Part IV. Megamodels in a Software Factory
40. Requirements and Test Megamodels

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

Version 15-0.16, 23.01.16

1) Traceability and Megamodels
2) Requirements Management and Tracing in a Megamodel
3) Tracing Requirements and Testing
4) Tracing Goals and Requirements with ODRE

DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

Literature

- Regina Hebig and Andreas Seibel and Holger Giese. On the Unification of Megamodels. Proceedings of the 4th International Workshop on Multi-Paradigm Modeling (MPM 2010). Electronic Communications of the EASST Volume 42 (2011). ISSN 1863-2122. Guest Editors: Vasco Amaral, Hans Vangheluwe, Cecile Hardebolle, Lazlo Lengyel
    - http://www.easst.org/eceasst/
- [CH06] K. Czarnecki and S. Helsen. Feature-based survey of model transformation approaches. IBM Systems Journal, Vol 45, No 3, 2006.

References

- [Grammel] Birgit Grammel. Automatic Generation of Trace Links in Model-driven Software Development. PhD Thesis, Technische Universität Dresden, 2014.
  - http://nbn-resolving.de/urn:nbn:de:bsz:14-qucosa-155839
- Katja Siegemund, Edward J. Thomas, Yuting Zhao, Jeff Pan, and Uwe Assmann. Towards Ontology-driven Requirements Engineering. Semnatic Web Enabled Software Engineering (SWESE) Workshop at ISWC 2011, Koblenz
  - http://iswc2011.semanticweb.org/fileadmin/iswc/papers/workshops/swese/4.pdf
- [Mylopoulos1999] John Mylopoulos, Lawrence Chung, and Eric Yu. From Object-oriented to Goal-oriented Requirements Analysis. Communications of the ACM, 42(1):31 37, 1999.
- [Zowghi2002] Didar Zowghi and Vincenzo Gervasi. The Three Cs of Requirements: Consistency, Completeness, and Correctness. In Proceedings of 8th International Workshop on Requirements Engineering: Foundation for Software Quality, (REFSQ'02), 2002.
- [Lamsweerde2000] Axel van Lamsweerde. Requirements Engineering in the year 00: A Research Perspective. In International Conference on Software Engineering, pages 5, 19, 2000.
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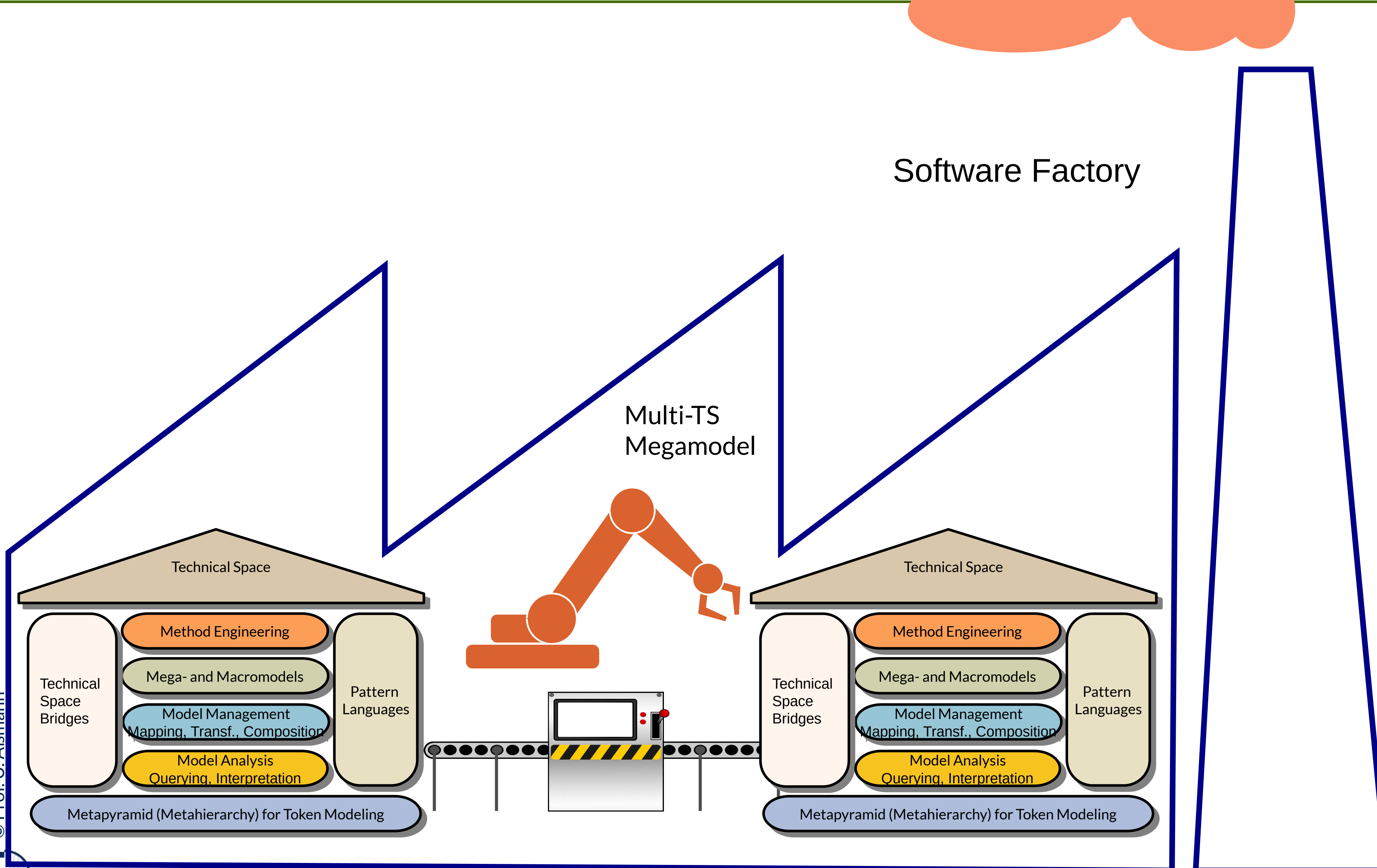
Q12: A Software Factory's Heart: the Multi-TS Megamodel



Software Factories

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

Jack Greenfield

40.1 Traceability between Models

Why Traceability in a Megamodel?

[Grammel]

System Comprehension:

- To improve orientation by navigating via trace links along model transformation chains

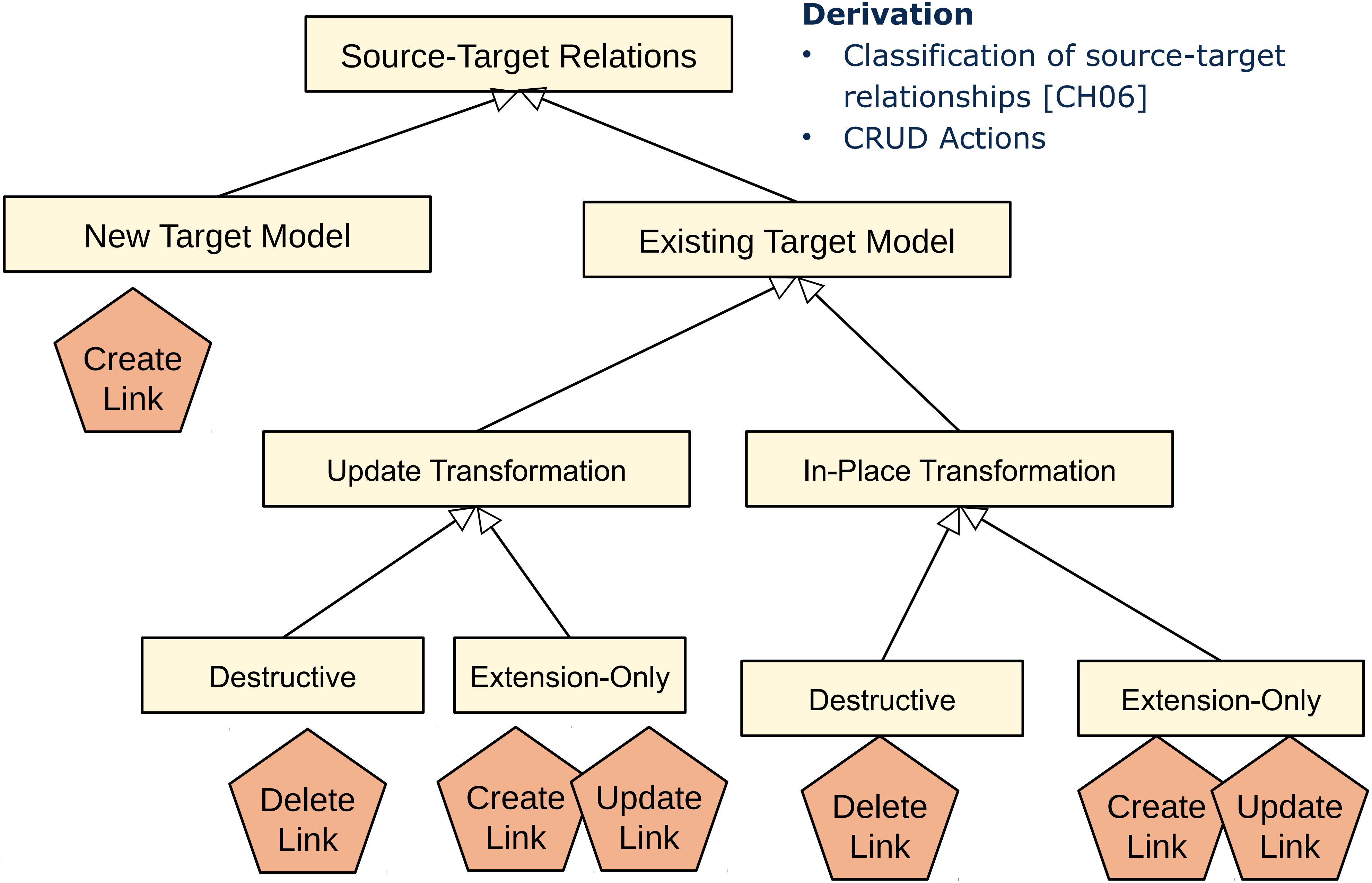
- **Change Impact Analysis**:
  - to analyze the impact of a model change on other models
  - to analyze the impact of a model change on existing *generated* or *transformed* output
  - To enable to do model synchronization (hot updating dependent parts)
- **Orphan Analysis:** finding orphaned elements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

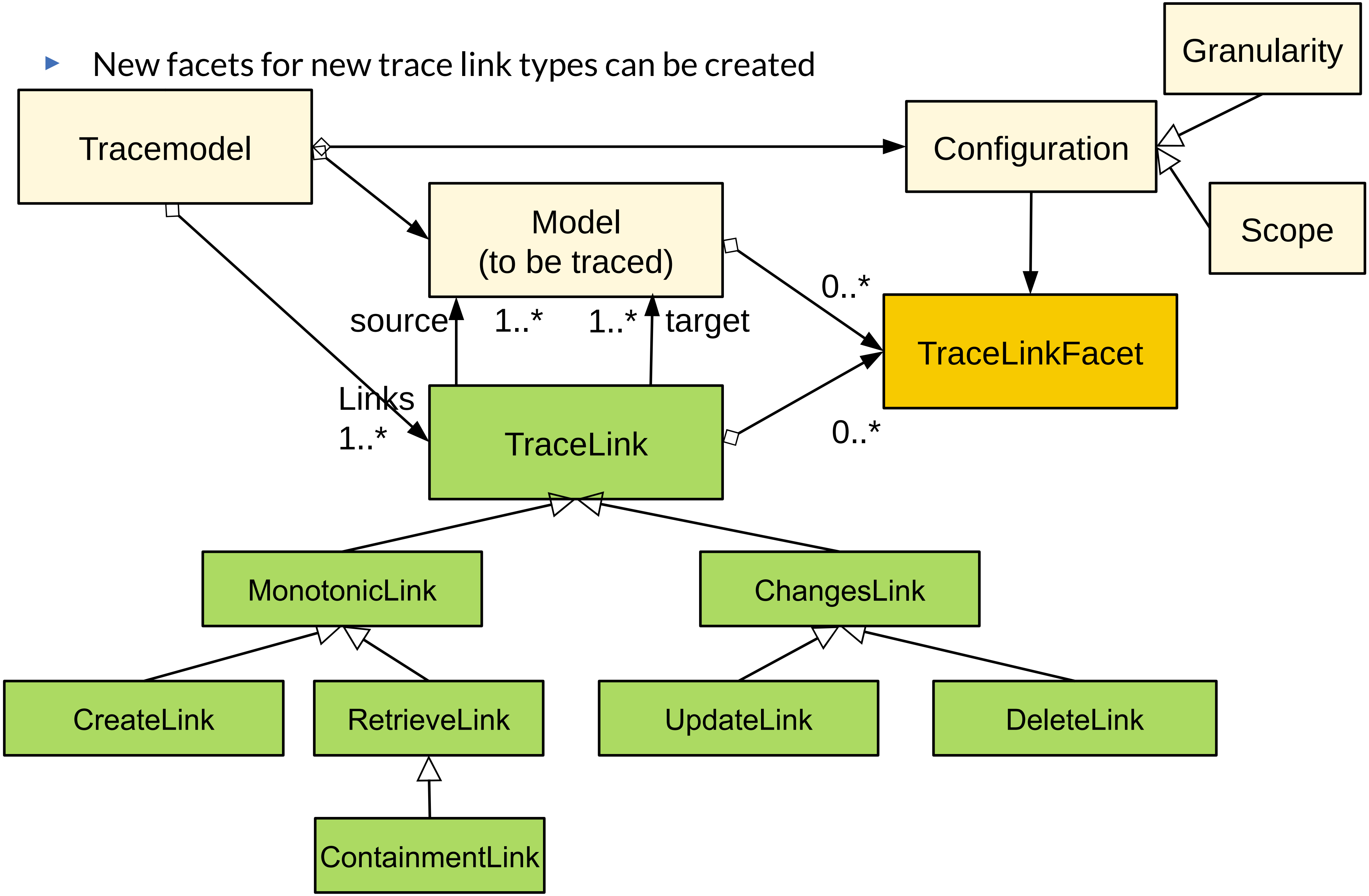


Derivation

- Classification of source-target relationships [CH06]
- CRUD Actions

Extensible Traceability Metamodel acc. to Grammel

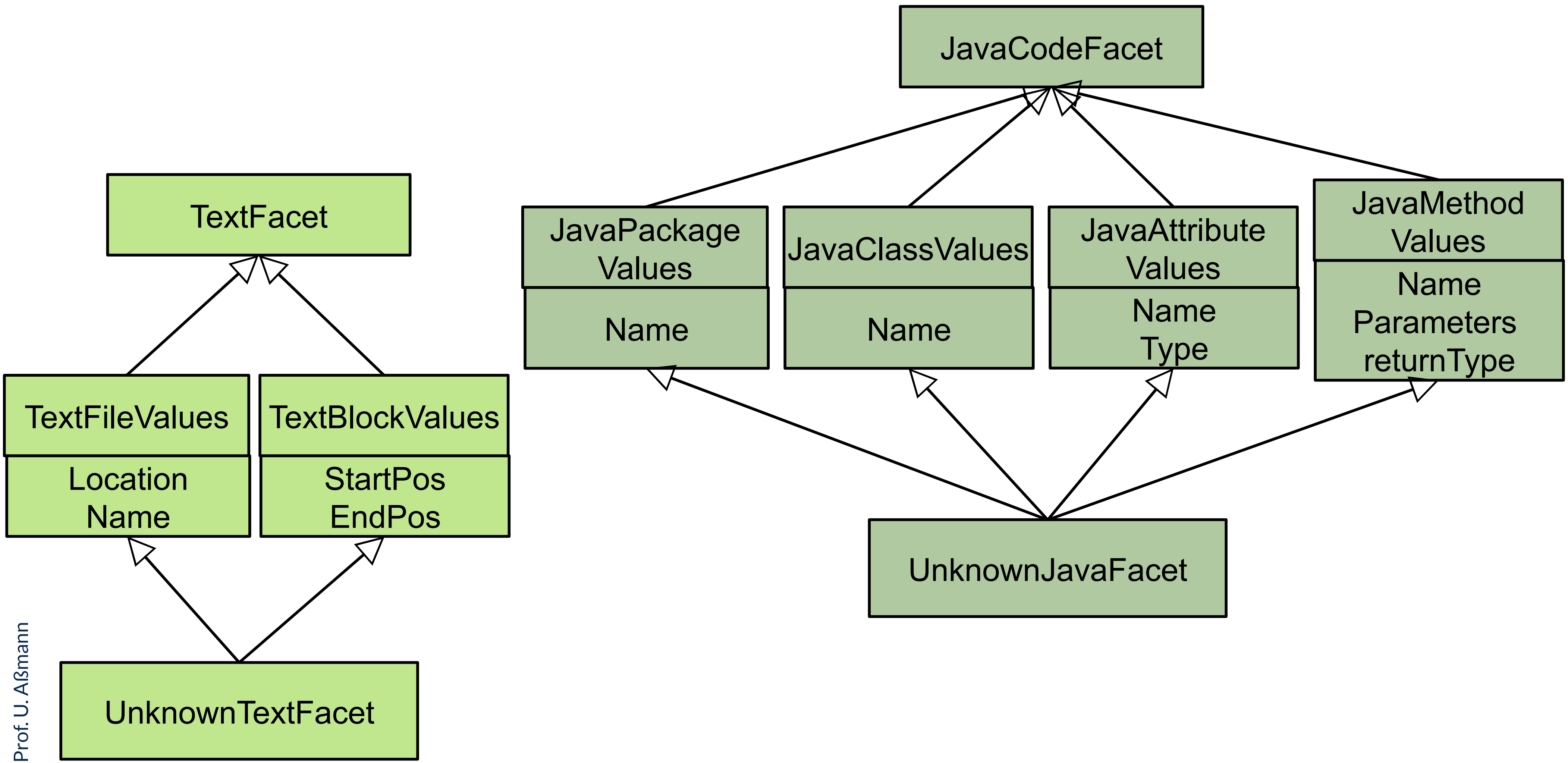
- New facets for new trace link types can be created



Examples for TraceLinkFacet

[Grammel]

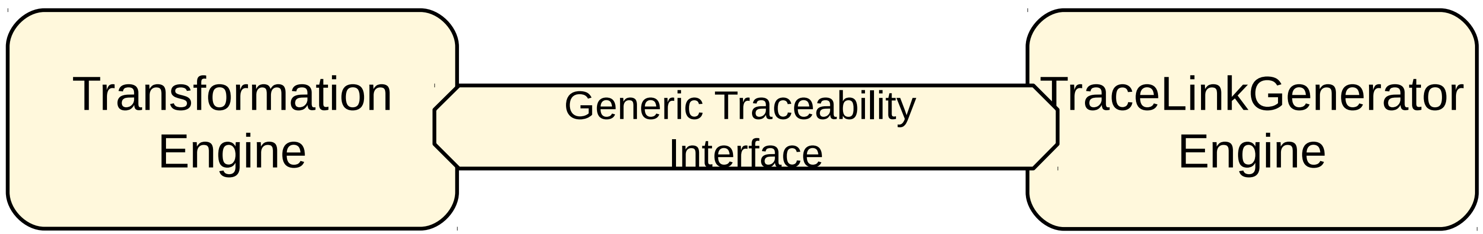
- Facets factorize inheritance hierarchies; new facets extend inheritance hierarchies

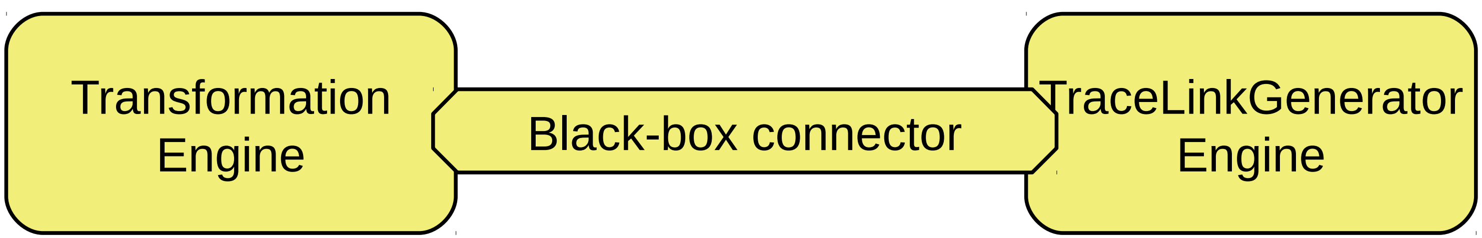


Adding a Trace Link Generator to Tools

[Grammel]

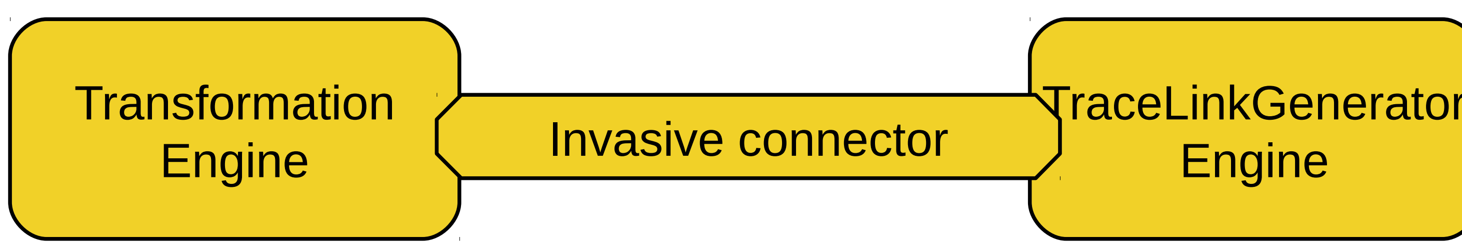
- TraceLinkGenerators can be connected in two ways, following a generic traceability interface:





Transformation engine must know and call the generator

Transformation engine need not know but is extended Invasively or by AOP



Traceability in Megamodels

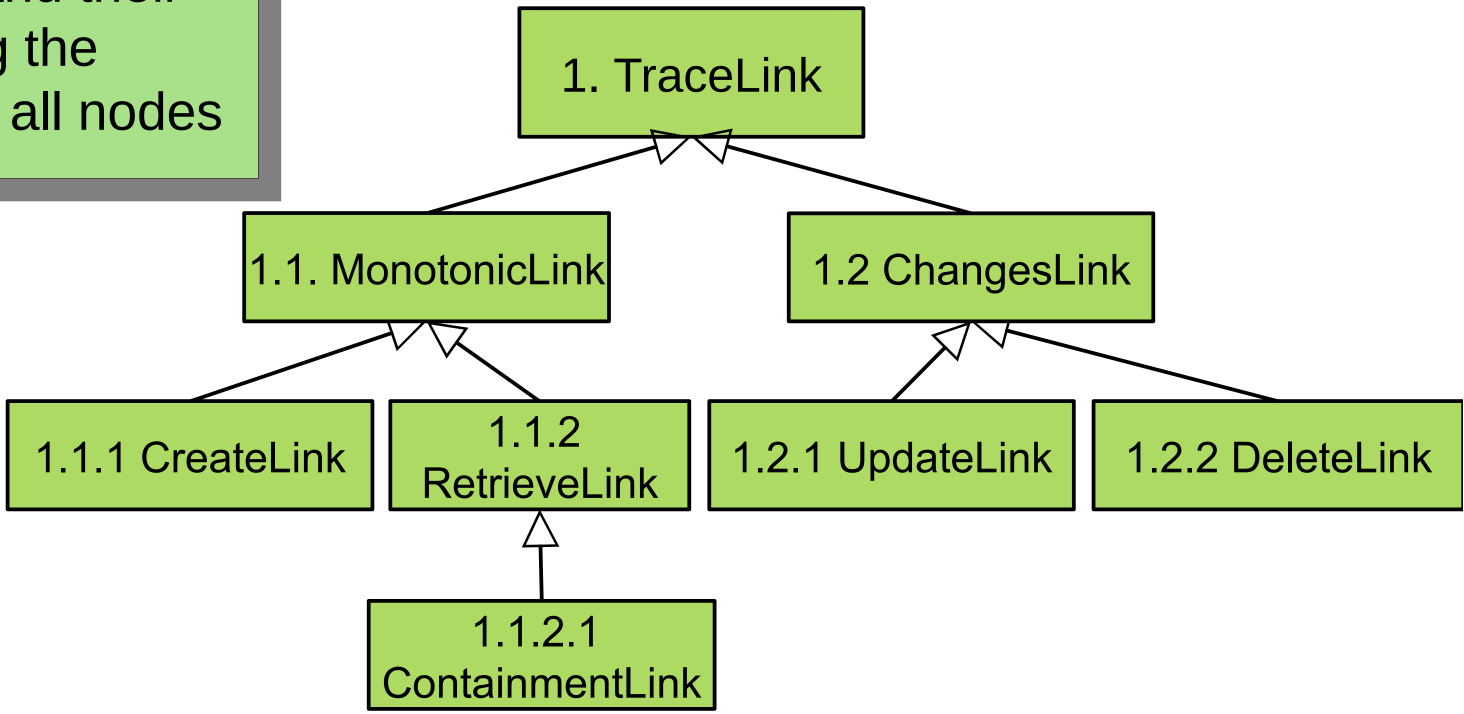
- Piecemeal growth of megamodels in the software process:
  - Start with requirements, then add more stuff and models
- **Add links**
  - **Create links** are drawn between model element MA from model A and model element MB whenever MB is generated or added because of MA
  - **Retrieve links** are drawn when MB is extracted 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

Traceability in Megamodels 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 megamodel*

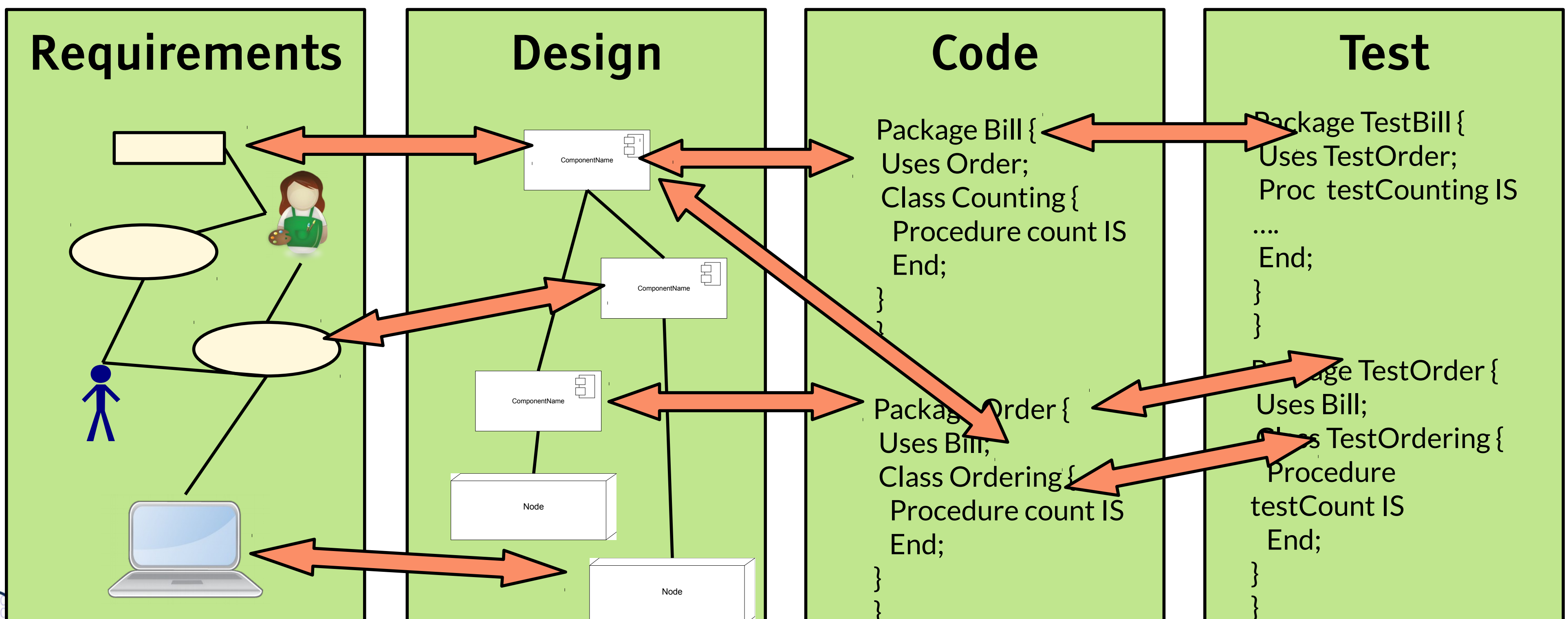
In link-treeware, megamodels maintain *tracelink models* linking and tracing all models and their elements by referencing the hierarchical numbers of all nodes

Hierarchical numbering of the classes in an inheritance tree:



Q12: The ReDeCT Problem and its Macromodel

- The inter-model mappings between the Requirements, Design model, Code, Test cases are traceability links stemming for example from:
  - Lifted results of deep model analysis (reachability analysis)
  - Generated trace links from added trace link generators
- A **ReDeCT macromodel** has maintained intermodel mappings between all 4 models



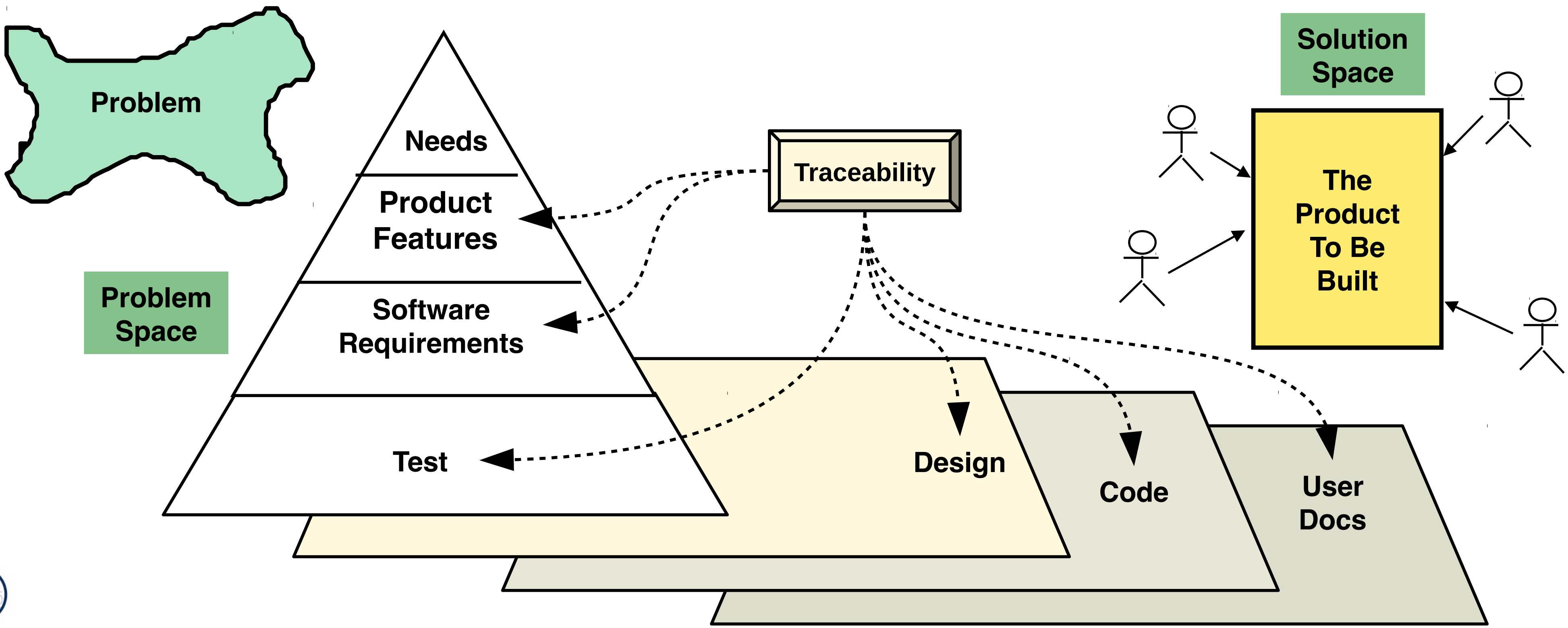
40.2. Megamodels for Test and Requirements Management

Tool References

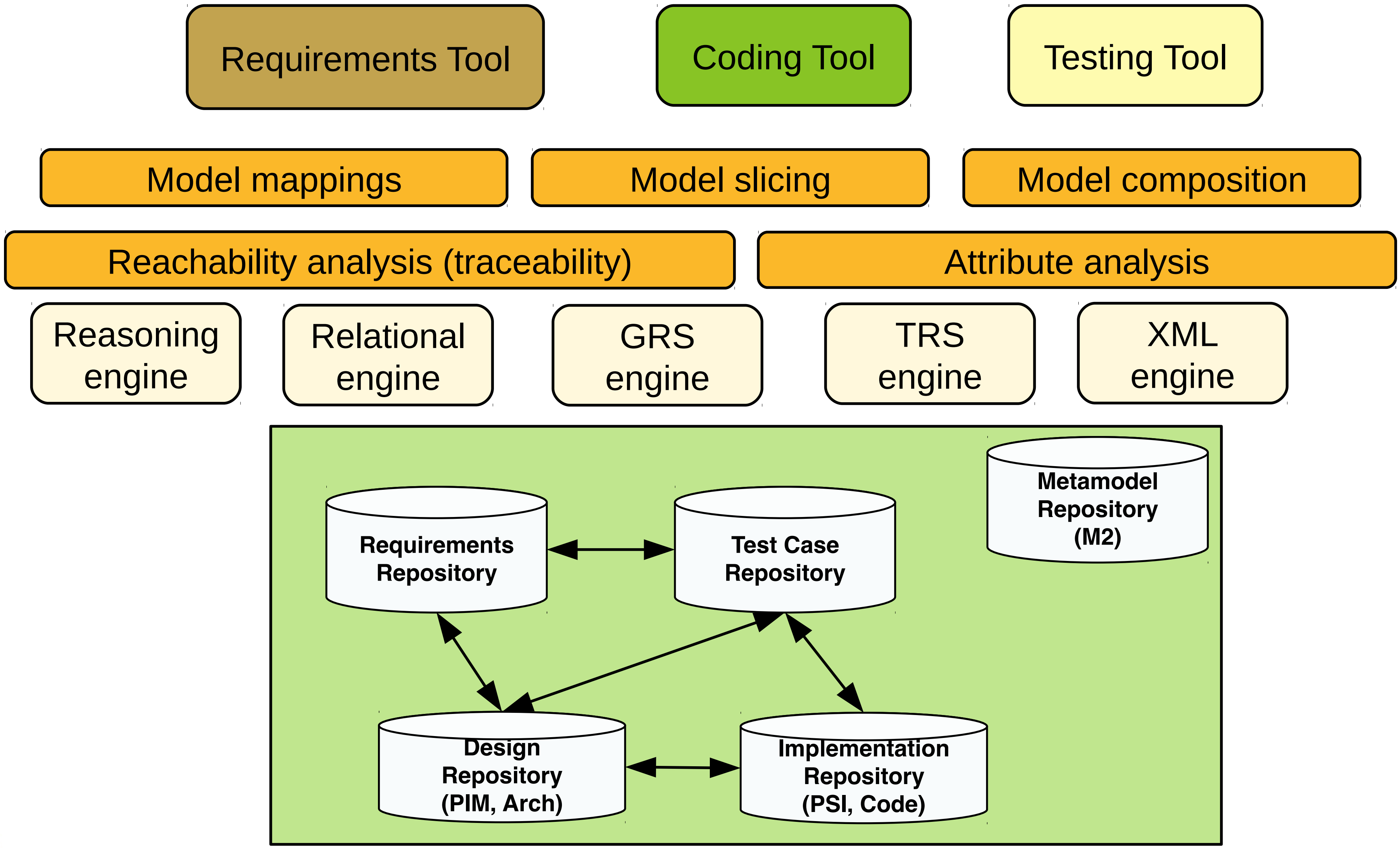
- [RPro] Requisite Pro User's Guide
  - ftp://ftp.software.ibm.com/software/rational/docs/v2003/win_solutions/rational_requisitepro/reqpro_user.pdf
- Dominic Tavassoli, IBM Software. Requirements Definition and Management - Ten steps to better requirements management. June 2009
  - ftp://ftp.software.ibm.com/software/emea/de/rational/neu/Ten_steps_to_better_requirements_management_EN_2009.pdf
- Tools: http://www.jiludwig.com/Requirements_Management_Tools.html
- Free community-licensed tool Axiom (Windows, Linux): http://www.iconcur-software.com/
  - http://d60f31wukcdjk.cloudfront.net/docs/Axiom_4_User_Manual.pdf
- Teach videos of Axiom
  - http://www.iconcur-software.com/resources.html
  - Video on linking matrix (traceability matrix) http://iconcur-software.com/tutorials/matrix.htm

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)

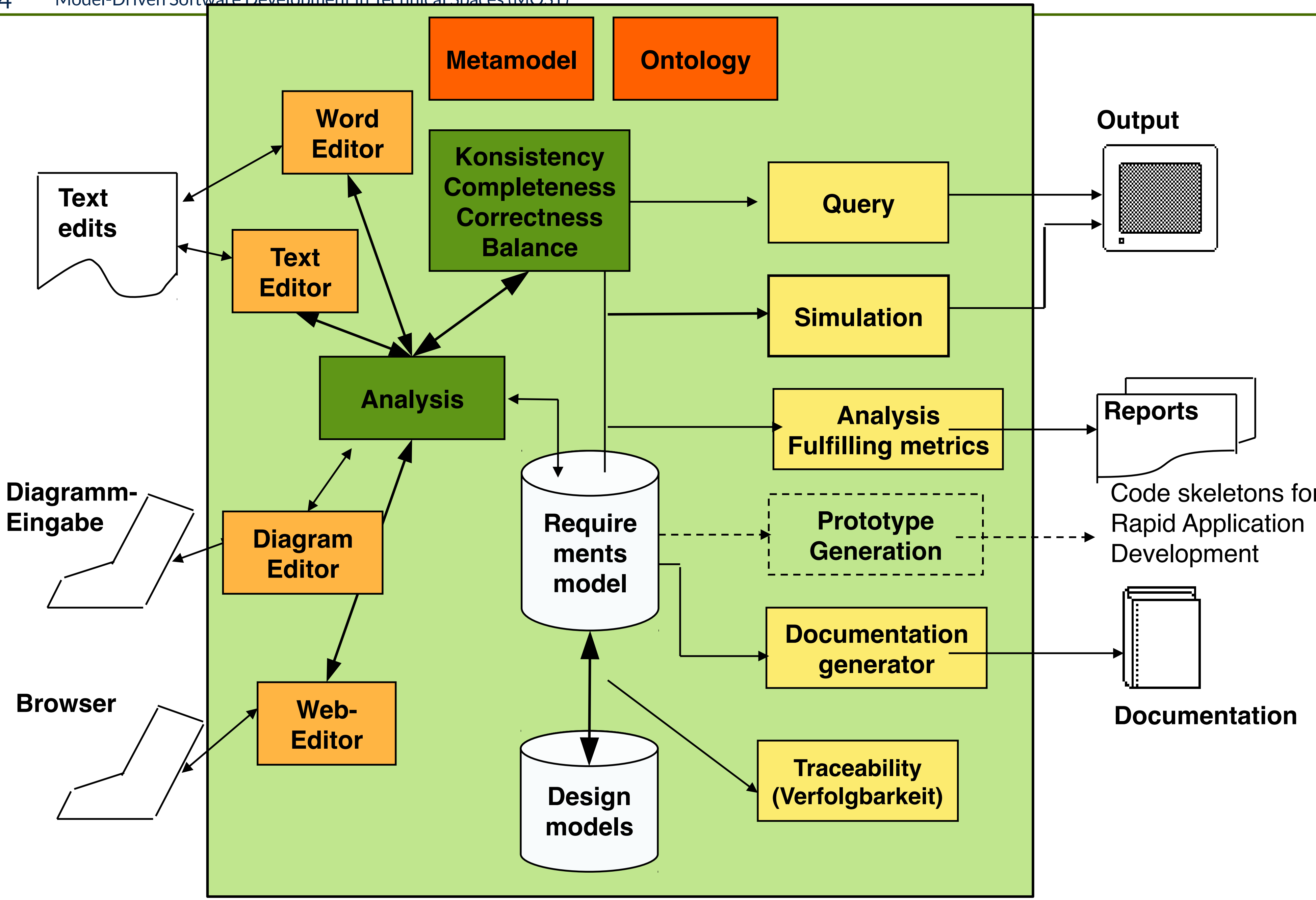


Deficiencies of Current RE Methods

- 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

40.2.2 Metamodel-Based Requirements Management

Requirements Tools on the Requirement Database



Metamodeling of Requirements

- Metamodeling is very helpful in RM
  - Requirements are domain-specific, i.e., need domain models
  - The granularity of requirements is very different, and need to be balanced
    - → metamodeling helps to type the requirements
  - Requirements can be treated as models, and **model mappings** can map them to design, implementation, and test models (**traceability, Verfolgbarkeit)**
- Many requirement tools are metamodel-controlled
  - typing requirements
  - linking them

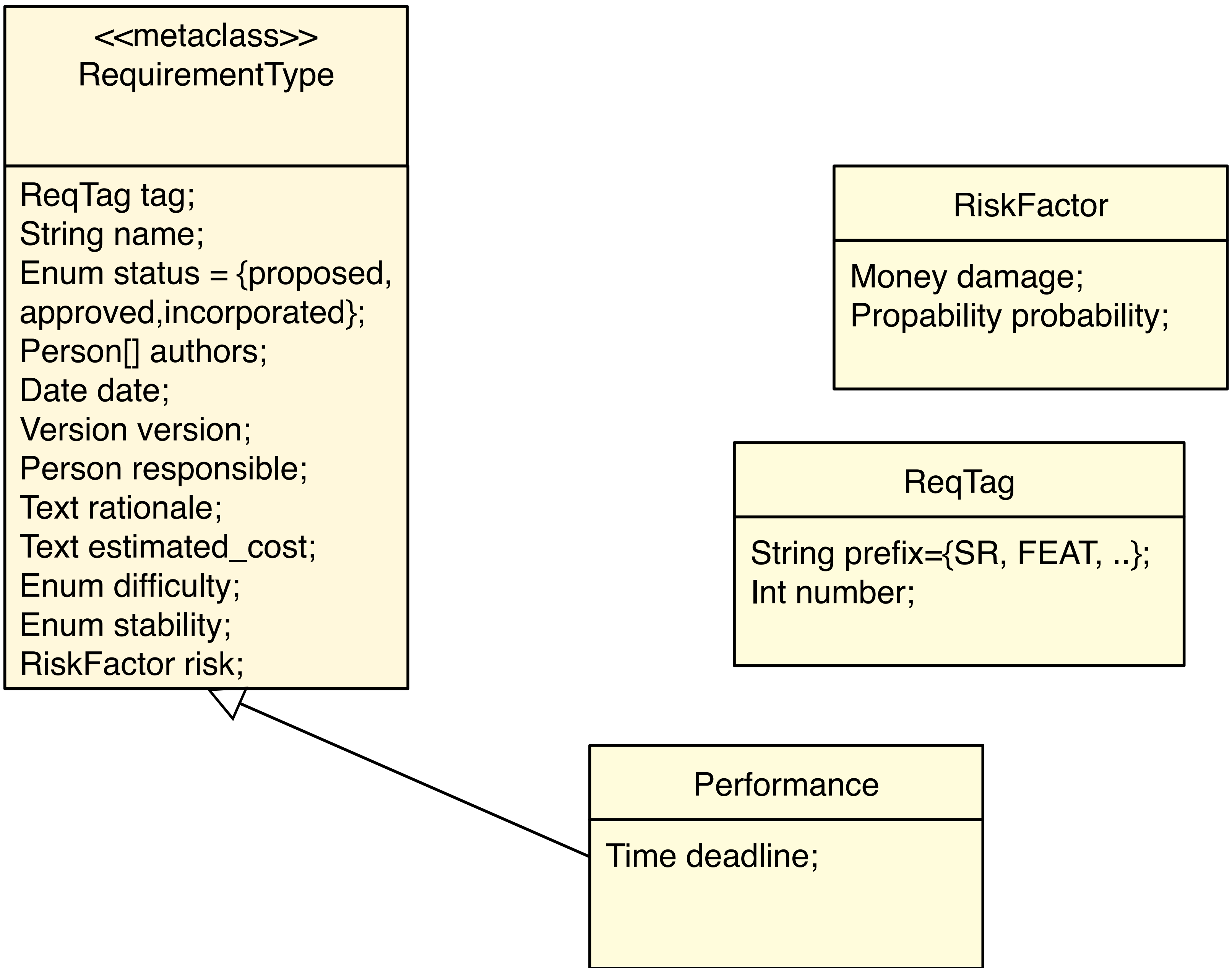
40.2.3 Requisite Pro

RequisitePro (IBM)

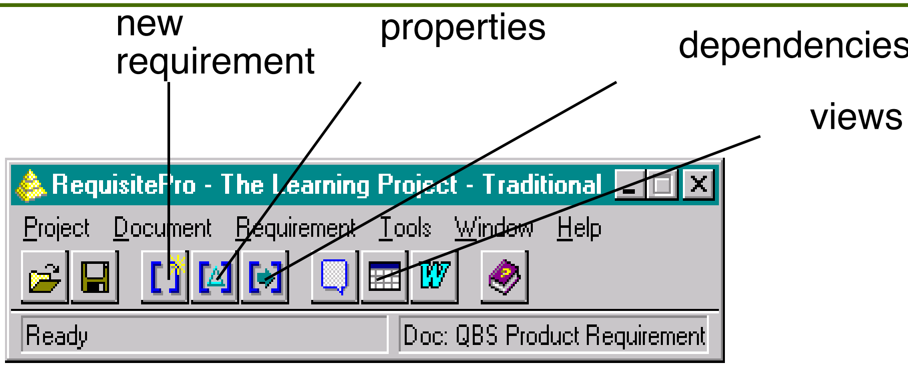
- **Metamodel-driven Repository of requirements (requirements database)**
  - Metamodel for requirements (**requirement types)** in metalanguage ERD
    - Attributes: Status, Priority, Difficulty, Stability, Costs
    - Dependencies and traces of requirements
    - Hierarchical requirements
    - Views on requirements
  - Query facility; configuraiton managment
  - Integration into processes and IDE, e.g., Rational Unified Process with Rational Rose UML, ClearCase and MS Project.
- **Traceability Matrix** allows for linking requirements with test cases (direct inter-model mapping)
- Create **software requirements specifications (SRS)** with template documents:
  - Support of different types of SRS (system product, software, service).

http://www-142.ibm.com/software/products/de/de/reqpro/
ftp://ftp.software.ibm.com/software/rational/docs/v2003/win_solutions/rational_requisitepro/reqpro_user.pdf
http://public.dhe.ibm.com/common/ssi/ecm/en/rad10955usen/RAD10955USEN.PDF

Metaclass RequirementType (Ex.)

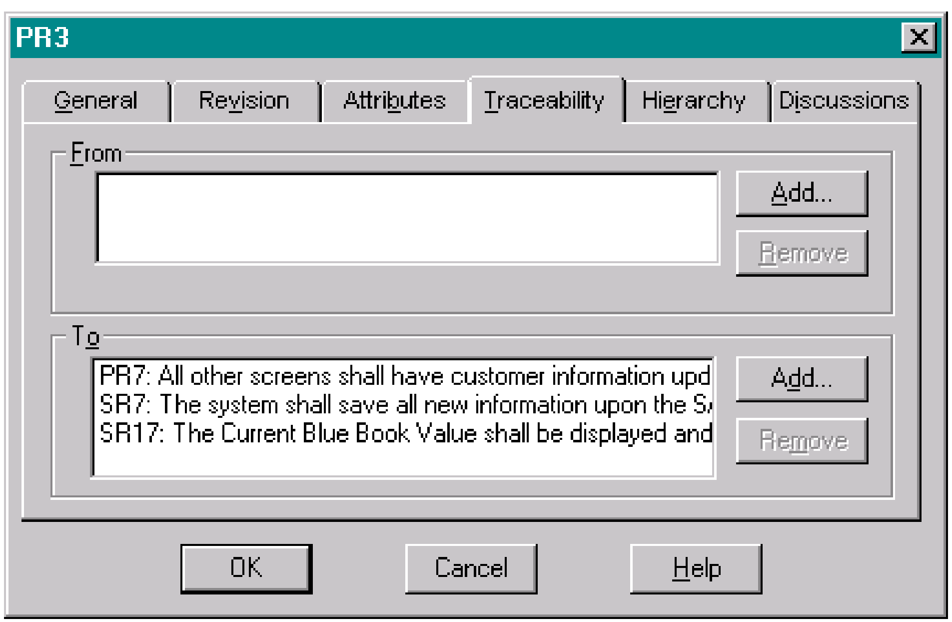


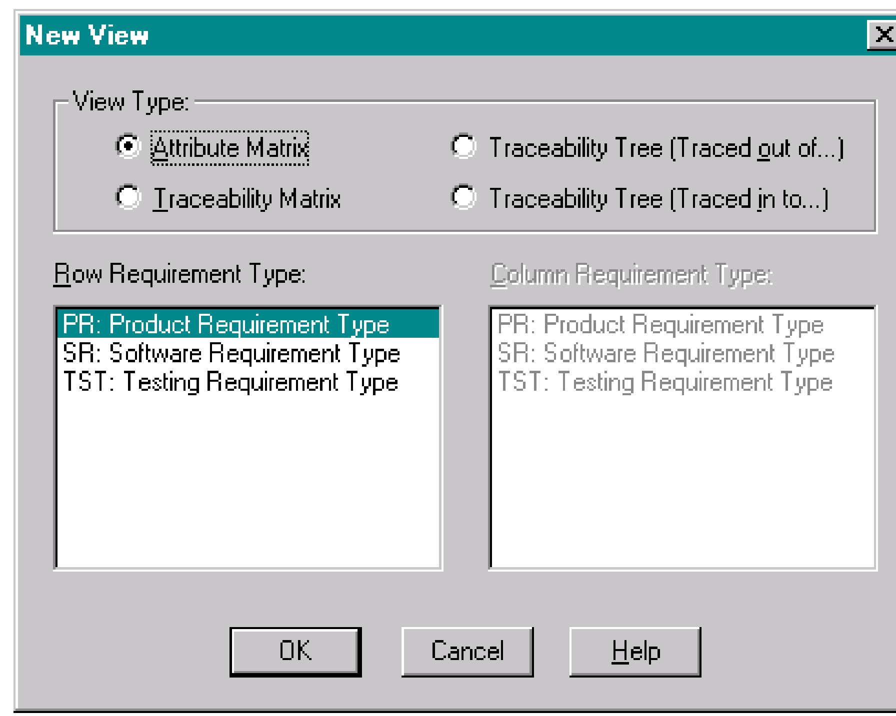
RequisitePro – Main Windows



Selection of different requirements types and views

Description of Requirement **PR3**





FURPS Classification of Requirements

FURPS delivers RequirementTypes for RequisitePro

[Wikipedia] [Grady/Caswell] in Hewlett-Packard

- **Functionality** - Feature set, Capabilities, Generality
  - Semi-functionality: Security
- **Qualities:**
  - **Usability** - Human factors, Aesthetics, Consistency, Documentation
  - **Reliability** - Frequency/severity of failure, Recoverability, Predictability, Accuracy, Mean time to failure
  - **Performance** - Speed, Efficiency, Resource consumption, Throughput, Response time
  - **Supportability** - Testability, Extensibility, Adaptability, Maintainability, Compatibility, Configurability, Serviceability, Installability, Localizability, Portability

FURPS+ (FURPS-DIIP)

- IBM: http://www.ibm.com/developerworks/rational/library/4706.htm
- http://www.ibm.com/developerworks/rational/library/4708-pdf.pdf
- **Design Requirement:** a constraint on the design of a system
  - Architecture Requirement: a constraint on the architecture
- **Implementation Requirement:** a constraint on the code of the system
- **Interface Requirement:** a constraint on the external interfaces of the system (the "context model")
- **Physical Requirement:** a constraint on the hardware environment

Attribute Matrix of Requisite Pro

- The attribute matrix is a hierarchical table (relation) of requirement objects and their attributes
  - Super and subrequirements
  - Priority and Status, and other attributes

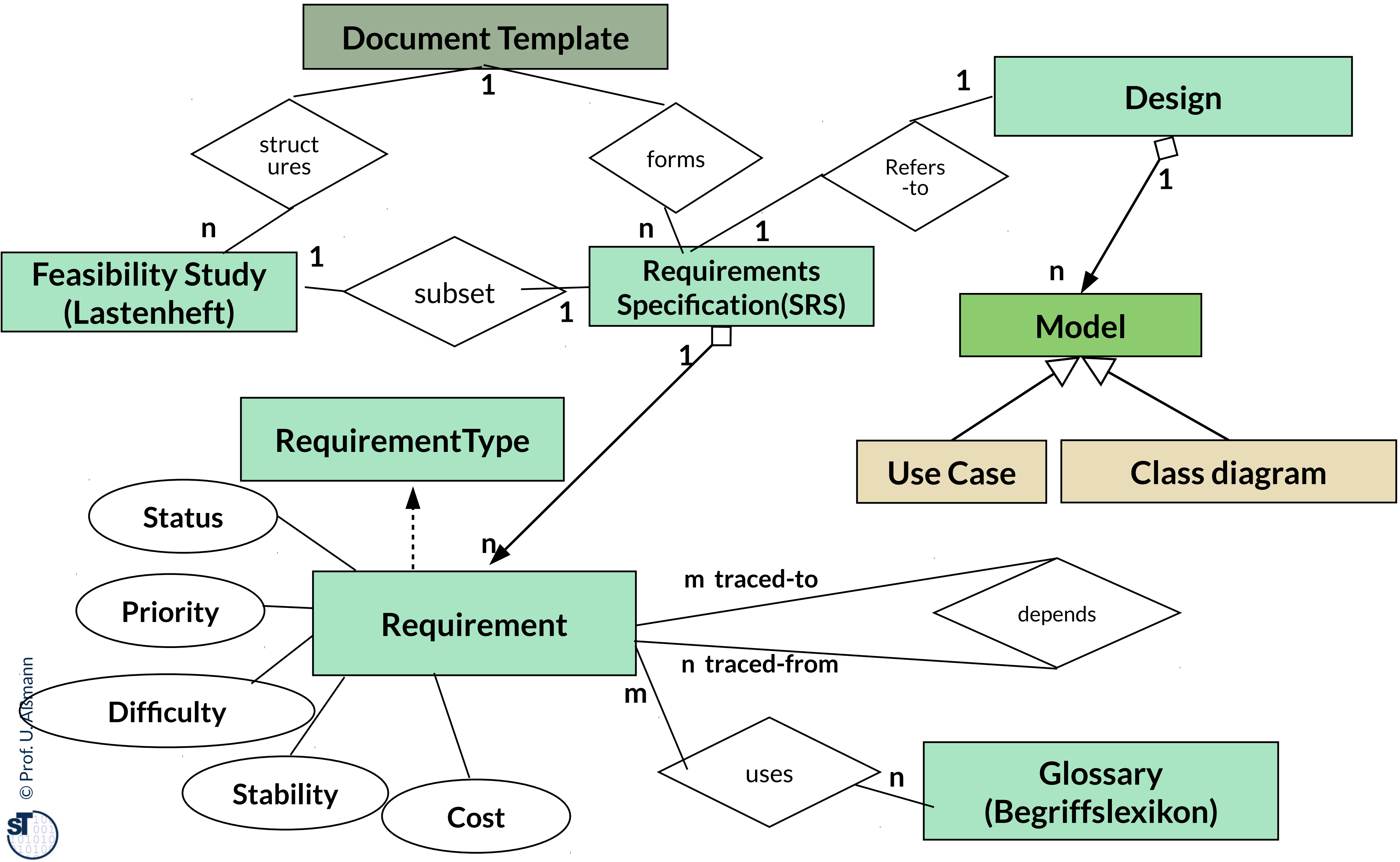
Formalizing Requirement Texts

- If requirements are entered in free text (in Word processor), they can be **formalized by text mining** with
  - Verb-noun-analysis
  - Keyword identification: MUST, MAY, SHALL, SHOULD, WILL, CUSTOMER
  - Markup information, such as section headers, emphasizing, etc.
  - Concept recognition by looking up nouns in domain models (glossaries, taxonomies, ontologies)
- Requirements can also be recognized from tables in Word documents [RPro]

Traceability with Direct Model Mappings

- The Traceability Matrix connects and relates requirements by **direct traces** and **indirect traces** over **trace_to** and **trace_from** relationships
  - The trace relationship is a model mapping within the requirements model
  - External projects can be imported, and traces to their public requirements can be defined
- Direct traces are entered
  - into a form
  - into the corresponding bitfield of the traceability matrix
- If somebody changes the requirements later, the trace links become **suspect** and should be checked

Metamodel of Requirements Managements in RequisitePro (Metalanguage ERD)



Other Tools

CaliberRM	Borland	http://www.borland.com/us/products/caliber/index.aspx
DOORS	IBM	http://www-01.ibm.com/software/awdtools/doors/ http://www.docstoc.com/docs/90794258/Getting-the-most-out-of-DOORS-for-requirements---NJIT-Computer

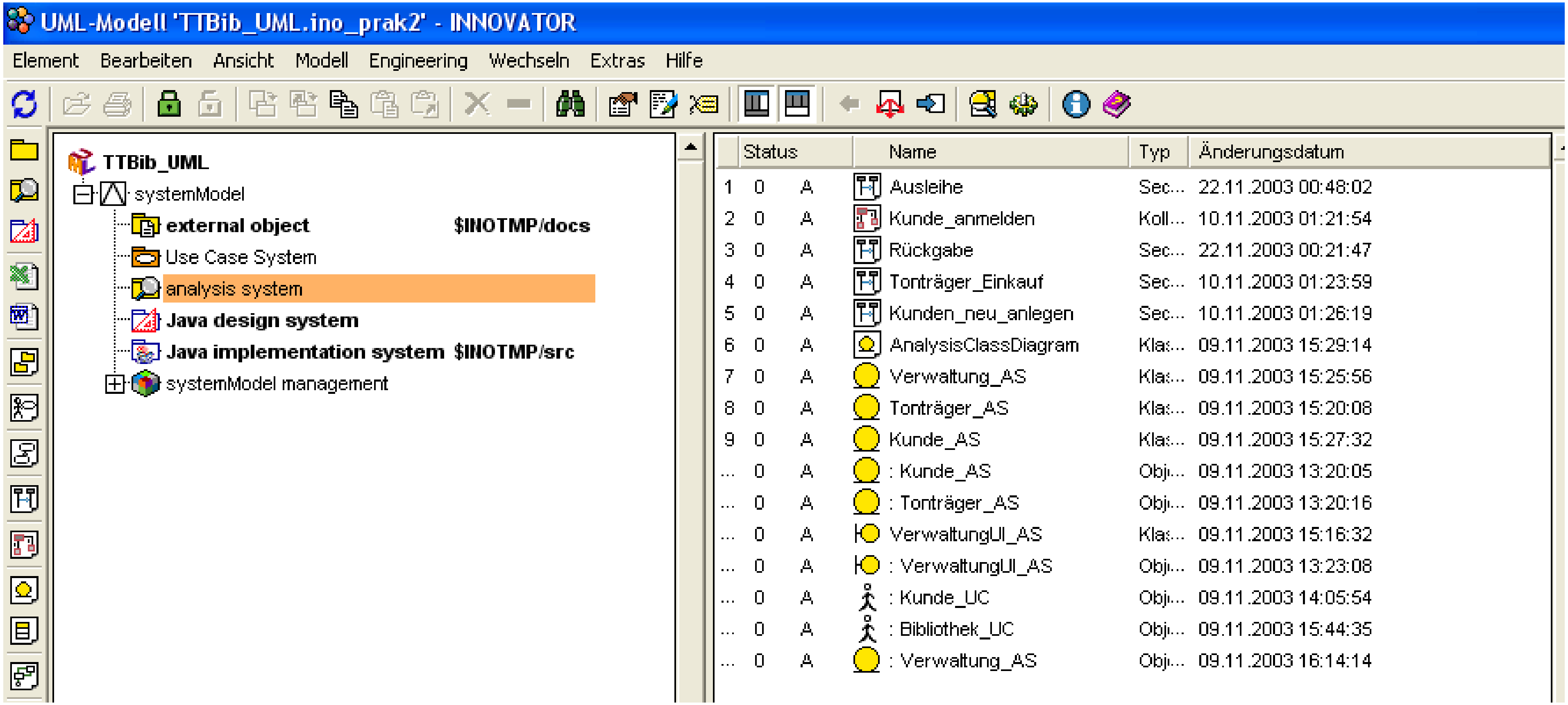
70.3 Traceability in Practical RM Tools

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

Model Mapping in MID INNOVATOR

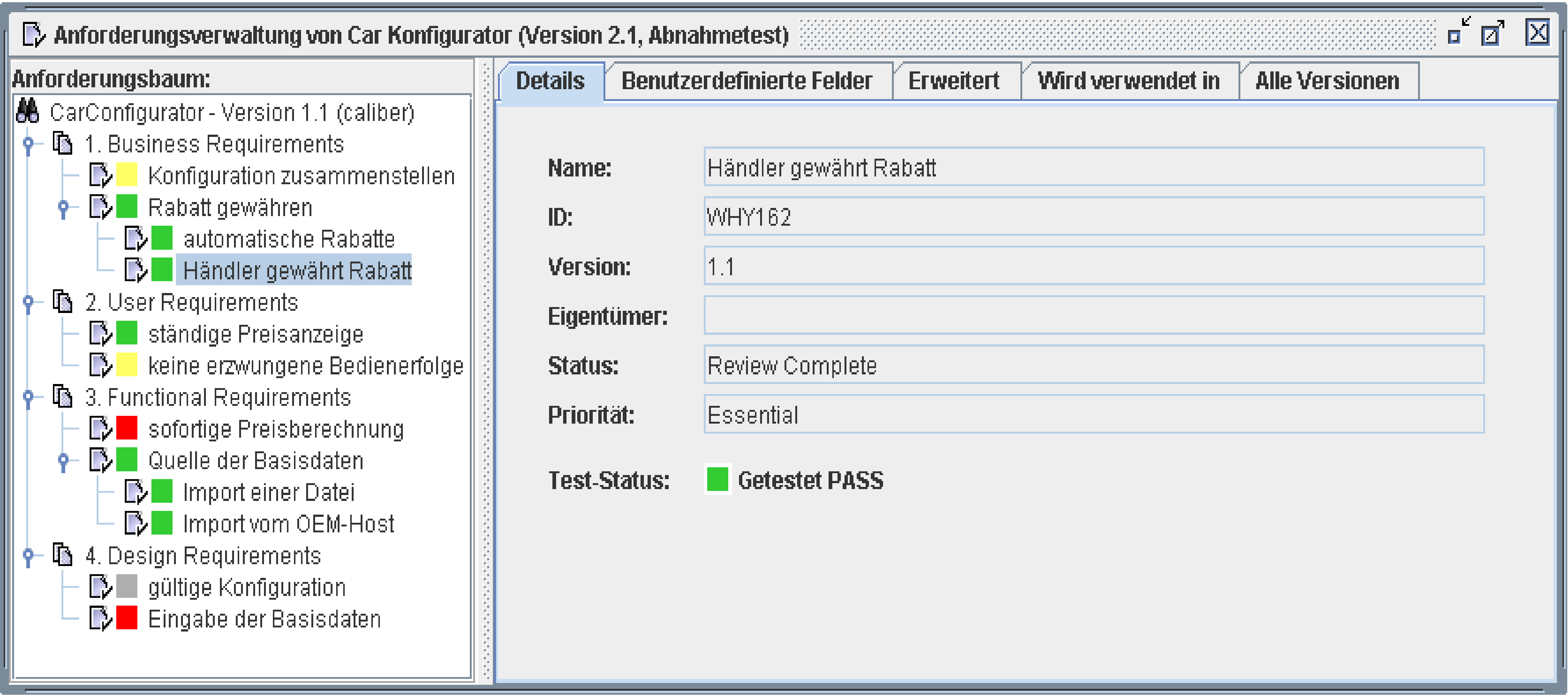
- Innovator can be employed simultaneously for requirements, design and implementation models
- How to relate these models?

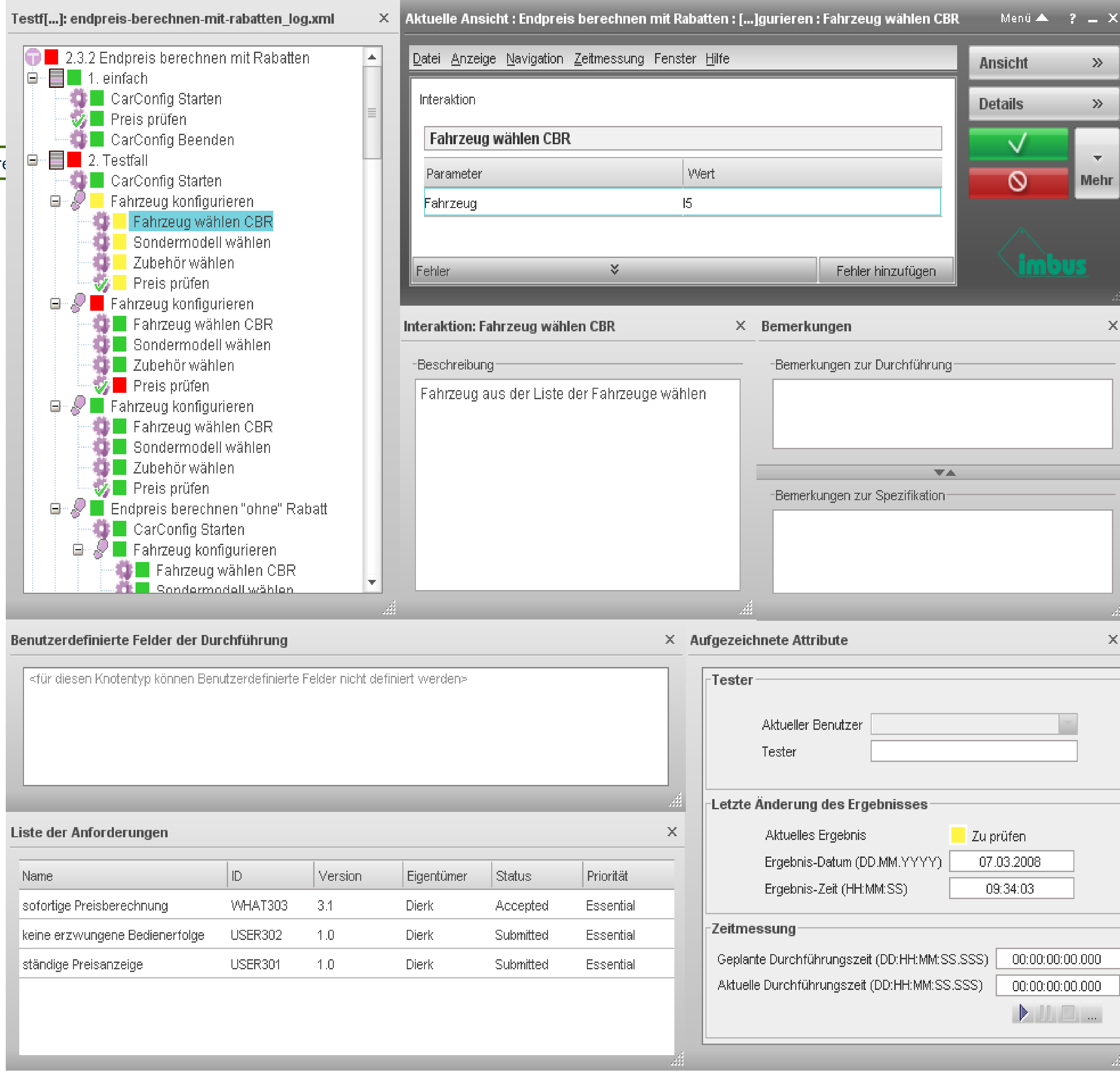


Example: imbus TestBench

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

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




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
Menü
Datei Anzeige Navigation Zeitmessung Fenster Hilfe
Ansicht
Details
Mehr
Interaktion
Fahrzeug wählen CBR
Parameter
Wert
Fahrzeug
I5
Fehler
Fehler hinzufügen
imbus
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>
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
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)
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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

40.4 Traceability to Goals in Goal Models with Ontology-Driven Requirements Engineering (ODRE)

Uwe Aßmann[1], Katja Siegemund[1], Edward J. Thomas[2], Jeff Pan[2], Yuting Zhao[2]

1 Technische Universität Dresden, Germany

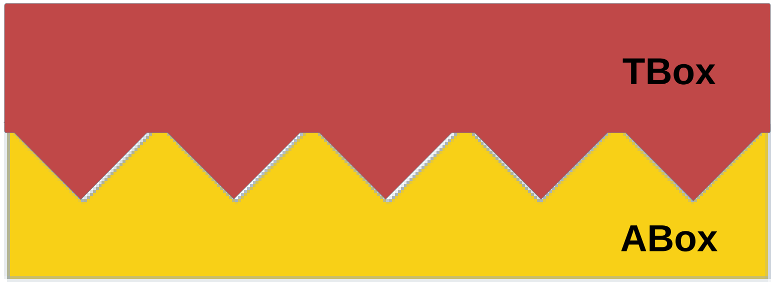
2 University of Aberdeen, UK

SWESE Oct 24, 2011

DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

Why Ontology-Driven Requirements Engineering (ODRE)?

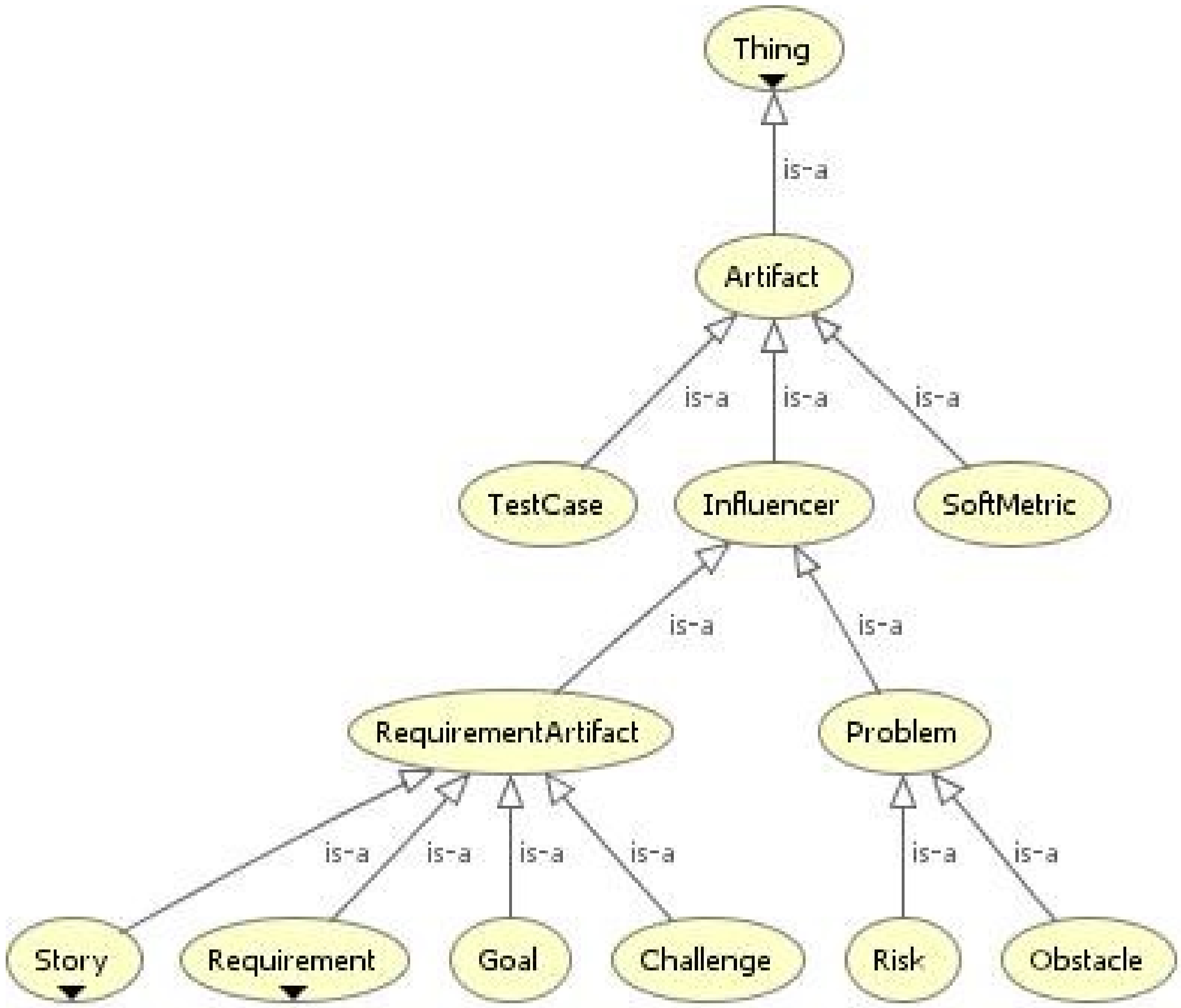
- Objective: Trace **goals from a goal model** to **requirements** to **designs** and **domain models**
- Use graph-logic isomorphism to store requirements and their requirement types in logic, more precisely, in an OWL ontology
  - Provide a metamodel (T-Box of requirements ontology) with a huge set of relevant metadata and requirement relationships
- Use reasoning services to
  - provide meaningful checks for completeness and consistency, e.g., as queries to the A-Box with SparQL
  - Make specific suggestions to repair inconsistencies and incompleteness
- Ontology consists of T- and A-Box
  - TBox (Terminological Box) provides metadata
  - ABox (Axiom Box, Fact Base) provides requirements, goals, relationships,...



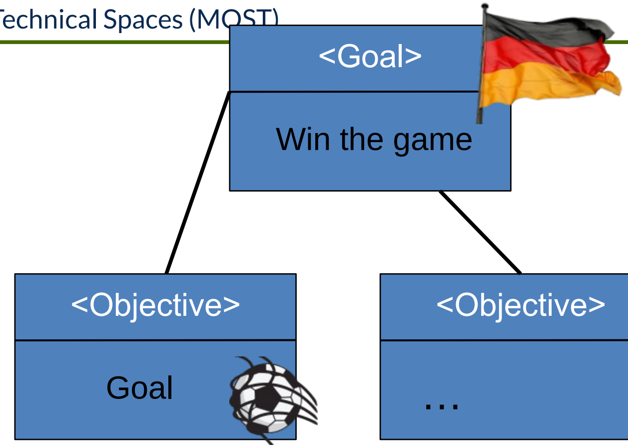
ODRE Needs Goal-Oriented RE (GORE)

- Lamsweerde defines **goals** as "declarative statements of intent to be achieved by the system under consideration" [Lamsweerde2000]
- Benefits of explicit specification of goals in GORE:
  - Goals drive the identification of requirements
  - Goals provide a criterion for sufficient completeness of a requirement specification
    - Specification of pertinent requirements
    - Relationships between goals and requirements can help to choose the best one
  - Concrete requirements may change over time whereas goals pertain stable

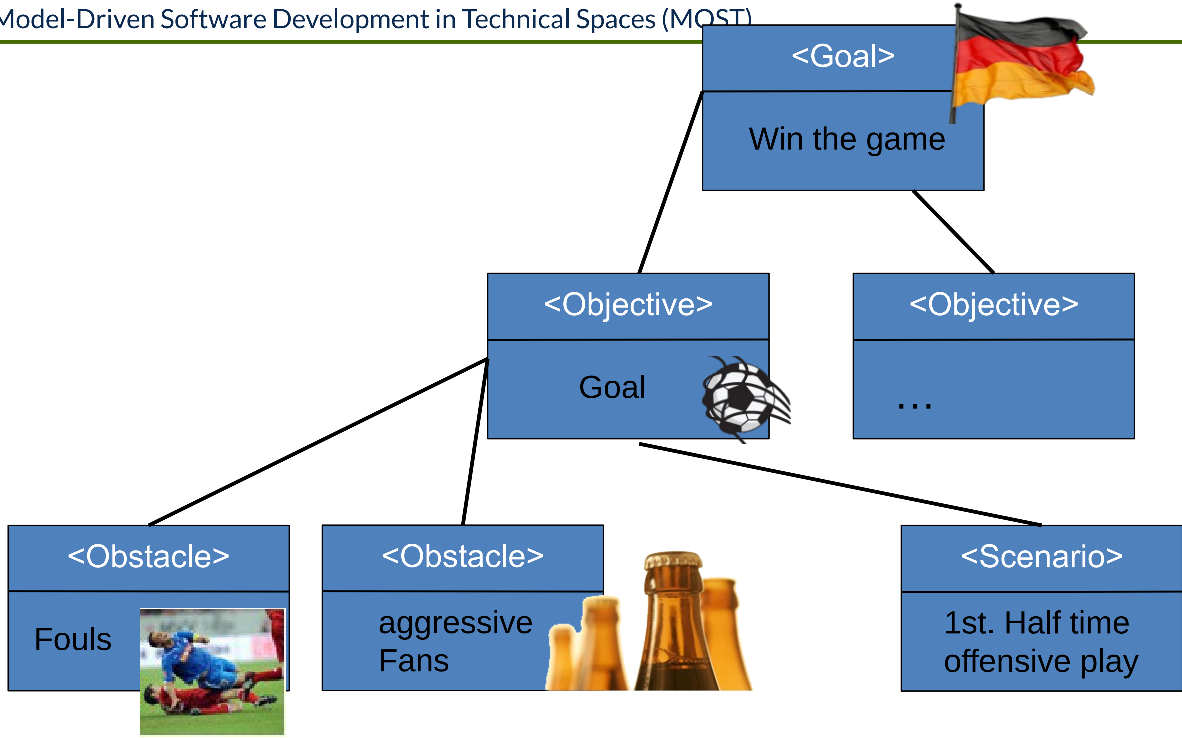
Goal-Oriented Requirements Engineering (GORE) – TBox of GORE Ontology



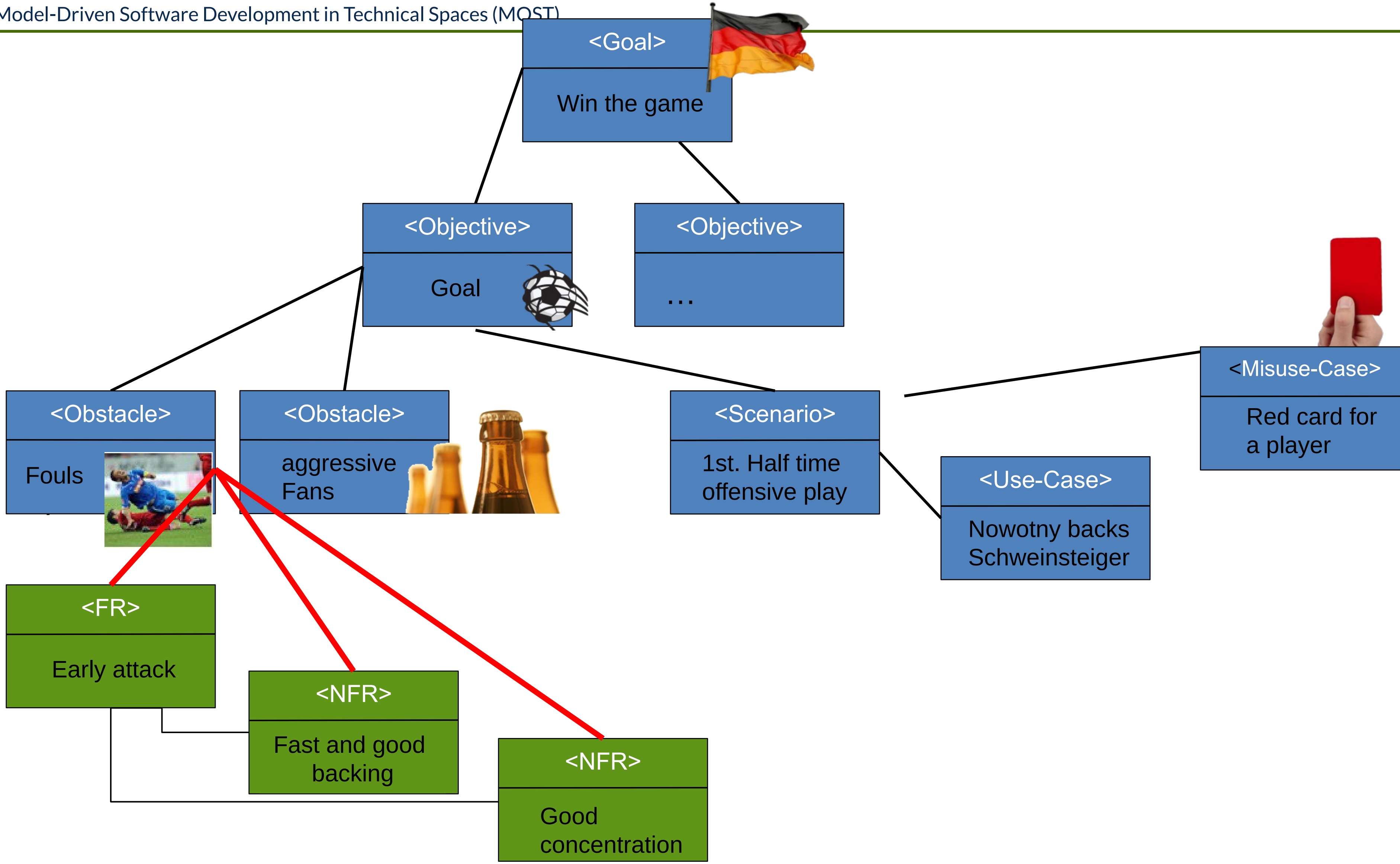
Goal-Oriented RE (Motivation Example)



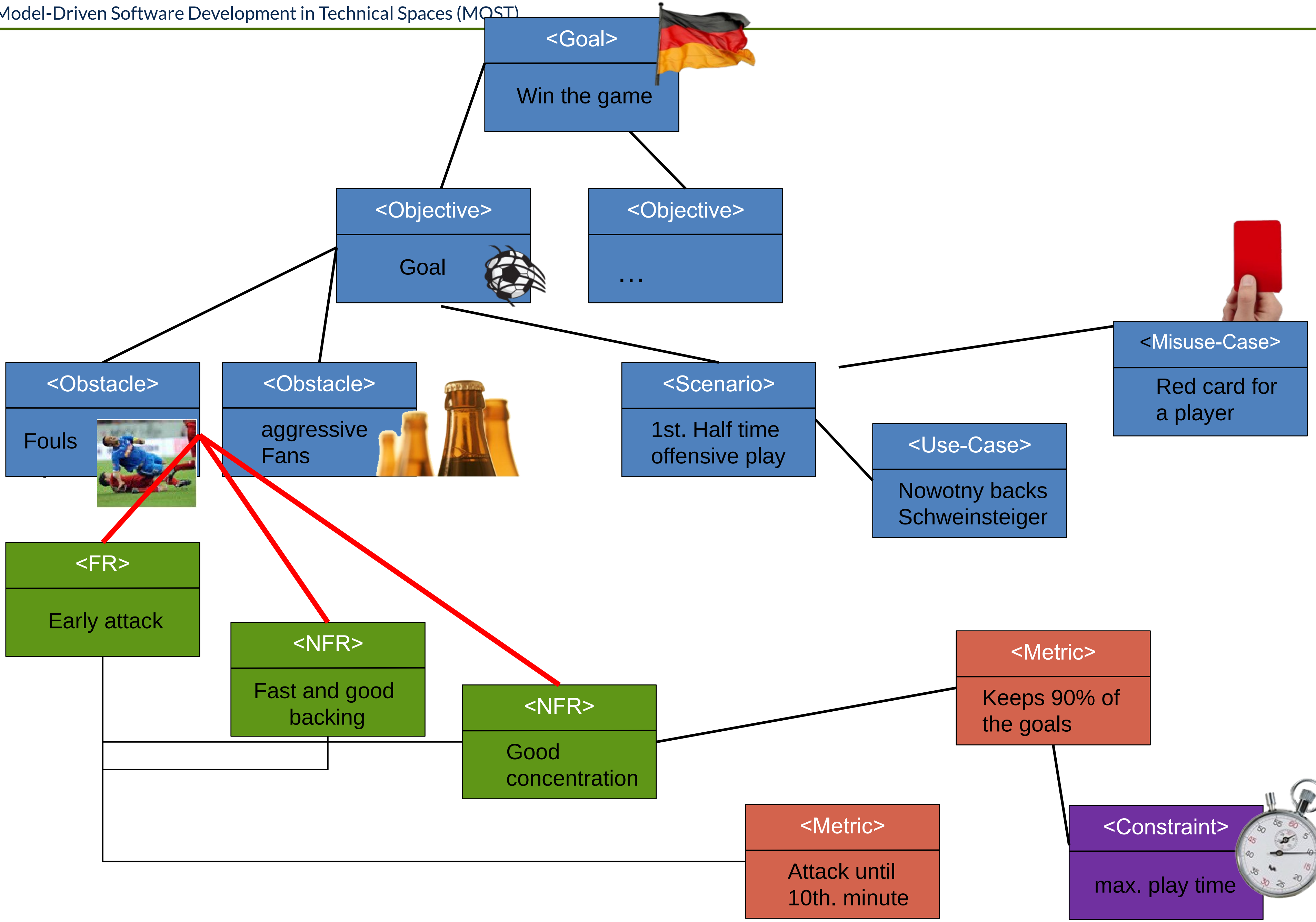
Goal-Oriented RE (Motivation Example)



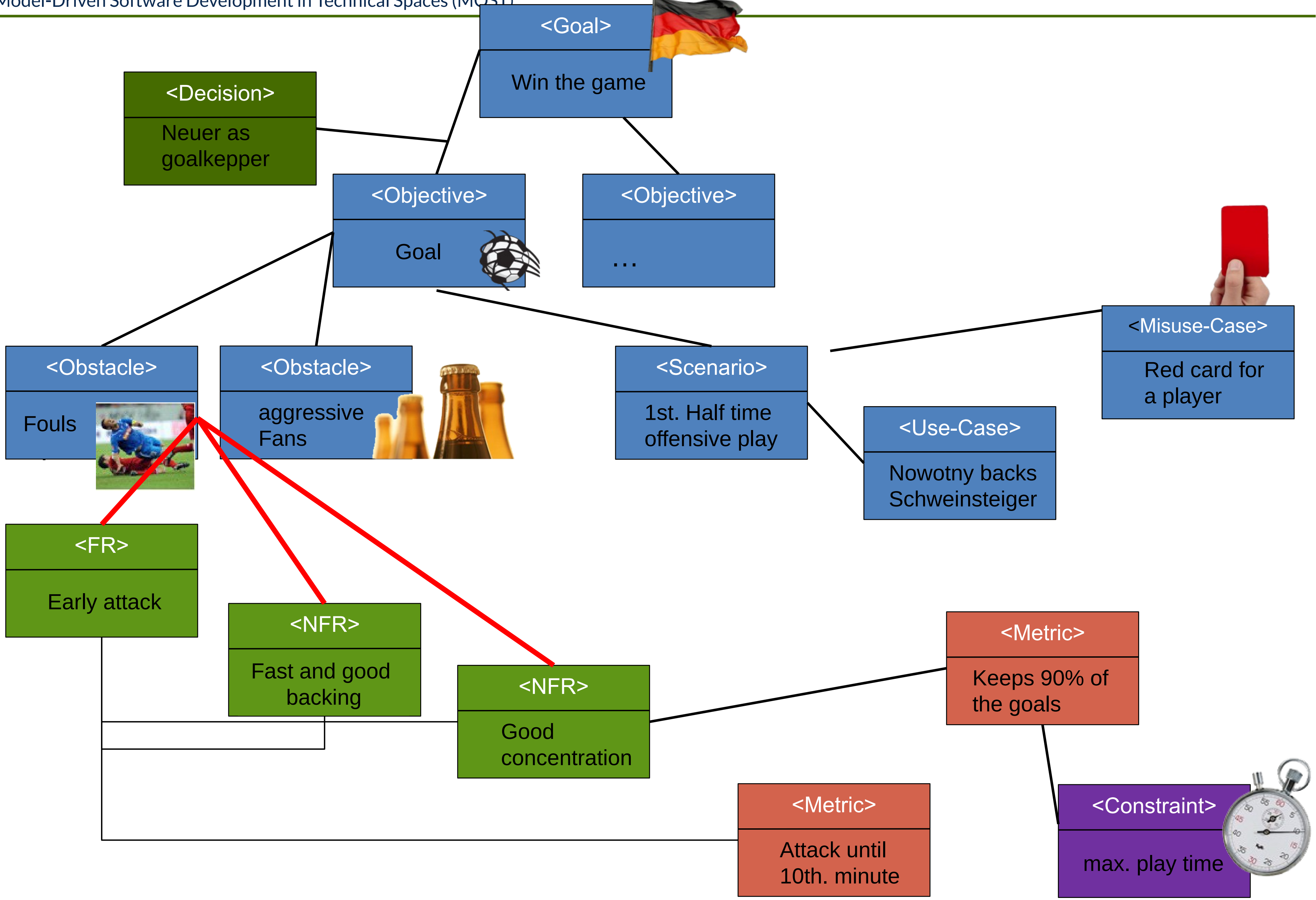
Goal-Oriented RE (Motivation Example)



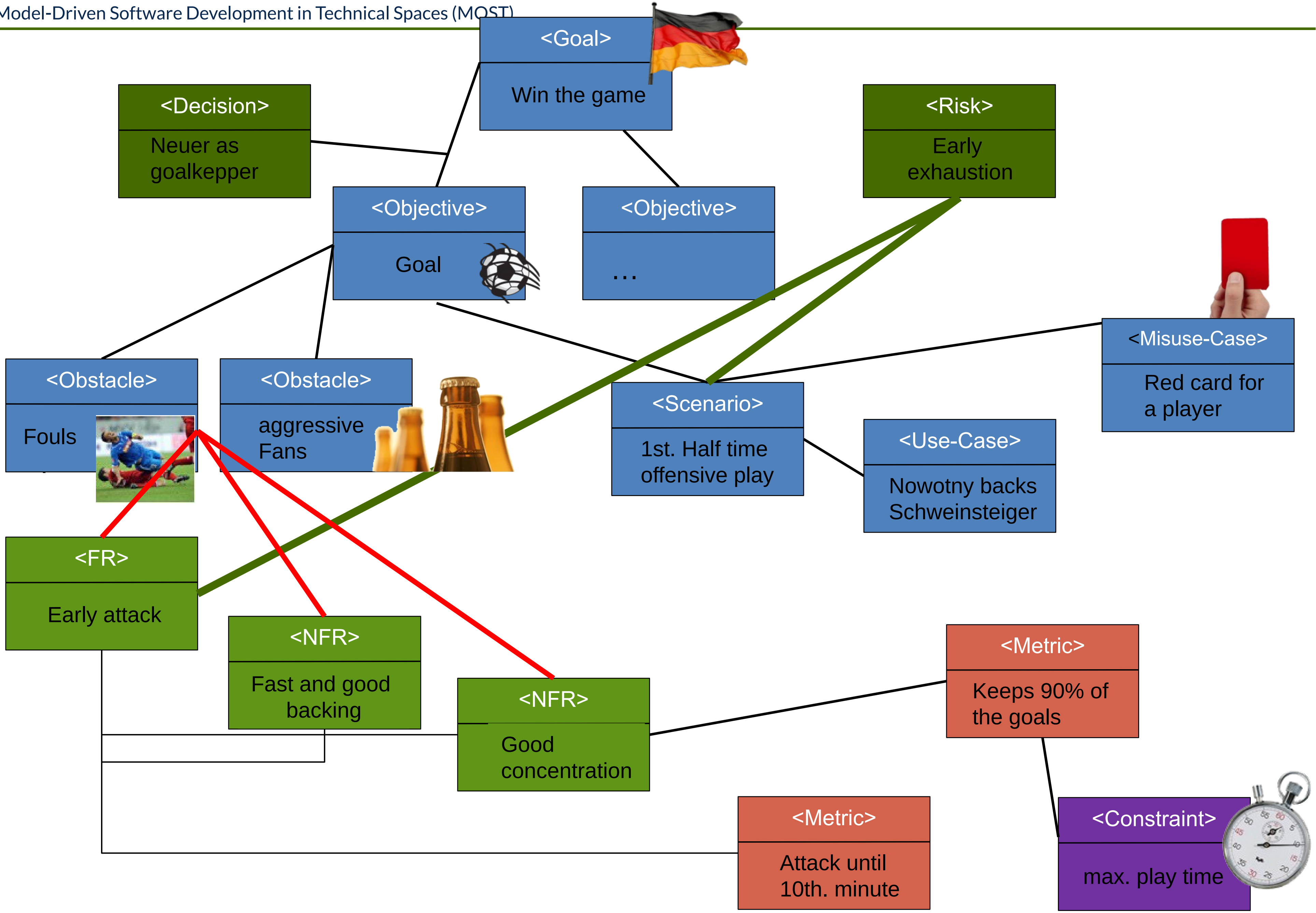
Goal-Oriented RE (Motivation Example)



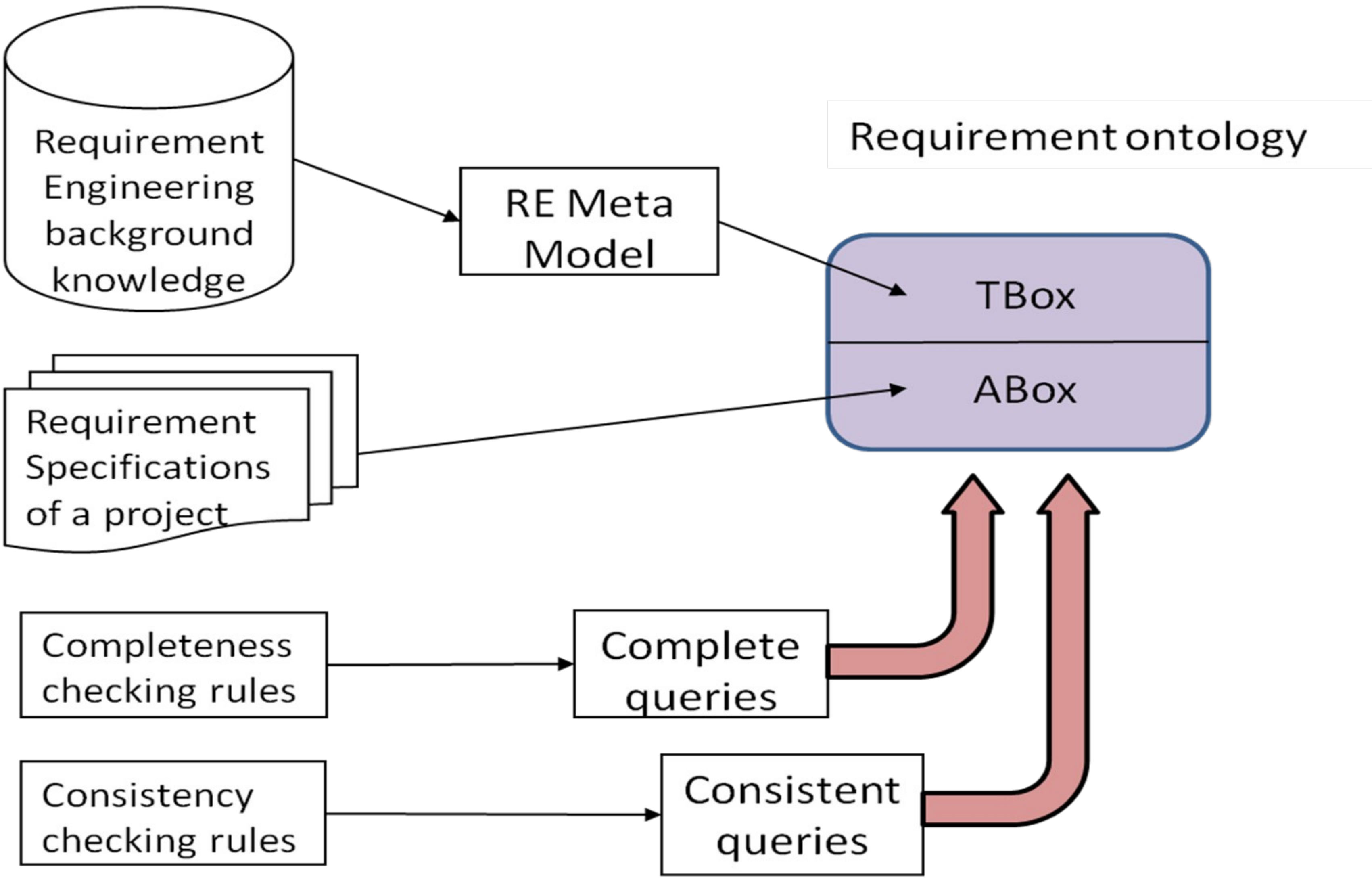
Goal-Oriented RE (Motivation Example)



Goal-Oriented RE (Motivation Example)



Architecture for ODRE Tool



Reasoning for RE – Completeness Check

- Example of Completeness Rule:

> "Every Functional Requirement (FR) must define whether it is mandatory or optional. "

- The GORE ontology of Lambsweerde needs about 50 completeness rules
  - Implemented as SPARQL queries on the A-Box
  - The requirements model is deemed incomplete if a specific rule fails
  - Reasoning Strategy: Closed World Reasoning (for negation as failure)
    - supported by SPARQL 1.1 and TrOWL reasoner

Reasoning for RE – Completeness Check (Example)

> "Every Functional Requirement (FR) must define whether it is mandatory or optional. "

- SPARQL rule:

```
IF FR is NOT mandatory AND NOT optional THEN
     Print error: "You did not specify whether
       the following FRs are mandatory or optional:
       [FR_n].“
      "Please specify whether these FRs are mandatory
       or optional."
```

Reasoning for RE – Completeness Check (Example)

- Extract of individuals and relationships of the A-Box from the SPARQL analysis :

  isRelatedTo(Goal2;UseCase7)
  NonFunctionalRequirement (NonFunctionalRequirement1)
  IsOptional(NonFunctionalRequirement1; true)
  FunctionalRequirement(FunctionalRequirement1)

```
Error.
You did not specify whether the following FR are mandatory or
optional:
FunctionalRequirement1. Please specify this attribute for the FR:
FunctionalRequirement1. Every FR must specify AT LEAST ONE
requirement relationship.
```

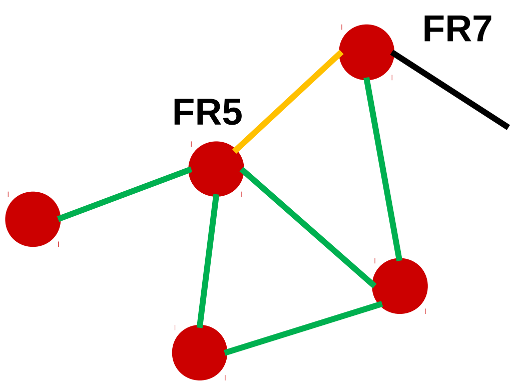
Reasoning for RE – Consistency Check

- GORE needs 6 consistency rules among requirement artefacts (valid relations between requirement artefacts)
  - Based on a chosen subset of requirement artefacts
  - Consistency rules are encoded as DL axioms in the A-Box
- Instance specific error messages resulting from validation displayed by Guidance Engine

Reasoning for RE – Consistency Check (Example)

- Extract of individuals and relationships of the A-Box from the SPARQL analysis :

isExclusionOf (FunctionalRequirement5; FunctionalRequirement7)
ChosenRequirement(FunctionalRequirement5)
ChosenRequirement(FunctionalRequirement7)




```
Error.
The following requirements exclude others:
FunctionalRequirement5.
Please choose one of the following options:

Suggestion.
Exclude the following requirements from the chosen requirement
set: FunctionalRequirement5. OR
Find alternatives for: FunctionalRequirement5 or
Revise the requirement relationships of(FunctionalRequirement5,
FunctionalRequirement7).
```

Reasoning for RE – Verification Methods (Example)

- **Consistency check of requirement selection (6 rules)**

Excluding requirements must not be included in one set.

```
IF excluding requirements are included in one set
THEN print error: "The following requirements exclude
    Others: [R_n]."
"Please choose one of the following options:
Exclude the following requirements: [R_n],
Find alternatives for [R_n] or
Revise the requirement relationships of [[R x, R y],... ]."
```

Status of ODRE

- All Requirement artefacts and meaningful relationships can be captured within an Ontology Metamodel
- ODRE Approach detects **inconsistent** and **incomplete** requirements
- Standard tooling (reasoners) are useful
  - Specification of requirements uses OWA
  - Verification needs CWA
- First evaluation proves applicability for medium requirement specifications
  - Problem: available requirement specifications do not provide sufficient information (much less than could be captured by ODRE)
  - Primary evaluation within MOST Project
    - Capture all requirement artefacts
    - Detect all inconsistencies and incomplete metadata
  - PhD Thesis of Katja Siegemund (2014)

The End