32. Macromodels in One Technical Space

Prof. Dr. U. Aßmann

Technische Universität Dresden

Institut für Software- und Multimediatechnik

http://st.inf.tu-dresden.de/teaching/most

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1) Model-Driven Architecture (MDA)
2) MDA Toolkits
3) Traceability in Model Transformations
4) Direct Model Mappings between Requirements and Tests
5) RoSIMDA – a Very Simple MDA with Trace Mappings as Role-Play Relations

Literature

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- Birgit Grammel. Automatic Generation of Trace Links in Model-driven Software Development. PhD thesis, Technische Universität Dresden, Fakultät Informatik, February 2014.
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- Kevin Lano. Catalogue of Model Transformations: http://www.dcs.kcl.ac.uk/staff/kcl/tcat.pdf
- Implementation in ATL
  - http://www.eclipse.org/m2m/atl/atlTransformations/EquivalenceAttributesAssociations/EquivalenceAttributesAssociations.pdf

Literature on MDA

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    - https://www.omg.org/mda/mda_files/SuccessStory_DBB_4pages.pdf
- Alan Brown. An introduction to Model Driven Architecture. Part I: MDA and today's systems
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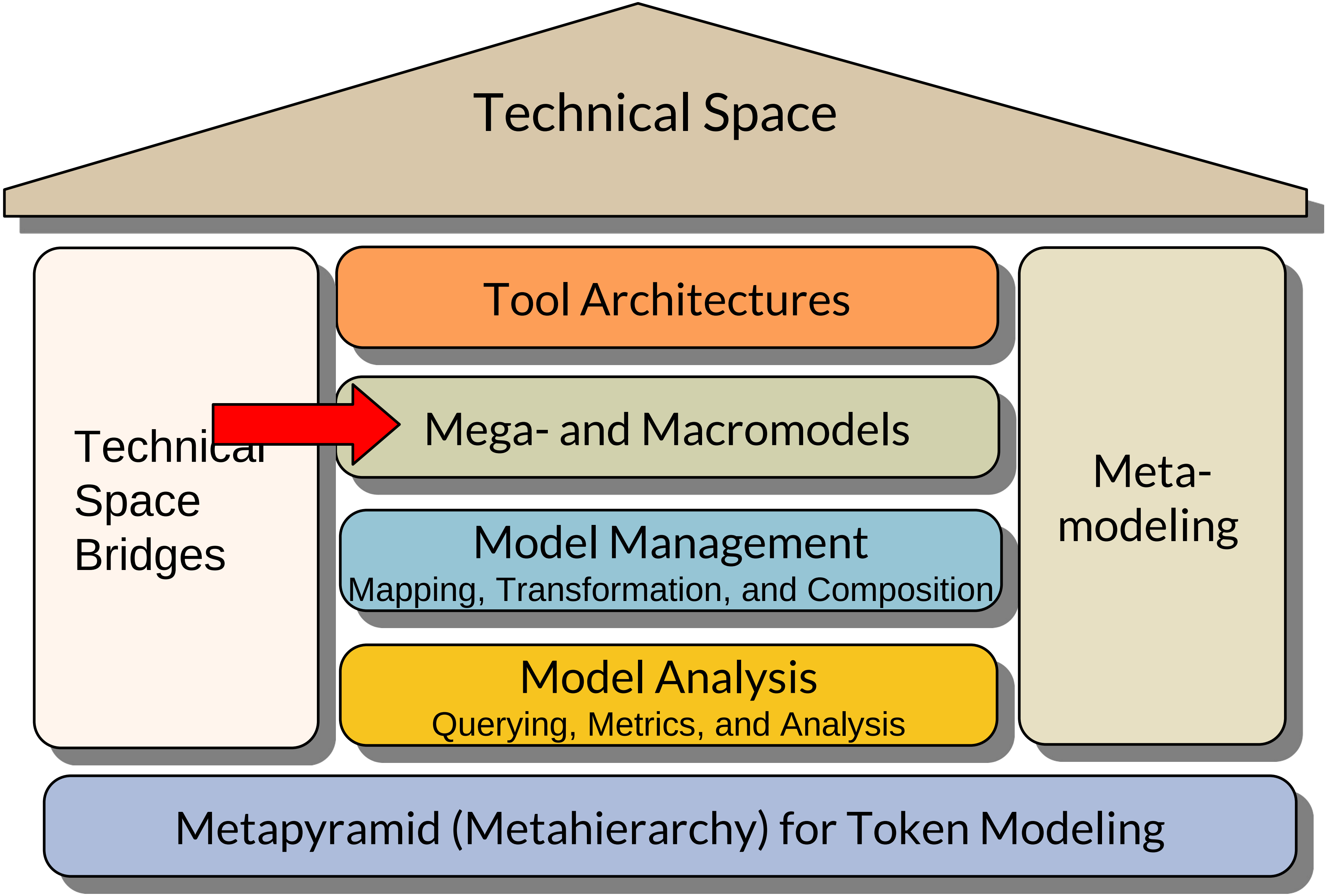
    - Teaser chapter
      https://www.researchgate.net/publication/220693090_Model_Driven_Architecture_-_eine_praxisorientierte_Einfuhrung_in_die_MDA

Q10: The House of a Technical Space


Technical Space

Technical Space Bridges

Tool Architectures

Mega- and Macromodels

Model Management

Mapping, Transformation, and Composition

Model Analysis

Querying, Metrics, and Analysis

Meta-modeling

Metapyramid (Metahierarchy) for Token Modeling

Software Factories

A **software factory** schema essentially defines a recipe for building members of a software product family.

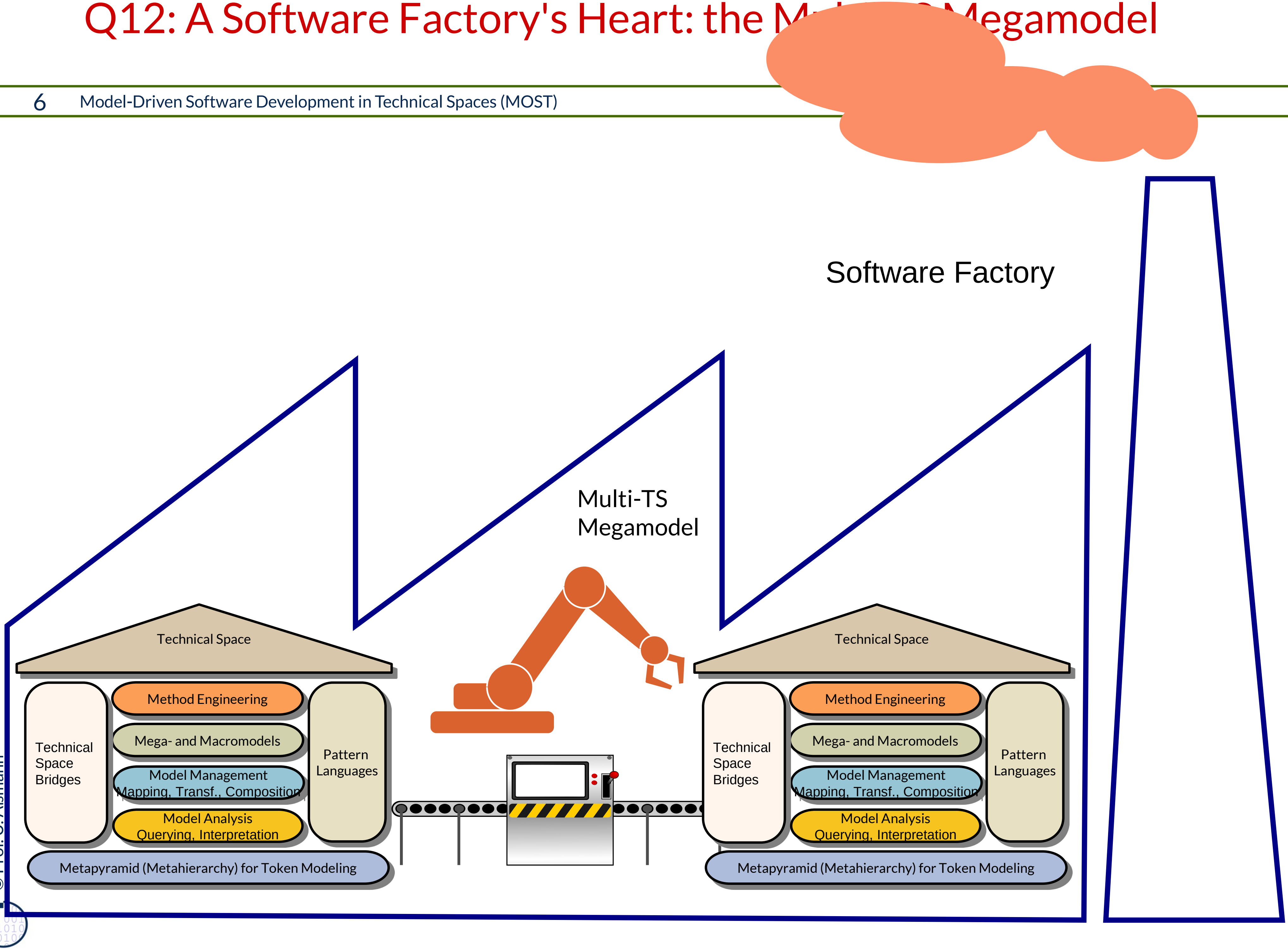
Jack Greenfield

https://www.researchgate.net/publication/213883069_Software_Factories_Assembling_Applications_with_Patterns_Frameworks_Models_and_Tools

In this course:

A **software factory** combines the languages and tools of several technical spaces to create software and cyber-physical systems product families.

Q12: A Software Factory's Heart: the M[illegible] Megamodel


Software Factory
Multi-TS Megamodel
Technical Space
Method Engineering
Mega- and Macromodels
Model Management Mapping, Transf., Composition
Model Analysis Querying, Interpretation
Technical Space Bridges
Pattern Languages
Metapyramid (Metahierarchy) for Token Modeling
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Metapyramid (Metahierarchy) for Token Modeling

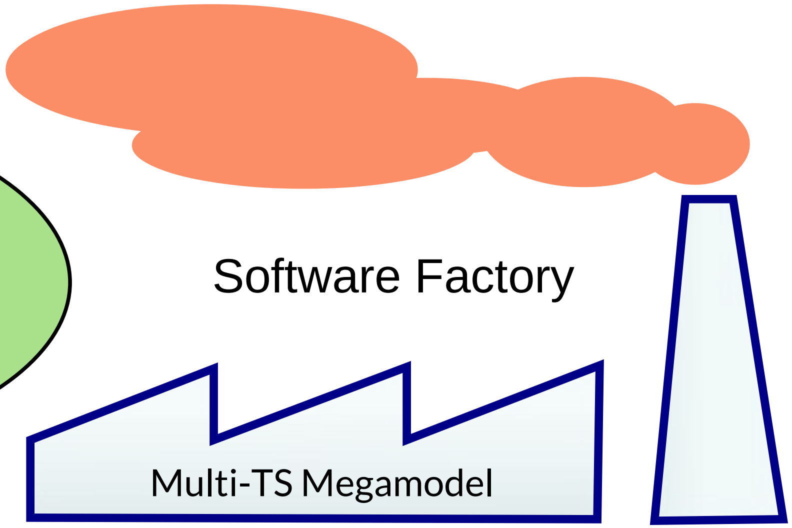
32.1 Model-Driven Architecture (MDA) (Modellgetriebene Architektur)

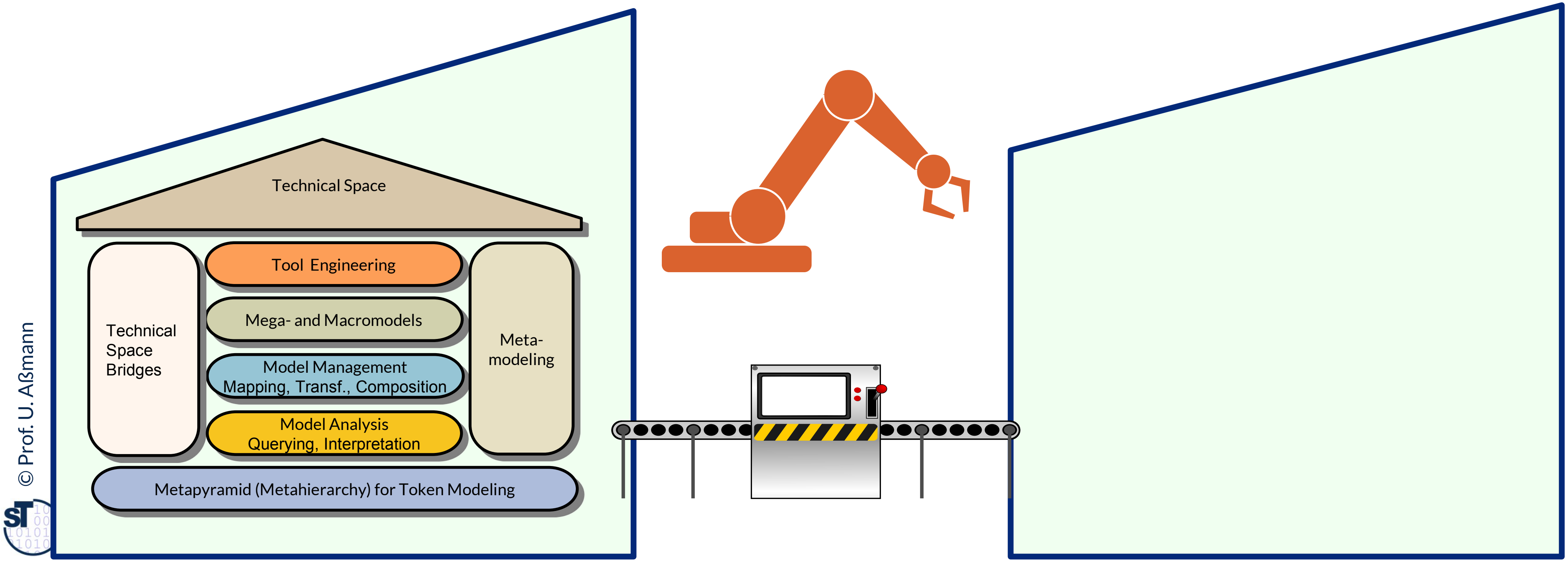
MDA is a trademark of OMG

MDA is an industrial megamodel in the spirit of ReDeCT.
Its instances in software product are multimodels, connecting several ***model abstraction levels.***

Software Factories with Only 1 Technical Space

In this chapter:
1-TS Megamodels
MDA, RoSI-MA




Technical Space

Technical Space Bridges

Tool Engineering

Mega- and Macromodels

Model Management
Mapping, Transf., Composition

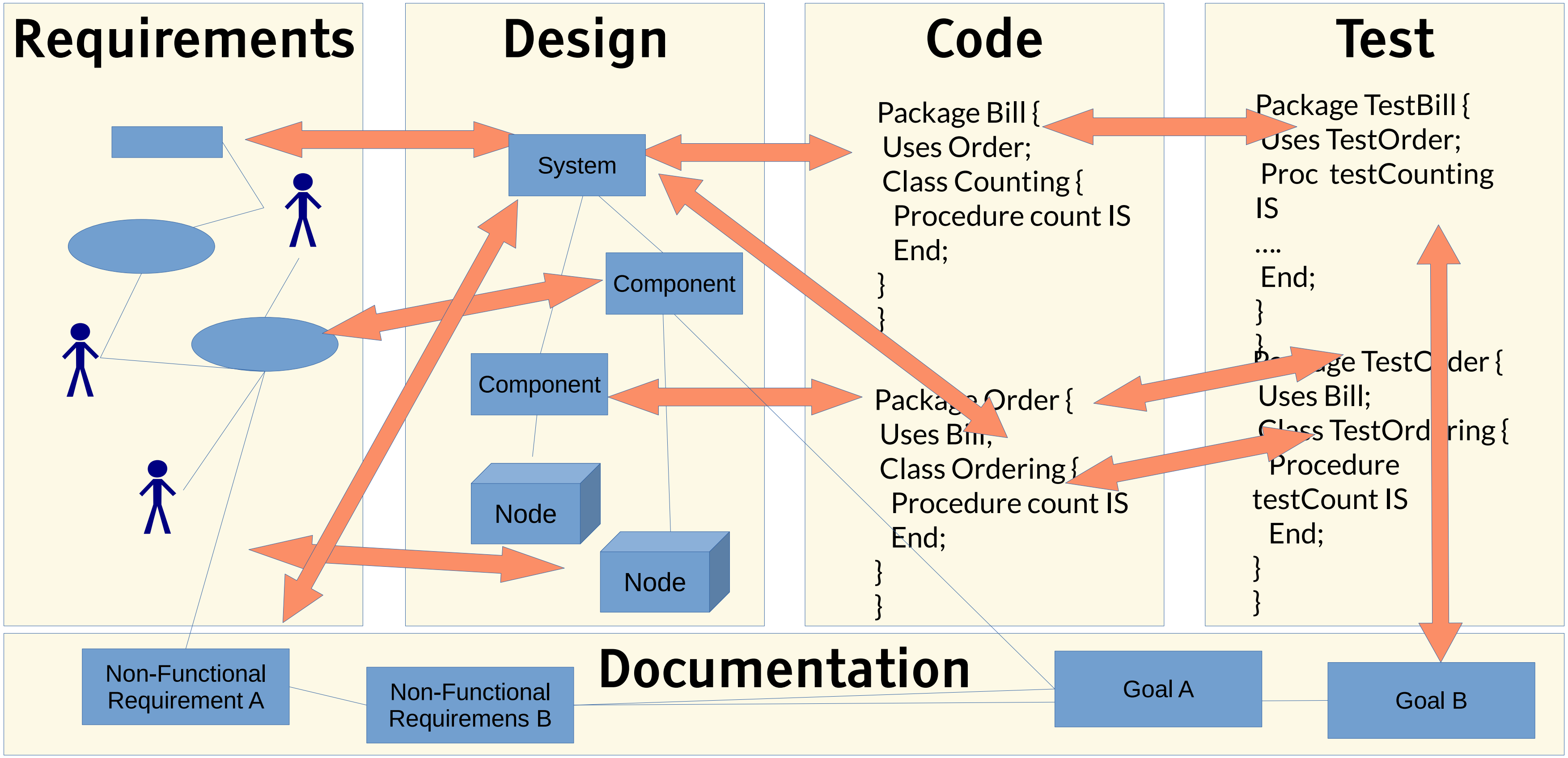
Model Analysis
Querying, Interpretation

Meta-modeling

Metapyramid (Metahierarchy) for Token Modeling

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



```
Package Bill {
 Uses Order;
 Class Counting {
   Procedure count IS
   End;
 }
}
```

```
Package Order {
 Uses Bill;
 Class Ordering {
   Procedure count IS
   End;
 }
}
```

```
Package TestBill {
 Uses TestOrder;
 Proc testCounting
IS
....
 End;
}
}
```

```
Package TestOrder {
 Uses Bill;
 Class TestOrdering {
   Procedure
testCount IS
   End;
}
}
```

Overview Table for Link-Tree Macromodels

The Link-Treeware TS is well apt for macromodel construction in a software factory

- A tree node abstracts a subtree (representant)
  - Attributes and attributions are *composable partial mappings* from treenodes
- RAGs are useful for all kinds of structure- and function-modeling in Link-Tree Macromodels, because they abbreviate dependencies in several models with cross-model relations.
  - In a macromodel under an artificial root (rooted macromodel), attributions can work on the SUM to ensure the constraints
- Relational RAGs (RelRAGs) are useful, because they have bidirectional constraints

	(Plain) MDA	General SUM	Skeleton SUM (partial function extension)
RAGs in Repositories	Markings		Repository-SUM: get/put as higher-order attributions of link trees
			• Javadoc-SUM
RAGs in Data-flow architectures	Needs trace models	get/put as model transformations (lenses)	Flow-SUM: Communicating link trees; In-place transformations of SUM
			• Google Docs, Stream-Based MDA

Model-Driven Software Development (MDSD) in 1 Technical Space

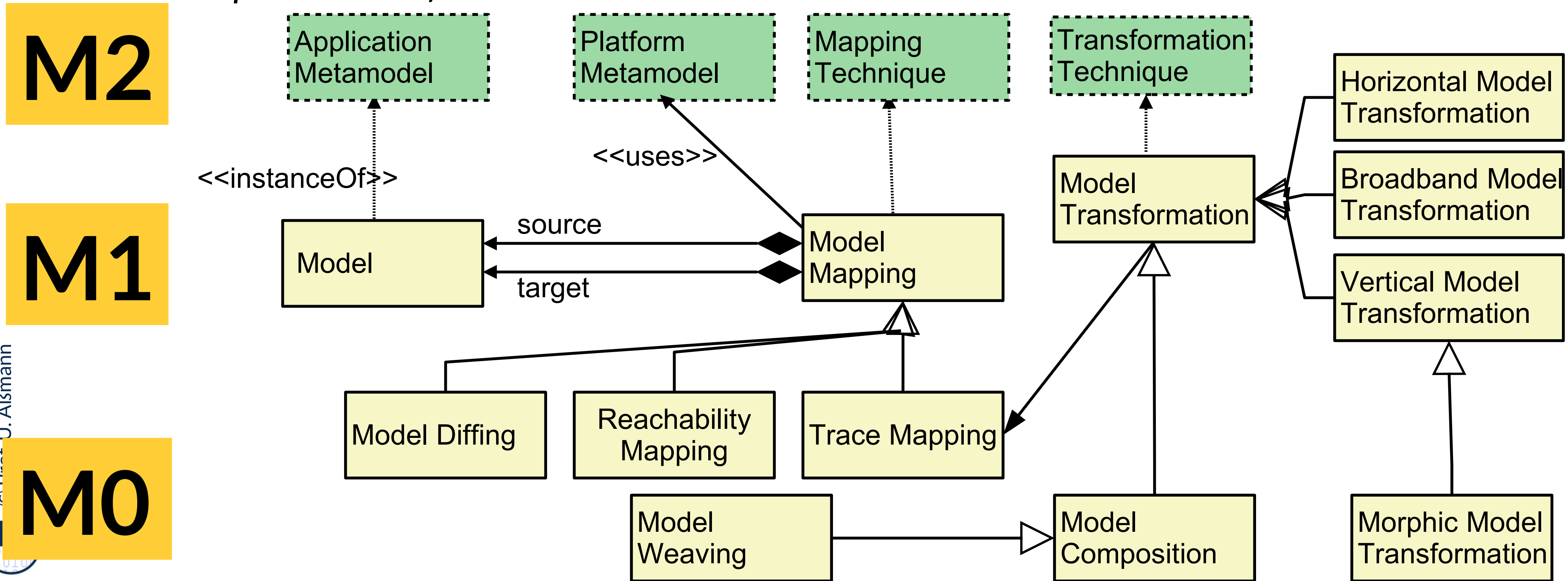
- **MDSD in 1-TS** falls into several main development methods with a macromodels:
  - Engineering with metamodels in ReDeCT-like megamodels (integrated software life-cycle management tools):
    - for integrated requirements, documentation, and testing along the life-cycle
    - Model-Driven Architecture (MDA) (MDA toolkits)
  - Engineering with DSL (domain-specific modeling, DSM) (Meta-CASE toolkits)
    - For simplifying the specification of domain-specific software
- **Model mappings** correlate models
  - capturing *reachability* informations (path abbreviations)
  - defining *trace* relations between model elements
  - From them, model transformations can easily be derived
- **Model transformations**
  - **Horizontal model transformations** transform a model within a single language
  - **Vertical model transformations** transform a model from a higher-level language to a lower-lewel language (**lowering**)
  - **Broadband model transformations (lowerings)** transform a model from a higher-level set into a lower-level set of a broadband (wide-spectrum) language
- **Model compositions** compose models with extensions
  - **Model weavings** extend models by other models and weave them together

Model-Driven Architecture (MDA)

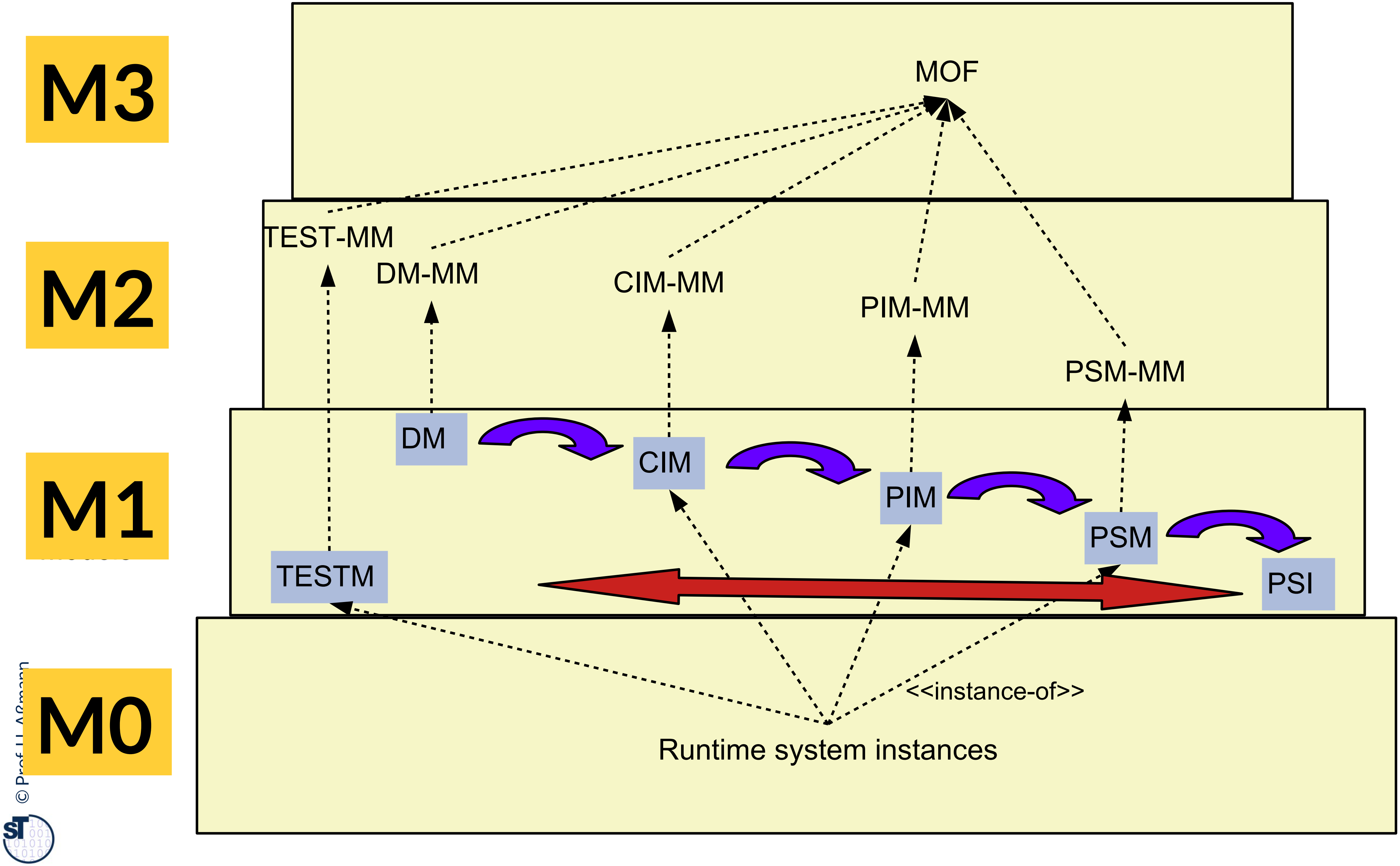
- Model-Driven Architecture (MDA) is a macromodel similar to ReDoDECT, but distinguishes more models:
  - Platform-independent model (architectural)
  - Platform-specific model (in modeling language equivalent to coding language)
  - Platform-specific implmentation (in coding language)
- On the other hand, documentation is neglected :-(
- MDA uses *model mappings, horizontal and vertical model transformations*, as well as *code generation*

What are Model Mappings?

- Model mappings are link graphs between model elements of different models
- Mappings are ***automatic*** or ***semi-automatic***:
  - A model mapping can be generated from a model difference analysis
  - Some are step-wise refinement of the model by transformation (in MDA)
- A model mapping is ***horizontal***, if on the same abstraction level (CIM, PIM, PSM, PSI)
  - It is ***vertical***, if abstraction level is crossed (e.g., PIM-2-PSM)
- A ***model transformation*** is a specific model mapping creating a "create trace mapping" with *create links*
- A ***morphic model transformation*** transforms 1 element of a PIM into 1 or n elements on PSM



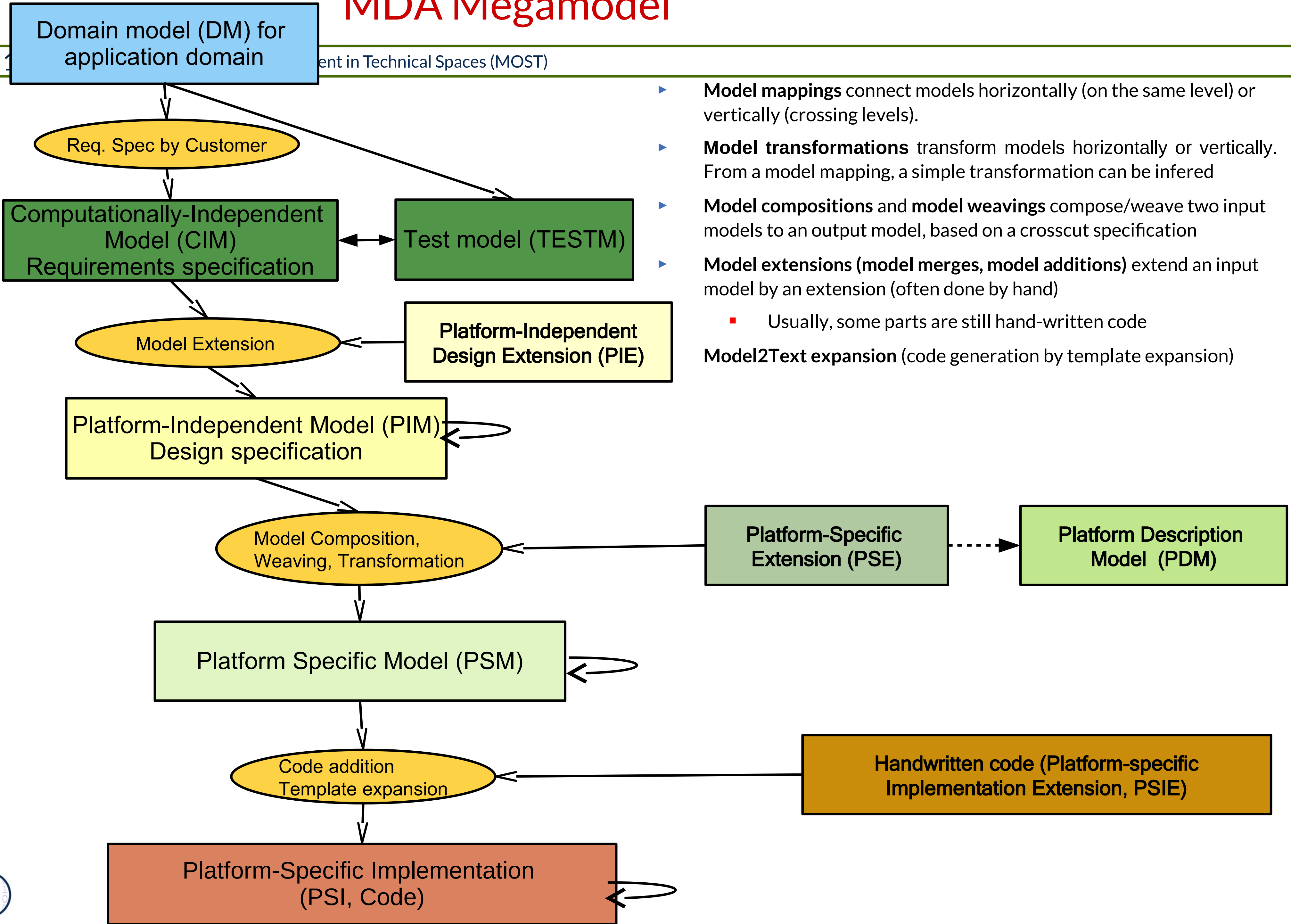
The MDA Megamodel, a Specific Variant of ReDoDeCT, Embedded in the MOF Metapyramid



Q9: Model Mappings and Model Weavings in the MDA Megamodel

- **Model mappings** connect models horizontally (on the same level) or vertically (crossing levels).
- **Model transformations** transform models horizontally or vertically. From a model mapping, a simple transformation can be infered
- **Model compositions** and **model weavings** compose/weave two input models to an output model, based on a crosscut specification
- **Model extensions (model merges, model additions)** extend an input model by an extension (often done by hand)
  - Usually, some parts are still hand-written code

Model2Text expansion (code generation by template expansion)



Domain model (DM) for application domain

Req. Spec by Customer

Computationally-Independent Model (CIM) Requirements specification

Test model (TESTM)

Model Extension

Platform-Independent Design Extension (PIE)

Platform-Independent Model (PIM) Design specification

Model Composition, Weaving, Transformation

Platform-Specific Extension (PSE)

Platform Description Model (PDM)

Platform Specific Model (PSM)

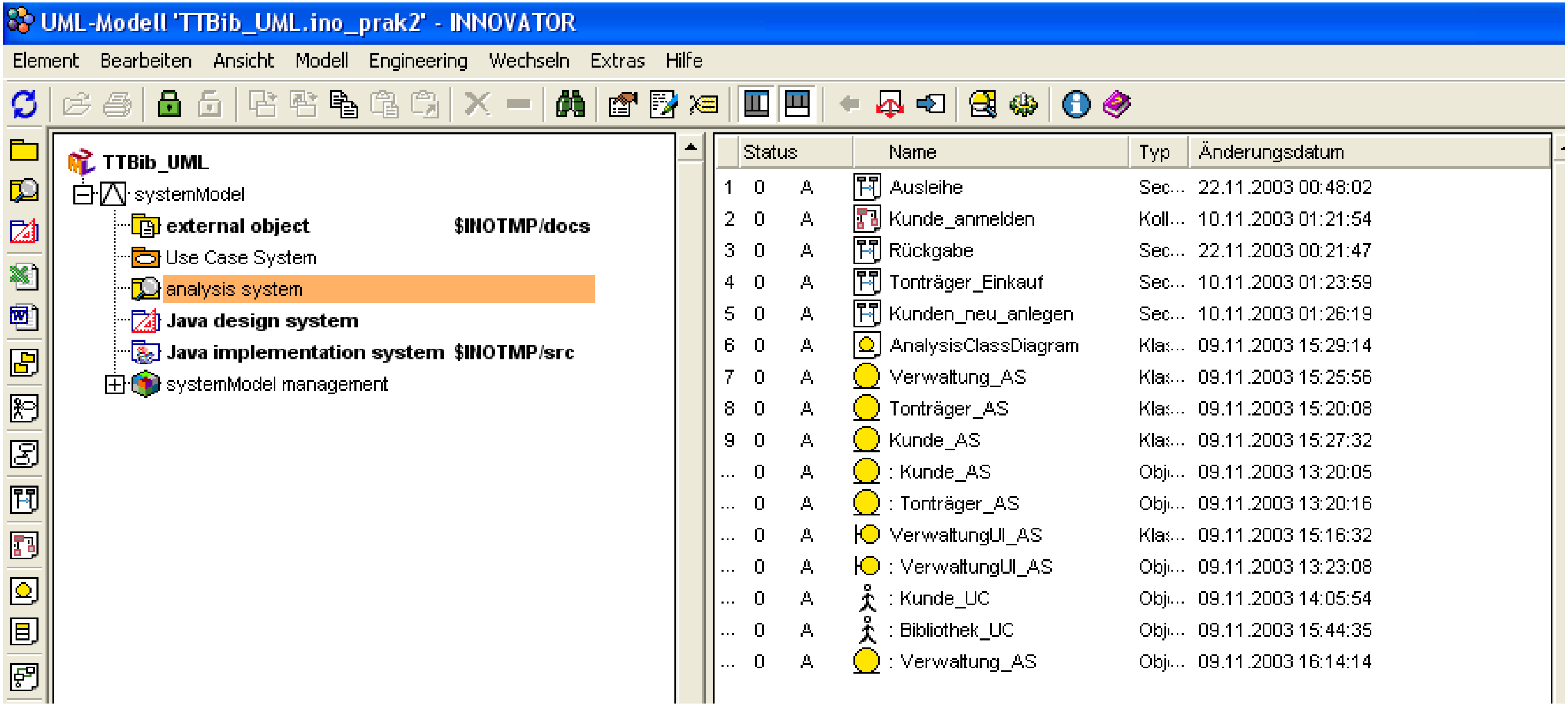
Code addition Template expansion

Handwritten code (Platform-specific Implementation Extension, PSIE)

Platform-Specific Implementation (PSI, Code)

PIM and PSM and Model Mapping in MID INNOVATOR

- Innovator can specify transformations between its models [MID]



TTBib_UML
- systemModel
  - external object $INOTMP/docs
  - Use Case System
  - analysis system
  - Java design system
  - Java implementation system $INOTMP/src
  - systemModel management

	Status		Name	Typ	Änderungsdatum
1	0	A	Ausleihe	Sec...	22.11.2003 00:48:02
2	0	A	Kunde_anmelden	Koll...	10.11.2003 01:21:54
3	0	A	Rückgabe	Sec...	22.11.2003 00:21:47
4	0	A	Tonträger_Einkauf	Sec...	10.11.2003 01:23:59
5	0	A	Kunden_neu_anlegen	Sec...	10.11.2003 01:26:19
6	0	A	AnalysisClassDiagram	Kla:...	09.11.2003 15:29:14
7	0	A	Verwaltung_AS	Kla:...	09.11.2003 15:25:56
8	0	A	Tonträger_AS	Kla:...	09.11.2003 15:20:08
9	0	A	Kunde_AS	Kla:...	09.11.2003 15:27:32
...	0	A	: Kunde_AS	Obj...	09.11.2003 13:20:05
...	0	A	: Tonträger_AS	Obj...	09.11.2003 13:20:16
...	0	A	VerwaltungUI_AS	Kla:...	09.11.2003 15:16:32
...	0	A	: VerwaltungUI_AS	Obj...	09.11.2003 13:23:08
...	0	A	: Kunde_UC	Obj...	09.11.2003 14:05:54
...	0	A	: Bibliothek_UC	Obj...	09.11.2003 15:44:35
...	0	A	: Verwaltung_AS	Obj...	09.11.2003 16:14:14

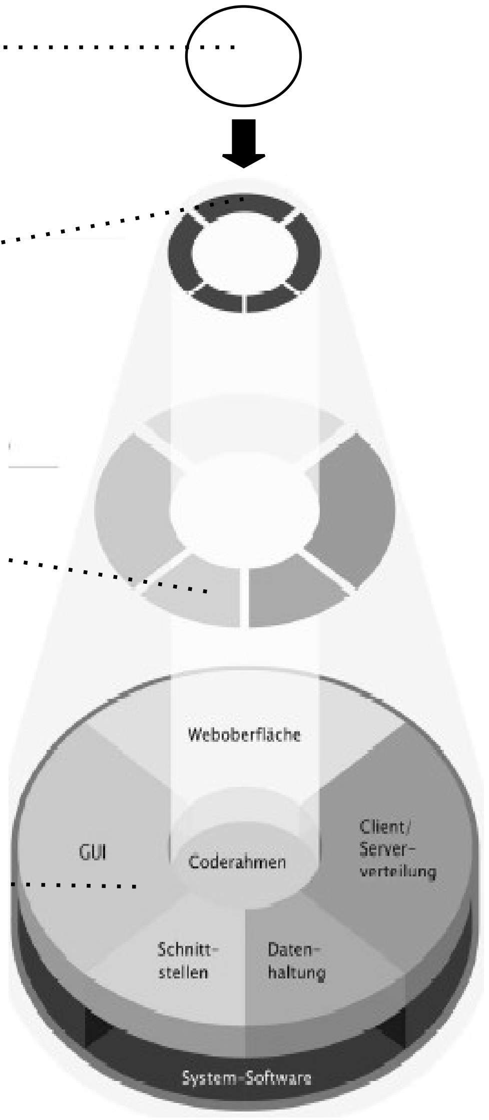
Example: PIM and PSM Extend the CIM in the Janus Toolkit

Domain model (DM) and requirements model (**CIM**,
Computation independent model)

Platform-independent Model
(PIM)
Application architecture

Platform-specific Model (PSM)
Specific applicaiton parts
Communication

Platform-specific Implementation (PSI)
Handwriten additions
in programming language



- In the MDA, there are **model mappings** between the models DM - CIM – PIM – PSM - PSI

Quelle: Warum JANUS MDA und MDA JANUS ist; Whitepaper der Firma otris Software AG Dortmund; URL: www.otris.de
http://pi.informatik.uni-siegen.de/stt/15_3/15_3_weg_01.gif

Model Management in Megamodels

- In the MDA megamodel,because MDA *enriches models from top to bottom,* the mappings between models must be maintained with a model algebra:
  - Model difference analysis (Diff, comm of models)
    - Version management
    - Konfiguration management
  - Model composition
    - Lookup and query of model elements
    - Union, compose, weave, unweave of models

32.1.2 Different Forms of MDA

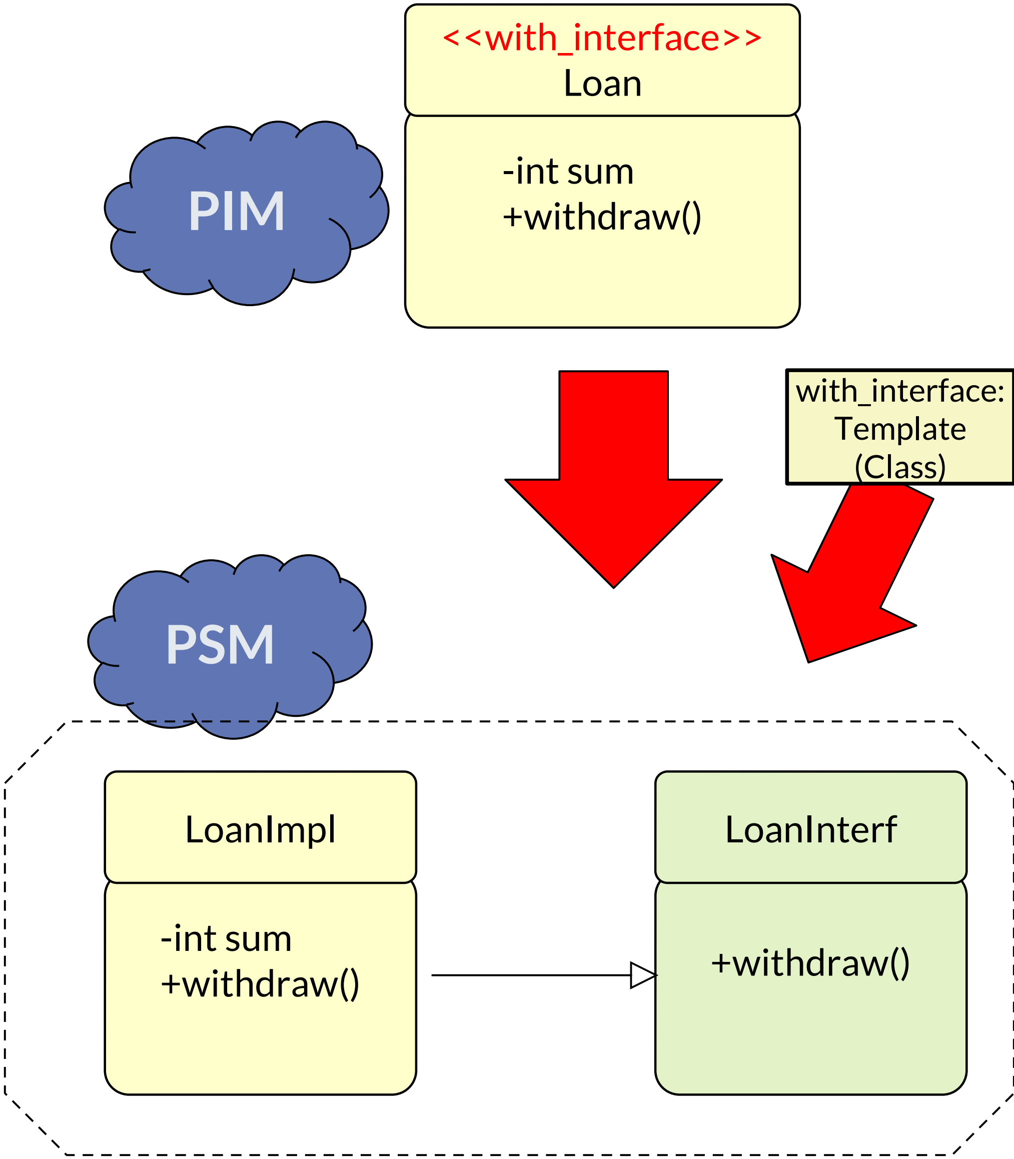
Different forms of MDA

- A ***transformative MDA*** uses refinement transformations for variation
  - introduces trace links (32.3)
- An MDA is called ***component-based (CoMDA)*** if the variation action is the exchange of an implementation behind an interface, or if the component model is used for exchange
  - RoSIMDA MDA (32.5)
- A ***transformative CoMDA*** uses point-wise refinement transformations on a model-based component model
  - for instance, refinements in Petrinets
    - combining trace links and component-based MDA (32.3 and 32.5)
- A **MDA-SUM** uses transformative or component-based MDA for realizing *views* on a *single underlying model (SUM)* (next chapter)

32.1.3 Morphic Model Mappings and Transformations

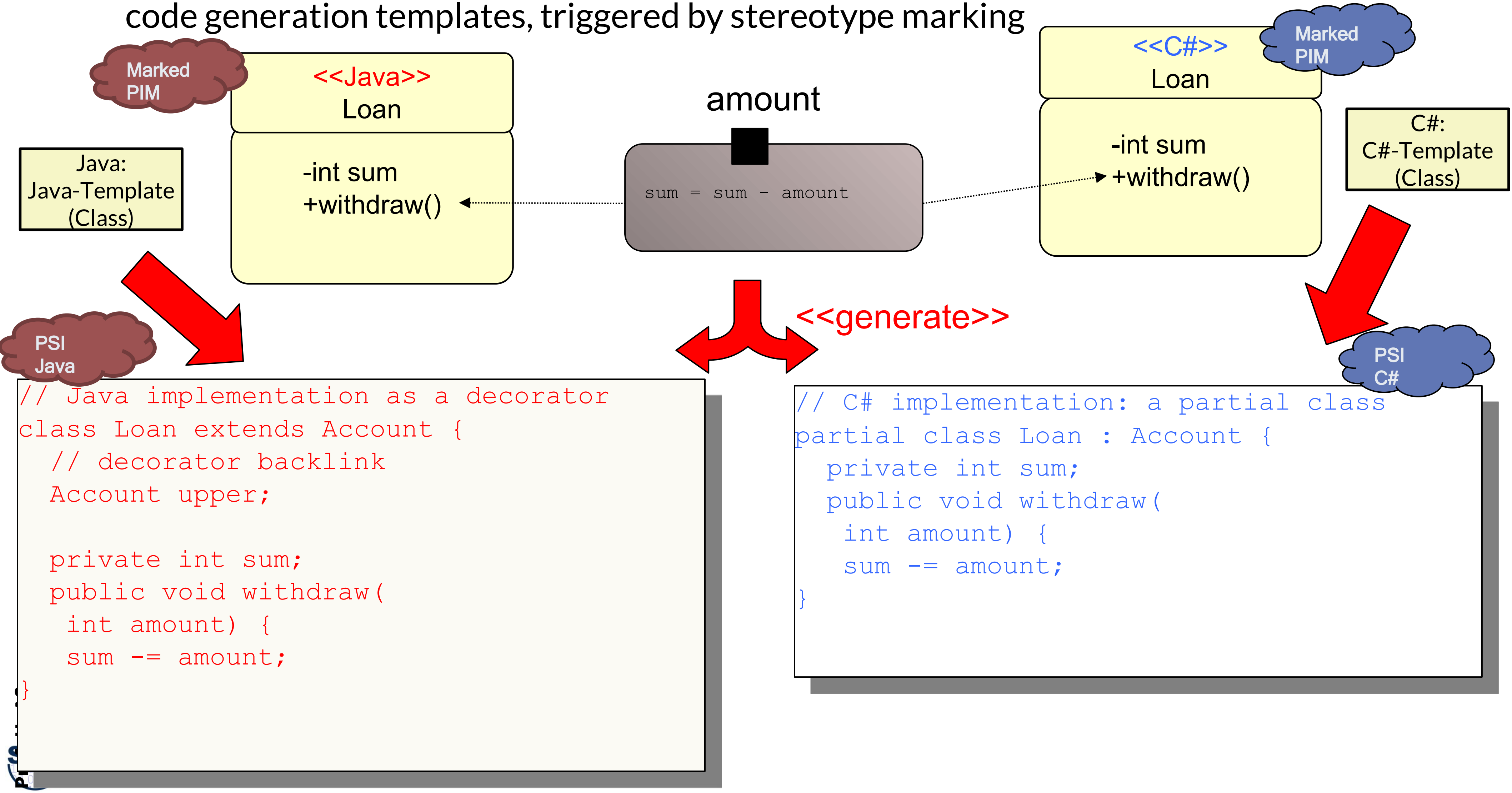
Morphic Mappings and Pointwise Transformations on Marked PIMs

- **Morphic mappings (1:1 or 1:n)** are defined by ***marked PIMs***:
  - Stereotypes introduce a mapping from 1 element of the PIM to n elements in the PSM
  - Supported by many MDA tools, such as AndroMDA
- The stereotype creates a mapping between a PIM class and a set of PSM classes
  - The stereotype tells the MDA system how to *transform* the PIM class to the PSM (stereotype triggers template extension)
  - The stereotypes partition the PSM: The border of a partition is demarcated by the PIM stereotype tag
- Example: automatic creation of interfaces for implementation classes
- Easy traceability by morphic mapping



Example of a Marked PIM and the Induced Pointwise Model Transformations

- Tags (stereotypes) may denote different class implementations in a PSM or PSI
- Here: mapping of a class and activity diagram to different languages, using different code generation templates, triggered by stereotype marking



```
// Java implementation as a decorator
class Loan extends Account {
  // decorator backlink
  Account upper;

  private int sum;
  public void withdraw(
   int amount) {
   sum -= amount;
}
```

```
// C# implementation: a partial class
partial class Loan : Account {
  private int sum;
  public void withdraw(
   int amount) {
   sum -= amount;
}
```

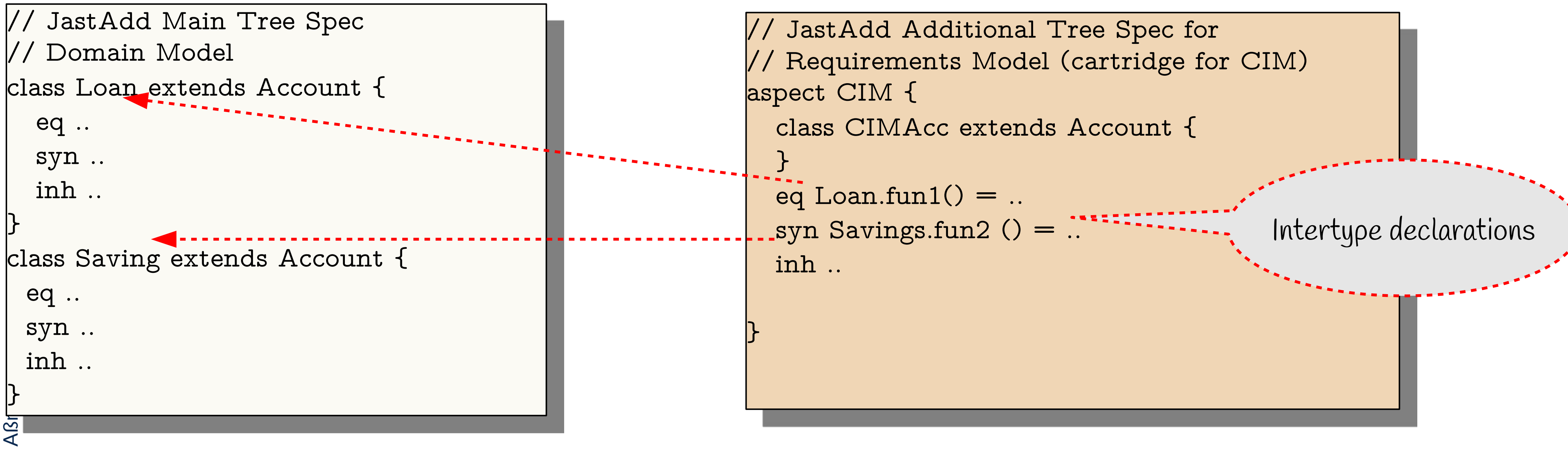
Cartridges are Transformation Libraries for Marked PIMs

- A **Cartridge** is a plugin to an MDA tool defining both the model mapping and the model transformation
  - For vertical and horizontal transformations
  - Definition of stereotypes for PIM markings in vertical transformations
    - Manual marking of the PIM
    - Selective transformation of the marked PIM classes
  - Automatic transformation using the mapping and transformations from the cartridge
    - No manual specifications of mappings and transformations necessary

32.1.4 Cartridges (Platform Extensions) in RAGs and JastAdd

RAG Modules Compose Extensions into CIM or PIM

- The basic module can be DM, DM+CIM, DM+CIM+PIM
  - Extensions are PSE, PSI
- Due to the declarativeness of attributions, modules can be unified by term (tree unification)
  - Names of the classes serve as unificator



```
// JastAdd Main Tree Spec
// Domain Model
class Loan extends Account {
   eq ..
   syn ..
   inh ..
}
class Saving extends Account {
  eq ..
  syn ..
  inh ..
}
```

```
// JastAdd Additional Tree Spec for
// Requirements Model (cartridge for CIM)
aspect CIM {
   class CIMAcc extends Account {
   }
   eq Loan.fun1() = ..
   syn Savings.fun2 () = ..
   inh ..

}
```

Intertype declarations

Ex.: JastAdd Aspects are Cartridges

- A JastAdd Aspect, like a cartridge, extends a set of Main Tree Nodes and their attributions with new attributions [Hedin09]
  - *Intertype declarations* distribute a class definition over several files of MDA
  - (Declarative) aspect files are composed by class unification

```
// JastAdd Main Tree Spec
// Domain Model
class Loan extends Account {
  eq ..
  syn ..
  inh ..
}
```

```
// JastAdd Additional Tree Spec
aspect CIM {
  eq Loan.fun1()
  eq ..
  syn ..
  inh ..
}
```

```
// JastAdd Additional Tree Spec
aspect PIM {
  eq Loan.fun2()
  eq ..
  syn ..
  inh ..
}
```

```
// JastAdd Additional Tree Spec
aspect PSM {
  eq Loan.fun3()
  eq ..
  syn ..
  inh ..
}
```

```
// JastAdd Additional Tree Spec
aspect PSI {
  eq Loan.fun4()
  eq ..
  syn ..
  inh ..
}
```

```
// JastAdd Additional Tree Spec
aspect TestM {
  eq Loan.test_fun1()
  eq ..
  syn ..
  inh ..
```

MDA by Composition of RAG Aspects

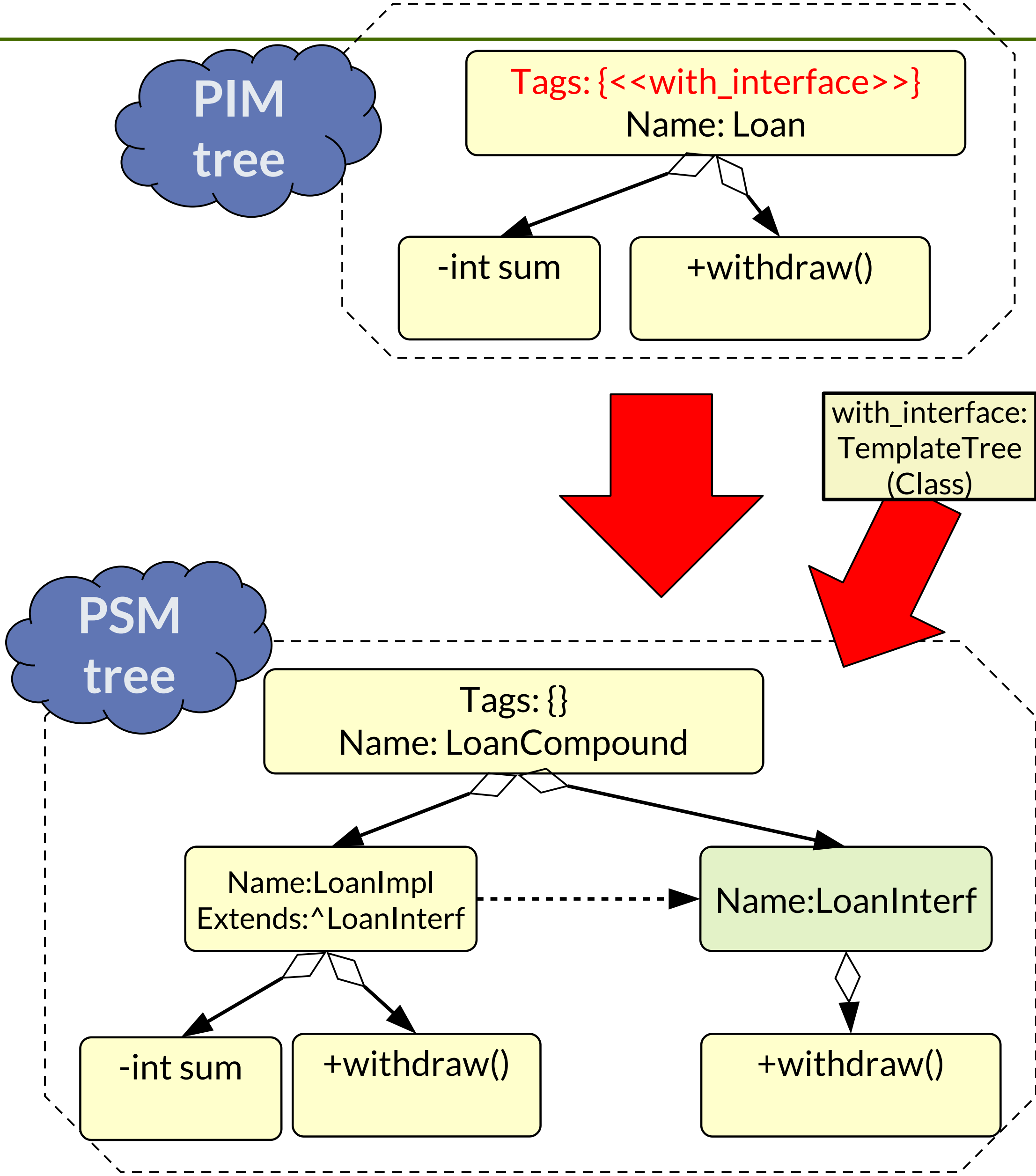
- RAG modules, e.g., JastAdd aspects, can be used as MDA cartridges
  - They compose class extensions “around” class names
  - Model weaving is done by class composition
  - Intertype declarations introduce “mixins” into classes of main syntax tree
- Model Refinement (in MDA) is done by modular composition (aspect composition) with intertype declarations
  - Model synchronisation is done by re-composition
  - RAG-MDA supports **composable macromodels**
- Model mappings achieved by common class names
  - Tracing is easy (common classes for extensions)

RAG modules, e.g., JastAdd aspects, can be used as MDA cartridges

32.1.5 Morphic Model Transformations in JastAdd

Morphic Transformations on Marked PIMs

- **Morphic mappings (1:1 or 1:n)** can be realized by JastAdd Rewrite operations or Term rewrite operations (Stratego, Xcerpt)
  - If Users add a stereotype to a node of a PIM
  - Rewrites can reduce them
- The rewrite is a replace operation of the marked node by its “implementation”
- Rewrite rule transforms redex of upper model to snippet in lower model
- Easy traceability by morphic mapping
- The PIM tree as well as the PSM tree are represented by the top node
- The PIM tree snippet and the PSM tree snippet are *homomorphic regions*



32.2 MDA Toolkits

Some MDA Tools

	Integrated into	URL
AndroMDA	Eclipse	http://www.andromda.org/
XText, Xpand	Eclipse	http://www.eclipse.org/Xtext/
IBM Rational Suite Software Architect	Eclipse	
BITplan smart Generator	Eclipse	http://www.bitplan.com/
Epsilon	Eclipse	https://www.eclipse.org/epsilon/

[Petrasch, R., Meimberg, O.: Model Driven Architecture - eine praxisorientierte Einführung in die MDA; dpunkt-verlag 2006]

Important Features of MDA Toolkits

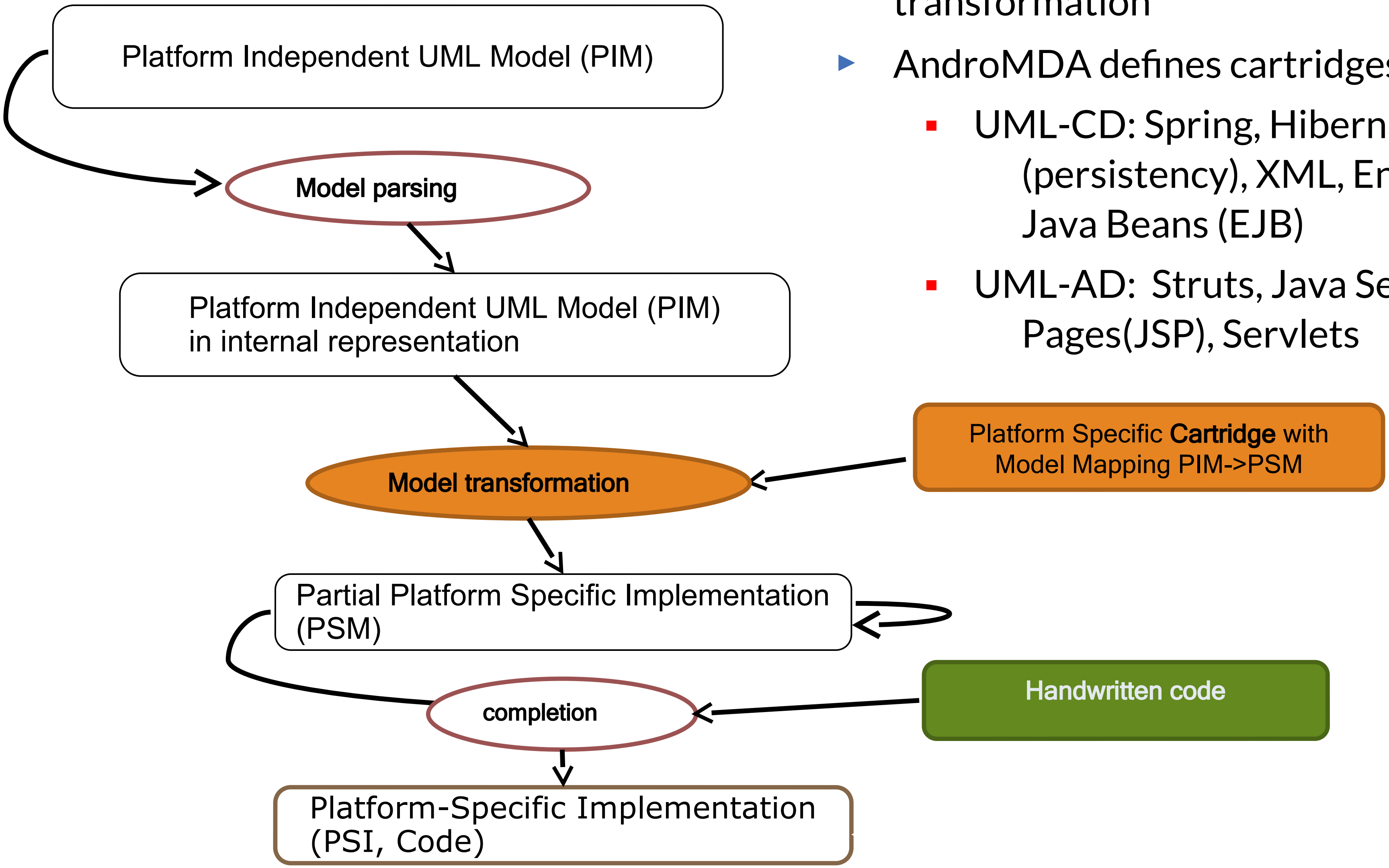
- **Model-to-Model Mapping** bzw. **Model-to-Model Transformation** (e.g., PIM to PSM) with cartridges
- **User definition of model transformation cartridges** with query and transformation languages
  - e.g., with QVT, ATL, Graph writing or XML Rewriting
- **Forward- und Reverse-Engineering**
  - Code generation (Model-to-Code Transformation, PSM to PSI)
    - Mapping to a programming language (e.g., with JMI)
- **Roundtrip-Engineering** between models and code
- **Single underlying model (SUM):** forming views by get and put operations
- **Model-driven Testing:** generation of test cases ad test data based on models

[Petrasch, R., Meimberg, O.: Model Driven Architecture - eine praxisorientierte Einführung in die MDA; dpunkt-verlag 2006]

32.2.1 AndroMDA, a Leading MDA Toolkit Focusing on PIM-PSM Transformations

[www.androMDA.org]

- AndroMDA defines model mappings in platform-specific cartridges.


Platform Independent UML Model (PIM)
Model parsing
Platform Independent UML Model (PIM) in internal representation
Model transformation
Platform Specific Cartridge with Model Mapping PIM->PSM
Partial Platform Specific Implementation (PSM)
Handwritten code
completion
Platform-Specific Implementation (PSI, Code)

- A cartridge contains a mapping from UML to e.g., Java, C# or C++ and a model transformation
- AndroMDA defines cartridges for
  - UML-CD: Spring, Hibernate (persistency), XML, Enterprise Java Beans (EJB)
  - UML-AD: Struts, Java Server Pages(JSP), Servlets

32.2.2 MDA Toolkit ArcStyler

ArcStyler is a toolkit working with several UML-editors such as MagicDraw or Rational Rose

- Cartridges for model mappings and transformations
- **Object Modeler** for requirements modeling; based on CRC-Cards
- **Pattern Refinement Assistant** transforms the domain model interactively into a PIM UML-model (with MagicDraw or Rational Rose)
  - With annotation of design decisions
- **Refinement of the PIM**
  - Horizontal refinement on PIM level
  - Vertical transformation to PSM or PSI (code generation)
- **Code completion (Codevervollständigung)** and optimization for an application platform
- **Component generation** for user interface
- Generation for build tools
- Generation for database persistency

http://www.software-kompetenz.de/servlet/is/27460/?print=true

Versteegen, G.: Wege aus der Plattformabhängigkeit - Hoffnungsträger Model Driven Architecture; Computerwoche 29(2002) Nr. 5 vom 1. Febr. 2002

Process Engineering with ArcStyler

UML modeling
- components
- associations

(logical structure; PIMs)

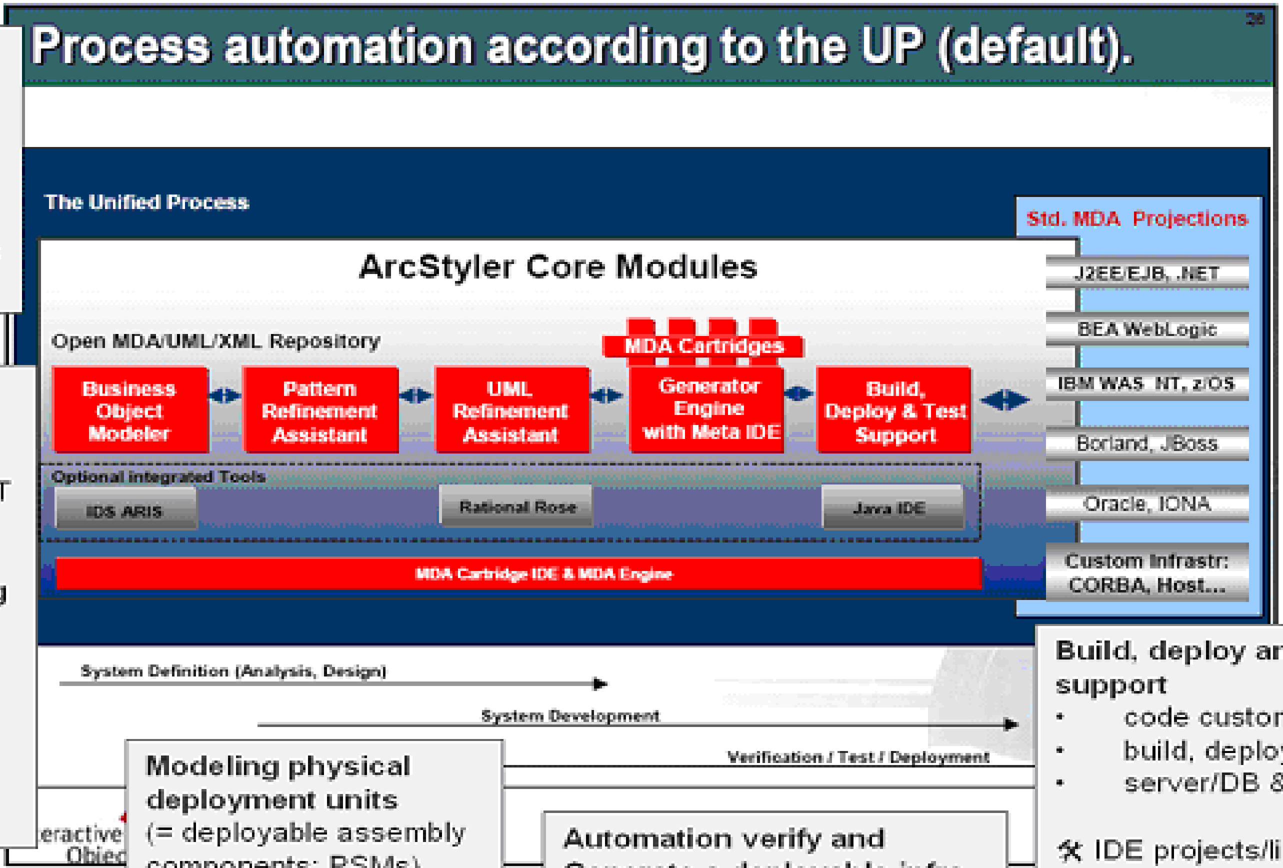
🛠 design assistants
🛠 wizards

Technical refinement of UML comonent model for J2EE/.NET target platforms

Technical Modeling
- EJB/.NET marks
- archive

(packages components)

🛠 defaults



Process automation according to the UP (default).

The Unified Process

ArcStyler Core Modules

Open MDA/UML/XML Repository

MDA Cartridges

Business Object Modeler ↔ Pattern Refinement Assistant ↔ UML Refinement Assistant ↔ Generator Engine with Meta IDE ↔ Build, Deploy & Test Support ↔

Optional integrated Tools: IDS ARIS, Rational Rose, Java IDE

MDA Cartridge IDE & MDA Engine

Std. MDA Projections
- J2EE/EJB, .NET
- BEA WebLogic
- IBM WAS NT, z/OS
- Borland, JBoss
- Oracle, IONA
- Custom Infrastr: CORBA, Host...

System Definition (Analysis, Design)

System Development

Verification / Test / Deployment

eractive Objec

Modeling physical deployment units (= deployable assembly components; PSMs)
- EJB archive

(deployment packages for EJB containers), .NET-C.

Automation verify and Generate a deployable infra-structure (+ test/ build env.)

🛠 MDA engine code generator
🛠 MDA-Cartridges

Build, deploy and test support
- code customization
- build, deploy in container
- server/DB & client startup

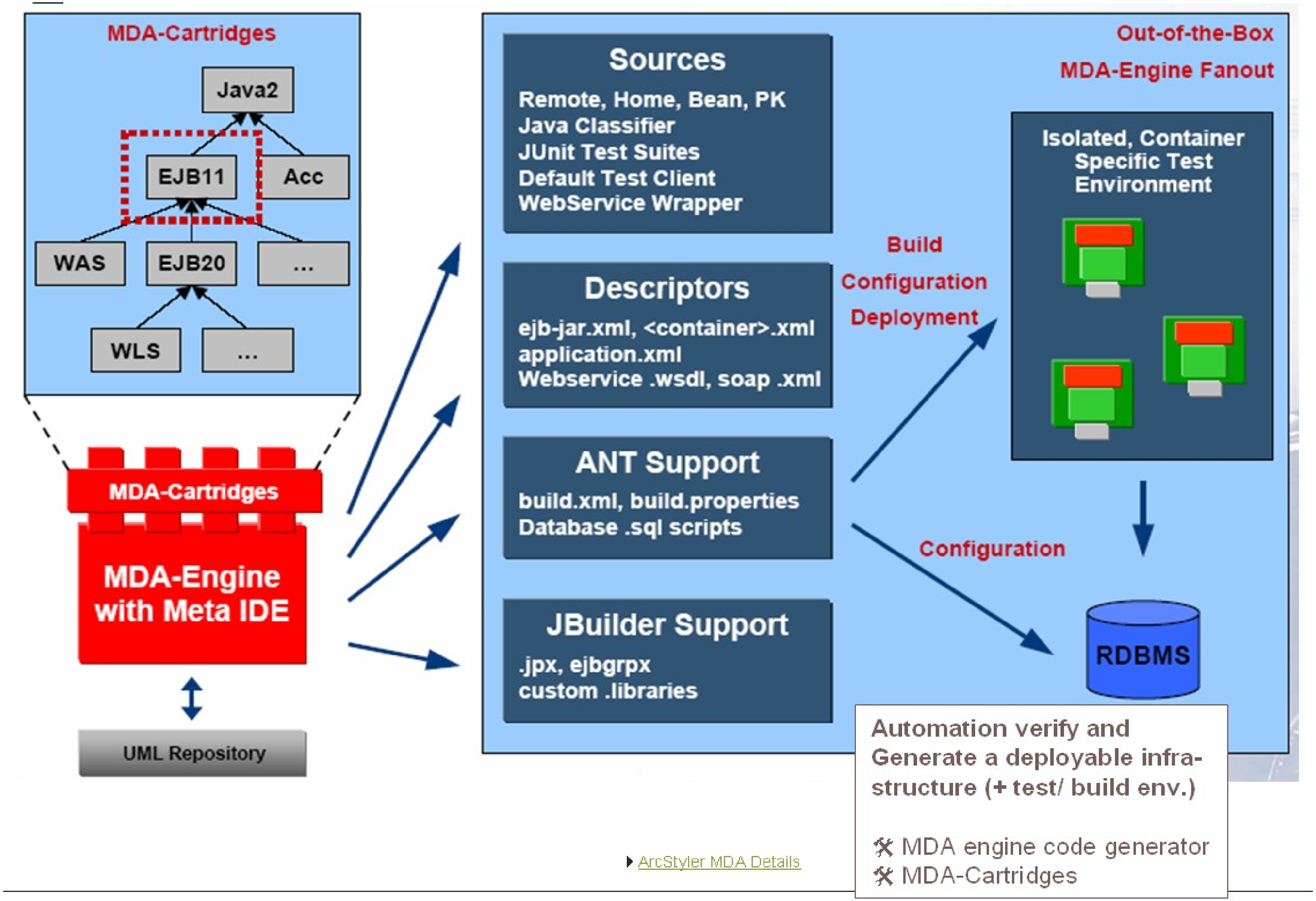
🛠 IDE projects/libs
🛠 ANT scripts + properties

▸ ArcStyler Overview

https://www.omg.org/mda/mda_files/P2A_Tutorial.pdf

http://www.interactive-objects.com/products/arcstyler/supportdocumentation.html
http://arcstyler.software.informer.com/

Cartridges and Generated Artifacts



Automation verify and Generate a deployable infra-structure (+ test/ build env.)

🛠 MDA engine code generator
🛠 MDA-Cartridges

Quelle: Butze, D.: Entwicklung eines Praktikums für die werkzeuggestützte Softwareentwicklung nach der Model-Driven-Architecture; Großer Beleg an der Fakultät Informatik der TU Dresden 2004

32.3 Traceability between Models

- Model transformations generate trace mappings

omitted in 2021/22

Advantages of Model Mappings

- **Error tracing**
  - When an error occurs during testing or runtime, we want to trace back the error to a design element or requirements element
- **Traceability**
  - We want to know which requirement (feature) influences which design, code, and test elements, so that we can demarcate modules in the solution space (product line development)
- **Synchronization in Development:**
  - Two models are called **synchronized**, if the change of one of them leads automatically to a hot-update of the other
- **Cohesion of Distributed Information:**
  - Two related model elements may contain distributed information about a thing. The relation allows for reconstructing the full information
  - Example:
    - Storing two roles of an object in two different models (See “Amoeba Object Pattern”)
    - Splitting the representation of the requirements on an object and its design in requirements vs design model

Different Forms of Model Mappings

- **Directly specified mappings** specify a deterministic mapping function between a source and target model.
  - Direct mappings are specified in GUI or text files
  - Direct mappings may be ***complete*** or ***incomplete***
- **Recursive mappings** are defined in a functional language
  - **Denotational semantics** is a complete direct mapping of two languages
  - The **coverage** of the source model must be ensured (completeness of specification)
- **General mappings** may be intensionally specified. Source and target models are mapped
  - With graph reachability expressions (QVT-R, TgreQL, EARS)
  - With query expressions (Semmle.QL)
  - With expressions in a logic (F-Datalog)
- **Inter-model mappings** are defined between model elements of different models
- **Lifted inter-model mappings** are lifted from intra-model element mappings

Why Traceability in a Macromodel?

[Grammel]

System Comprehension:

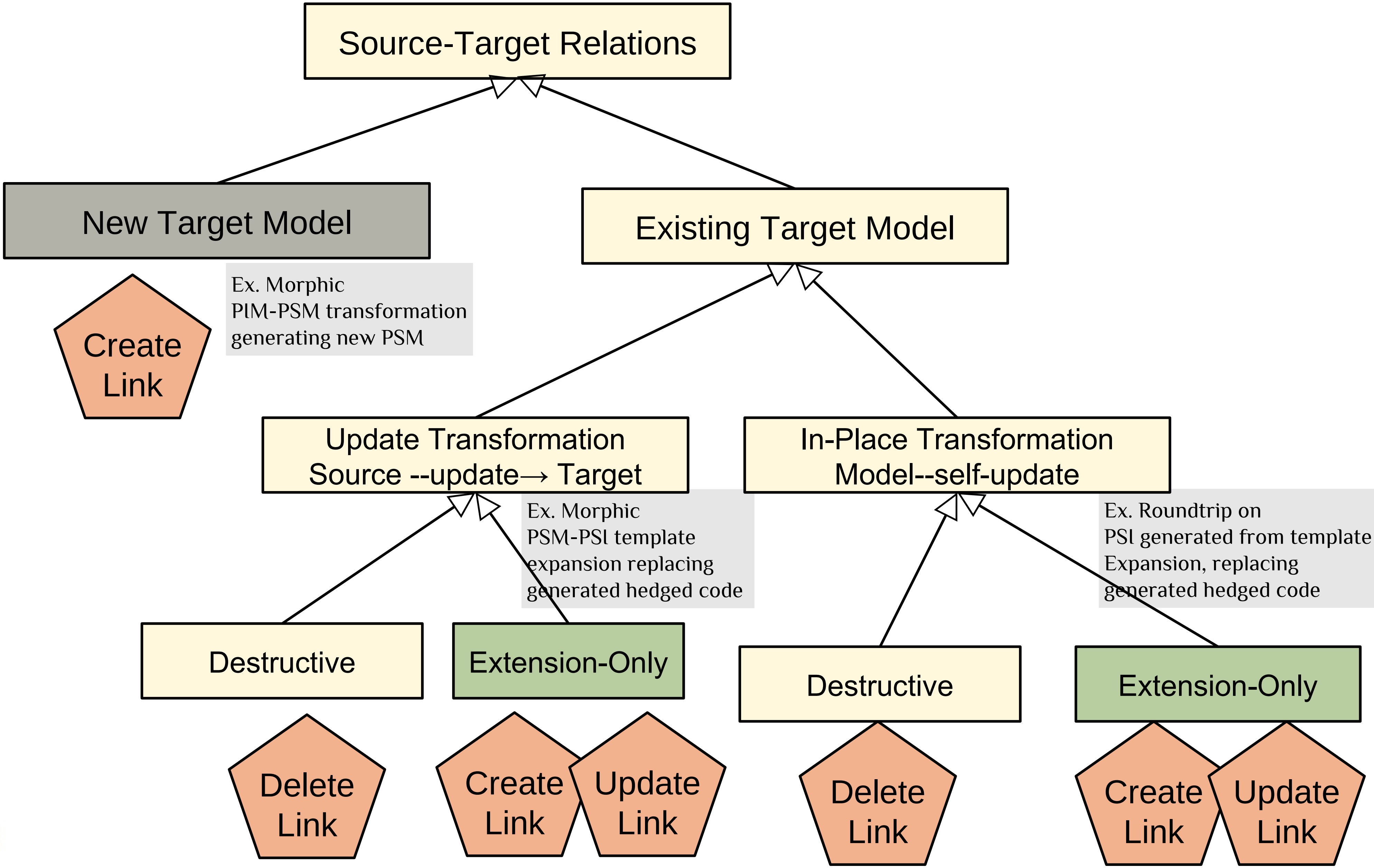
  - Trace mappings improve orientation in multimodels by navigating via trace links along model transformation chains
- **Change Impact Analysis**:
  - to analyze the impact of a model change on other models
  - to analyze the impact of a model change on existing *generated* or *transformed* output
  - To enable to do model synchronization (hot updating dependent parts)
- **Orphan Analysis:** finding orphaned elements in models

Validation and Verification:

- **System Validation:** Connecting the requirements with the customer's goals and problems (see ZOPP method)
- **(Test) Coverage analysis**: to determine whether all requirements were covered by test cases in the development life cycle
- **Debugging**: To locate bugs when tracing code back to requirements
  - To locate bugs during the development of transformation programs

Traceability Metamodel: CRUD Types of Trace Links between Model Elements of Different Models

[Grammel]



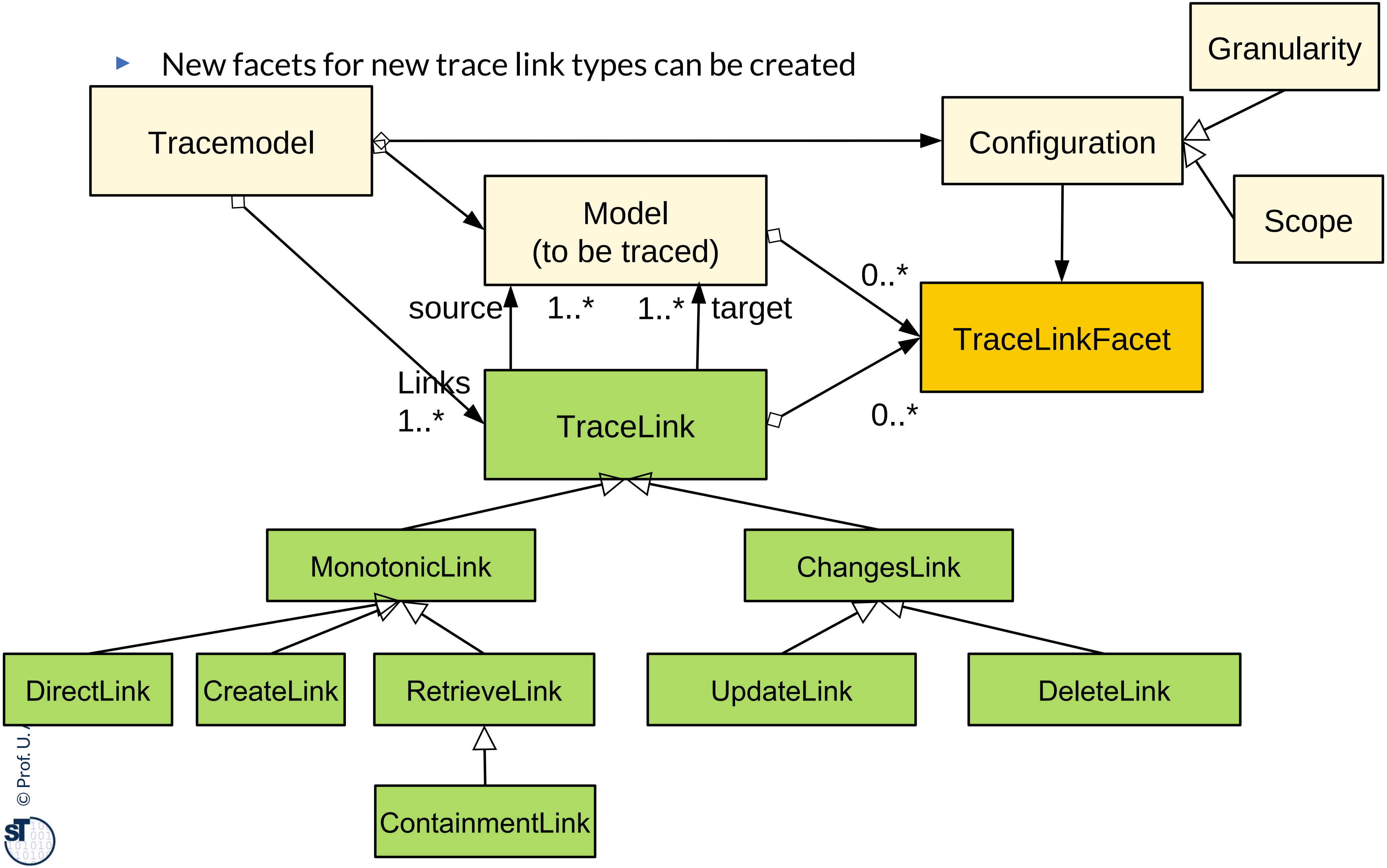
Ex. Morphic
PIM-PSM transformation
generating new PSM

Ex. Morphic
PSM-PSI template
expansion replacing
generated hedged code

Ex. Roundtrip on
PSI generated from template
Expansion, replacing
generated hedged code

Extensible Traceability Metamodel acc. to Grammel

- New facets for new trace link types can be created



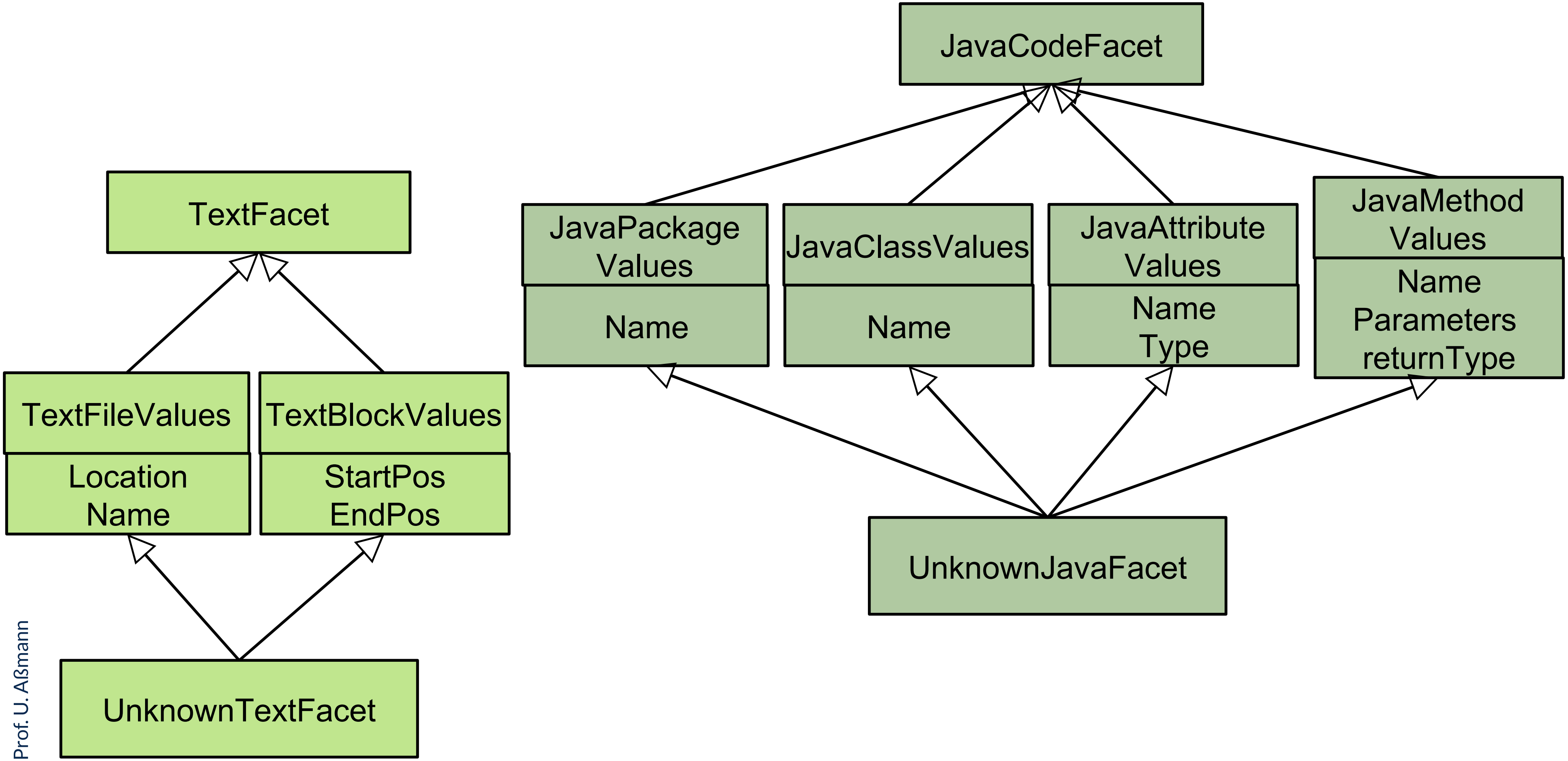
Traceability in Macromodels

- Piecemeal growth of macromodels in the software process:
  - Start with requirements, then add more stuff and models
- **Add links**
  - **Symmetric "Direct" (auto-drawn) links** are drawn between model element MA from model A and model element MB whenever MB is related to MA
    - Specified by hand or found by a model difference, model analysis or a model query
  - **Create links** are drawn between model element MA from model A and model element MB whenever MB is generated or added because of MA
  - **Retrieve links** are drawn when MB is extracted (queried) from a model A and added to another model B
  - **Containment links** are drawn, when in a new model B the model element MA is contained in another model element MB'
  - **Delete links** are drawn if In model B the model element MB should be deleted
  - **Update links** are drawn if MA has changed and MB should be changed too

Examples for TraceLinkFacet

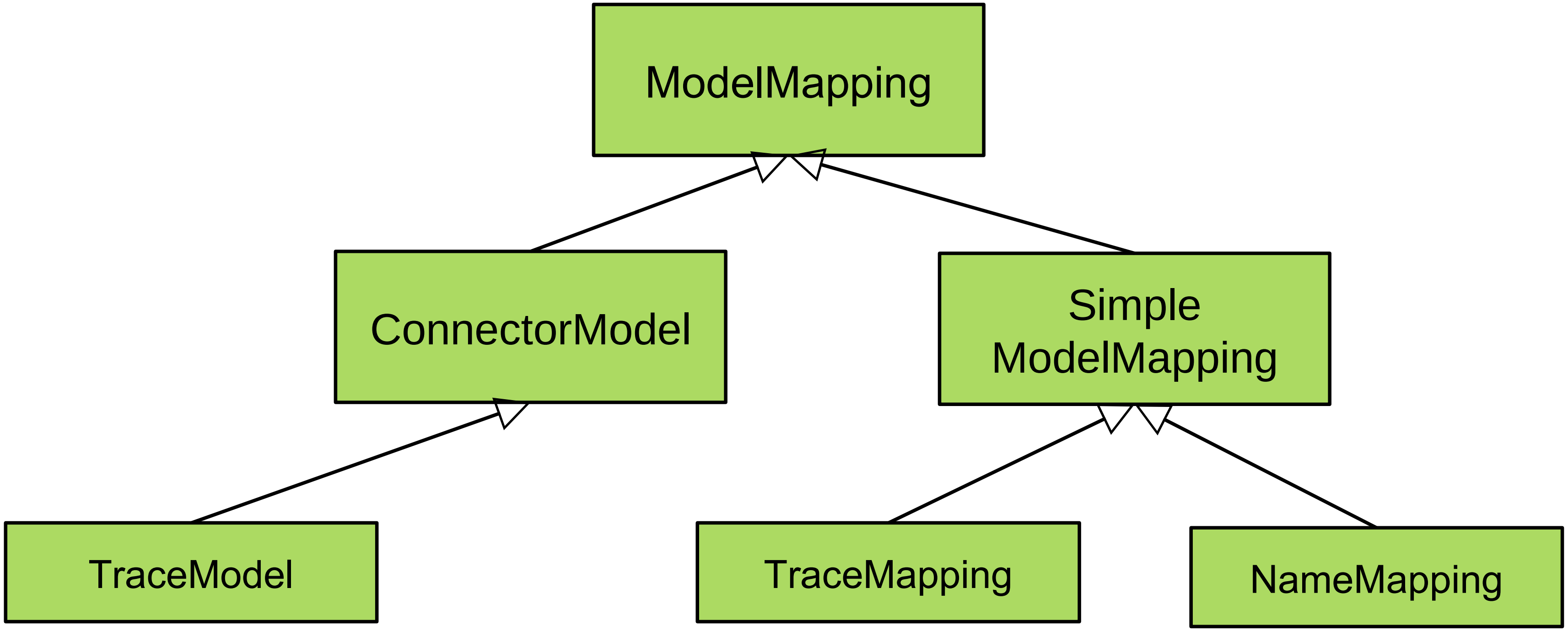
[Grammel]

- Facets factorize inheritance hierarchies; new facets extend inheritance hierarchies



Different Kinds of Trace Models

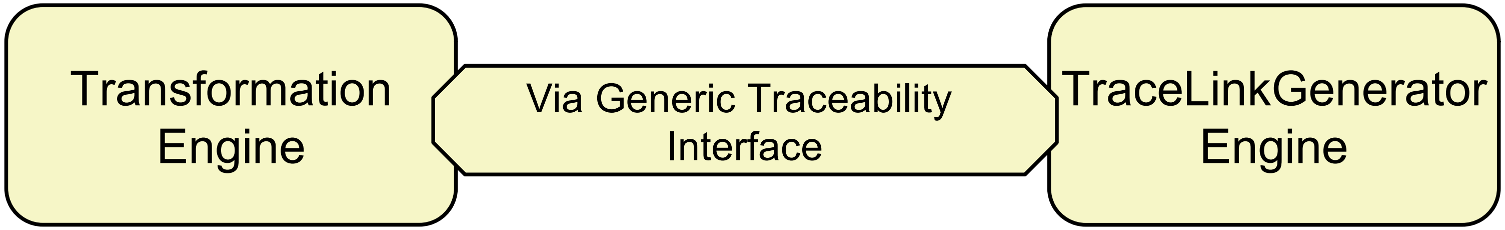
- So far, trace mappings were realized as associations in a **simple model mapping**
- The trace metamodel can be extended to describe a ***trace model***, a specific form of ***connector model***

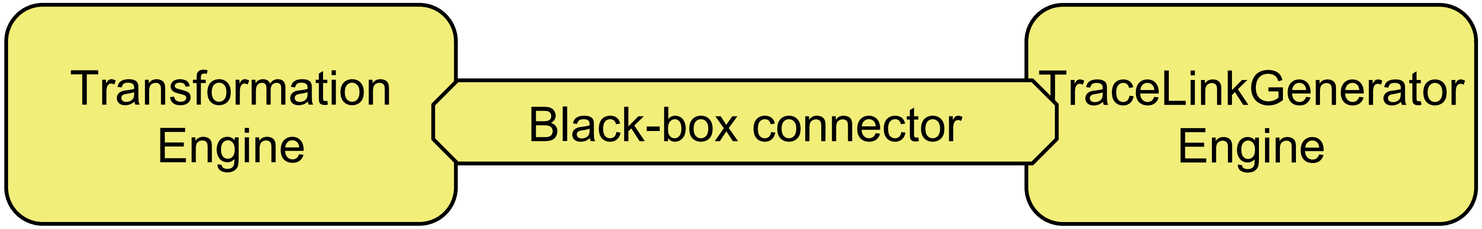


Adding a Trace Link Generator to Tools

[Grammel]

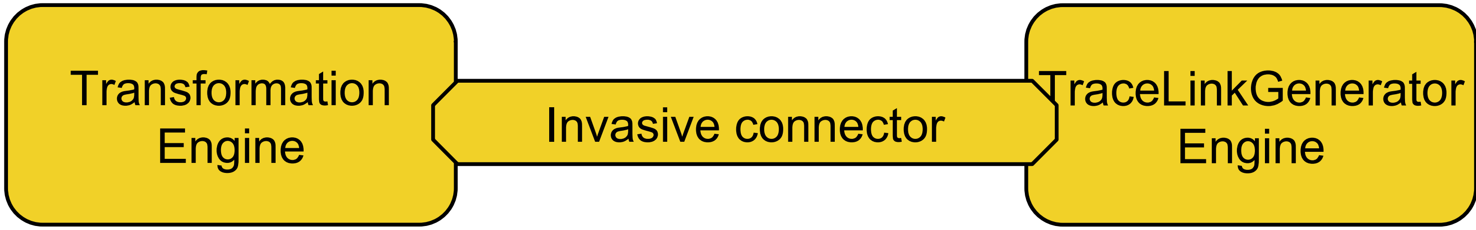
- TraceLinkGenerators for Trace Models must be written by hand
- They can be connected to transformation engines and cartriges in three ways, following a ***generic traceability interface***:





Transformation engine must know and call the generator

Transformation engine need not know but is extended Invasively or woven By AOP

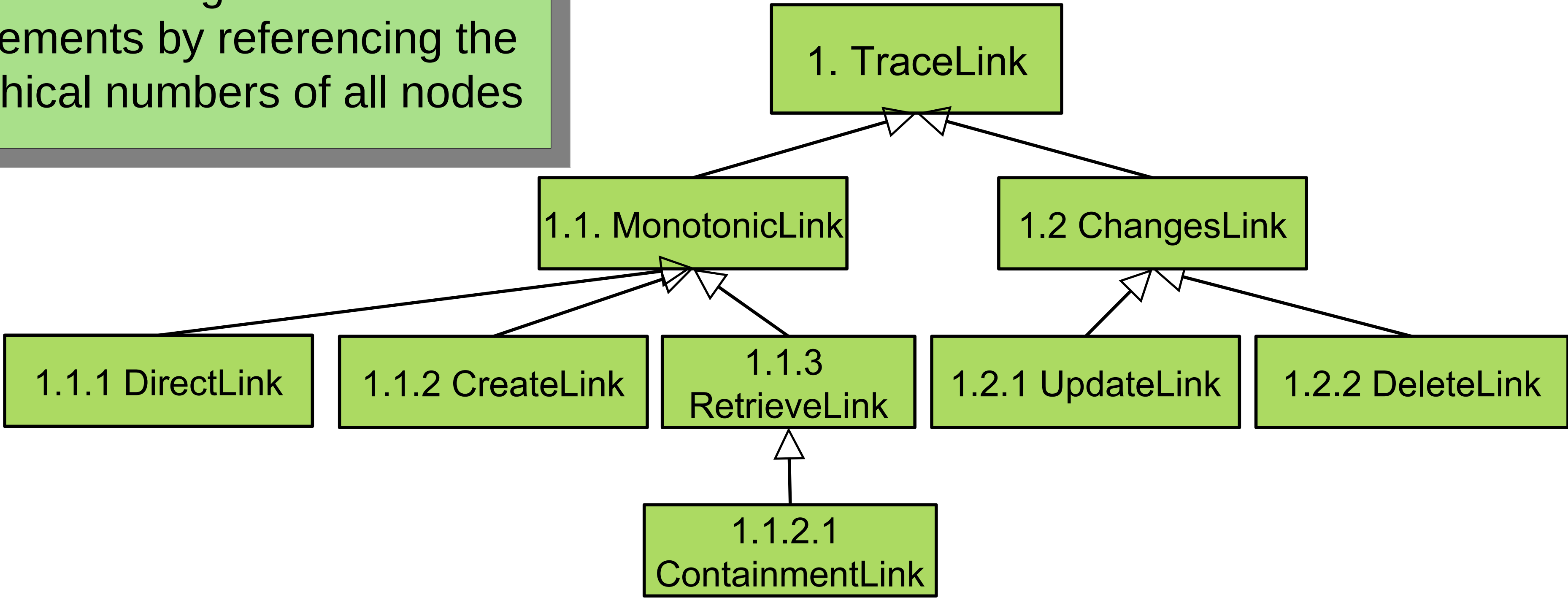


Traceability in Macromodels with Models from Link-Treeware

- In link-tree models, a skeleton tree exists, in which every model element has a unique *tree node number (hierarchical number)*
- Trace links can be added with tree node number and stored externally of the model *in the macromodel*

In link-treeware, macromodels maintain *trace(link) models* linking and tracing all models and their elements by referencing the hierarchical numbers of all nodes

Hierarchical numbering of the classes in an inheritance tree:

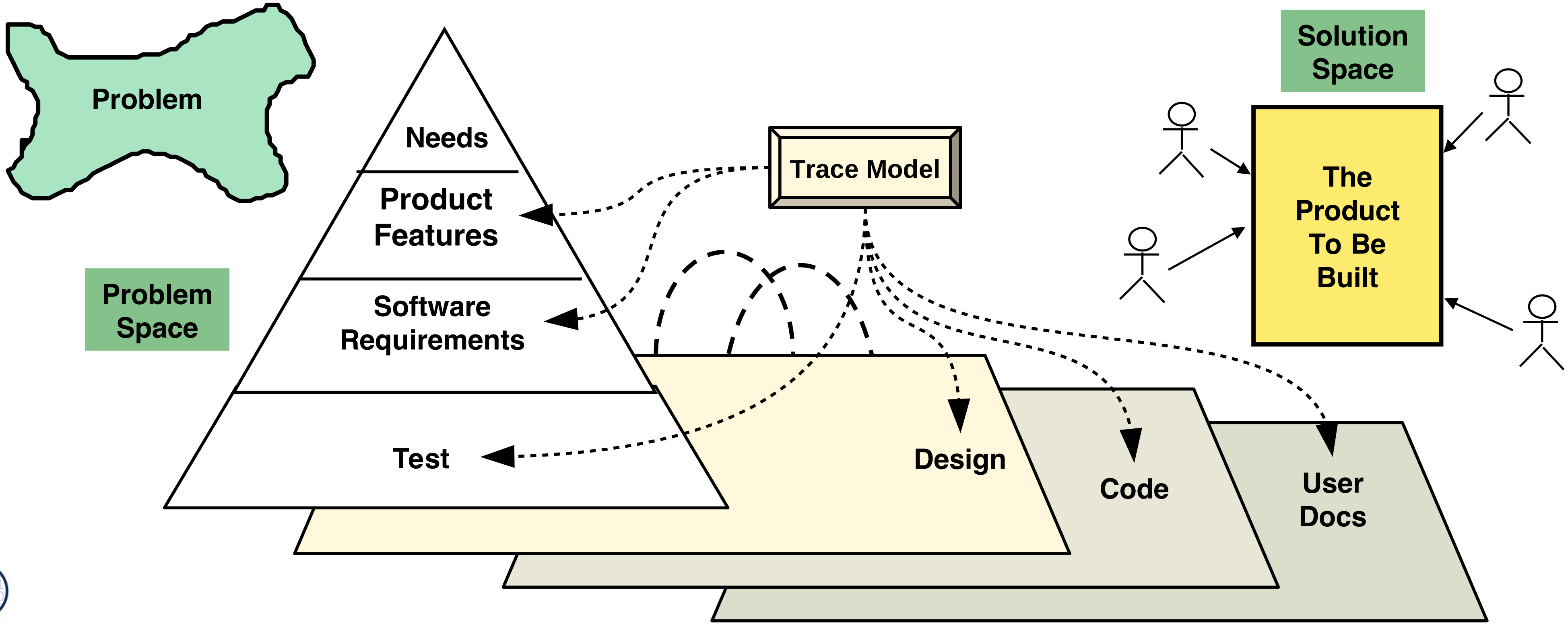


32.4 Traceability in Practical Requirements Management Tools

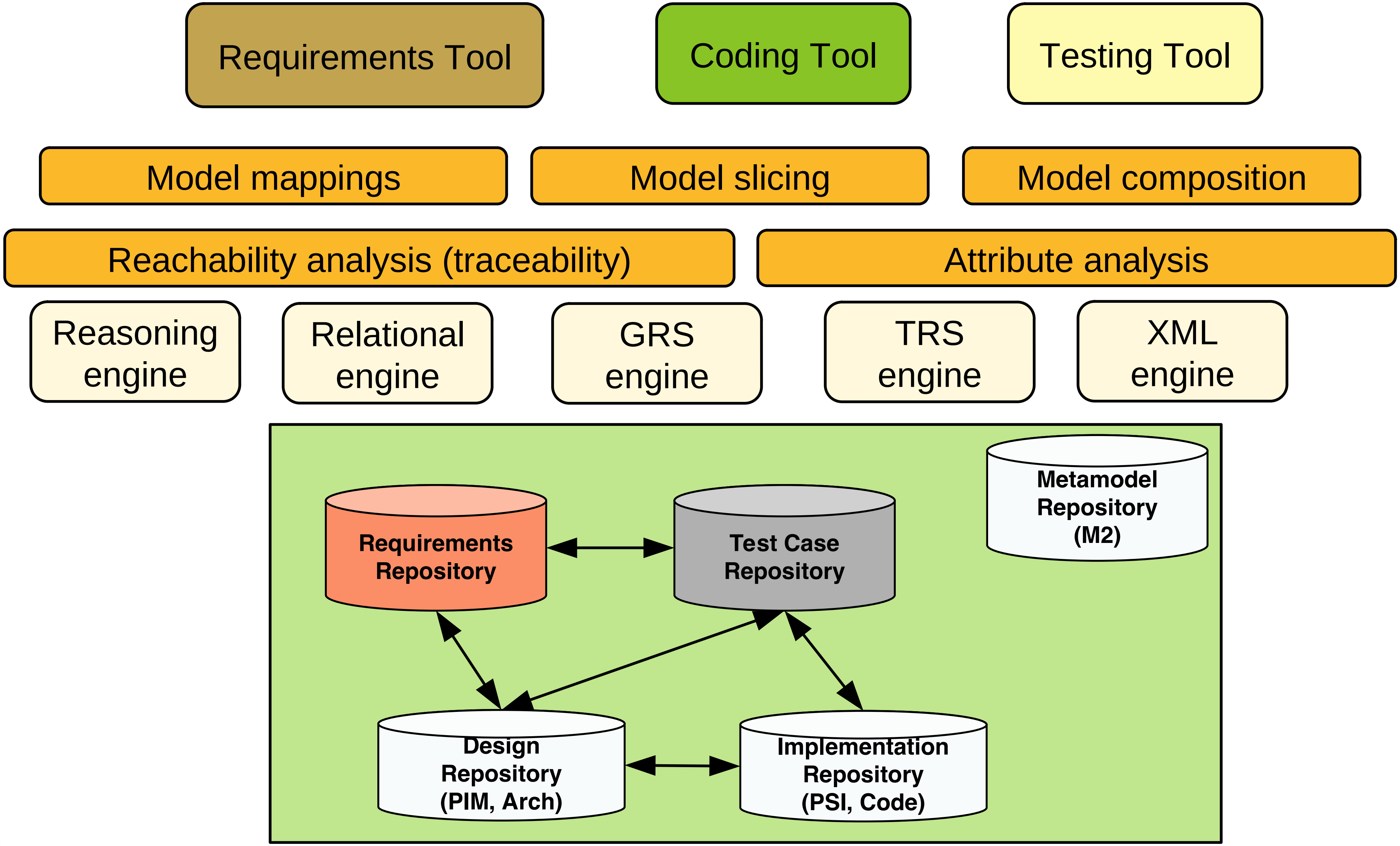
omitted in 2021/22

Introduction to Requirements Management (RM)

- RM bridges the needs of the customer to testing, design, coding, and documentation
- RM continuously manages requirements in the entire software life cycle
- RM relies on inter-model mappings between requirements, test cases, design, and code



Tools in an Integrated Development Environment (IDE)



Requirements Tool

Coding Tool

Testing Tool

Model mappings

Model slicing

Model composition

Reachability analysis (traceability)

Attribute analysis

Reasoning engine

Relational engine

GRS engine

TRS engine

XML engine

Requirements Repository

Test Case Repository

Metamodel Repository (M2)

Design Repository (PIM, Arch)

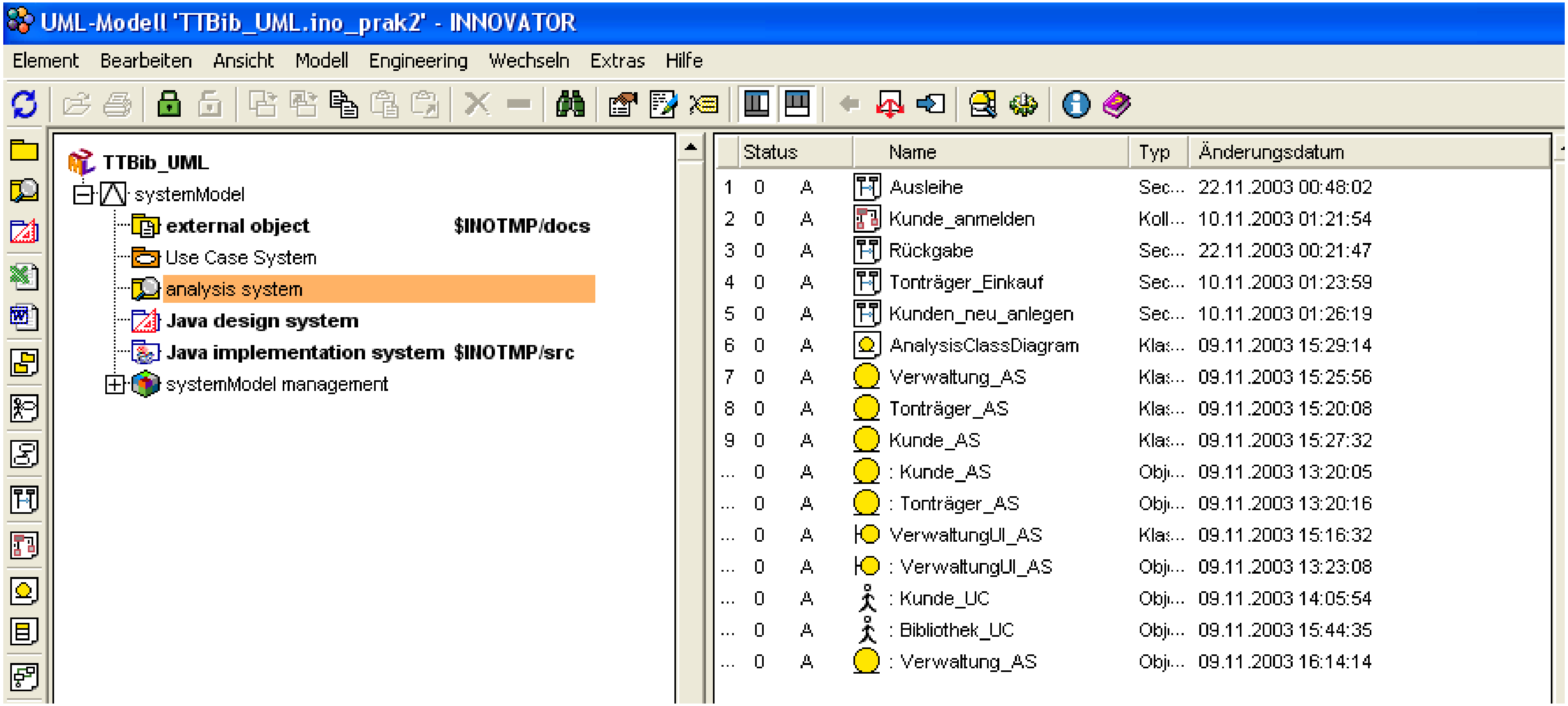
Implementation Repository (PSI, Code)

Deficiencies of Current RE Methods

- Relationships among requirements are inadequately captured
  - Causal relationship between consistency, completeness and correctness [Zowghi2002]
  - Completeness and consistency are not verified
- Requirement problems (e.g. conflicts, incompleteness) are detected too late or not all
- Relationships between requirements and dependent artifacts are insufficiently managed (test, documentation, design, code)
- Desirable:
  - Models for RE need richer and higher-level **abstractions** (goals, problems, needs) to validate that they are fulfilled [Mylopoulos1999]
    - Metamodels can be used to define these concepts
    - Ontologies deliver reasoning services
  - **Model mappings (direct and indirect)** between the artifacts (design, code) and the goals, problems, needs of the customer
    - Based on the model mappings, the requirements are consistently managed with design, code, and documentation

Model Mapping in MID INNOVATOR

- Innovator can be employed simultaneously for requirements, design and implementation models
- How to relate these models?



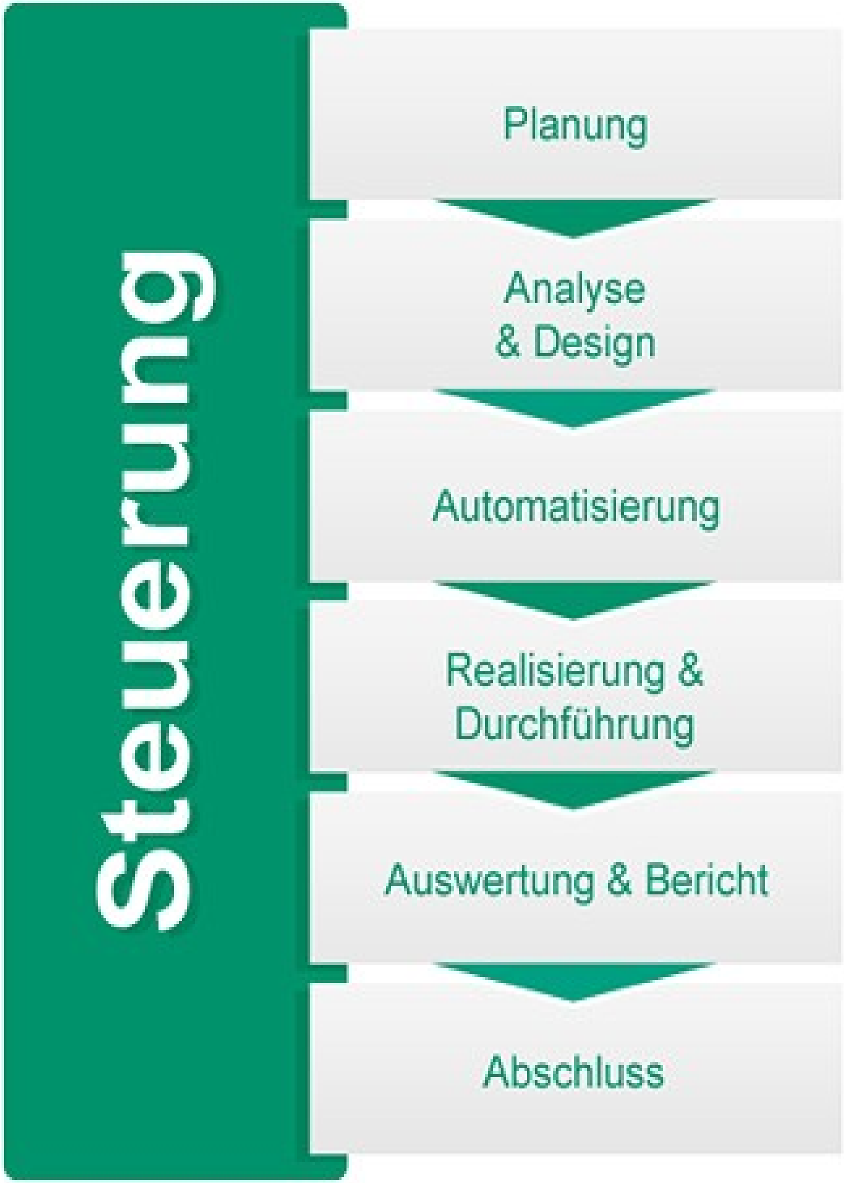
TTBib_UML
- systemModel
  - external object $INOTMP/docs
  - Use Case System
  - analysis system
  - Java design system
  - Java implementation system $INOTMP/src
  - systemModel management

	Status		Name	Typ	Änderungsdatum
1	0	A	Ausleihe	Sec...	22.11.2003 00:48:02
2	0	A	Kunde_anmelden	Koll...	10.11.2003 01:21:54
3	0	A	Rückgabe	Sec...	22.11.2003 00:21:47
4	0	A	Tonträger_Einkauf	Sec...	10.11.2003 01:23:59
5	0	A	Kunden_neu_anlegen	Sec...	10.11.2003 01:26:19
6	0	A	AnalysisClassDiagram	Kla:...	09.11.2003 15:29:14
7	0	A	Verwaltung_AS	Kla:...	09.11.2003 15:25:56
8	0	A	Tonträger_AS	Kla:...	09.11.2003 15:20:08
9	0	A	Kunde_AS	Kla:...	09.11.2003 15:27:32
...	0	A	: Kunde_AS	Obj...	09.11.2003 13:20:05
...	0	A	: Tonträger_AS	Obj...	09.11.2003 13:20:16
...	0	A	VerwaltungUI_AS	Kla:...	09.11.2003 15:16:32
...	0	A	: VerwaltungUI_AS	Obj...	09.11.2003 13:23:08
...	0	A	: Kunde_UC	Obj...	09.11.2003 14:05:54
...	0	A	: Bibliothek_UC	Obj...	09.11.2003 15:44:35
...	0	A	: Verwaltung_AS	Obj...	09.11.2003 16:14:14

Direct Traceability

- With a **direct model mapping**, a requirements model can be linked
  - to a test case specification
  - to a documentation
  - to an architectural specification
  - via the architectural specification, to the classes and procedures in the code

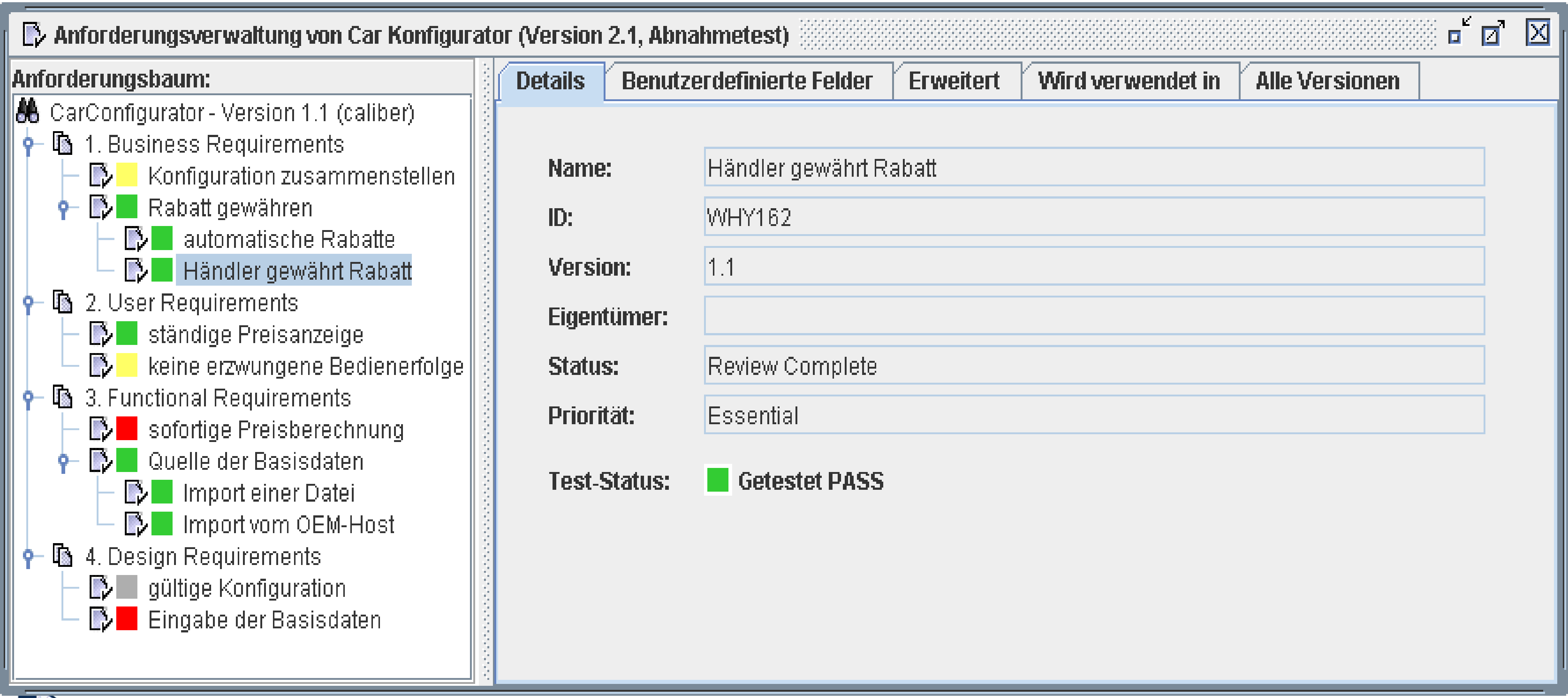
Example: imbus TestBench



http://www.imbus.de/produkte/imbus-testbench/hauptfunktionen/

Requirements get “red-yellow-green” Test Status Attribute

- Test status is an attribute in the requirements tree that contains a **direct link** to the result of a corresponding test case

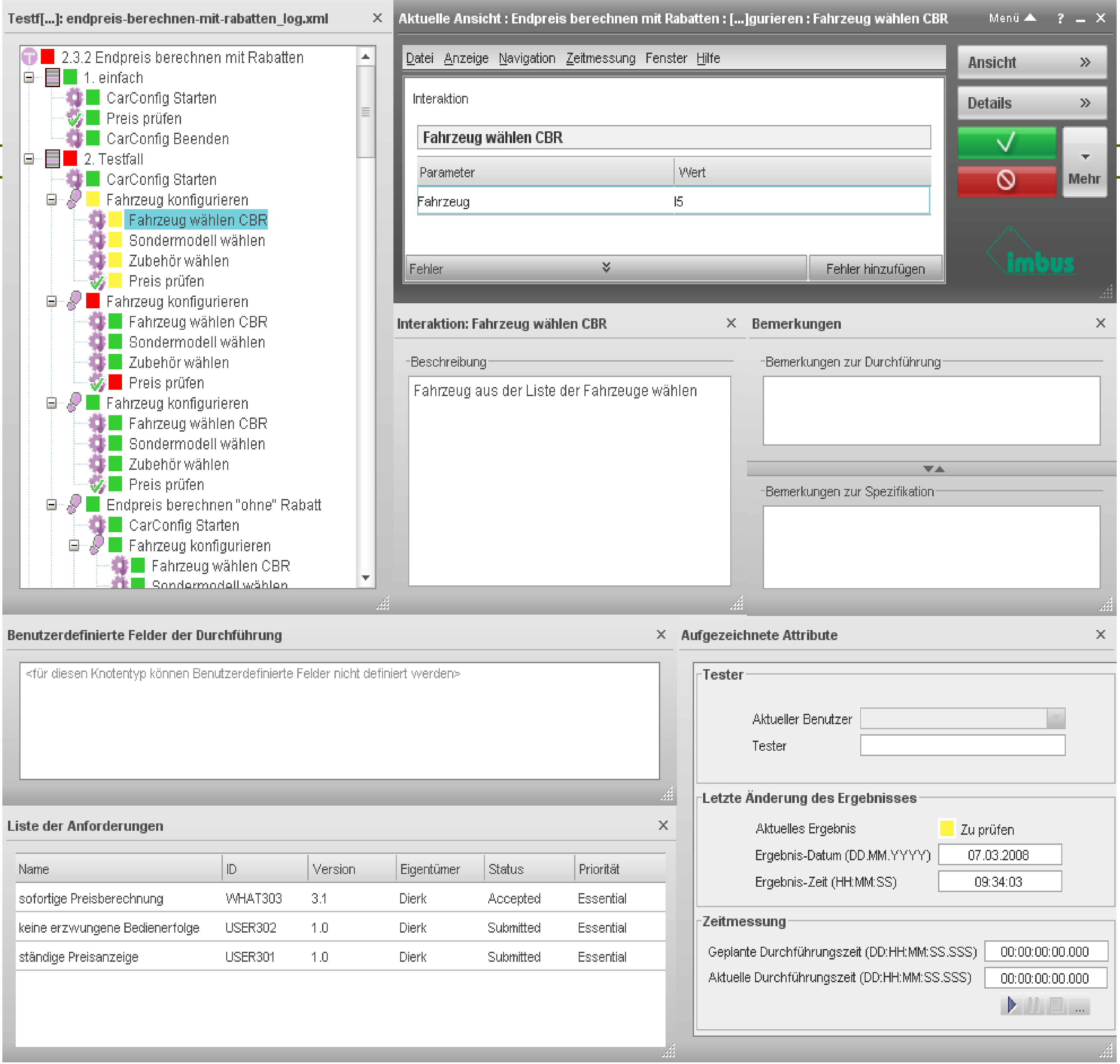


Anforderungsverwaltung von Car Konfigurator (Version 2.1, Abnahmetest)
Details
Benutzerdefinierte Felder
Erweitert
Wird verwendet in
Alle Versionen

Anforderungsbaum:

- CarConfigurator - Version 1.1 (caliber)
  - 1. Business Requirements
    - 🟨 Konfiguration zusammenstellen
    - 🟩 Rabatt gewähren
      - 🟩 automatische Rabatte
      - 🟩 Händler gewährt Rabatt
  - 2. User Requirements
    - 🟩 ständige Preisanzeige
    - 🟨 keine erzwungene Bedienerfolge
  - 3. Functional Requirements
    - 🟥 sofortige Preisberechnung
    - 🟩 Quelle der Basisdaten
      - 🟩 Import einer Datei
      - 🟩 Import vom OEM-Host
  - 4. Design Requirements
    - ⬜ gültige Konfiguration
    - 🟥 Eingabe der Basisdaten

Name:	Händler gewährt Rabatt
ID:	WHY162
Version:	1.1
Eigentümer:	
Status:	Review Complete
Priorität:	Essential
Test-Status:	🟩 Getestet PASS



Testf[...]: endpreis-berechnen-mit-rabatten_log.xml

- 🟥 2.3.2 Endpreis berechnen mit Rabatten
  - 🟩 1. einfach
    - 🟩 CarConfig Starten
    - 🟩 Preis prüfen
    - 🟩 CarConfig Beenden
  - 🟥 2. Testfall
    - 🟩 CarConfig Starten
    - 🟨 Fahrzeug konfigurieren
      - 🟨 Fahrzeug wählen CBR
      - 🟨 Sondermodell wählen
      - 🟨 Zubehör wählen
      - 🟨 Preis prüfen
    - 🟥 Fahrzeug konfigurieren
      - 🟩 Fahrzeug wählen CBR
      - 🟩 Sondermodell wählen
      - 🟩 Zubehör wählen
      - 🟥 Preis prüfen
    - 🟩 Fahrzeug konfigurieren
      - 🟩 Fahrzeug wählen CBR
      - 🟩 Sondermodell wählen
      - 🟩 Zubehör wählen
      - 🟩 Preis prüfen
    - 🟩 Endpreis berechnen "ohne" Rabatt
      - 🟩 CarConfig Starten
      - 🟩 Fahrzeug konfigurieren
        - 🟩 Fahrzeug wählen CBR
        - 🟩 Sondermodell wählen

Aktuelle Ansicht : Endpreis berechnen mit Rabatten : [...]gurieren : Fahrzeug wählen CBR

Interaktion

Fahrzeug wählen CBR

Parameter	Wert
Fahrzeug	I5

Interaktion: Fahrzeug wählen CBR

Beschreibung

Fahrzeug aus der Liste der Fahrzeuge wählen

Bemerkungen

Bemerkungen zur Durchführung

Bemerkungen zur Spezifikation

Benutzerdefinierte Felder der Durchführung

<für diesen Knotentyp können Benutzerdefinierte Felder nicht definiert werden>

Aufgezeichnete Attribute

Tester

Aktueller Benutzer

Tester

Letzte Änderung des Ergebnisses

Aktuelles Ergebnis 🟨 Zu prüfen

Ergebnis-Datum (DD.MM.YYYY) 07.03.2008

Ergebnis-Zeit (HH:MM:SS) 09:34:03

Zeitmessung

Geplante Durchführungszeit (DD:HH:MM:SS.SSS) 00:00:00:00.000

Aktuelle Durchführungszeit (DD:HH:MM:SS.SSS) 00:00:00:00.000

Liste der Anforderungen

Name	ID	Version	Eigentümer	Status	Priorität
sofortige Preisberechnung	WHAT303	3.1	Dierk	Accepted	Essential
keine erzwungene Bedienerfolge	USER302	1.0	Dierk	Submitted	Essential
ständige Preisanzeige	USER301	1.0	Dierk	Submitted	Essential

Direct Model Mappings between Requirements and Test Tools

- Most often, these tools are in Link-treeware (hierarchical requirements, hierarchical test cases and test suites)
- → The trace models can be stored externally in the megamodel
  - Every trace link refers to link-tree node numbers in the requirements and test specifications

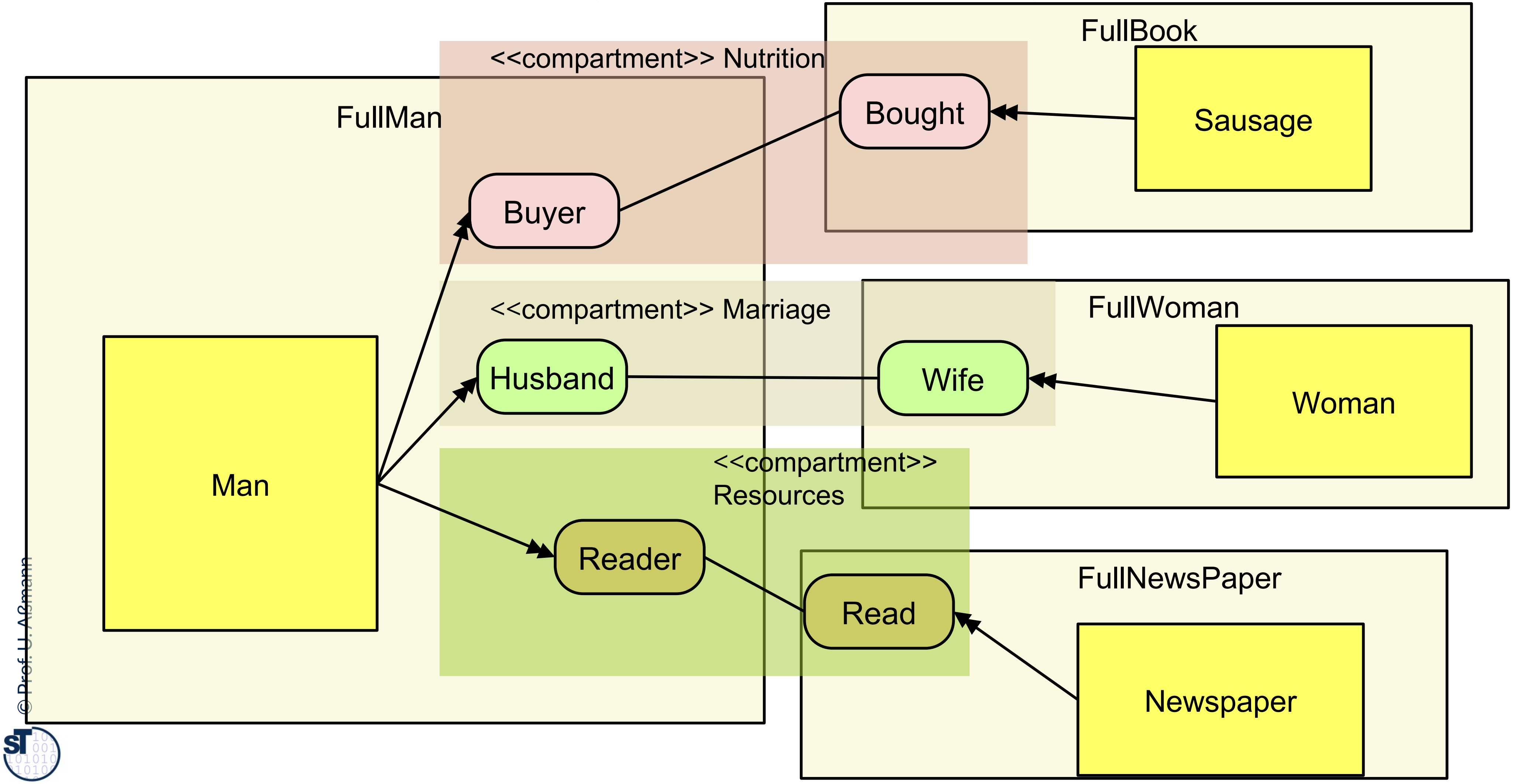
32.5 The MDA Macromodel of RoSI (RoSI-MDA): Representing Trace Mappings as Role-Playing

- What happens if contexts and roles are available in models?
- The Megamodel of RoSI and its traceability of model elements is extremely simple, because the role-based models and metamodels are factorizing objects
- RoSI-MDA is homogeneous Macromodel

Remember: The Steimann Factorization of Natural and Role Types

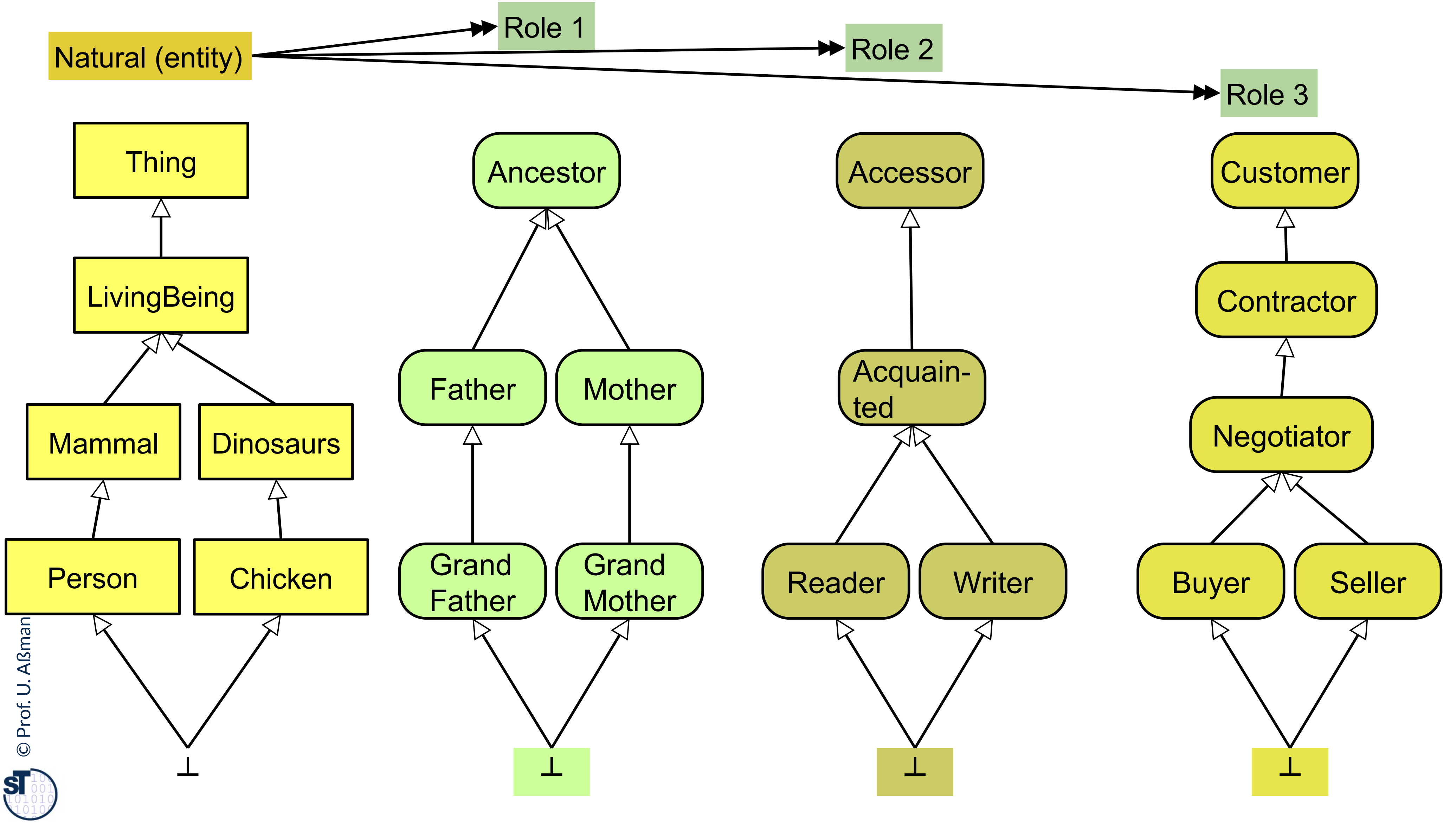
Splitting a full type into its *natural* and *role-type* components

- FullType = Natural x (role-type, role-type, ...)
- FullPerson = Person x (Reader, Father, Customer, ..)



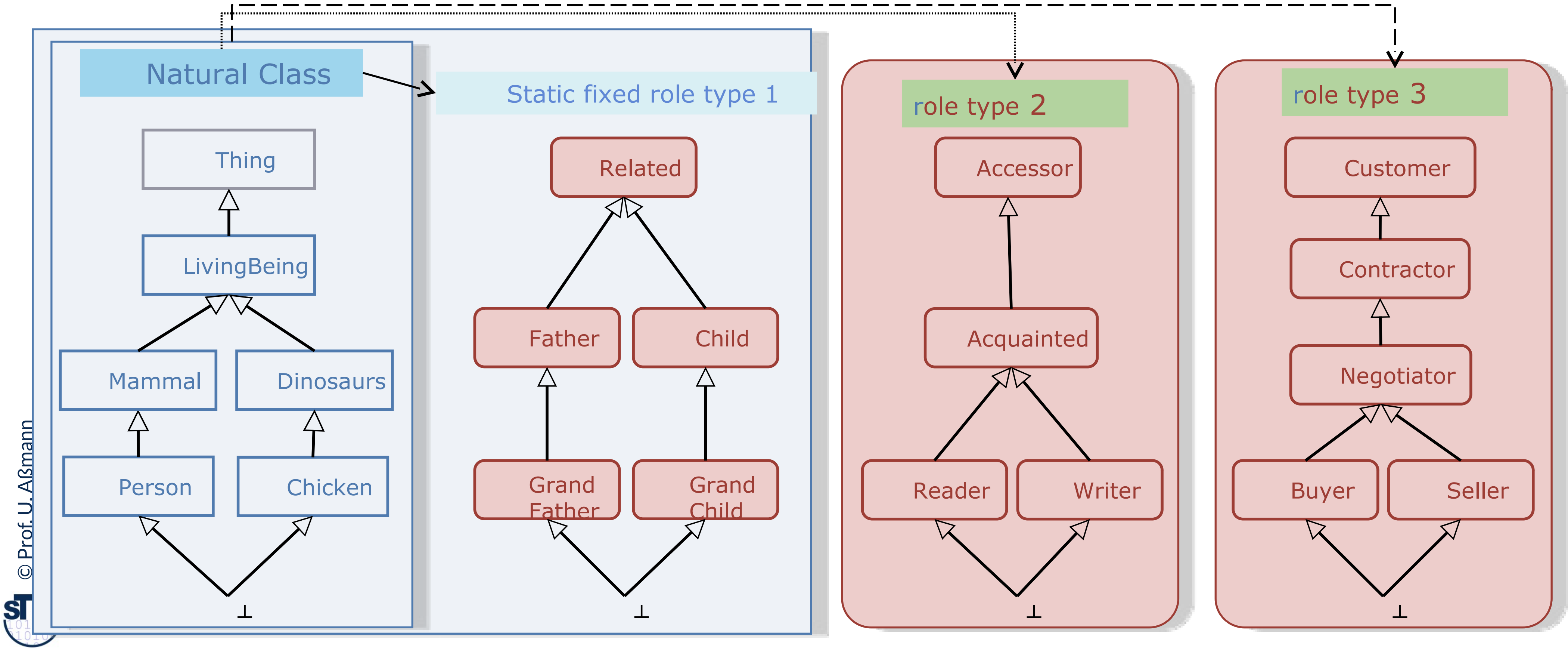
Remember: Full Type is from Inheritance Product Lattice

Q: What is a reading buying grandfather person? (A: tuple type)



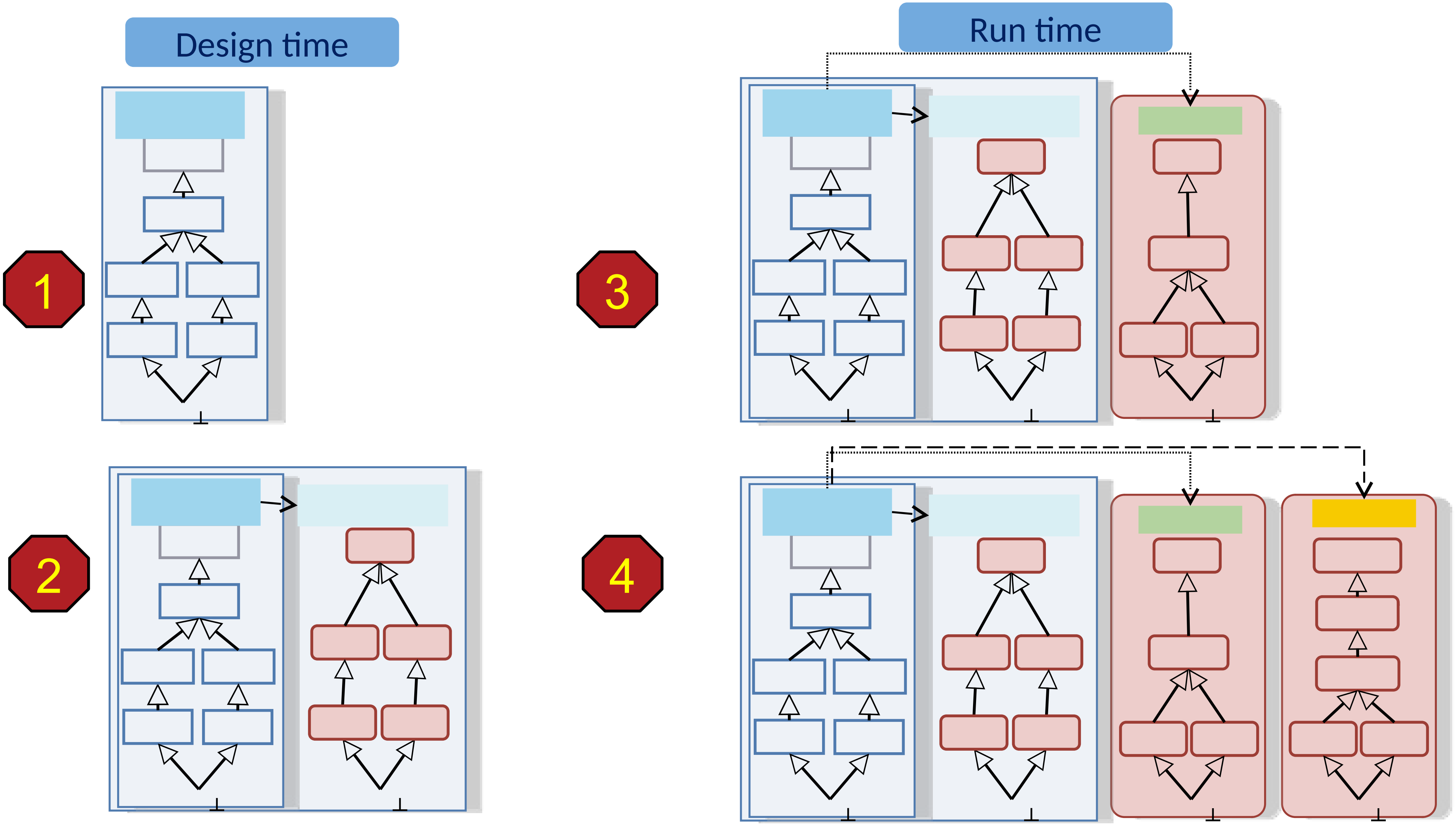
Scalable Bindung Time of Contexts with the Factorization

- **Scalable Binding**: Roles can also be bound statically, if mixins are used as implementation (fixing the context)
- Consequences for object life time, cohesion, allocation, adaptation, reconfiguration



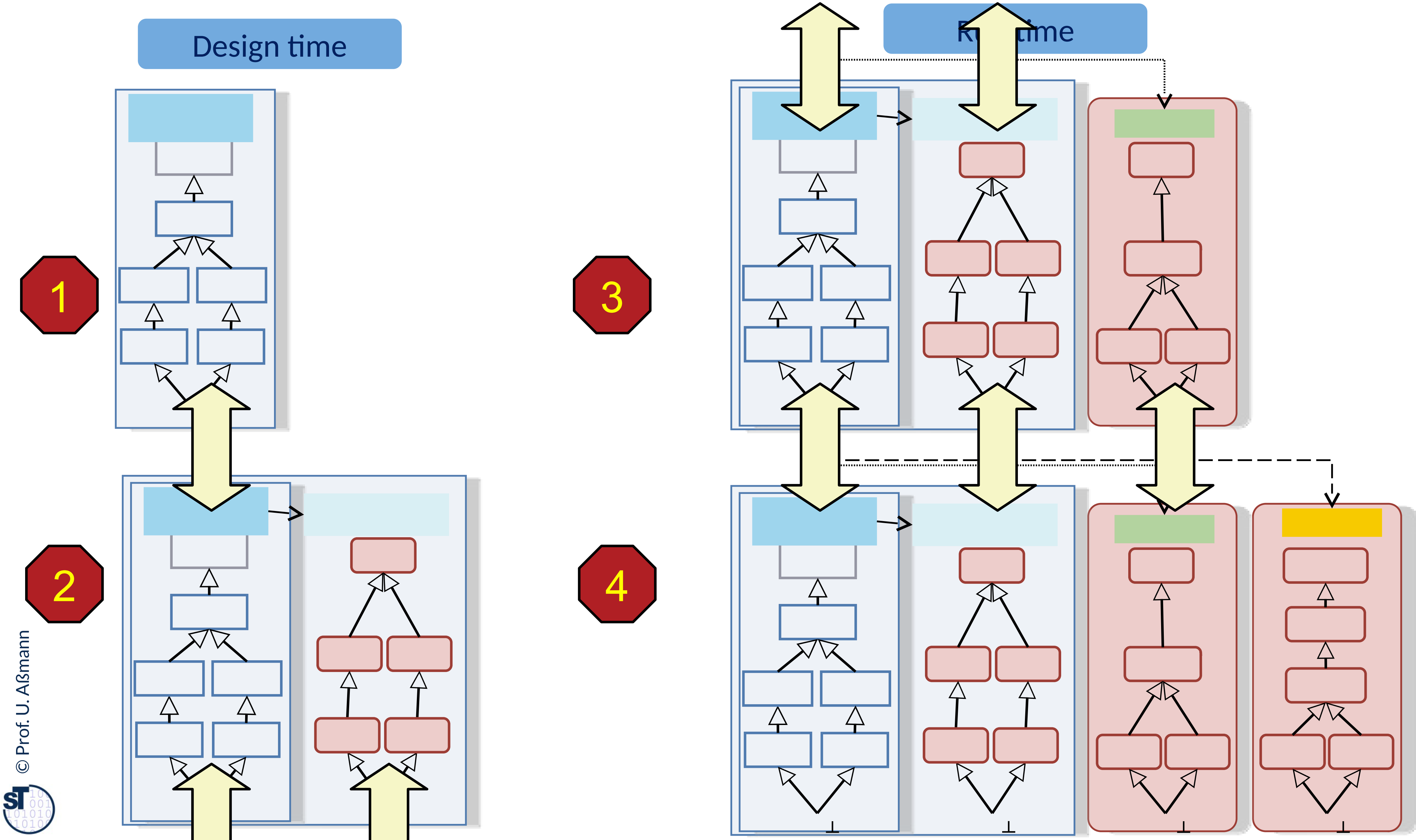
RoSI Macromodel (RoSI-MDA): Refinement by Role Allocation

- ***Refinement*** by allocation of further roles – static roles at design time, dynamic roles at runtime
- In RoSI-MA, the role-play relation is subset of the traceability relation



RoSI-MDA: Traceability in Refinement by Role Allocation

- ***Refinement*** by allocation of further roles – static roles at design time, dynamic roles at runtime



RoSI Macromodel (RoSI-MDA): Cross-Layer Role-Based Refinement in the Software Life Cycle

- Refinement by allocation of roles provides **simple traceability** because Natural objects STAY the same
- Trace mapping *is* role-play relation joined with context-role matrix
- Platform properties are „technical“ roles of the objects
  - Technical plattforms are static contexts
  - Dynamic contexts (place, time, service quality)

Causal Mapping of contexts and fludity From requirements level to runtime

	Natural	Fixed Role 1	Fixed Role 2	Fixed Role 3	Fixed Role 4	Dynamic role 1	Dynamic role 2	Dynamic role 3
Domain Model	Person							
Requirements	Person	Customer						
Design	Person	Customer	Customer Design					
PSM	Person	Customer	Customer Design	Platform-specific Behavior				
Implementation	Person	Customer	Customer Design	Platform-specific Behavior	Full static behavior			
Run time context 1	Person	Customer	Customer Design	Platform-specific Behavior	Full static behavior	Behavior in Context 1		
Run time context 2	Person	Customer	Customer Design	Platform-specific Behavior	Full static behavior	Behavior in Context 1	Behavior in Context 2	
Run time context 3	Person	Customer	Customer Design	Platform-specific Behavior	Full static behavior	Behavior in Context 1	Behavior in Context 2	Behavior in Context 3

Advantages of RoSI-MDA (Role-Based MDA)

- Very simple, component MDA with easy traceability:
  - Cores of objects map 1:1 from CIM via PIM and PSM into the application PSI (context-role matrix)
  - Variability via new roles for PIM, PSM, PSI
  - “object fattening” through the MDA
- Projection (get) and reintegration (put) is simple for MDA-SUM

End

- Why do the models of MDA form a macromodel, while MDA is a megamodel?
- Which trace link types are important for MDA?
- Why is a context-role-based model better for traceability?
- How does JastAdd aspects achieve MDA refinement?
  - How is traceability achieved?
  - How model synchronisation?
- How does RoSI-MDA achieve global traceability from requirements to run time?
- How will megamodel look like that provides Link-tree-based models and Role-based factorization of objects?
  - How does a trace link look like?
  - Where are the trace links stored?
  - Why can XML be used as simple exchange format in these megamodels?

32. Macromodels in One Technical Space

Prof. Dr. U. Aßmann
Technische Universität Dresden
Institut für Software- und Multimediatechnik
http://st.inf.tu-dresden.de/teaching/most

Version 21-0.2, 22.01.22

1) Model-Driven Architecture (MDA)
2) MDA Toolkits
3) Traceability in Model Transformations
4) Direct Model Mappings between Requirements and Tests
5) RoSIMDA – a Very Simple MDA with Trace Mappings as Role-Play Relations

Literature

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Literature on MDA

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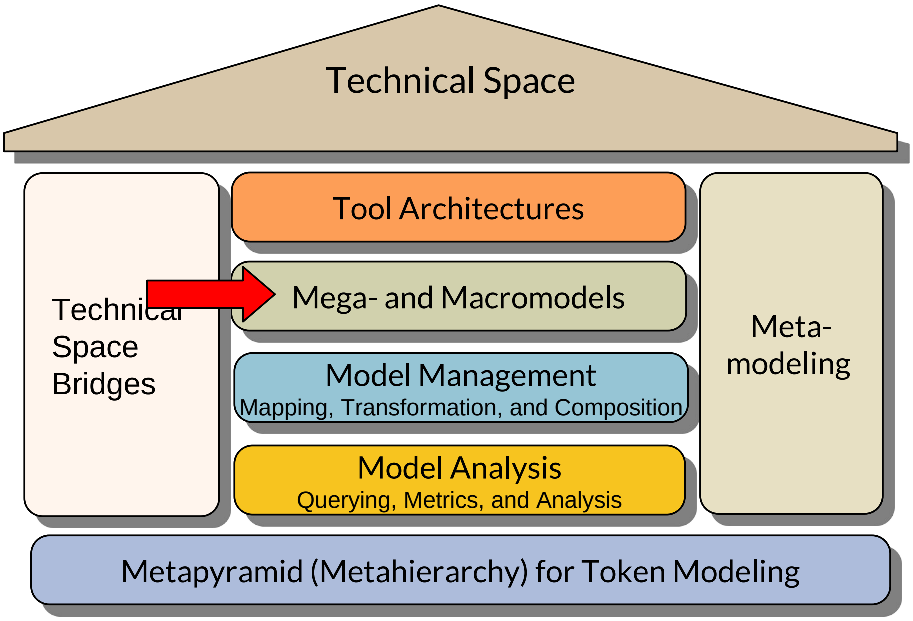
- Petrasch, R., Meimberg, O.: Model Driven Architecture - eine praxisorientierte Einführung in die MDA. Dpunkt-Verlag. 2006
  - Teaser chapter https://www.researchgate.net/publication/220693090_Model_Driven_Architecture_-_eine_praxisorientierte_Einfuhrung_in_die_MDA

Q10: The House of a Technical Space



Software Factories

A **software factory** schema essentially defines a recipe for building members of a software product family.

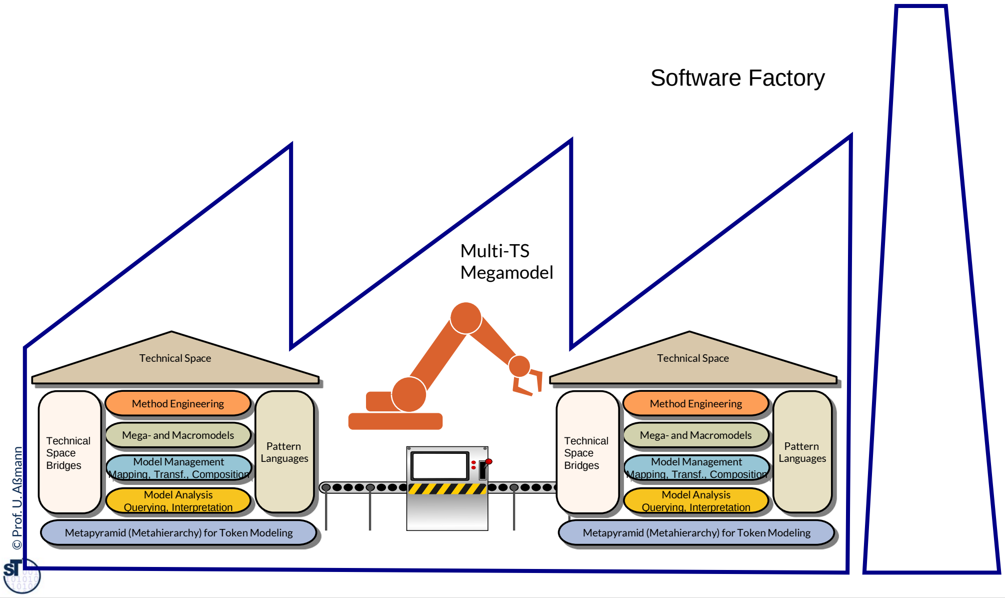
Jack Greenfield

https://www.researchgate.net/publication/213883069_Software_Factories_Assembling_Applications_with_Patterns_Frameworks_Models_and_Tools

In this course:

A **software factory** combines the languages and tools of several technical spaces to create software and cyber-physical systems product families.

Q12: A Software Factory's Heart: the M[illegible] Megamodel

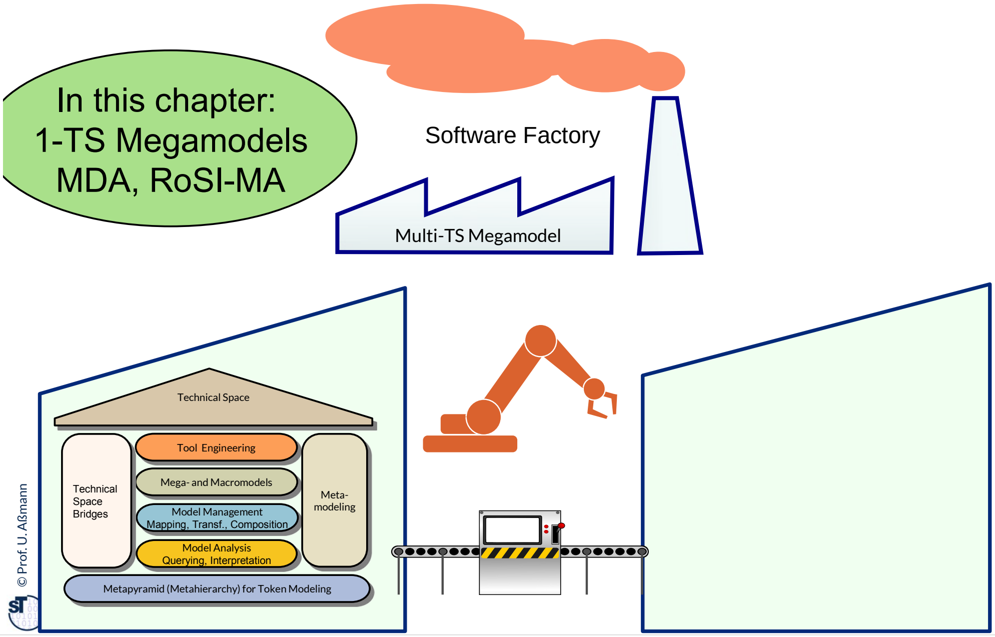

Software Factory
Multi-TS Megamodel
Technical Space
Method Engineering
Mega- and Macromodels
Model Management Mapping, Transf., Composition
Model Analysis Querying, Interpretation
Technical Space Bridges
Pattern Languages
Metapyramid (Metahierarchy) for Token Modeling
Technical Space
Method Engineering
Mega- and Macromodels
Model Management Mapping, Transf., Composition
Model Analysis Querying, Interpretation
Technical Space Bridges
Pattern Languages
Metapyramid (Metahierarchy) for Token Modeling

32.1 Model-Driven Architecture (MDA) (Modellgetriebene Architektur)

MDA is a trademark of OMG

MDA is an industrial megamodel in the spirit of ReDeCT.
Its instances in software product are multimodels, connecting several ***model abstraction levels.***

Software Factories with Only 1 Technical Space



In this chapter:
1-TS Megamodels
MDA, RoSI-MA

Software Factory

Multi-TS Megamodel

Technical Space

Technical Space Bridges

Tool Engineering

Mega- and Macromodels

Model Management
Mapping, Transf., Composition

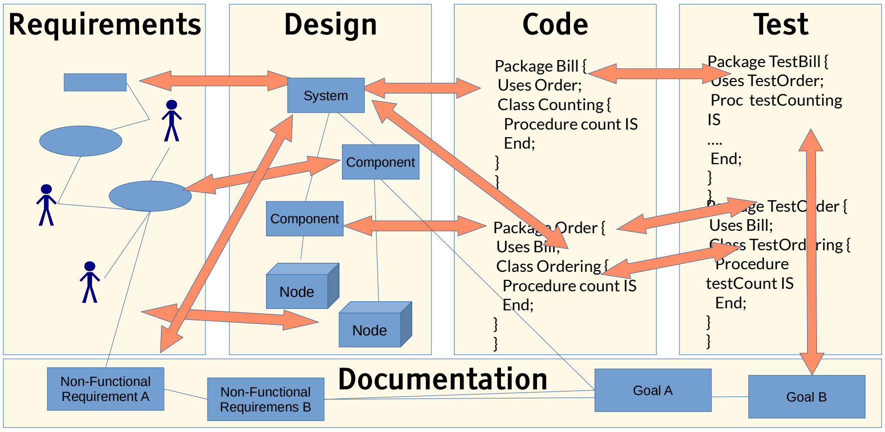
Model Analysis
Querying, Interpretation

Meta-modeling

Metapyramid (Metahierarchy) for Token Modeling

Q12: The ReDoDeCT Problem and its Macromodel

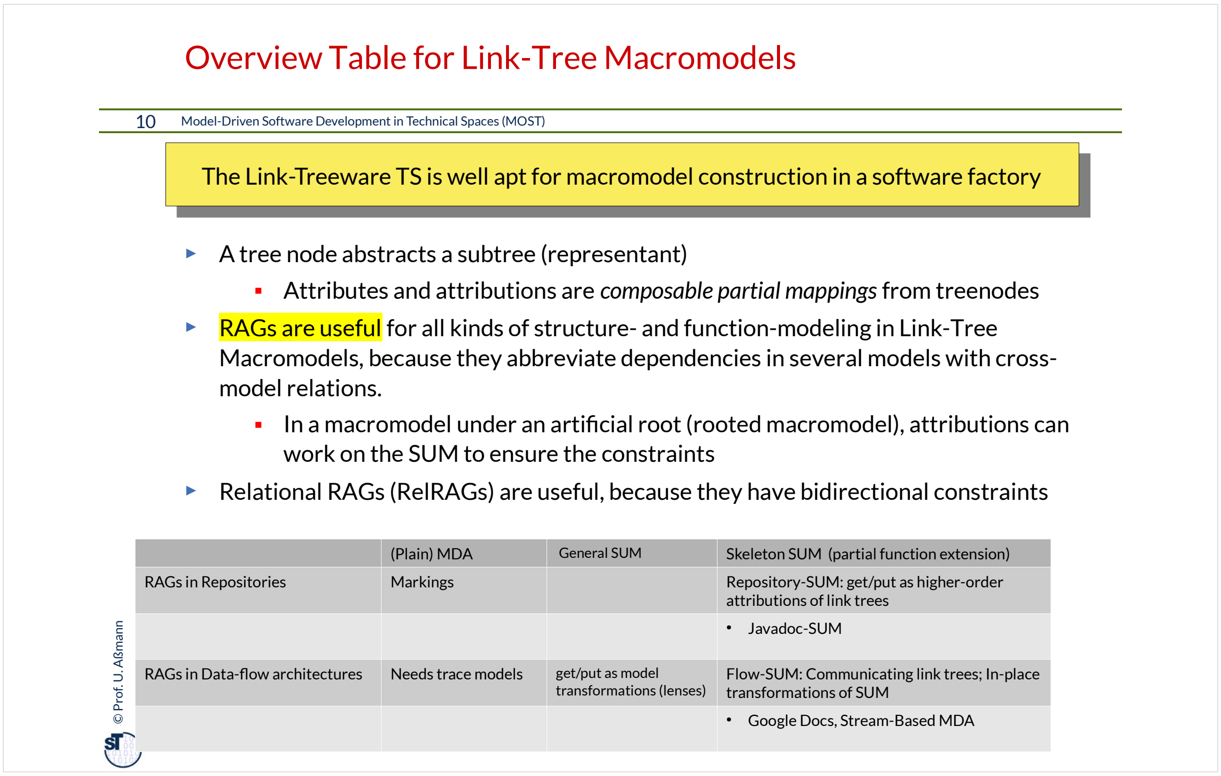
- The **ReDoDeCT problem** is the problem how requirements, documentation, design, code, and tests are related (→ V model)
- Mappings between the Requirements model, Documentation files, Design model, Code, Test cases
- A **ReDoDeCT macromodel** has maintained mappings between all 5 models



```
Package Bill {
 Uses Order;
 Class Counting {
  Procedure count IS
  End;
 }
}

Package Order {
 Uses Bill;
 Class Ordering {
  Procedure count IS
  End;
 }
}
```

```
Package TestBill {
 Uses TestOrder;
 Proc  testCounting
IS
....
 End;
}
}
Package TestOrder {
 Uses Bill;
 Class TestOrdering {
  Procedure
testCount IS
  End;
 }
}
```



Overview Table for Link-Tree Macromodels

The Link-Treeware TS is well apt for macromodel construction in a software factory

- A tree node abstracts a subtree (representant)
  - Attributes and attributions are *composable partial mappings* from treenodes
- RAGs are useful for all kinds of structure- and function-modeling in Link-Tree Macromodels, because they abbreviate dependencies in several models with cross-model relations.
  - In a macromodel under an artificial root (rooted macromodel), attributions can work on the SUM to ensure the constraints
- Relational RAGs (RelRAGs) are useful, because they have bidirectional constraints

	(Plain) MDA	General SUM	Skeleton SUM (partial function extension)
RAGs in Repositories	Markings		Repository-SUM: get/put as higher-order attributions of link trees
			• Javadoc-SUM
RAGs in Data-flow architectures	Needs trace models	get/put as model transformations (lenses)	Flow-SUM: Communicating link trees; In-place transformations of SUM
			• Google Docs, Stream-Based MDA

Other Examples form

•Olympic ring decomposition (EAI) marks all modules with “rings” and thereby decomposes them (course ST-1)

•VSUM (Reussner, Burger et al) generates dependent parts by create trace links

Model-Driven Software Development (MDSD) in 1 Technical Space

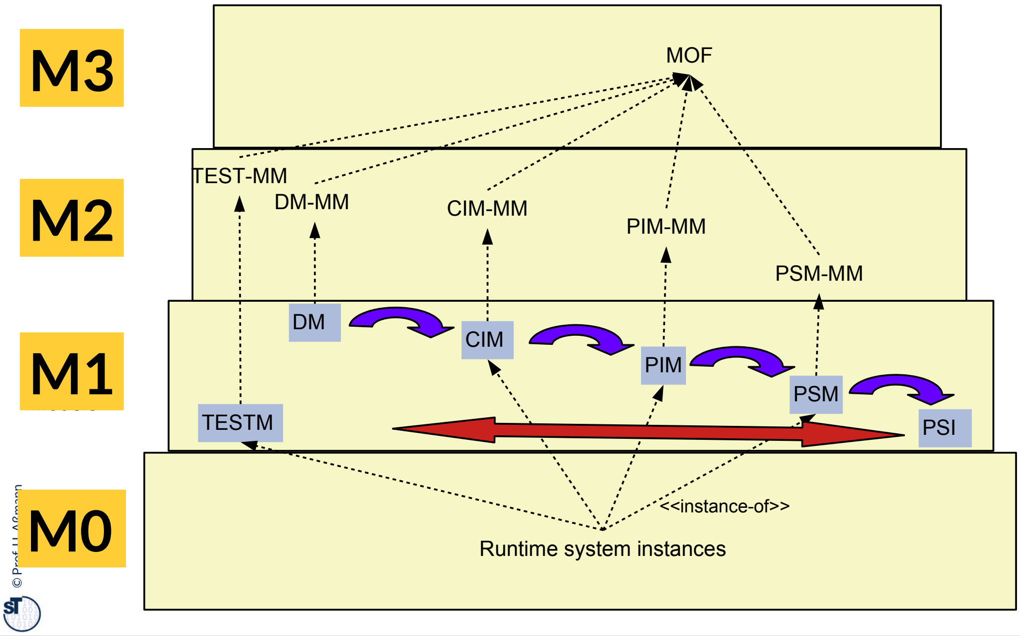
- **MDSD in 1-TS** falls into several main development methods with a macromodels:
  - Engineering with metamodels in ReDeCT-like megamodels (integrated software life-cycle management tools):
    - for integrated requirements, documentation, and testing along the life-cycle
    - Model-Driven Architecture (MDA) (MDA toolkits)
  - Engineering with DSL (domain-specific modeling, DSM) (Meta-CASE toolkits)
    - For simplifying the specification of domain-specific software
- **Model mappings** correlate models
  - capturing *reachability* informations (path abbreviations)
  - defining *trace* relations between model elements
  - From them, model transformations can easily be derived
- **Model transformations**
  - **Horizontal model transformations** transform a model within a single language
  - **Vertical model transformations** transform a model from a higher-level language to a lower-lewel language (**lowering**)
  - **Broadband model transformations (lowerings)** transform a model from a higher-level set into a lower-level set of a broadband (wide-spectrum) language
- **Model compositions** compose models with extensions
  - **Model weavings** extend models by other models and weave them together

Model-Driven Architecture (MDA)

- Model-Driven Architecture (MDA) is a macromodel similar to ReDoDECT, but distinguishes more models:
  - Platform-independent model (architectural)
  - Platform-specific model (in modeling language equivalent to coding language)
  - Platform-specific implmentation (in coding language)
- On the other hand, documentation is neglected :-(
- MDA uses *model mappings*, *horizontal and vertical model transformations*, as well as *code generation*

Transformations...

The MDA Megamodel, a Specific Variant of ReDoDeCT, Embedded in the MOF Metapyramid

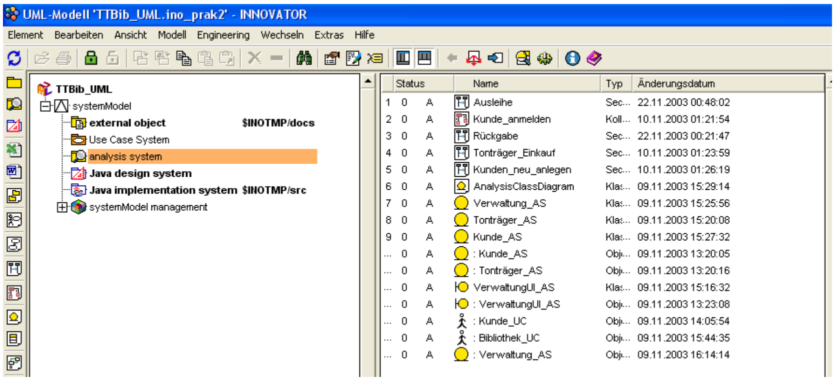


describing the situation in which the system will be used

A CIM is a model of a system that shows the system in the environment in which it will operate, and thus it helps in presenting exactly what the system is expected to do.

PIM and PSM and Model Mapping in MID INNOVATOR

- Innovator can specify transformations between its models [MID]



```
TTBib_UML
  systemModel
    external object              $INOTMP/docs
    Use Case System
    analysis system
    Java design system
    Java implementation system  $INOTMP/src
  systemModel management
```

	Status		Name	Typ	Änderungsdatum
1	0	A	Ausleihe	Sec...	22.11.2003 00:48:02
2	0	A	Kunde_anmelden	Koll...	10.11.2003 01:21:54
3	0	A	Rückgabe	Sec...	22.11.2003 00:21:47
4	0	A	Tonträger_Einkauf	Sec...	10.11.2003 01:23:59
5	0	A	Kunden_neu_anlegen	Sec...	10.11.2003 01:26:19
6	0	A	AnalysisClassDiagram	Klas...	09.11.2003 15:29:14
7	0	A	Verwaltung_AS	Klas...	09.11.2003 15:25:56
8	0	A	Tonträger_AS	Klas...	09.11.2003 15:20:08
9	0	A	Kunde_AS	Klas...	09.11.2003 15:27:32
...	0	A	: Kunde_AS	Obj...	09.11.2003 13:20:05
...	0	A	: Tonträger_AS	Obj...	09.11.2003 13:20:16
...	0	A	VerwaltungUI_AS	Klas...	09.11.2003 15:16:32
...	0	A	: VerwaltungUI_AS	Obj...	09.11.2003 13:23:08
...	0	A	: Kunde_UC	Obj...	09.11.2003 14:05:54
...	0	A	: Bibliothek_UC	Obj...	09.11.2003 15:44:35
...	0	A	: Verwaltung_AS	Obj...	09.11.2003 16:14:14

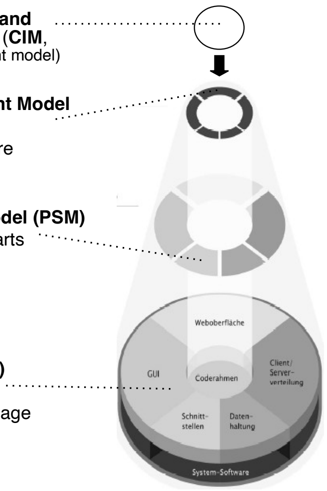
Example: PIM and PSM Extend the CIM in the Janus Toolkit

Domain model (DM) and requirements model (**CIM**, Computation independent model)

Platform-independent Model (PIM)
Application architecture

Platform-specific Model (PSM)
Specific applicaiton parts
Communication

Platform-specific Implementation (PSI)
Handwriten additions
in programming language



- In the MDA, there are **model mappings** between the models DM - CIM – PIM – PSM - PSI

Quelle: Warum JANUS MDA und MDA JANUS ist; Whitepaper der Firma otris Software AG Dortmund; URL: www.otris.de
http://pi.informatik.uni-siegen.de/stt/15_3/15_3_weg_01.gif

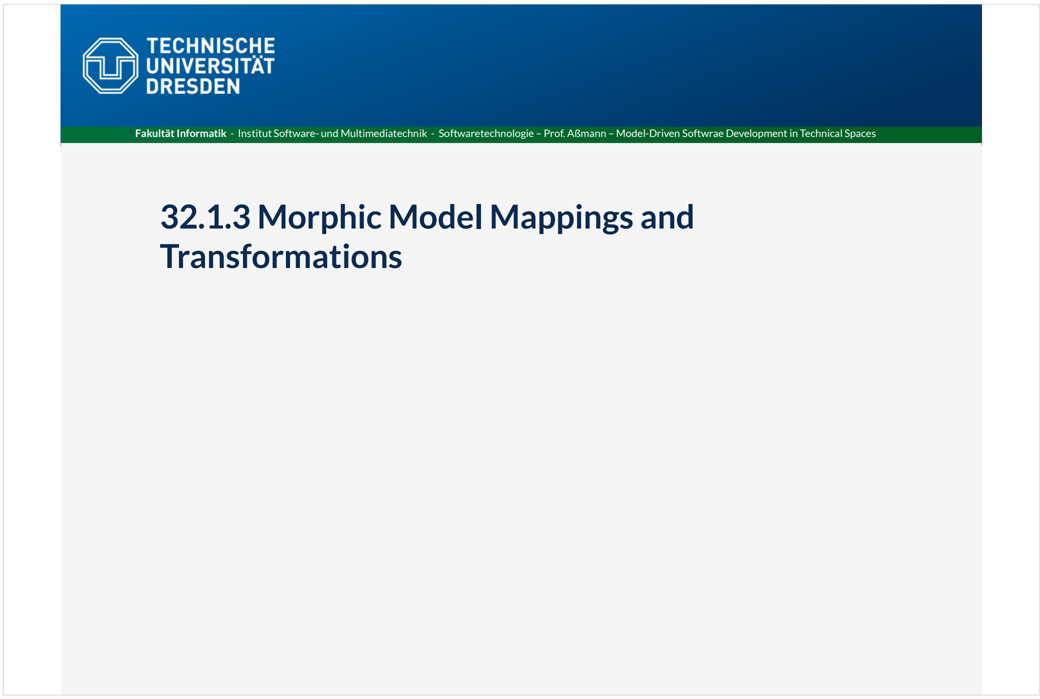
Model Management in Megamodels

- In the MDA megamodel,because MDA *enriches models from top to bottom*, the mappings between models must be maintained with a model algebra:
  - Model difference analysis (Diff, comm of models)
    - Version management
    - Konfiguration management
  - Model composition
    - Lookup and query of model elements
    - Union, compose, weave, unweave of models

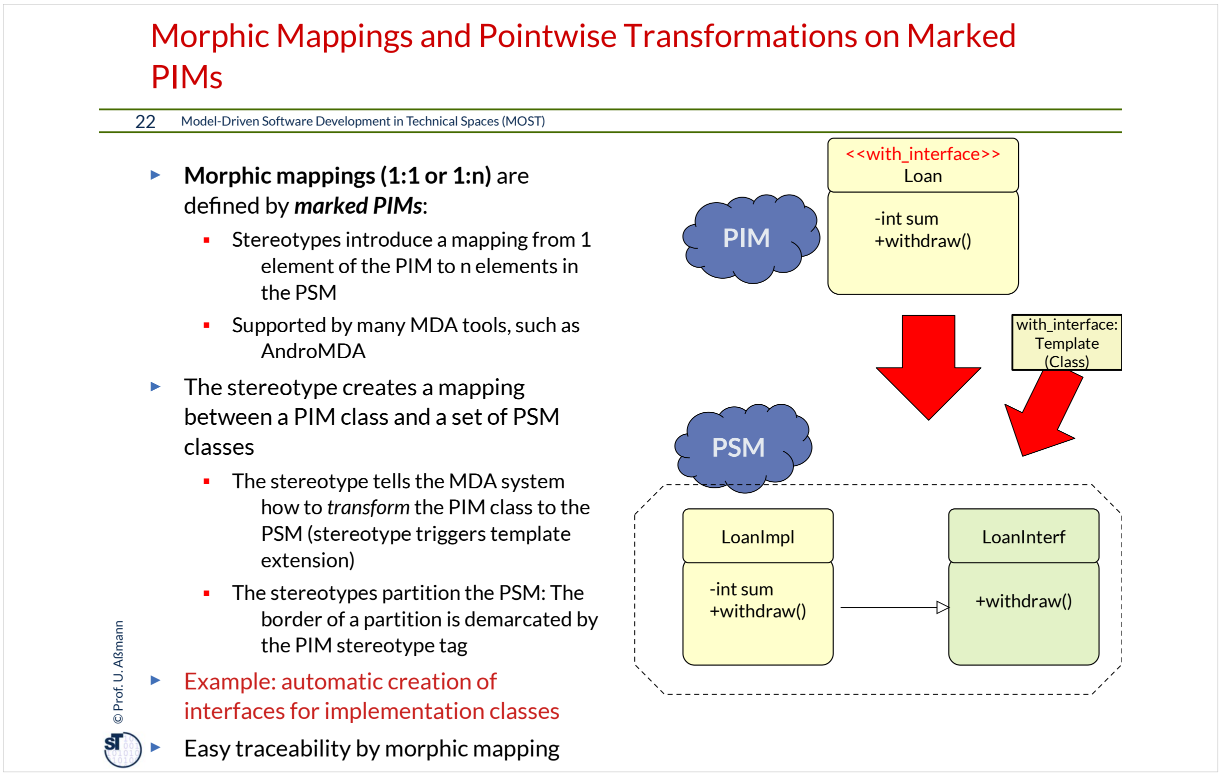
32.1.2 Different Forms of MDA

Different forms of MDA

- A ***transformative MDA*** uses refinement transformations for variation
    - introduces trace links (32.3)
- An MDA is called ***component-based (CoMDA)*** if the variation action is the exchange of an implementation behind an interface, or if the component model is used for exchange
    - RoSIMDA MDA (32.5)
- A ***transformative CoMDA*** uses point-wise refinement transformations on a model-based component model
    - for instance, refinements in Petrinets
        - combining trace links and component-based MDA (32.3 and 32.5)
- A **MDA-SUM** uses transformative or component-based MDA for realizing *views* on a *single underlying model (SUM)* (next chapter)



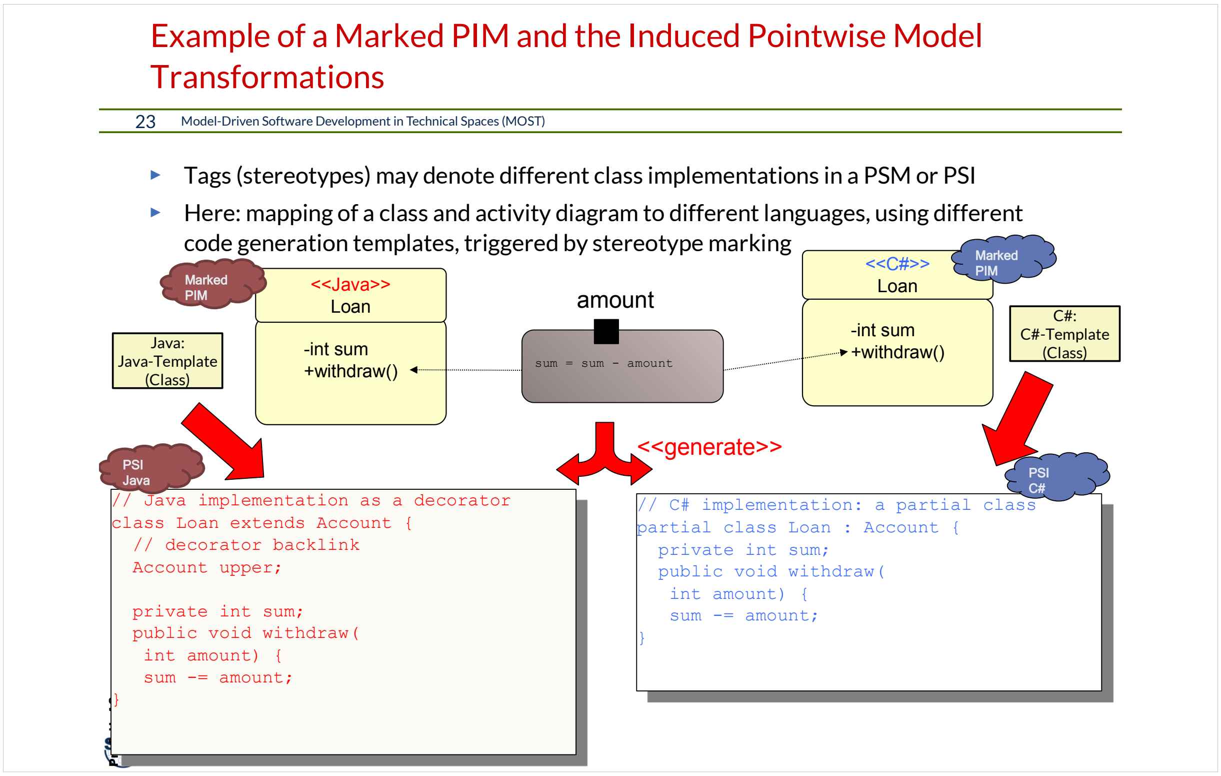
32.1.3 Morphic Model Mappings and Transformations



Morphic Mappings and Pointwise Transformations on Marked PIMs

- **Morphic mappings (1:1 or 1:n)** are defined by ***marked PIMs***:
  - Stereotypes introduce a mapping from 1 element of the PIM to n elements in the PSM
  - Supported by many MDA tools, such as AndroMDA
- The stereotype creates a mapping between a PIM class and a set of PSM classes
  - The stereotype tells the MDA system how to *transform* the PIM class to the PSM (stereotype triggers template extension)
  - The stereotypes partition the PSM: The border of a partition is demarcated by the PIM stereotype tag
- Example: automatic creation of interfaces for implementation classes
- Easy traceability by morphic mapping

Example: different class implementations of a connector class in a PIM



Example of a Marked PIM and the Induced Pointwise Model Transformations

- Tags (stereotypes) may denote different class implementations in a PSM or PSI
- Here: mapping of a class and activity diagram to different languages, using different code generation templates, triggered by stereotype marking

```
// Java implementation as a decorator
class Loan extends Account {
  // decorator backlink
  Account upper;

  private int sum;
  public void withdraw(
   int amount) {
   sum -= amount;
}
```

```
// C# implementation: a partial class
partial class Loan : Account {
  private int sum;
  public void withdraw(
   int amount) {
   sum -= amount;
}
```

1) Umarbeiten auf code models
2) Petri netze zeigen oder statecharts

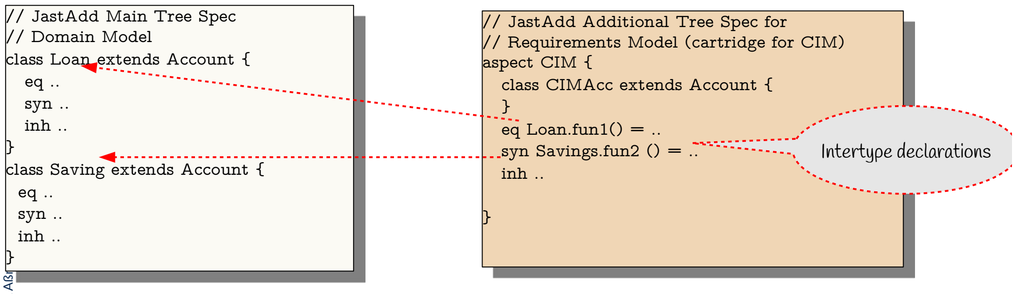
Cartridges are Transformation Libraries for Marked PIMs

- A **Cartridge** is a plugin to an MDA tool defining both the model mapping and the model transformation
  - For vertical and horizontal transformations
  - Definition of stereotypes for PIM markings in vertical transformations
    - Manual marking of the PIM
    - Selective transformation of the marked PIM classes
  - Automatic transformation using the mapping and transformations from the cartridge
    - No manual specifications of mappings and transformations necessary

32.1.4 Cartridges (Platform Extensions) in RAGs and JastAdd

RAG Modules Compose Extensions into CIM or PIM

- The basic module can be DM, DM+CIM, DM+CIM+PIM
  - Extensions are PSE, PSI
- Due to the declarativeness of attributions, modules can be unified by term (tree unification)
  - Names of the classes serve as unificator



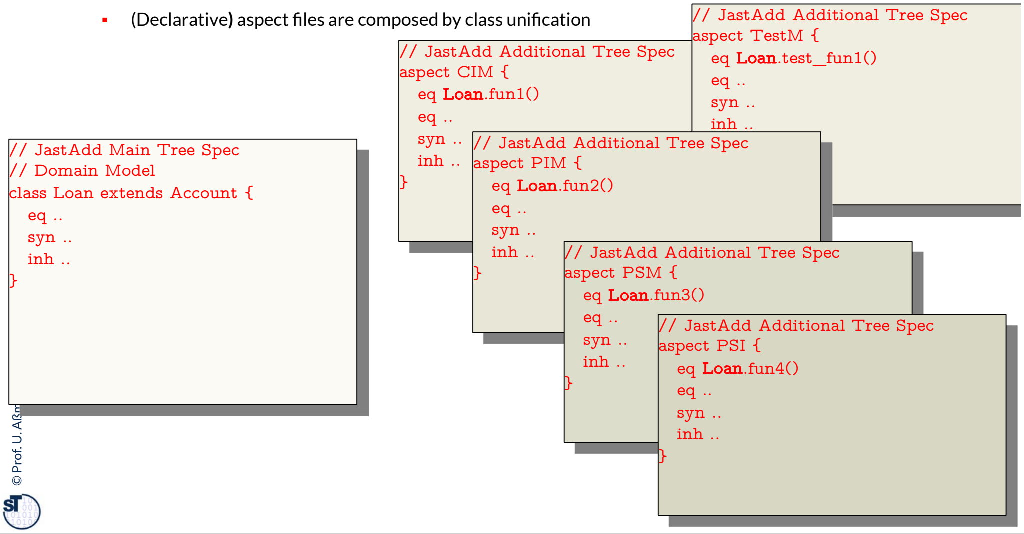
```
// JastAdd Main Tree Spec
// Domain Model
class Loan extends Account {
  eq ..
  syn ..
  inh ..
}
class Saving extends Account {
  eq ..
  syn ..
  inh ..
}
```

```
// JastAdd Additional Tree Spec for
// Requirements Model (cartridge for CIM)
aspect CIM {
  class CIMAcc extends Account {
  }
  eq Loan.fun1() = ..
  syn Savings.fun2 () = ..
  inh ..

}
```

Ex.: JastAdd Aspects are Cartridges

- A JastAdd Aspect, like a cartridge, extends a set of Main Tree Nodes and their attributions with new attributions [Hedin09]
  - *Intertype declarations* distribute a class definition over several files of MDA
  - (Declarative) aspect files are composed by class unification



```
// JastAdd Main Tree Spec
// Domain Model
class Loan extends Account {
  eq ..
  syn ..
  inh ..
}
```

```
// JastAdd Additional Tree Spec
aspect TestM {
  eq Loan.test_fun1()
  eq ..
  syn ..
  inh ..
```

```
// JastAdd Additional Tree Spec
aspect CIM {
  eq Loan.fun1()
  eq ..
  syn ..
  inh ..
}
```

```
// JastAdd Additional Tree Spec
aspect PIM {
  eq Loan.fun2()
  eq ..
  syn ..
  inh ..
}
```

```
// JastAdd Additional Tree Spec
aspect PSM {
  eq Loan.fun3()
  eq ..
  syn ..
  inh ..
}
```

```
// JastAdd Additional Tree Spec
aspect PSI {
  eq Loan.fun4()
  eq ..
  syn ..
  inh ..
}
```

MDA by Composition of RAG Aspects

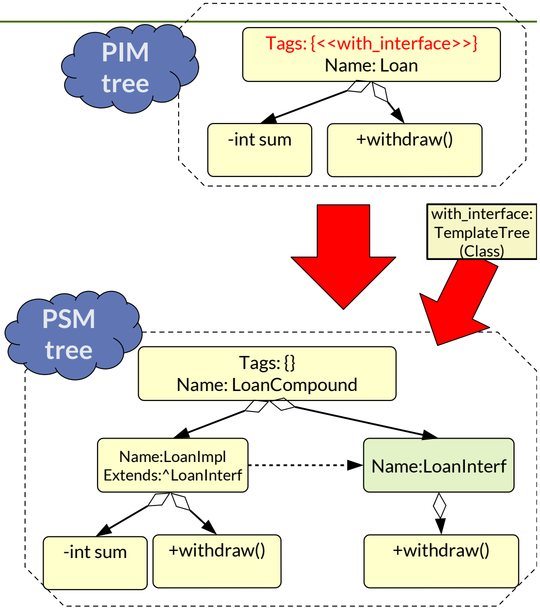
- RAG modules, e.g., JastAdd aspects, can be used as MDA cartridges
  - They compose class extensions “around” class names
  - Model weaving is done by class composition
  - Intertype declarations introduce “mixins” into classes of main syntax tree
- Model Refinement (in MDA) is done by modular composition (aspect composition) with intertype declarations
  - Model synchronisation is done by re-composition
  - RAG-MDA supports **composable macromodels**
- Model mappings achieved by common class names
  - Tracing is easy (common classes for extensions)

RAG modules, e.g., JastAdd aspects, can be used as MDA cartridges

32.1.5 Morphic Model Transformations in JastAdd

Morphic Transformations on Marked PIMs

- **Morphic mappings (1:1 or 1:n)** can be realized by JastAdd Rewrite operations or Term rewrite operations (Stratego, Xcerpt)
  - If Users add a stereotype to a node of a PIM
  - Rewrites can reduce them
- The rewrite is a replace operation of the marked node by its "implementation"
- Rewrite rule transforms redex of upper model to snippet in lower model
- Easy traceability by morphic mapping
- The PIM tree as well as the PSM tree are represented by the top node
- The PIM tree snippet and the PSM tree snippet are *homomorphic regions*



Example: different class implementations of a connector class in a PIM

32.2 MDA Toolkits

Some MDA Tools

	Integrated into	URL
AndroMDA	Eclipse	http://www.andromda.org/
XText, Xpand	Eclipse	http://www.eclipse.org/Xtext/
IBM Rational Suite Software Architect	Eclipse	
BITplan smart Generator	Eclipse	http://www.bitplan.com/
Epsilon	Eclipse	https://www.eclipse.org/epsilon/

[Petrasch, R., Meimberg, O.: Model Driven Architecture - eine praxisorientierte Einführung in die MDA; dpunkt-verlag 2006]

Important Features of MDA Toolkits

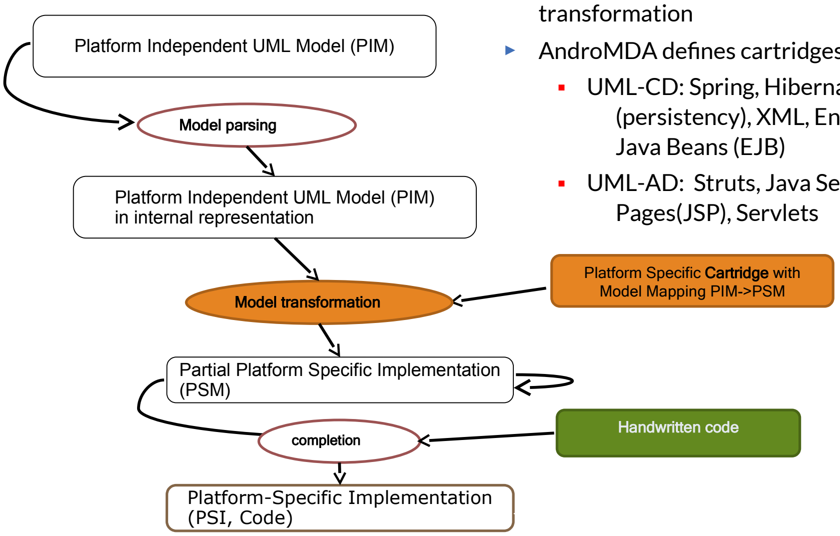
- **Model-to-Model Mapping** bzw. **Model-to-Model Transformation** (e.g., PIM to PSM) with cartridges
- **User definition of model transformation cartridges** with query and transformation languages
  - e.g., with QVT, ATL, Graph writing or XML Rewriting
- **Forward- und Reverse-Engineering**
  - Code generation (Model-to-Code Transformation, PSM to PSI)
    - Mapping to a programming language (e.g., with JMI)
- **Roundtrip-Engineering** between models and code
- **Single underlying model (SUM):** forming views by get and put operations
- **Model-driven Testing:** generation of test cases ad test data based on models

[Petrasch, R., Meimberg, O.: Model Driven Architecture - eine praxisorientierte Einführung in die MDA; dpunkt-verlag 2006]

32.2.1 AndroMDA, a Leading MDA Toolkit Focusing on PIM-PSM Transformations

[www.androMDA.org]

- AndroMDA defines model mappings in platform-specific cartridges.


Platform Independent UML Model (PIM)
Model parsing
Platform Independent UML Model (PIM) in internal representation
Model transformation
Platform Specific Cartridge with Model Mapping PIM->PSM
Partial Platform Specific Implementation (PSM)
completion
Handwritten code
Platform-Specific Implementation (PSI, Code)

- A cartridge contains a mapping from UML to e.g., Java, C# or C++ and a model transformation
- AndroMDA defines cartridges for
  - UML-CD: Spring, Hibernate (persistency), XML, Enterprise Java Beans (EJB)
  - UML-AD: Struts, Java Server Pages(JSP), Servlets

32.2.2 MDA Toolkit ArcStyler

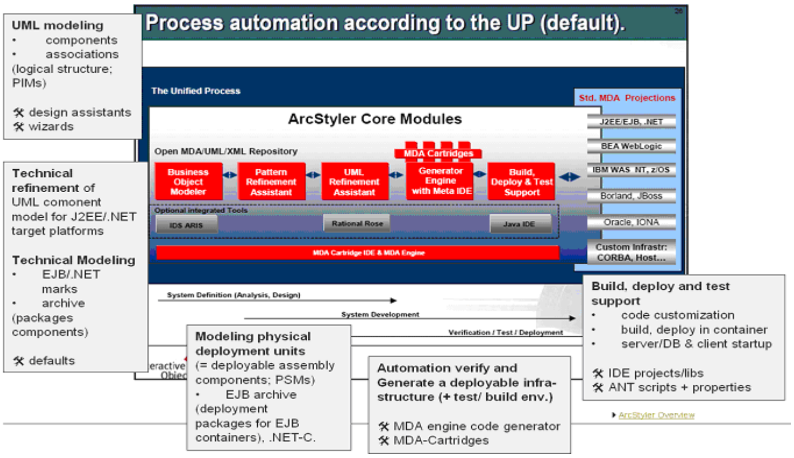
ArcStyler is a toolkit working with several UML-editors such as MagicDraw or Rational Rose

- Cartridges for model mappings and transformations
- **Object Modeler** for requirements modeling; based on CRC-Cards
- **Pattern Refinement Assistant** transforms the domain model interactively into a PIM UML-model (with MagicDraw or Rational Rose)
  - With annotation of design decisions
- **Refinement of the PIM**
  - Horizontal refinement on PIM level
  - Vertical transformation to PSM or PSI (code generation)
- **Code completion (Codevervollständigung)** and optimization for an application platform
- **Component generation** for user interface
- Generation for build tools
- Generation for database persistency

http://www.software-kompetenz.de/servlet/is/27460/?print=true

Versteegen, G.: Wege aus der Plattformabhängigkeit - Hoffnungsträger Model Driven Architecture; Computerwoche 29(2002) Nr. 5 vom 1. Febr. 2002

Process Engineering with ArcStyler


Process automation according to the UP (default).
The Unified Process
Std. MDA Projections
ArcStyler Core Modules
Open MDA/UML/XML Repository
MDA Cartridges
Business Object Modeler
Pattern Refinement Assistant
UML Refinement Assistant
Generator Engine with Meta IDE
Build, Deploy & Test Support
Optional integrated Tools
IDS ARIS
Rational Rose
Java IDE
MDA Cartridge IDE & MDA Engine
J2EE/EJB, .NET
BEA WebLogic
IBM WAS NT, z/OS
Borland, JBoss
Oracle, IONA
Custom Infrastr: CORBA, Host...
System Definition (Analysis, Design)
System Development
Verification / Test / Deployment
ArcStyler Overview

UML modeling
- components
- associations

(logical structure; PIMs)

⚒ design assistants
⚒ wizards

Technical refinement of UML comonent model for J2EE/.NET target platforms

Technical Modeling
- EJB/.NET marks
- archive

(packages components)

⚒ defaults

Modeling physical deployment units
(= deployable assembly components; PSMs)
- EJB archive

(deployment packages for EJB containers), .NET-C.

Automation verify and Generate a deployable infra-structure (+ test/ build env.)

⚒ MDA engine code generator
⚒ MDA-Cartridges

Build, deploy and test support
- code customization
- build, deploy in container
- server/DB & client startup

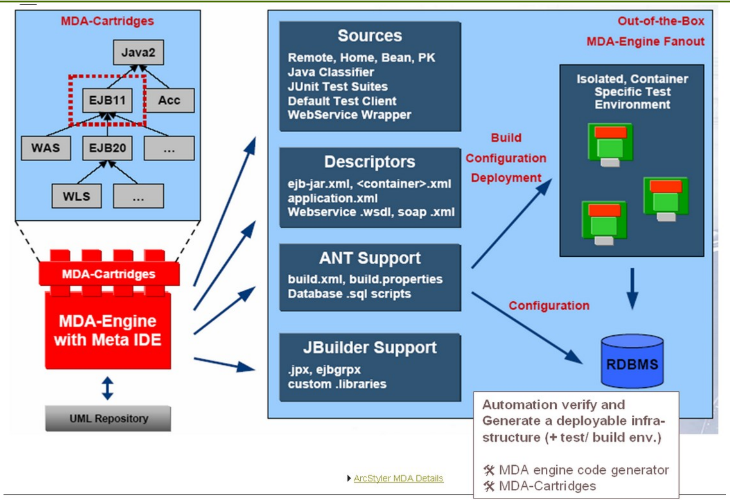
⚒ IDE projects/libs
⚒ ANT scripts + properties

https://www.omg.org/mda/mda_files/P2A_Tutorial.pdf

http://www.interactive-objects.com/products/arcstyler/supportdocumentation.html

http://arcstyler.software.informer.com/

Cartridges and Generated Artifacts



MDA-Cartridges

Java2

EJB11

Acc

WAS

EJB20

...

WLS

...

MDA-Cartridges

MDA-Engine with Meta IDE

UML Repository

Sources

Remote, Home, Bean, PK
Java Classifier
JUnit Test Suites
Default Test Client
WebService Wrapper

Descriptors

ejb-jar.xml, <container>.xml
application.xml
Webservice .wsdl, soap .xml

ANT Support

build.xml, build.properties
Database .sql scripts

JBuilder Support

.jpx, ejbgrpx
custom .libraries

Out-of-the-Box
MDA-Engine Fanout

Build
Configuration
Deployment

Isolated, Container Specific Test Environment

Configuration

RDBMS

Automation verify and Generate a deployable infra-structure (+ test/ build env.)

🛠 MDA engine code generator
🛠 MDA-Cartridges

ArcStyler MDA Details

Quelle: Butze, D.: Entwicklung eines Praktikums für die werkzeuggestützte Softwareentwicklung nach der Model-Driven-Architecture; Großer Beleg an der Fakultät Informatik der TU Dresden 2004

32.3 Traceability between Models

- Model transformations generate trace mappings

omitted in 2021/22

Advantages of Model Mappings

- **Error tracing**
  - When an error occurs during testing or runtime, we want to trace back the error to a design element or requirements element
- **Traceability**
  - We want to know which requirement (feature) influences which design, code, and test elements, so that we can demarcate modules in the solution space (product line development)
- **Synchronization in Development:**
  - Two models are called **synchronized**, if the change of one of them leads automatically to a hot-update of the other
- **Cohesion of Distributed Information:**
  - Two related model elements may contain distributed information about a thing. The relation allows for reconstructing the full information
  - Example:
    - Storing two roles of an object in two different models (See “Amoeba Object Pattern”)
    - Splitting the representation of the requirements on an object and its design in requirements vs design model

Different Forms of Model Mappings

- **Directly specified mappings** specify a deterministic mapping function between a source and target model.
  - Direct mappings are specified in GUI or text files
  - Direct mappings may be ***complete*** or ***incomplete***
- **Recursive mappings** are defined in a functional language
  - **Denotational semantics** is a complete direct mapping of two languages
  - The **coverage** of the source model must be ensured (completeness of specification)
- **General mappings** may be intensionally specified. Source and target models are mapped
  - With graph reachability expressions (QVT-R, TgreQL, EARS)
  - With query expressions (Semmle.QL)
  - With expressions in a logic (F-Datalog)
- **Inter-model mappings** are defined between model elements of different models
- **Lifted inter-model mappings** are lifted from intra-model element mappings

Why Traceability in a Macromodel?

[Grammel]

System Comprehension:

  - Trace mappings improve orientation in multimodels by navigating via trace links along model transformation chains

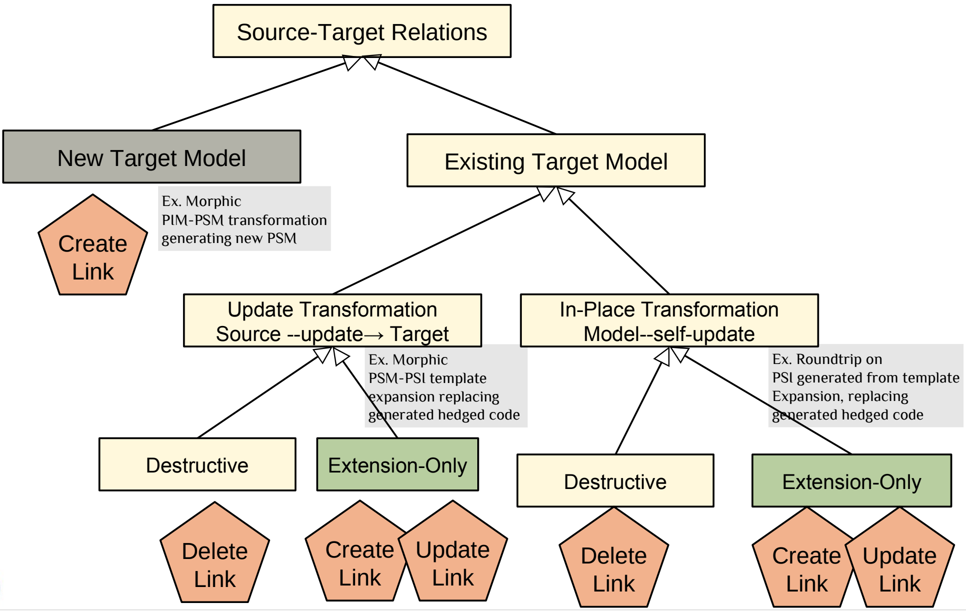
- **Change Impact Analysis**:
  - to analyze the impact of a model change on other models
  - to analyze the impact of a model change on existing *generated* or *transformed* output
  - To enable to do model synchronization (hot updating dependent parts)
- **Orphan Analysis:** finding orphaned elements in models

Validation and Verification:

- **System Validation:** Connecting the requirements with the customer's goals and problems (see ZOPP method)
- **(Test) Coverage analysis**: to determine whether all requirements were covered by test cases in the development life cycle
- **Debugging**: To locate bugs when tracing code back to requirements
  - To locate bugs during the development of transformation programs

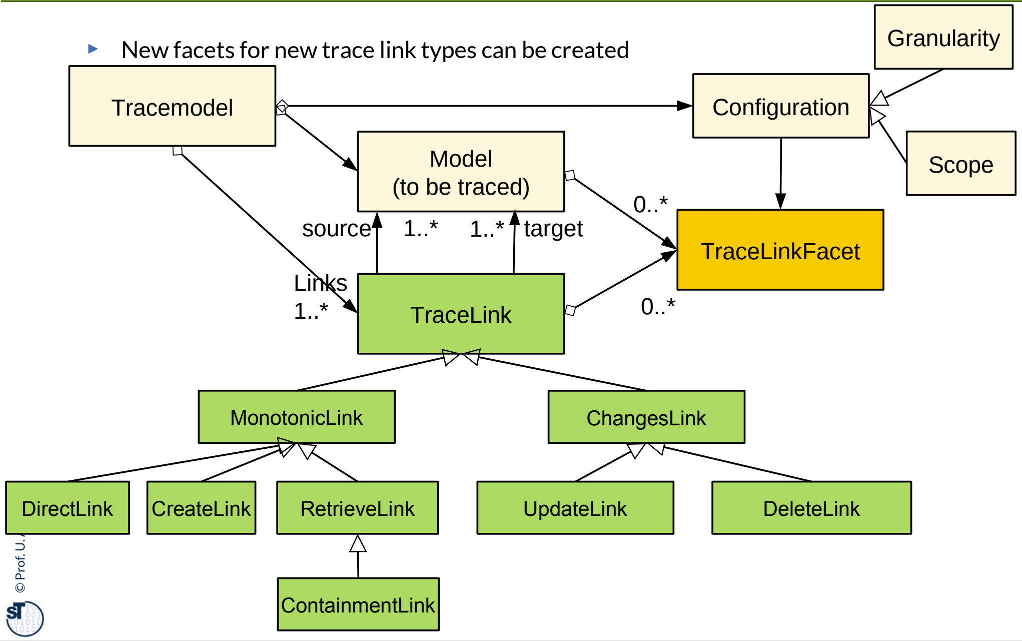
Traceability Metamodel: CRUD Types of Trace Links between Model Elements of Different Models

[Grammel]



Extensible Traceability Metamodel acc. to Grammel

- New facets for new trace link types can be created



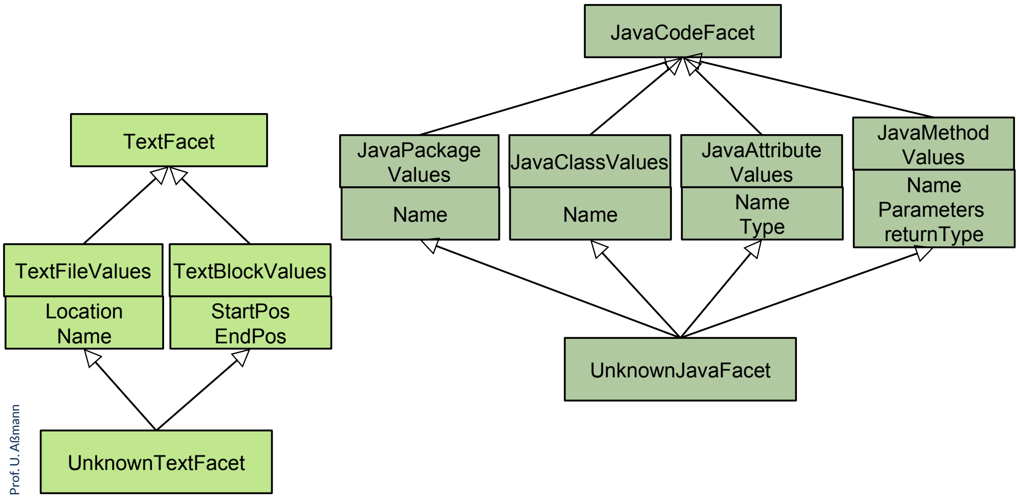
Traceability in Macromodels

- Piecemeal growth of macromodels in the software process:
  - Start with requirements, then add more stuff and models
- **Add links**
  - **Symmetric "Direct" (auto-drawn) links** are drawn between model element MA from model A and model element MB whenever MB is related to MA
    - Specified by hand or found by a model difference, model analysis or a model query
  - **Create links** are drawn between model element MA from model A and model element MB whenever MB is generated or added because of MA
  - **Retrieve links** are drawn when MB is extracted (queried) from a model A and added to another model B
  - **Containment links** are drawn, when in a new model B the model element MA is contained in another model element MB'
  - **Delete links** are drawn if In model B the model element MB should be deleted
  - **Update links** are drawn if MA has changed and MB should be changed too

Examples for TraceLinkFacet

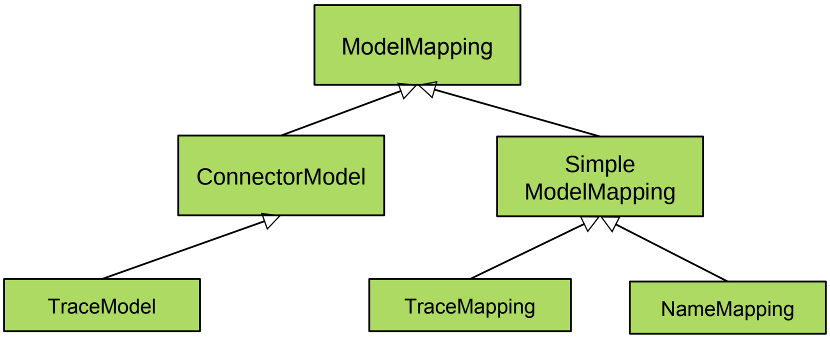
[Grammel]

- Facets factorize inheritance hierarchies; new facets extend inheritance hierarchies



Different Kinds of Trace Models

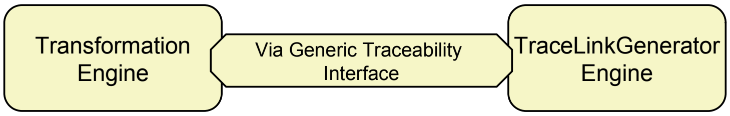
- So far, trace mappings were realized as associations in a **simple model mapping**
- The trace metamodel can be extended to describe a ***trace model***, a specific form of ***connector model***

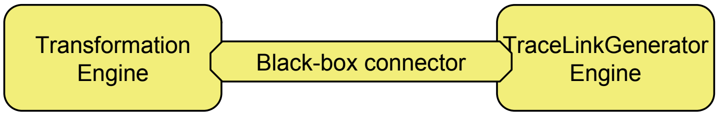


Adding a Trace Link Generator to Tools

[Grammel]

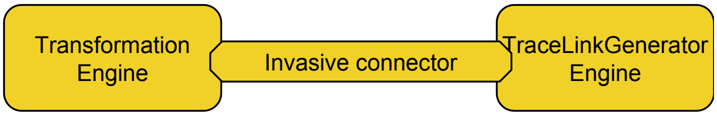
- TraceLinkGenerators for Trace Models must be written by hand
- They can be connected to transformation engines and cartriges in three ways, following a ***generic traceability interface***:





Transformation engine must know and call the generator

Transformation engine need not know but is extended Invasively or woven By AOP

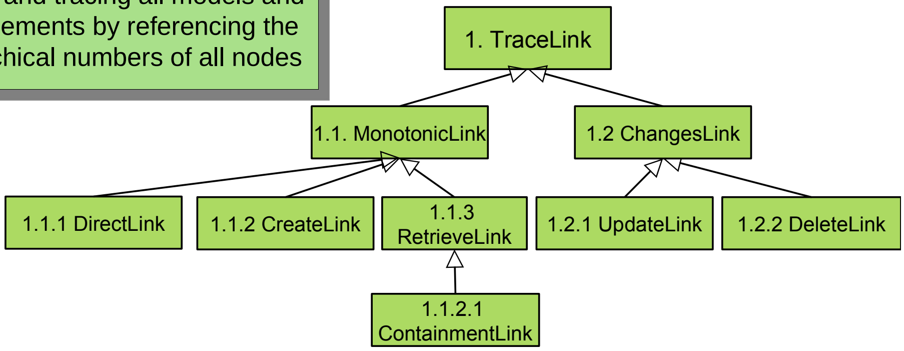


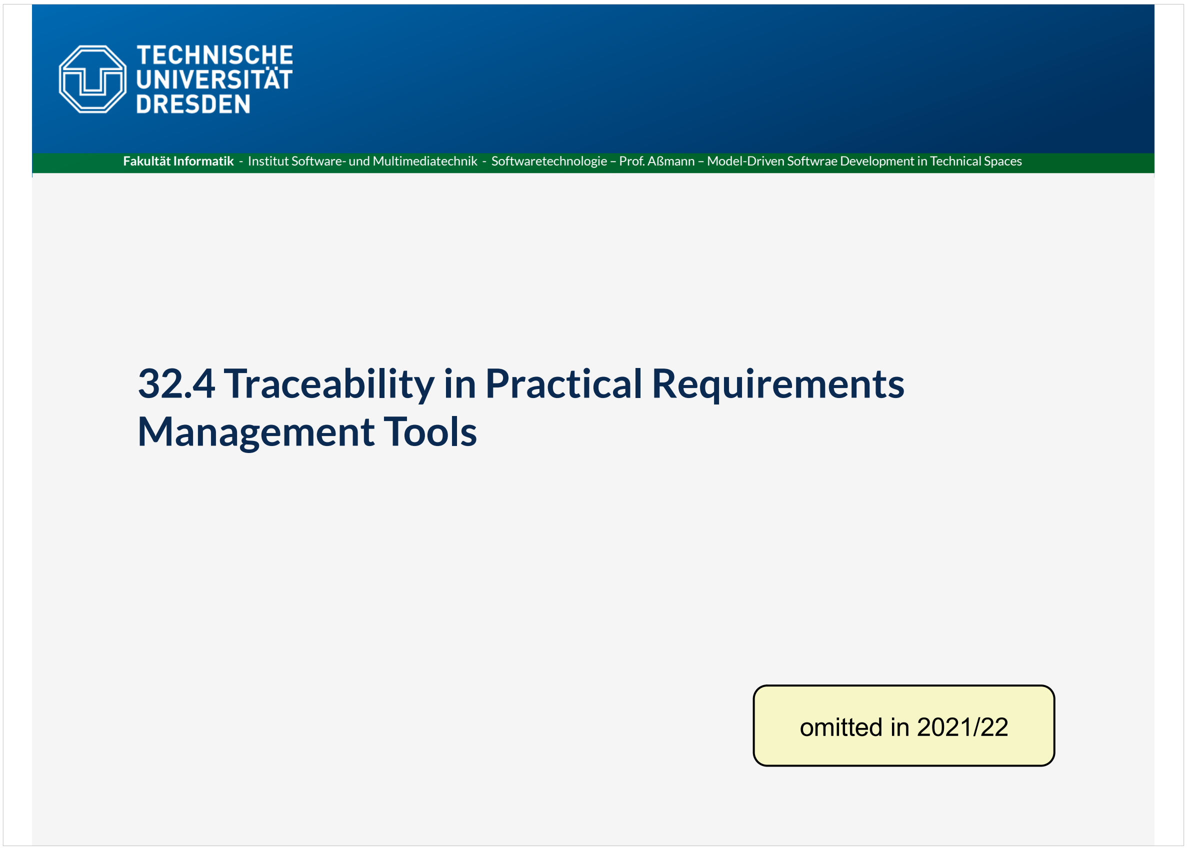
Traceability in Macromodels with Models from Link-Treeware

- In link-tree models, a skeleton tree exists, in which every model element has a unique *tree node number (hierarchical number)*
- Trace links can be added with tree node number and stored externally of the model *in the macromodel*

In link-treeware, macromodels maintain *trace(link) models* linking and tracing all models and their elements by referencing the hierarchical numbers of all nodes

Hierarchical numbering of the classes in an inheritance tree:



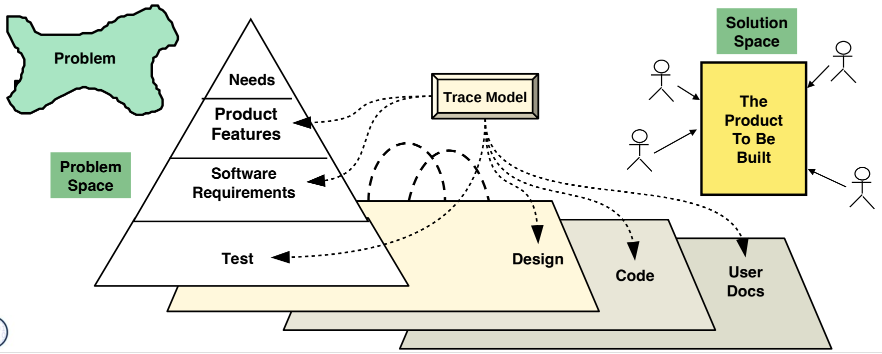


32.4 Traceability in Practical Requirements Management Tools

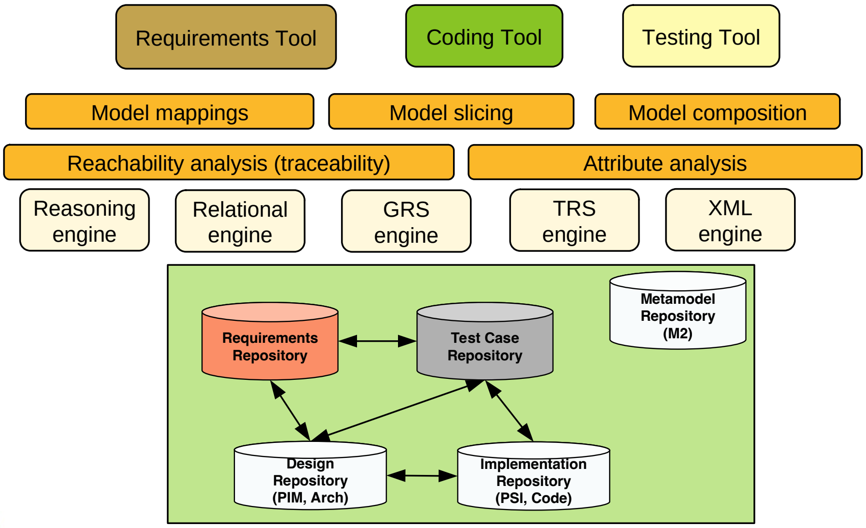
omitted in 2021/22

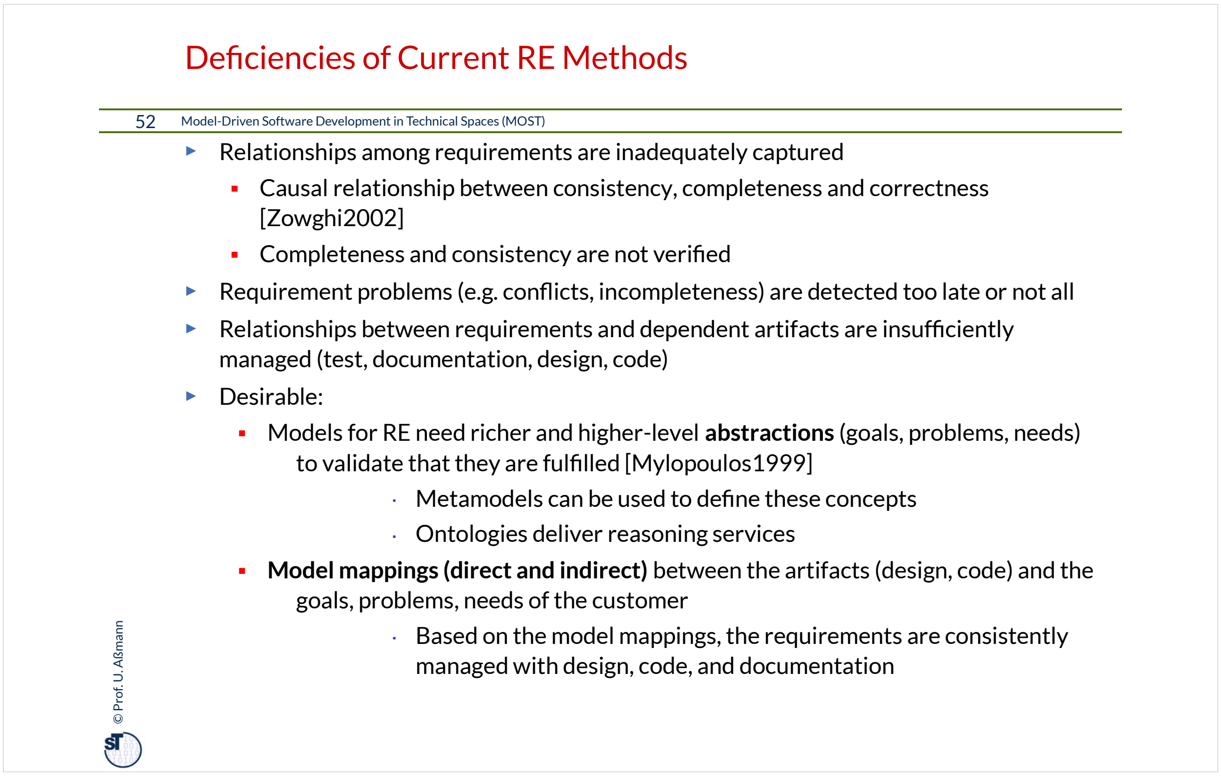
Introduction to Requirements Management (RM)

- RM bridges the needs of the customer to testing, design, coding, and documentation
- RM continuously manages requirements in the entire software life cycle
- RM relies on inter-model mappings between requirements, test cases, design, and code



Tools in an Integrated Development Environment (IDE)





Deficiencies of Current RE Methods

- Relationships among requirements are inadequately captured
  - Causal relationship between consistency, completeness and correctness [Zowghi2002]
  - Completeness and consistency are not verified
- Requirement problems (e.g. conflicts, incompleteness) are detected too late or not all
- Relationships between requirements and dependent artifacts are insufficiently managed (test, documentation, design, code)
- Desirable:
  - Models for RE need richer and higher-level **abstractions** (goals, problems, needs) to validate that they are fulfilled [Mylopoulos1999]
    - Metamodels can be used to define these concepts
    - Ontologies deliver reasoning services
  - **Model mappings (direct and indirect)** between the artifacts (design, code) and the goals, problems, needs of the customer
    - Based on the model mappings, the requirements are consistently managed with design, code, and documentation

Requirement knowledge is not sufficiently covered: Intentions, risks, obstacles and decisions are not documented during RE and thus, are not available at later stages during software development.

Relationships among requirements are inadequately covered: requirements instead of defining which kind of relation is meant (e.g. excluding, alternative, generalization).

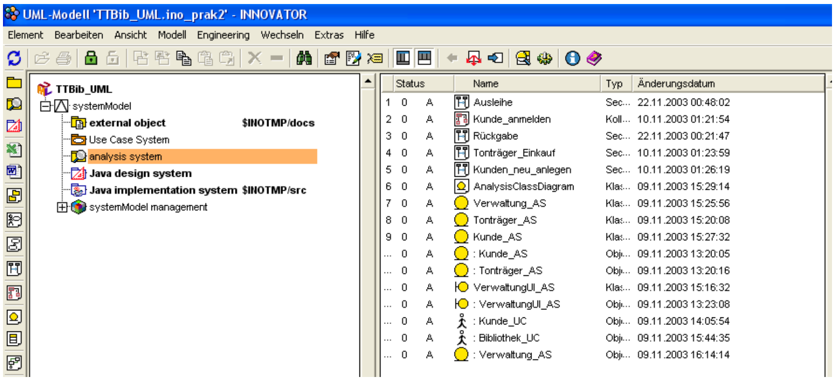
vicious circle of completeness, correctness and consistency (Zowghi et. Al)

Zowghi et. al. ([3]) describes this **vicious circle** as a causal relationship between consistency, completeness and correctness. From a formal point of view, correctness is usually meant to be the combination of consistency and completeness. Therefore, the ability to detect and repair inconsistent and incomplete requirements is crucial to the successful development of requirements specications

Complete metadata for requirements, that is data about that requirement rather than data listed in the requirement [6]), ensure completeness. Though current RE tools provide means for capturing requirements, they fail in providing sufficient support for metadata about requirements and leave it to the requirements engineer to define them. Another shortcoming of RE tools is the lack of tests for completeness, that is, checking whether all important metadata are available. This way, the requirement engineer would detect missing but relevant information easily.

Model Mapping in MID INNOVATOR

- Innovator can be employed simultaneously for requirements, design and implementation models
- How to relate these models?



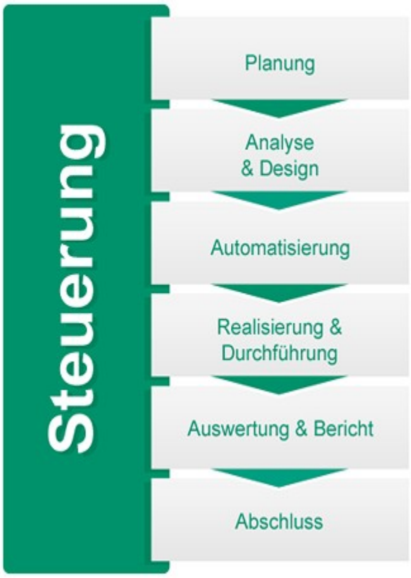
TTBib_UML
- systemModel
  - external object $INOTMP/docs
  - Use Case System
  - analysis system
  - Java design system
  - Java implementation system $INOTMP/src
  - systemModel management

	Status		Name	Typ	Änderungsdatum
1	0	A	Ausleihe	Sec...	22.11.2003 00:48:02
2	0	A	Kunde_anmelden	Koll...	10.11.2003 01:21:54
3	0	A	Rückgabe	Sec...	22.11.2003 00:21:47
4	0	A	Tonträger_Einkauf	Sec...	10.11.2003 01:23:59
5	0	A	Kunden_neu_anlegen	Sec...	10.11.2003 01:26:19
6	0	A	AnalysisClassDiagram	Klas...	09.11.2003 15:29:14
7	0	A	Verwaltung_AS	Klas...	09.11.2003 15:25:56
8	0	A	Tonträger_AS	Klas...	09.11.2003 15:20:08
9	0	A	Kunde_AS	Klas...	09.11.2003 15:27:32
...	0	A	: Kunde_AS	Obj...	09.11.2003 13:20:05
...	0	A	: Tonträger_AS	Obj...	09.11.2003 13:20:16
...	0	A	VerwaltungUI_AS	Klas...	09.11.2003 15:16:32
...	0	A	: VerwaltungUI_AS	Obj...	09.11.2003 13:23:08
...	0	A	: Kunde_UC	Obj...	09.11.2003 14:05:54
...	0	A	: Bibliothek_UC	Obj...	09.11.2003 15:44:35
...	0	A	: Verwaltung_AS	Obj...	09.11.2003 16:14:14

Direct Traceability

- With a **direct model mapping**, a requirements model can be linked
  - to a test case specification
  - to a documentation
  - to an architectural specification
  - via the architectural specification, to the classes and procedures in the code

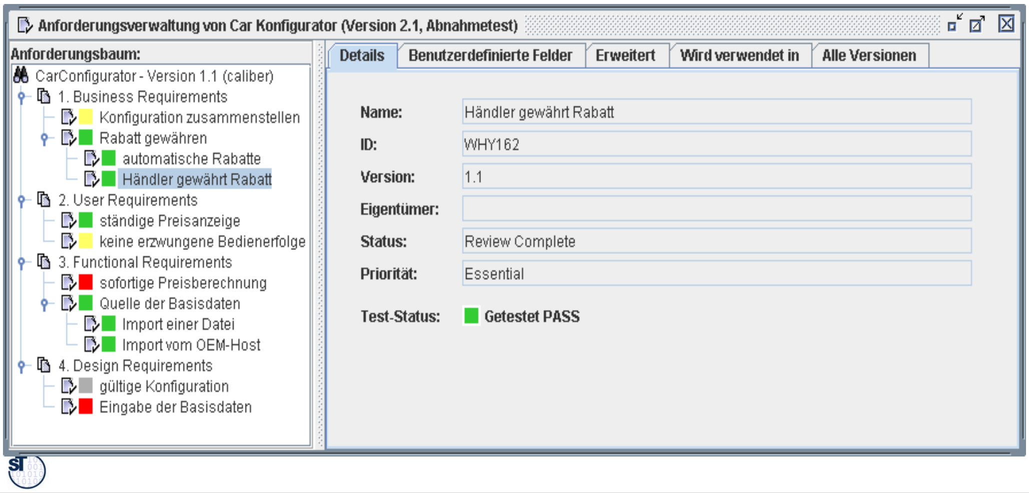
Example: imbus TestBench



http://www.imbus.de/produkte/imbus-testbench/hauptfunktionen/

Requirements get “red-yellow-green” Test Status Attribute

- Test status is an attribute in the requirements tree that contains a **direct link** to the result of a corresponding test case



Anforderungsverwaltung von Car Konfigurator (Version 2.1, Abnahmetest)

Anforderungsbaum:

- CarConfigurator - Version 1.1 (caliber)
  - 1. Business Requirements
    - 🟨 Konfiguration zusammenstellen
    - 🟩 Rabatt gewähren
      - 🟩 automatische Rabatte
      - 🟩 Händler gewährt Rabatt
  - 2. User Requirements
    - 🟩 ständige Preisanzeige
    - 🟨 keine erzwungene Bedienerfolge
  - 3. Functional Requirements
    - 🟥 sofortige Preisberechnung
    - 🟩 Quelle der Basisdaten
      - 🟩 Import einer Datei
      - 🟩 Import vom OEM-Host
  - 4. Design Requirements
    - ⬜ gültige Konfiguration
    - 🟥 Eingabe der Basisdaten

Name: Händler gewährt Rabatt

ID: WHY162

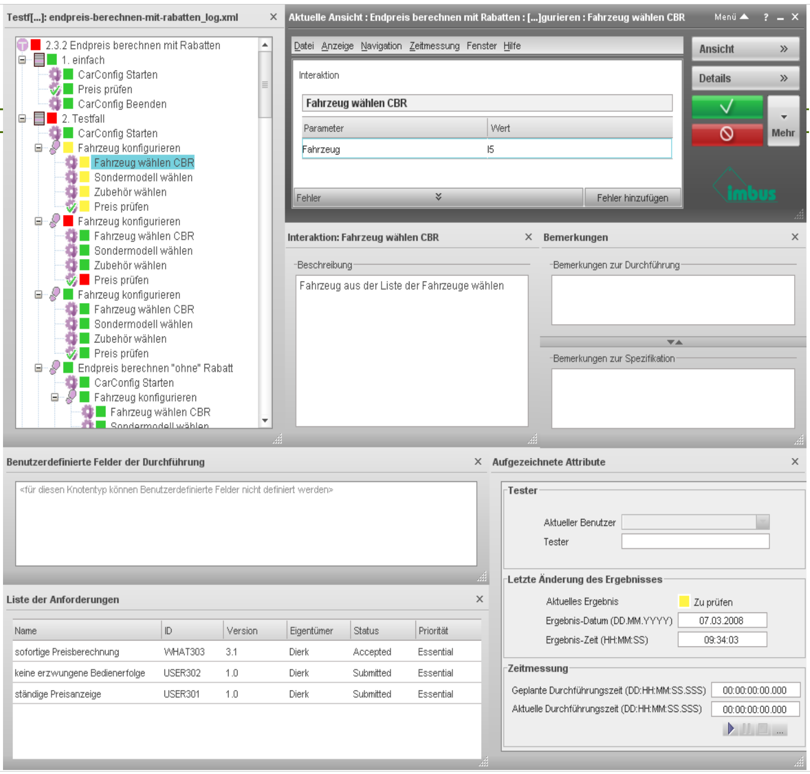
Version: 1.1

Eigentümer:

Status: Review Complete

Priorität: Essential

Test-Status: 🟩 Getestet PASS


Testf[...]: endpreis-berechnen-mit-rabatten_log.xml
Aktuelle Ansicht : Endpreis berechnen mit Rabatten : [...]gurieren : Fahrzeug wählen CBR
Menü
Datei
Anzeige
Navigation
Zeitmessung
Fenster
Hilfe
Ansicht »
Details »
Mehr
Fehler
Fehler hinzufügen
imbus
Interaktion: Fahrzeug wählen CBR
Bemerkungen
Benutzerdefinierte Felder der Durchführung
Liste der Anforderungen
Aufgezeichnete Attribute

- 🟥 2.3.2 Endpreis berechnen mit Rabatten
  - 🟩 1. einfach
    - 🟩 CarConfig Starten
    - 🟩 Preis prüfen
    - 🟩 CarConfig Beenden
  - 🟥 2. Testfall
    - 🟩 CarConfig Starten
    - 🟨 Fahrzeug konfigurieren
      - 🟨 Fahrzeug wählen CBR
      - 🟨 Sondermodell wählen
      - 🟨 Zubehör wählen
      - 🟨 Preis prüfen
    - 🟥 Fahrzeug konfigurieren
      - 🟩 Fahrzeug wählen CBR
      - 🟩 Sondermodell wählen
      - 🟩 Zubehör wählen
      - 🟥 Preis prüfen
    - 🟩 Fahrzeug konfigurieren
      - 🟩 Fahrzeug wählen CBR
      - 🟩 Sondermodell wählen
      - 🟩 Zubehör wählen
      - 🟩 Preis prüfen
    - 🟩 Endpreis berechnen "ohne" Rabatt
      - 🟩 CarConfig Starten
      - 🟩 Fahrzeug konfigurieren
        - 🟩 Fahrzeug wählen CBR
        - 🟩 Sondermodell wählen

Interaktion

Fahrzeug wählen CBR

Parameter	Wert
Fahrzeug	I5

Beschreibung

Fahrzeug aus der Liste der Fahrzeuge wählen

Bemerkungen zur Durchführung

Bemerkungen zur Spezifikation

<für diesen Knotentyp können Benutzerdefinierte Felder nicht definiert werden>

Name	ID	Version	Eigentümer	Status	Priorität
sofortige Preisberechnung	WHAT303	3.1	Dierk	Accepted	Essential
keine erzwungene Bedienerfolge	USER302	1.0	Dierk	Submitted	Essential
ständige Preisanzeige	USER301	1.0	Dierk	Submitted	Essential

Tester

Aktueller Benutzer:

Tester:

Letzte Änderung des Ergebnisses

Aktuelles Ergebnis: 🟨 Zu prüfen

Ergebnis-Datum (DD.MM.YYYY): 07.03.2008

Ergebnis-Zeit (HH:MM:SS): 09:34:03

Zeitmessung

Geplante Durchführungszeit (DD:HH:MM:SS.SSS): 00:00:00:00.000

Aktuelle Durchführungszeit (DD:HH:MM:SS.SSS): 00:00:00:00.000

Direct Model Mappings between Requirements and Test Tools

- Most often, these tools are in Link-treeware (hierarchical requirements, hierarchical test cases and test suites)
- → The trace models can be stored externally in the megamodel
  - Every trace link refers to link-tree node numbers in the requirements and test specifications

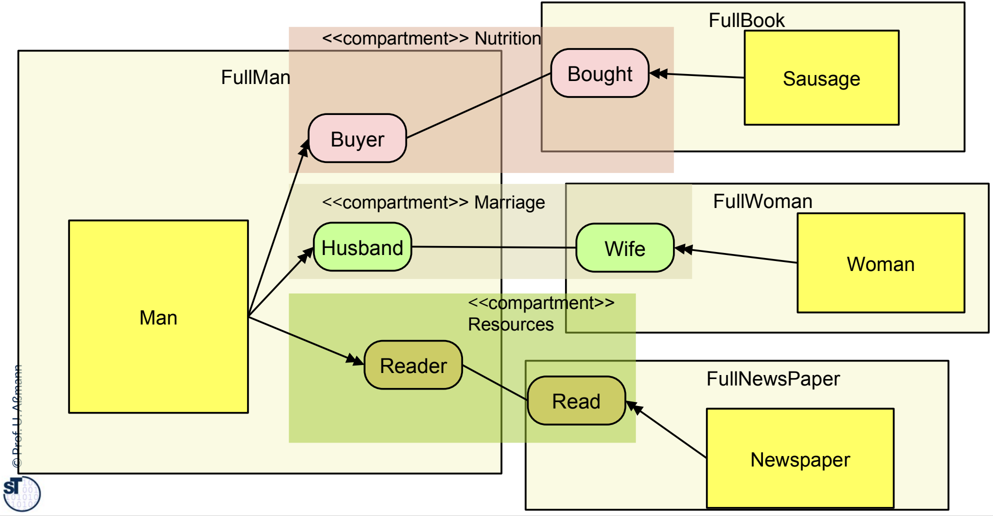
32.5 The MDA Macromodel of RoSI (RoSI-MDA): Representing Trace Mappings as Role-Playing

- What happens if contexts and roles are available in models?
- The Megamodel of RoSI and its traceability of model elements is extremely simple, because the role-based models and metamodels are factorizing objects
- RoSI-MDA is homogeneous Macromodel

Remember: The Steimann Factorization of Natural and Role Types

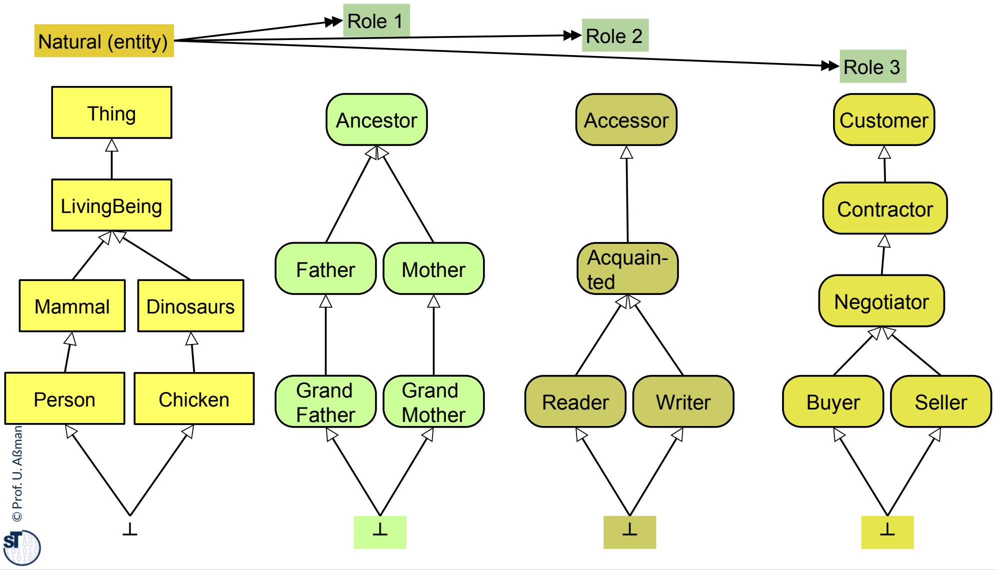
Splitting a full type into its *natural* and *role-type* components

- FullType = Natural x (role-type, role-type, ...)
- FullPerson = Person x (Reader, Father, Customer, ..)



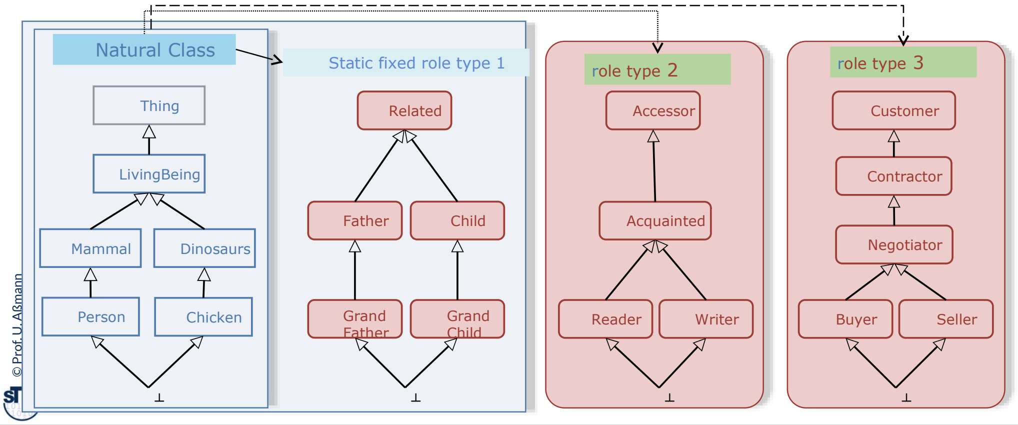
Remember: Full Type is from Inheritance Product Lattice

Q: What is a reading buying grandfather person? (A: tuple type)

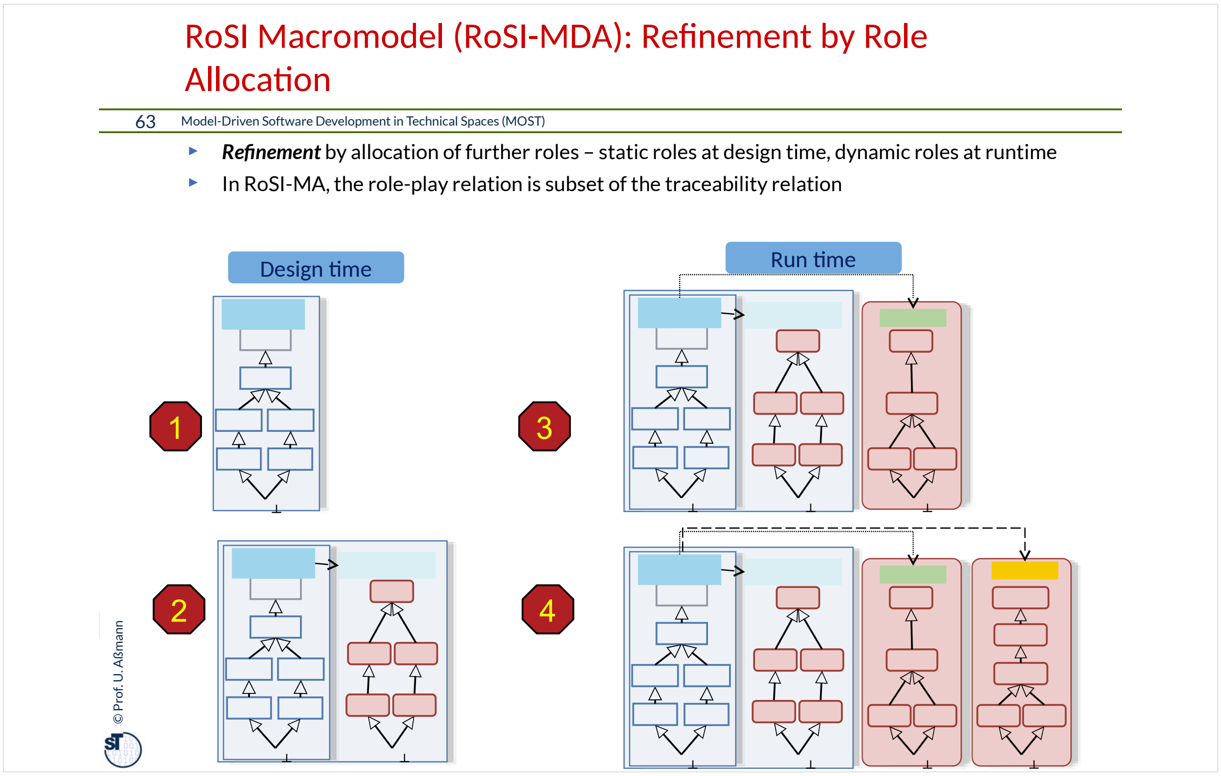


Scalable Bindung Time of Contexts with the Factorization

- **Scalable Binding**: Roles can also be bound statically, if mixins are used as implementation (fixing the context)
- Consequences for object life time, cohesion, allocation, adaptation, reconfiguration



OPTIONAL



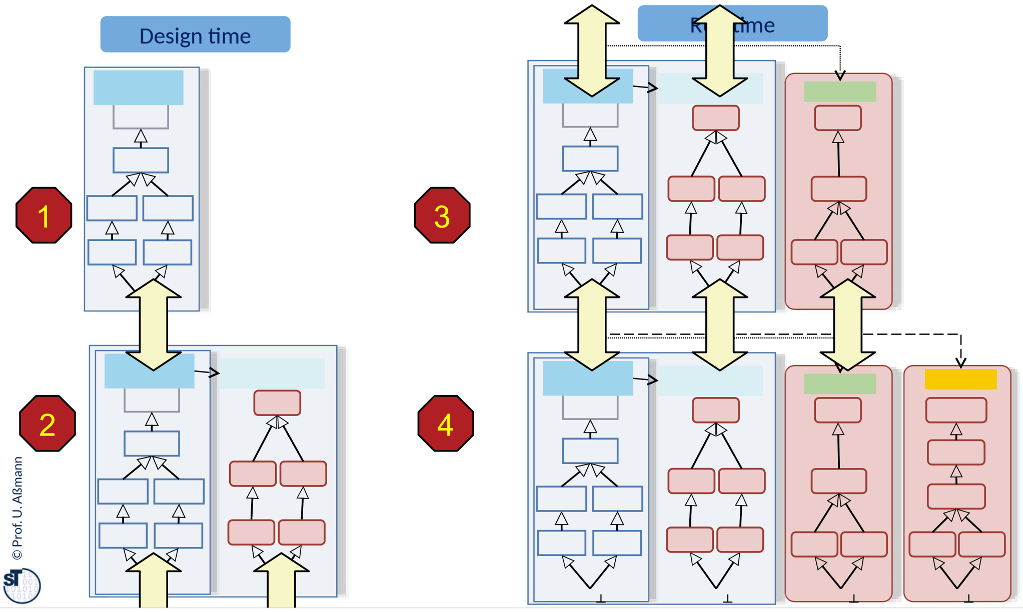
RoSI Macromodel (RoSI-MDA): Refinement by Role Allocation

- ***Refinement*** by allocation of further roles – static roles at design time, dynamic roles at runtime
- In RoSI-MA, the role-play relation is subset of the traceability relation

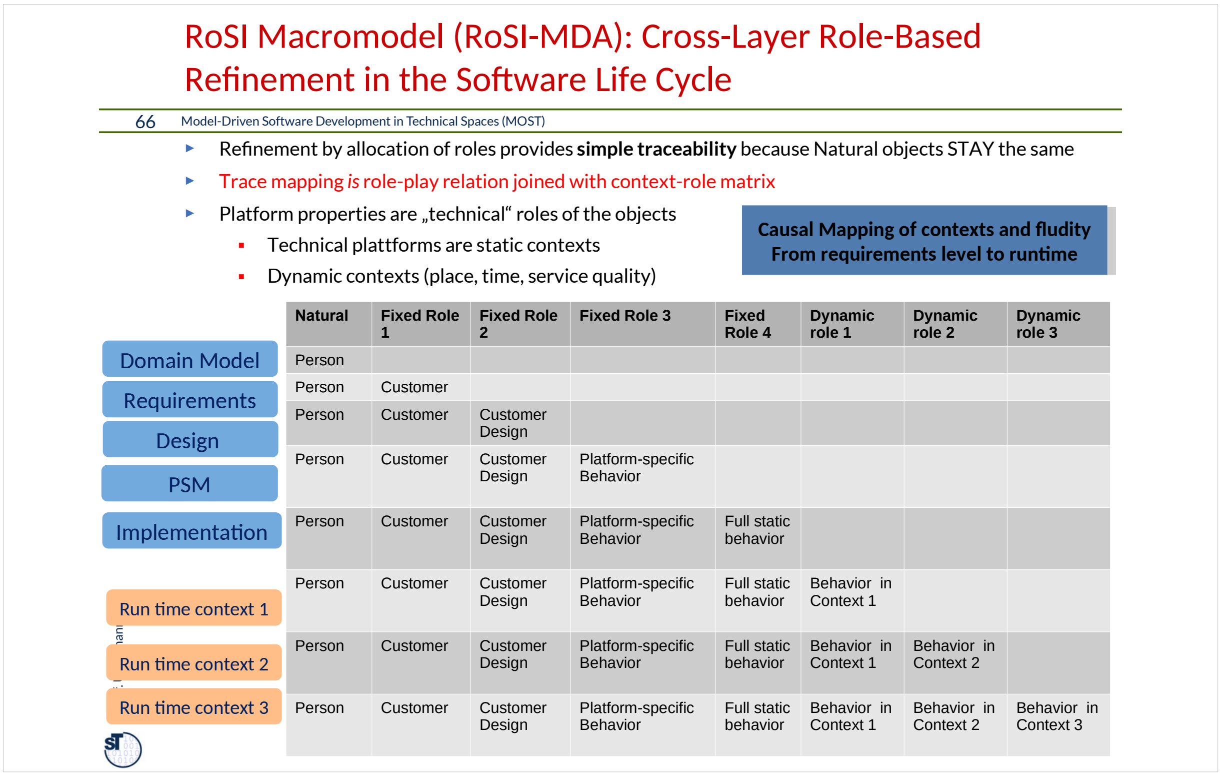
Die Faktorisierung hilft, die Traceability von natürlichen Objekten zu verbessern, denn sie können nun von Rollen unterschieden werden

RoSI-MDA: Traceability in Refinement by Role Allocation

- ***Refinement*** by allocation of further roles – static roles at design time, dynamic roles at runtime



Die Faktorisierung hilft, die Traceability von natürlichen Objekten zu verbessern, denn sie können nun von Rollen unterschieden werden



RoSI Macromodel (RoSI-MDA): Cross-Layer Role-Based Refinement in the Software Life Cycle

- Refinement by allocation of roles provides **simple traceability** because Natural objects STAY the same
- Trace mapping *is* role-play relation joined with context-role matrix
- Platform properties are „technical" roles of the objects
  - Technical plattforms are static contexts
  - Dynamic contexts (place, time, service quality)

Causal Mapping of contexts and fludity From requirements level to runtime

	Natural	Fixed Role 1	Fixed Role 2	Fixed Role 3	Fixed Role 4	Dynamic role 1	Dynamic role 2	Dynamic role 3
Domain Model	Person							
Requirements	Person	Customer						
Design	Person	Customer	Customer Design					
PSM	Person	Customer	Customer Design	Platform-specific Behavior				
Implementation	Person	Customer	Customer Design	Platform-specific Behavior	Full static behavior			
Run time context 1	Person	Customer	Customer Design	Platform-specific Behavior	Full static behavior	Behavior in Context 1		
Run time context 2	Person	Customer	Customer Design	Platform-specific Behavior	Full static behavior	Behavior in Context 1	Behavior in Context 2	
Run time context 3	Person	Customer	Customer Design	Platform-specific Behavior	Full static behavior	Behavior in Context 1	Behavior in Context 2	Behavior in Context 3

Die Faktorisierung hilft, die Traceability von natürlichen Objekten zu verbessern, denn sie können nun von Rollen unterschieden werden

Advantages of RoSI-MDA (Role-Based MDA)

- Very simple, component MDA with easy traceability:
  - Cores of objects map 1:1 from CIM via PIM and PSM into the application PSI (context-role matrix)
  - Variability via new roles for PIM, PSM, PSI
  - “object fattening” through the MDA
- Projection (get) and reintegration (put) is simple for MDA-SUM

End

- Why do the models of MDA form a macromodel, while MDA is a megamodel?
- Which trace link types are important for MDA?
- Why is a context-role-based model better for traceability?
- How does JastAdd aspects achieve MDA refinement?
  - How is traceability achieved?
  - How model synchronisation?
- How does RoSI-MDA achieve global traceability from requirements to run time?
- How will megamodel look like that provides Link-tree-based models and Role-based factorization of objects?
  - How does a trace link look like?
  - Where are the trace links stored?
  - Why can XML be used as simple exchange format in these megamodels?