Query/Views/Transformations

An introduction to the MOF 2.0 QVT standard with focus on the Operational Mappings

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Context of this work

- The present courseware has been elaborated in the context of the MODELWARE European IST FP6 project (http://www.modelware-ist.org/).

- Co-funded by the European Commission, the MODELWARE project involves 19 partners from 8 European countries. MODELWARE aims to improve software productivity by capitalizing on techniques known as Model-Driven Development (MDD).

- To achieve the goal of large-scale adoption of these MDD techniques, MODELWARE promotes the idea of a collaborative development of courseware dedicated to this domain.

- The MDD courseware provided here with the status of open source software is produced under the EPL 1.0 license.
Prerequisites

To be able to understand this lecture, a reader should be familiar with the following concepts, languages, and standards:

- Model Driven Engineering (MDE)
- The role of model transformations in MDE
- UML
- OCL
- MOF
- Basic programming concepts
Outline

- Overview of QVT
- QVT Requirements
- QVT Languages:
  - Relations
  - Core
- Presentation of Operational Mappings
  - Case Study: Flattening UML Inheritance Hierarchies
  - Basic Language Constructs
- Conclusions
Overview

- **QVT** stands for Query/Views/Transformations
- **OMG** standard language for expressing queries, views, and transformations on MOF models
- **OMG QVT Request for Proposals (QVT RFP, ad/02-04-10)** issued in 2002
- Seven initial submissions that converged to a common proposal
- Current status (June, 2006): final adopted specification, **OMG document ptc/05-11-01**
QVT Operational Context

- Abstract syntax of the language is defined as MOF 2.0 metamodel
- Transformations (Tab) are defined on the base of MOF 2.0 metamodels (MMa, MMb)
- Transformations are executed on instances of MOF 2.0 metamodels (Ma)
# Requirements for QVT Language

## Some requirements formulated in the QVT RFP

<table>
<thead>
<tr>
<th>Mandatory requirements</th>
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<tbody>
<tr>
<td>Query language</td>
<td>Proposals shall define a language for querying models</td>
</tr>
<tr>
<td>Transformation language</td>
<td>Proposals shall define a language for transformation definitions</td>
</tr>
<tr>
<td>Abstract syntax</td>
<td>The abstract syntax of the QVT languages shall be described as MOF 2.0 metamodel</td>
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<tr>
<td>Paradigm</td>
<td>The transformation definition language shall be declarative</td>
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<tr>
<td>Input and output</td>
<td>All the mechanisms defined by proposals shall operate on models instances of MOF 2.0 metamodel</td>
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<table>
<thead>
<tr>
<th>Optional requirements</th>
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<tbody>
<tr>
<td>Directionality</td>
<td>Proposals may support transformation definitions that can be executed in two directions</td>
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<tr>
<td>Traceability</td>
<td>Proposals may support traceability between source and target model elements</td>
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<tr>
<td>Reusability</td>
<td>Proposals may support mechanisms for reuse of transformation definitions</td>
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<tr>
<td>Model update</td>
<td>Proposals may support execution of transformations that update an existing model</td>
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QVT Architecture

- Layered architecture with three transformation languages:
  - Relations
  - Core
  - Operational Mappings

- Black Box is a mechanism for calling external programs during transformation execution
### Conformance Points for QVT Tools

<table>
<thead>
<tr>
<th>Language Dimension</th>
<th>Interoperability Dimension</th>
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<tbody>
<tr>
<td></td>
<td>Syntax Executable</td>
</tr>
<tr>
<td>Core</td>
<td></td>
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<tr>
<td>Relations</td>
<td></td>
</tr>
<tr>
<td>Operational Mappings</td>
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</tbody>
</table>

- **Language dimension** indicates the language a tool may execute
- **Interoperability dimension** indicates the syntax that a tool can read
- **12 possible conformance points**

*Note: Conformance to QVT is defined for tools and not for languages. The term “QVT compliant language” is not defined in the specification.*
QVT Languages

- Relations
  - Declarative transformation language
  - Specification of relations over model elements

- Core
  - Declarative transformation language
  - Simplification of Relations language

- Operational Mappings
  - Imperative transformation language
  - Extends Relations language with imperative constructs

QVT is a set of three languages that collectively provide a hybrid “language”. 
Overview of Relations Language

- Declarative language based on relations defined on model elements in metamodels
- Object patterns that may be matched and instantiated
- Automatic handling of traceability links
- Transformations are potentially multidirectional
- Supported execution scenarios:
  - Check-only: verifies if given models are related in a certain way
  - Unidirectional transformations
  - Multidirectional transformations
  - Incremental update of existing models
Overview of Core Language

- Declarative language based on relations defined on model elements in metamodels
- Simpler object patterns
- Manual handling of traceability links
- Equal expressivity compared to the Relations language
- More verbose than the Relations language
- Core and Relations support the same set of execution scenarios

Usage options:
- Simple transformation language
- Reference point for defining the semantics of the Relations language
Outline

- Overview of QVT
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- QVT Languages:
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  - Core
- Presentation of Operational Mappings
  - Case Study: Flattening UML Inheritance Hierarchies
  - Basic Language Constructs
- Conclusions
Operational Mappings Language

This lecture presents Operational Mappings in details based on an example case study

- Case study: Flattening UML class hierarchies
- Overall transformation structure
- Mapping rules
- Querying source models
- Object resolution operations
- Creating target objects
- Flow of control
- Other features
Case Study

Flattening UML class hierarchies: given a source UML model transform it to another UML model in which only the leaf classes (classes not extended by other classes) in inheritance hierarchies are kept.

Rules:
- Transform only the leaf classes in the source model
- Include the inherited attributes and associations
- Attributes with the same name override the inherited attributes
- Copy the primitive types
Source and Target Metamodel: SimpleUML
Example Input Model
Example Output Model

Course
- name : String

PhDStudent
- name : String
- ssn : String
- school : String

attends

Address
- street : String
- city : String

residesAt

Professor
- name : FullName
- ssn : String
- organizationName : String

residesAt

«primitive type»
- String

FullName
- firstName : String
- lastName : String

supervisor

carOwnership

Car
Model Transformation expressed in Operational Mappings Language

Overall structure of a transformation program:

```plaintext
transformation SimpleUML2FlattenSimpleUML(in source : SimpleUML
out target : SimpleUML);
```

**Signature:**
Declares the transformation name and the source and target metamodels.

**Entry point:**
The execution of the transformation starts here by executing the operations in the body of `main`

**Transformation elements:**
Transformation consists of mapping operations and helpers. They form the transformation logic.
Mapping Operations

- A mapping operation maps one or more source elements into one or more target elements
- Always unidirectional
- Selects source elements on the base of a type and a Boolean condition (guard)
- Executes operations in its body to create target elements
- May invoke other mapping operations and may be invoked
- Mapping operations may be related by inheritance
Mapping Operations: Example (1)

- Consider the rule that transforms only leaf classes
  - Selects only classes without subclasses
  - Collects all the inherited properties
  - Creates new class in the target model

```plaintext
mapping Class::leafClass2Class(in model : Model) : Class
  when {not model.allInstances(Generalization)->exists(g |
    g.general = self)}
{
  name:= self.name;
  abstract:= self.abstract;
  attributes:=
    self.derivedAttributes()]->map property2property(self)->asOrderedSet();
}
```
Mapping Operations: Example (2)

Operation Signature and Guard

```
mapping Class::leafClass2Class(in model : Model) : Class
    when {not model.allInstances(Generalization)->exists(g | g.general = self)}
```

The Guard is an OCL expression used to filter source elements of a given type. The mapping operation is executed only on elements for which the guard expression is evaluated to true.
Mapping Operations: Example (3)

Operation Body

The predefined variable `self` refers to the source element on which the operation is executed.

name := self.name;
abstract := self.abstract;
attributes :=
    self.derivedAttributes() -> map property2property(self) -> asOrderedSet();

The left-hand side of the assignments denotes properties of the target element.

Invocation of helper derivedAttributes

The keyword `map` is used to invoke another mapping operation named `property2property` over the elements returned by the helper `derivedAttributes`.

The mapping operation body contains initialization expressions for the properties of the target element. When an operation is executed over a source element the `self` variable is bound to it and an instance of the target type is created. Then the operation body is executed.
Helpers

- Helpers are operations associated to a type that return a result
- Both primitive and model types can be used
- Helpers may be used to perform complex navigations over source models
- Helpers have:
  - List of input parameters
  - An executable body
- Helper types:
  - Side-effect free: Query helper;
  - With side effect over input parameters: Helper
The query derivedAttributes is a side-effect free helper defined on classes. It returns an ordered set of properties that contains the attributes defined in a given class and the attributes derived from its super classes. Derived attributes are overridden by the defined attributes with the same name. Note that this is a recursive helper. The variable self refers to the class on which the helper is executed.

```query
Class::derivedAttributes() : OrderedSet(Property){
    if self.generalizations->isEmpty() then self.attributes
    else
        self.attributes->union(
            self.generalizations->collect(g |
                g.general.derivedAttributes()->select(attr |
                    not self.attributes->exists(att | att.name = attr.name)
                )
            )
        )->flatten()
    )->asOrderedSet()
}
```
Invoking Mapping Operations

Assume we have a mapping operation property2property that simply copies a property of a source class to a property of the target class. The target class is already created by the previously shown rule leafClass2Class.

In order to invoke property2property on every attribute of the source class we use the notation "->map". It implies an iteration over a list of source elements.

The notation "object.map" invokes a mapping operation on object as a source element.

```
attributes:=
    self.derivedAttributes()->map property2property(self)->asOrderedSet();
```

```
mapping Property::property2property(in ownerClass : Class) : Property{
    name:= self.name;
    type:= self.type;
    owner:= ownerClass;
}
```
Resolving Object References

Assume that we write a mapping operation that transforms associations in the source model to associations in the target model. In the target model an association relates two classes derived from other two classes in the source model. To identify these two classes in the target model the transformation engine maintains links among source and target model elements. These links are used for resolving object references from source to target model elements and back.

An example of a mapping operation that transforms associations and uses resolution of object references:

```java
mapping Association::copyAssociation(sourceClass : Class) : Association {
    name:=self.name;
    source:=sourceClass.resolveByRule('leafClass2Class', Class)->first();
    target:= self.target.resolveByRule('leafClass2Class', Class)->first();
}
```

`resolveByRule` is an operation that looks for model elements of a given type (Class) in the target model derived from a source element by applying a given rule (leafClass2Class).
General Structure of Mapping Operations

```
mapping Type::operationName(((in|out|inout) pName : pType)* ) : (rName : rType)+
when {guardExpression}
{
  init {}
  population {}
  end {}
}
```

- **init {}**
  - init section contains code executed before the instantiation of the declared result elements.

- **population {}**
  - There exists an implicit instantiation section that creates all the output parameters not created in the init section. The trace links are created in the instantiation section.
  - population section contains code that sets the values or the result and the parameters declared as `out` or `inout`. The `population` keyword may be skipped. Population section is the default section in the operation body.

- **end {}**
  - end section contains code executed before exiting the operation.
Object Creation and Population

Apart from the implicit creation of objects in the instantiation section there is an operation for creating and populating objects in mapping operations.

Operation object:

```object
p : Property {
    name:= self.name;
    type:= self.type;
    owner:= ownerClass;
}
```
Operational Mappings is an imperative language. While many algorithms may be implemented just by a set of mapping operations that invoke each other and are supported by OCL expressions for navigation and iteration, there are cases where more sophisticated control flow is needed. The following imperative constructs are available:

- **Compute**
- **While**
- **forEach**
- **Break**
- **Continue**
- **If-then-else**
Features not Covered in the Lecture

- Packaging facilities:
  - transformation libraries
  - reuse of libraries

- Reuse facilities:
  - rule inheritance and merging
  - disjunctions of mapping operations

- Constructor operations

- Intermediate data

- Reusing and extending transformations

- Operation post condition: where clause

For more details consult the QVT specification: OMG document ptc/05-11-01
Conclusions (1)

- QVT: Query/Views/Transformations - the OMG standard language for model transformations in MDA/MDE;
- The issue of Views over models is not addressed;
- Query language based on OCL;
- A family of three transformation languages:
  - Relations: declarative language
  - Core: declarative language, simplification of Relations;
  - Operational Mappings: imperative transformation language that extends relations;
- Collectively QVT languages form a hybrid language;
Conclusions (2)

- Tool support is still insufficient (at the time of preparing of this lecture - June 2006);
- QVT is not proved yet in non-trivial industrial like scenarios;
- Many issues need further exploration:
  - Performance;
  - Testing;
  - Scalability of transformations;
  - Ease of use;
  - Handling change propagation;
  - Incremental transformations;
  - Adequacy of the reuse mechanisms;
Additional Materials

This lecture is accompanied by an implementation of the presented case study. The code, the documentation, and the example models are available from the MODELWARE web site.