54. How to Synchronize Models with Triple Graph Grammars for Data Connection

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Version 21-0.5, 29.01.22

1) Triple Graph Grammars
2) Specifying TGG in MOFLON
3) Using TGG in MOFLON
4) The Tornado mapping method

Literature

- [ES89] Gregor Engels, Wilhelm Schäfer. Programming Environments, Concepts and Realization (in German), 1989, Teubner-Verlag Stuttgart
- Anthony Anjorin, Erhan Leblebici, and Andy Schürr. 20 years of triple graph grammars: A roadmap for future research. ECEASST, 73, 2015.
- F. Klar, A. Königs, A. Schürr: "Model Transformation in the Large", Proceedings of the the 6th joint meeting of the European software engineering conference and the ACM SIGSOFT symposium on the foundations of software engineering, New York: ACM Press, 2007; 285-294. http://www.idt.mdh.se/esec-fse-2007/
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- T. Fischer, J. Niere, L. Torunski, and A. Zündorf, 'Story Diagrams: A new Graph Rewrite Language based on the Unified Modeling Language', in Proc. of the 6th International Workshop on Theory and Application of Graph Transformation (TAGT), Paderborn, Germany (G. Engels and G. Rozenberg, eds.), LNCS 1764, pp. 296--309, Springer Verlag, November 1998. http://www.upb.de/cs/ag-schaefer/Veroeffentlichungen/Quellen/Papers/1998/TAGT1998.pdf

Literature

- [KS05] Alexander Königs, Andy Schürr. Multi-Domain Integration with MOF and extended Triple Graph Grammars. Technical Report. University of Technology Darmstadt. Dagstuhl Seminar Proceedings 04101
    - http://drops.dagstuhl.de/opus/volltexte/2005/22
- Alexander Königs, Andy Schürr. MDI: a rule-based multi-document and tool integration approach. Softw Syst Model (2006) 5:349–368 DOI 10.1007/s10270-006-0016-x
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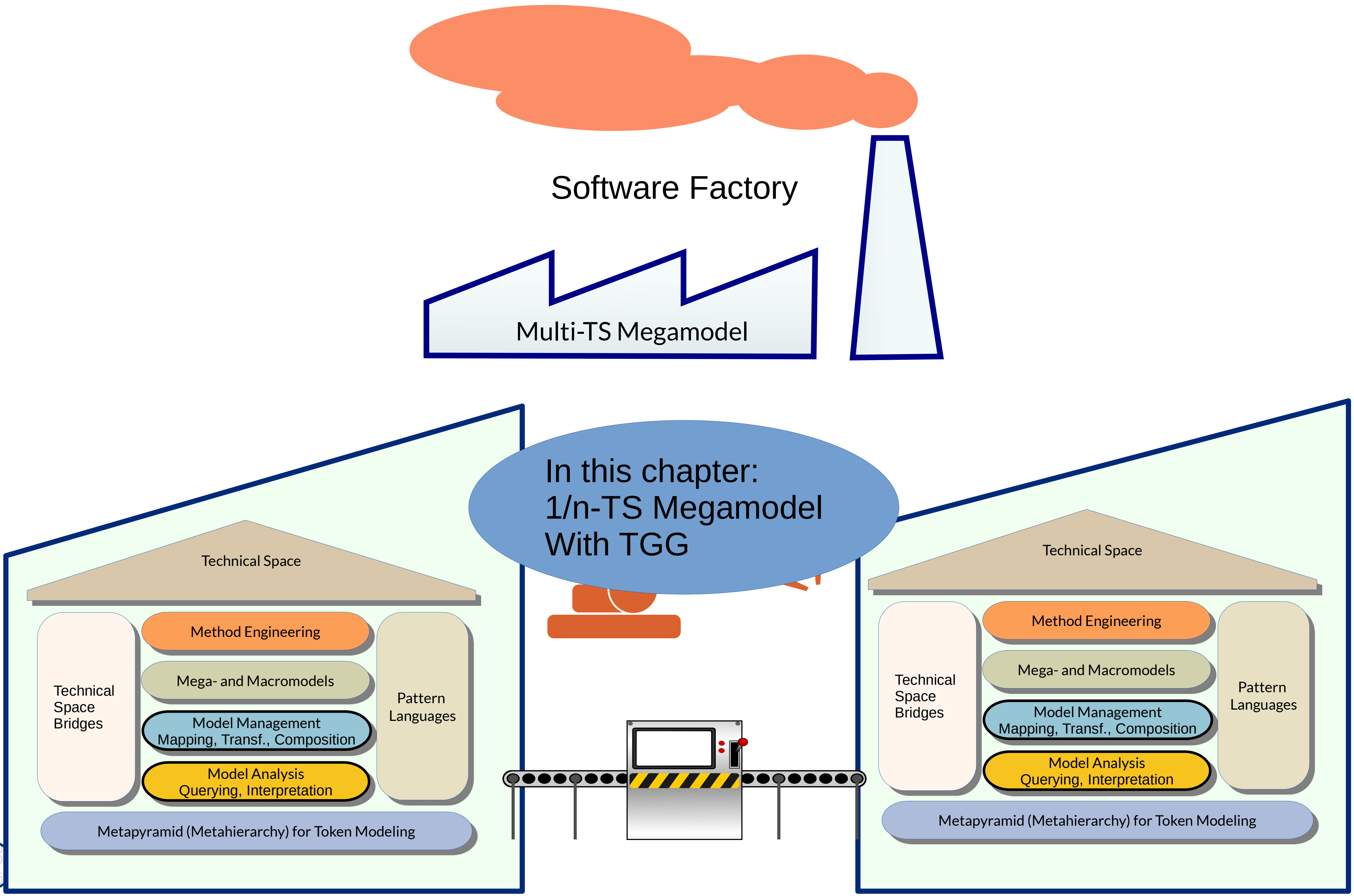
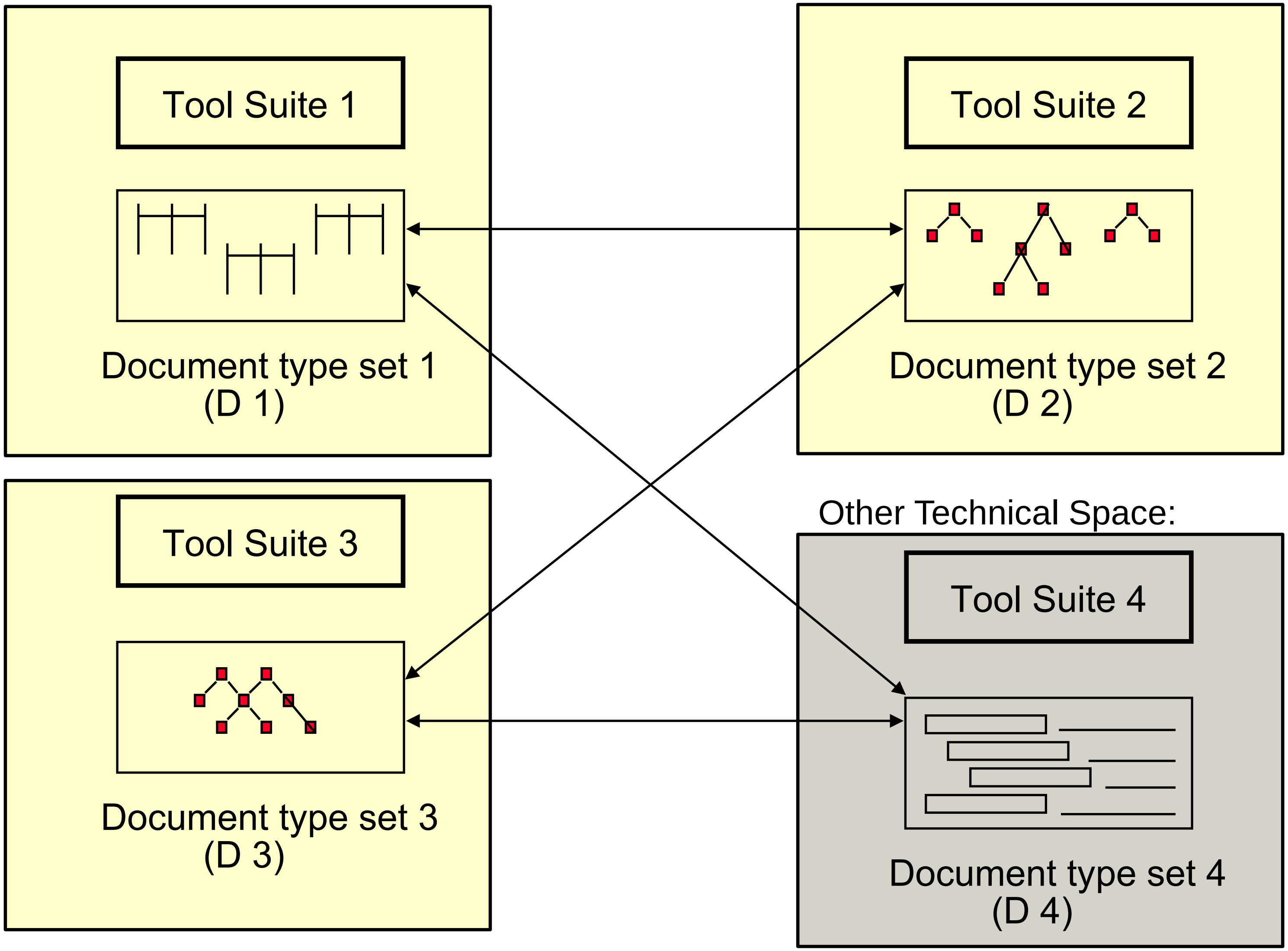
Q13: A Software Factory's Heart: the Multi-TS Megamodel



Integration of Tool Suites by Data Connection

[ES89, 6, S. 11]

- Material of several tool (suites) can be ***data-connected*** by transformations or access adaptations

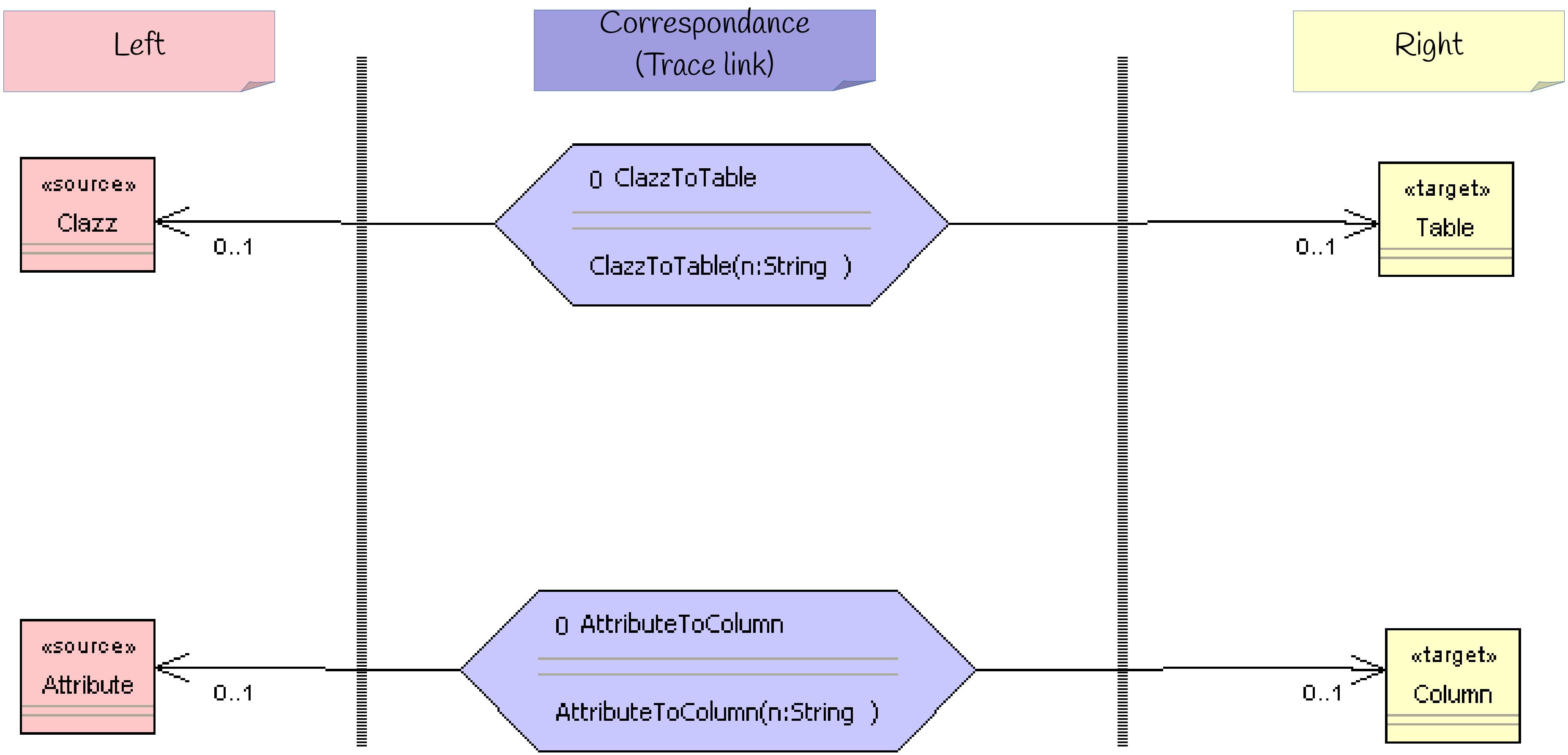


54.1 „Synchronizing“ Models with Triple Graph Grammars

- Mapping graphs to other graphs, also in data connections of different tools
- Specification of mappings with mapping rules
- Incremental transformation
- Traceability

Triple Graph Grammars – Moflon Example

- A **Triple Graph Grammar (TGG)** is a mapping-oriented transformation system, consisting of rules with three „areas" (better called **metamodel mapping grammars**)
  - Left side: (source) graph pattern 1 in (source) graph 1
  - Right side: (target) graph pattern 2 in (target) graph 2
  - **Middle: relational expression (net)** relating graph pattern 1 and 2 (trace model)



Basic Types of Synchronization Rules

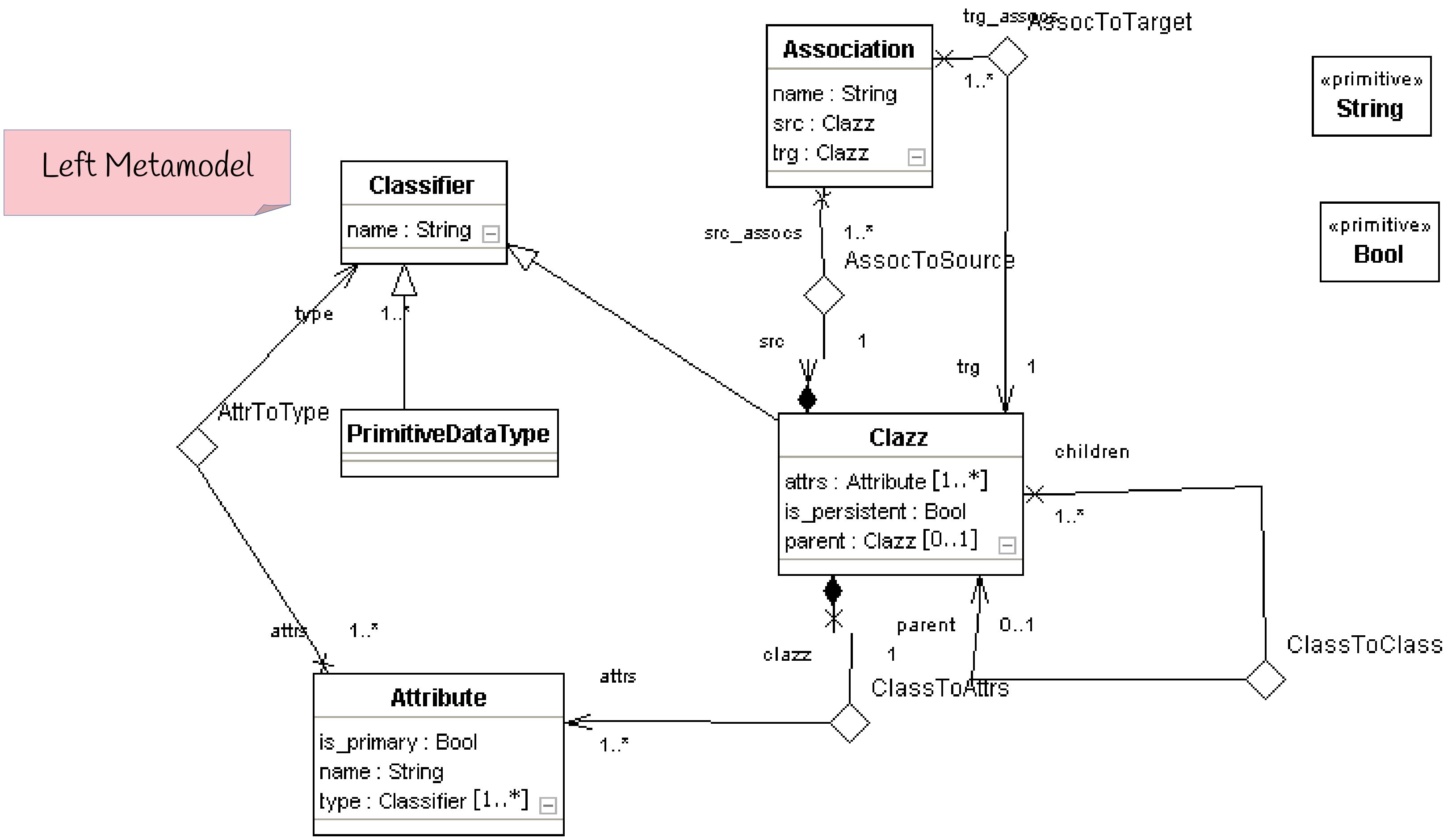
Depending on the modification colors, a TGG rule can be checking or creating the correspondance.

Rule classes from [KS05] Koenigs/Schuerr 2005:

- **Consistency Checking rules** – test whether both patterns exist
  - modification color is black (test)
- **Traceability relationship creating rule** – add a trace relation between elements of both sides
  - modification color is green in correspondance part (add)
- **Create model element** in one domain matching its correspondant
  - modification color is green on one side (add)
- **Lower layer create model element** – create model in a lower grammar layer
  - modification color is green on lower layer (add)

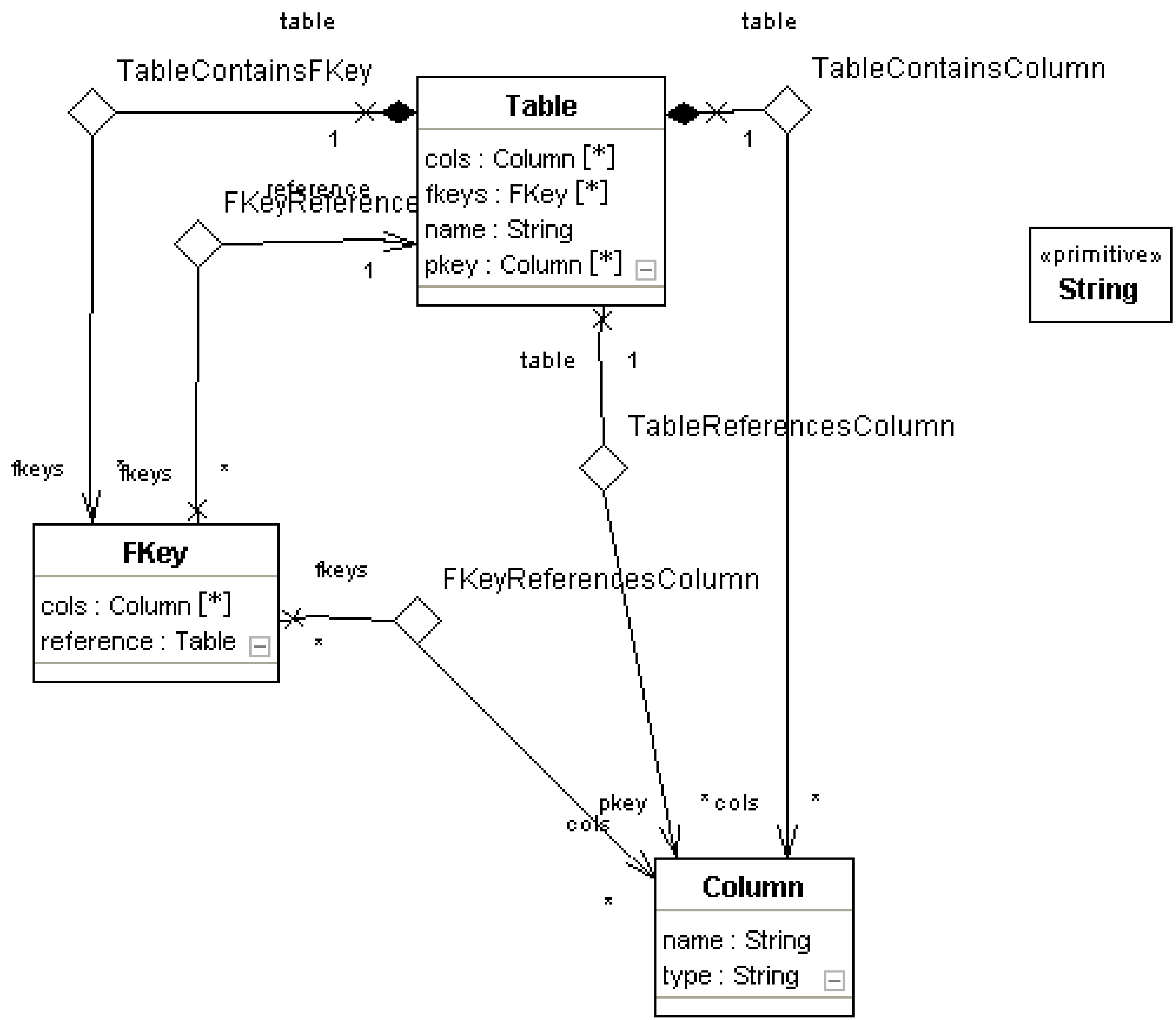
54.2.1. Mapping Objects to Tables (Object-Relational Mapping, ORM)

- Synchronize Class-Diagram-metamodel (CD) with a relational schema (RS): object-relational mapping (ORM)



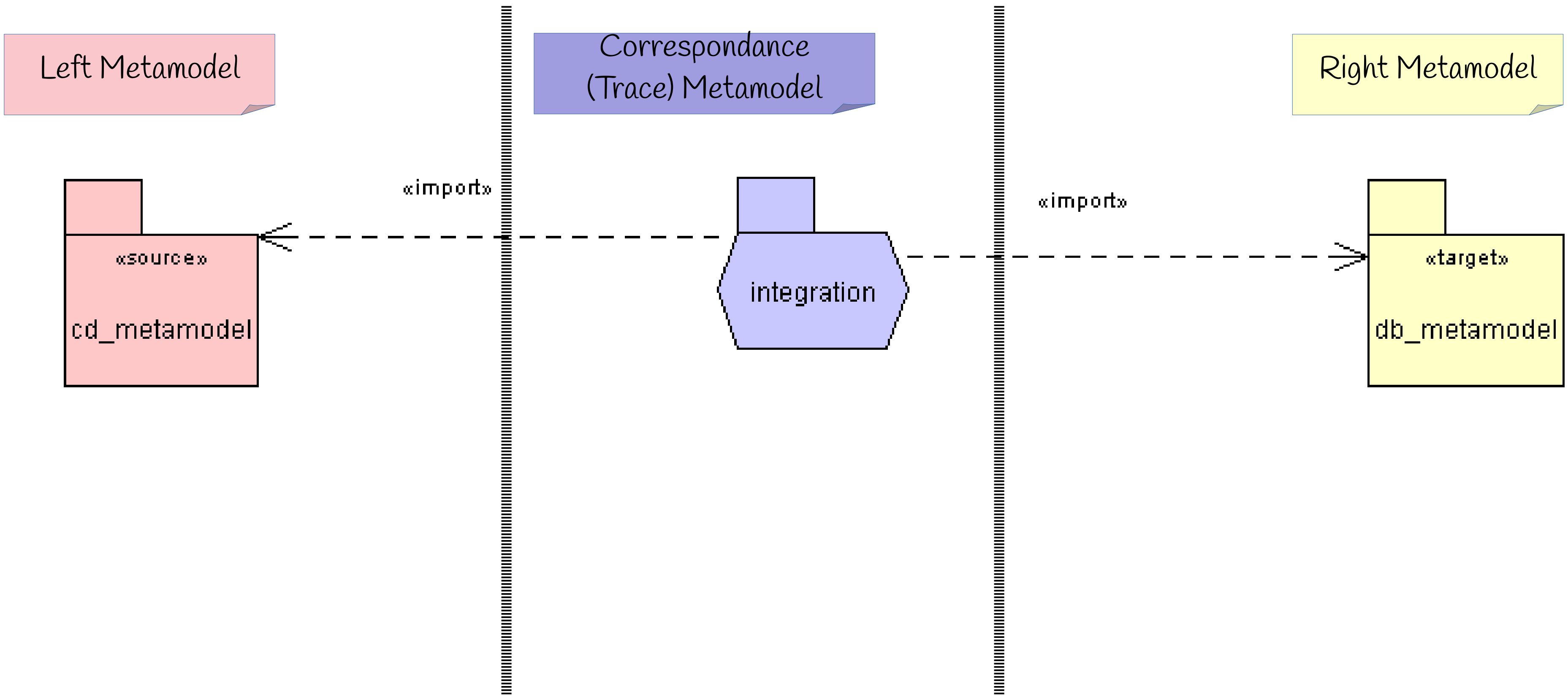
Right Metamodel: Relational Metamodel (DB, relational schema)

Right Metamodel



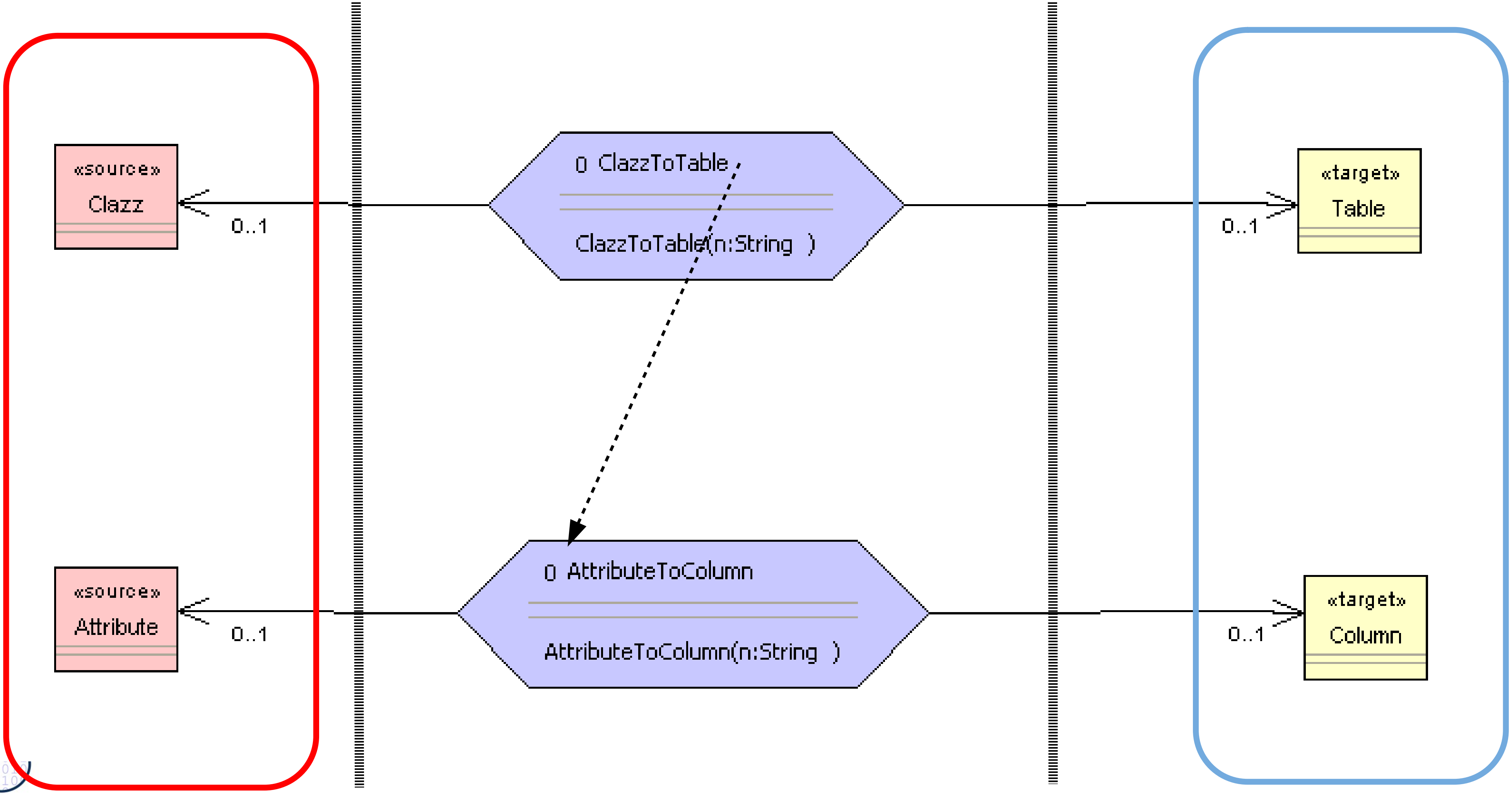
TGG for Object–Relational Mapping (ORM)

- The metamodel mapping grammar of a TGG has a top rule (start rule) which describes the relationship of the graphs on topmost level



Example of Consistency-Checking Rule

- From the top-rule `ClazzToTable`, other TGG rules are associated („called"/"invoked")
- In this case, the TGG only checks (black color – TEST)
- Q: What happens, if both sides are in different Technical Spaces?



TGG Specify Transformation Bridges Between Roles and Technical Spaces

- TGG can also be used to data-exchange and synchronize Material classes and roles
  - between two material objects
  - between two tools with different repositories
    - even in different technical spaces
- The only assumption: 1:1 mappings of model elements

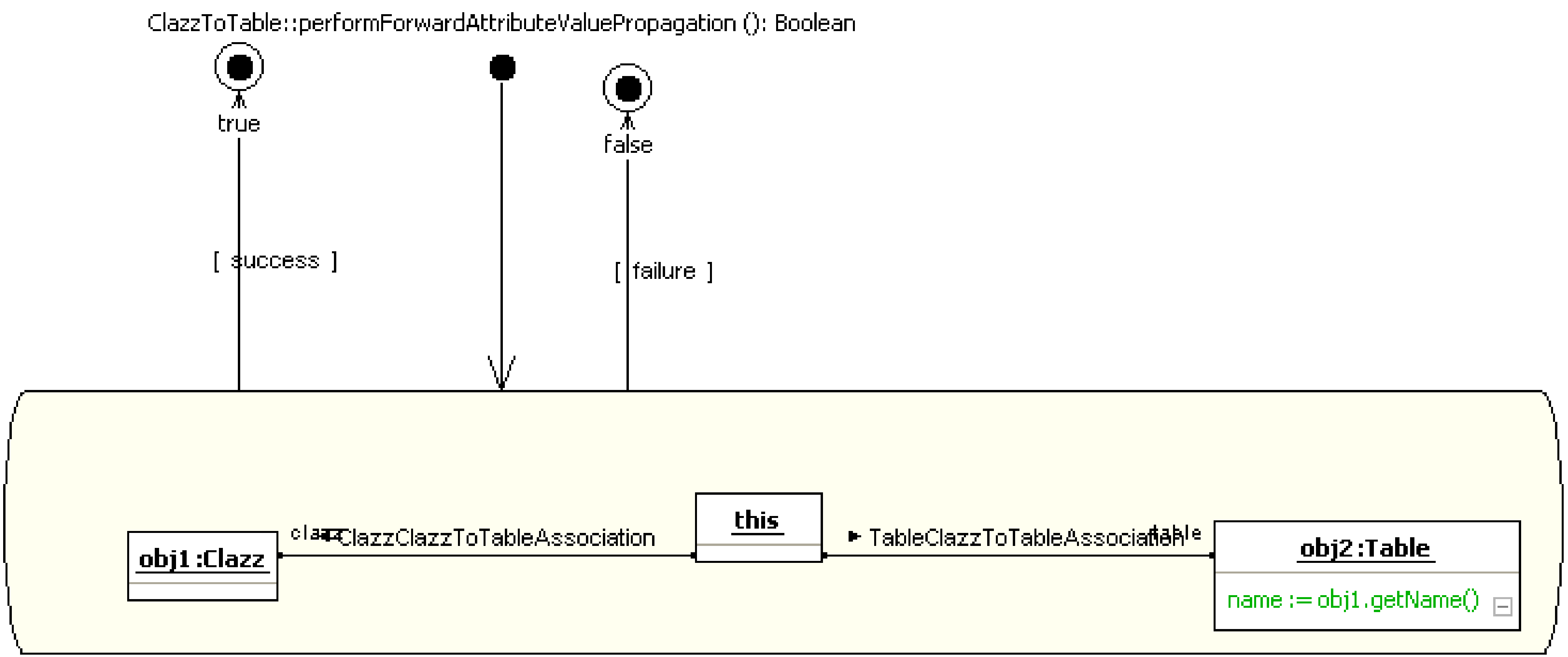
TGG are a fine technique to build *transformation bridges for data connection* between tools, even in different technical spaces.

54.2. Triple Graph Grammars in MOFLON

- MOFLON in MOF Technical Space
- eMOFLON in EMOF TS

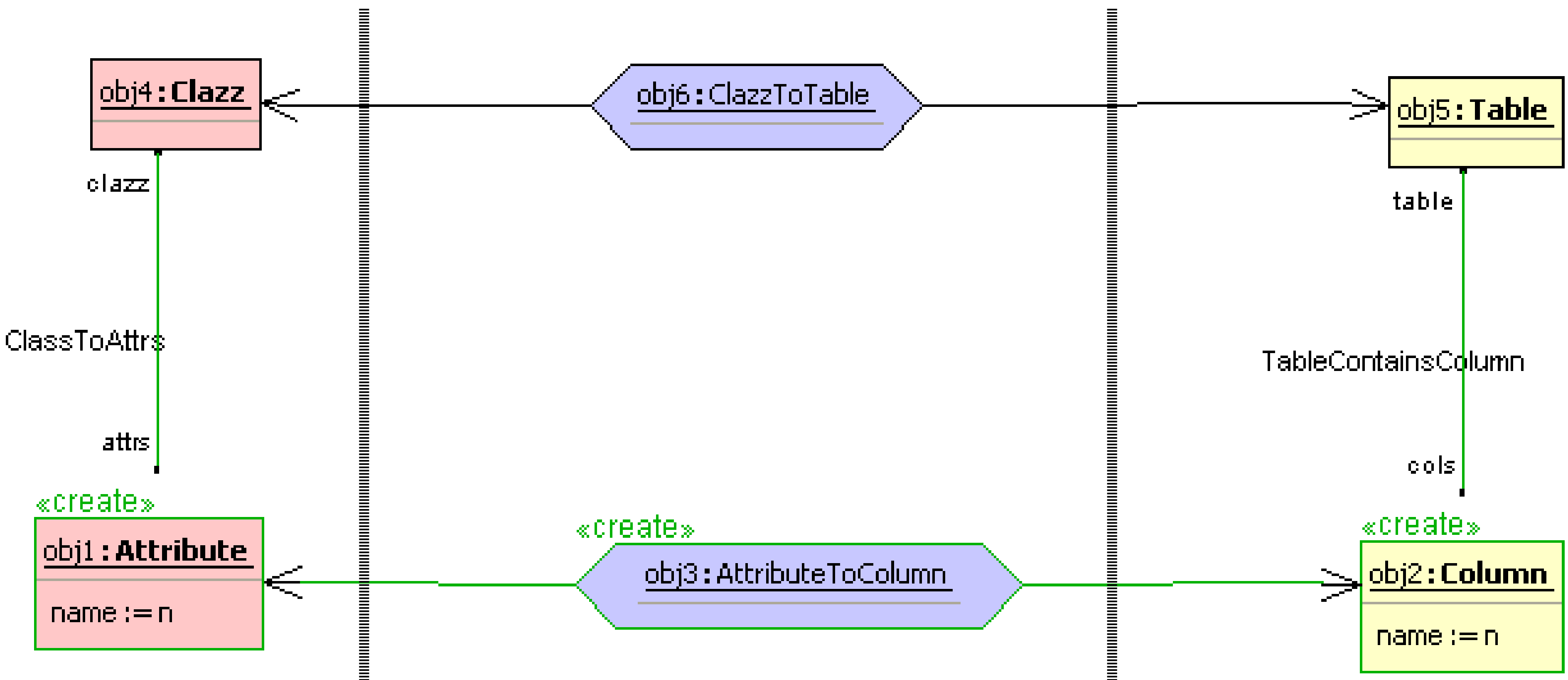
Triple Graph Grammars – Moflon Example

- Because they are named, TGG rules can be started by Fujaba Storyboards (activity diagrams)
- The activites can be associated to a transformation class ClazzToTable



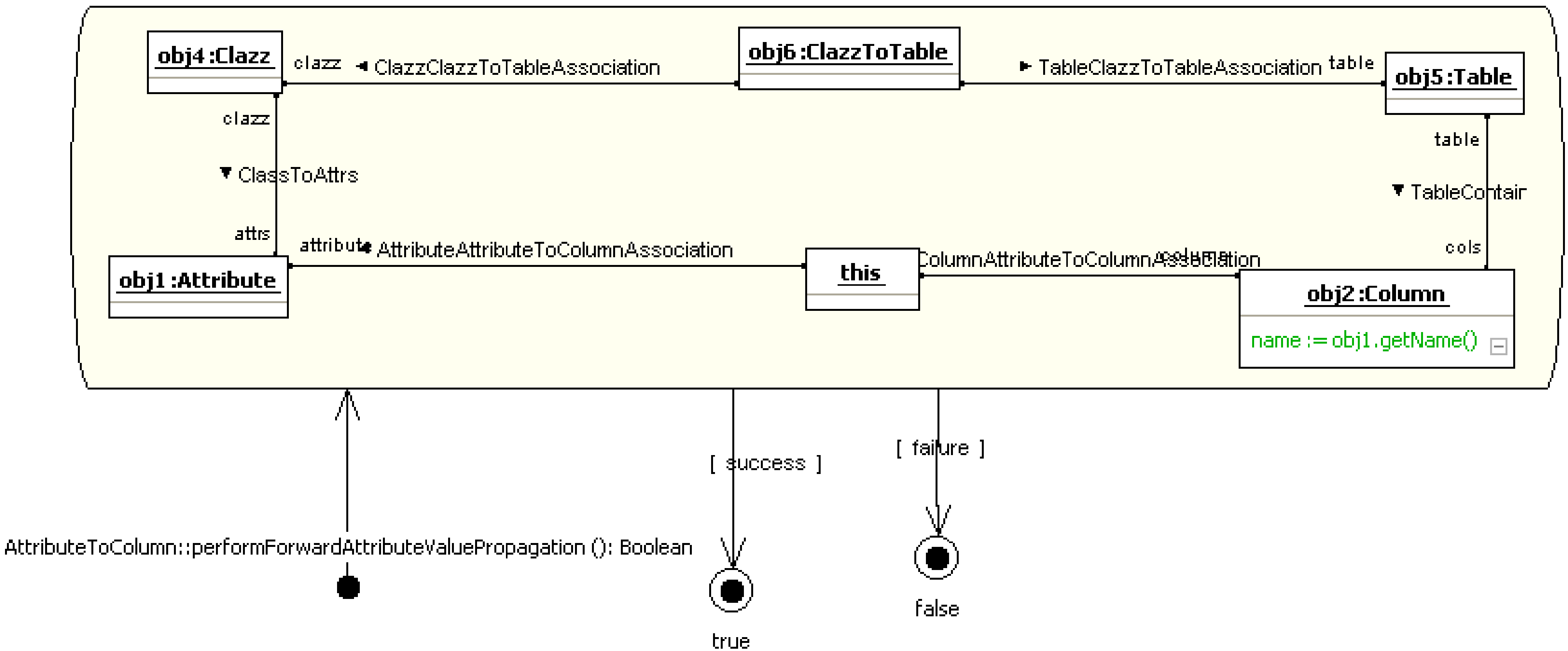
Example of Lower-Level-Creation Rule

- *Lower-level-creation rule* creates lower level elements and a pairwise correspondance of model elements on both sides
  - Here, objects on the lower level are created anew if needed from the tested upper level



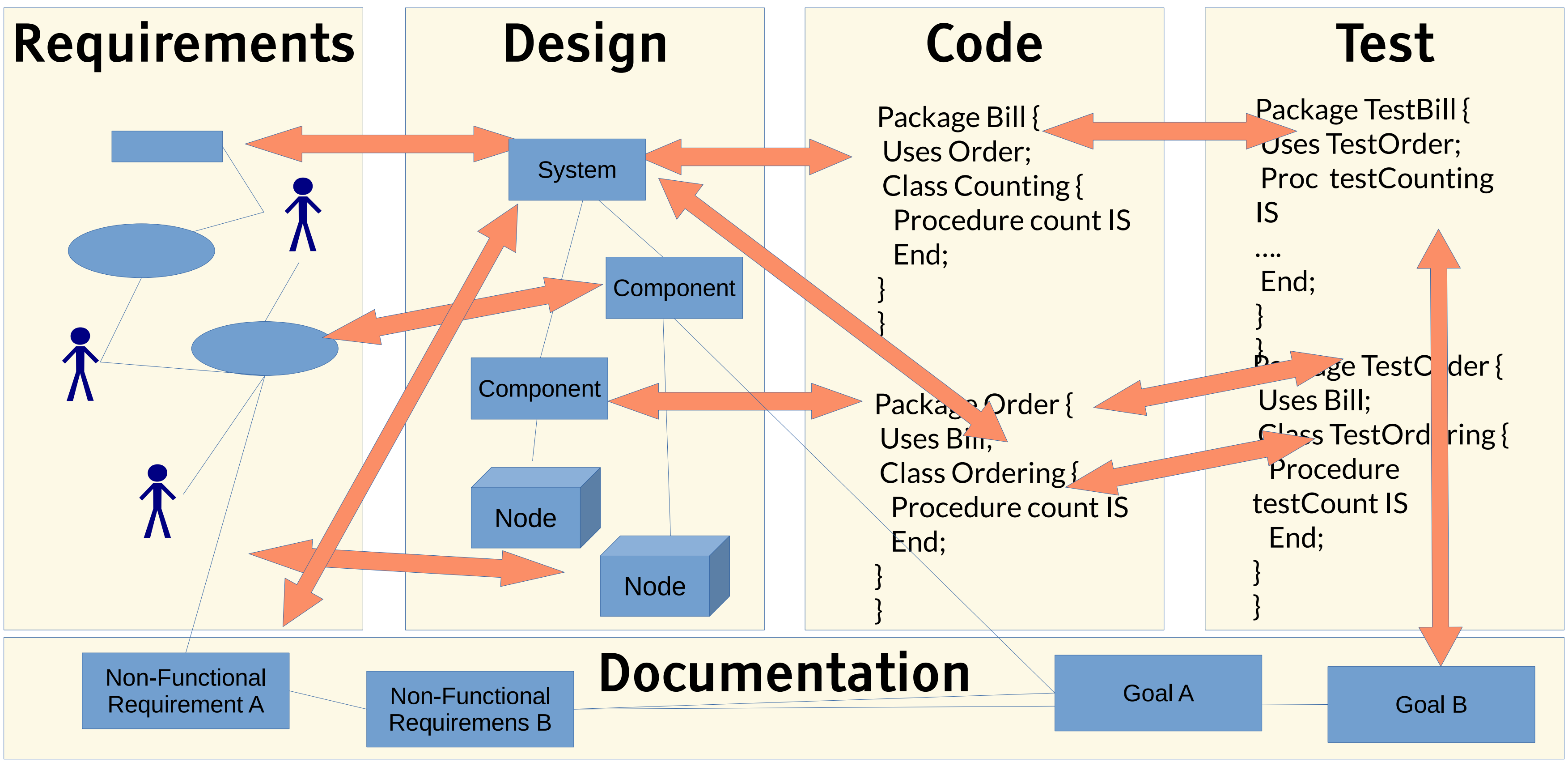
Triple Graph Grammars – Moflon Example

- Notation in Moflon/Fujaba Storyboards
- Checking a pattern with adding an attribute to `obj2`

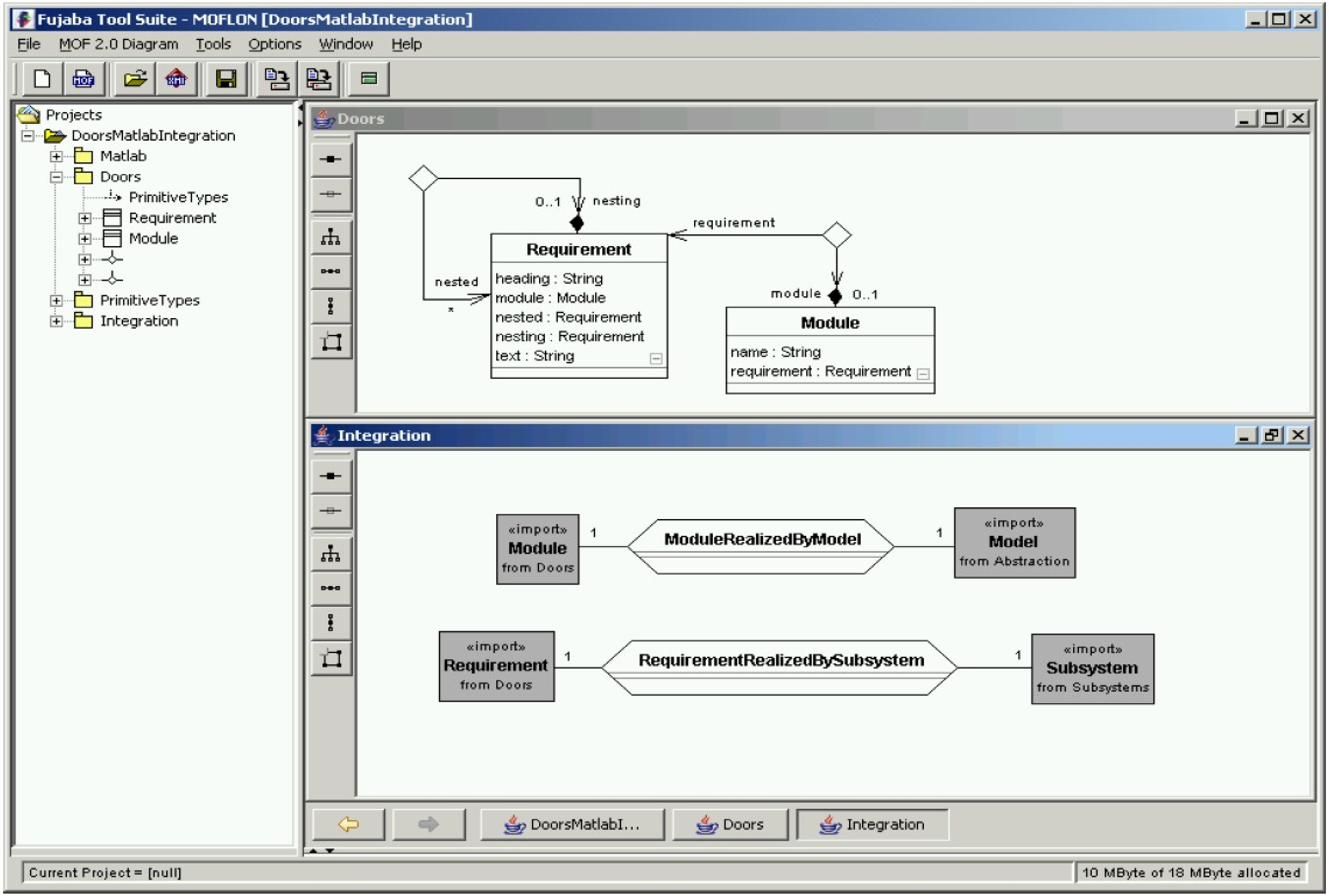


Q12: The ReDoDeCT Problem and its Macromodel

- The **ReDoDeCT problem** is the problem how requirements, documentation, design, code, and tests are related (→ V model)
- Mappings between the Requirements model, Documentation files, Design model, Code, Test cases
- A **ReDoDeCT macromodel** has maintained mappings between all 5 models

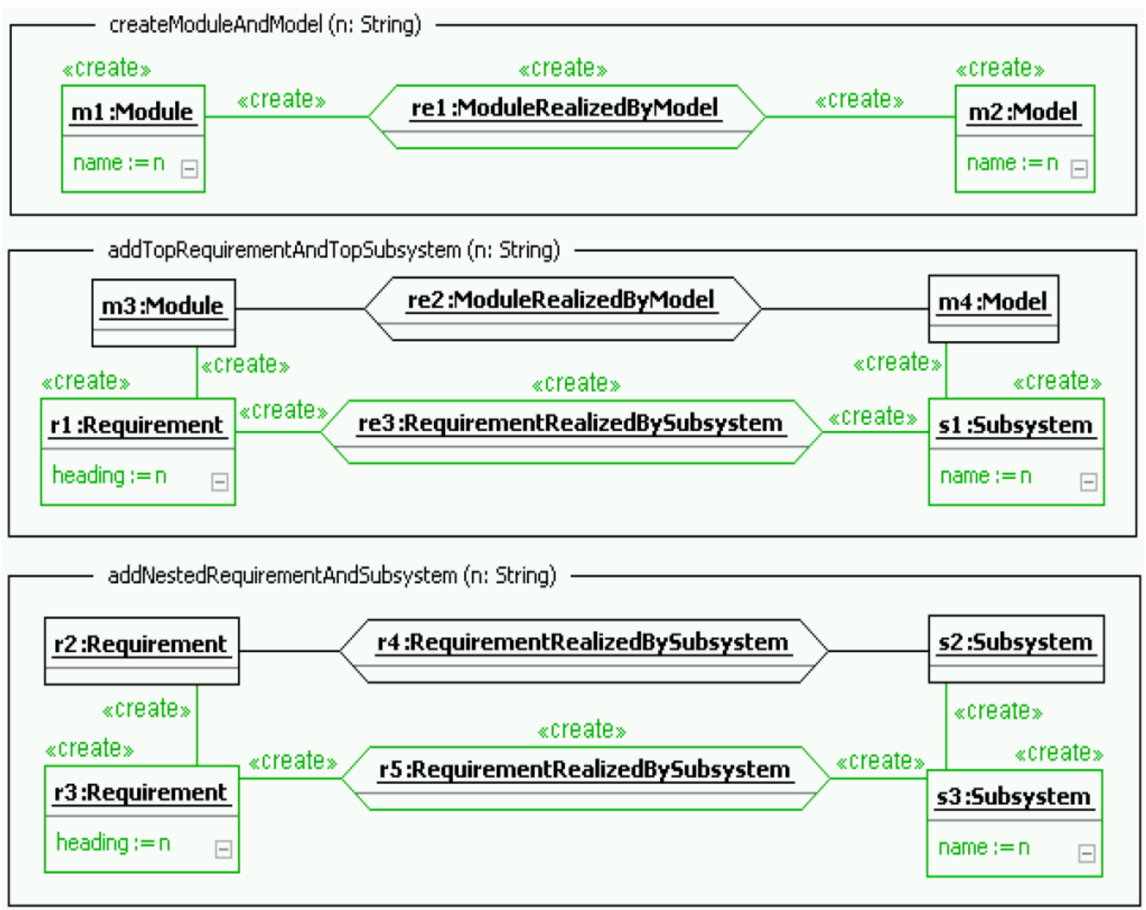


Ex. 2: TGG Coupling of Requirements Specification and Design



TGG Coupling Requirements Specification and Design

- This TGG grammar builds up a module-requirements graph
- Starting from a relation "ModuleRealizedByModel" and "RequirementRealizedBySubsystem"



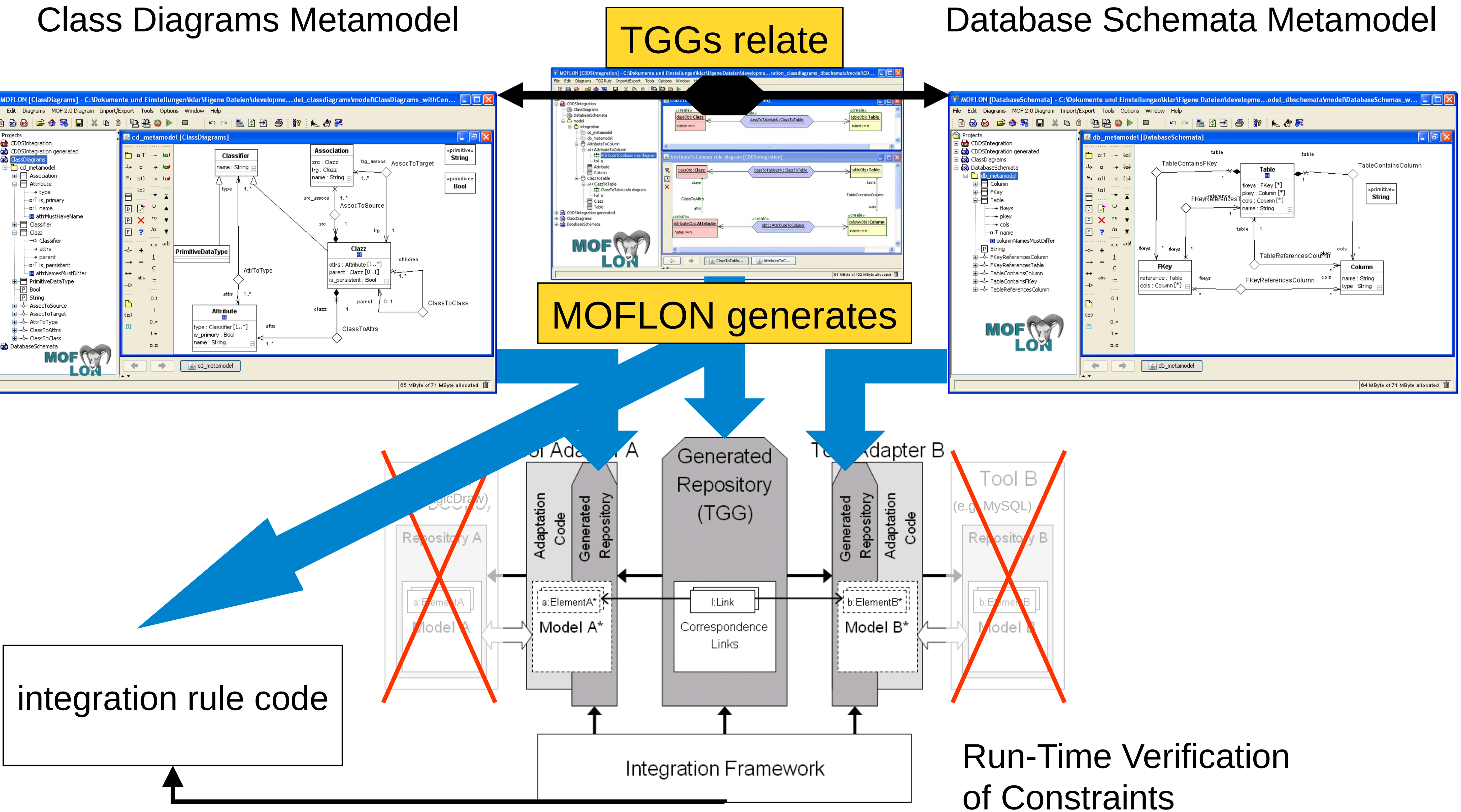
initial, creational

lower-layer creational

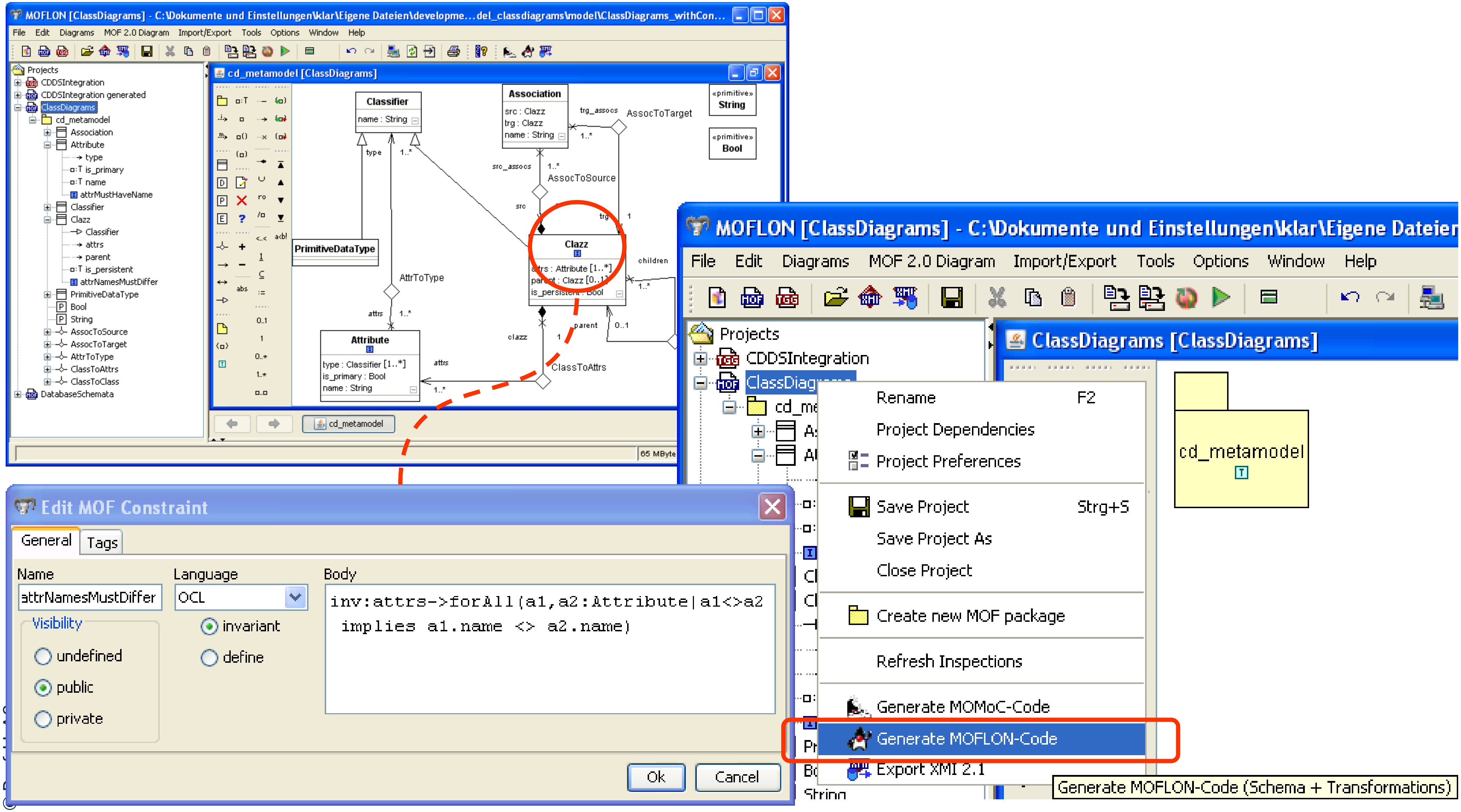
lower-layer creational

54.3. Using Triple Graph Grammars in MOFLON

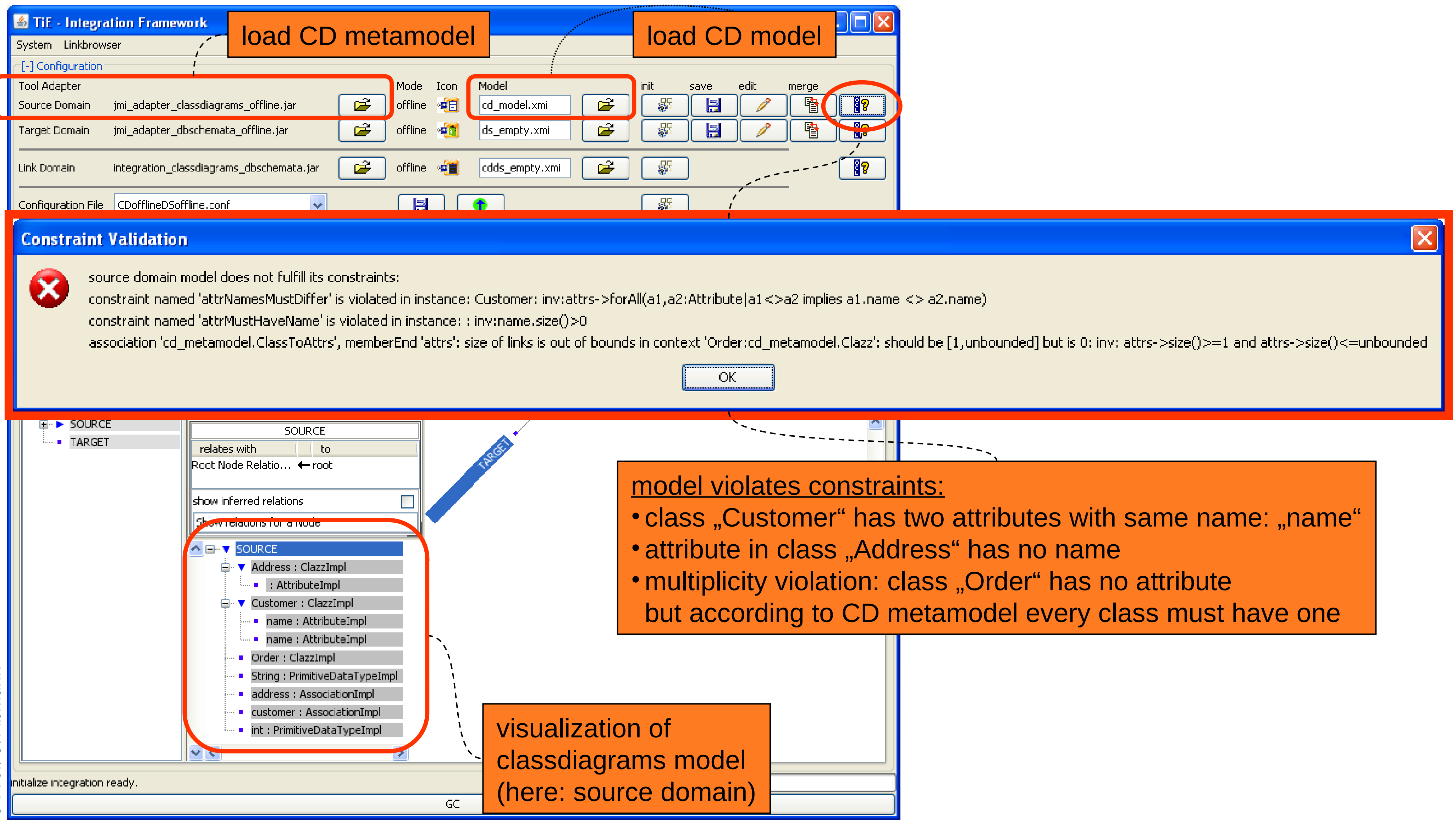
Example: Object-Relational Mapping "TiE-CD-DB": (ClassDiagrams / DatabaseSchema)



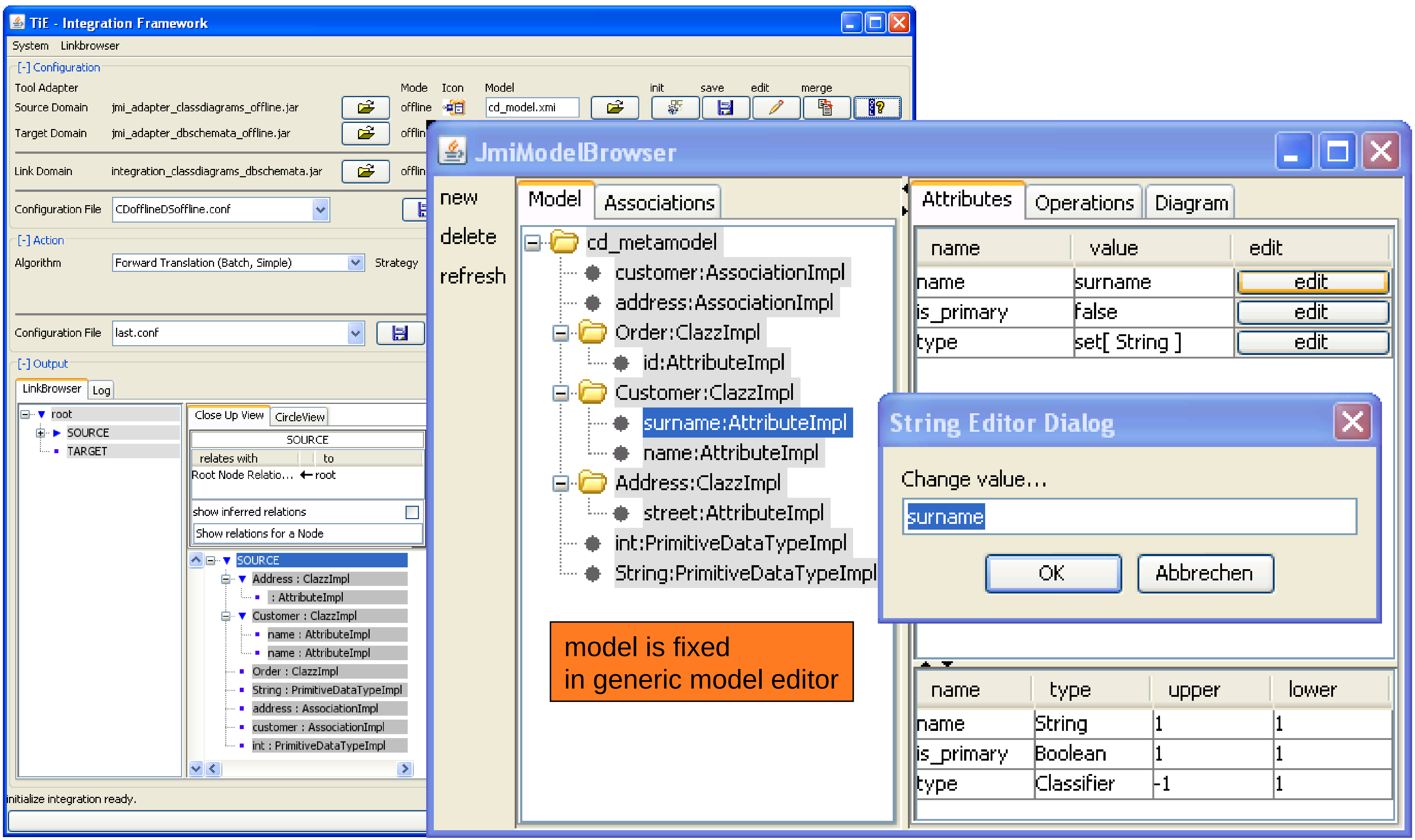
TiE-CD-DB – Constraints in Class Diagrams (1)
Generate Code from MOF model (CD metamodel)



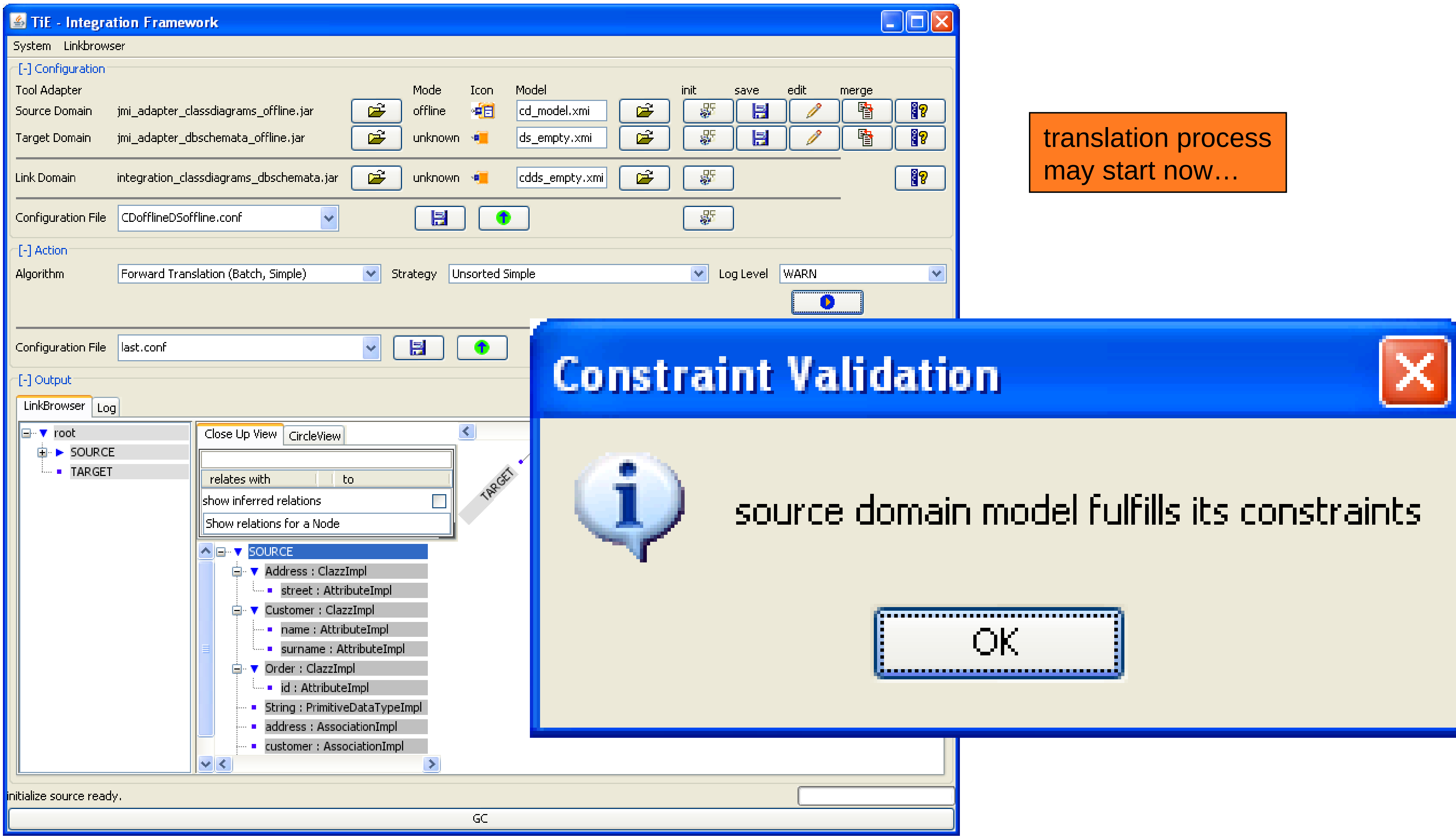
TiE-CD-DB – Constraints in Class Diagrams (2)
Loading Metamodels and Models



TiE-CD-DB – Constraints in Class Diagrams (3) Model Browser

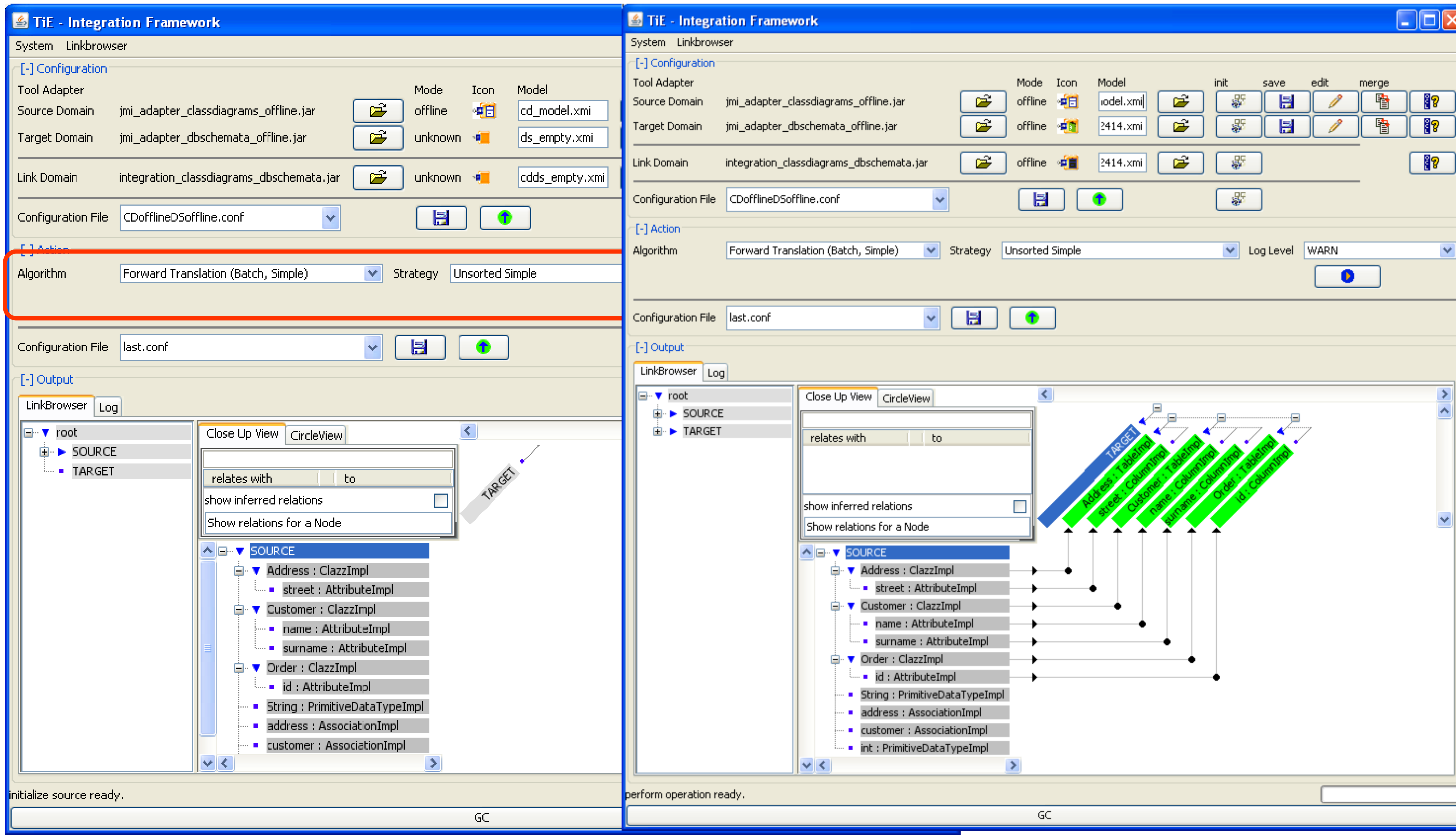


TiE-CD-DB – Constraints in Class Diagrams (4) Integration Framework



translation process may start now…

TiE-CD-DB – Constraints in Class Diagrams (5) Forward Translation to DB representation



Other Software Engineering Applications of Model Synchronization

- Mapping a PIM to a PSM in Model-Driven Architecture
- Graph Structurings (see course ST-II)
- Refactorings (see Course DPF)
- Semantic refinements
- Round-Trip Engineering (RTE)

54.4 The Tornado Method: Specification of TGG Rules using Textual Concrete Syntax

- Slides about Tornado courtesy to Mirko Seifert and Christian Werner
- Presented at Fujaba Days 2009, Eindhoven, The Netherlands, 16.11.2009
- Christian Werner. Konzeption und Implementierung eines Debuggers für textuelle Triple Graph Grammar Regeln. Belegarbeit, Lehrstuhl Softwaretechnologie, 2010, TU Dresden
  - available on request

Motivation for Textual Syntax of TGG

- TGGs are fine for model synchronization, but writing TGG rules is not always easy

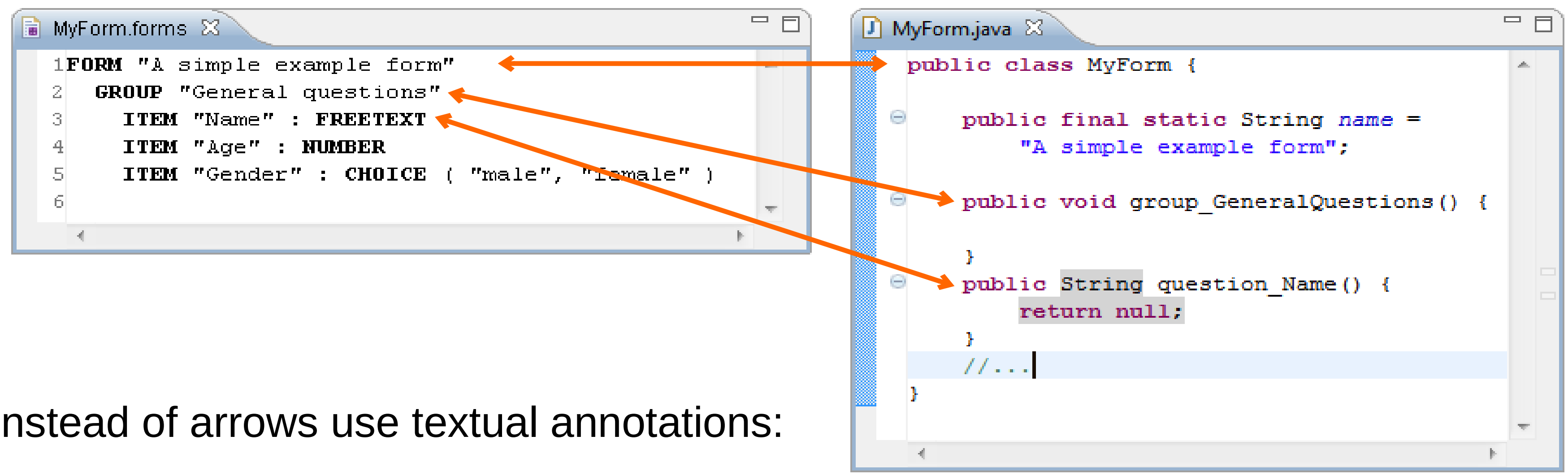
  Why?

- Rule specification typically on the level of abstract syntax
  - Complex abstract syntax (AS) graphs vs. simple concrete syntax (CS) fragments
  - Rule designers not always familiar with AS
- Rule specification is based on graphical syntax
  - But: There is lots of textual (modelling) languages
  - Gap: Graphical rules vs. textual models
  - Large graphical rules are hard to read

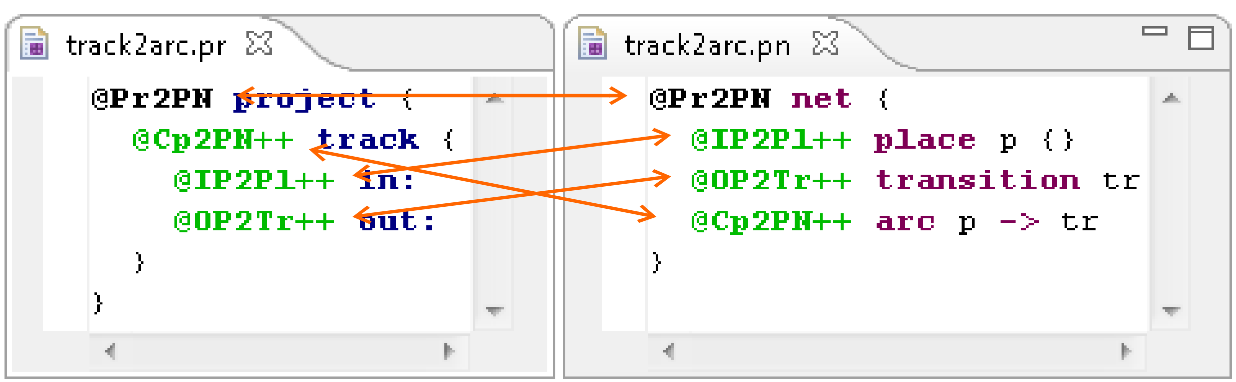
Can we do better?

Idea for Rule Specification in EMFText

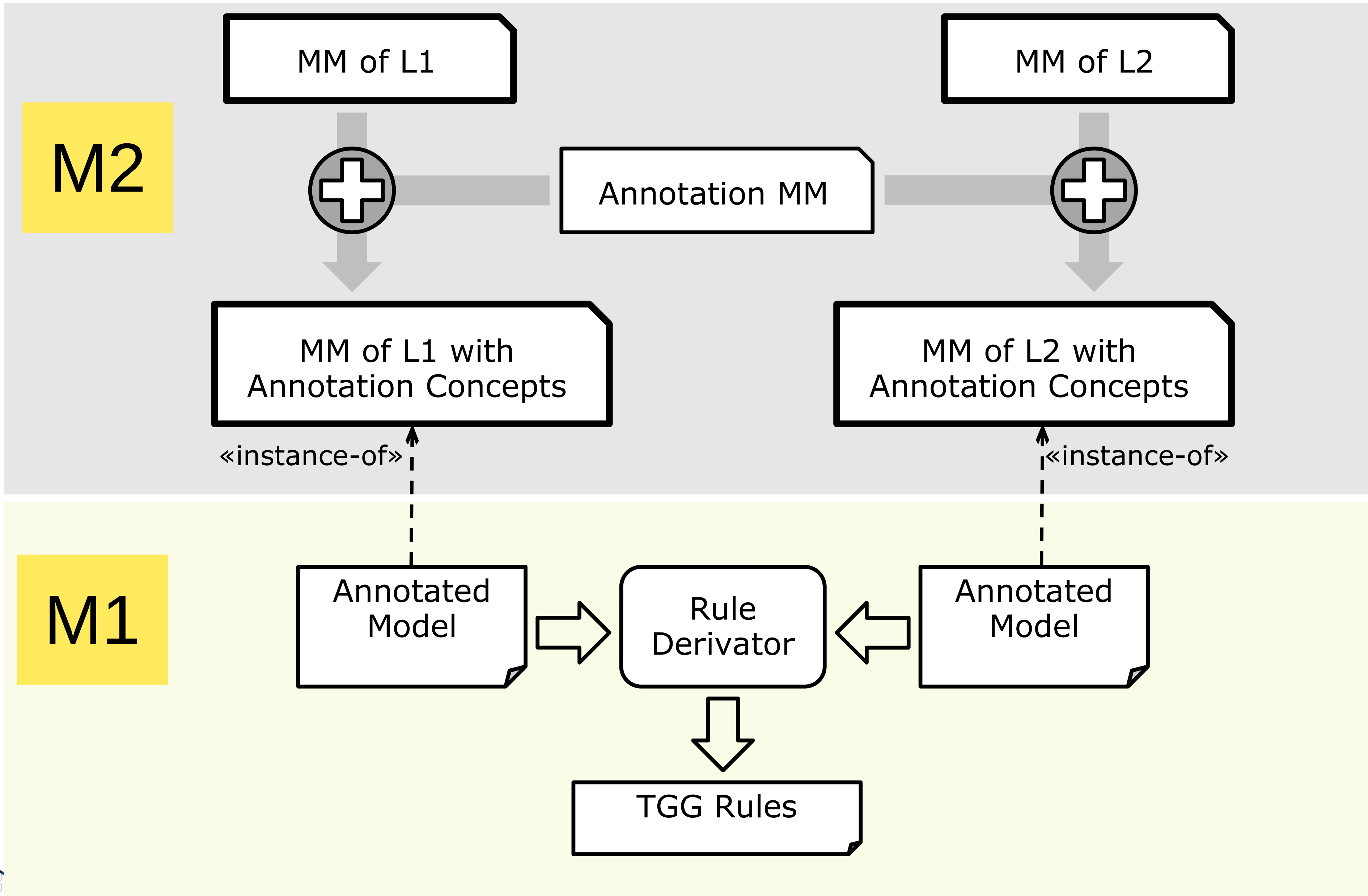
- employ EMFText; use concrete textual syntax of involved languages
- derive rules from pairs of models
- do it in a generic way (automatic application to any language)



Instead of arrows use textual annotations:

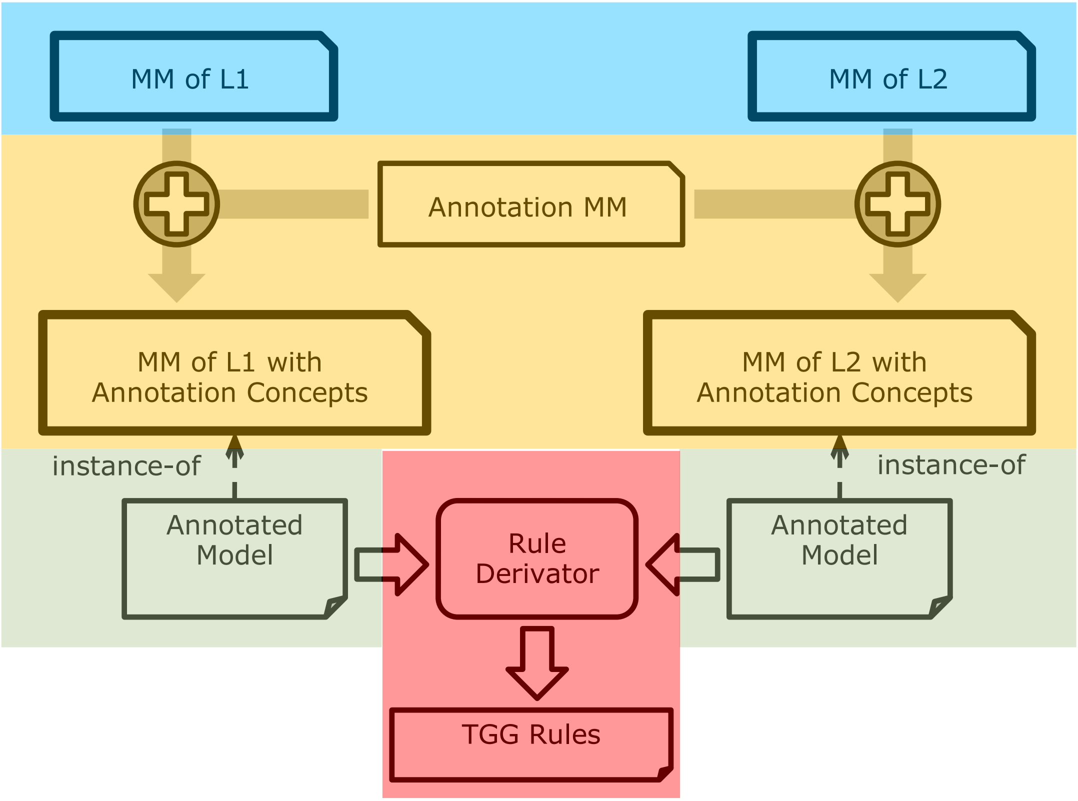


Tornado Generation Process of TGG Rules



Generation Steps of Tornado Method

1. Make meta models extensible
2. Extend meta models (with annotation concepts)
3. Extend concrete syntax
4. Derive rules from model pairs



Step 1 – Getting (more) Extensible Metamodels

Extensibility provided by Ecore (EMOF):

- Add new metaclasses (i.e., new complex types)
- Reference existing metaclasses (Reuse)
- Subclass existing metaclasses

What is missing in EMOF:

- Distinction between subtyping and inheritance
- Extensibility for primitive types
- Example:
    - Can't add things that do not have a property year
    - Can't add subtypes for EString

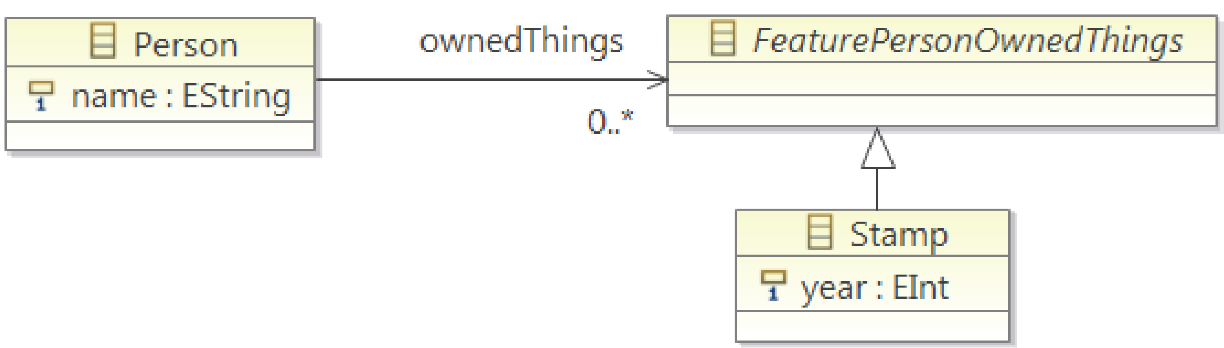
Step 1a – Getting Extensible Metamodels

Separate subtyping and inheritance (algorithm from [HJSWB]):

For each feature's type that has at least one superclass or defines at least one feature:

- Introduce a new abstract metaclass Feature<ClassName><FeatureName>
- Change the type of the feature to the new metaclass
- Make the former type of the feature a subclass of the new metaclass

Example:



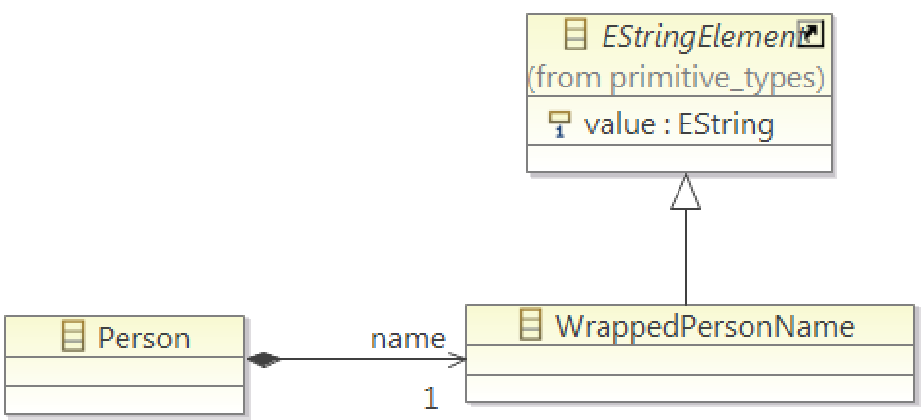
Step 1b – Getting Extensible Metamodels

Wrap primitive types (also from [HJSWB]):

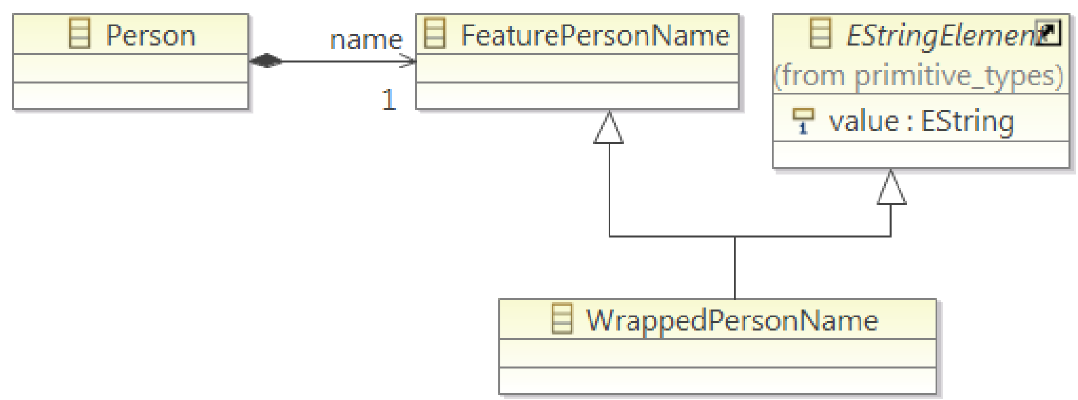
For each attribute that has a primitive type:

- Create a new subclass of the primitive type wrapper class
- Replace attribute with reference to new subclass

Example:



Wrapped attribute



Wrapped attribute after step 1a)

Step 2 – Extending Metamodels with Annotation Concepts

Goal:

- Every model element can be annotated

HowTo:

- For each meta class X create new metaclass AnnotableX with
  - Reference to class Annotation (to store the annotation)
  - Reference to the original class X (to store the data of X)
  - Make AnnotableX a subclass of each feature class that X inherits from (to make AnnotableX usable wherever X can be used)

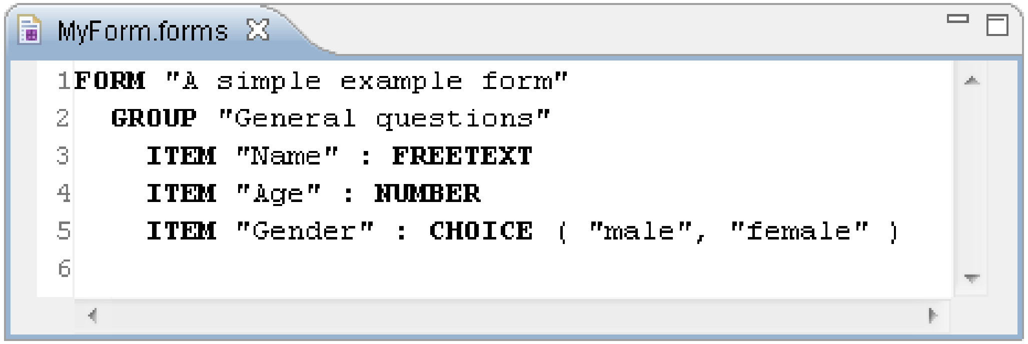
Step 3 – Extending the Concrete Syntax Specification

- Steps 1 and 2 added annotations concepts on the level of abstract syntax, but concrete one is need to write them down
- Textual syntax tools (e.g., EMFText, xText and TCS) use one rule per metaclass
  - Retain the existing syntax rules
  - Add syntax rules for new annotation classes in meta model

```
Form          ::= "FORM" name['"','"'] groups*;
AnnotableForm ::= (identifier[IDENT])+ (type[TYPE])? form;
```

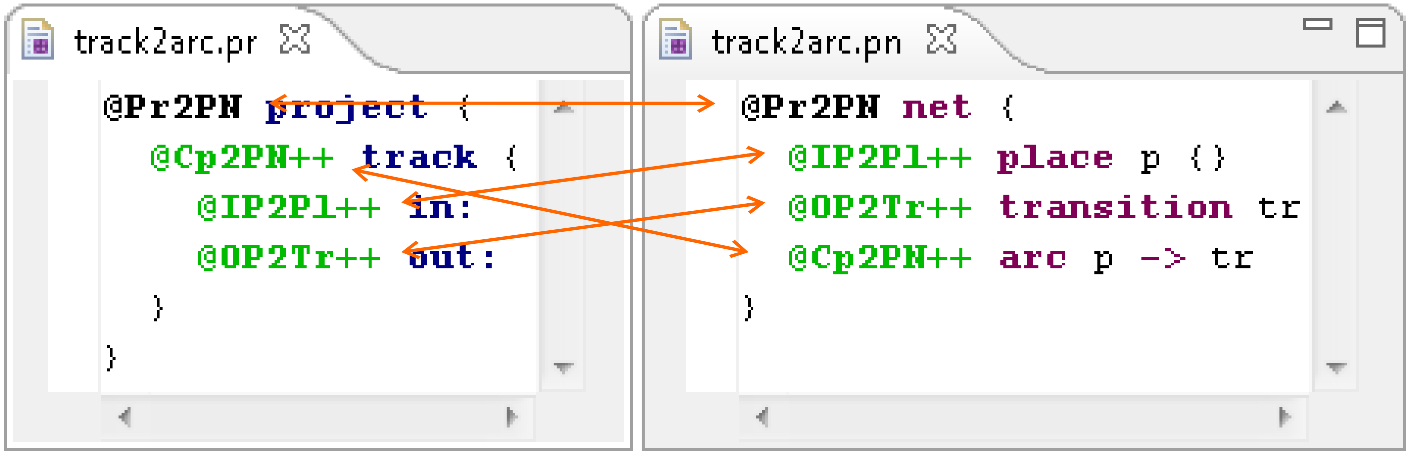
```
@1  !     FORM "A simple example form"
```

```
IDENT is some identifer starting
      with an @
TYPE  is !, ++ or --
```



Step 3 – Extended Concrete Syntax

Rail tracks to Petrinet example



(bold black and green elements are new – TGG rule annotations)

Step 4 – Deriving Rules from Model Pairs

- For each annotated model element, create a rule node
- For each set of model elements that are annotated with the same identifier,
    - create a correspondence node and create links connecting the new correspondence node with the respective rule nodes
- Mark all rule nodes as "create" where the corresponding model element is annotated as create element
- For each pair of model elements that is connected by exactly one reference
    - create a link between the respective rule nodes
- For each pair of model elements that is connected by multiple references
    - use the references specified in the annotation
    - and create links between the respective rule nodes

track2arc.pr

```
@Pr2PN project {
  @Cp2PN++ track {
    @IP2Pl++ in:
    @OP2Tr++ out:
  }
}
```

track2arc.pn

```
@Pr2PN net {
  @IP2Pl++ place p {}
  @OP2Tr++ transition tr
  @Cp2PN++ arc p -> tr
}
```

Step 4 – Deriving Rules from Model Pairs

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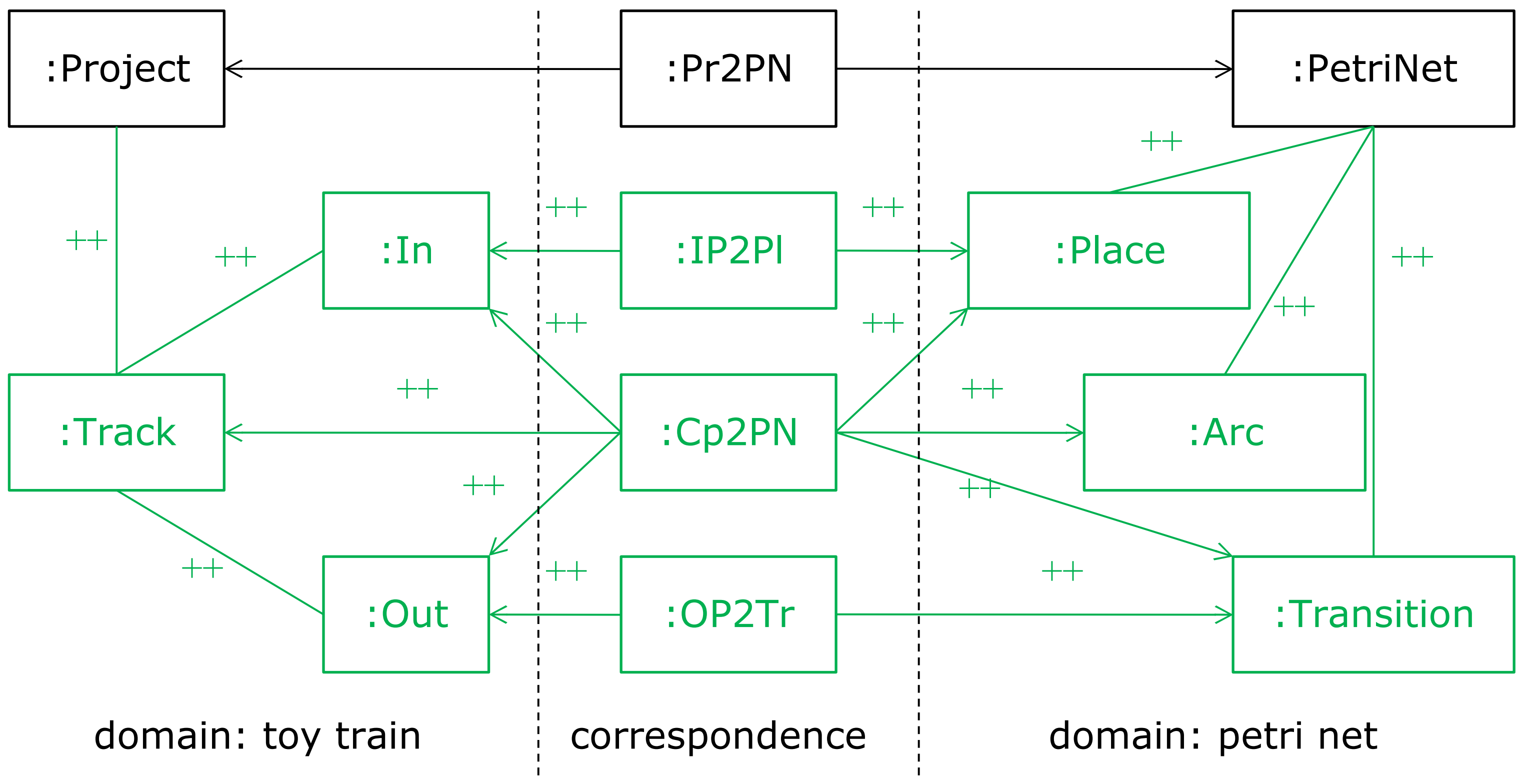

Restrictions of Tornado

Constraints

- Can be derived (e.g., equality if attribute values match), but:
  - What about boolean attributes?
  - What about more complex constraints (a.name == b.id)?

Negative Application Conditions

- May need additional annotations

Concrete Syntax (CS) restricts rules that can be specified

- If AS is less restrictive than CS (e.g., metaclasses with empty CS)

Conclusion of (Experimental) Tornado Method

Textual (modelling) languages can be automatically extended with:

- annotation support (This whole stuff is for free!)
- other features (More stuff is for free as well! See e.g. [1])

- Rule specification using concrete syntax seems intuitive
- Combines benefits of specification by example (CS) and classic rule specification (precision)
- Debugging based on CS is enabled
- More annotations may be needed, but can easily be added
- Metamodelling languages should support extensibility to its full extent

Looking for a student to combine Tornado with GrGen!

The End: What Have We Learned

- Graph rewrite systems are tools to transform graph-based models and graph-based program representations
- MOFLON supports OCL queries and constraints
- TGG enable to bidirectionally map models and synchronize them
- Why can a TGG also be called a *metamodel mapping grammar?*
- Correspondances in models can be expressed by annotations

This slide set needs much more care and examples.
NOT, FORALL, etc.

Literature

- [ES89] Gregor Engels, Wilhelm Schäfer. Programming Environments, Concepts and Realization (in German), 1989, Teubner-Verlag Stuttgart
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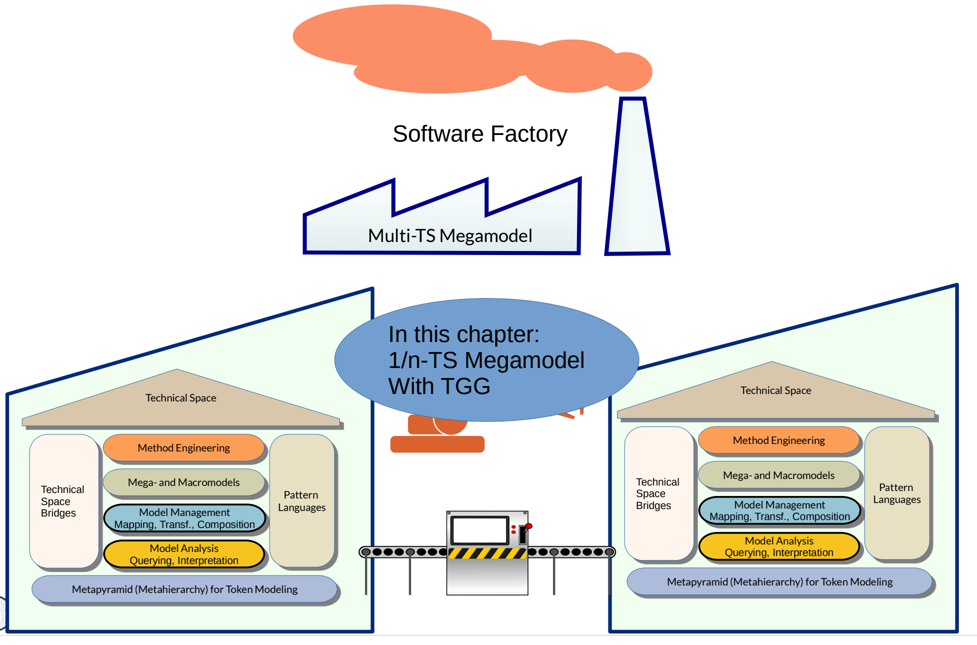

Integration of Tool Suites by Data Connection

 [ES89, 6, S. 11]

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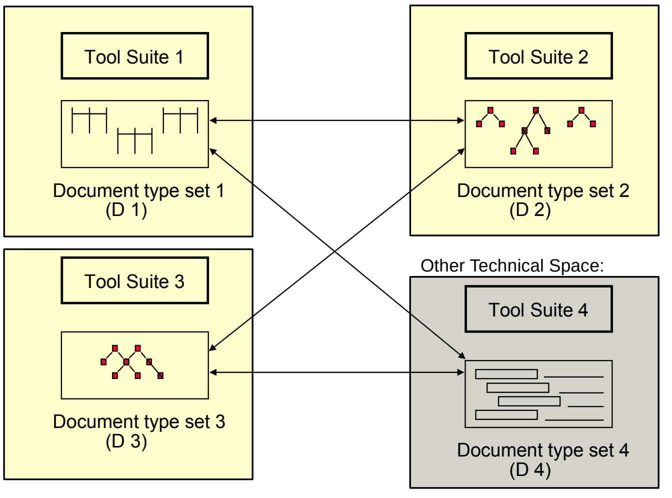

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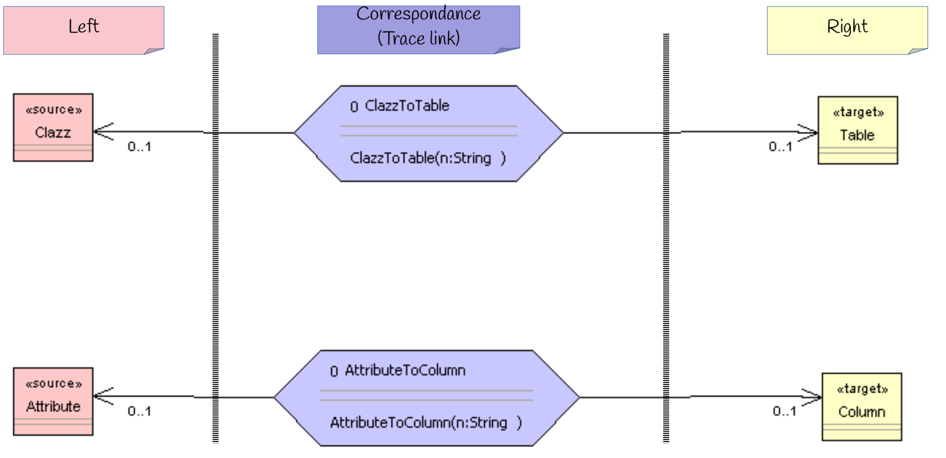

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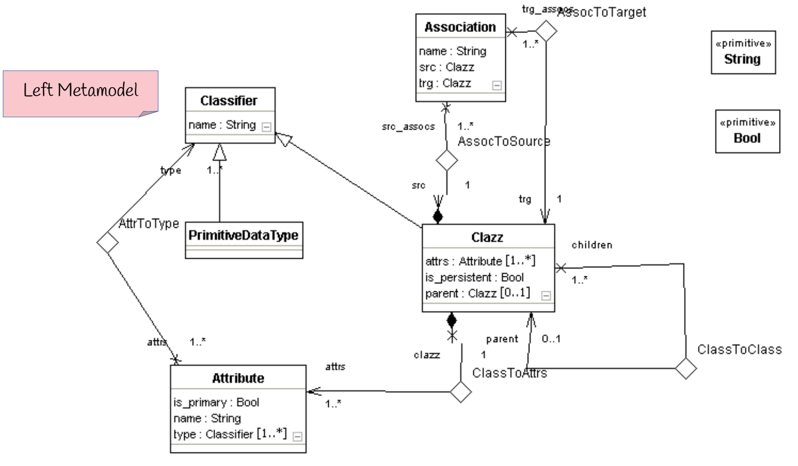
  - modification color is green on one side (add)
- **Lower layer create model element** – create model in a lower grammar layer
  - modification color is green on lower layer (add)

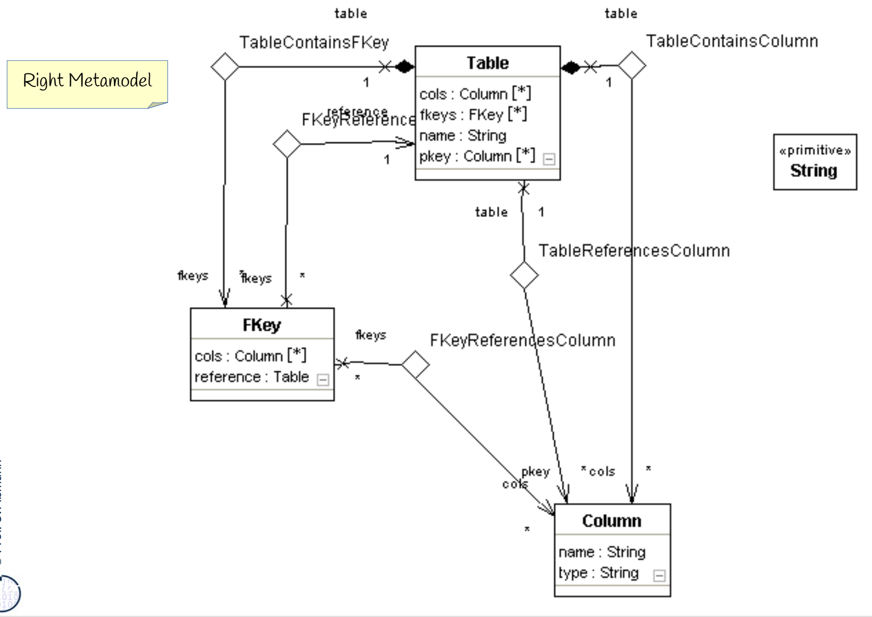
54.2.1. Mapping Objects to Tables (Object-Relational Mapping, ORM)

TGG for Object–Relational Mapping (ORM)
Left Metamodel: Class Diagram Metamodel (CD)

- Synchronize Class-Diagram-metamodel (CD) with a relational schema (RS): object-relational mapping (ORM)

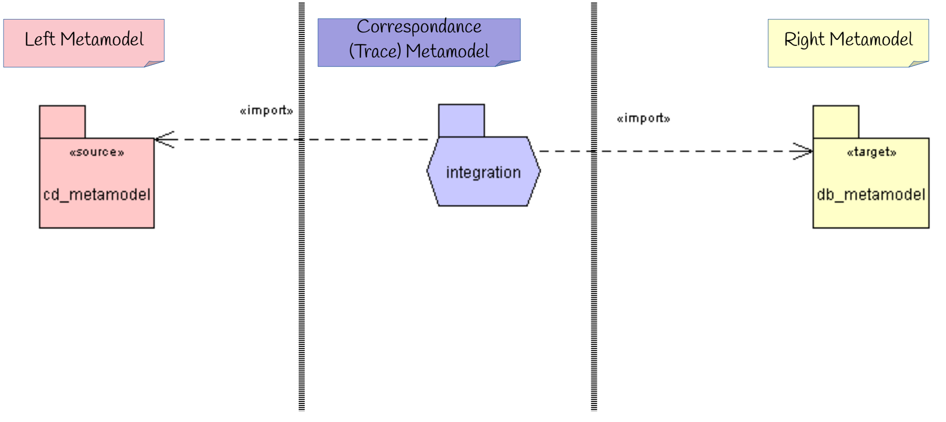


Right Metamodel:
Relational Metamodel (DB, relational schema)



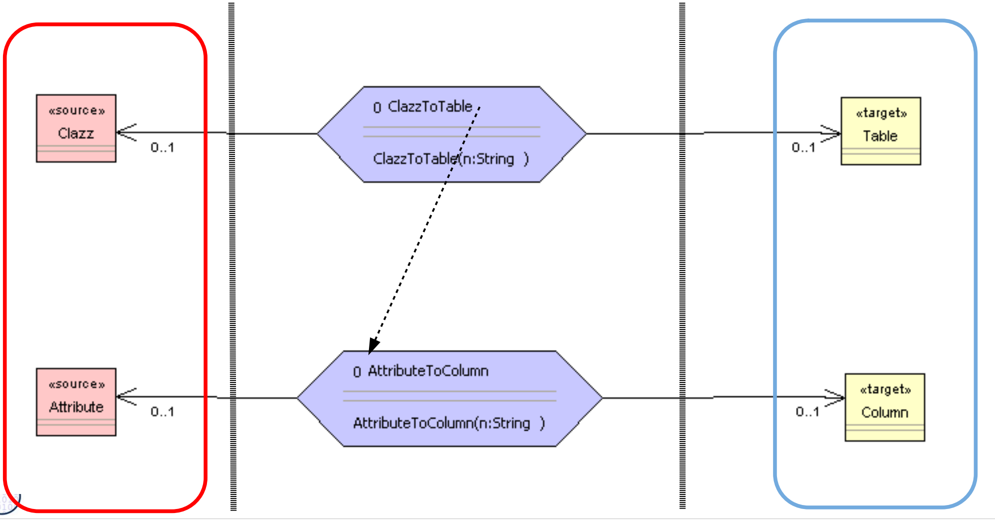
TGG for Object–Relational Mapping (ORM)

- The metamodel mapping grammar of a TGG has a top rule (start rule) which describes the relationship of the graphs on topmost level



Example of Consistency-Checking Rule

- From the top-rule `ClazzToTable`, other TGG rules are associated („called"/"invoked")
- In this case, the TGG only checks (black color – TEST)
- Q: What happens, if both sides are in different Technical Spaces?



TGG Specify Transformation Bridges Between Roles and Technical Spaces

- TGG can also be used to data-exchange and synchronize Material classes and roles
  - between two material objects
  - between two tools with different repositories
    - even in different technical spaces
- The only assumption: 1:1 mappings of model elements

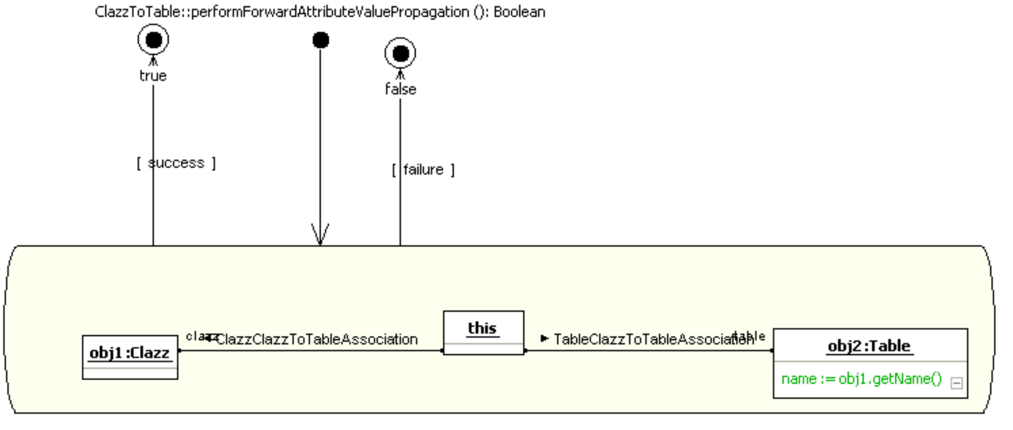
TGG are a fine technique to build *transformation bridges for data connection* between tools, even in different technical spaces.

54.2. Triple Graph Grammars in MOFLON

- MOFLON in MOF Technical Space
- eMOFLON in EMOF TS

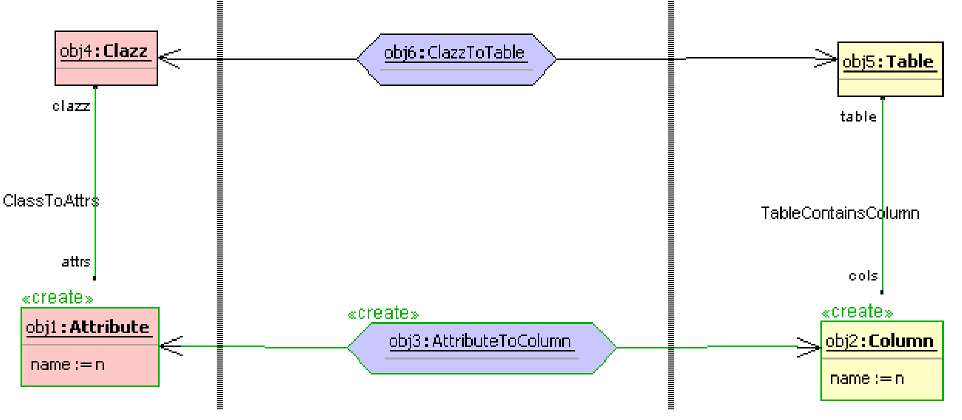
Triple Graph Grammars – Moflon Example

- Because they are named, TGG rules can be started by Fujaba Storyboards (activity diagrams)
- The activites can be associated to a transformation class ClazzToTable



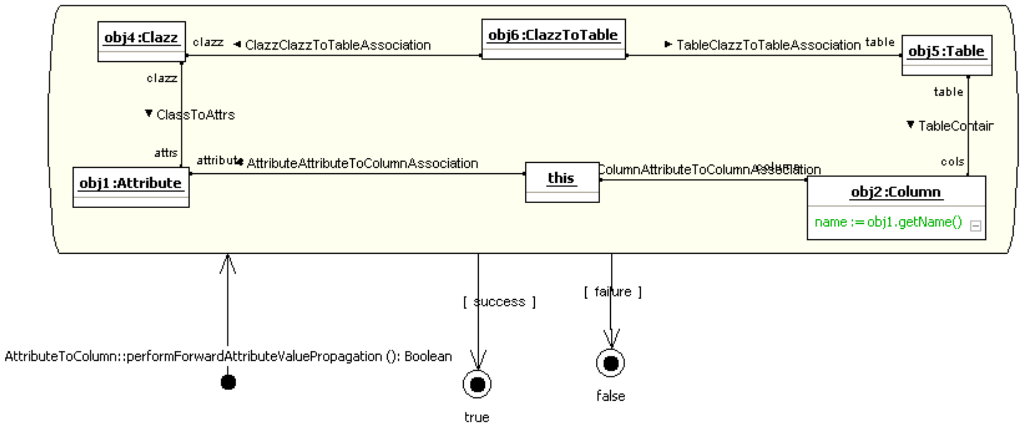
Example of Lower-Level-Creation Rule

- *Lower-level-creation rule* creates lower level elements and a pairwise correspondance of model elements on both sides
  - Here, objects on the lower level are created anew if needed from the tested upper level



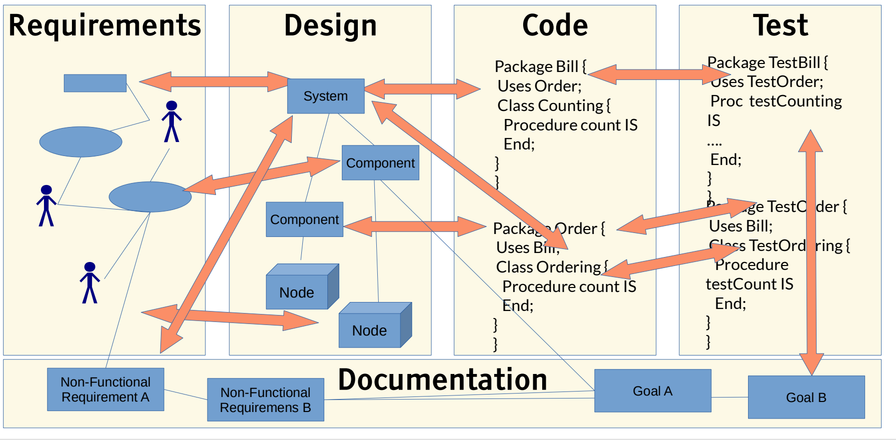
Triple Graph Grammars – Moflon Example

- Notation in Moflon/Fujaba Storyboards
- Checking a pattern with adding an attribute to `obj2`

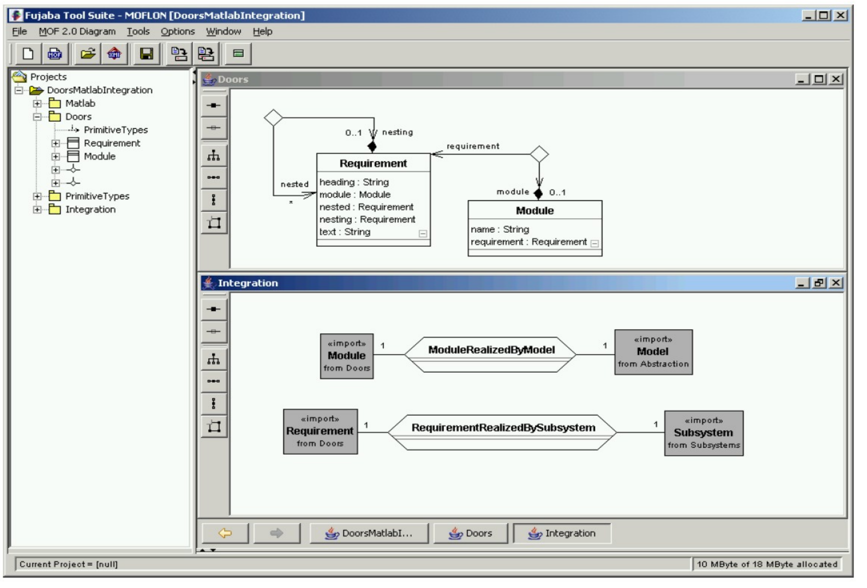


Q12: The ReDoDeCT Problem and its Macromodel

- The **ReDoDeCT problem** is the problem how requirements, documentation, design, code, and tests are related (→ V model)
- Mappings between the Requirements model, Documentation files, Design model, Code, Test cases
- A **ReDoDeCT macromodel** has maintained mappings between all 5 models

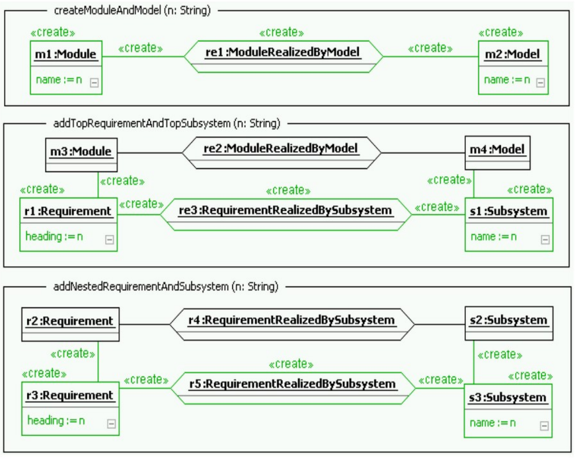


Ex. 2: TGG Coupling of Requirements Specification and Design



TGG Coupling Requirements Specification and Design

- This TGG grammar builds up a module-requirements graph
- Starting from a relation "ModuleRealizedByModel" and "RequirementRealizedBySubsystem"

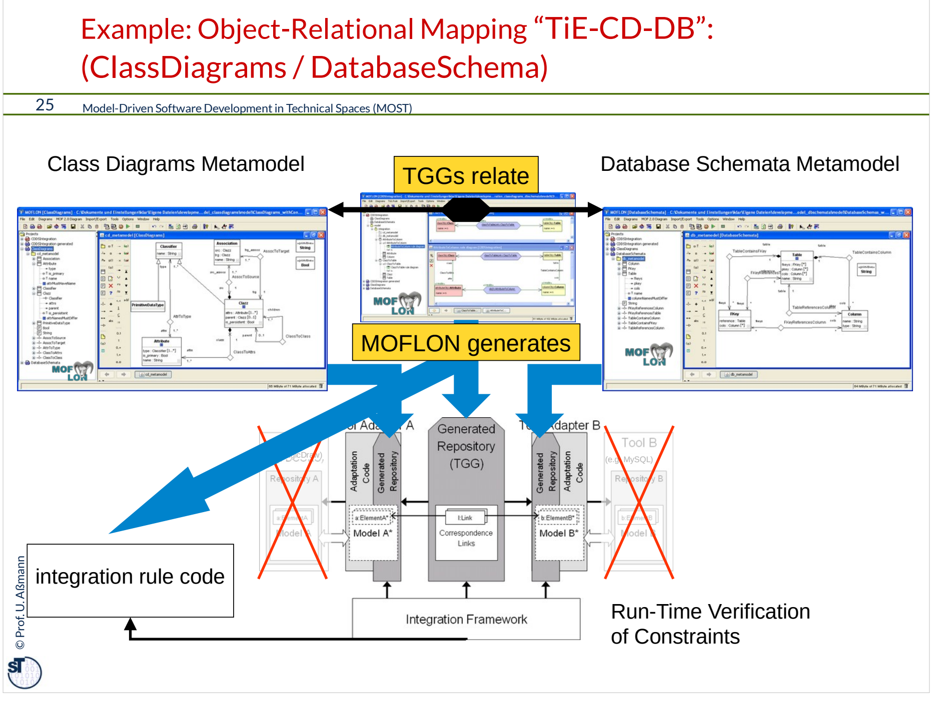


initial, creational

lower-layer creational

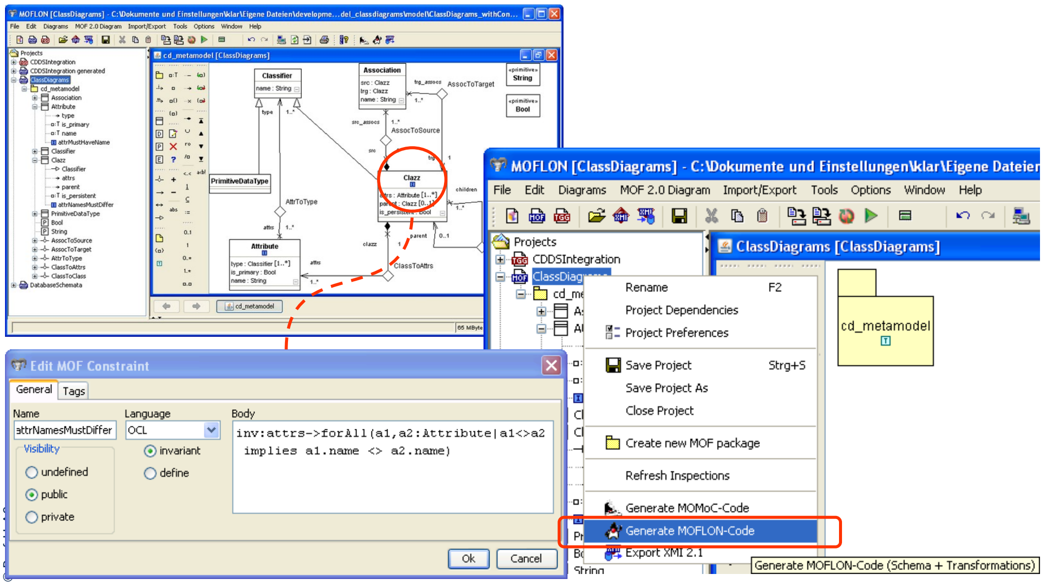
lower-layer creational

54.3. Using Triple Graph Grammars in MOFLON

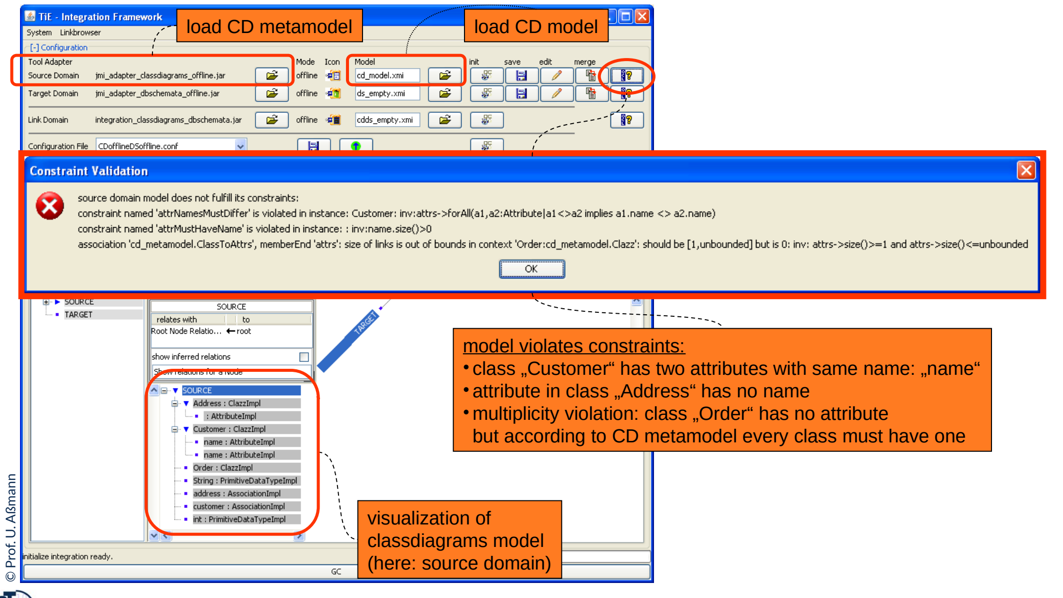


shows how our architecture is realized with the MOFLON metamodeling and translation specification approach

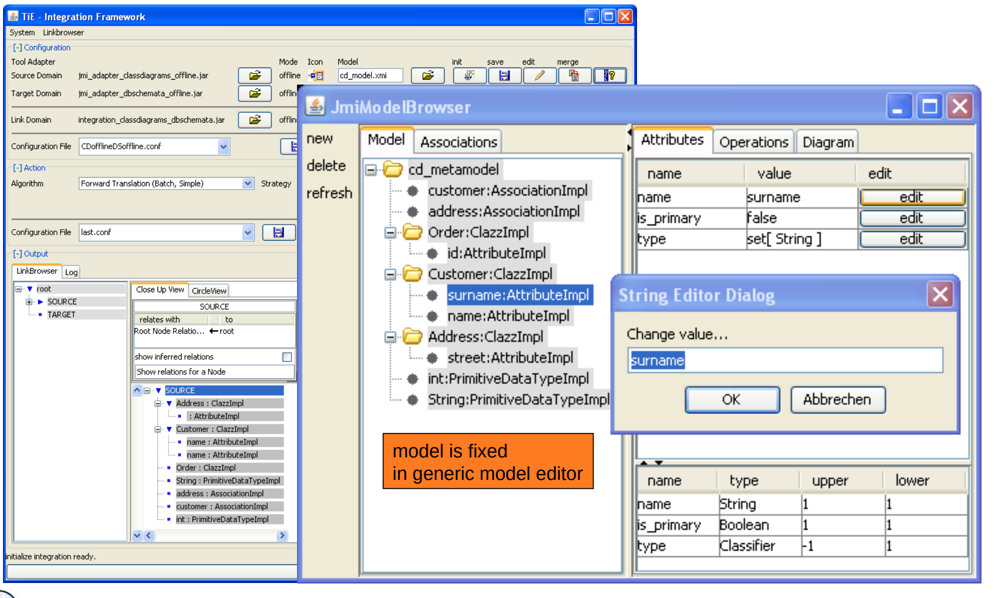
TiE-CD-DB – Constraints in Class Diagrams (1)
Generate Code from MOF model (CD metamodel)



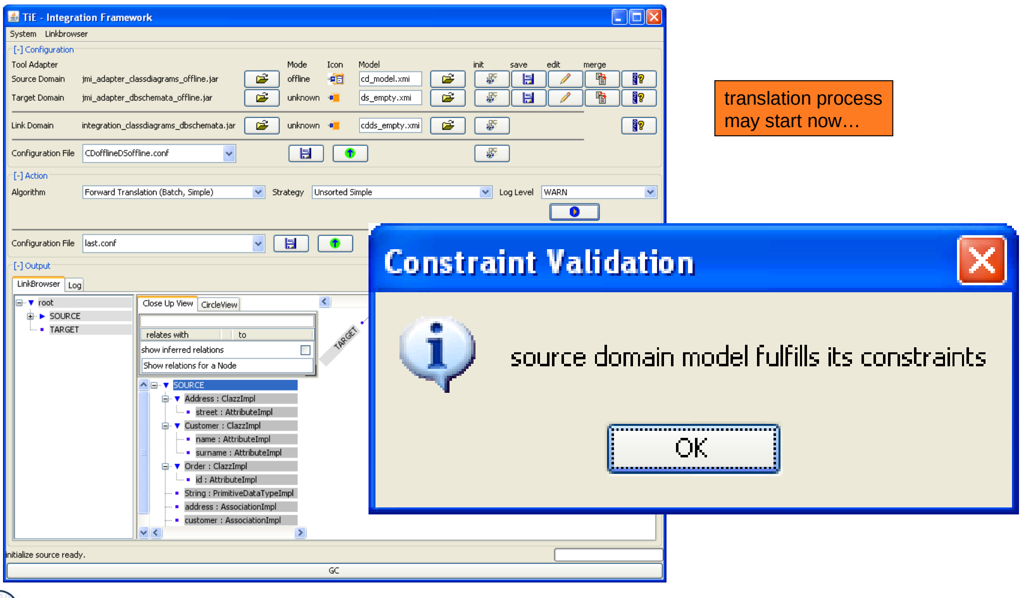
TiE-CD-DB – Constraints in Class Diagrams (2)
Loading Metamodels and Models



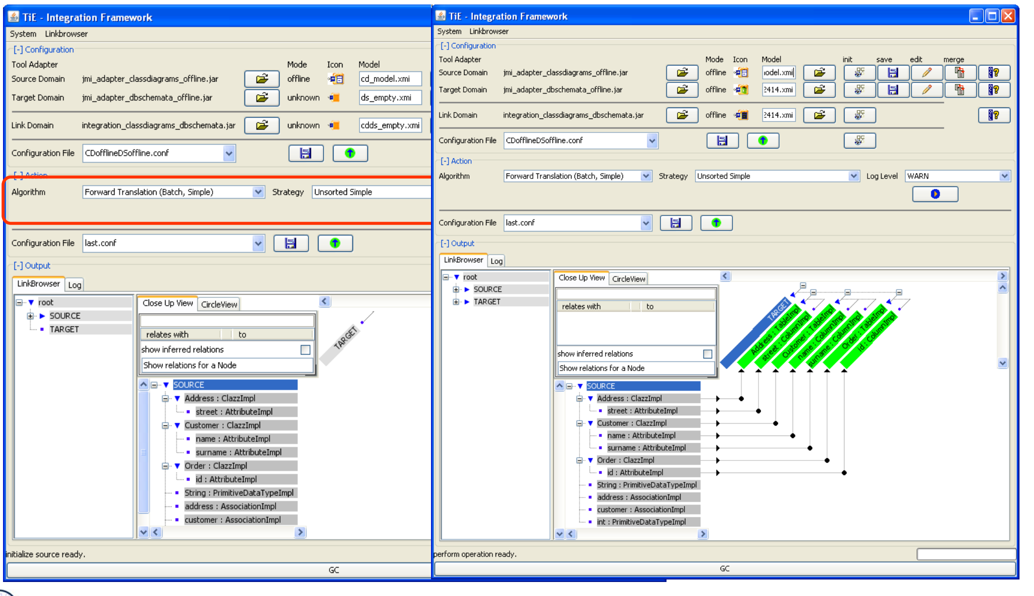
TiE-CD-DB – Constraints in Class Diagrams (3) Model Browser



TiE-CD-DB – Constraints in Class Diagrams (4) Integration Framework



translation process may start now…



Other Software Engineering Applications of Model Synchronization

- Mapping a PIM to a PSM in Model-Driven Architecture
- Graph Structurings (see course ST-II)
- Refactorings (see Course DPF)
- Semantic refinements
- Round-Trip Engineering (RTE)

TECHNISCHE UNIVERSITÄT DRESDEN

54.4 The Tornado Method: Specification of TGG Rules using Textual Concrete Syntax

- Slides about Tornado courtesy to Mirko Seifert and Christian Werner
- Presented at Fujaba Days 2009, Eindhoven, The Netherlands, 16.11.2009
- Christian Werner. Konzeption und Implementierung eines Debuggers für textuelle Triple Graph Grammar Regeln. Belegarbeit, Lehrstuhl Softwaretechnologie, 2010, TU Dresden
  - available on request

Motivation for Textual Syntax of TGG

- TGGs are fine for model synchronization, but writing TGG rules is not always easy

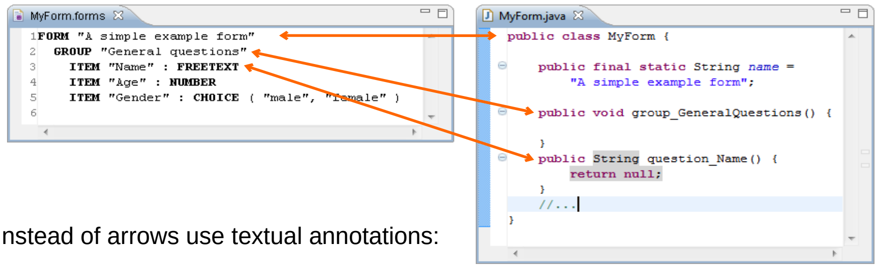
  Why?

- Rule specification typically on the level of abstract syntax
  - Complex abstract syntax (AS) graphs vs. simple concrete syntax (CS) fragments
  - Rule designers not always familiar with AS
- Rule specification is based on graphical syntax
  - But: There is lots of textual (modelling) languages
  - Gap: Graphical rules vs. textual models
  - Large graphical rules are hard to read

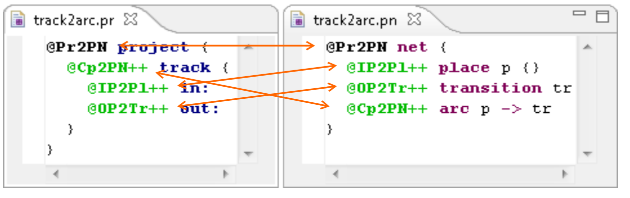
Can we do better?

Idea for Rule Specification in EMFText

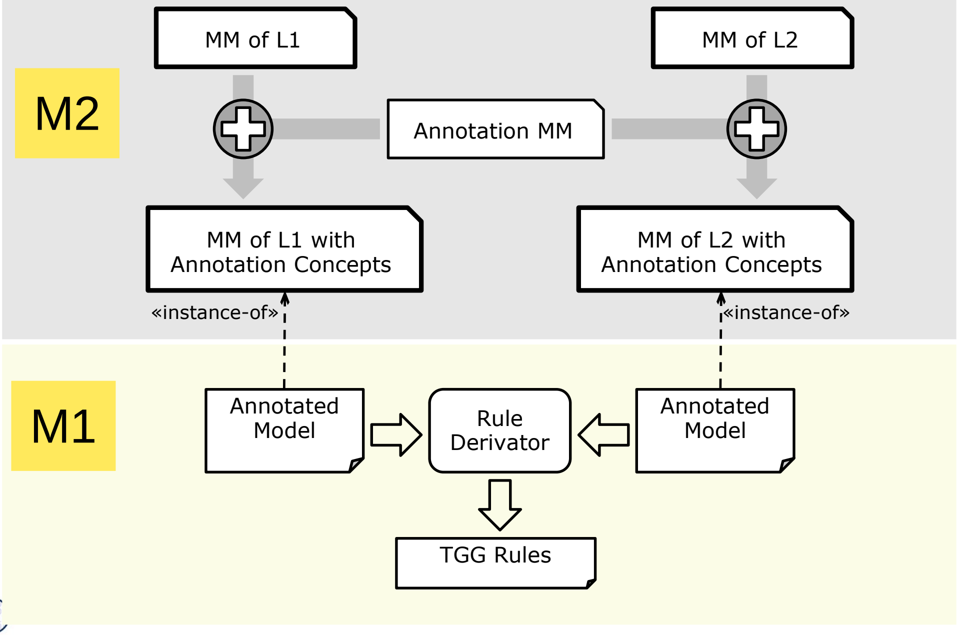
- employ EMFText; use concrete textual syntax of involved languages
- derive rules from pairs of models
- do it in a generic way (automatic application to any language)



Instead of arrows use textual annotations:

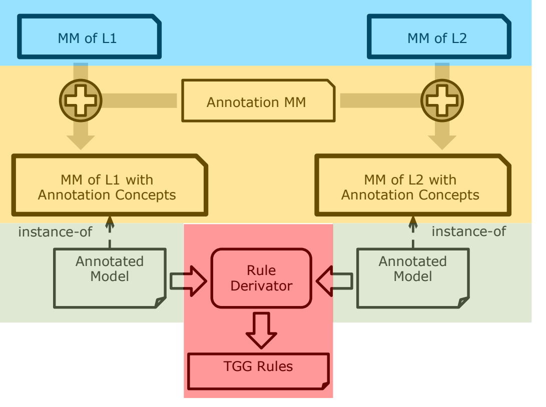


Tornado Generation Process of TGG Rules



Generation Steps of Tornado Method

1. Make meta models extensible
2. Extend meta models (with annotation concepts)
3. Extend concrete syntax
4. Derive rules from model pairs



Step 1 – Getting (more) Extensible Metamodels

Extensibility provided by Ecore (EMOF):

- Add new metaclasses (i.e., new complex types)
- Reference existing metaclasses (Reuse)
- Subclass existing metaclasses

What is missing in EMOF:

- Distinction between subtyping and inheritance
- Extensibility for primitive types
- Example:
  - Can't add things that do not have a property year
  - Can't add subtypes for EString

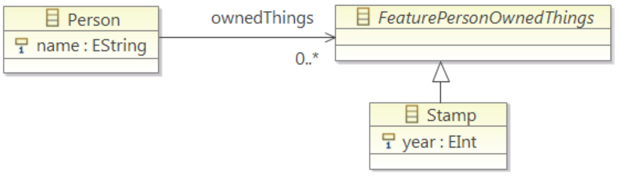
Step 1a – Getting Extensible Metamodels

Separate subtyping and inheritance (algorithm from [HJSWB]):

For each feature's type that has at least one superclass or defines at least one feature:

- Introduce a new abstract metaclass Feature<ClassName><FeatureName>
- Change the type of the feature to the new metaclass
- Make the former type of the feature a subclass of the new metaclass

Example:



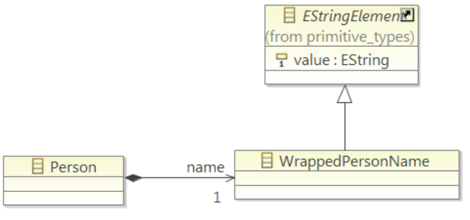
Step 1b – Getting Extensible Metamodels

Wrap primitive types (also from [HJSWB]):

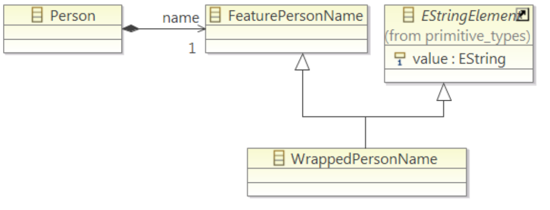
For each attribute that has a primitive type:

- Create a new subclass of the primitive type wrapper class
- Replace attribute with reference to new subclass

Example:

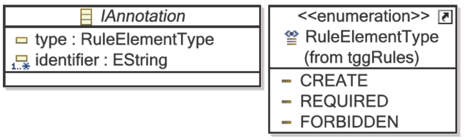


Wrapped attribute



Wrapped attribute after step 1a)

Step 2 – Extending Metamodels with Annotation Concepts



Goal:

- Every model element can be annotated

HowTo:

- For each meta class X create new metaclass AnnotableX with
  - Reference to class Annotation
    (to store the annotation)
  - Reference to the original class X
    (to store the data of X)
  - Make AnnotableX a subclass of each feature class that X inherits from
    (to make AnnotableX usable wherever X can be used)

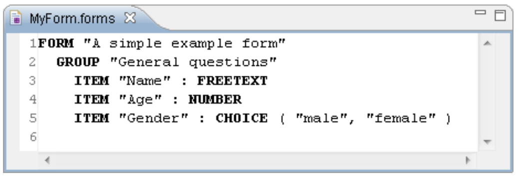
Step 3 – Extending the Concrete Syntax Specification

- Steps 1 and 2 added annotations concepts on the level of abstract syntax, but concrete one is need to write them down
- Textual syntax tools (e.g., EMFText, xText and TCS) use one rule per metaclass
  - Retain the existing syntax rules
  - Add syntax rules for new annotation classes in meta model

```
Form          ::= "FORM" name['"','"'] groups*;
AnnotableForm ::= (identifier[IDENT])+ (type[TYPE])? form;
```

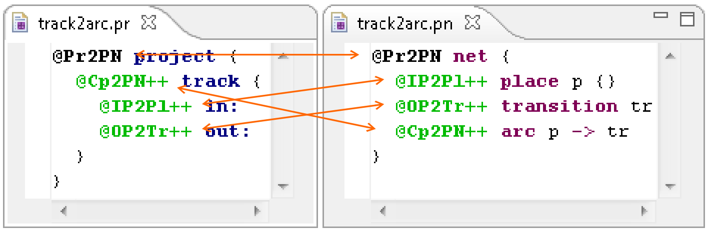
```
@1  !     FORM "A simple example form"
```

```
IDENT is some identifer starting
      with an @
TYPE  is !, ++ or --
```



Step 3 – Extended Concrete Syntax

Rail tracks to Petrinet example



(bold black and green elements are new – TGG rule annotations)

Step 4 – Deriving Rules from Model Pairs

- For each annotated model element, create a rule node
- For each set of model elements that are annotated with the same identifier,
  - create a correspondence node and create links connecting the new correspondence node with the respective rule nodes
- Mark all rule nodes as "create" where the corresponding model element is annotated as create element
- For each pair of model elements that is connected by exactly one reference
  - create a link between the respective rule nodes
- For each pair of model elements that is connected by multiple references
  - use the references specified in the annotation
  - and create links between the respective rule nodes

track2arc.pr

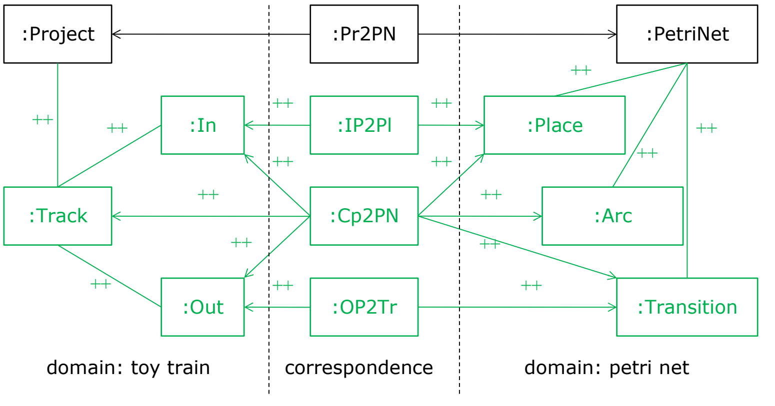
```
@Pr2PN project {
  @Cp2PN++ track {
    @IP2Pl++ in:
    @OP2Tr++ out:
  }
}
```

track2arc.pn

```
@Pr2PN net {
  @IP2Pl++ place p {}
  @OP2Tr++ transition tr
  @Cp2PN++ arc p -> tr
}
```

Step 4 – Deriving Rules from Model Pairs

Rail tracks to Petrinet example



Restrictions of Tornado

Constraints

- Can be derived (e.g., equality if attribute values match), but:
    - What about boolean attributes?
    - What about more complex constraints (a.name == b.id)?

Negative Application Conditions

- May need additional annotations

Concrete Syntax (CS) restricts rules that can be specified

- If AS is less restrictive than CS (e.g., metaclasses with empty CS)

Conclusion of (Experimental) Tornado Method

Textual (modelling) languages can be automatically extended with:

- annotation support (This whole stuff is for free!)
- other features (More stuff is for free as well! See e.g. [1])

- Rule specification using concrete syntax seems intuitive
- Combines benefits of specification by example (CS) and classic rule specification (precision)
- Debugging based on CS is enabled
- More annotations may be needed, but can easily be added
- Metamodelling languages should support extensibility to its full extent

Looking for a student to combine Tornado with GrGen!

The End: What Have We Learned

- Graph rewrite systems are tools to transform graph-based models and graph-based program representations
- MOFLON supports OCL queries and constraints
- TGG enable to bidirectionally map models and synchronize them
- Why can a TGG also be called a *metamodel mapping grammar?*
- Correspondances in models can be expressed by annotations