# Model Transformation Techniques

*(or: Why I'd like write programs that write programs rather than write programs)*

***Prof. Jean-Marc Jézéquel***
**(Univ. Rennes 1 & INRIA)**
**Triskell Team @ IRISA**
Campus de Beaulieu
F-35042 Rennes Cedex
Tel : +33 299 847 192 Fax : +33 299 847 171
e-mail : jezequel@irisa.fr
http://www.irisa.fr/prive/jezequel

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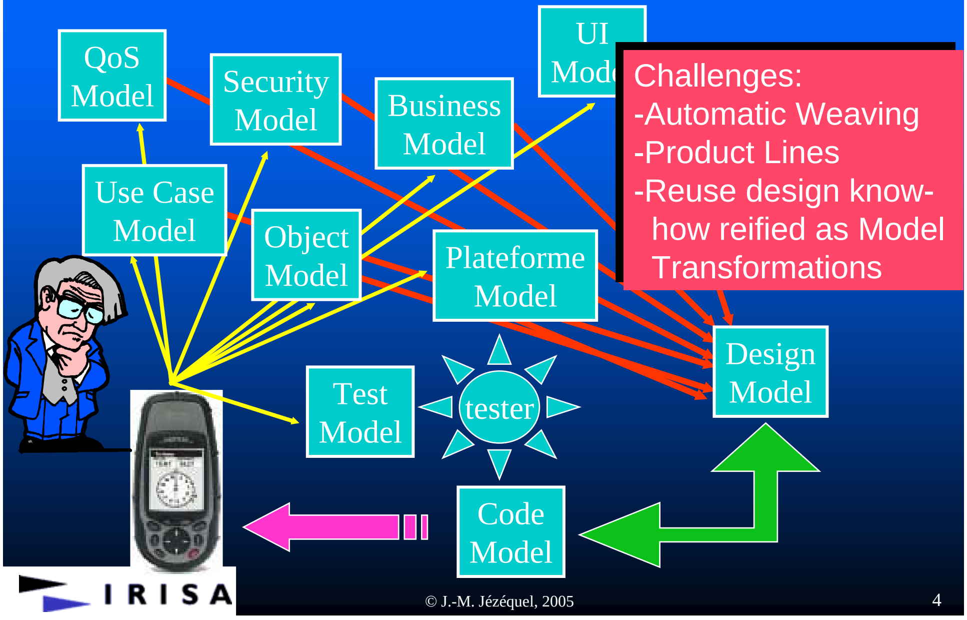
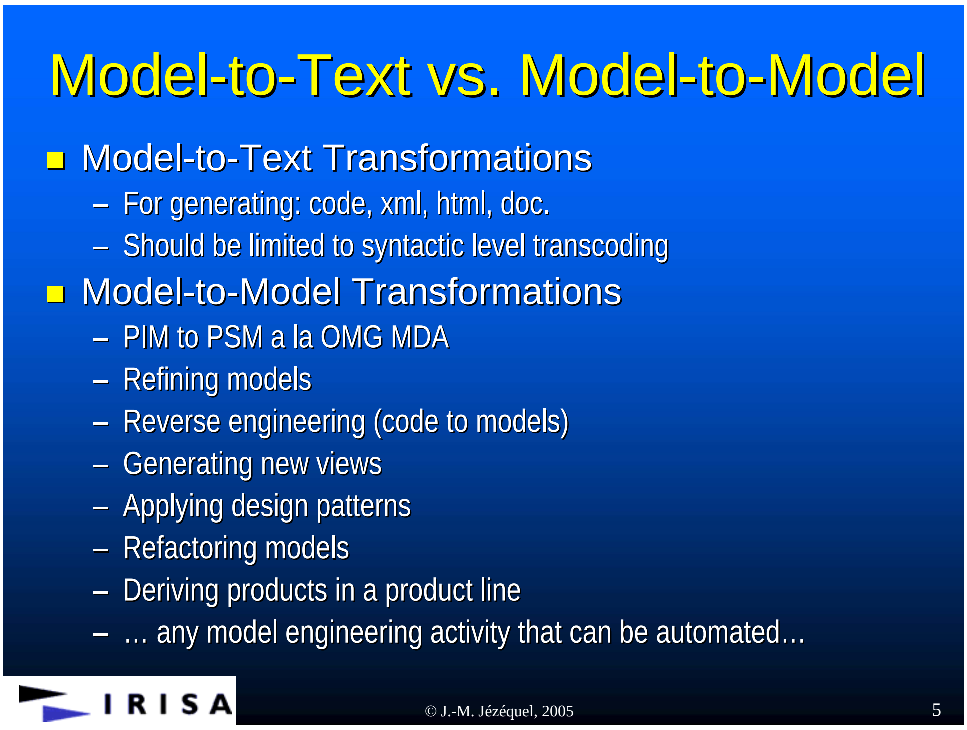
## Modeling and Weaving



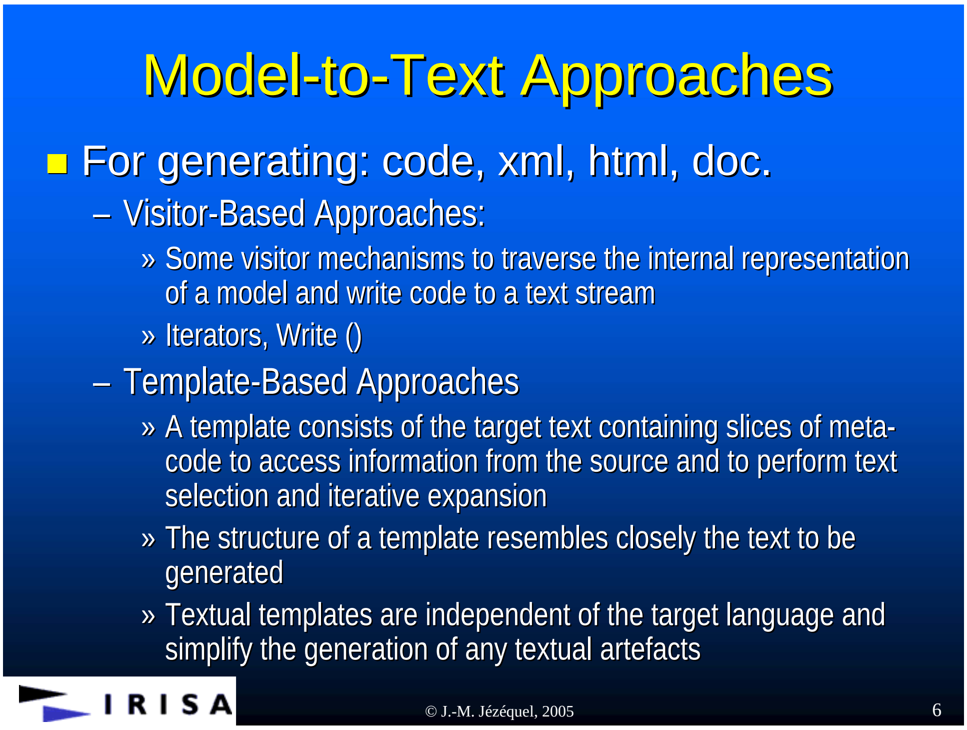
QoS Model
Security Model
Business Model
UI Mode
Use Case Model
Object Model
Plateforme Model
Design Model
Test Model
tester
Code Model

Challenges:
- Automatic Weaving
- Product Lines
- Reuse design know-how reified as Model Transformations



# Model-to-Text vs. Model-to-Model

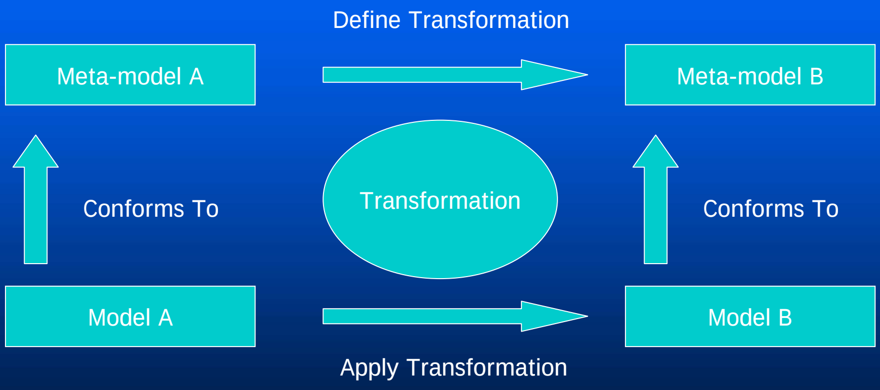
- Model-to-Text Transformations
  - For generating: code, xml, html, doc.
  - Should be limited to syntactic level transcoding
- Model-to-Model Transformations
  - PIM to PSM a la OMG MDA
  - Refining models
  - Reverse engineering (code to models)
  - Generating new views
  - Applying design patterns
  - Refactoring models
  - Deriving products in a product line
  - … any model engineering activity that can be automated…



# Model-to-Text Approaches

- For generating: code, xml, html, doc.
  - Visitor-Based Approaches:
    - » Some visitor mechanisms to traverse the internal representation of a model and write code to a text stream
    - » Iterators, Write ()
  - Template-Based Approaches
    - » A template consists of the target text containing slices of meta-code to access information from the source and to perform text selection and iterative expansion
    - » The structure of a template resembles closely the text to be generated
    - » Textual templates are independent of the target language and simplify the generation of any textual artefacts

# Transformation Architecture


Define Transformation

Meta-model A

Meta-model B

Conforms To

Transformation

Conforms To

Model A

Model B

Apply Transformation

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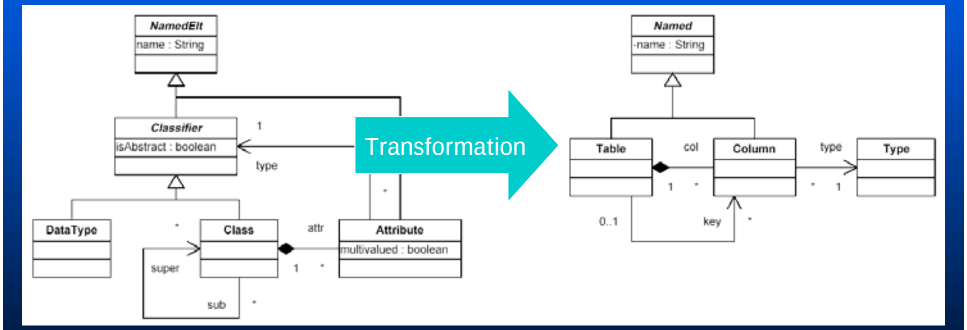
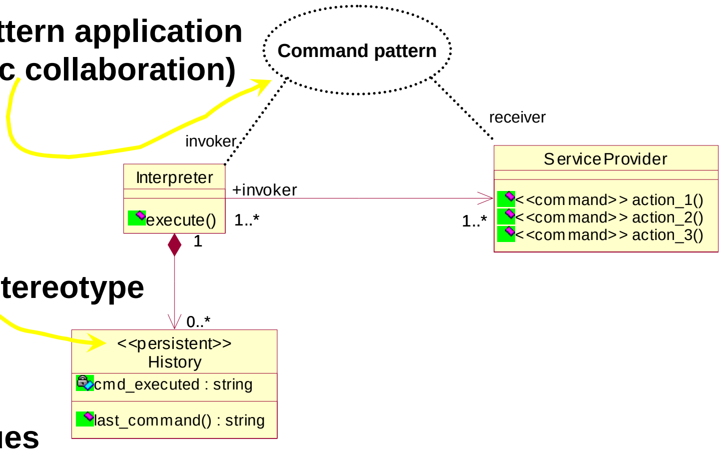
# Model-to-Model: Typical Example

From UML to RDBMS



# M2M: Reuse Engineering Know-How (Design/Test/…)

**Design pattern application (parametric collaboration)**



**Element stereotype**

**…and also**
**Tagged values**
**& Contracts**

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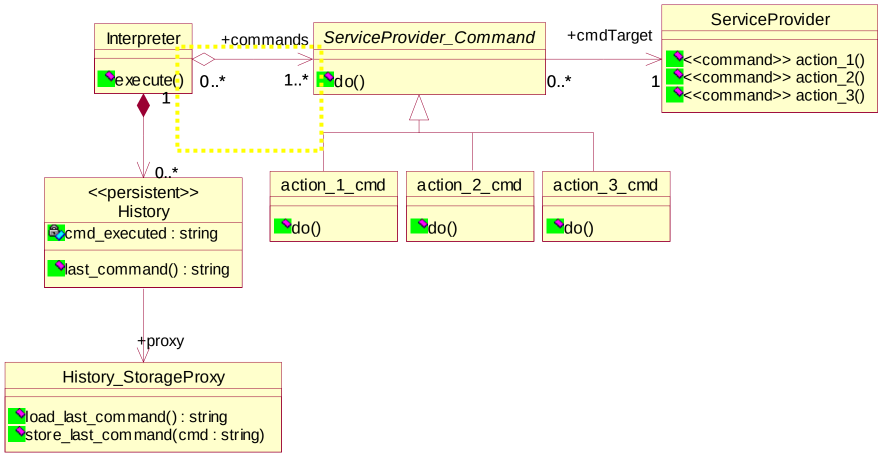
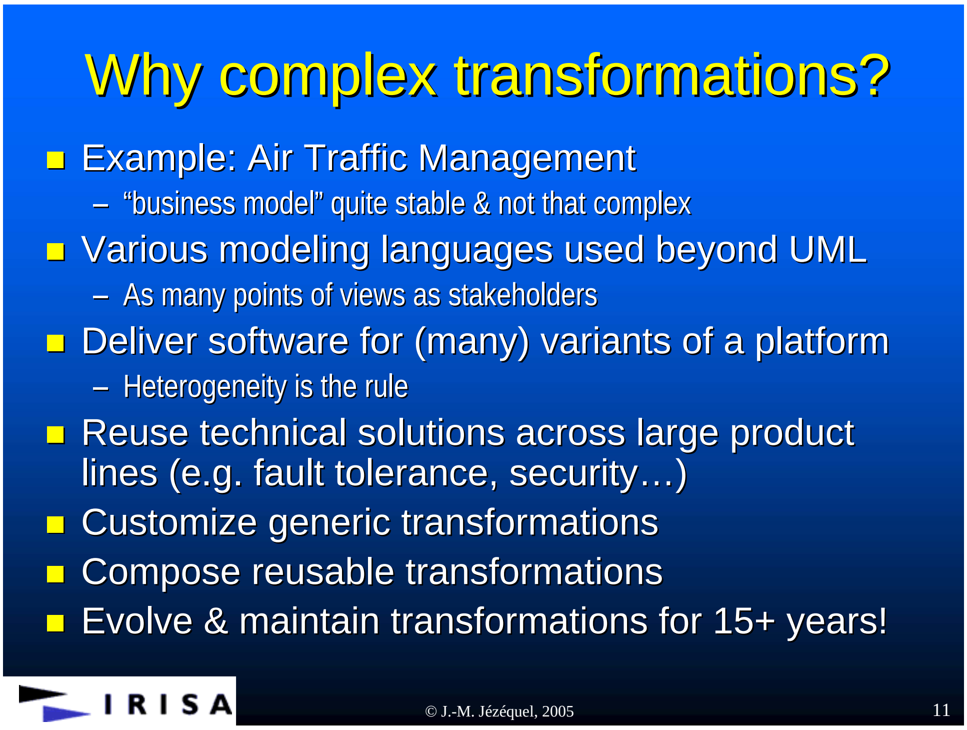
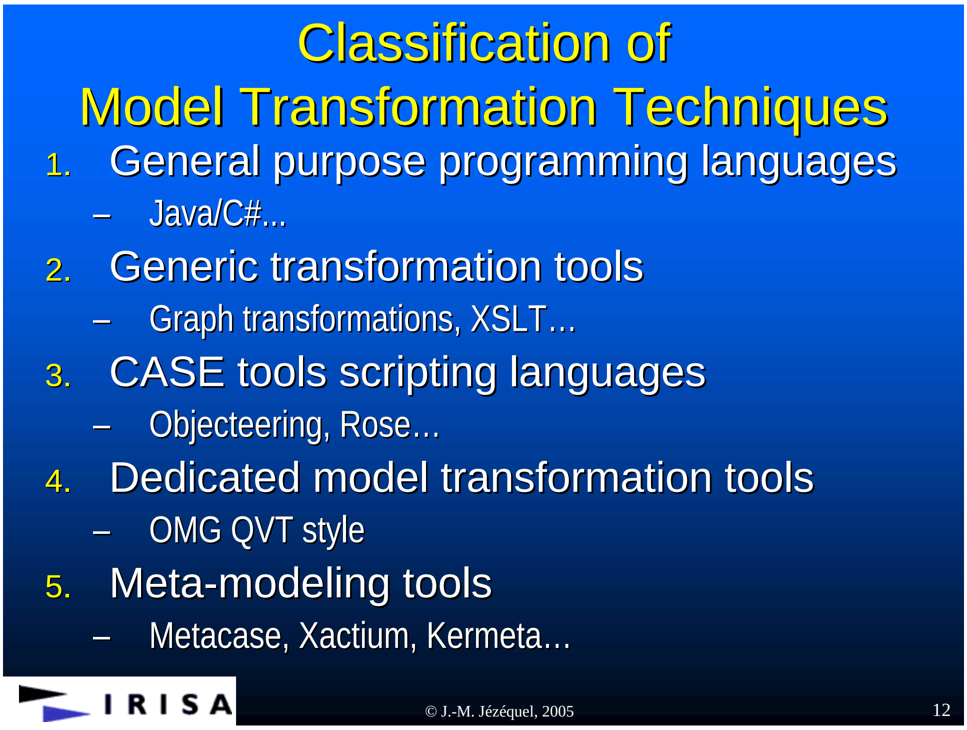
# The result we want : design patterns application





## Why complex transformations?

- Example: Air Traffic Management
  - "business model" quite stable & not that complex
- Various modeling languages used beyond UML
  - As many points of views as stakeholders
- Deliver software for (many) variants of a platform
  - Heterogeneity is the rule
- Reuse technical solutions across large product lines (e.g. fault tolerance, security…)
- Customize generic transformations
- Compose reusable transformations
- Evolve & maintain transformations for 15+ years!



## Classification of
## Model Transformation Techniques

1. General purpose programming languages
   - Java/C#...
2. Generic transformation tools
   - Graph transformations, XSLT…
3. CASE tools scripting languages
   - Objecteering, Rose…
4. Dedicated model transformation tools
   - OMG QVT style
5. Meta-modeling tools
   - Metacase, Xactium, Kermeta…

# 1. General purpose language approach

- Java, VB, C++, C#,... Your favorite language!
- Currently available in the tools via APIs
- Rules and scheduling implemented from scratch using the programming language
- Example:
  - – JMI (MOF-compliant Java Interface)
    - » JSR-000040 Java™ Metadata Interface

# JMI examples

```
package javax.jmi.model;

import javax.jmi.reflect.*;

public interface Attribute extends StructuralFeature {
    public boolean isDerived();
    public void setDerived(boolean newValue);
}
```

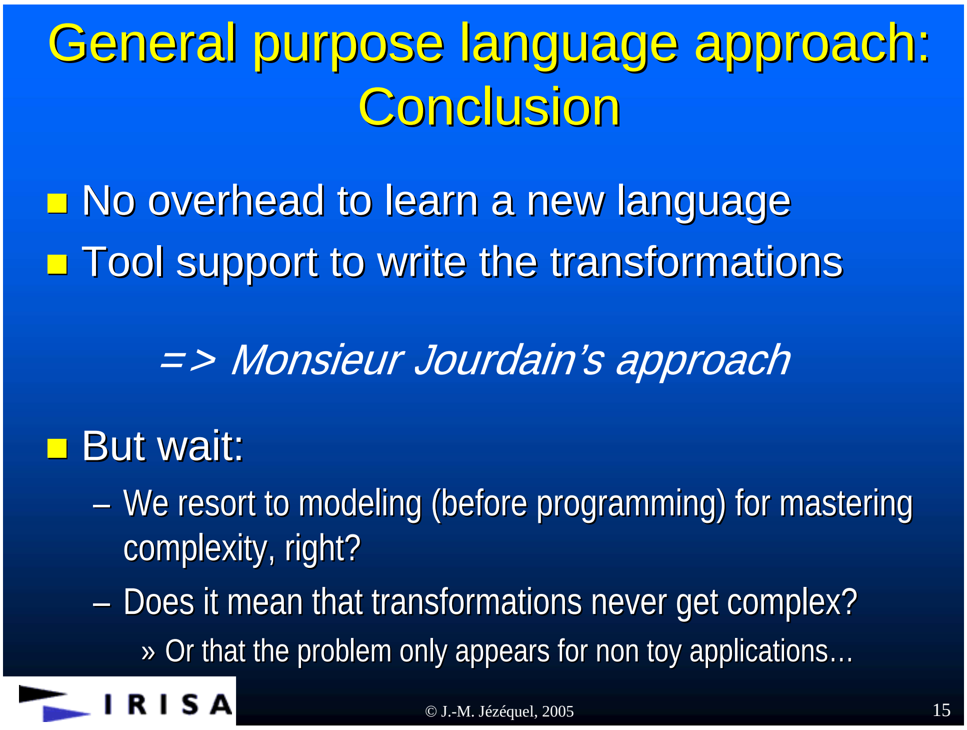
Attributes

Operations

```
package javax.jmi.model;

import javax.jmi.reflect.*;

public interface Operation extends BehavioralFeature {
    public boolean isQuery();
    public void setQuery(boolean newValue);
    public java.util.List getExceptions();
}
```

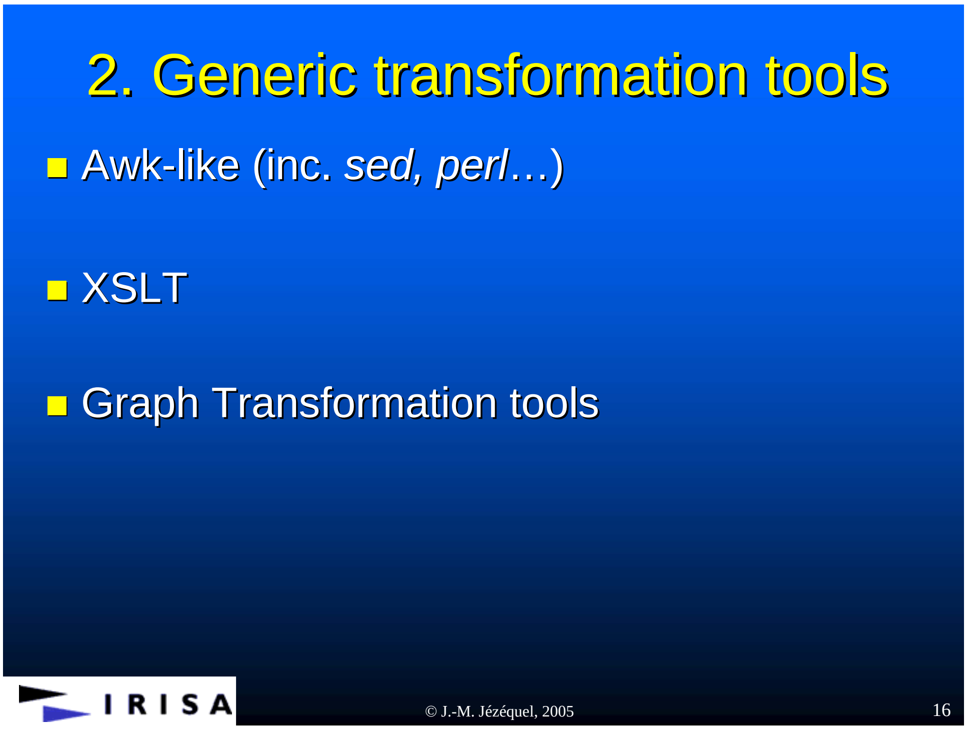


# General purpose language approach: Conclusion

- No overhead to learn a new language
- Tool support to write the transformations

*=> Monsieur Jourdain’s approach*

- But wait:
  - – We resort to modeling (before programming) for mastering complexity, right?
  - – Does it mean that transformations never get complex?
    - » Or that the problem only appears for non toy applications…



# 2. Generic transformation tools

- Awk-like (inc. *sed, perl*…)
- XSLT
- Graph Transformation tools

## Intermediate transformation language

- Typically XML based
  - But XML (XMI) is verbose
- XSLT can be used to transform XML trees into other (XML) (trees)
  - More batch than interactive
  - Parameters are passed by values
  - XSLT transformations are not really easy to maintain
- Better for simple transformations

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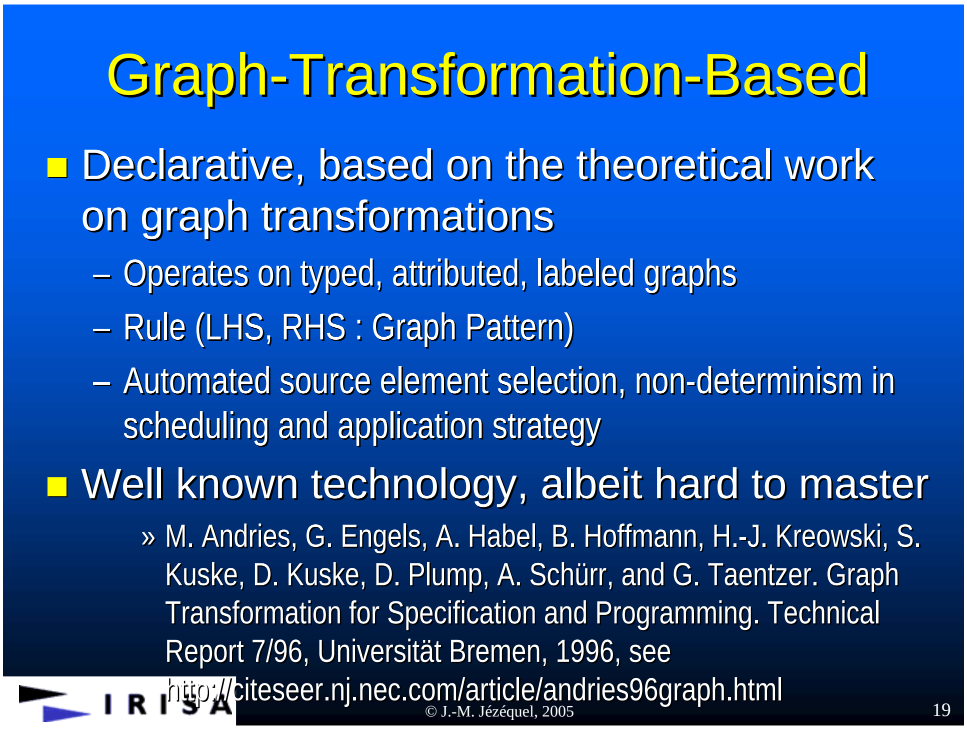
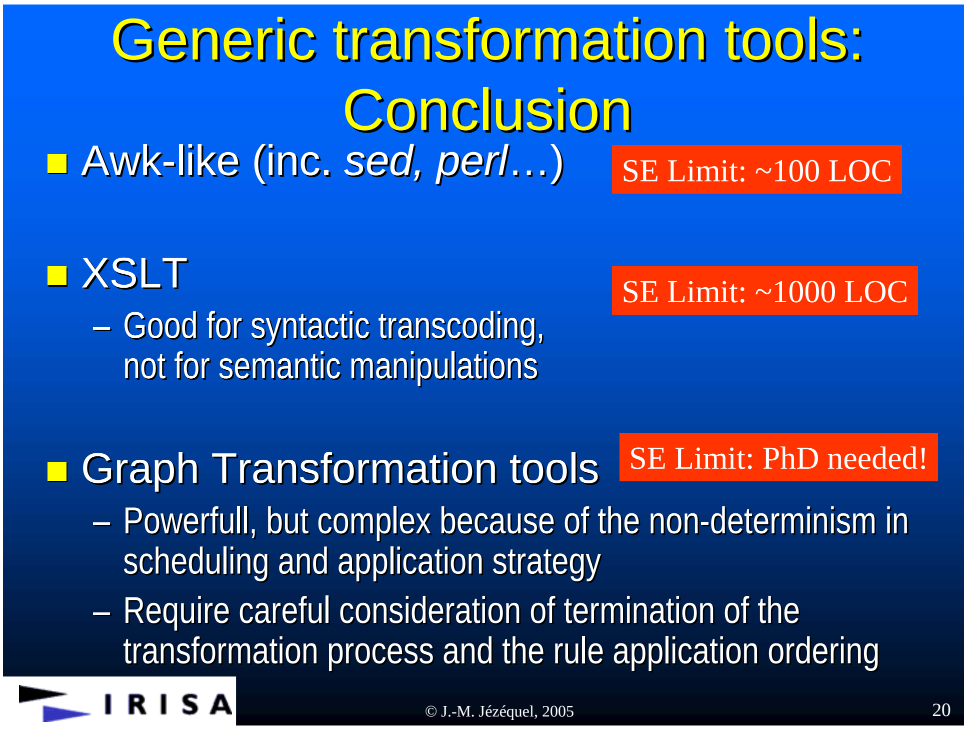
## Example of XSLT transformation

```
<xsl:template match="ECA.BusinessProcessPkg.OutputGroup |
                     ECA.BusinessProcessPkg.ExceptionGroup">
     param name="a"/>
      ariable name="ct" select="concat(@xmi.id,'.condTask')"/>
     sl:choose>
    <xsl:when test="self::node()[@isSynchronous = 'true']">
      <xsl:call-template name="condTaskTemplate">
        <xsl:with-param name="ct" select="$ct"/>
        <xsl:with-param name="a" select="$a"/>
      </xsl:call-template>
    </xsl:when>
    <xsl:otherwise>
      <xsl:call-template
          name="asyncCompoundTaskInputGroupOrActivityOutputGroup">
        <xsl:with-param name="a" select="$a"/>
      </xsl:call-template>
    </xsl:otherwise>
  </xsl:choose>
</xsl:template>
```



# Graph-Transformation-Based

- Declarative, based on the theoretical work on graph transformations
  - Operates on typed, attributed, labeled graphs
  - Rule (LHS, RHS : Graph Pattern)
  - Automated source element selection, non-determinism in scheduling and application strategy
- Well known technology, albeit hard to master
    - » M. Andries, G. Engels, A. Habel, B. Hoffmann, H.-J. Kreowski, S. Kuske, D. Kuske, D. Plump, A. Schürr, and G. Taentzer. Graph Transformation for Specification and Programming. Technical Report 7/96, Universität Bremen, 1996, see http://citeseer.nj.nec.com/article/andries96graph.html



# Generic transformation tools: Conclusion

- Awk-like (inc. *sed, perl*…)

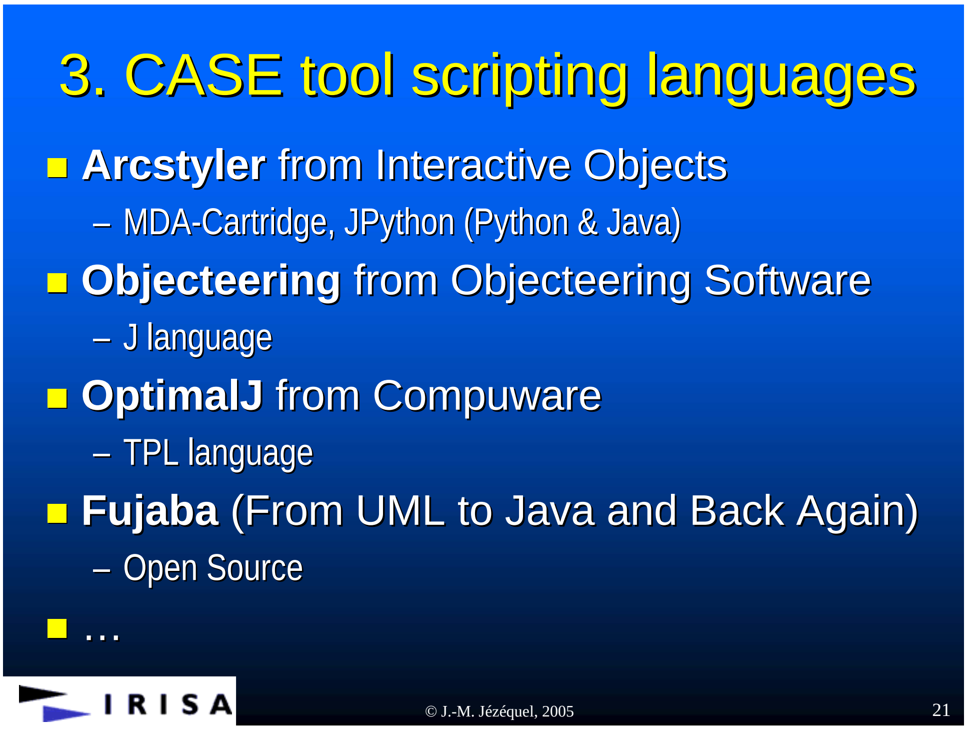
SE Limit: ~100 LOC

- XSLT
  - Good for syntactic transcoding, not for semantic manipulations

SE Limit: ~1000 LOC

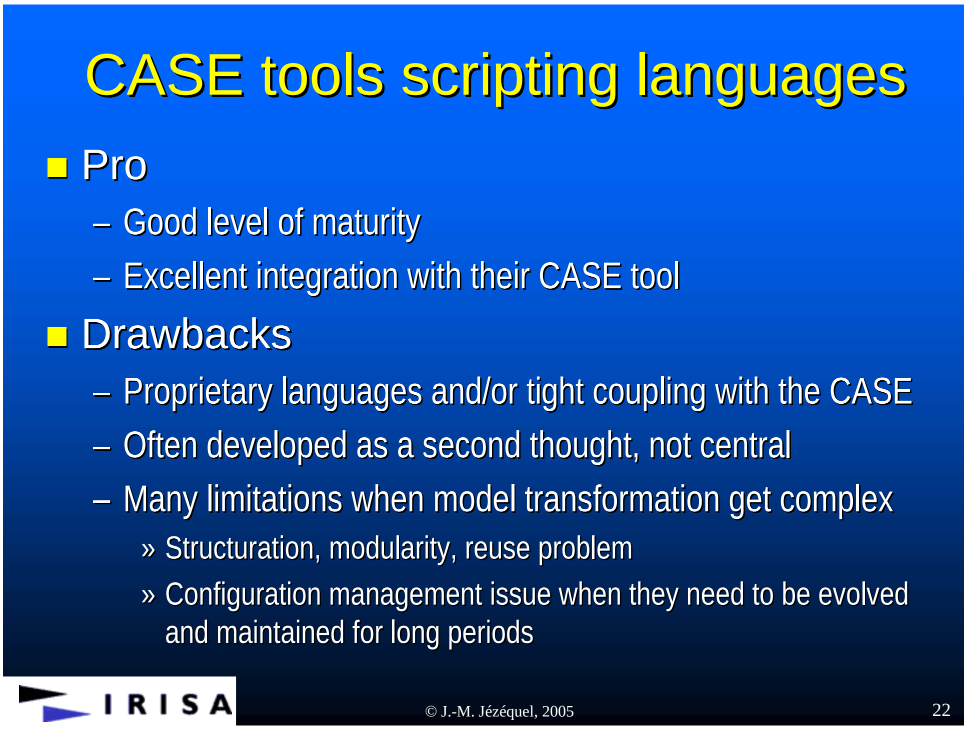
- Graph Transformation tools
  - Powerfull, but complex because of the non-determinism in scheduling and application strategy
  - Require careful consideration of termination of the transformation process and the rule application ordering

SE Limit: PhD needed!



## 3. CASE tool scripting languages

- **Arcstyler** from Interactive Objects
  - MDA-Cartridge, JPython (Python & Java)
- **Objecteering** from Objecteering Software
  - J language
- **OptimalJ** from Compuware
  - TPL language
- **Fujaba** (From UML to Java and Back Again)
  - Open Source
- …



## CASE tools scripting languages

- Pro
  - Good level of maturity
  - Excellent integration with their CASE tool
- Drawbacks
  - Proprietary languages and/or tight coupling with the CASE
  - Often developed as a second thought, not central
  - Many limitations when model transformation get complex
    - » Structuration, modularity, reuse problem
    - » Configuration management issue when they need to be evolved and maintained for long periods

# 4. Dedicated Transformation Language

- OMG QVT style
  - Kind of DSL for transformation
- Simplify development and maintenance of model-transformations
- Higher expression power
- Enhanced structuration
  - Composition of rules
  - Interoperability

# MOF 2.0 Queries/Views/Transformations RFP

- Define a language for querying MOF models
- Define a language for transformation definitions
- Allow for the creation of views of a model
- Ensure that the transformation language is declarative and expresses complete transformations
- Ensure that incremental changes to source models can be immediately propagated to the target models
- Express all new languages as MOF models

# Query

- An expression evaluated over a model
  - Returns one or more instances of types defined either in the source model or by the query language
- OCL is an example of a query language

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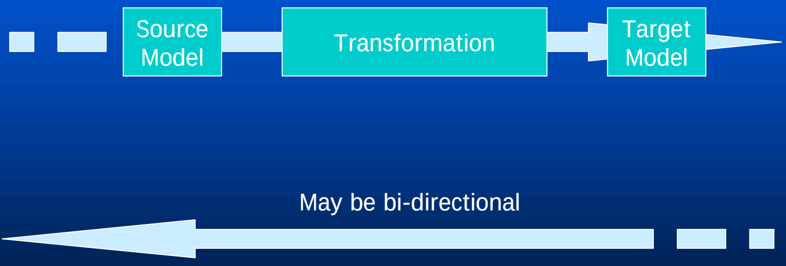
# View

- A view is a model that is completely derived from another model
  - The meta-model of the view is typically not the same as the meta-model of the source

# Transformation

- A transformation generates target models from source models



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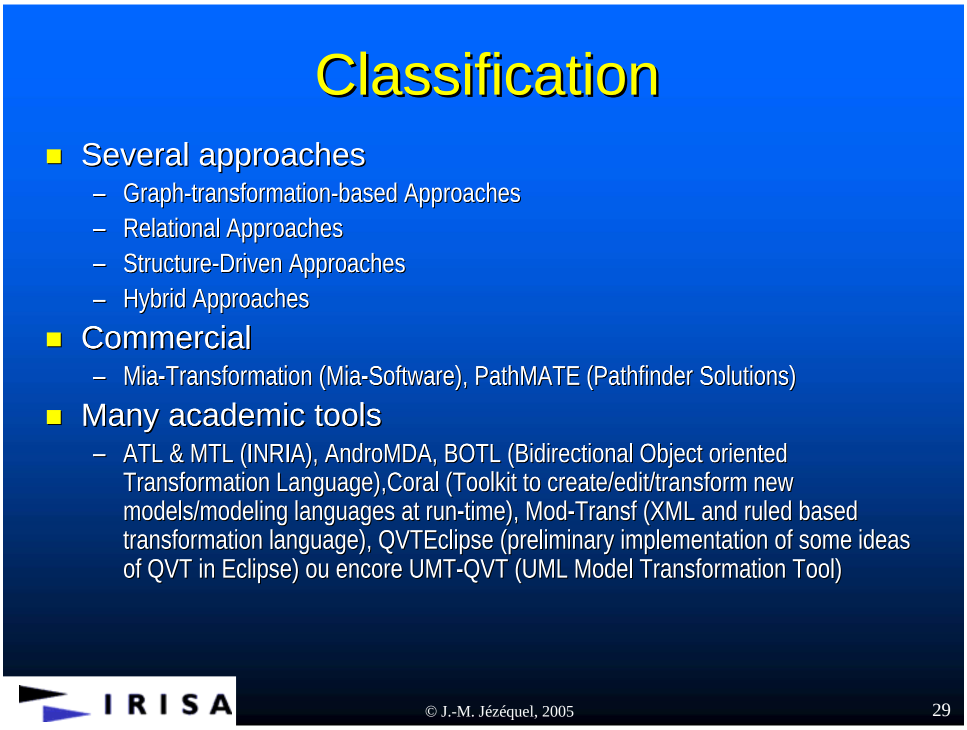
# Q vs V vs T

- A query is a restricted kind of view
- A view is a restricted kind of transformation
  - The target model cannot be modified independently of the source model
- A transformation generates target models from source models



## Classification

- Several approaches
  - Graph-transformation-based Approaches
  - Relational Approaches
  - Structure-Driven Approaches
  - Hybrid Approaches
- Commercial
  - Mia-Transformation (Mia-Software), PathMATE (Pathfinder Solutions)
- Many academic tools
  - ATL & MTL (INRIA), AndroMDA, BOTL (Bidirectional Object oriented Transformation Language),Coral (Toolkit to create/edit/transform new models/modeling languages at run-time), Mod-Transf (XML and ruled based transformation language), QVTEclipse (preliminary implementation of some ideas of QVT in Eclipse) ou encore UMT-QVT (UML Model Transformation Tool)

## Declarative

- Declarative languages describe relationships between variables in terms of functions or inference rules and the language executor (interpreter or compiler) applies some fixed algorithm to these relations to produce a result

# Imperative

- Any programming language that specifies explicit manipulation of the state of the computer system, not to be confused with a procedural language

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# Declarative vs. Imperative Style

- Declarative (what to do)
  - Invariant relations between source and target models
- Imperative (how to do it)
  - How to derive a target from a source
- May be combined via pre- and post-conditions

Declarative Pre-Condition

Imperative Rule

Declarative Post-Condition

# Execution Strategy

- Invocation of the transformation rules
  - Explicit, via invocation operations (Java like)
  - Implicit, based on context and rules’ signature (Prolog like)

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# Trace

- Trace associates one (or more) target element with the source elements that lead to its creation
  - For Round-trip development
  - Incremental propagation

- Rules may be able to match elements based on the trace without knowing the rules that created the trace

# Rule

- Rules are the units in which transformations are defined
  - A rule is responsible for transforming a particular selection of the source model to the corresponding target model elements.

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# Declaration

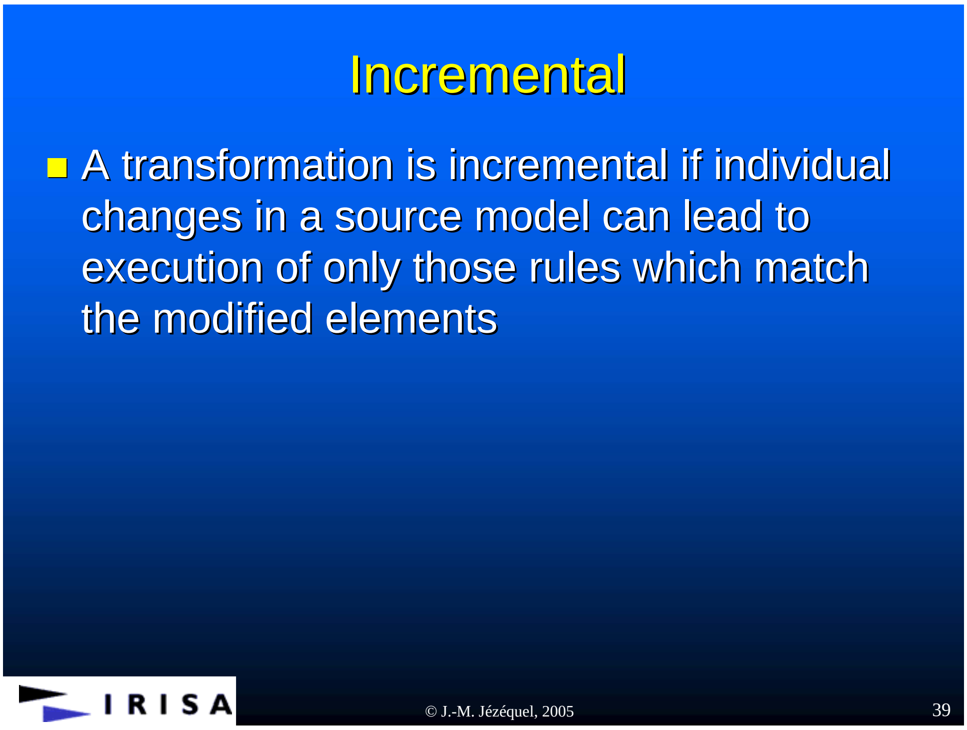
- A declaration is a specification of a relation between elements in the LHS and RHS models

# Implementation

- An implementation is an imperative specification of how to create target model elements from source model elements
  - An implementation explicitly constructs elements in the target model
  - Implementations are typically directed

# Match

- A match occurs during the application of a transformation when elements from the LHS and/or RHS model are identified as meeting the constraints defined by the declaration of a rule
  - A match triggers the creation (or update) of model elements in the target model



## Incremental

- A transformation is incremental if individual changes in a source model can lead to execution of only those rules which match the modified elements

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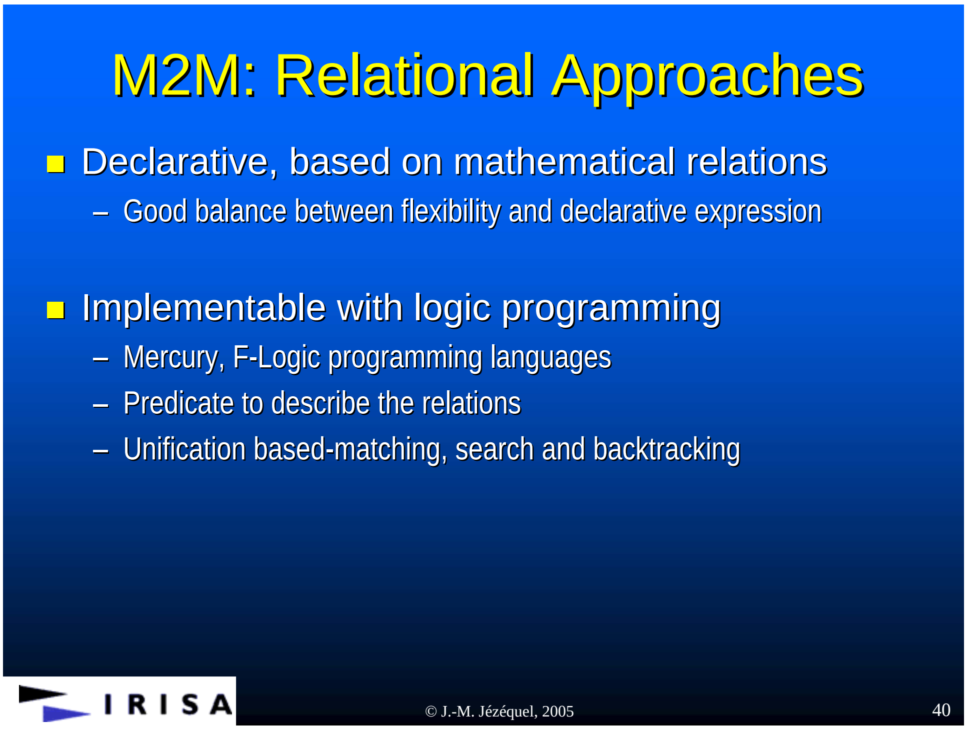

## M2M: Relational Approaches

- Declarative, based on mathematical relations
  - Good balance between flexibility and declarative expression
- Implementable with logic programming
  - Mercury, F-Logic programming languages
  - Predicate to describe the relations
  - Unification based-matching, search and backtracking

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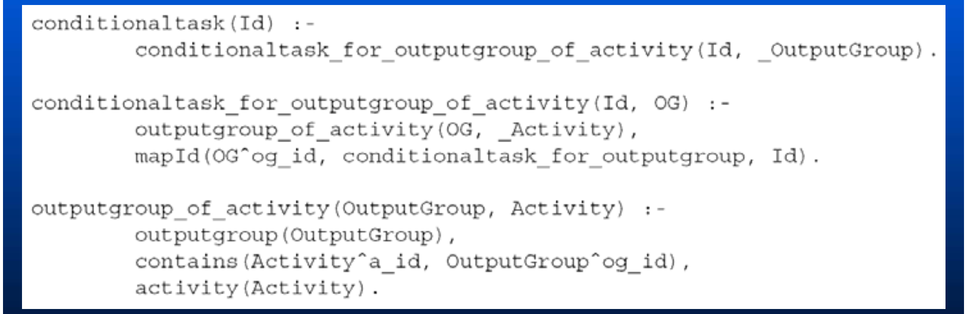
# Example of logic programming

- Excerpt of Mercury code



```
conditionaltask(Id) :-
        conditionaltask_for_outputgroup_of_activity(Id, _OutputGroup).

conditionaltask_for_outputgroup_of_activity(Id, OG) :-
        outputgroup_of_activity(OG, _Activity),
        mapId(OG^og_id, conditionaltask_for_outputgroup, Id).

outputgroup_of_activity(OutputGroup, Activity) :-
        outputgroup(OutputGroup),
        contains(Activity^a_id, OutputGroup^og_id),
        activity(Activity).
```

# M2M : Structure-Driven Approaches

- 1st Phase
  - Creation of hierarchical structure of target model
- 2nd Phase
  - Set the attributes and references in the target

- Users provide the transformation rules
- Framework determines the scheduling

## M2M : Structure-Driven Approaches

- Pragmatic approaches developed in the context of EJB and Databases schema generation from UML models
- Strong support for 1-to-1 and 1-to-n correspondence between source and target
- Unclear how well these approaches can support other kinds of applications

## M2M : Hybrid Approaches - others

- Any combination of different techniques

- Practical approaches are very likely to have the hybrid character

# Dedicated model transformation tools: Conclusion

- How many developers are familiar with the prolog-like style of rules writing?

- Where is the advantage of a dedicated explicit language vs. a general purpose language?

- Hybrid Languages or transformation libraries for general purpose languages…

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# 5. Meta-modeling tools

- **Build (OO) Models of Transformations**
- **Use MDE to run them**

- **Commercial tools:**
  - MetaEdit+ from MetaCase
  - XMF-Mosaic from Xactium

- **Open-Source**
  - KerMeta from INRIA
  - www.kermeta.org

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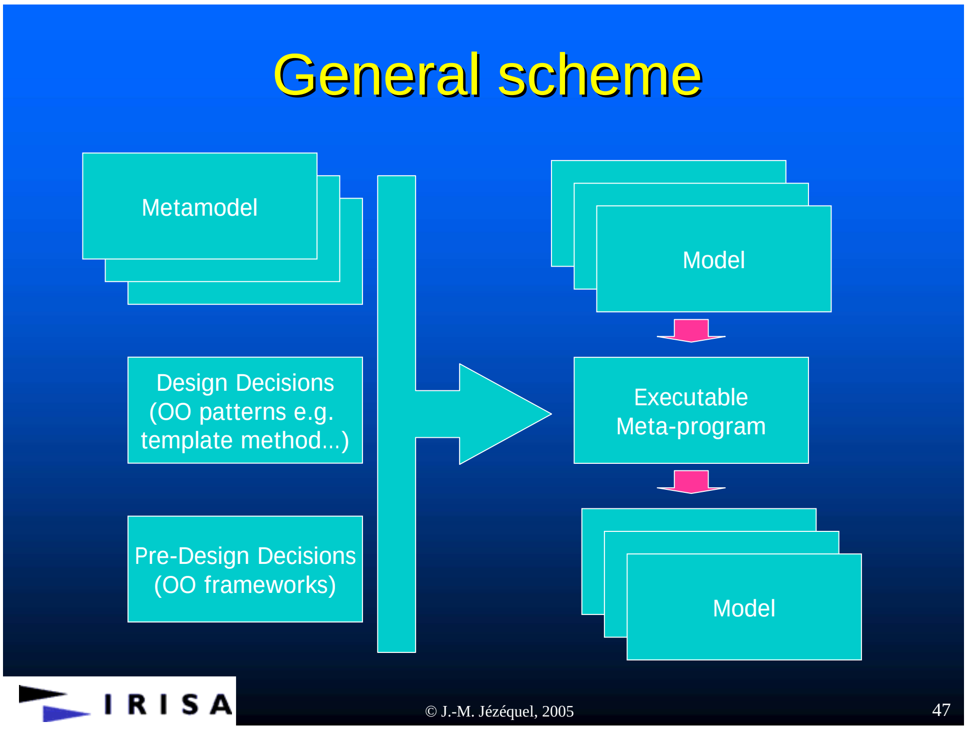

# General scheme

Metamodel

Design Decisions (OO patterns e.g. template method...)

Pre-Design Decisions (OO frameworks)

Model

Executable Meta-program

Model

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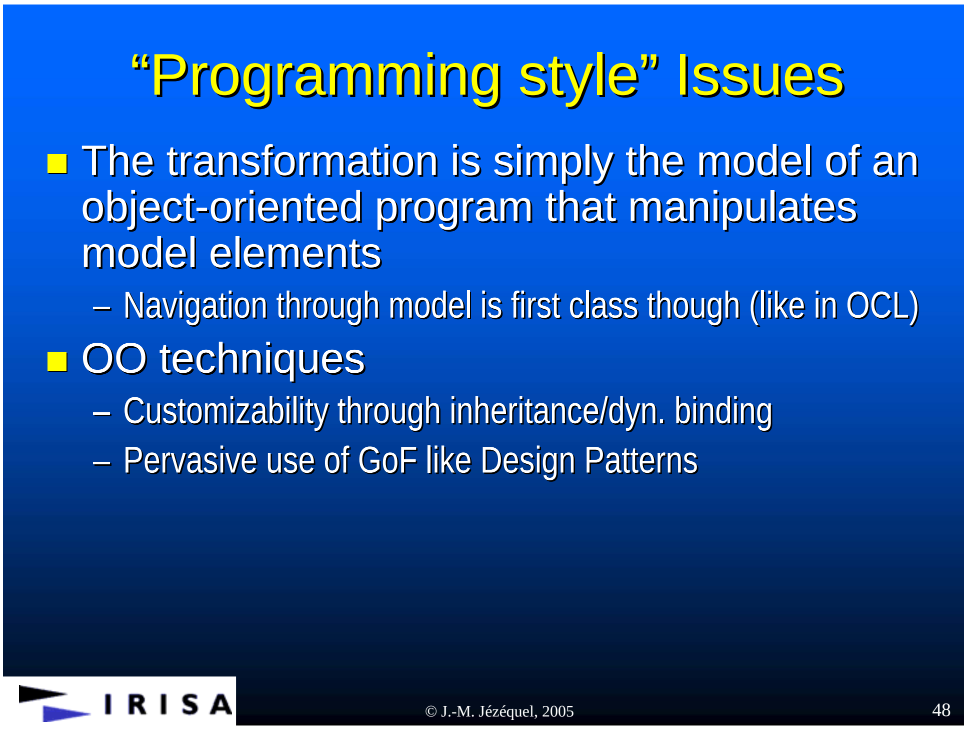

# “Programming style” Issues

- The transformation is simply the model of an object-oriented program that manipulates model elements
  - Navigation through model is first class though (like in OCL)
- OO techniques
  - Customizability through inheritance/dyn. binding
  - Pervasive use of GoF like Design Patterns

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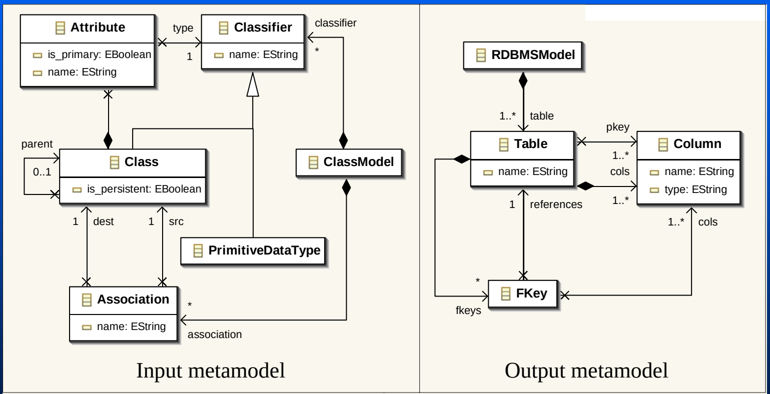
# Defining the metamodels



Input metamodel

Output metamodel

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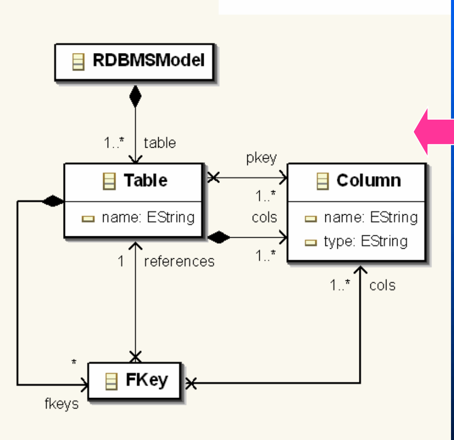
# Visual / Textual



```
package RDBMSMM;
require kermeta
using kermeta::standard
class Table{
        attribute name : String
        attribute cols : Column[1..*]
        reference pkey : Column[1..*]
        attribute fkeys : FKey[0..*]
}
class FKey{
        reference references : Table
        reference cols : Column[1..*]
}
class Column{
        attribute name : String
        attribute type : String
}
class RDBMSModel{
        attribute table : Table[1..*]
}
```

# UML2RDBMS template method

- Create tables
  - Tables are created from classes marked as persistent in the input model
- Create columns
  - For each persistent class process all attributes and outgoing associations to create corresponding columns. The foreign keys are created but the *cols* property cannot be filled and the corresponding columns cannot be created because primary keys of *references* table cannot be known before it has been processed.
- Update foreign-keys
  - The foreign-key columns are created in the table that contains the foreign-key and the property *cols* of foreign-keys is updated.

*=> Handle details/variability into subclasses*

---

# Writing the transformation

Loading ECore and Kermeta metamodels

```
package Class2RDBMS;
require kermeta        // The kermerta standard library
require "trace.kmt     // The trace framework
require "../metamodels/ClassMM.ecore"  // Input metamodel in ecore
require "../metamodels/RDBMSMM.kmt“ // Output metamodel in kermeta
[...]
class Class2RDBMS
{
  /** The trace of the transformation */
  reference class2table : Trace<Class, Table>

  /** Set of keys of the output model */
  reference fkeys : Collection<FKey>
[...]
```

```
operation transform(inputModel : ClassModel) : RDBMSModel is do
// Initialize the trace
class2table := Trace<Class, Table>.new
class2table.create
fkeys := Set<FKey>.new
```

Trace Initialization

```
result := RDBMSModel.new
// Create tables
getAllClasses(inputModel).select{ c | c.is_persistent }.each{ c |
  var table : Table init Table.new
  table.name := c.name
  class2table.storeTrace(c, table)
  result.table.add(table)
```

Create Tables

```
}
// Create columns
getAllClasses(inputModel).select{ c | c.is_persistent }.each{ c |
  createColumns(class2table.getTargetElem(c), c, "")
```

Create Columns

```
}
// Create foreign keys
fkeys.each{ k | k.createFKeyColumns }
```

Update Foreign Keys

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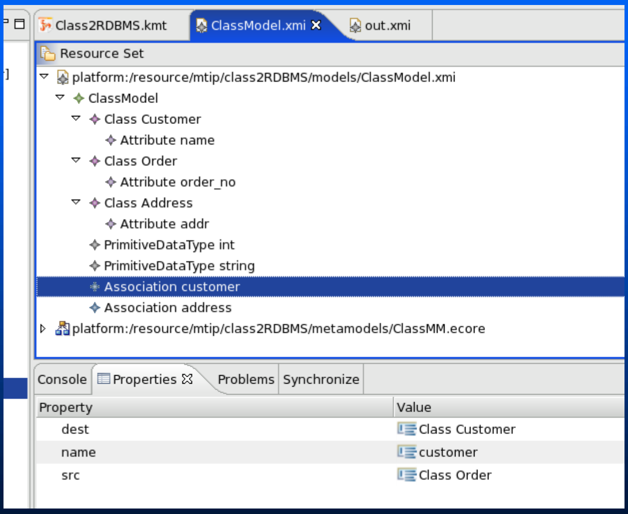
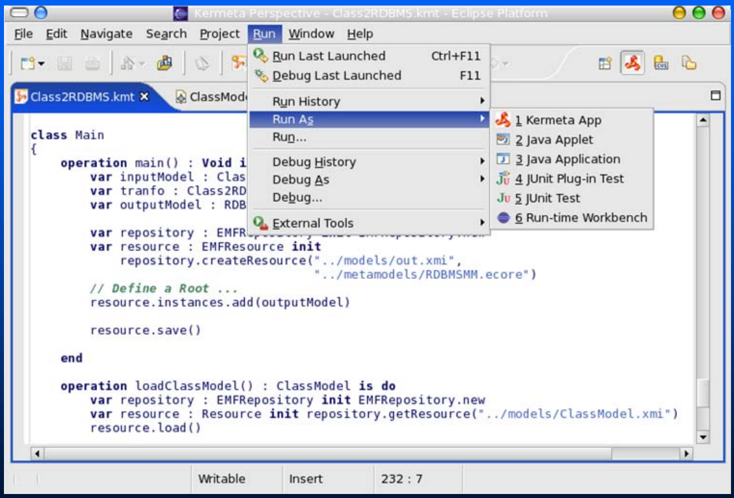
# Getting the input model



```
Resource Set
▽ platform:/resource/mtip/class2RDBMS/models/ClassModel.xmi
  ▽ ClassModel
    ▽ Class Customer
        Attribute name
    ▽ Class Order
        Attribute order_no
    ▽ Class Address
        Attribute addr
      PrimitiveDataType int
      PrimitiveDataType string
      Association customer
      Association address
▷ platform:/resource/mtip/class2RDBMS/metamodels/ClassMM.ecore
```

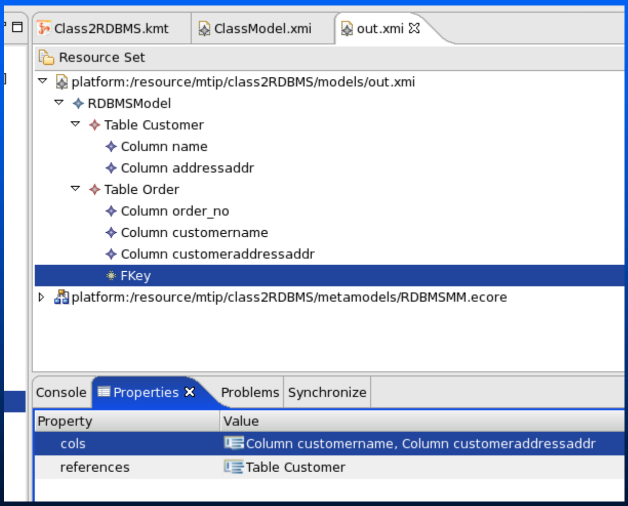
| Property | Value |
|---|---|
| dest | Class Customer |
| name | customer |
| src | Class Order |

# Executing the transformation



```
class Main
{
    operation main() : Void i
        var inputModel : Clas
        var tranfo : Class2RD
        var outputModel : RDB

        var repository : EMFR
        var resource : EMFResource init
            repository.createResource("../models/out.xmi",
                                      "../metamodels/RDBMSMM.ecore")
        // Define a Root ...
        resource.instances.add(outputModel)

        resource.save()

    end

    operation loadClassModel() : ClassModel is do
        var repository : EMFRepository init EMFRepository.new
        var resource : Resource init repository.getResource("../models/ClassModel.xmi")
        resource.load()
```

# Generated output model



- platform:/resource/mtip/class2RDBMS/models/out.xmi
  - RDBMSModel
    - Table Customer
      - Column name
      - Column addressaddr
    - Table Order
      - Column order_no
      - Column customername
      - Column customeraddressaddr
      - FKey
- platform:/resource/mtip/class2RDBMS/metamodels/RDBMSMM.ecore

| Property | Value |
|---|---|
| cols | Column customername, Column customeraddressaddr |
| references | Table Customer |

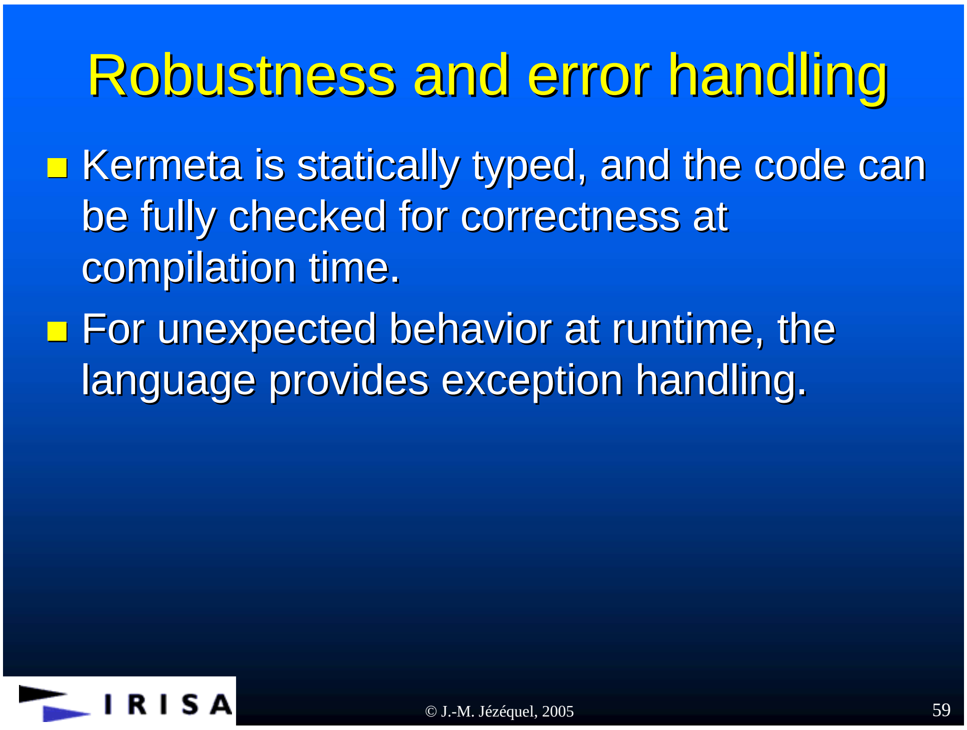
# Object-orientation

- Classes and relations, multiple inheritance, late binding, static typing, class genericity, exception, typed function objects
- OO techniques such as patterns, may be applied to model transformations
  - Template method as above
  - Command, undo-redo
    - » Refactorings example

```
abstract class RefactoringCommand
{
    operation check() : Boolean is abstract
    operation transform() : Void is abstract
    operation revert() : Void is abstract
}
```

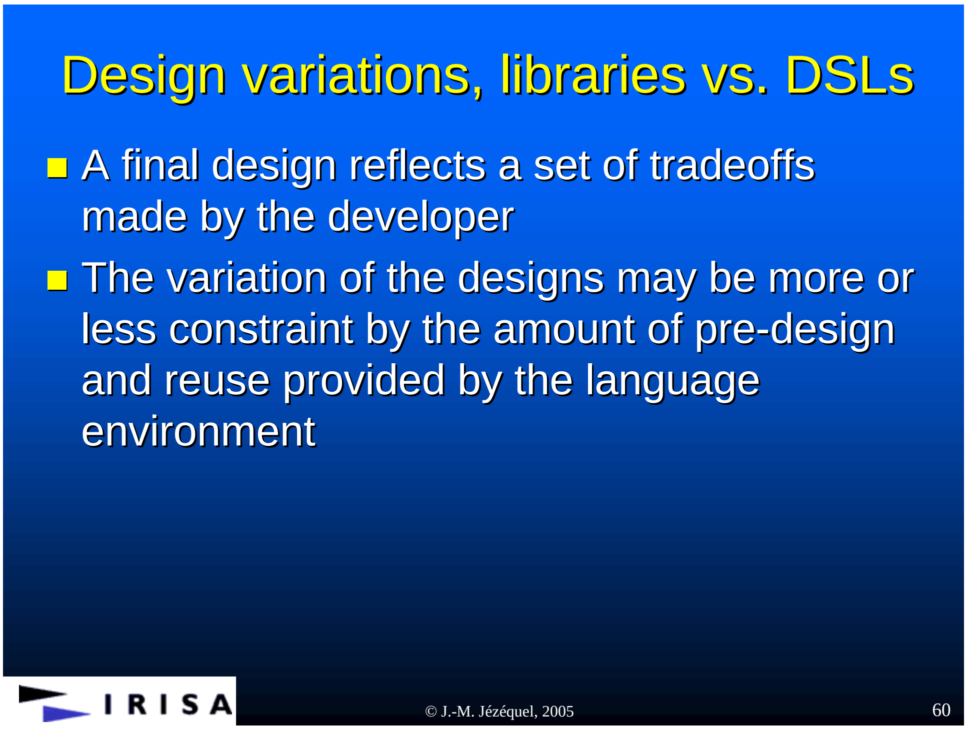
# Composition of transformations

- Packages, classes, operations and methods, inheritance and late bindings
- Rule recursivity is handled by function recursivity



## Robustness and error handling

- Kermeta is statically typed, and the code can be fully checked for correctness at compilation time.
- For unexpected behavior at runtime, the language provides exception handling.



## Design variations, libraries vs. DSLs

- A final design reflects a set of tradeoffs made by the developer
- The variation of the designs may be more or less constraint by the amount of pre-design and reuse provided by the language environment

# Software Engineering Concerns

- Modularity in the small and the large
  - classes & packages
- Reliability
  - static typing, typed function objects and exception handling
- Extensibility and reuse
  - inheritance, late binding and genericity
- V & V
  - test cases

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# Conclusion

- Transformations are Assets
  - apply sound SE principles: Modeling!
    - » from requirements, analysis, design, to implementation, V&V, and Configuration Management
- Developing Model Transformations in-the-large is not different from developing software
  - Unclear Requirements, Bugs,
  - Learning Curve (yet another language)
- A specific language does not help much to address these generic SE issues
  - Rely on proven techniques: OO languages, patterns, frameworks

➡ Model-Driven Approach to Model Transformation