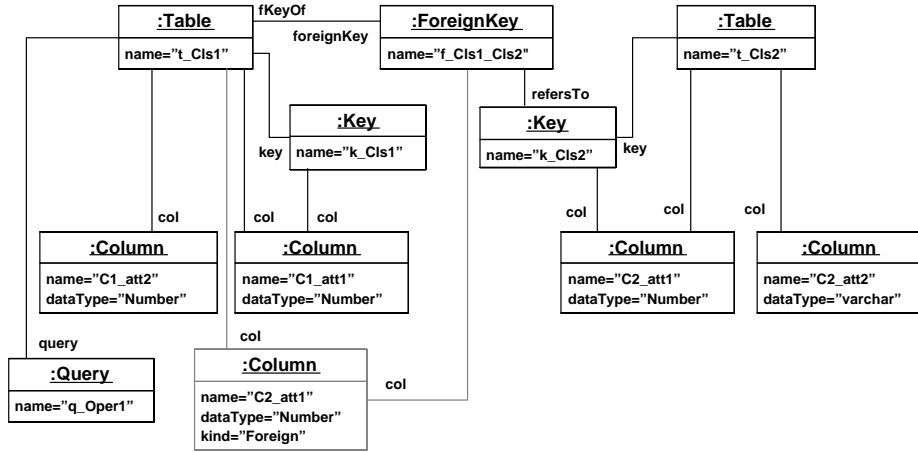


Fig. 11. The resultant RDBMS Model

7.3 Creating a Mapping

The example so far dealt with the relation between the UML Model and the RDBMS Model. In other words, given a UML model and a RDBMS model, we can check them using the relations specifications to see if they are valid transformations of each other.

However if we wanted to generate RDBMS model, given the UML model, then we would have to refine the specifications and create an implementation which can take in the UML model and generate an RDBMS model out of it. If one wished to actually transform a UML model to RDBMS and back again, then the relation would have to be refined to two separate mappings to implement it. As mentioned earlier in subsection 4.3, in the case of mappings, the second (target) domain gets substituted by an action body which implements the transformation based on the input domain.

We provide a mapping for a small subsection of the transformations example in subsection 7.1 consisting of Classes and Attributes only.

Consider the relation between Classes and Tables - cXt shown in subsection 7.1. A corresponding mapping is as follows:

```

mapping M_cXt refines cXt{
  domain {(Class)[ name = cn, kind = "persistent" ]}
  body {(Table)[ name = "t_" + cn ,
                 key = (Key)[ name = "k_" + cn ]]
  }
}

```

Herein, the second domain (corresponding to table) is replaced by a body which contains an expression which creates the Table and the Key elements as per the specifications. This particular mapping is very simple.

Below we show a mapping of the relation $atXcol$ which involves *if* conditions in the *when* block:

```

mapping M_atXcol refines atXcol{
  domain { (Attribute)[ name = attN, kind = k,

```

```

        type = (PrimitiveDataType)[ name = pType ] ]
    }
    body { (Column)[ name = attN,
                    kind = k,
                    type = if (pType = 'Integer') 'number' else 'varchar' ] }
}

```

In this mapping, the *when* clause of the relationship containing the *if else* assignment has been appropriately modified and introduced in the expression of the *body* to set the *type* of the column.

Moving onto a little bit more complex mapping, we now include a mapping for the relation *clAtXtbCo* between Classes and Attributes and their corresponding Tables and Columns from subsection 7.1:

```

mapping M_clAtXtbCo refines clAtXtbCo {
  domain {(Class)[ name = cn, kind = "persistent", attrs = A]}
  body { (Table,t) [ name = "t_" + cn,
                    col = A->iterate(a, cols = Set{} |
                                   cols->including(M_atXcol(a)) )
                    key = (Key)[ name = "k_" + cn,
                                   col = t.col->collect( c |
                                                         c.kind = "primary" )] ]
  }
}

```

Herein, each attribute is iterated through and mapped to a column using the submapping *M_atXcol*. Similarly, the keys are mapped after selecting the columns which are of kind *primary*.

This mapping transforms a given Class and Attribute model to a corresponding RDBMS model. In order to perform a transformation from an RDBMS model to a UML model a reverse mapping would have to be defined. However, all these transformed models can be checked for conformance to the transformation specifications using the relation specifications which we have defined in subsection 7.1 .

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 involving relations and then refined it to mappings which could be used to generate transformed models from a source model. 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.

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.

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