The Art of Model Transformation with Operational QVT

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QVTO Key Concepts

Operational QVT (QVTO)

- operates with EMF models
- uses OCL for model navigation
- Main goal - model modification and transformation
- required an explicit and complete algorithm model-to-model mapping

QVTO structure

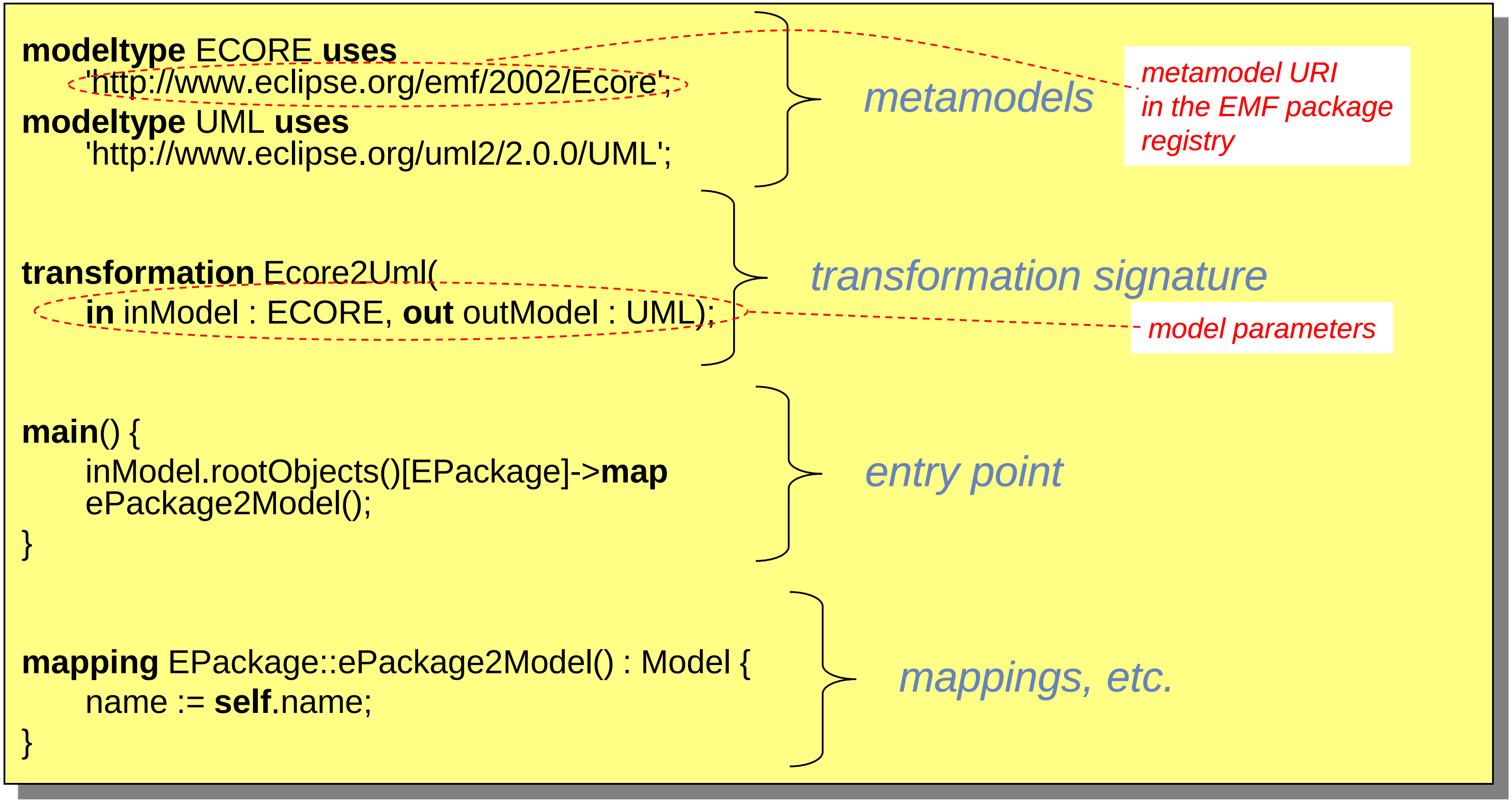
- QVTOperational package – general structuring elements and top-level constructions
- ImperativeOCL package – extension to OCL expressions and type system
- Standard Library

QVTOperational package

- Transformation declaration
- Imperative operations (mappings, helpers, queries, constructors)
- Intermediate data
- Object creation and update mechanism
- Trace resolution expressions

Operational Transformation 1

A simple transformation example



```
modeltype ECORE uses
      'http://www.eclipse.org/emf/2002/Ecore';
modeltype UML uses
      'http://www.eclipse.org/uml2/2.0.0/UML';


transformation Ecore2Uml(
      in inModel : ECORE, out outModel : UML);


main() {
      inModel.rootObjects()[EPackage]->map
      ePackage2Model();
}


mapping EPackage::ePackage2Model() : Model {
      name := self.name;
}
```

metamodels

metamodel URI in the EMF package registry

transformation signature

model parameters

entry point

mappings, etc.

Operational Transformation 2

The content of the transformation definition may be placed within the transformation element:

```
modeltype ECORE uses 'http://www.eclipse.org/emf/2002/Ecore';
modeltype UML uses 'http://www.eclipse.org/uml2/2.0.0/UML';

transformation Ecore2Uml(in inModel : ECORE, out outModel : UML) {
		main() {
				inModel.rootObjects()[EPackage]->map ePackage2Model();
		}

		mapping EPackage::ePackage2Model() : Model {
		    name := self.name;
		}
}
```

Imperative Operations

- define an imperative body
- enriched signature

Types of QVTO imperative operations

- – Entry operation
- – Mappings
- – Helpers
- – Queries
- – Constructors

Entry Operation

An *entry operation* is the entry point for the execution of a transformation.

```
main() {
        inModel.rootObjects()[EPackage]->map ePackage2Model();
}
```

Typically refers to model parameters and invokes top-level mappings.

Helpers and Queries

A *helper* is an operation that performs a computation on one or more source objects and provides a result. It is illegal to create or update object instances except for pre-defined types like sets, tuples, and for intermediate properties.

```
helper EPackage::someHelper1() : Set(String) {
	if (self.name = 'A') then {
		return Set {'B'};
	} endif;
	return Set {self.name};
}
```

A *query* is a “read-only” helper which is not allowed to create or update any objects.

```
query EPackage::getNameAtoB() : String {
	if (self.name = 'A') then {
		return 'B';
	} endif;
	return self.name;
}
```

```
helper EPackage::someHelper2() : Set(String) = Set{self.name};
query EPackage::getName() : String = self.name;
```

Constructors

A *constructor* is an operation that defines how to create and populate the properties of an instance of a given class.

```
constructor EClass::EClass(s : String, op : EOperation) {
    name := s;
    eOperations += op;
}
```

Calling the constructor:

```
new EClass(“AClass", new EOperation());
```

Mappings

A mapping between one or more source model elements into one or more target model elements.

```
<mapping> ::= <qualifier>* 'mapping' <param_direction>? (<context_type>::)? <identifier>
                              '(' <param_list>? ')' (':' param_list)? <mapping_extension>* <when>?
                              '{' <mapping_body> '}'
```

Most typical case:

```
mapping <context_classifier>::<mapping_name> ( <paramers> ) : <return_type> {
     <mapping body>
}
```

```
mapping ECORE::EPackage::ePackage2Package() : UML::Package {
     name := self.name;
}

ePackage.map ePackage2Package(); // calling a mapping for a single context
ePackages->map ePackage2Package(); // calling a mapping consequently for a collection of contexts
```

Mapping Parameters Direction Kind

```
mapping EPackage::someMapping(in a : EClass) : Package {
    name := self.name;
}

mapping EPackage::someMapping(in a : EClass, inout b : EAttribute) : Model {
  name := self.name + a.name;
  b.name := b.name + '123';
}


mapping inout  EPackage::ePackage2Package() : Package {
    name := self.name + ‘123’;
    self.name := result.name +  ‘456’;
}
```

Mapping parameter direction kind

- ***in*** – object passed for read-only access, the default direction
- ***inout*** – object passed for update, retains its value
- ***out*** – parameter receives new value (not necessarily newly created object)

Mappings – when clause

```
mapping EPackage::ePackage2Package() : Package
                        when {self.name <> null} {
    name := self.name;
}
```

WHEN-clause contains a Boolean condition

self.name = null
(condition not satisfied)

Invocation:

- in standard mode

when-clause acts as a guard which filters input parameters

```
a.map ePackage2Package();
```

- mapping not executed
- **null** returned

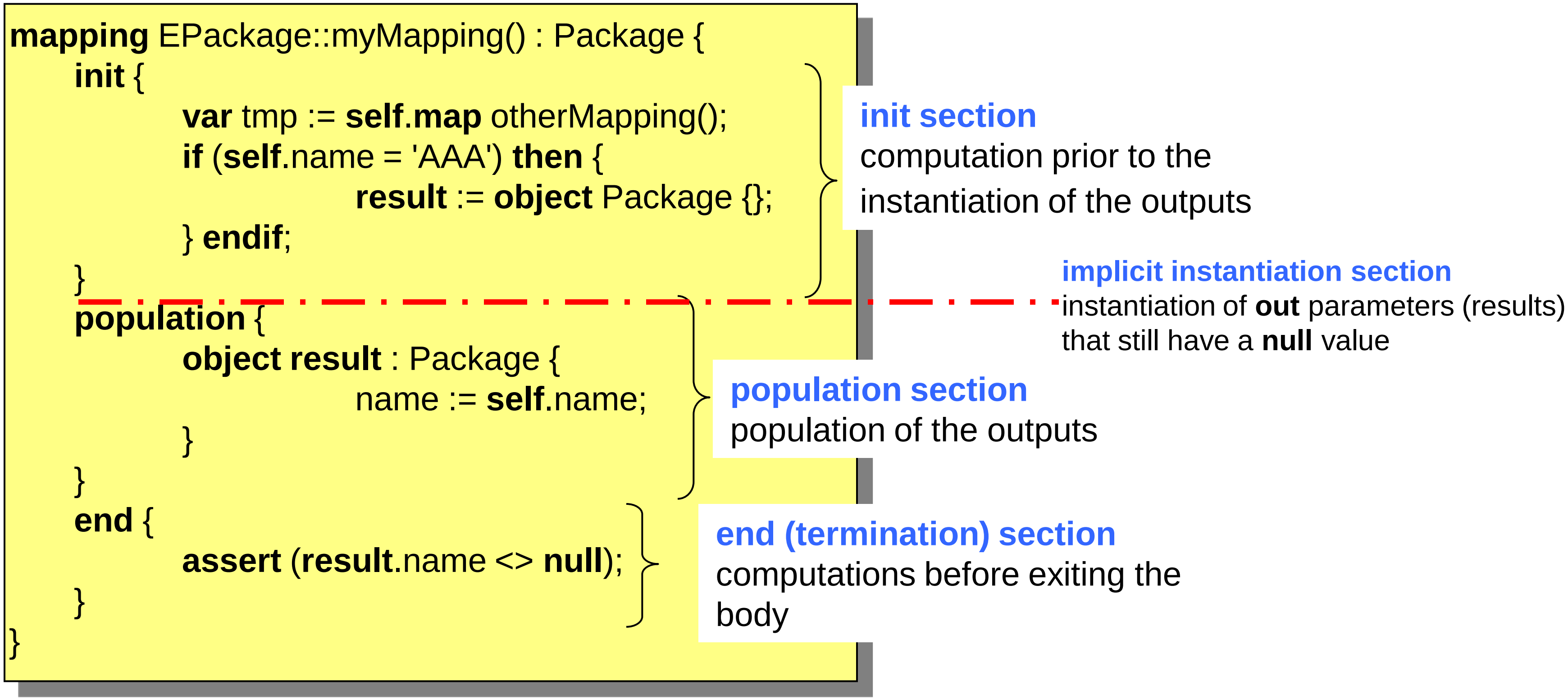
- in strict mode

when-clause acts as a pre-condition which must always hold

```
a.xmap ePackage2Package();
```

- mapping not executed
- exception thrown

Mapping Body – General Form



```
mapping EPackage::myMapping() : Package {
    init {
        var tmp := self.map otherMapping();
        if (self.name = 'AAA') then {
            result := object Package {};
        } endif;
    }
    population {
        object result : Package {
            name := self.name;
        }
    }
    end {
        assert (result.name <> null);
    }
}
```

init section
computation prior to the instantiation of the outputs

implicit instantiation section
instantiation of **out** parameters (results) that still have a **null** value

population section
population of the outputs

end (termination) section
computations before exiting the body

Predefined variables in mappings:

- **self** – refers to the context
- **result** – refers to the result

Mapping Body
Population Keyword Omitted

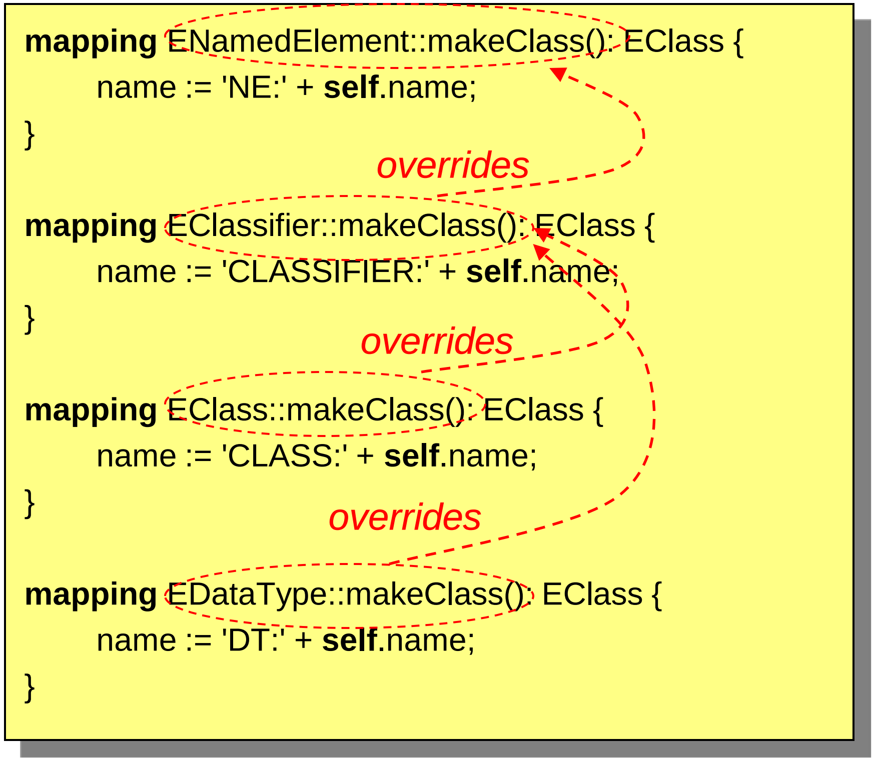
```
mapping EPackage::myMapping() : Package {
    init {
            var tmp := self.map otherMapping();
            if (self.name = 'AAA') then {
                        result := object Package {};
            } endif;
    }

    name := self.name;

    end {
            assert (result.name <> null);
    }
}
```

Direct access to properties of the result within the population section without the ‘population’ keyword!

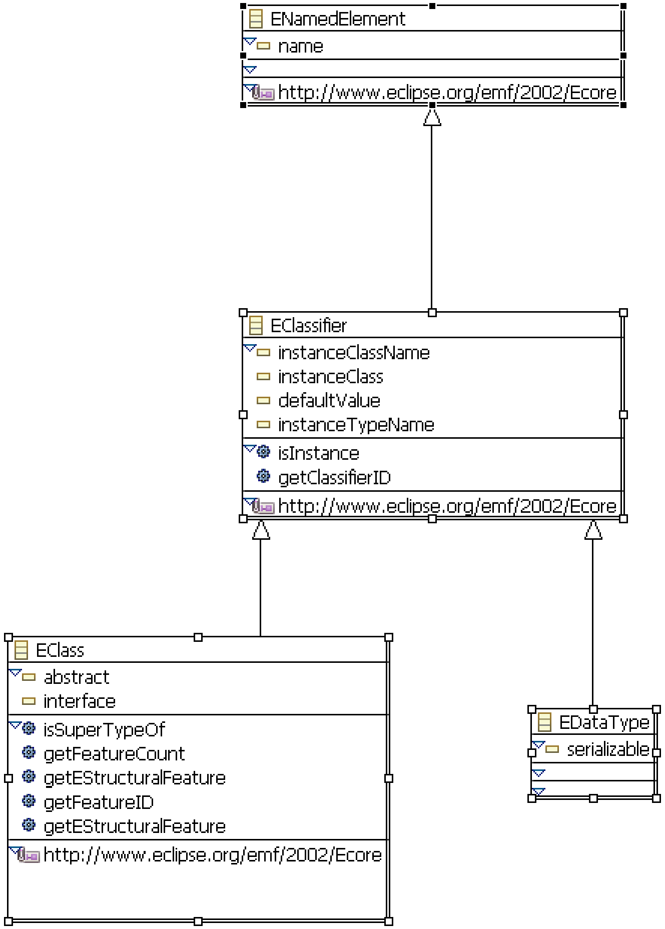
Omitted population keyword is the most typical case!

Overriding Mappings

Simple overriding:

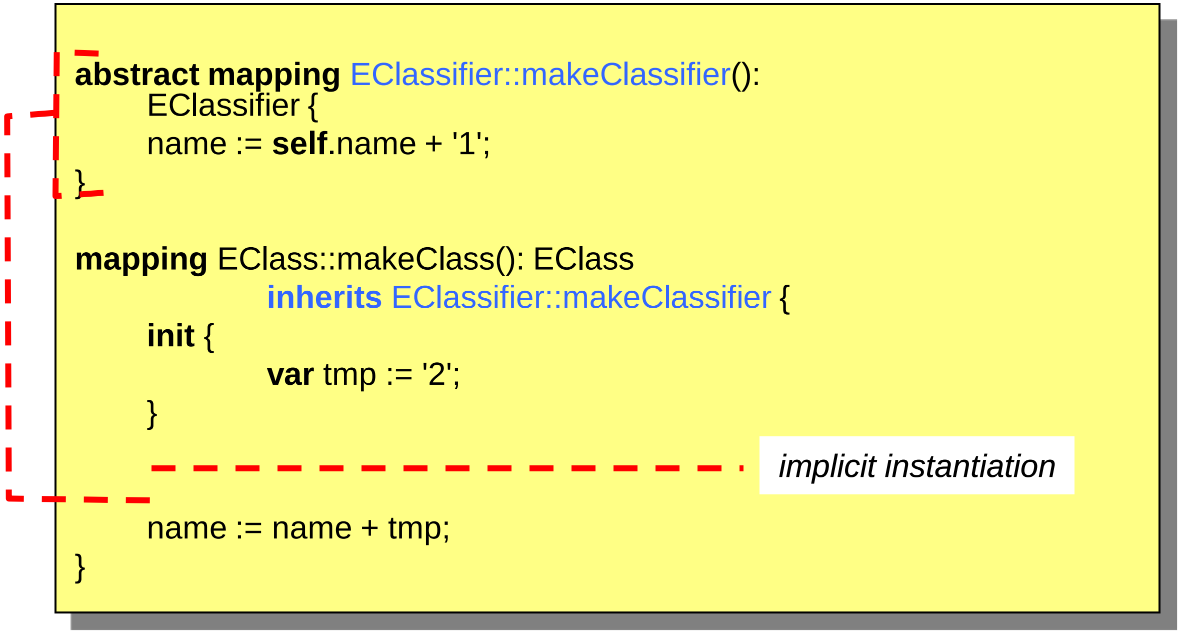


```
mapping ENamedElement::makeClass(): EClass {
      name := 'NE:' + self.name;
}
                        overrides

mapping EClassifier::makeClass(): EClass {
      name := 'CLASSIFIER:' + self.name;
}
                        overrides

mapping EClass::makeClass(): EClass {
      name := 'CLASS:' + self.name;
}
                        overrides

mapping EDataType::makeClass(): EClass {
      name := 'DT:' + self.name;
}
```



- *overrides*

Mapping Extension - inherits



```
abstract mapping EClassifier::makeClassifier():
        EClassifier {
        name := self.name + '1';
}

mapping EClass::makeClass(): EClass
                inherits EClassifier::makeClassifier {
        init {
                var tmp := '2';
        }

        name := name + tmp;
}
```

implicit instantiation

Execution flow:

- init section
  (of EClass::makeClass)
- instantiation section
  (of EClass::makeClass)
- inherited mapping(s)
  (EClassifier::makeClassifier)
- mapping population and
  termination sections
  (of EClass::makeClass)

Evaluation result:
result.name = self.name + ’12’

Mapping Extension - merges

```
abstract mapping EClassifier::makeClassifier(): EClassifier {
      name := name + '1';
}

mapping EClass::makeClass(): EClass
            merges EClassifier::makeClassifier {
      init {
            var tmp := '2';
      }
      name := self.name + tmp;
}
```

Execution flow:

- merging mapping (EClass::makeClassifier)
- merged mapping(s) (EClassifier::makeClassifier)

Evaluation result:
result.name = self.name + ’21’

Mapping Extension - disjuncts

```
mapping EClass::makeAClass(): EClass
    when {self.name <> null and self.name.startsWith('A')} {
            name := self.name + ‘A';
}

mapping EClass::makeBClass(): EClass
    when {self.name <> null and self.name.startsWith('B')} {
            name := self.name + ‘B';
}

mapping EClass::makeClass(): EClass
    disjuncts EClass::makeAClass, EClass::makeBClass {}
```

Execution flow:

- when-clauses of the disjuncted mappings are evaluated

  (- of EClass::makeAClass
  - of EClass::makeBClass)

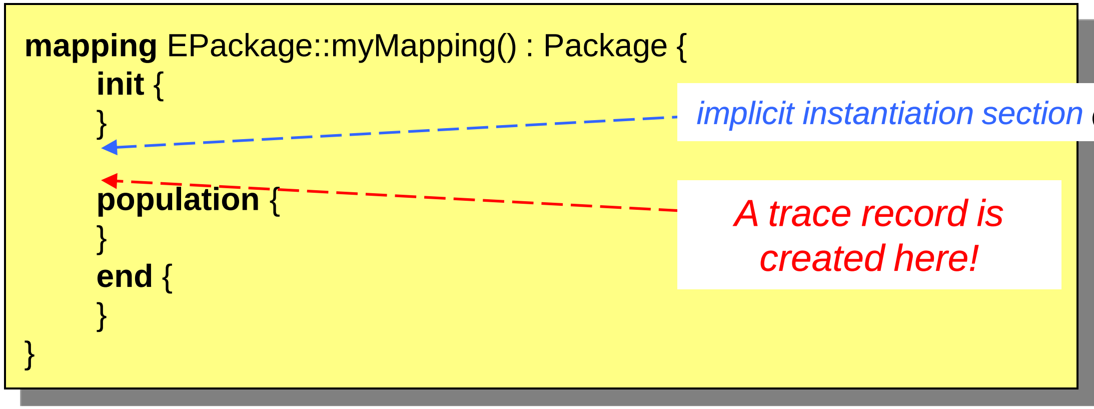
2. If all when-clauses are not satisfied **null** is returned
3. Otherwise, the first mapping with a **true** when-clause is executed

Evaluation results:

object EClass {name := ‘CClass’}.**map** makeClass() = **null**;
object EClass {name := ‘AClass’}.**map** makeClass().name = ‘AClassA’;
object EClass {name := ‘BClass’}.**map** makeClass().name = ‘BClassB’;

Traceability Concept

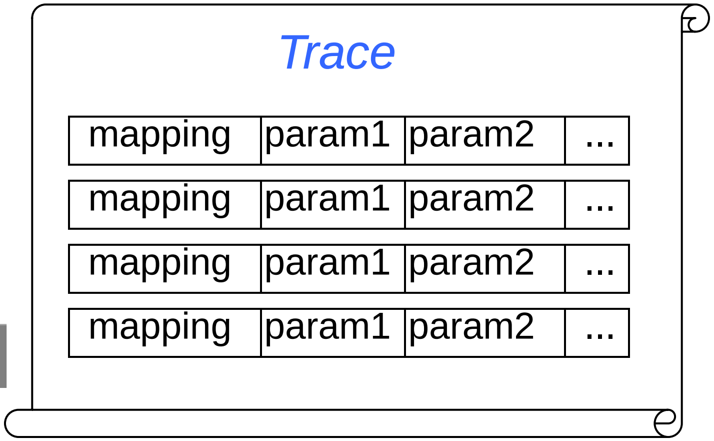
- Trace contains information about mapped objects
- Trace consists of trace records
- A trace record is created when a mapping is executed
- Trace records keep reference to the executed mapping and the mapping parameter values
- A trace record is created after the implicit instantiation section of the mapping is finished



```
mapping EPackage::myMapping() : Package {
        init {
        }

        population {
        }
        end {
        }
}
```

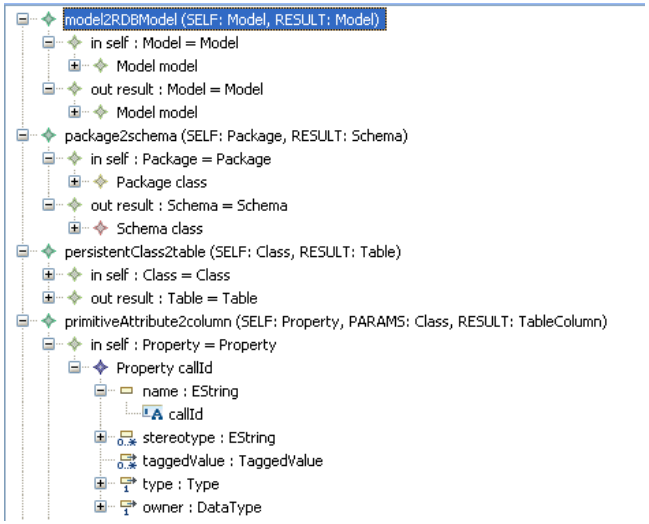
implicit instantiation section

A trace record is created here!



Trace

mapping	param1	param2	...
mapping	param1	param2	...
mapping	param1	param2	...
mapping	param1	param2	...



```
model2RDBModel (SELF: Model, RESULT: Model)
    in self : Model = Model
        Model model
    out result : Model = Model
        Model model
package2schema (SELF: Package, RESULT: Schema)
    in self : Package = Package
        Package class
    out result : Schema = Schema
        Schema class
persistentClass2table (SELF: Class, RESULT: Table)
    in self : Class = Class
    out result : Table = Table
primitiveAttribute2column (SELF: Property, PARAMS: Class, RESULT: TableColumn)
    in self : Property = Property
        Property callId
            name : EString
                callId
            stereotype : EString
            taggedValue : TaggedValue
            type : Type
            owner : DataType
```

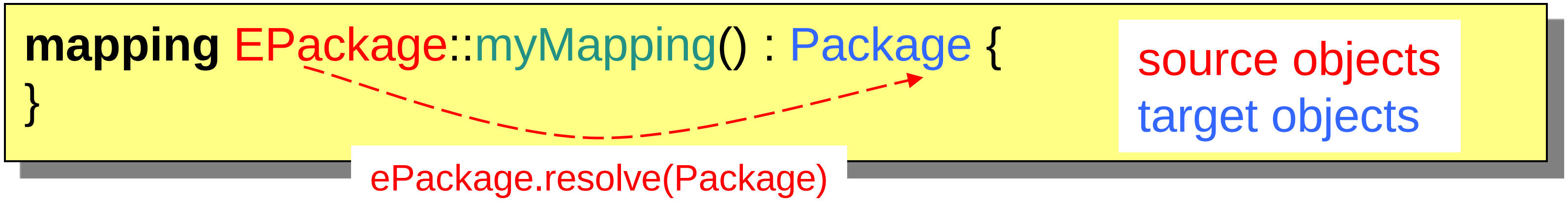
Usage:

- Prohibit duplicate execution with the same parameters
- Used in resolve expressions
- May be serialized after the transformation execution

Resolve Expressions 1

A *resolve expression* is an expression that inspects trace records to retrieve source or target objects which participated in the previous mapping executions.

- **resolve** – resolves target objects for a given source object
- **inv** (***invresolve***) – resolves source objects for a given target object
- **One** (***resolveOne***) – finds the first matching object
- **In** (***resolveIn***)– inspects trace records for a given mapping only
- **late** (***late resolve***) – performs resolution and assignment to some model object property after the transformation execution



```
mapping EPackage::myMapping() : Package {
}
```

source objects
target objects

ePackage.resolve(Package)

2^4=16 combinations, e.g. invresolveOne or late invresolveOneIn

Resolve Expressions 2

```
mapping EClassifier::c2c() : EClass {
            name := 'mapped' + self.name;
}

// somewhere in the code
var orig := object EClass { name := 'original' };
var mapped := orig.map c2c();

// in some other place
var res1 := orig.resolve(EClass);
var res2 := resolveoneIn(EClassifier::c2c, t : EClass
                                        | t.name.startsWith('mapped' );
var res3 := mapped.invresolveIn(EClassifier::c2c, EClass);
```

Filtering condition

- type
- boolean expression

Resolve expressions are a useful instrument of retrieving trace information!

Object Expression

An *object expression* is an *inline* instantiation facility.

```
object x:X { … } // An explicit variable here
object Y { … } // No referred variable here
object x: { … } // the type of 'x' is skipped here when already known
```

If **x** exists then it is updated, otherwise created and updated

```
object EPackage {
        name := ‘pack’;
        nsURI := ‘http://myuri.org’;
        eClassifiers += object EClass {
                name := ‘clazz’;
        }
}
```

Model Extents

A *model extent* is a container for model objects. For each model parameter there is a model extent.

```
modeltype ECORE uses 'http://www.eclipse.org/emf/2002/Ecore';

transformation transf(in m : ECORE, out x : ECORE, out y : ECORE);

main() {
    var a:= object EPackage@x {
        name := 'a'
    };

    var b:= object EPackage@y {
        name := 'b';
    };
}

mapping EClass::toClass() : EClass@y {
    name := self.name;
}
```

Refer to model extents with @model_parameter_name

Intermediate Properties

An *intermediate property* is a property defined as an extension of the type referred by the *context*.

- typically defined as class extensions of model metaclasses
- created temporarily by a transformation
- not a part of the output
- used for intermediate calculations associated with the instances of the extended class

```
intermediate property EClass::intermProp : String;

main() {
        object EClass {
                name := 'original';
                intermProp := 'abc'
        };
}
```

Intermediate Classes

An *intermediate class* is a class created temporarily by a transformation to perform some needed calculation but which is not part of the expected output.

```
intermediate class MyEPackage extends EPackage {
	myName : String;
}

mapping EClassifier::c2c() : EClass {
	object MyEPackage {
		name := 'name';
		myName := 'someThoughtfulName';
	}
}
```

ImperativeOCL package

- Assignments
- Variables
- Loops (while, forEach)
- Loop interrupt constructs (break, continue)
- Conditional execution workflow
- Convenient shorthand notation
- Mutable collections

Assignments

- Assignment to variables
- Assignment to properties (including complex nested constructions)

```
mapping EClassifier::c2c() : EClass {
      name := self.name;
}

mapping EPackage::p2p() : EPackage {
      name := nsPrefix := nsURI := ‘aaa’;
      eClassifiers += self.eClassifiers->map c2c();
      eClassifiers += object EClass {
                name := 'A‘
      };
      eSuperPackage.eSuperPackage.eSubpackages->any(true).name := 'A';
}
```

Variables in QVTO

OCL variables in **let** expression:

```
let a : String = 'aa' in /*some expression with a*/;
```

QVTO extends OCL with variable initialization expressions and assignments to variables:

```
var a : String := ‘A’; // full notation
var b := ‘B’; // type deduced from the initialization expression
var c : String; // default value assigned
```

```
mapping EPackage::p2p() : EPackage {
    var tmp := ‘A’ + self.name; // variable declaration and initialization
    name := tmp; // variable read access
    tmp := tmp + ‘B’ // variable modification
    eClassifiers += self.eClassifiers->map c2c();
    eClassifiers += object EClass {name := tmp}; // another access
}
```

While Loop

OCL iterator expressions iterate through collections and cannot be interrupted by break, continue or return statements.

They are rather specific, e.g.:

```
collection->collect( v : Type | expression-with-v )
```

While loop is a Java-like imperative cycle that can be interrupted by break, continue and return.

```
mapping EPackage::p2p() : EPackage {
        var i : Integer := 0;
        while (i < 10) {
            eClassifiers += object EClass {};
            i := i + 1;
        }
}
```

```
mapping EPackage::p2p() : EPackage {
    while (i := 0; i < 10) {
        eClassifiers += object EClass {};
        i := i + 1;
    };
}
```

ForEach Loop

ForEach evaluates some expression(s) for each element of a given collection.

```
var abc := Sequence {'a', 'b', 'a', 'b'};
var res : String := '';
abc->forEach(i) {
      res := res + i;
};

abc->forEach(i | i = 'b') { // forEach with a condition
      res := res + i;
};
```

forOne – equivalent to **forEach** with a **break** statement:

```
   abc->forOne(i | i = 'b') {
                res := res + i;
   };
```

⟺

```
   abc->forEach(i | i = 'b') {
                res := res + i;
                break;
   };
```

Loop Interruption
Break and Continue

break and **continue** – used within while, forEach loops and imperative iterators

```
var i : Integer := 0;
while (i < 10) {
        if (i = 3) then {
            i := i + 2;
            continue;
        } endif;
        if (i = 8) then {
            break;
        } endif;
        object EClass {};
        i := i + 1;
};
```

Operation Interruption - Return

return – used to interrupt imperative operations

```
query EPackage::getName() : String {
        if (self.name = 'A') then {
                return 'B';
        } endif;
        if (self.name = 'B') then {
                return 'C';
        } endif;
        return self.name;
}
```

Conditional Execution

- **If**-expression

```
if <condition> then {
    <expressions>;
} else {
    < expressions>;

} endif;
```

```
if <condition> then
    < expression>
else
    < expression>
endif;
```

- **Switch**-expression

```
switch {
    case (cond1) { <expressions>}
    case (cond2) <expression>;
    else <expression>;
};
```

```
var a : Collection(SomeType)
    := coll->switch(i) {
    case (cond_with_i_1) { <exprs_with_i>}
    case (cond_with_i_2) <expr_with_i>;
    else <expression_with_i>;
};
```

Imperative Iterators

New in QVTO:

- xcollect
- xselect
- collectselect
- collectOne
- selectOne
- collectselectOne

- *break*
- *continue*
- *return*
- *nulls skipped*

Inherited from OCL:

- collect
- select
- and others...

```
var coll := Sequence { object EClass { name := 'a'},
                       object EDataType { name := ‘b'},
                       object EClass { name := null}};
var c1 := coll->xcollect(i | i.name); // c1 = Sequence {‘a’, ‘b’}
var c2 := coll->collectOne(i | i.name); // c2 = ‘a’
```

Shorthand Notation

Convenient shorthand notation make code concise and effective:

- list->prop; // same as list->**xcollect**(i | i.prop)
- list[condition]; // same as list->**xselect**(i; condition)
- list->prop[startsWith("_")]) ; // same as list->**collectselect**(i;res= i.prop |
  // res.startsWith("_")) ;
- list->prop![startsWith("_")]) ; // calling **collectselectOne**(i;res= i.prop |
  // res.startsWith("_"))

QVTO shorthand snippet:

```
list->prop![startsWith("_")]);
```

The same in pure OCL:

list->**collect**(prop)->
select(**not ocllsUndefined**() **and**
startsWith("_"))->
first();

Mutable Collections

OCL collections – **Sequence**, **Bag**, **Set**, **OrderedSet** are immutable:

```
Sequence {'a', 'A', 'b'} -> select(equalsIgnoreCase('a')); // creates a new sequence
```

New in QVTO – mutable collections:

- **List** – mutable sequence
- **Dict** – mutable hash table

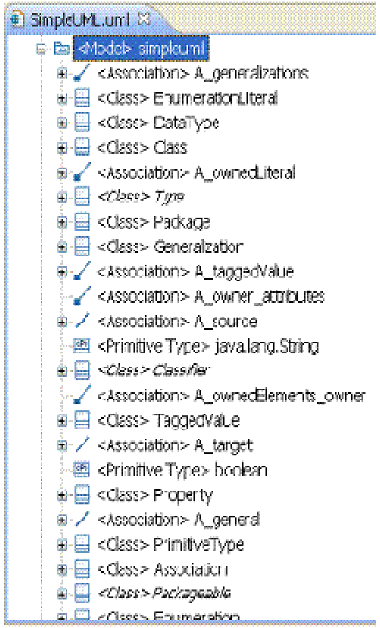
```
var dict : Dict(String, Integer) := Dict { 'key1' = 5 };
dict->put('key2', 10);
var i : Integer := dict->get('key1') * dict->get('key2'); // i = 50
```

Standard Library

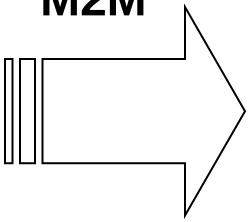
- Element operations
  - *subobjects //* all immediate sub objects of an object (in terms of containment)
  - *deepclone*
- Model operations
  - *rootObjects*
  - *copy // full copy of a model*
- String routines
  - *startsWith*
  - *indexOf*
- Mutable collection routines
  - *List::add*
  - *Dict::get*
- Transformation execution routines
  - *transform*

Generating Documentation

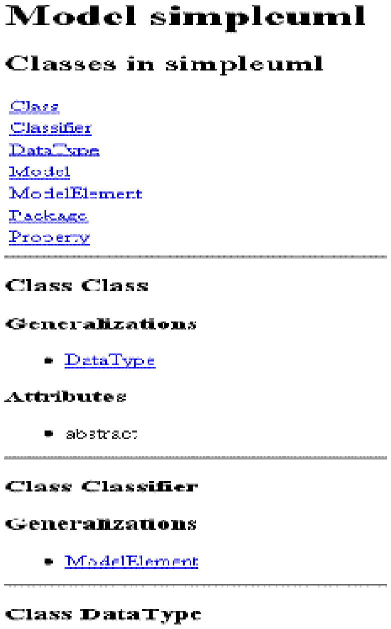
- Create XHTML documentation for the simple UML model
  - Input: UML model with classes
  - Output: XHTML document



```
SimpleUML.uml
<Model> simpleuml
  <Association> A_generalizations
  <Class> EnumerationLiteral
  <Class> DataType
  <Class> Class
  <Association> A_ownedLiteral
  <Class> Type
  <Class> Package
  <Class> Generalization
  <Association> A_taggedValue
  <Association> A_owner_attributes
  <Association> A_source
  <Primitive Type> java.lang.String
  <Class> Classifier
  <Association> A_ownedElements_owner
  <Class> TaggedValue
  <Association> A_target
  <Primitive Type> boolean
  <Class> Property
  <Association> A_general
  <Class> PrimitiveType
  <Class> Association
  <Class> Packageable
  <Class> Enumeration
```



M2M



Model simpleuml

Classes in simpleuml

Class
Classifier
DataType
Model
ModelElement
Package
Property

Class Class

Generalizations

- DataType

Attributes

- abstract

Class Classifier

Generalizations

- ModelElement

Class DataType

– UML metamodel: exists

– XHTML metamodel: generate from XSD

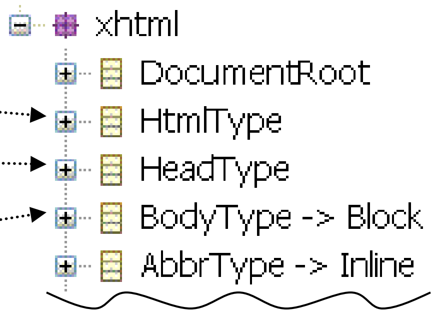
Generating Documentation

- Use existing XSDs to generate EMF metamodels
  - Generate EMF metamodel from XSD, deploy
  - Write transformation against the new metamodel
- Example: create HTML documentation for the simple UML model
  - xsd from http://www.w3.org/2002/08/xhtml/xhtml1-strict.xsd
  - Minor changes to xhtml.ecore, direct used from workspace
  - Create XHTML document that lists classes with their descriptions
  - Add debug and constraint capabilities
  - Compose QVTO transformations

UML to XHTML Example

- Start with empty XHTML document
  - Typical document contains

The **HTML** element representing document itself
The document head
The **HEAD** element
The **TITLE** element
The document body
The **BODY** element



xhtml
DocumentRoot
HtmlType
HeadType
BodyType -> Block
AbbrType -> Inline

- Highlights:
  - Create document's skeleton in main()
  - XSD-backed model requires instance of DocumentRoot as a root element
  - Modify xhtml.ecore to allow access to text parts of mixed references

UML to XHTML Example

- List all classes containing by the model
  - In XHTML that list represents as follows

```
<div>
  <h2>Classes in simpleuml</h2>
  <table>
     <tr>
        <td>Association</td>
     </tr>
     <tr>
        <td>Class</td>
     </tr>
     .....
  </table>
</div>
```

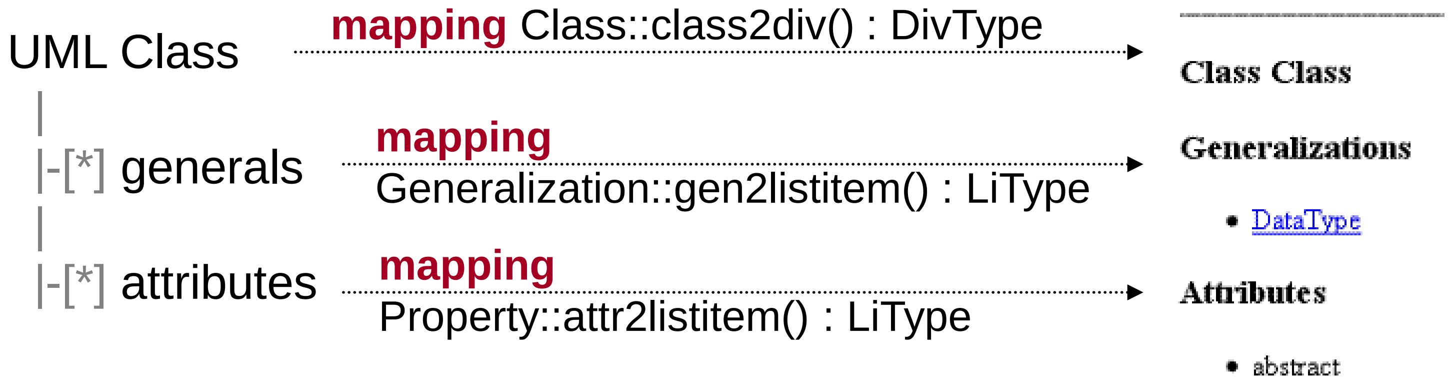
mapping Class::class2row() : TrType

  - UML classes is requested by (preserving lexical order on class names)

    query Package::allClasses() : **OrderedSet**(Class)

UML to XHTML Example

- Describe each UML class



UML Class
|
|-[*] generals
|
|-[*] attributes

mapping Class::class2div() : DivType

mapping Generalization::gen2listitem() : LiType

mapping Property::attr2listitem() : LiType

Class Class

Generalizations

- DataType

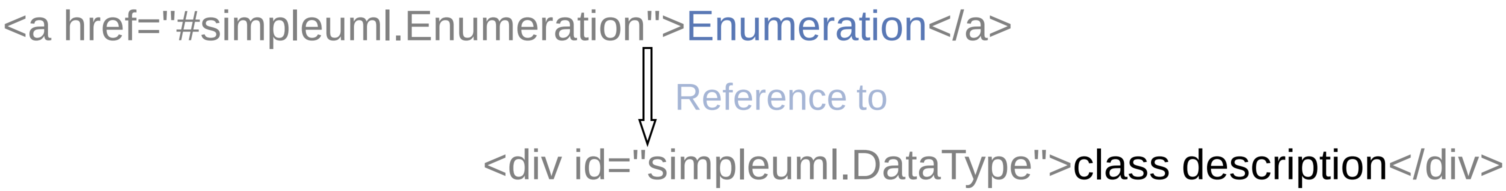
Attributes

- abstract

- Highlights:
  - evolve allClasses() query to mapping for achieving singleton behavior
  - filter empty generals/attributes sections by means of mapping guard ("when" clause)

UML to XHTML Example

- Beautify XHTML document
  - Add cross references



```
<a href="#simpleuml.Enumeration">Enumeration</a>
```

Reference to

```
<div id="simpleuml.DataType">class description</div>
```

  - **href** id is created by means of recurrent fullName() query

- Workflow examination
  - console debug output (appearance controlled via configuration property)
  - mapping preconditions with asserting

Transformation composition

- Compose just created transformation with the previous one
  - Chain Ecore2Uml and Uml2Xhtml

    - Chain by means of QVTO transformation's instantiation

      -
        ```
        var t : Transformation := new Uml2Xhtml(Uml, Xhtml);
        var s : Status := t.transform();
        ```

    - Chain by means of Ant script (QVT Operational Help gives an example)

      -
        ```
        <qvto:transformation
           uri="transforms/Uml2Xhtml.qvto“
           >
           …
        ```