12. An Overview of Technical Spaces

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1) Technical spaces
2) Model Management
3) Model Analysis
4) Mega- and Macromodels
5) Bridging Technical Spaces and Software Factories

Literature

- Regina Hebig, Andreas Seibel, Holger Giese. On the Unification of Megamodels. Electronic Communications of the EASST, Volume 42: Multi-Paradigm Modeling 2010, ISSN 1863-2122, TU Berlin
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Secondary Literature

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12.1 Technological & Technical Spaces

Technological Spaces

A ***technological space*** is a working context with a set of associated concepts, body of knowledge, tools, required skills, and possibilities.

- It is often associated to a given user community with shared know-how, educational support, common literature and even workshop and conference regular meetings.
  - Ex. compiler community, database community, semantic web community, automotive community
  - [Technological Spaces: an Initial Appraisal. Ivan Kurtev, Jean Bézivin, Mehmet Aksit. CoopIS, DOA'2002 Federated Conferences, Industrial Track. (2002) http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.109.332&rep=rep1&type=pdf]

Technical Spaces

A ***technical space*** is a metamodeling framework (in a technological space) with a metapyramid (metahierarchy), accompanied by a set of tools that operate on the models definable within the framework.

- [Model-based Technology Integration with the Technical Space Concept. Jean Bezivin and Ivan Kurtev. Metainformatics Symposium, 2005.]
  - http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.106.1366&rep=rep1&type=pdf
- Ingredients of a Technical Space (Technikraum):
  - A **metapyramid** (or **metahierarchy**) with data (tools, workflows, and materials on M0), Code and models (M1), languages (M2), and metalanguages (M3)
  - A **model management unit** (**model algebra** or **model composition system**)
  - **Multimodeling facilities** for **mega**- and **macromodels**
- Be aware: A technological space may contain several technical spaces:
  - Compiler community: Grammarware, Tree-Ware, Graph-Ware
  - Database community: Relational database model, csv-tables, XML
  - Business software: Reports in TextWare, TableWare

The Trick of the Metapyramid

Observation:
In the metapyramid of a technical space, tools can be applied on every level.

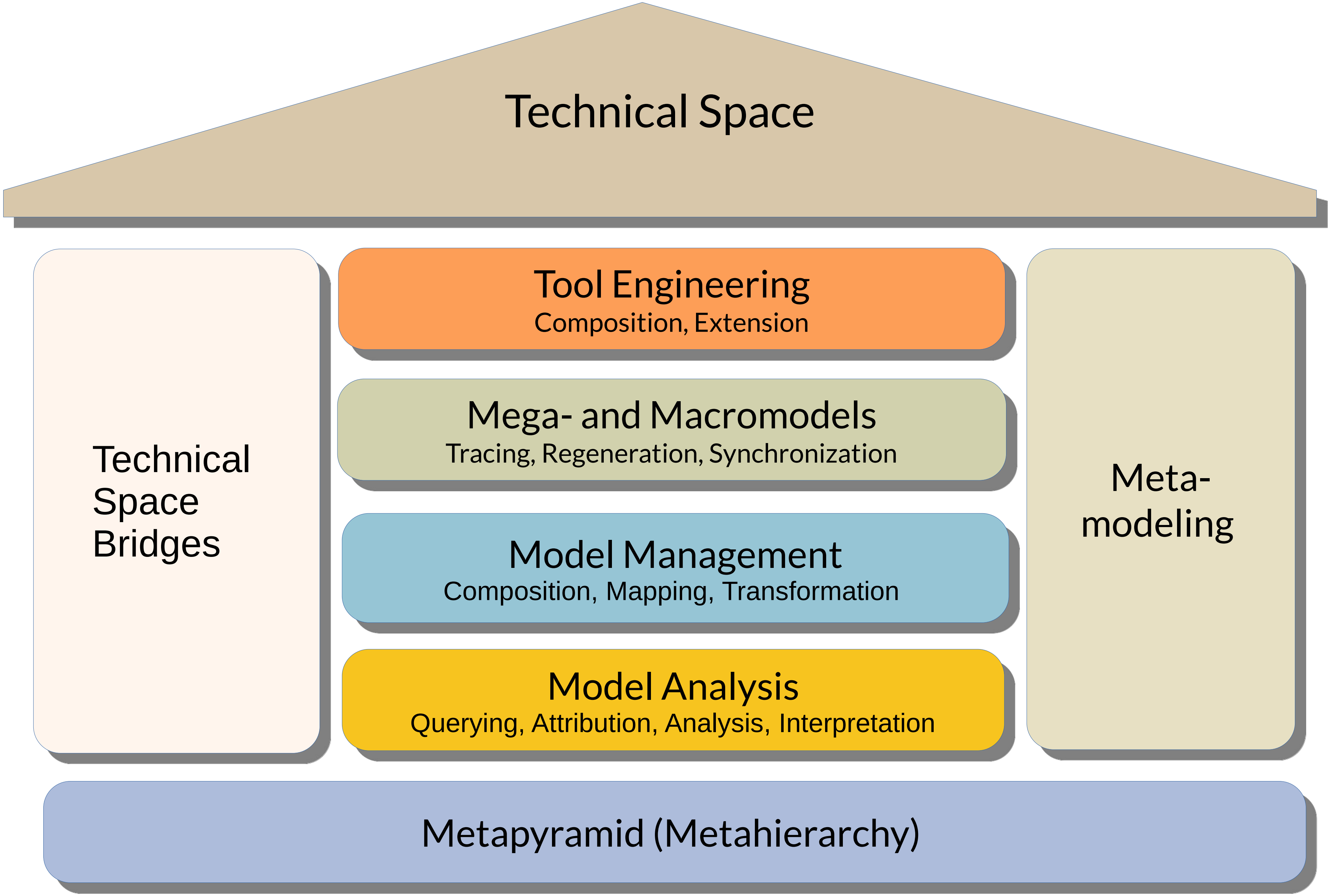
- **Level-independence:** Tools on level M[n-1] can work on M[n]
- Tools can be *lifted* from the object to the class to the metaclass level to the metametaclass level:
- **Object-manipulating tools** on M0 work for clabjects in models on M1
  - Graph-manipulating tools on M0 for models on M1
- **Class-manipulating tools** on M1 work for clabjects in metamodels on M2
  - Model-manipulating tools on M1 work for metamodels on M2
- **Metaclass-manipulating tools** on M2 work for clabjects in metamodels on M3
  - Metamodel-manipulating tools on M2 work for metametamodels on M3

Multimodeling in a Technical Space

Multimodeling is the act of combining diverse models.
[Brooks-Lee-Hanxleden]

- Model management
  - Model transformation
  - Model composition
- Multi-model management
  - Model mappings
  - Model relations
  - Model tracing
  - Model refinements
  - Model extensions

Q10: The House of a Technical Space



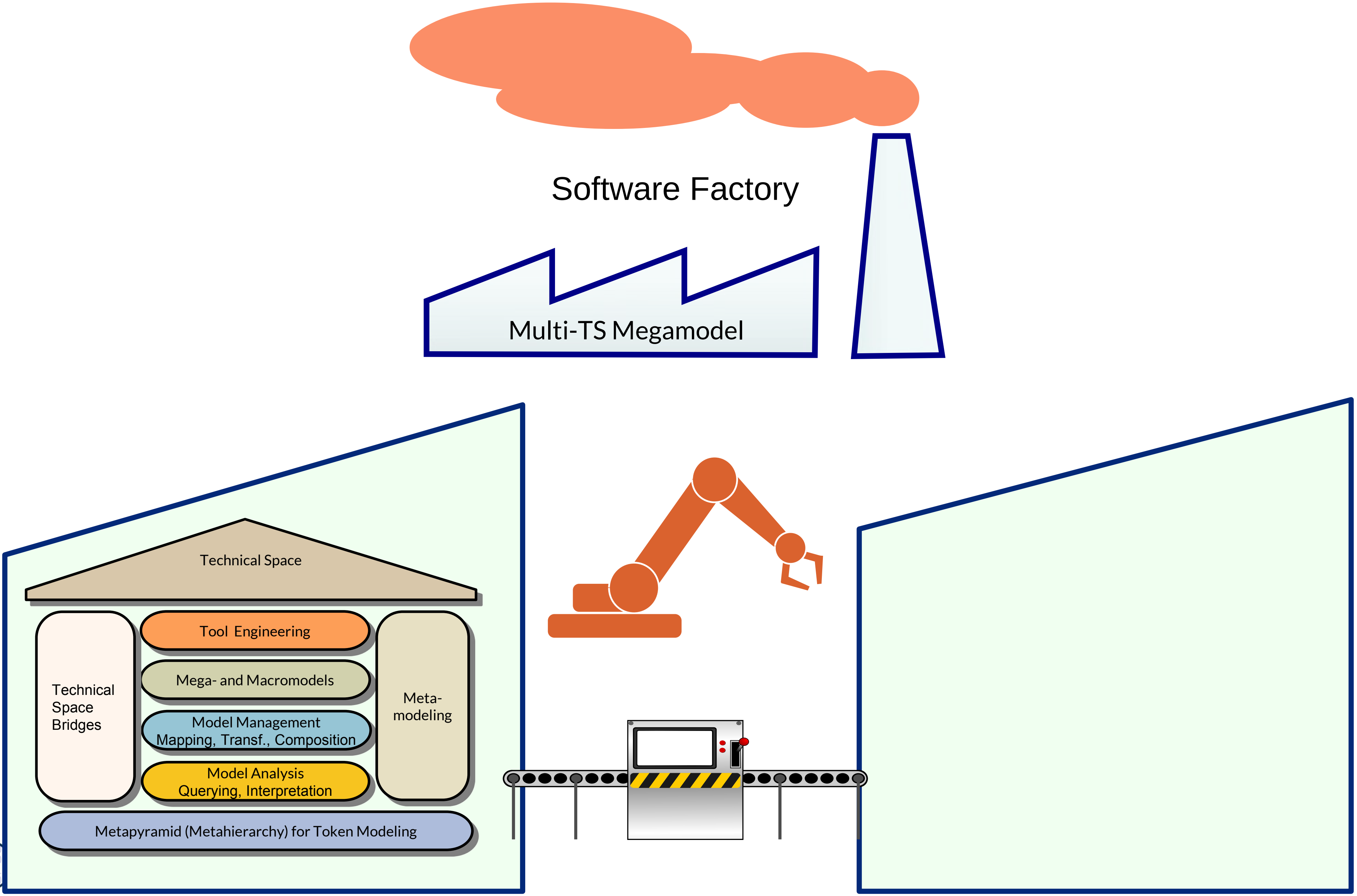
Software Factories (Old, somewhat superficial definition in literature)

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

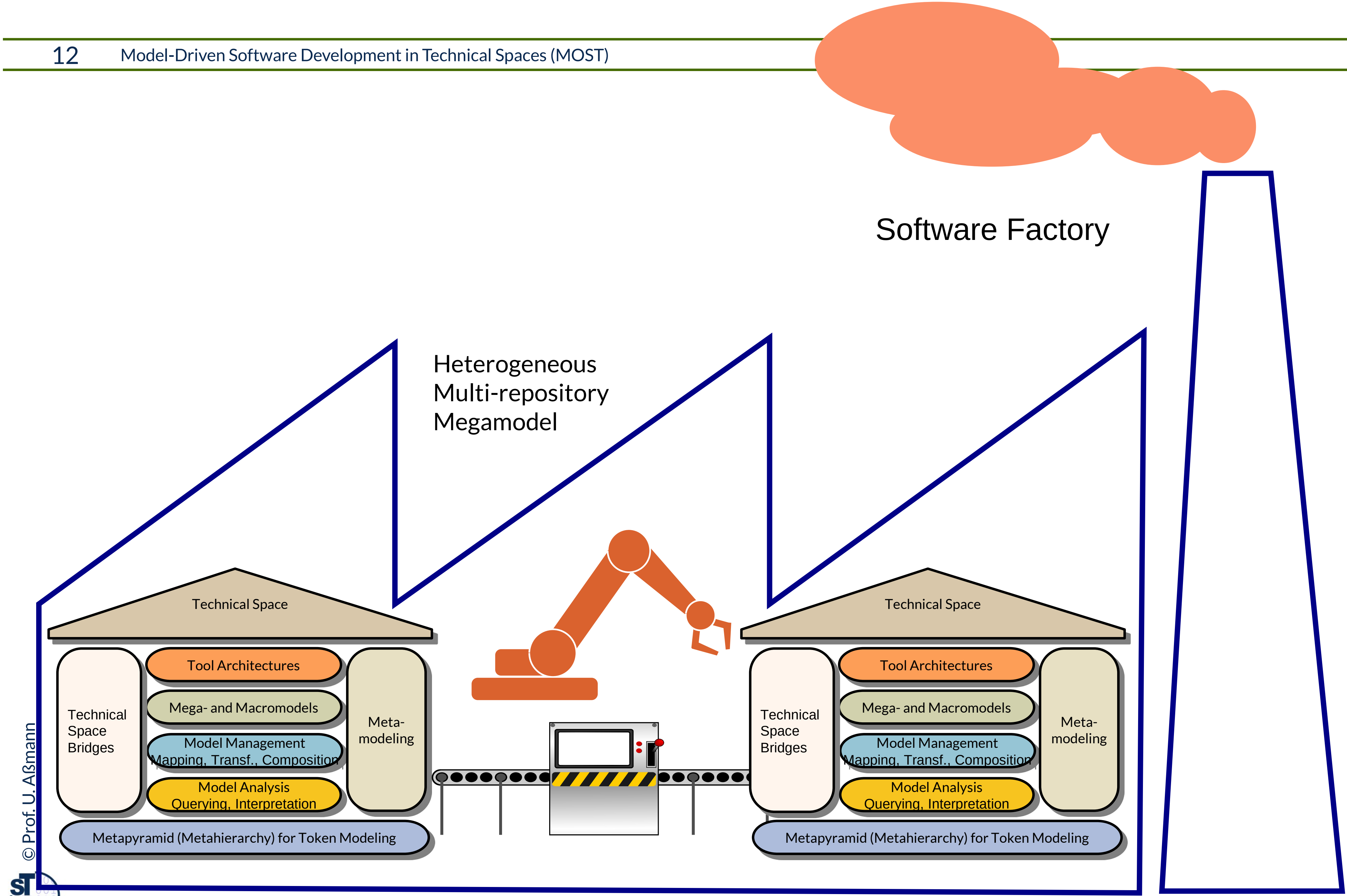
Jack Greenfield

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

Software Factories with Only 1 Technical Space



Q13: A Software Factory's Heart: the Multi-TS Megamodel



Q10: Overview of Technical Spaces in the Classical Metahierarchy

	Grammarware (Strings)	Text-ware	Table-ware		Treeware (trees)			Graphware/ Modelware			Role-Ware	Ontology-ware
	Strings	Text	Text-Table	Relational Algebra	NF2	XML	Link trees	MOF	Eclipse	CDIF	MetaEdit+	OWL-Ware
M3	EBNF	EBNF		CWM (common warehouse model)	NF2-language	XSD	JastAdd, Silver	MOF	Ecore, EMOF	ERD	GOPPR	RDFS OWL
M2	Grammar of a language	Grammar with line delimiters	csv-header	Relational Schema	NF2-Schema	XML Schema, e.g. xhtml	Specific RAG	UML-CD, -SC, OCL	UML, many others	CDIF-languages	UML, many others	HTML XML MOF UML DSL
M1	String, Program	Text in lines	csv Table	Relations	NF2-tree relation	XML-Documents	Link-Syntax-Trees	Classes, Programs	Classes, Programs	CDIF-Models	Classes, Programs	Facts (T-Box)
M0	Objects	Sequences of lines	Sequences of rows	Sets of tuples	trees	dynamic semantics in browser		Object nets	Hierarchical graphs	Object nets	Object nets	A-Box (RDF-Graphs)

12.2. Model Analysis in a Technical Space with Model Querying, Model Metrics, and Model Analysis

Discussing the internals of models and their model elements

The Internals of a Model

Model analysis techniques reveal the inner details of models.

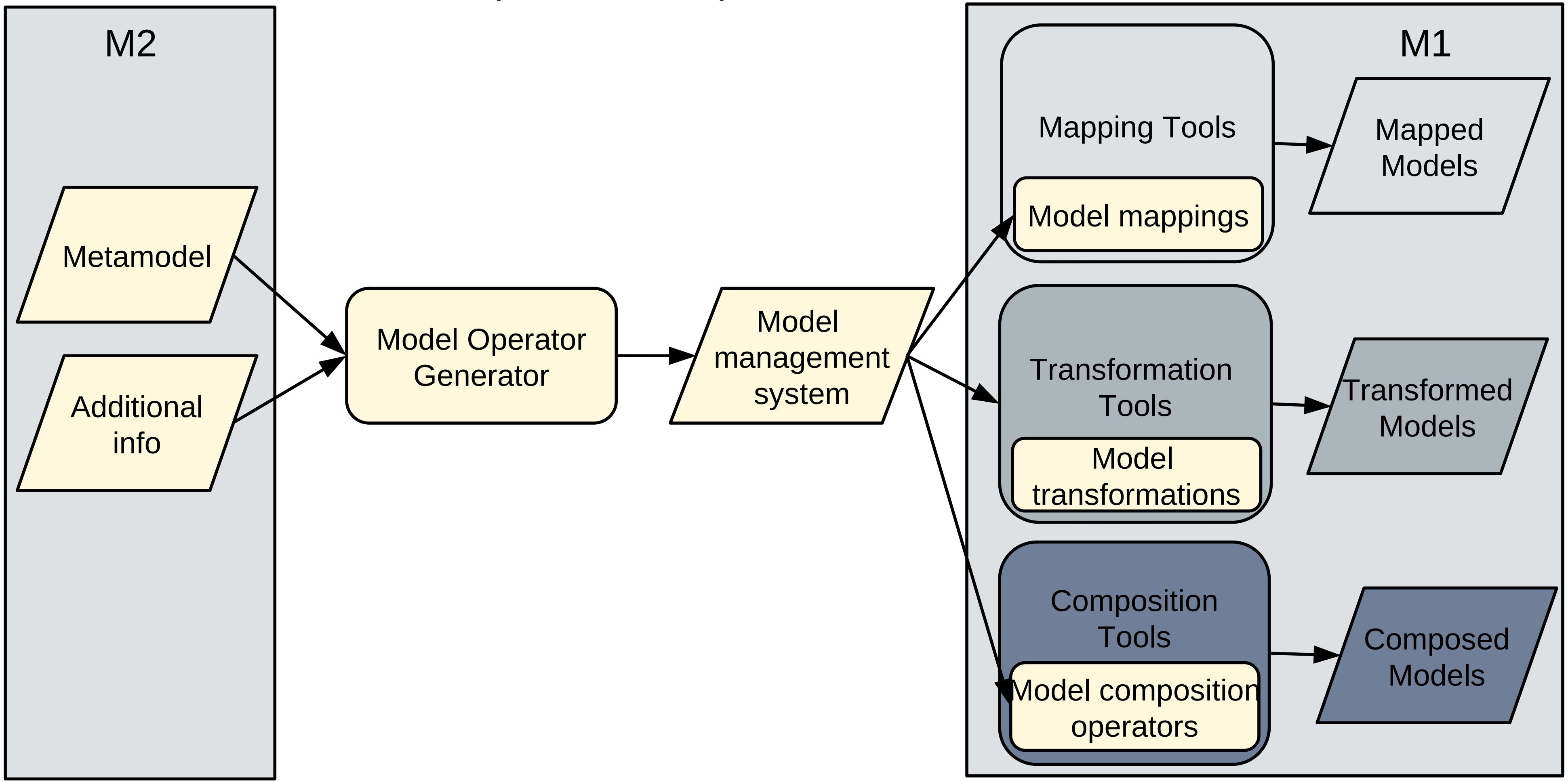
- **Model querying** searches patterns in models, described by a query or pattern match expression.
  - Searching for a method with a specific set of parameters
- **Model metrics** counts patterns in models
  - Counting the depth of the inheritance hierarchy
- **Model analysis** analyzes hidden knowledge from the models, making implicit knowledge explicit
  - Collecting information from the context to local neighborhood
- **Model deep analysis** interprets models
  - Value flow analysis between variables in programs

12.3. Model Management in a Technical Space with Model Mapping, Transformation and Composition

Discussing the relationships of models and their model elements

Model Management in a Technical Space

- A ***model management system*** *manages the relationships of models*, metamodels, metametamodels of a technical space as well as the relationships of their elements
  - Model mapping subsystem
  - Model transformation subsystem
  - Model composition subsystem

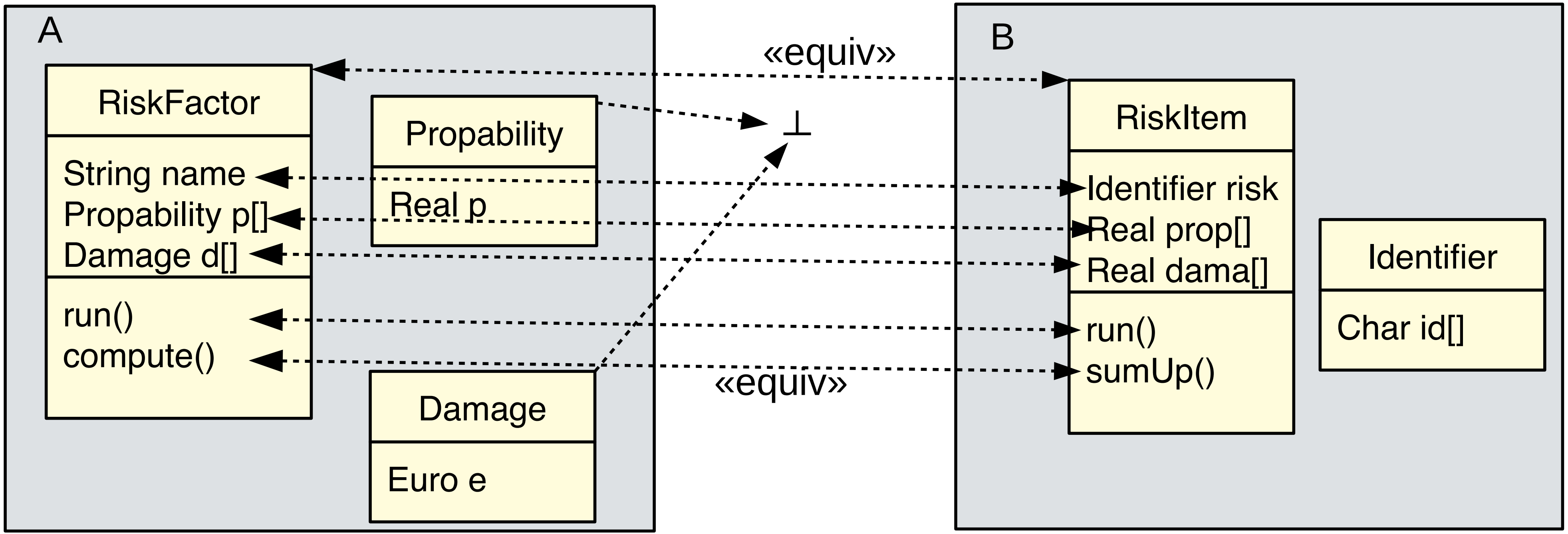


12.3.1. Model Mapping

Model Mappings

A ***model mapping*** is a mapping between the model elements of several models.

- An **equivalence mapping** records equivalent model elements in two models
- A **trace mapping** records during a model elaboration, model restructuring or model transformation, *which model elements are copied from model A to model B, or created in B.*
- A **synchronization mapping** records *hot-links* model elements from model A to model B.

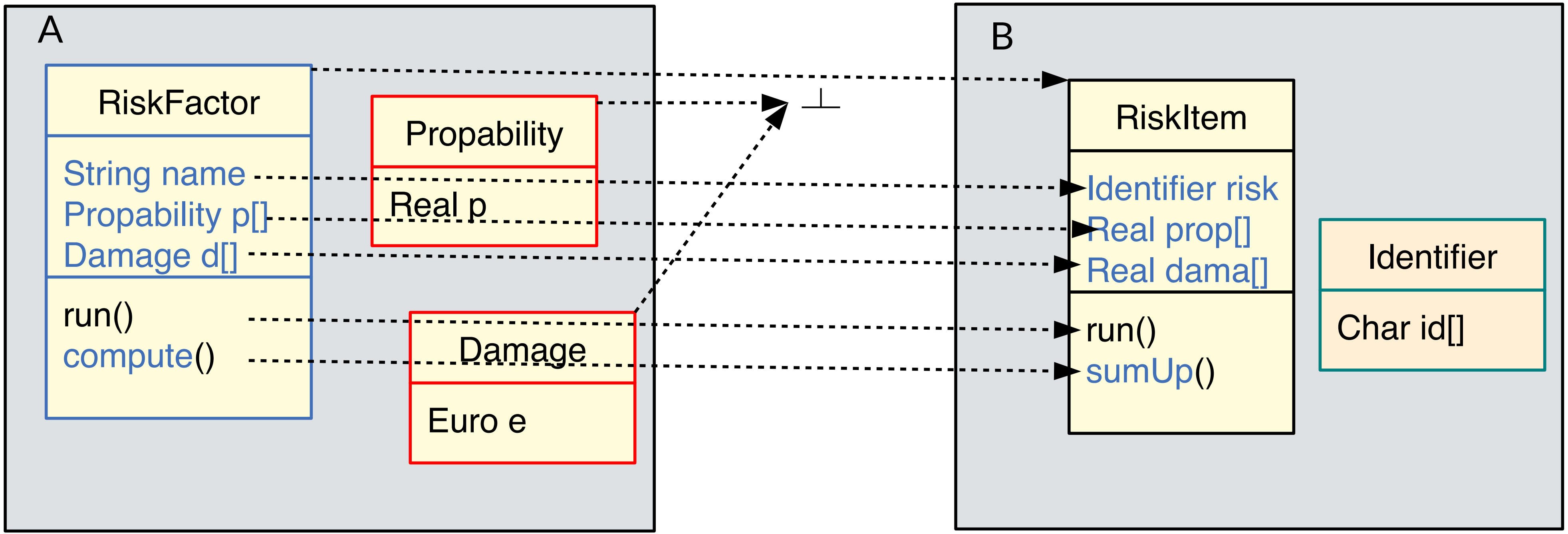


12.3.2. Model Transformation

Model Transformations

A ***model transformation*** is a program (or a specification how) to derive a model A from a model B.

- From a model mapping, two (partial) model transformations (forward and backward) may be derived.
  - Model transformation insert **trace mappings (links)** between the old and the new model elements
- Deleted model elements are framed red, added elements are framed green, modified

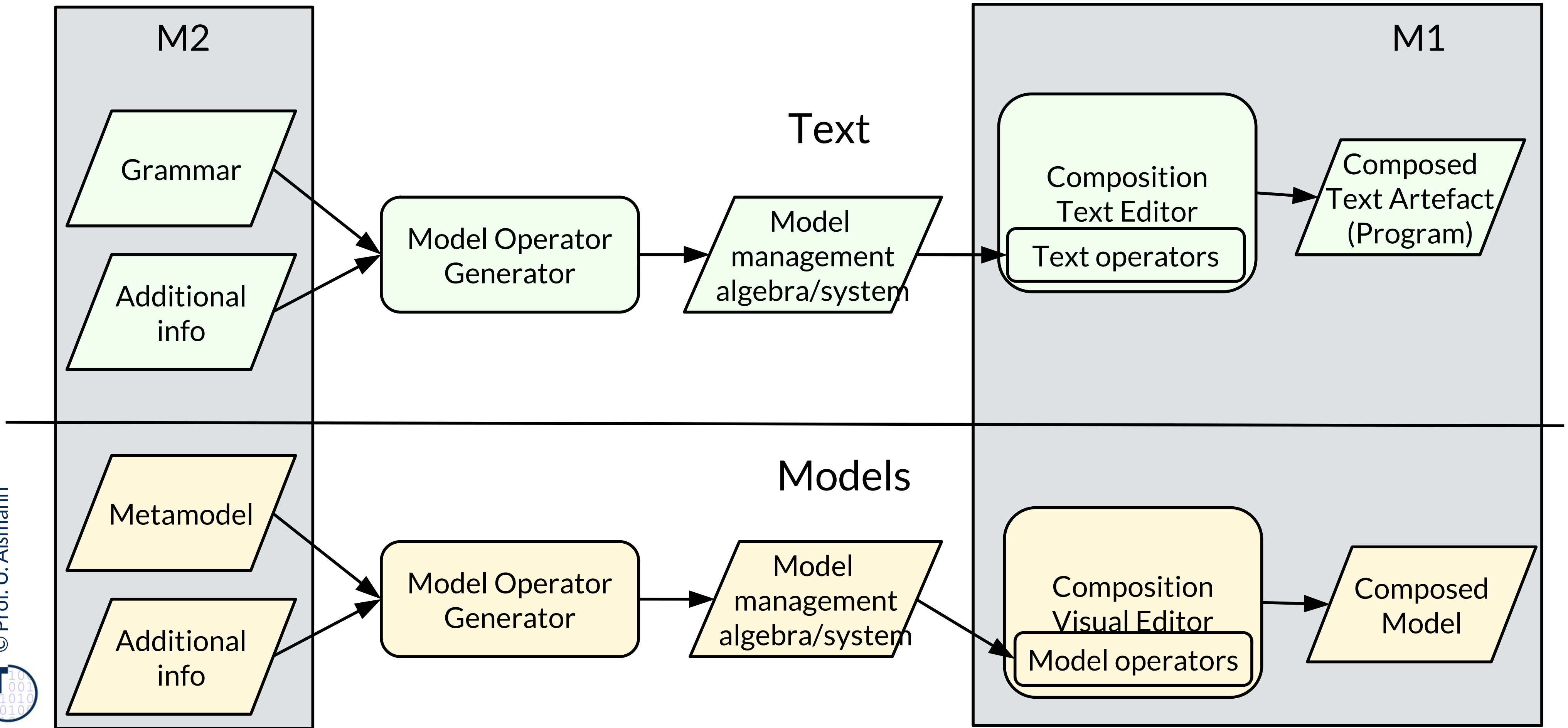


12.3.3. Model Composition with Model Algebrae and Composition Systems

Component-based Model Engineering (CBME)

Model Composition in a Technical Space

- A ***model composition system*** manages the relationships of models, metamodels, metametamodels of a technical space with a uniform model algebra
  - Operators on M1 can be generated from M2
  - Operators on M2 can be generated from M3

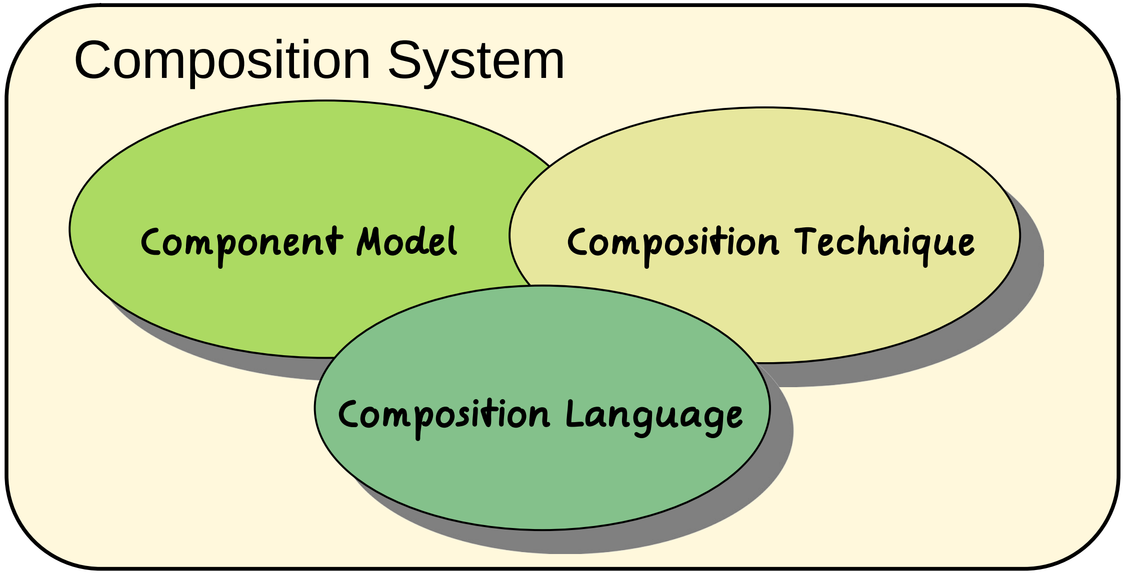


Simple Algebra for Models (on M1) and Metamodels (on M2)

- The most simple composition systems are *algebrae*, resulting in *algebraic composition.*
  - Models and metamodels can be grouped in packages (module)
  - A simple component model and composition system (see CBSE)
- Algebraic composition technique with operators on packages:
  - use (import) | merge (union) | Instance-of (element-of-reified-set)

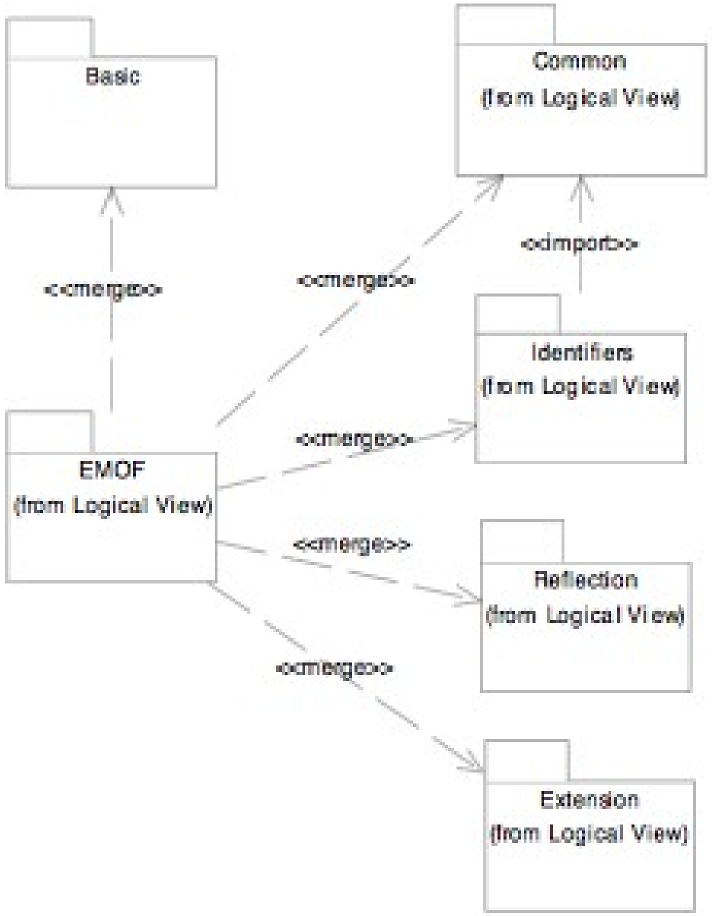
→ Metamodels are composed by unifying their views in the different packages

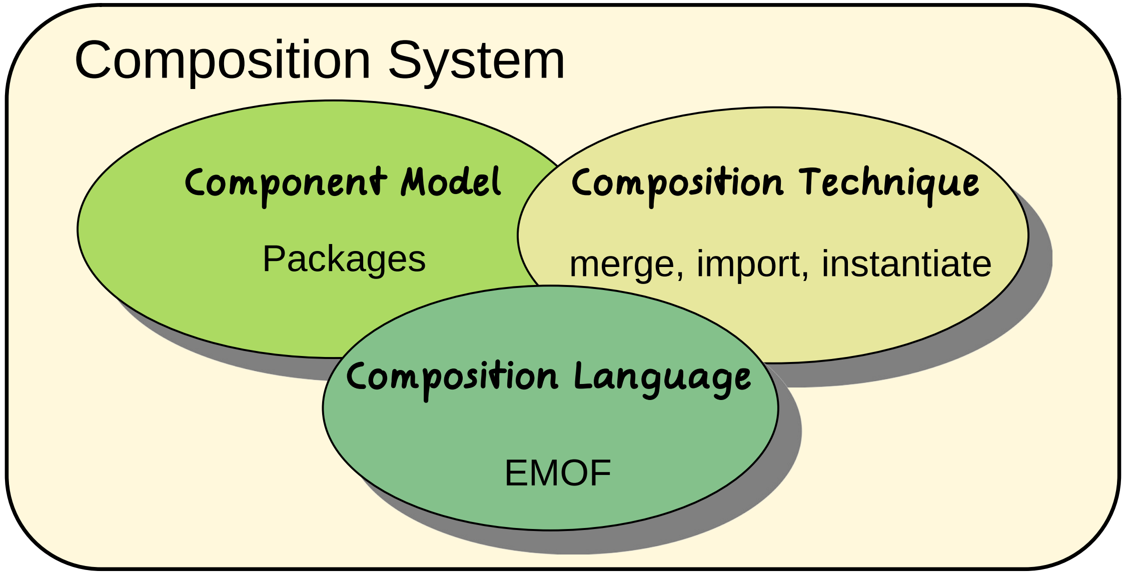
→ Metamodels can be composed from packages



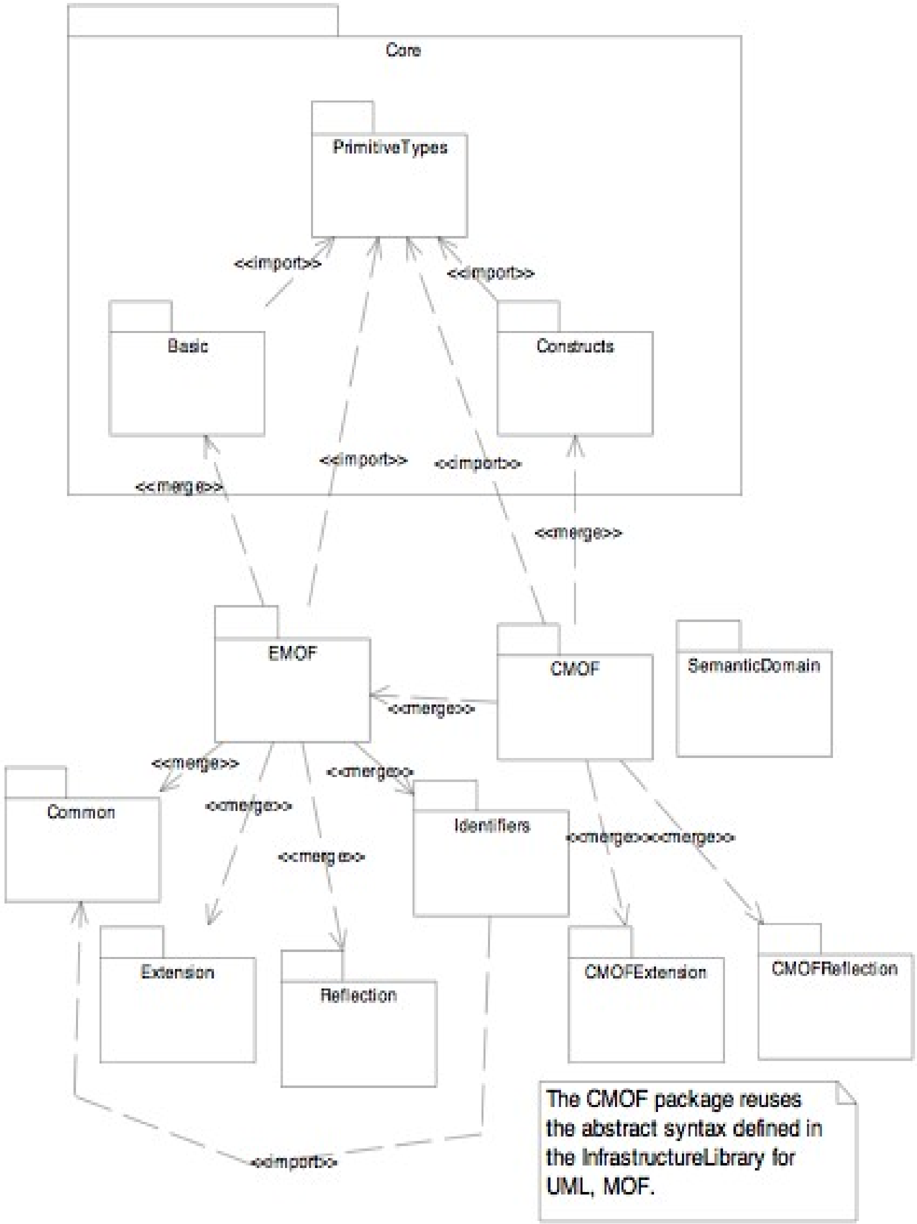
Ex.: EMOF Class Composition by EMOF Package Merge

[MOF]





Ex: CMOF Package Composition from UML Core and EMOF



[MOF]

12.3.4. Composing UML Metamodels in the MOF Technical Space

Benefit of UML-Metamodeling for MDSD Tools and Model-Driven Applications

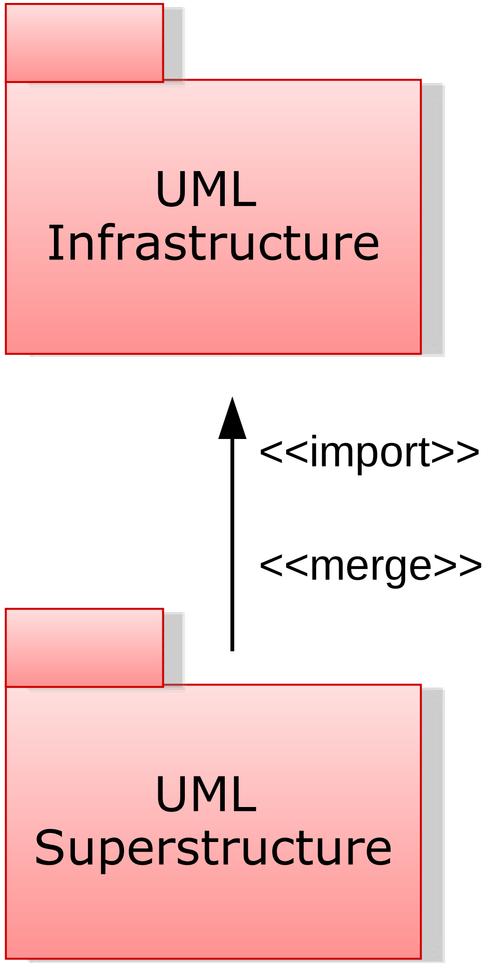
The language report of UML uses a simple metamodel algebra for the bottom-up composition of UML language.

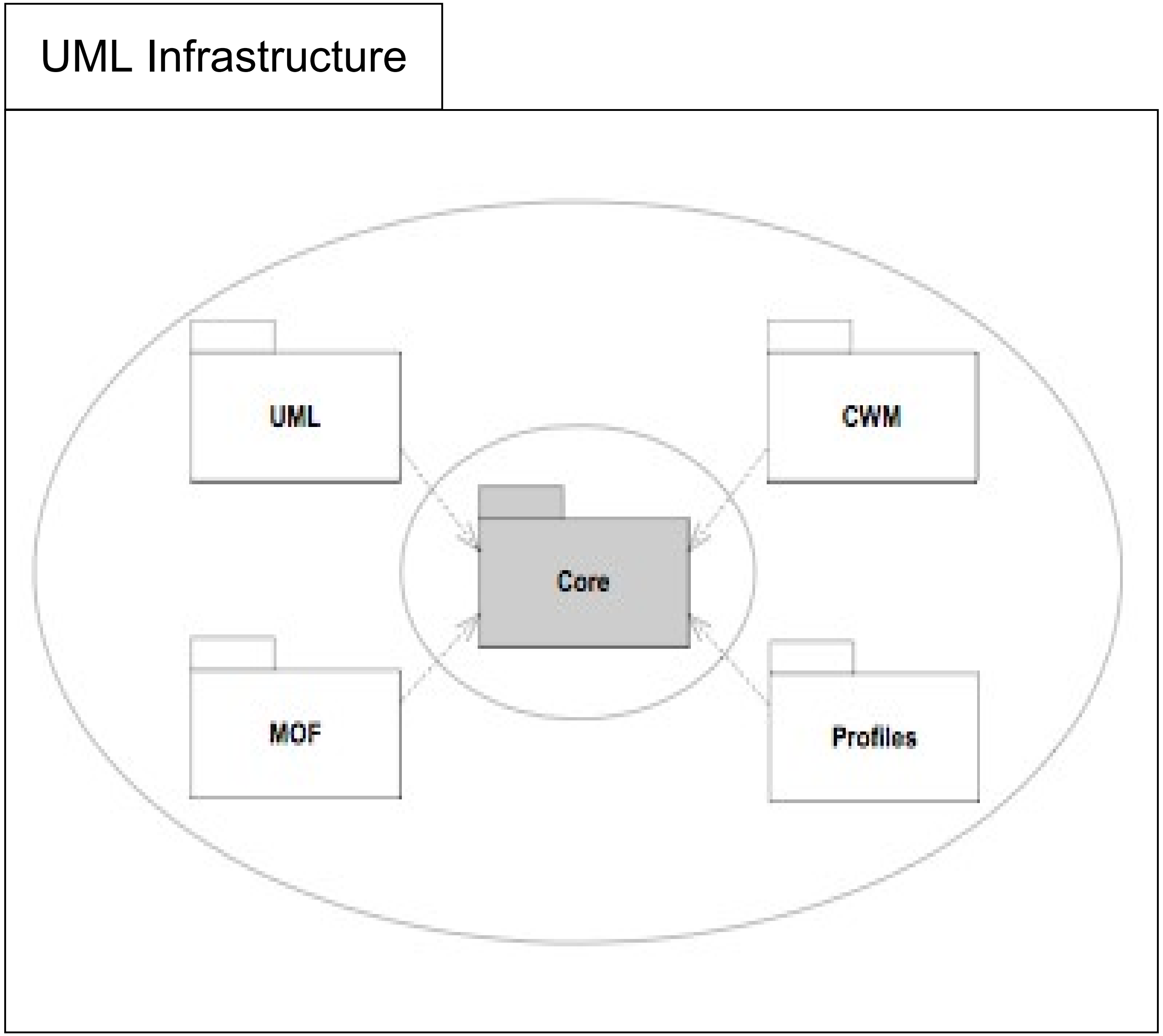
The UML-metamodel is a "logic" metamodel, because it is *composed:*

- Definition of merge operator composing metaclasses and metaclass-packages
- Defined in composable **packages**
  - With a clear **CMOF**-package architecture
  - uniform **package structure** and context-sensitive semantics for all diagrams such as Statecharts (UML-SC), Sequence Diagrams (UML-SD), etc.
- **Schemata for repositories** for uniform description of tools, materials, code, models (**metamodel-driven repositories)**
- **Exchange format** (XMI)

- The UML infrastructure can be used by MDSD applications

Coarse-Grain Structure of UML on M2





Packeting on all Layers

- All layers can be structed into packages

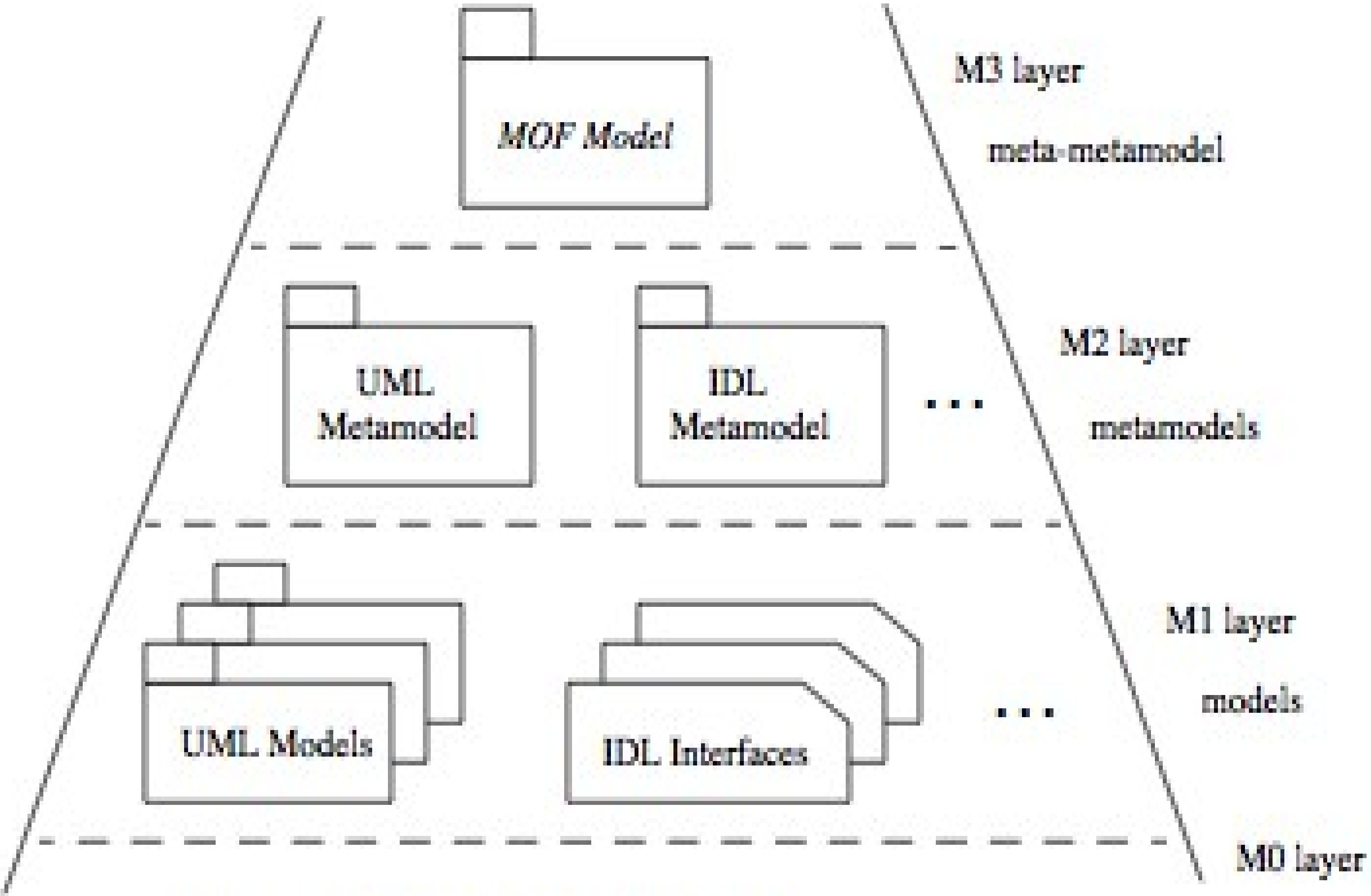
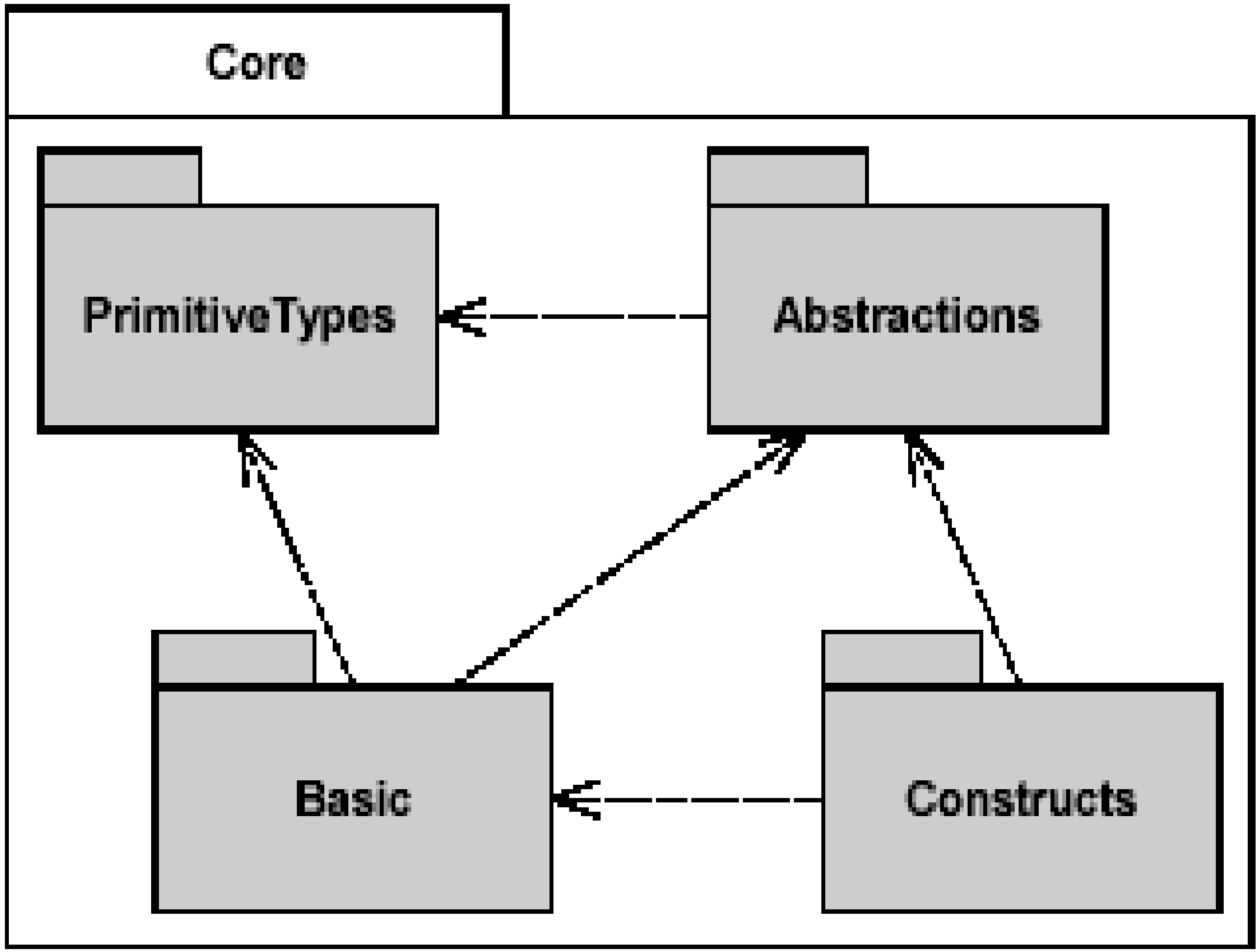


Figure 2-2 MOF Metadata Architecture

[MOF]

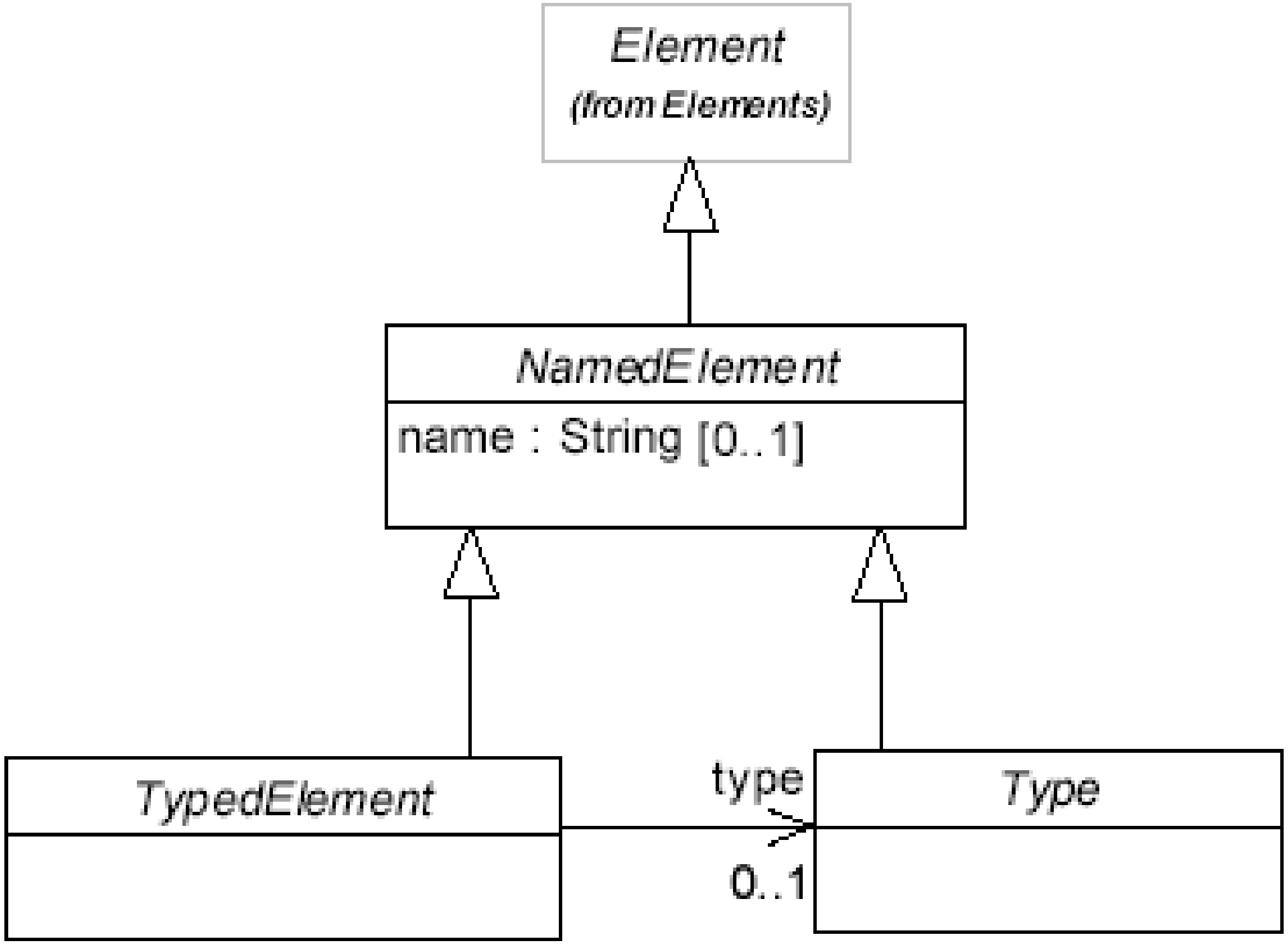
Core Package of the UML-Infrastructure Metamodel (M2)



Basic: basic constructs for XMI
Constructs: Metaclasses for modeling
Abstractions: abstract metaclasses
Primitive Types: basic types

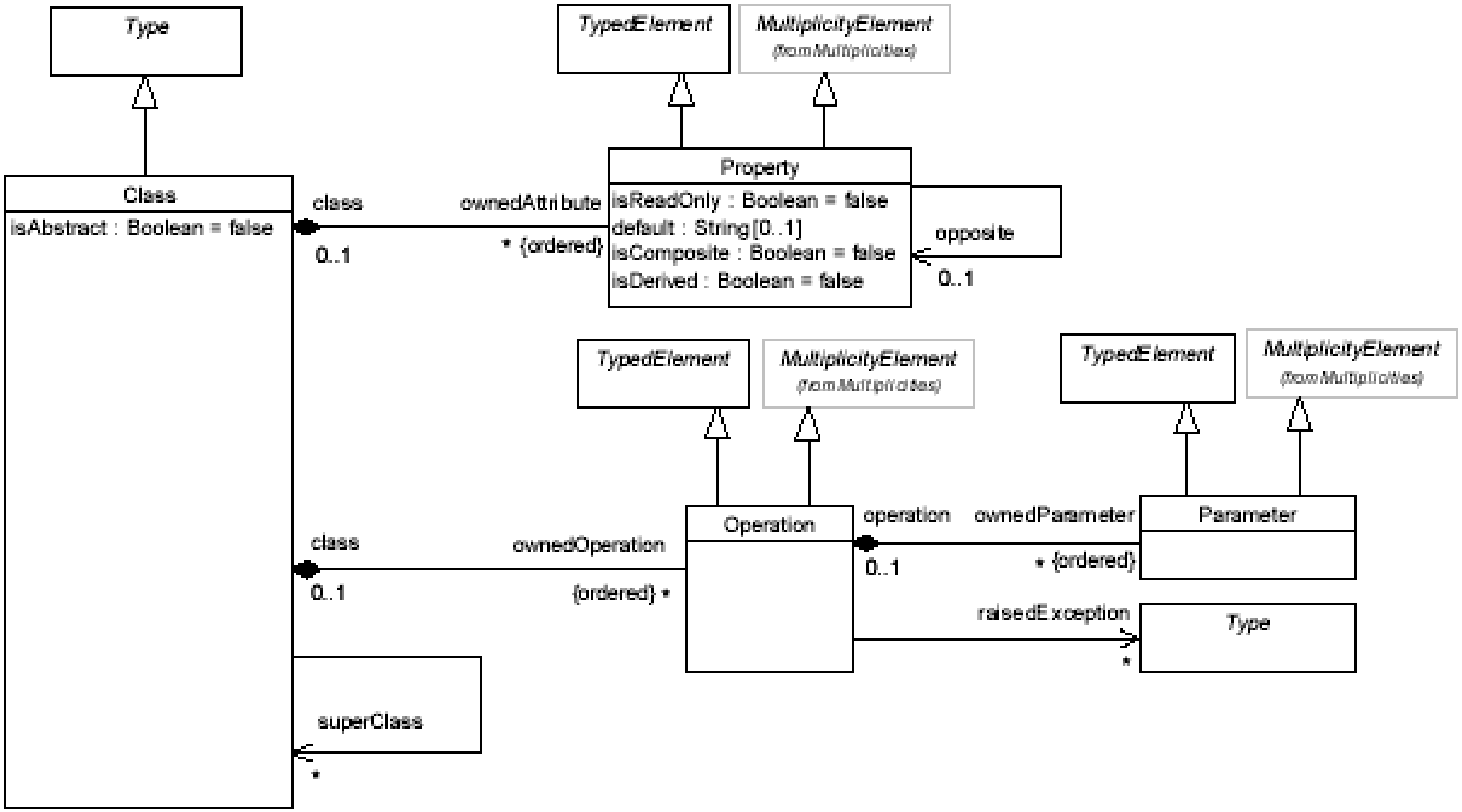
From: UML 2.0 Infrastructure Specification; OMG Adopted Specification ptc/03-09-15

Package Basic: Uses Types from CMOF



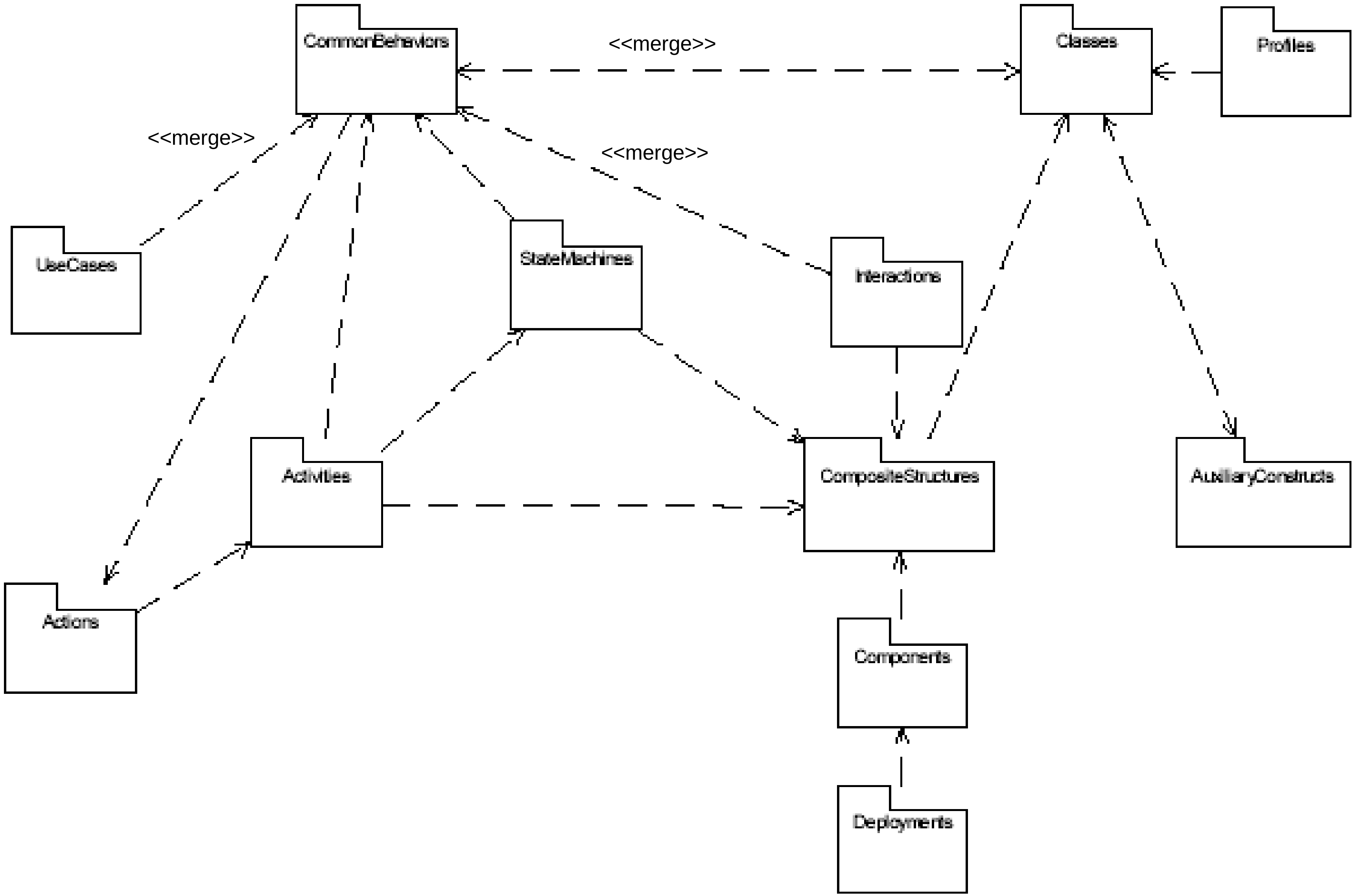
From: UML 2.0 Infrastructure Specification; OMG Adopted Specification ptc/03-09-15

Package Basic: Classes



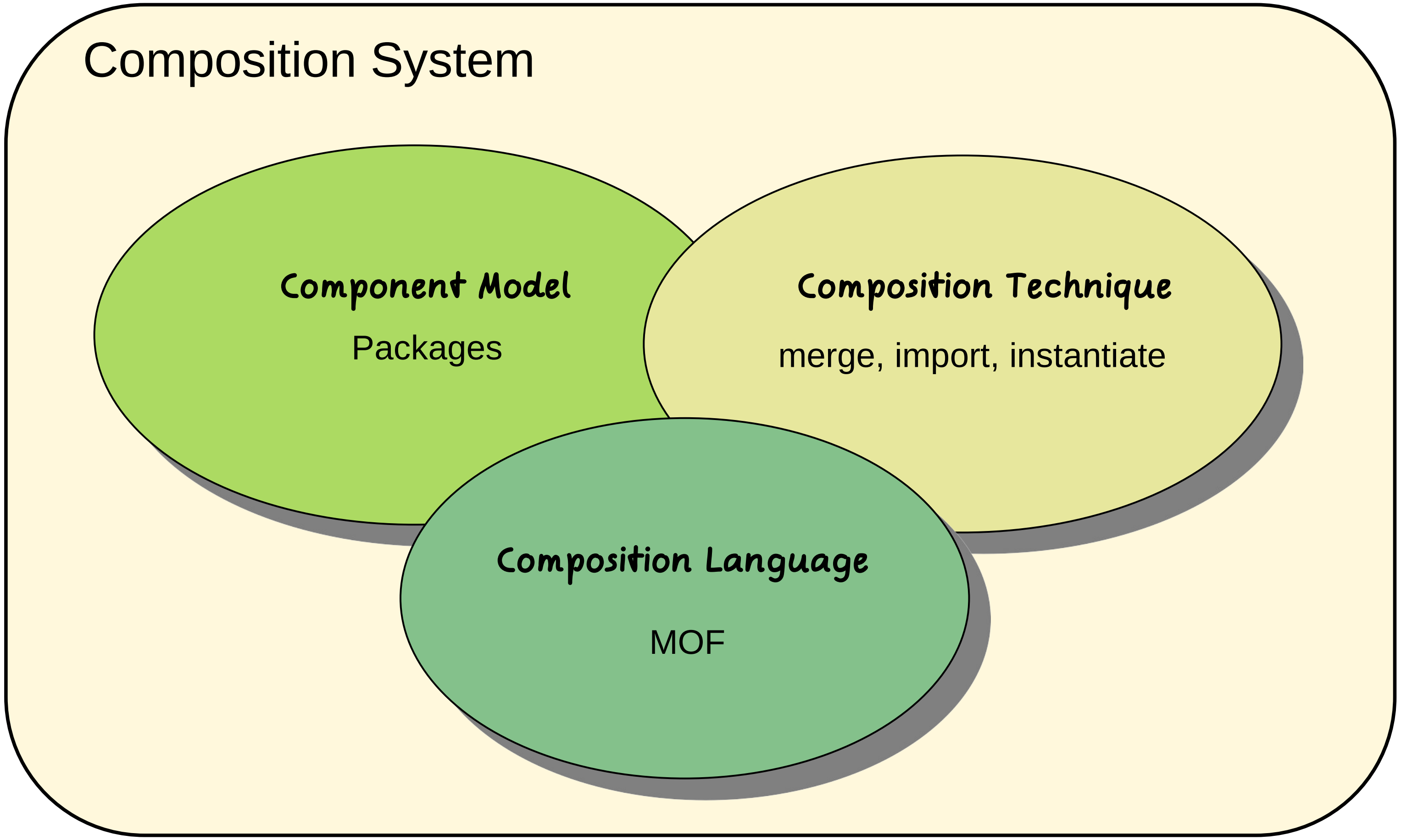
From: UML 2.0 Infrastructure Specification; OMG Adopted Specification ptc/03-09-15

Package Composition Architecture UML 2.0 (M2)



From: UML 2.0 Infrastructure Specification; OMG Adopted Specification ptc/03-09-15

Metamodel Composition – the Composition System of the UML Language Report



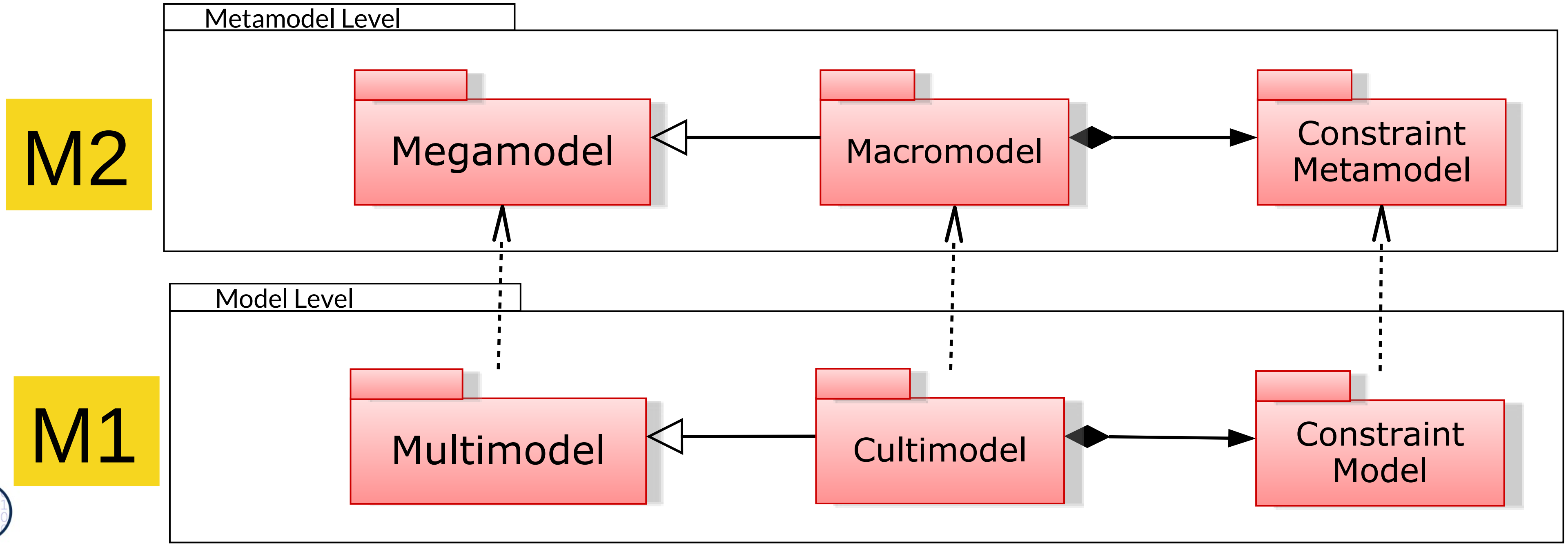
12.4 Mega- and Macromodels – Models about Models

In a technical space, a ***megamodel*** is an infrastructure for models and metamodels, systematically linking a set of models

Megamodels, Macromodels, Multi- and Cultimodels

> **The idea behind a *mega-model* is to define the set of entities and relations that are necessary to model some aspect about model-driven engineering (MDE).**
> **[Favre]**

- A ***multimodel*** is a set or graph of related models.
- A ***megamodel*** is a model for a multi-model.
  - The multimodel is an instance of the megamodel (element of the of the megamodel's language) [Hebig-Seibel-Giese]
  - A megamodel uses the model management system of the technical space
- A ***macromodel*** is a megamodel with a constraint metamodel. A ***cultimodel*** (consistent multimodel) is a wellformed multimodel according to its constraint model.
- Usually, a technical space has one or several mega/macromodels on M2, linking many models on M1
  - Clearifying the relationships of the M1 models by model transformations, model mappings, and model compositions

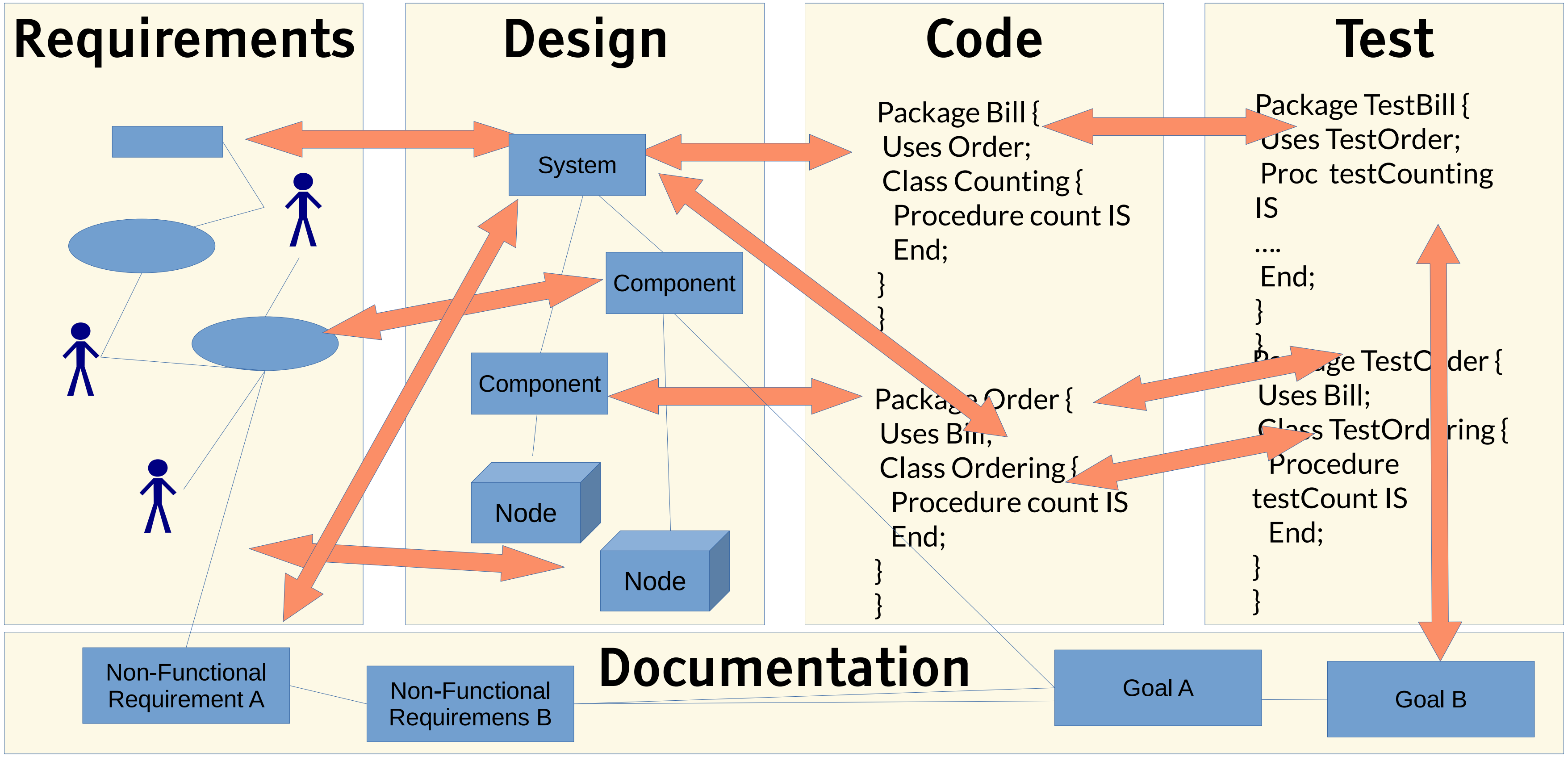


Cultimodels – Multimodels with Consistency Rules

- A ***cultimodel*** is an instance of a macromodel, i.e., a multimodel *fulfilling some consistency constraints over the models and their elements.*
  - The schema, the macromodel is adorned with a constraint metamodel
  - The graph of models in the multimodel obeys wellformedness constraints
  - There are **fine-grained relations** between model elements of the models, which also follow *consistency constraints*
    - **Equivalence mappings**
    - **Trace mappings** between old and new elements of a transformation
    - **Synchronization relations** for updating

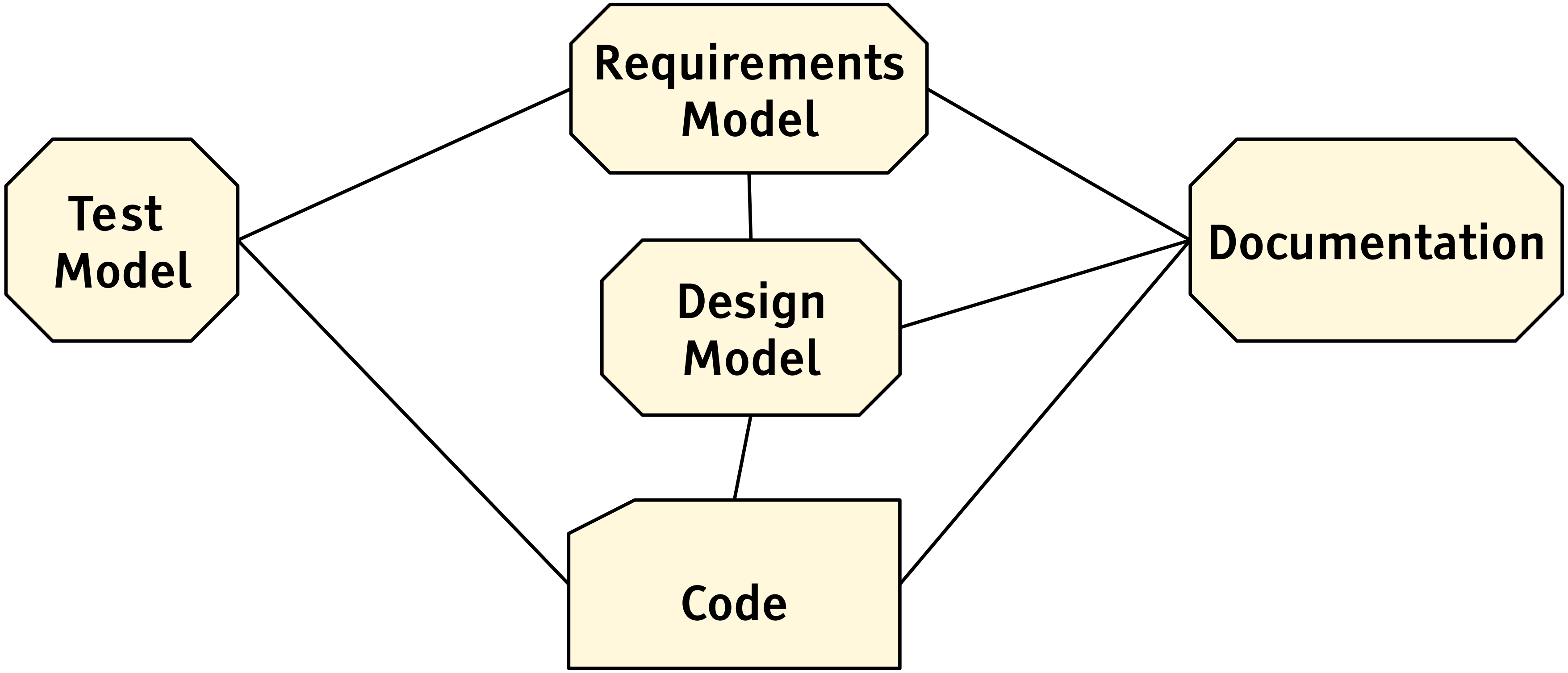
Q12: The ReDoDeCT Problem and its Macromodel

- 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



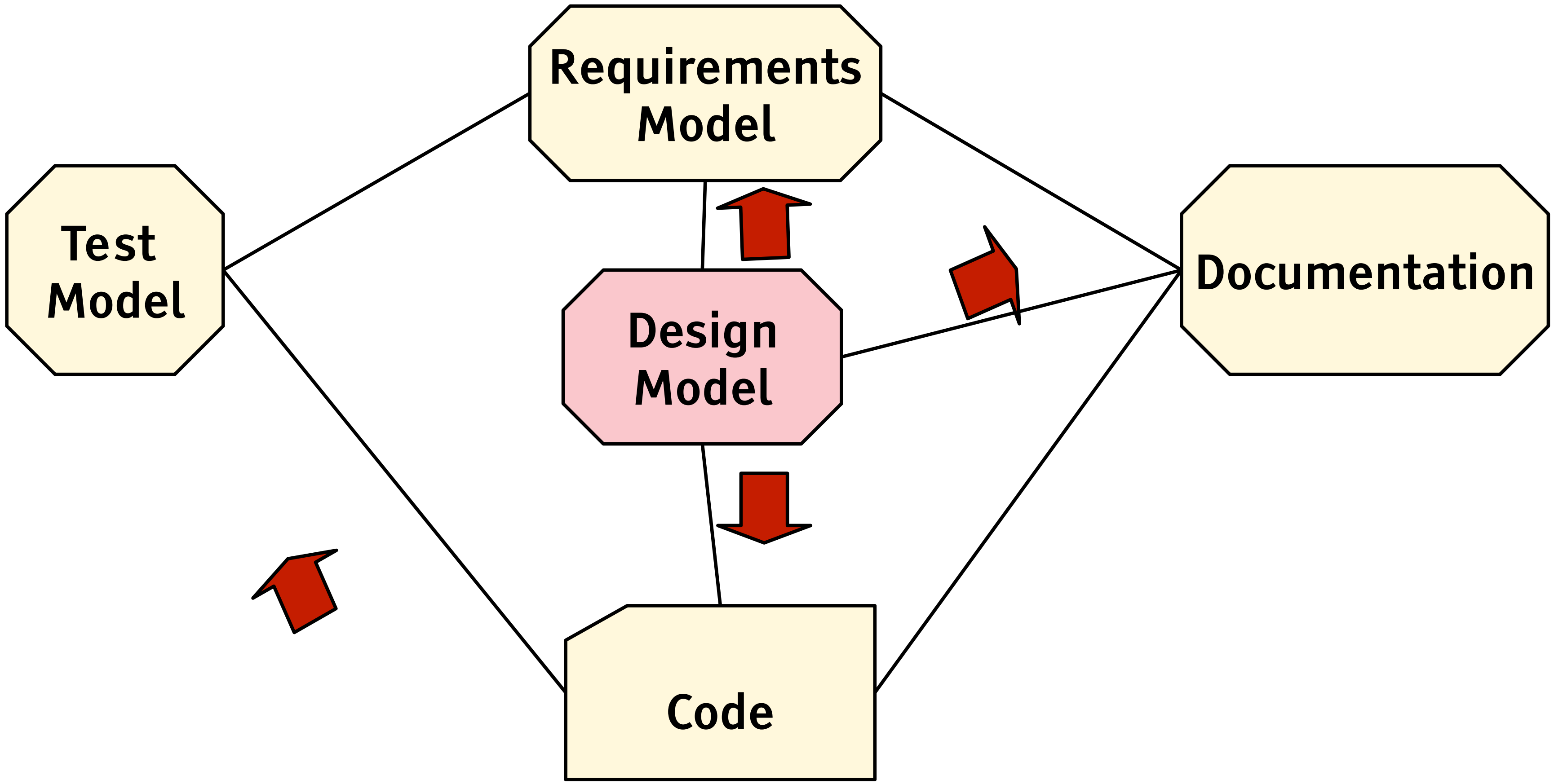
Model Synchronization in Macromodels

- ***Model synchronization*** keeps a set of connected models (the ***crowd***) *in* sync, i.e., consistent



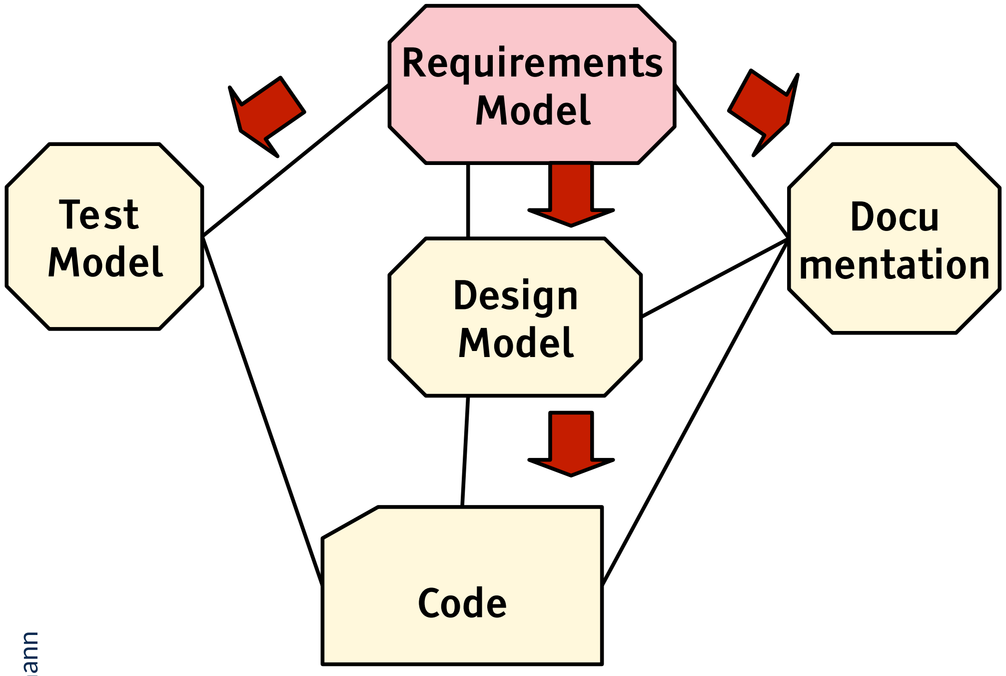
Model Synchronization in Macromodels

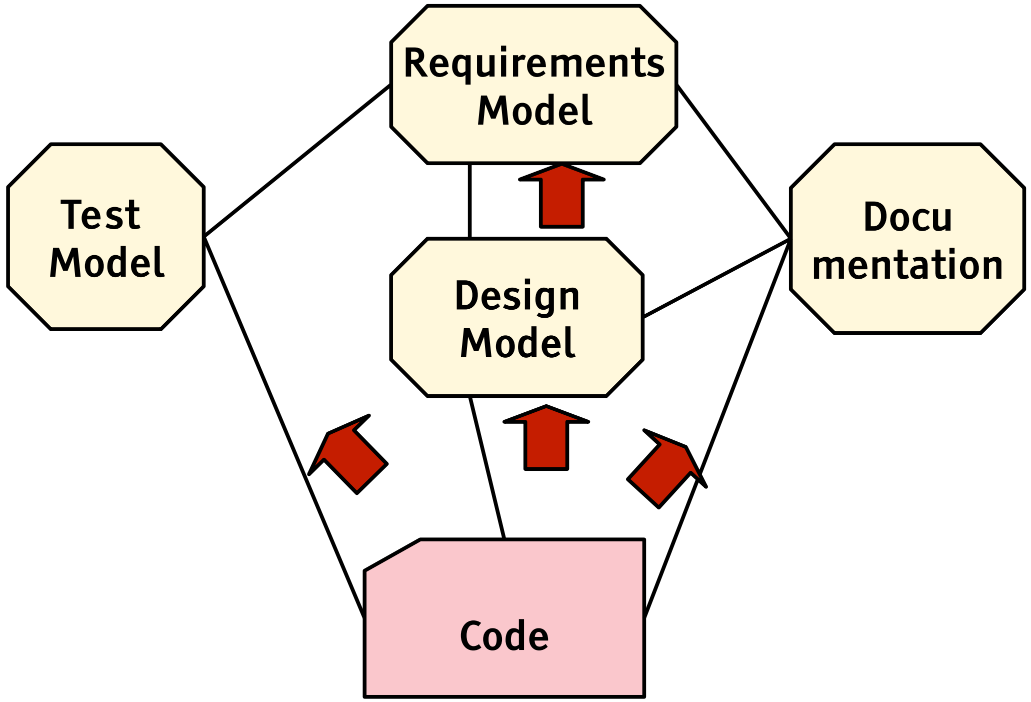
- In model synchronization, if an edit has occurred in a ***origin model***, all other connected models of a crowd (***dependent models***) are updated instantaneously, when one focus model changes



Round-Trip Engineering (RTE) Changes the Model-in-Focus of the Crowd

- RTE always performs ***model synchronization*** as a basic step
- *Model synchronization* requires synchronisation mappings from the changed model to the other models

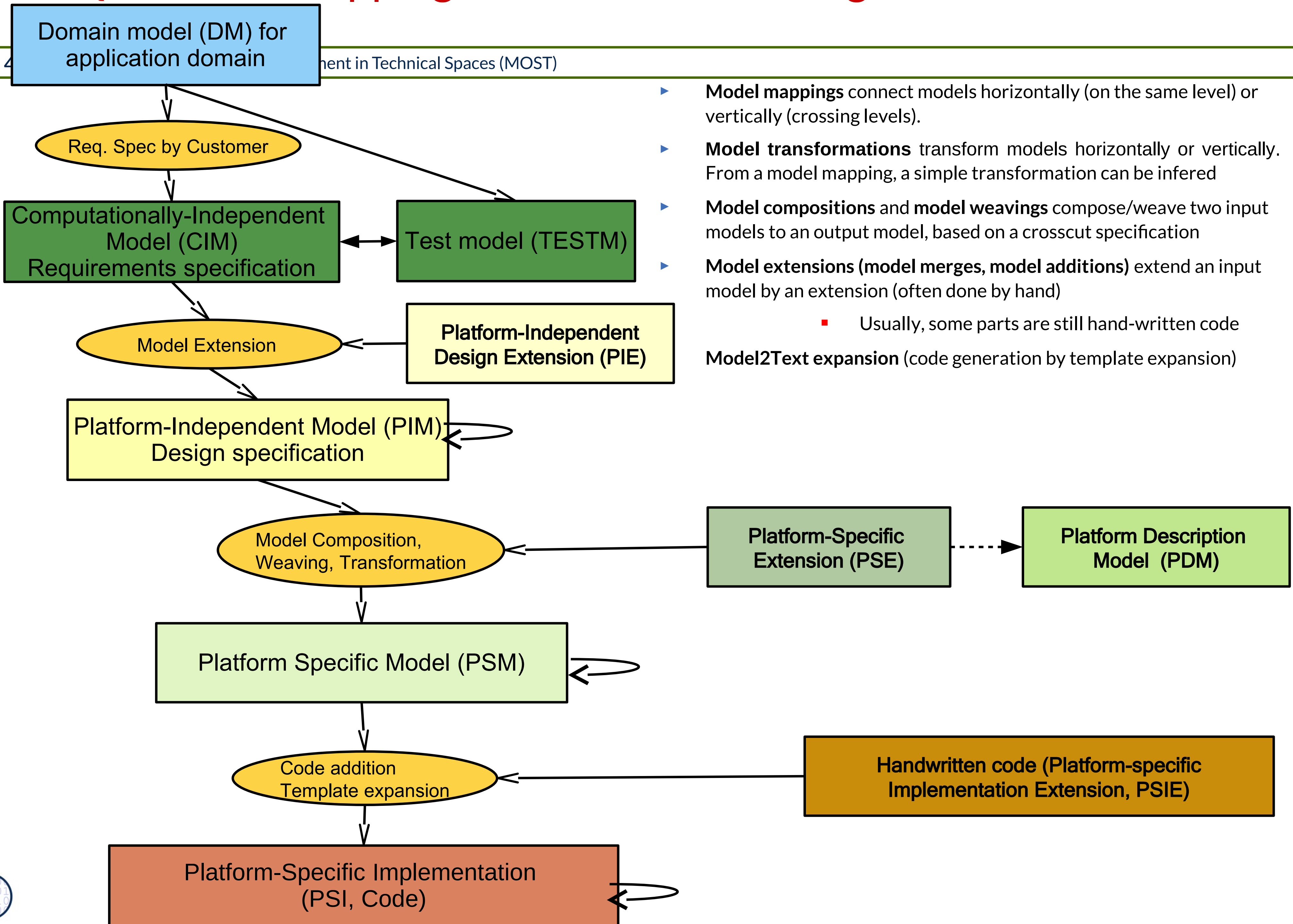




Advantages of Model Mappings in Macromodels

- **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

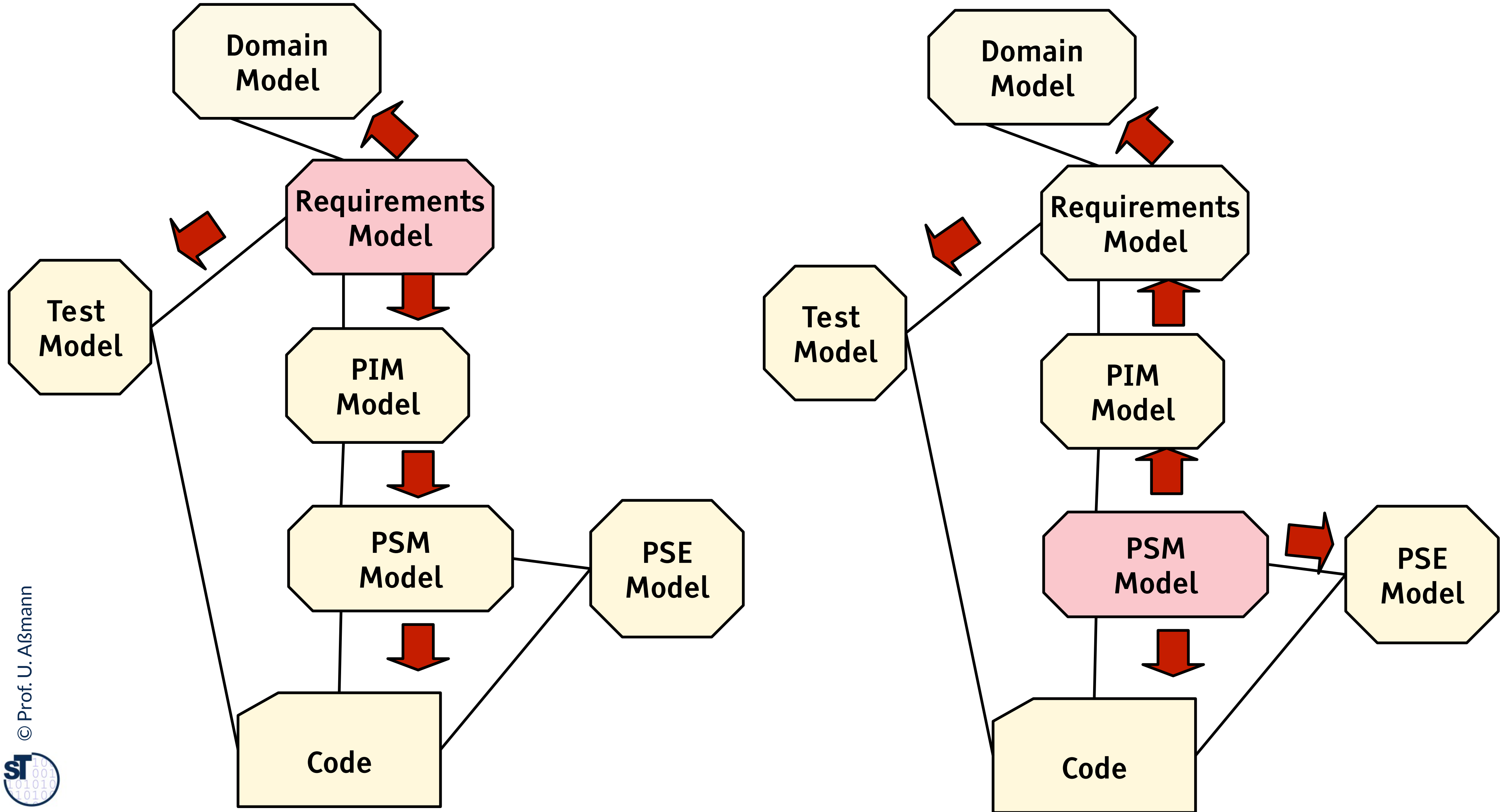
Q9: Model Mappings and Model Weavings in the MDA



- **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)

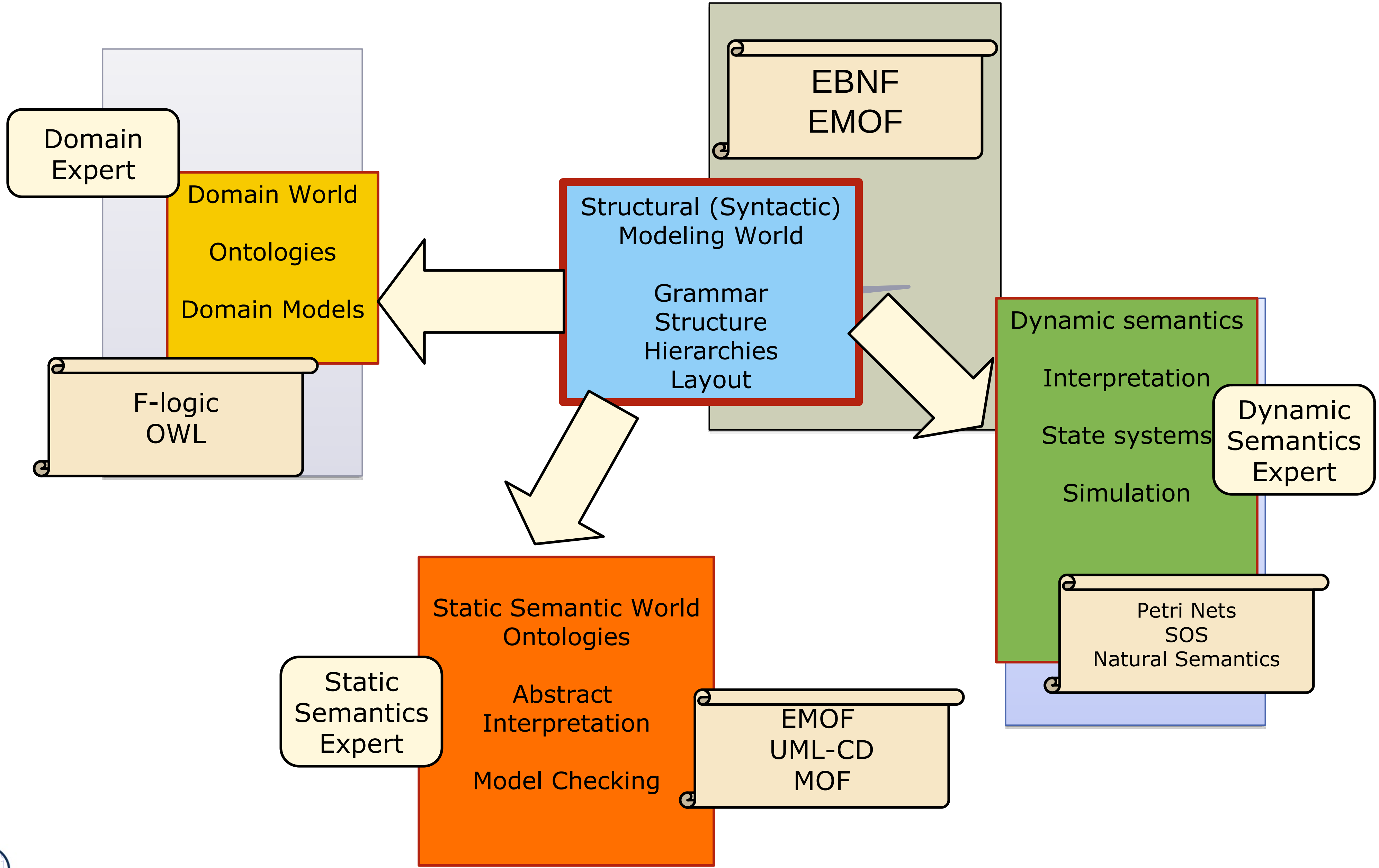
Round-Trip Engineering in MDA Multimodels



12.5. Briding Technical Spaces and Software Factories

- While one tool/application may live in one TS, for the communication with other tools/applications, **technical space bridges** have to be built.
- Usually, a technical spaces has a subsystem for **technical space bridging.**

An Application May Need Several Technical Spaces



Software Factories (refined, in this course)

A **software factory** is an environment to produce software and CPS product lines

- based on metamodeling, macromodels and pattern languages
- in one technical space
- or bridging several technical spaces

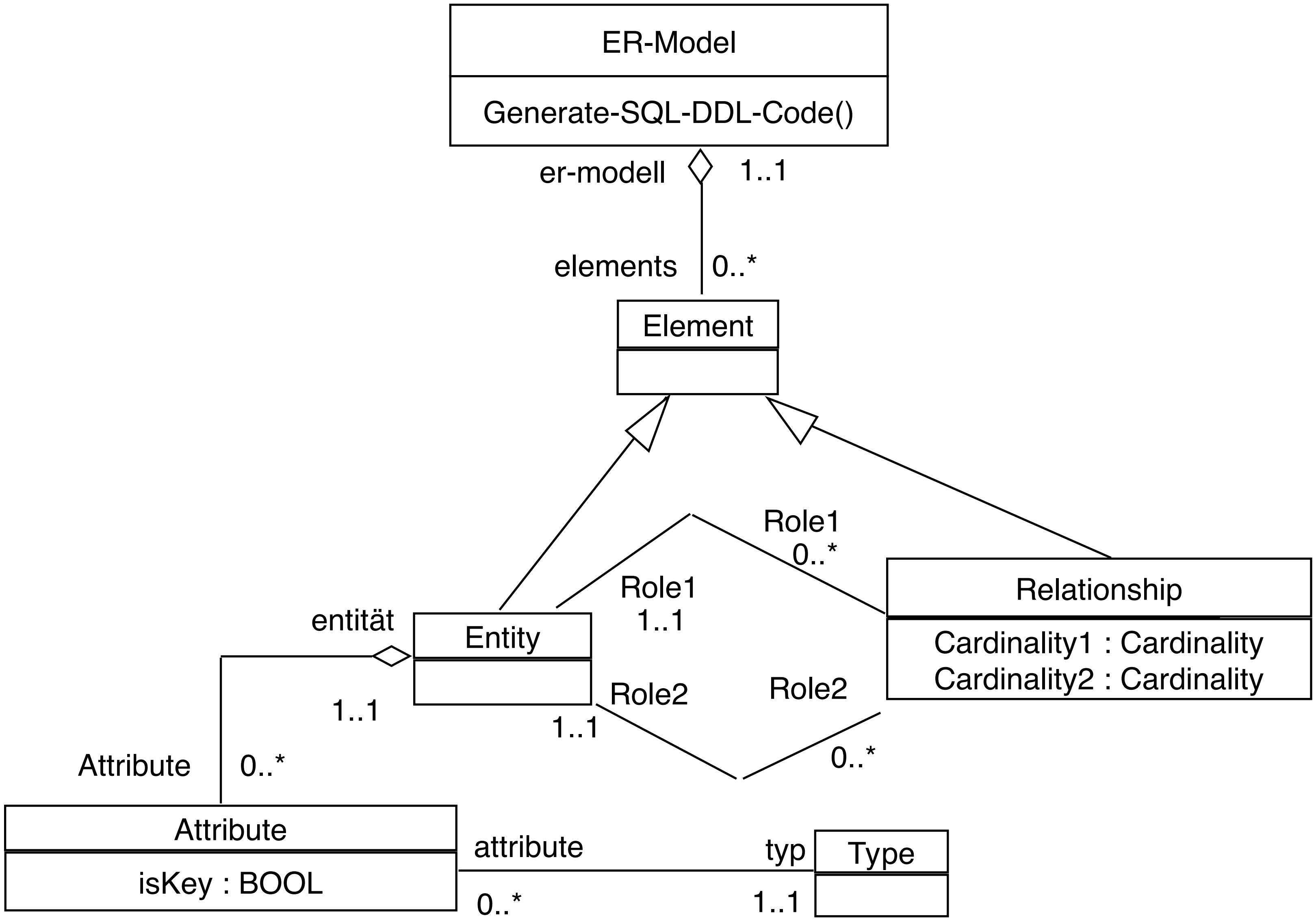
The End

- Why do different technical spaces exist?
- What is the difference between a technological and a technical space?
- Explain round-trip engineering and model synchronization.
- What is model mapping vs model transformation?
- Explain the different forms of model mappings.

12.A.1 Other Metalanguages and Technical Spaces

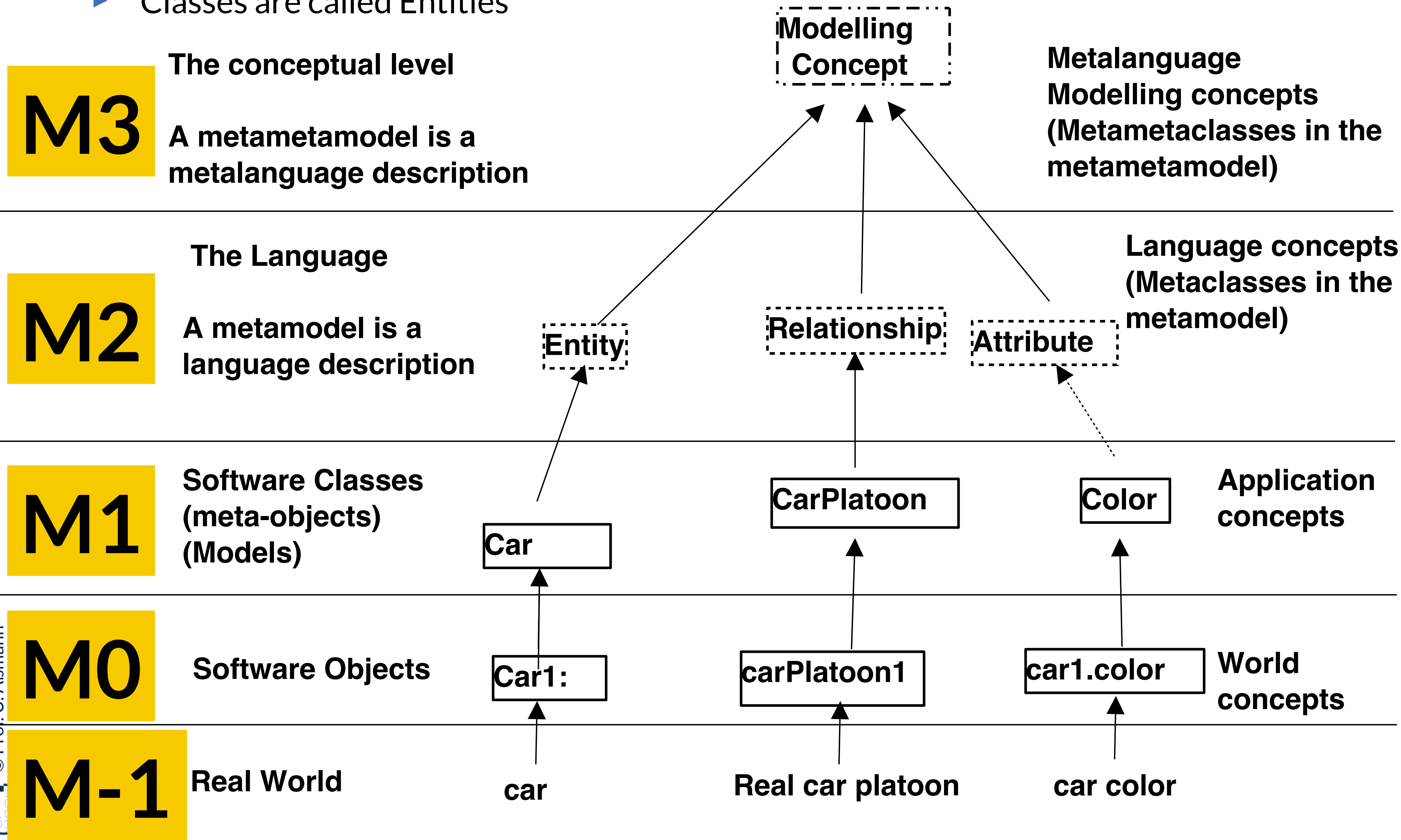
Metamodel of EntityRelationship Diagrams (ERD-ML) in MOF

- ERD is like MOF without inheritance



Metalevels in ERD

- Classes are called Entities



Ex.: IRDS/MOF Metahierarchy for Data Dictionaries in the Structured Analyse (SA)

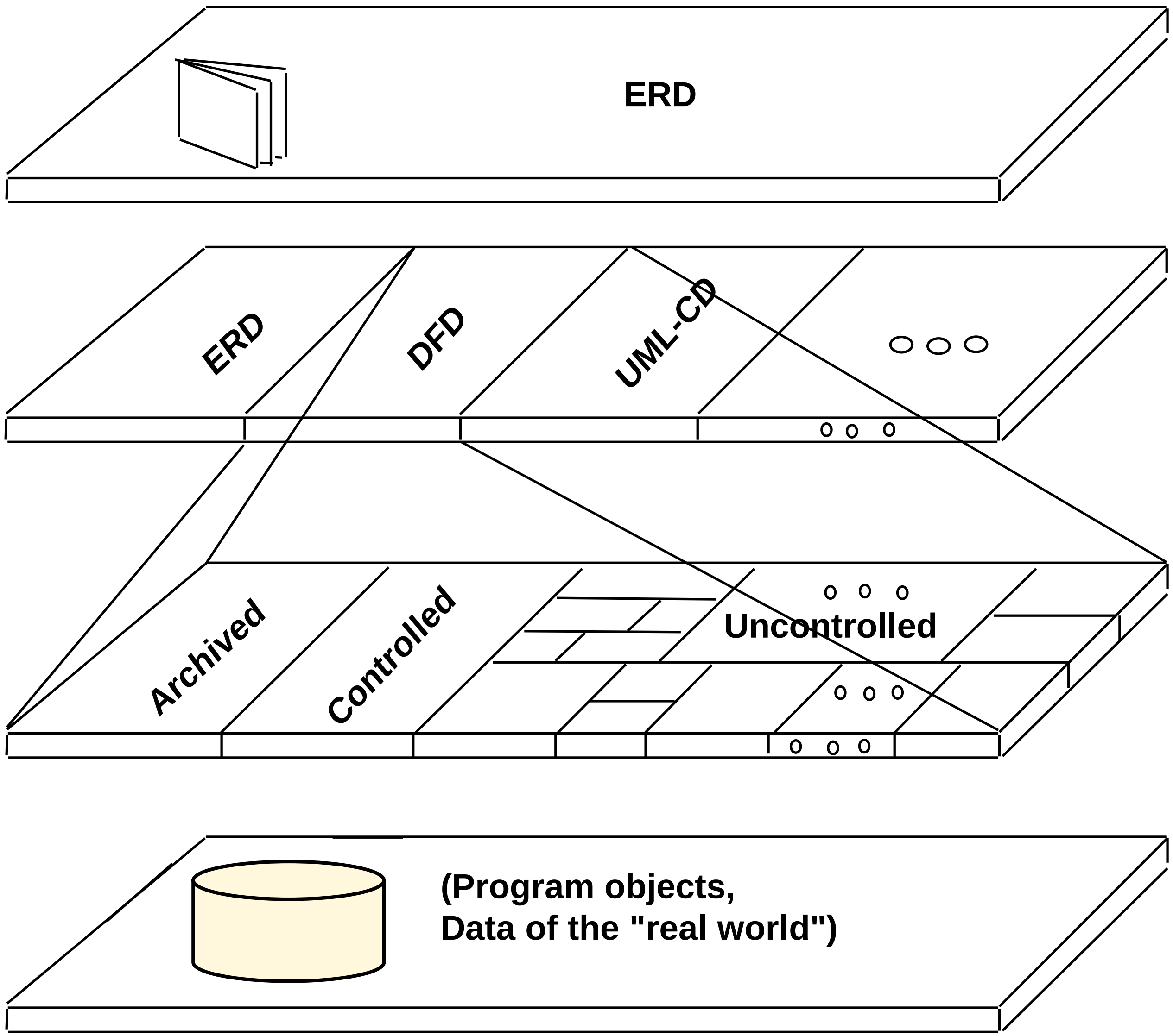
- IRDS was defined in the 70s to model (persistent) data structures of applications

M3 Dictionary Definition Schema Layer

M2 Dictionary Definition Layer

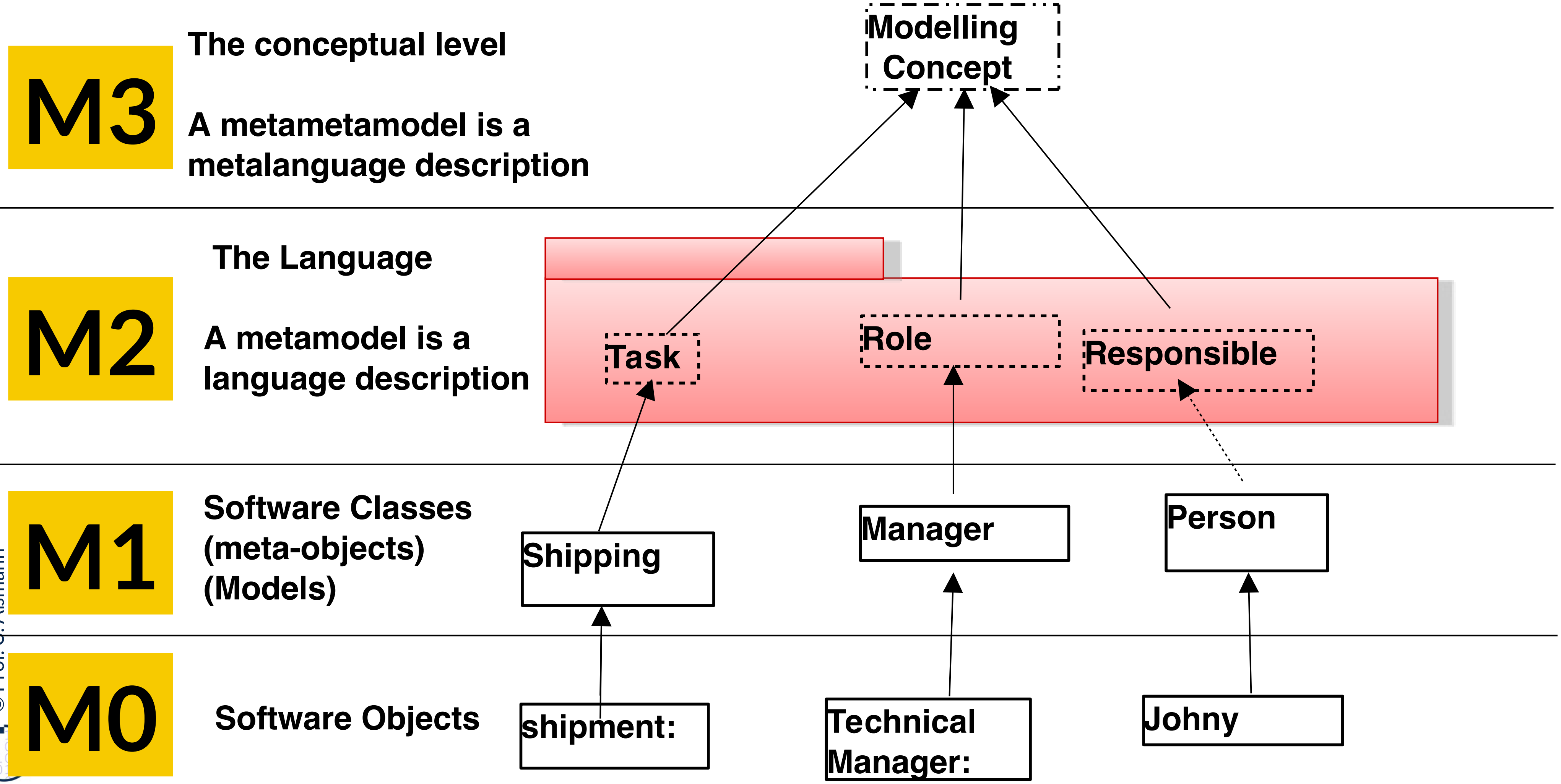
M1 Dictionary Layer

M0 Application-Layer



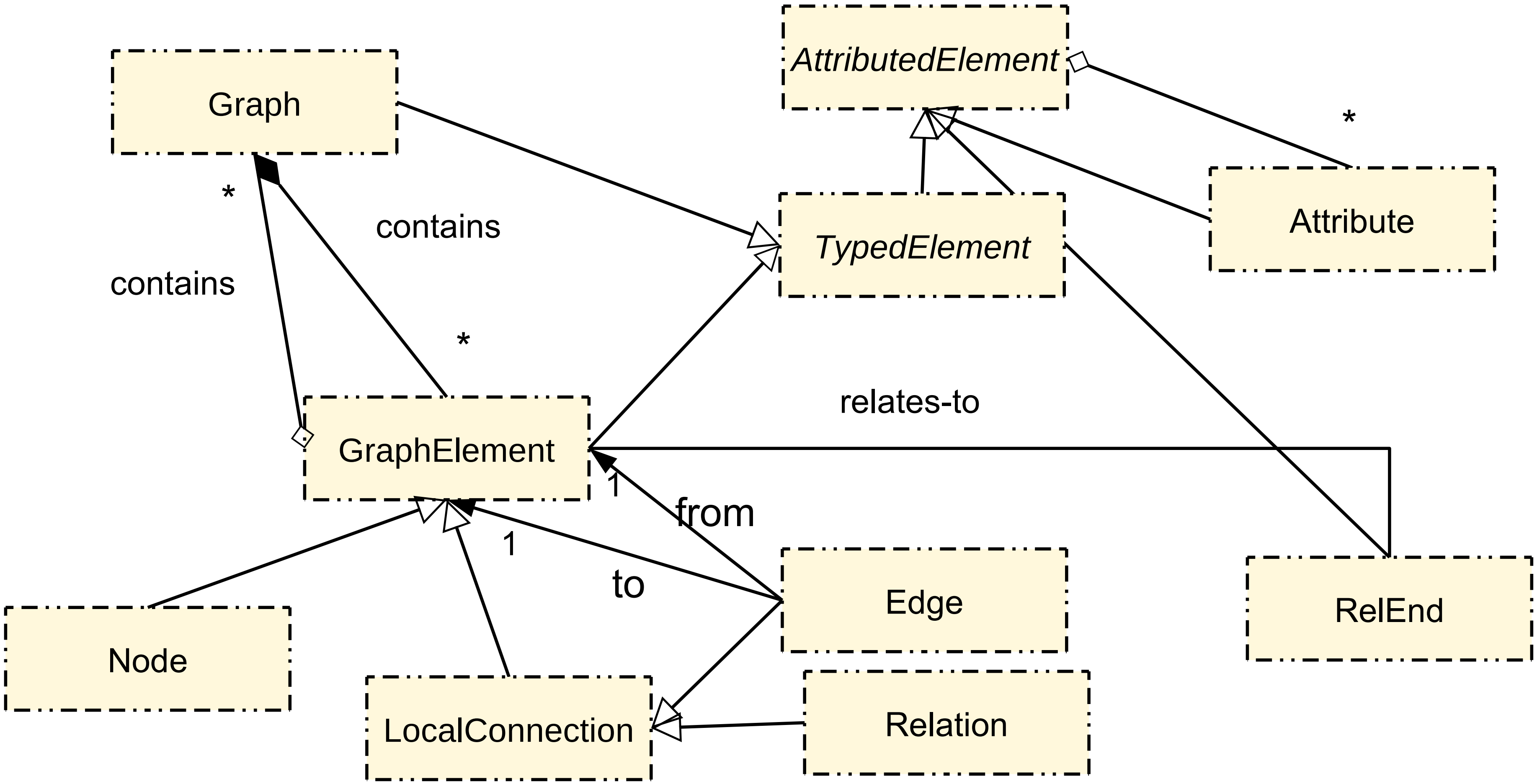
Ex.: Metahierarchy in Workflow Systems and Web Services (e.g., BPEL, BPMN, ARIS-EPK)

- It is possible to specify workflow languages with the metamodelling hierarchy
- BPEL and other workflow languages can be metamodeled
- **BPEL is metamodeled with the metalanguage XSD**



GXL Graph eXchange Language – a Technical Metametamodel

- GXL is a modern graph-language (graph-exchange format)
- Contains abstractions for elements of graphs usable for generic algorithms (e.g., flexible navigation)



Richard C. Holt, Andy Schürr,Susan Elliott Sim, Andreas Winter. GXL: A graph-based standard exchange format for reengineering. Science of Computer ProgrammingVolume 60, Issue 2, April 2006, Pages 149-170

GXL-based Metamodel of Typed Attributed Graph

- GXL can be used as metalanguage (Metametamodel) on M3, to type metamodels and DSL on M2
- For example, state machines
- Alternatively, GXL can also be used as DDL on M2 (it is a lifted metamodel)