12. An Overview of Technical Spaces

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1) Technical spaces
2) Model Management
3) Model Analysis
4) Mega- and Macromodels
5) Pattern Languages
6) Bridging Technical Spaces

Version 17-0.5, 23.10.17

DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

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.

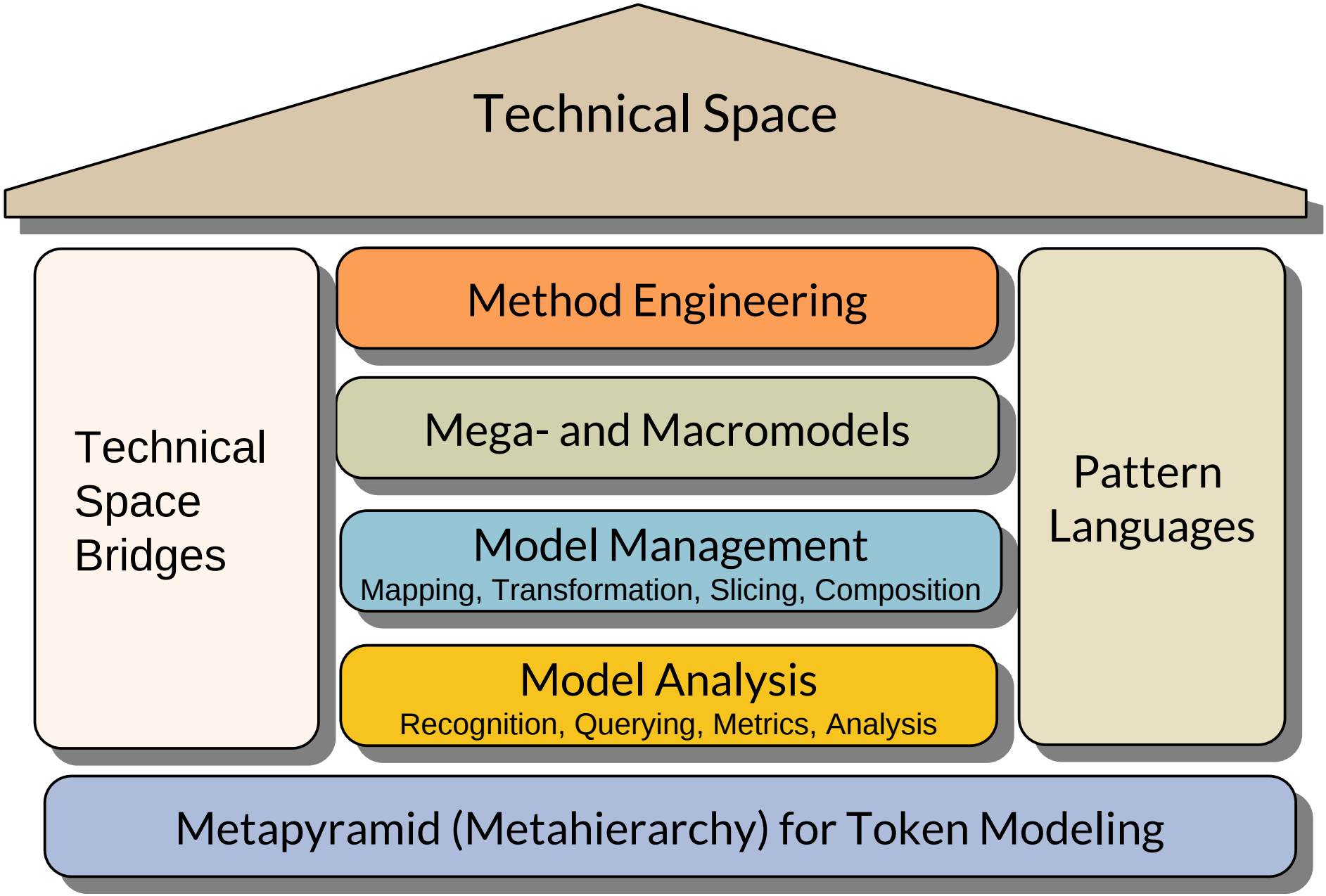
- [Model-based Technology Integration with the Technical Space Concept. Jean Bezivin and Ivan Kurtev. Metainformatics Symposium, 2005.]
  - http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.106.1366&rep=rep1&type=pdf
- Ingredients of a Technical Space (Technikraum):
  - A **metapyramid** (or **metahierarchy**) 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**)
  - A **macromodel**
- 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

Q10: The House of a Technical Space



Packeting on all Layers

- All layers can be structed into packages

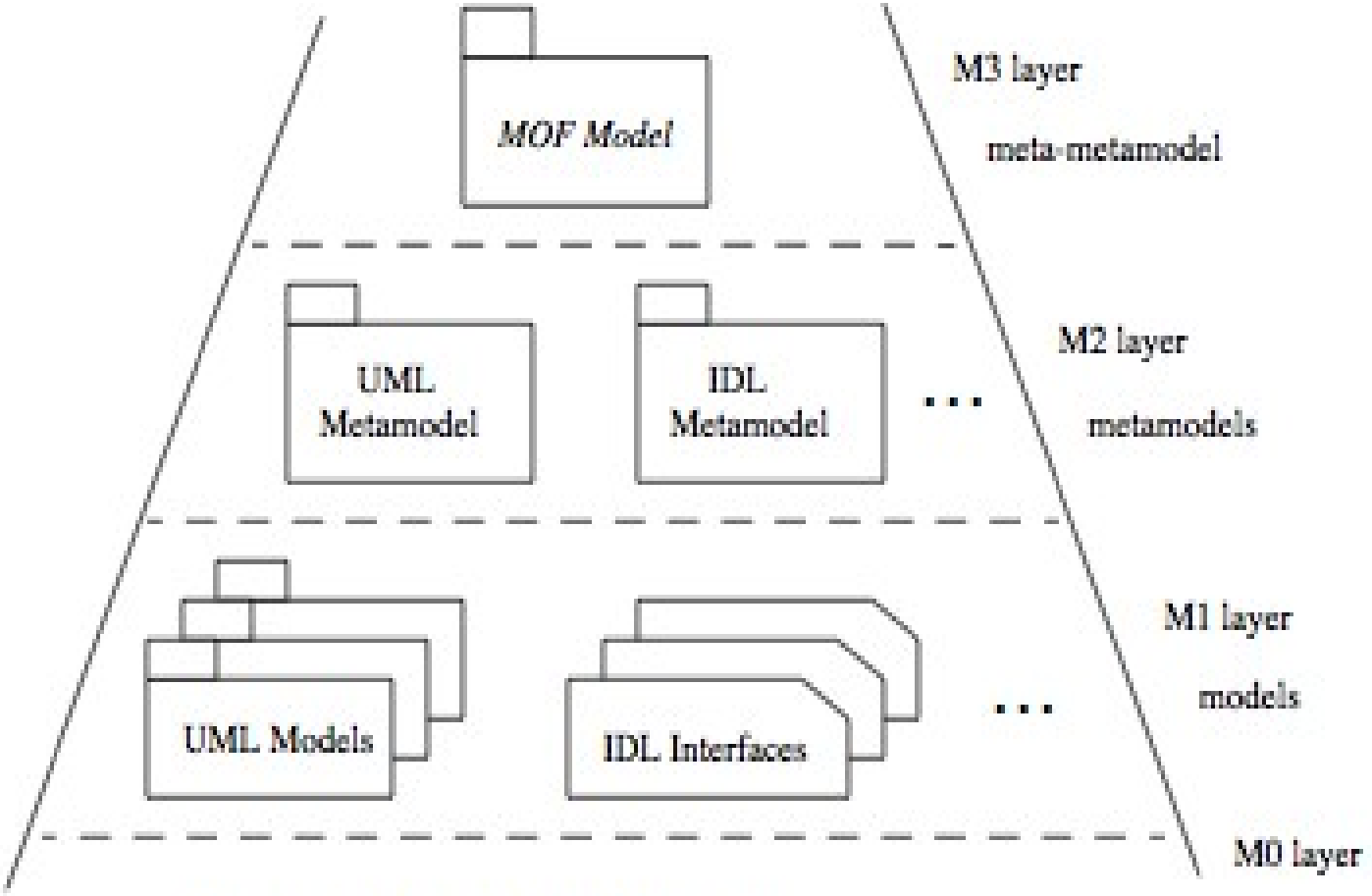


Figure 2-2 MOF Metadata Architecture

[MOF]

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.

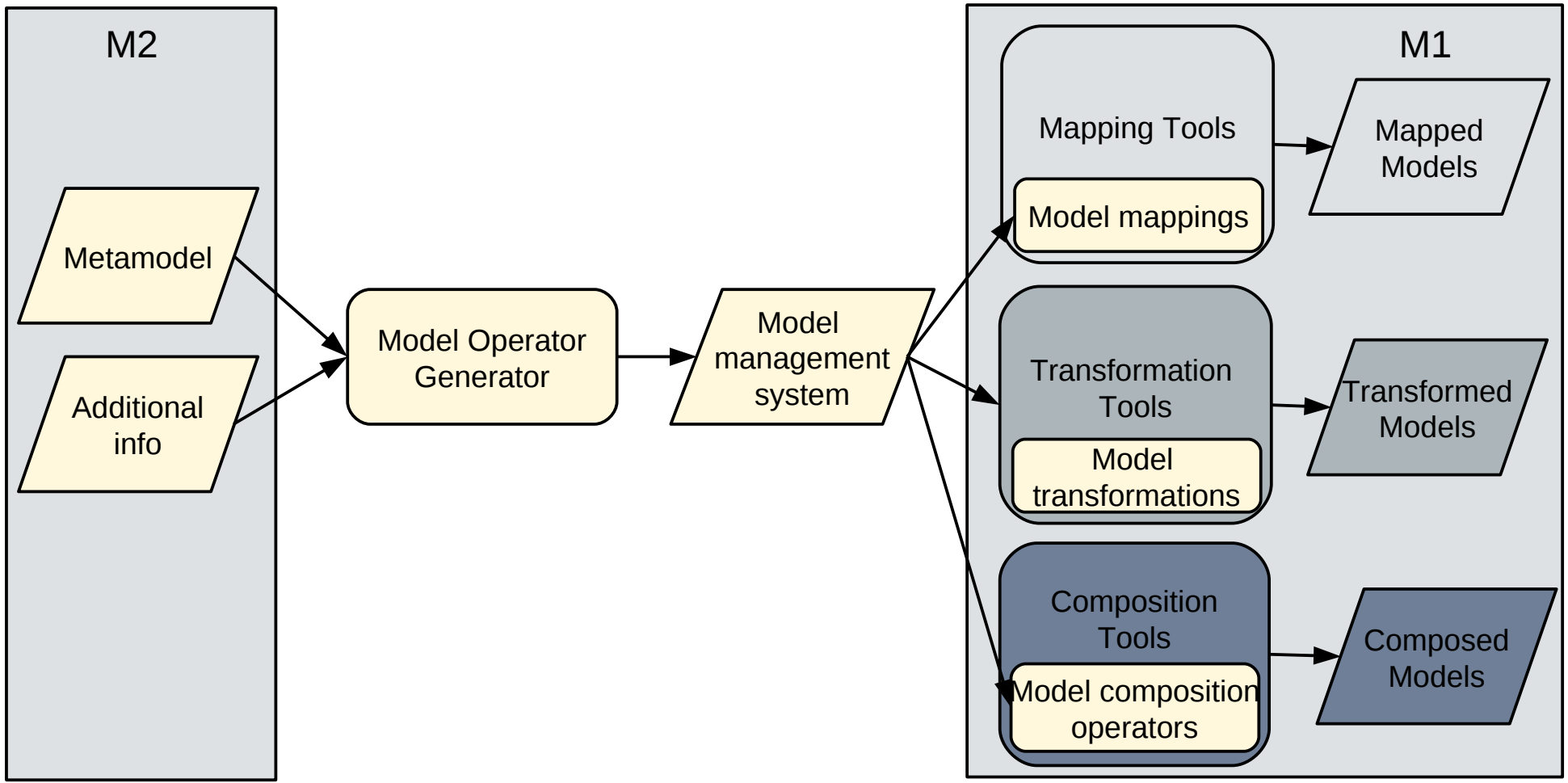
- **Model querying** searches patterns in models, described by a query or pattern match expression.
  - Searching for a method with a specific set of parameters
- **Model metrics** counts patterns in models
  - Counting the depth of the inheritance hierarchy
- **Model analysis** analyzes hidden knowledge from the models, making implicit knowledge explicit
  - 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

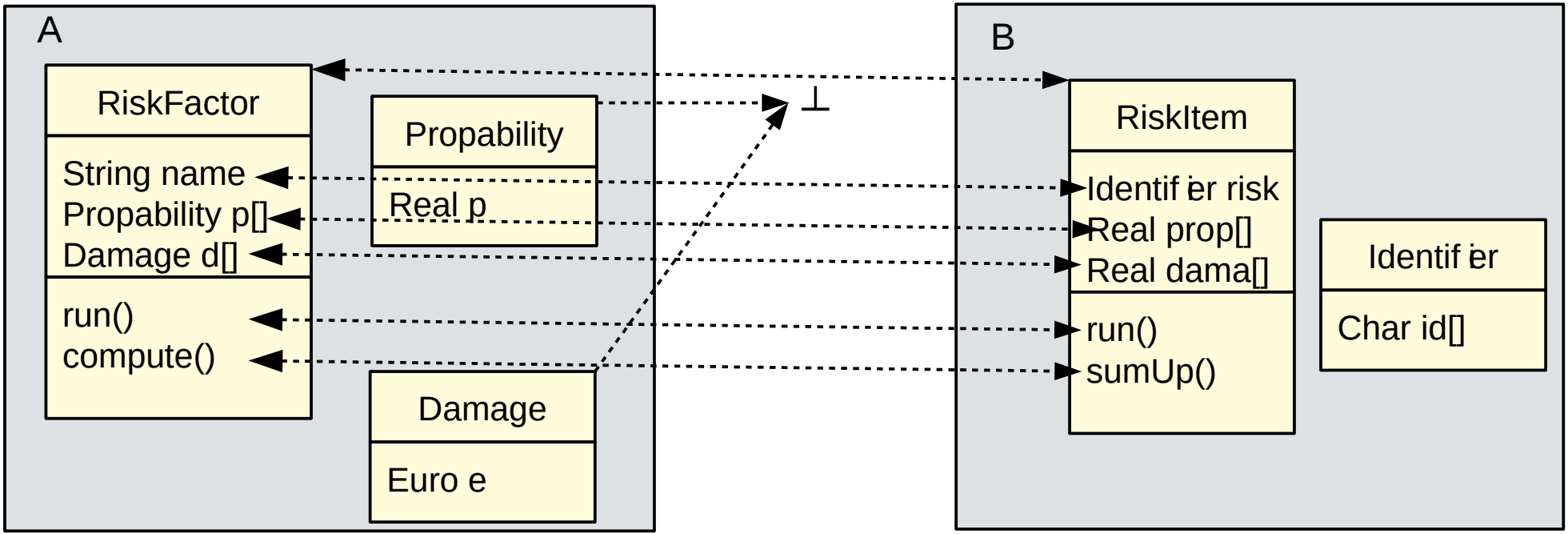


12.3.1. Model Mapping

Model Mappings

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

- 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.

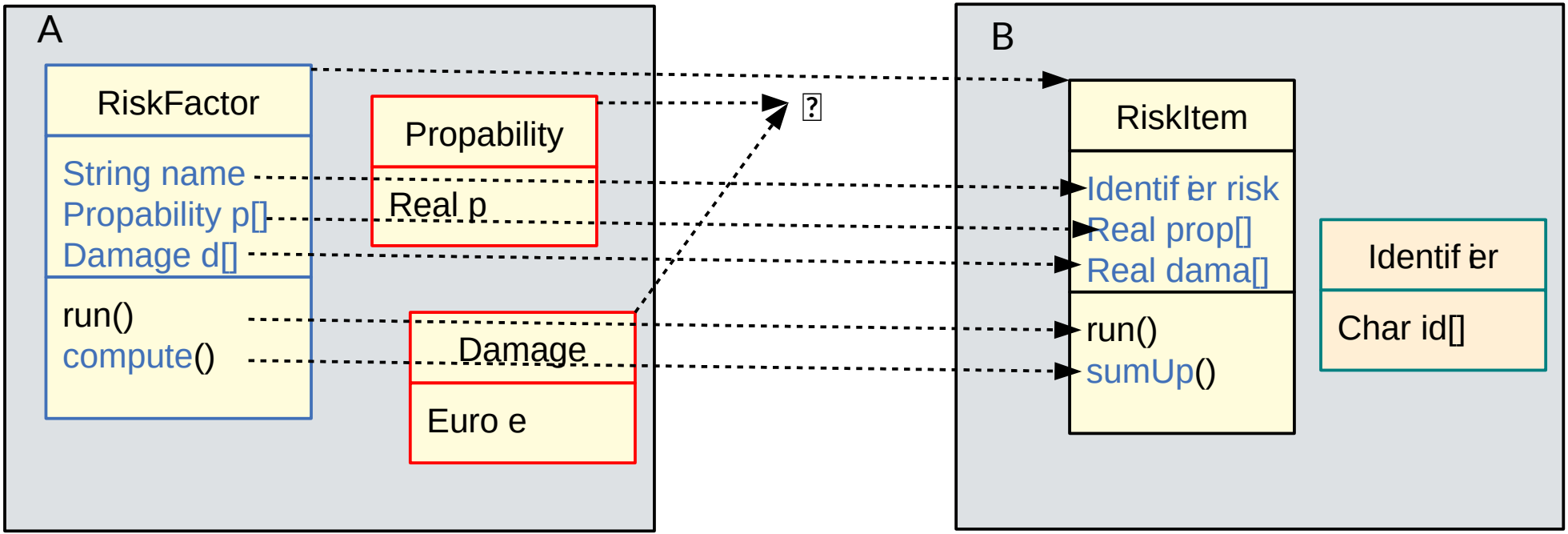


12.3.2. Model Transformation

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.
- Deleted model elements are framed red, added elements are framed green, modified blue

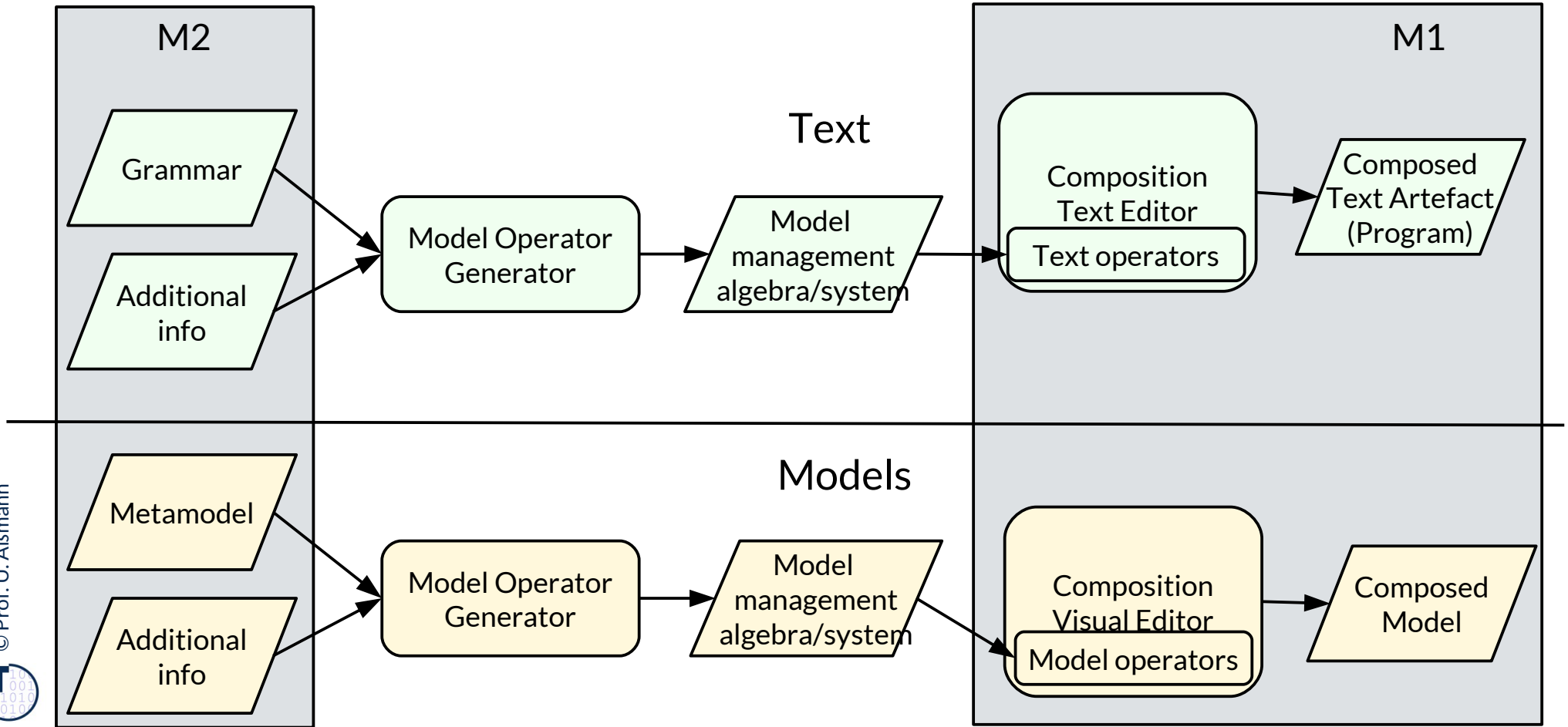


12.3.3. Model Composition with Model Algebrae and Composition Systems

Component-based Model Engineering (CBME)

Model Composition in a Technical Space

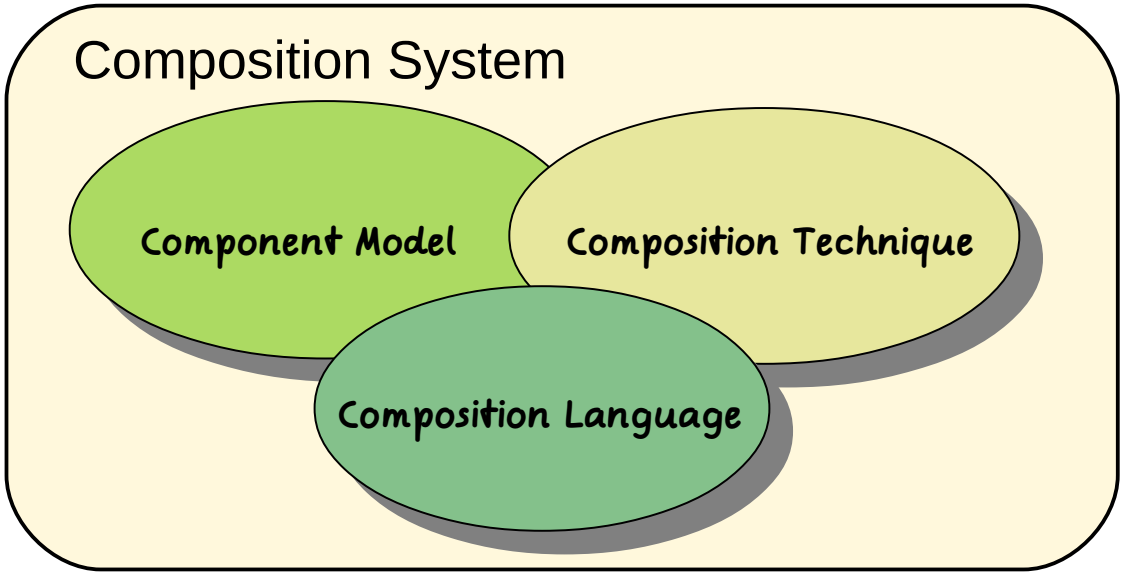
- A ***model composition system*** manages the relationships of models, metamodels, metametamodels of a technical space with a uniform model algebra
  - Operators on M1 can be generated from M2
  - Operators on M2 can be generated from M3



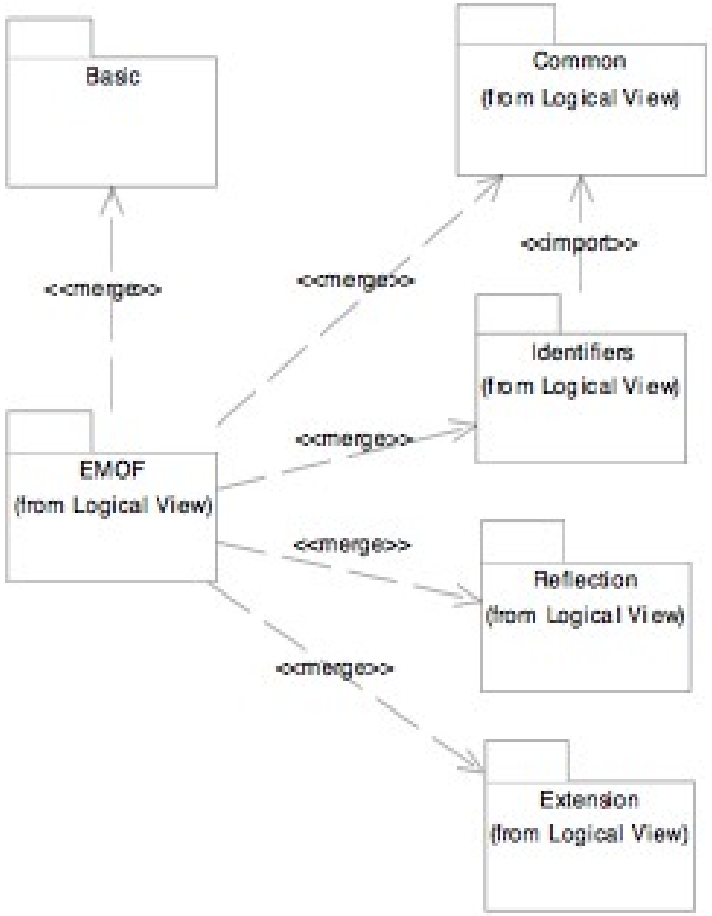
Simple Algebra for Models (on M1) and Metamodels (on M2)

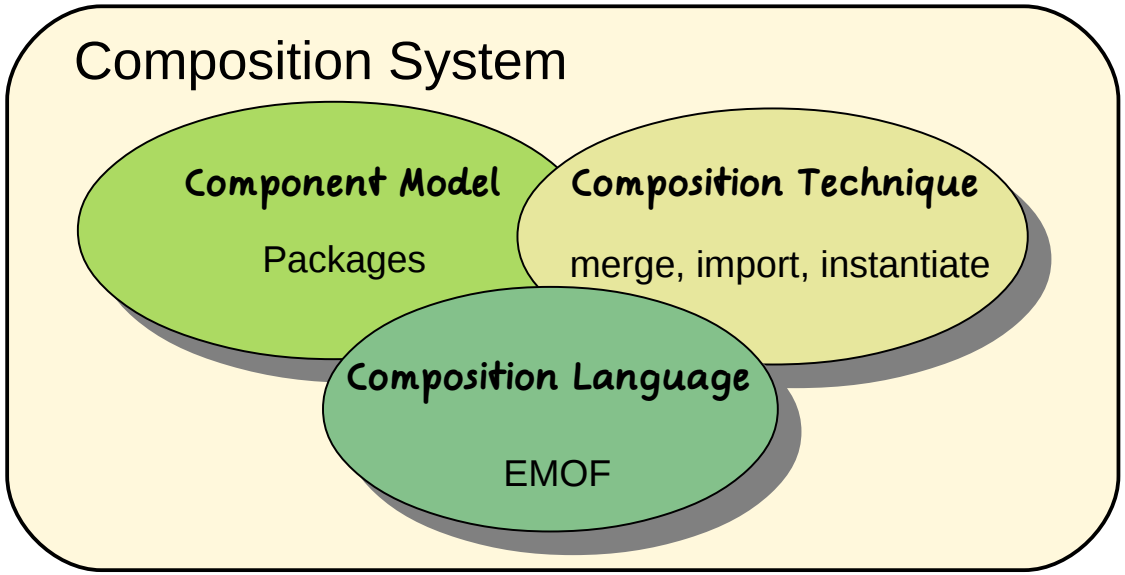
- Models and metamodels can be grouped in packages (module)
  - A simple component model and composition system (see CBSE)
- Algebraic composition technique with operators on packages:
  - use (import)
  - merge (union)
  - Instance-of (element-of-reified-set)

- Metamodels are composed by unifying their views in the different packages
- Metamodels can be composed from packages

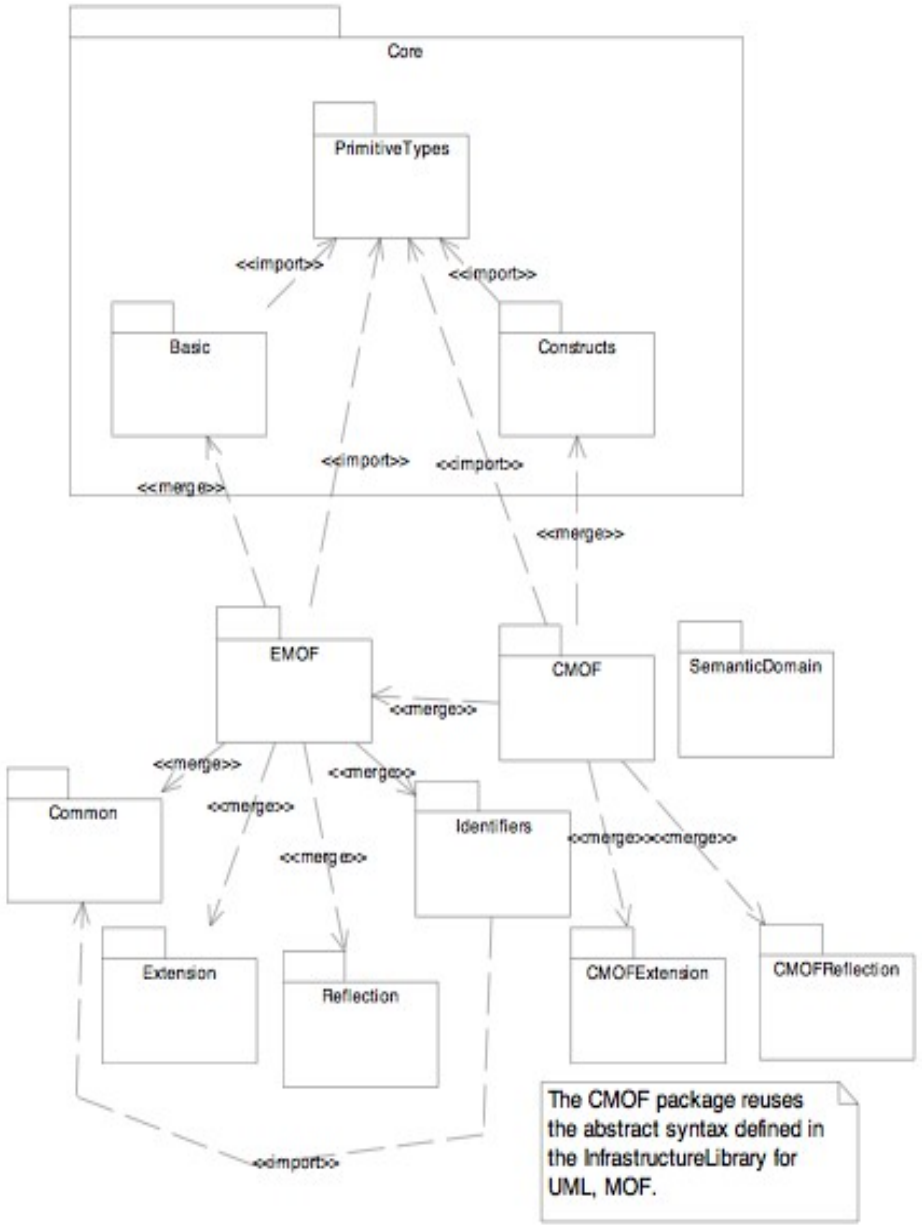


Ex.: EMOF Class Composition by EMOF Package Merge





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

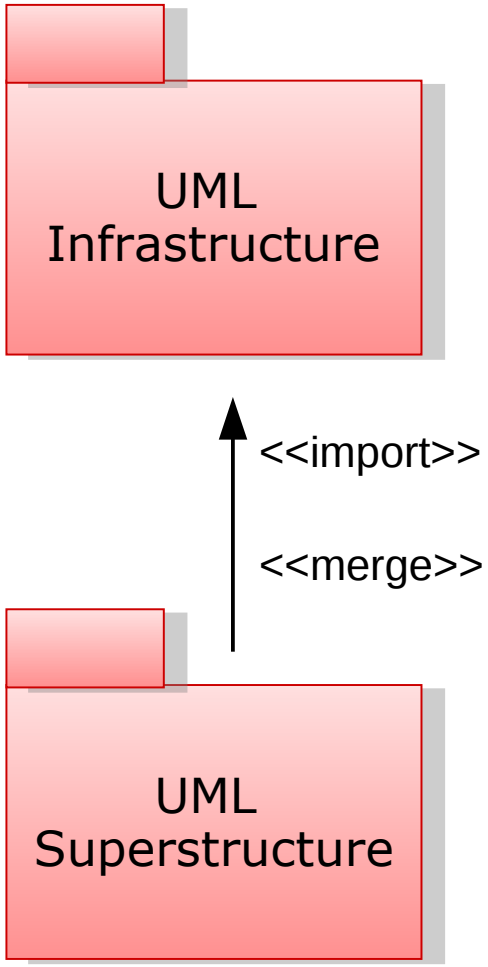
The language report of UML uses a simple metamodel algebra for the bottom-up composition of UML language.

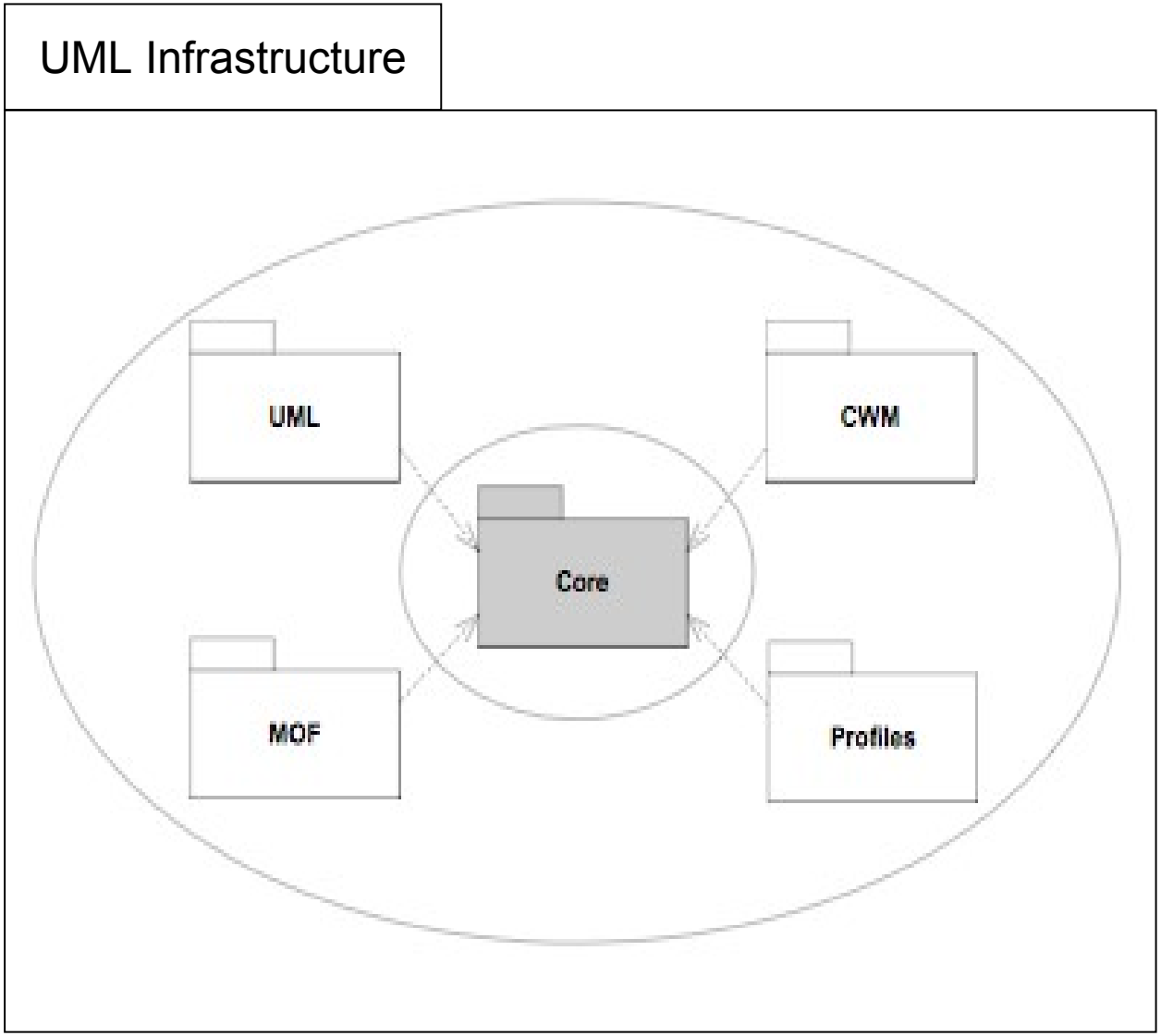
The UML-metamodel is a “logic” metamodel, because it is *composed:*

- 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)

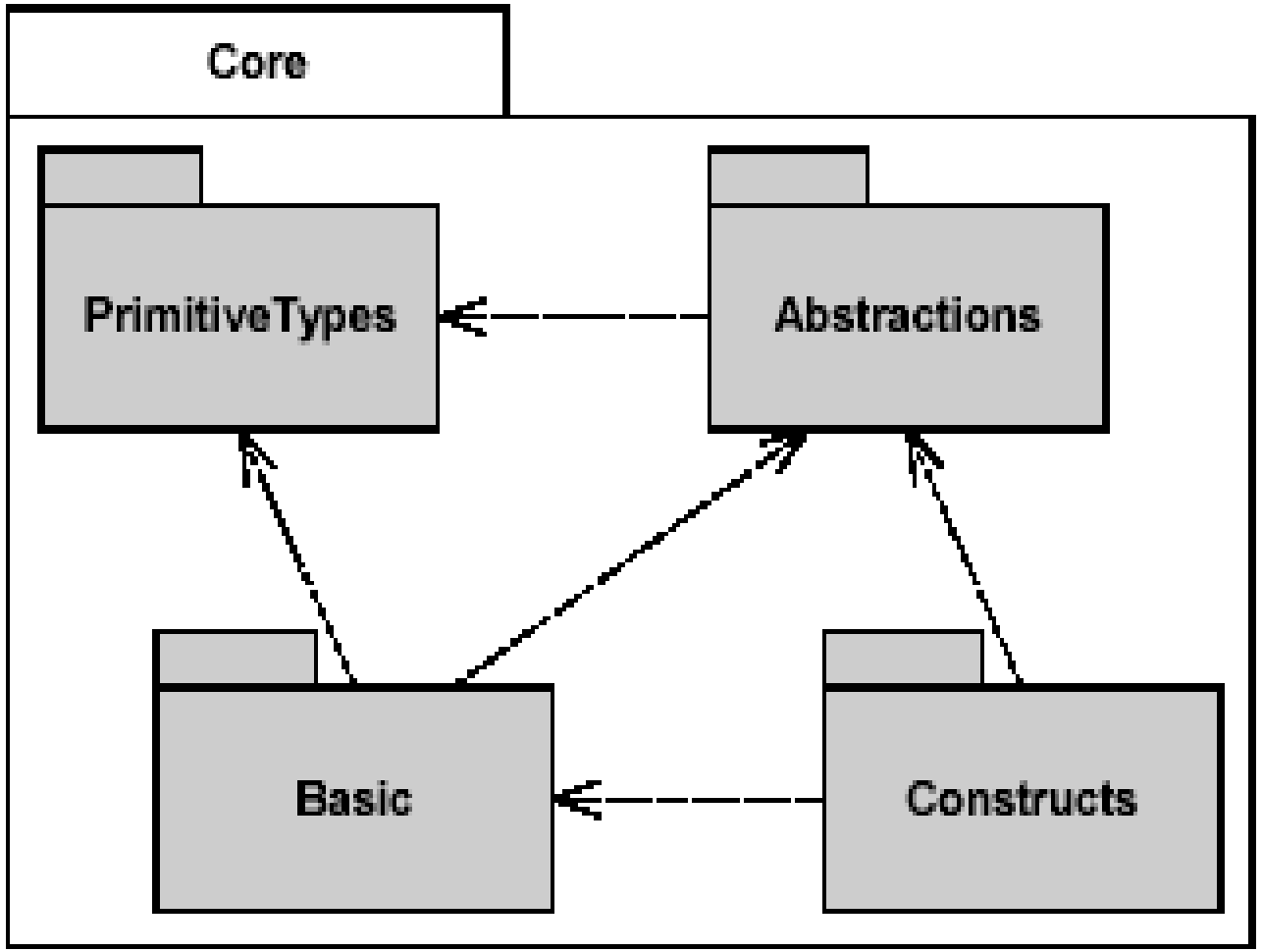
- The UML infrastructure can be used by MDSD applications

Coarse-Grain Structure of UML on M2





Core Package of the UML-Infrastructure Metamodel (M2)

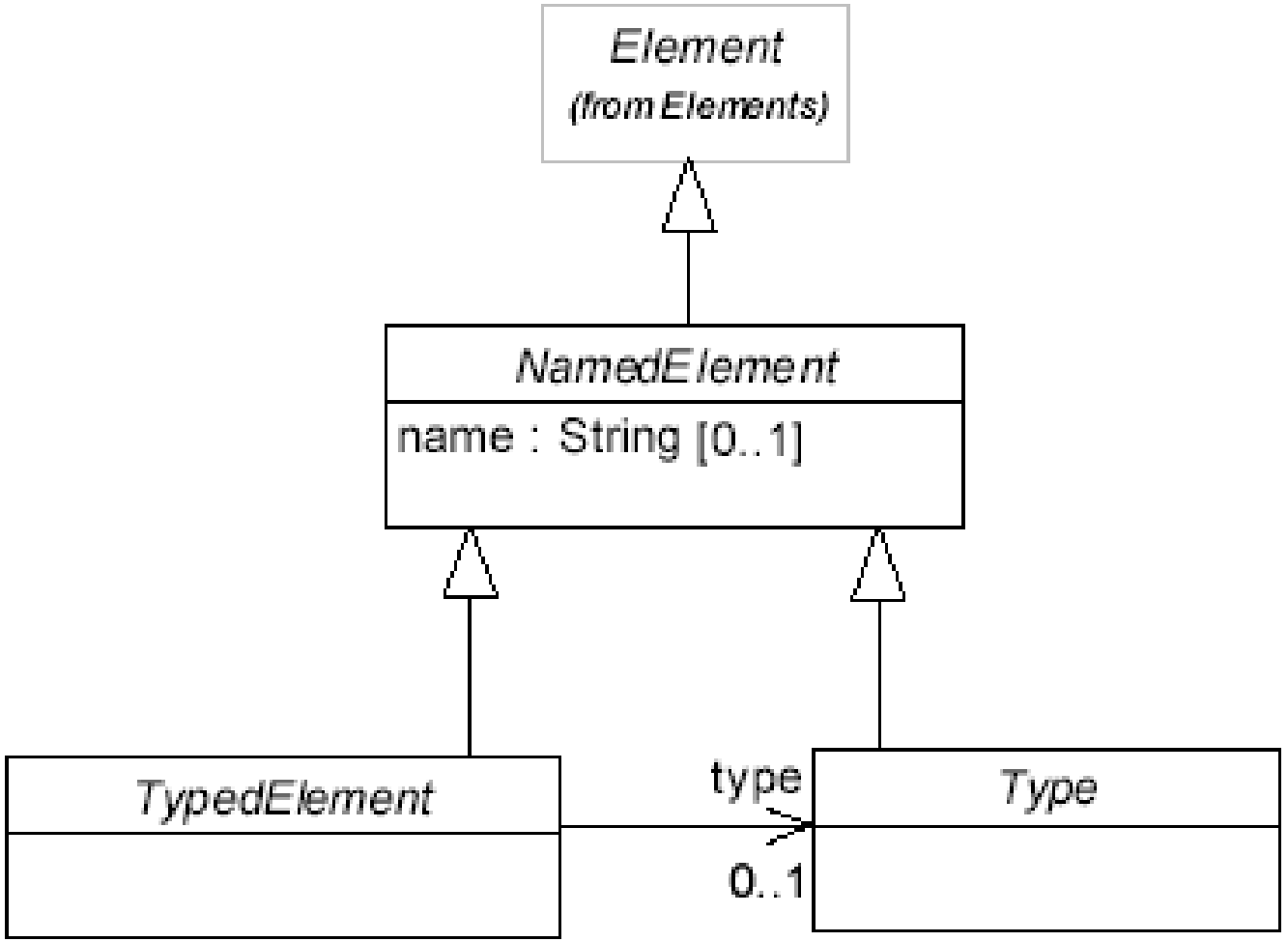


Basic: basic constructs for XMI
Constructs: Metaclasses for modeling

Abstractions: abstract metaclasses
Primitive Types: basic types

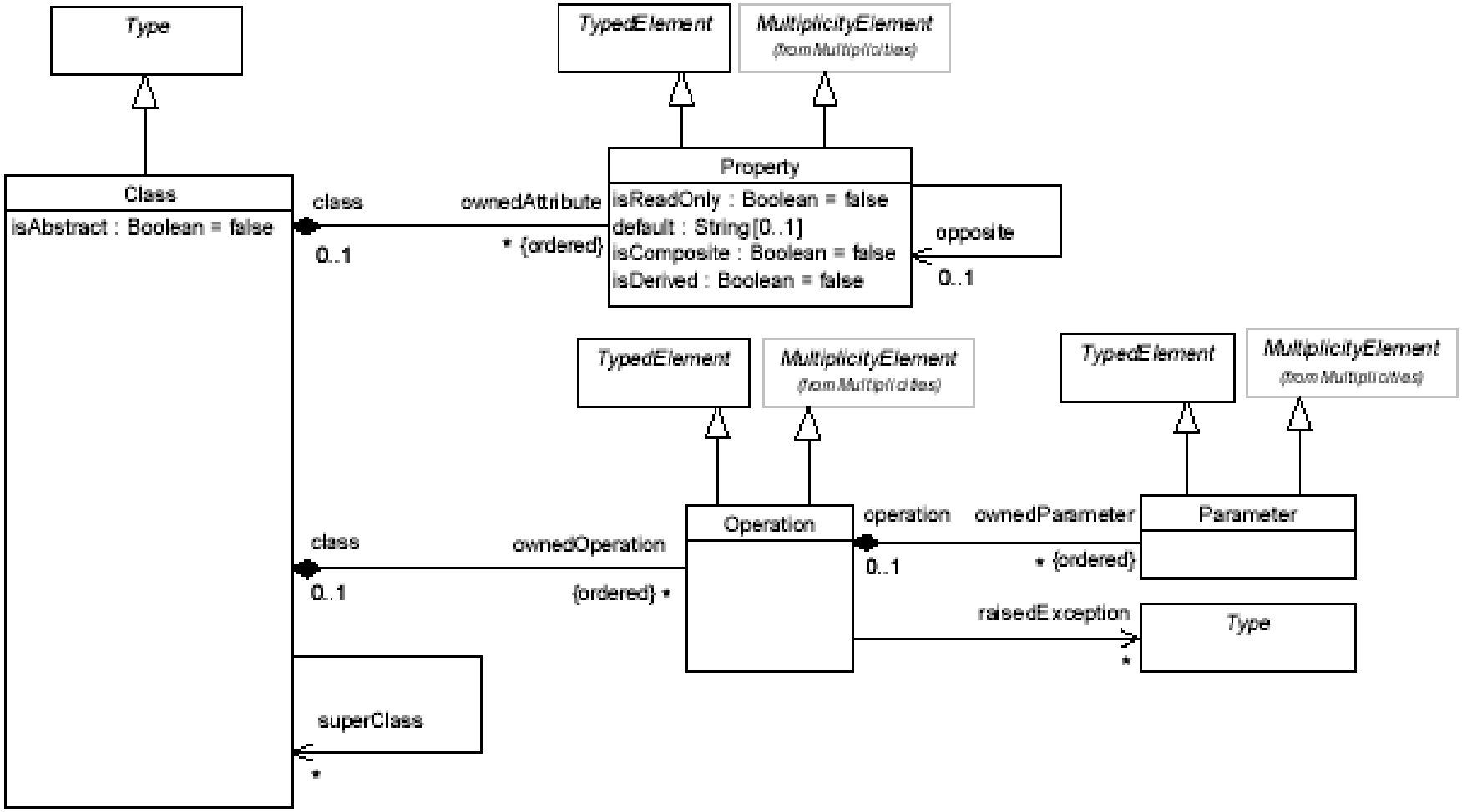
From: UML 2.0 Infrastructure Specification; OMG Adopted Specification ptc/03-09-15

Package Basic: Uses Types from CMOF



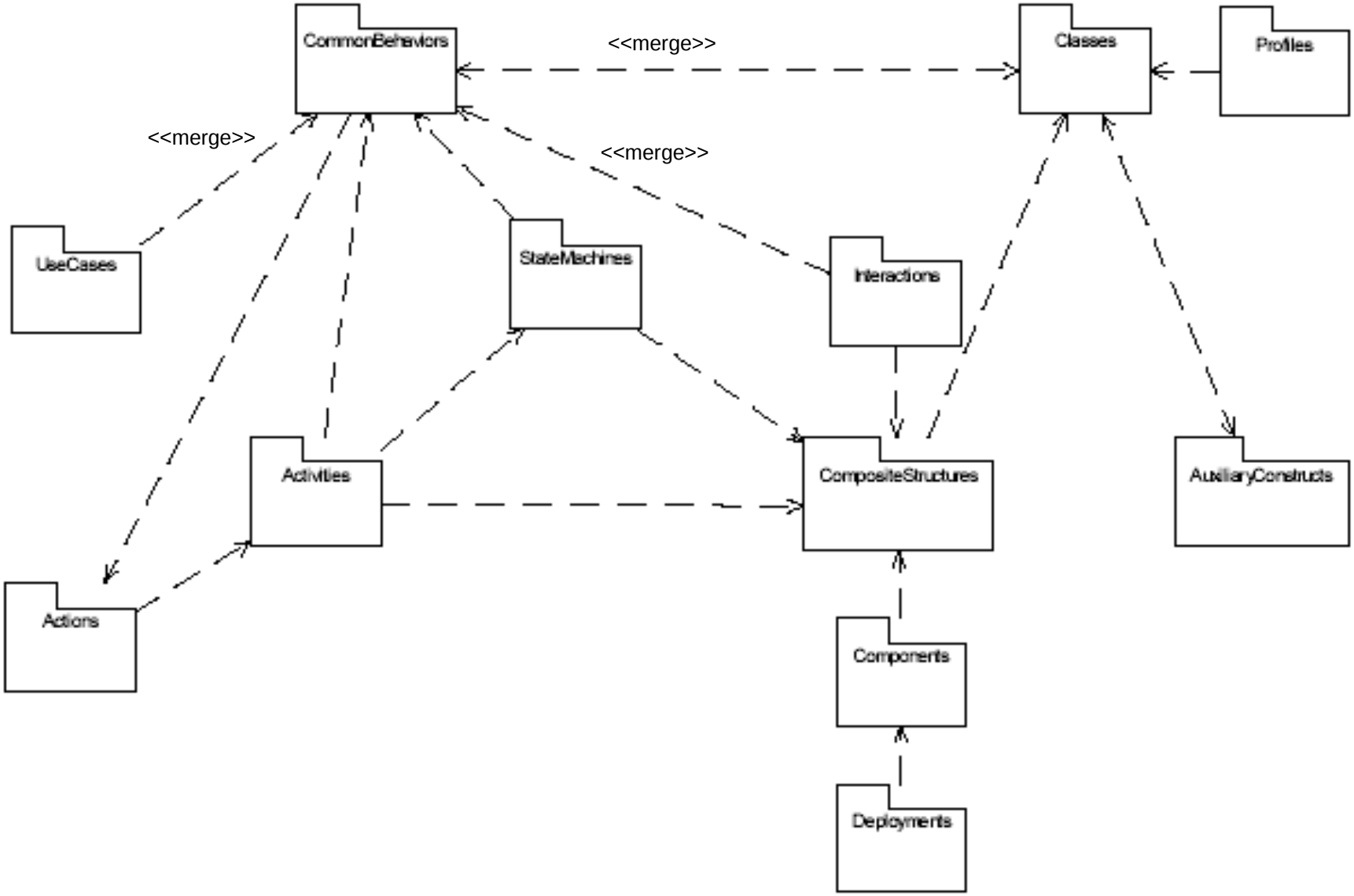
From: UML 2.0 Infrastructure Specification; OMG Adopted Specification ptc/03-09-15

Package Basic: Classes



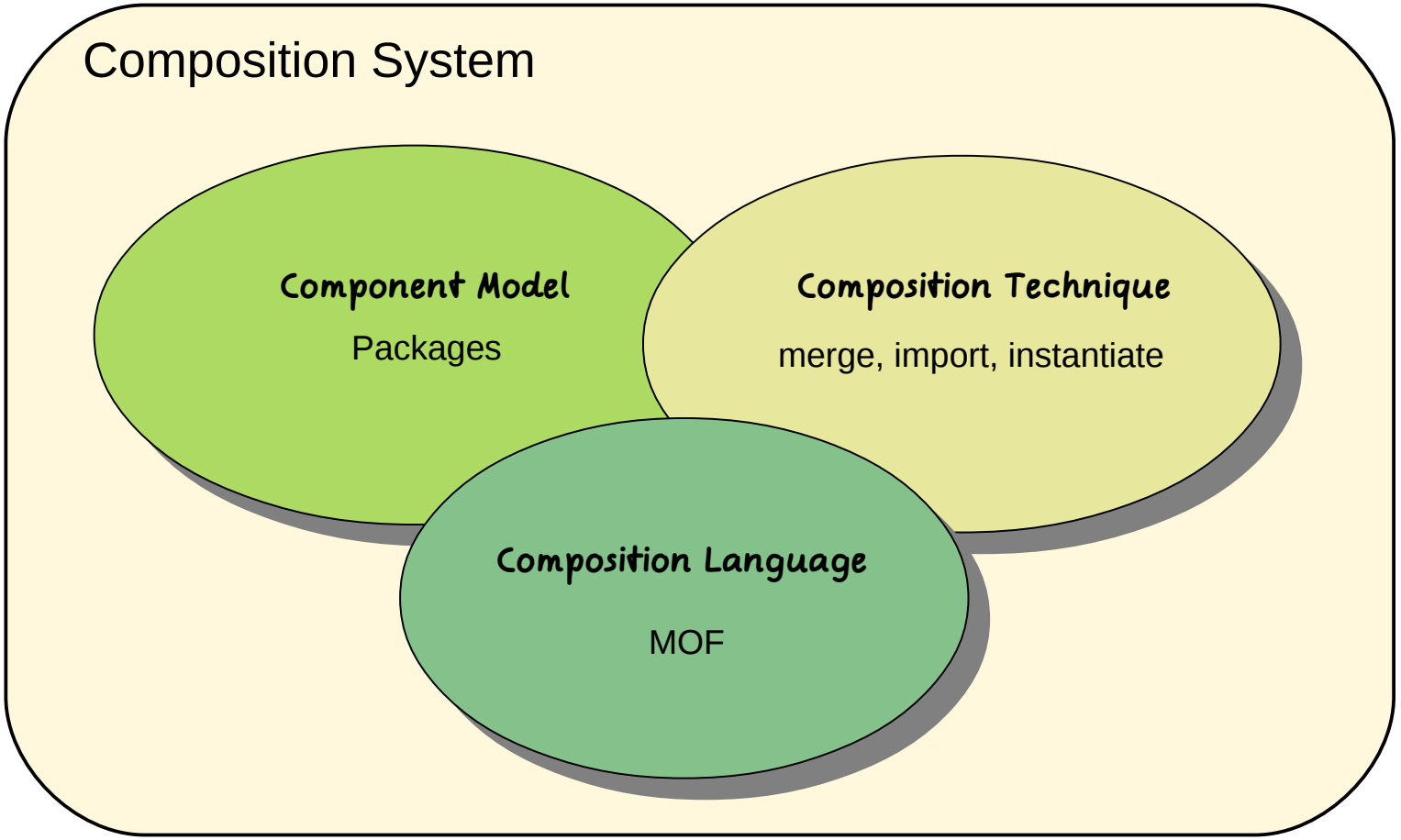
From: UML 2.0 Infrastructure Specification; OMG Adopted Specification ptc/03-09-15

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

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

Megamodels

- A ***megamodel*** is a model for a set or graph of models.
  - The graph of models is an instance of the megamodel (element of the of the language)
- Usually, a technical space has one or several megamodels on M1, linking many models on M1
  - Clearifying the relationships of the M1 models by model transformations, model mappings, and model compositions
  - A megamodel uses the model management system of the technical space

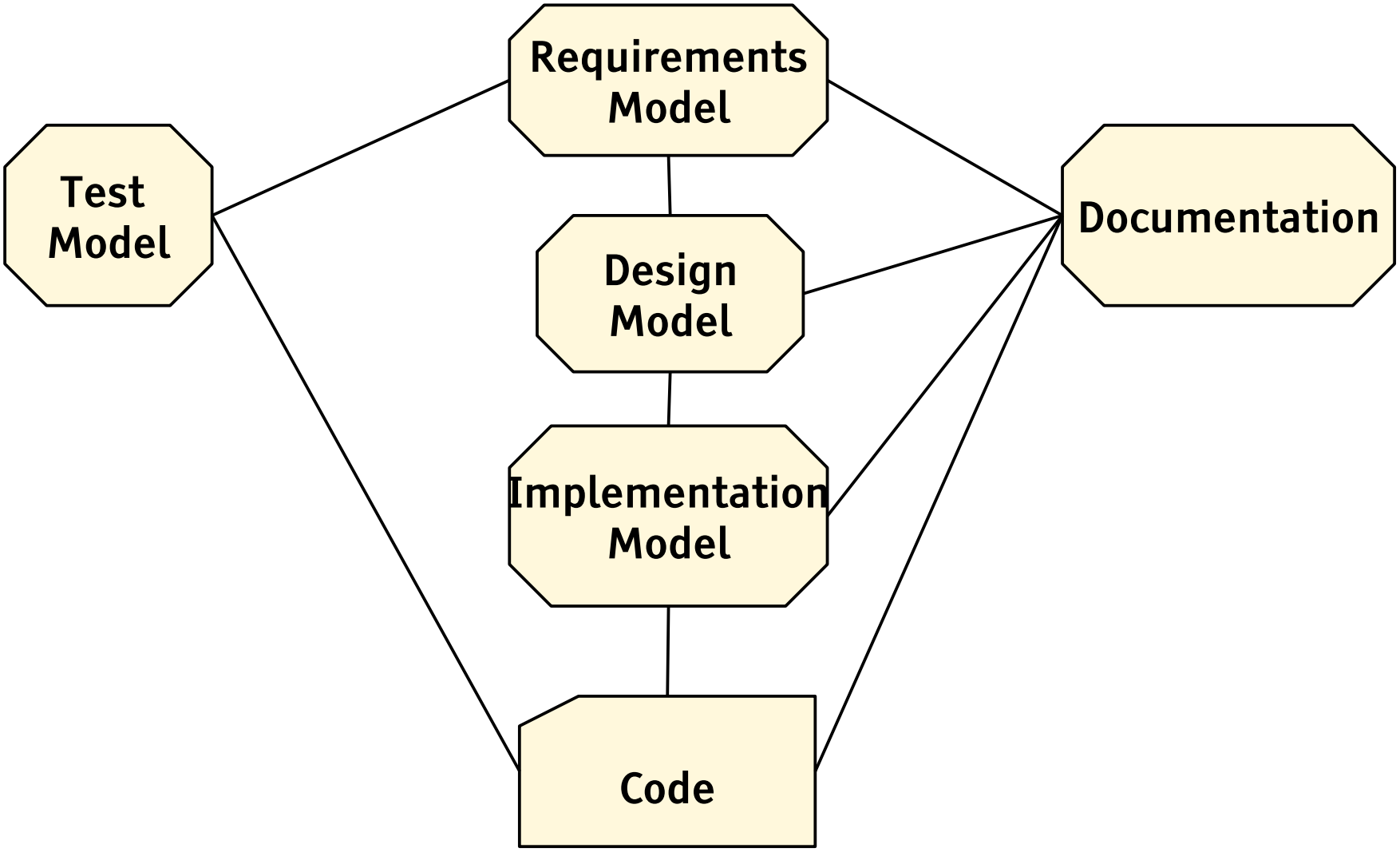
> The idea behind a *mega–model* is to define the set of entities and relations that are necessary to model some aspect about model–driven engineering (MDE).
>
> [Favre]

Macromodels – Megamodels with Consistency Rules

- A ***macromodel*** is a model for a set or graph of models *fulfilling some consistency constraints over the models and their elements*
  - The graph of models is an instance of the megamodel (element of the of the language)
  - The graph of models obeys wellformedness constraints
  - There are **fine-grained relations** between model elements of the models, which also follow *consistency constraints*
    - **Trace mappings** between tools, materials, automata
    - **Synchronization relations** for updating

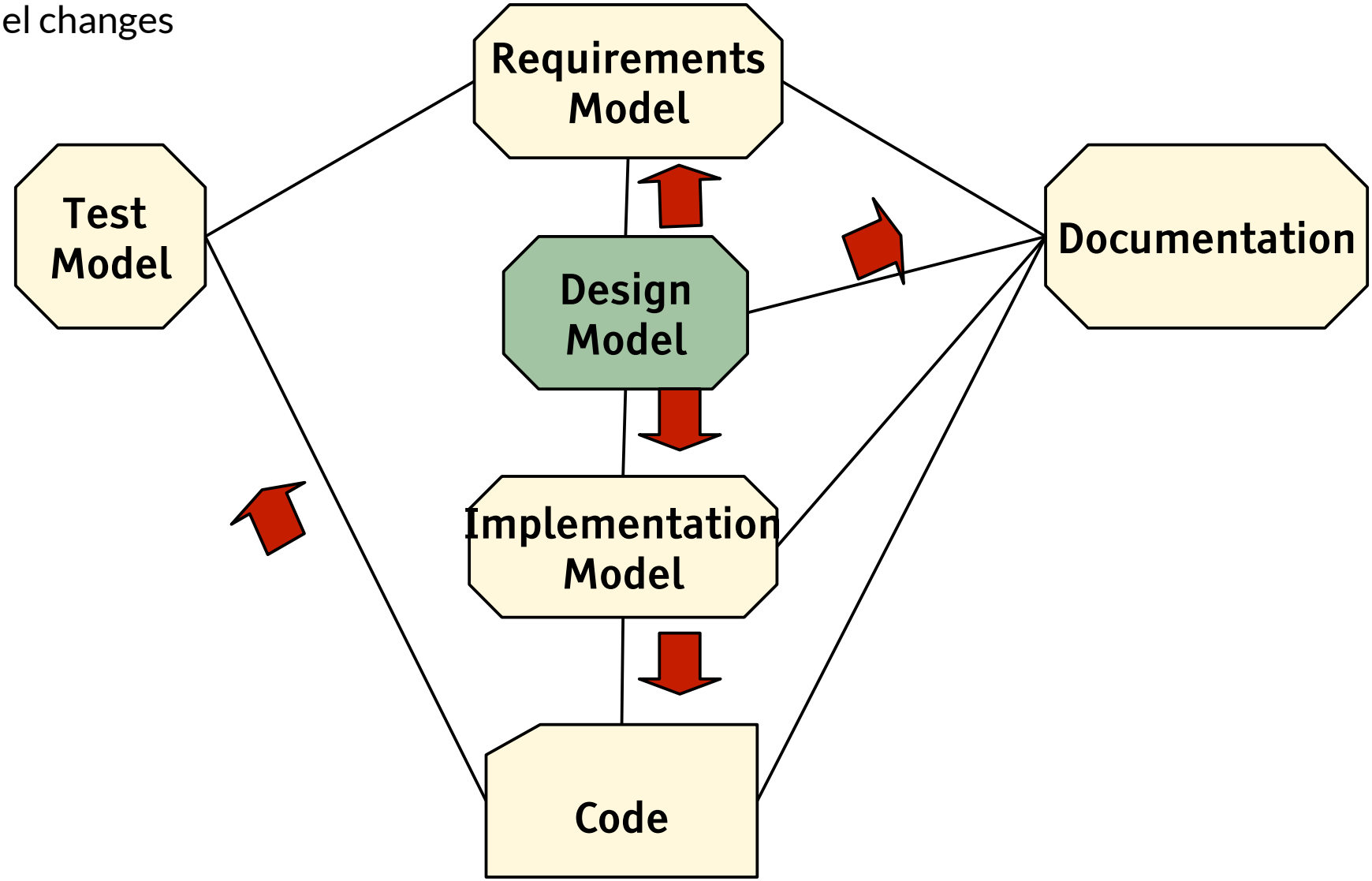
Model Synchronization in Macromodels

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



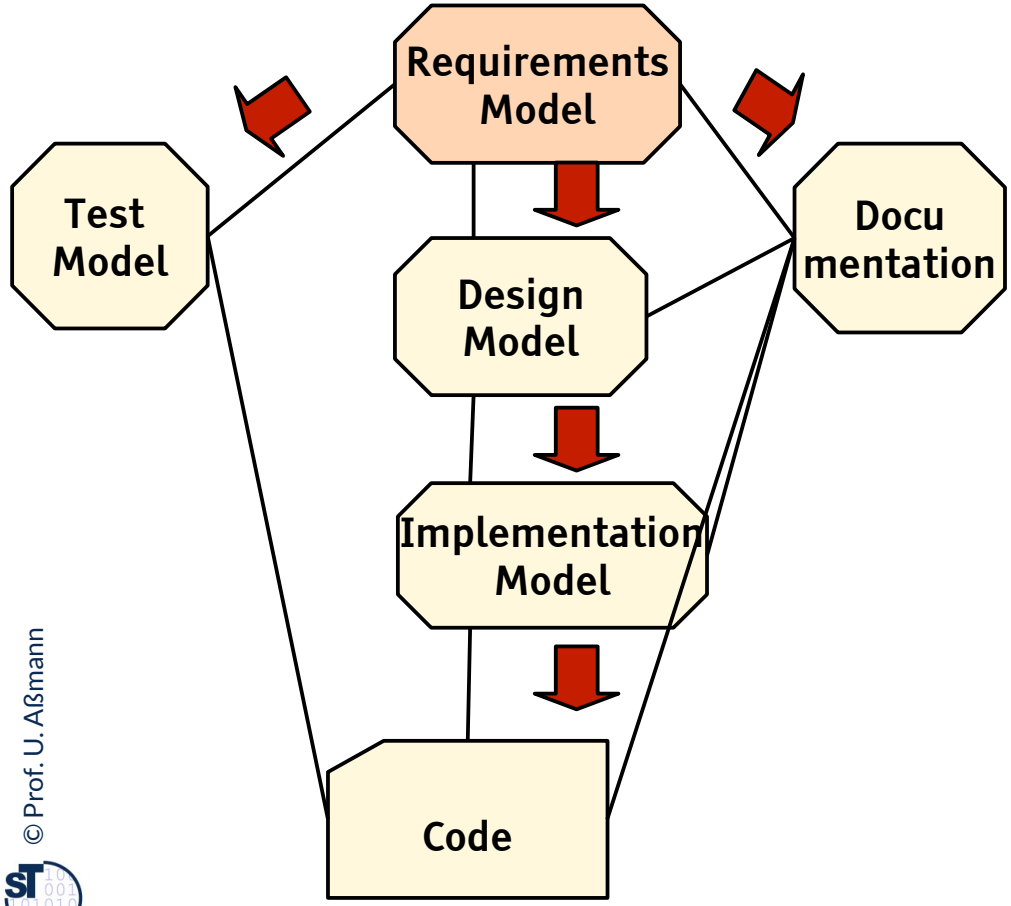
Model Synchronization in Macromodels

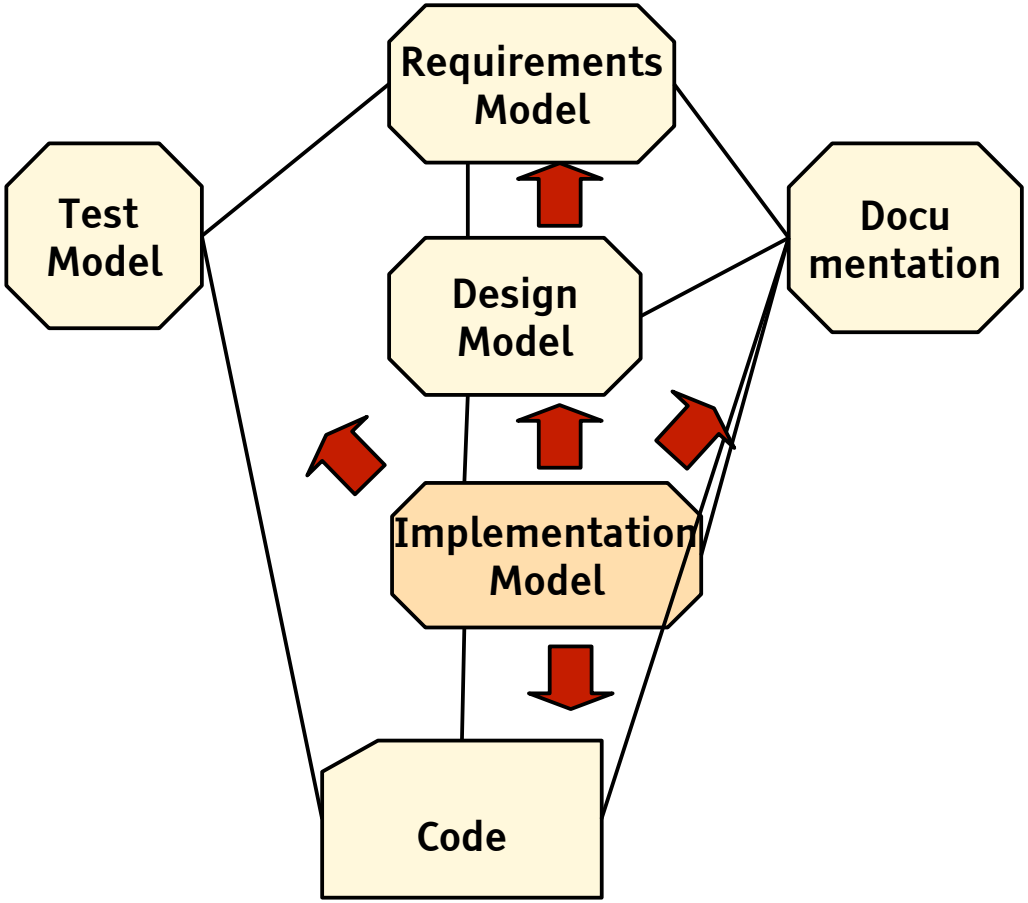
- In model synchronizsation, if an edit has occurred in a ***origin model***, all other connected models of a crowd (***dependent models***) are updated instantaneously, when one focus model changes



Round-Trip Engineering Changes the Model-in-Focus of the Crowd

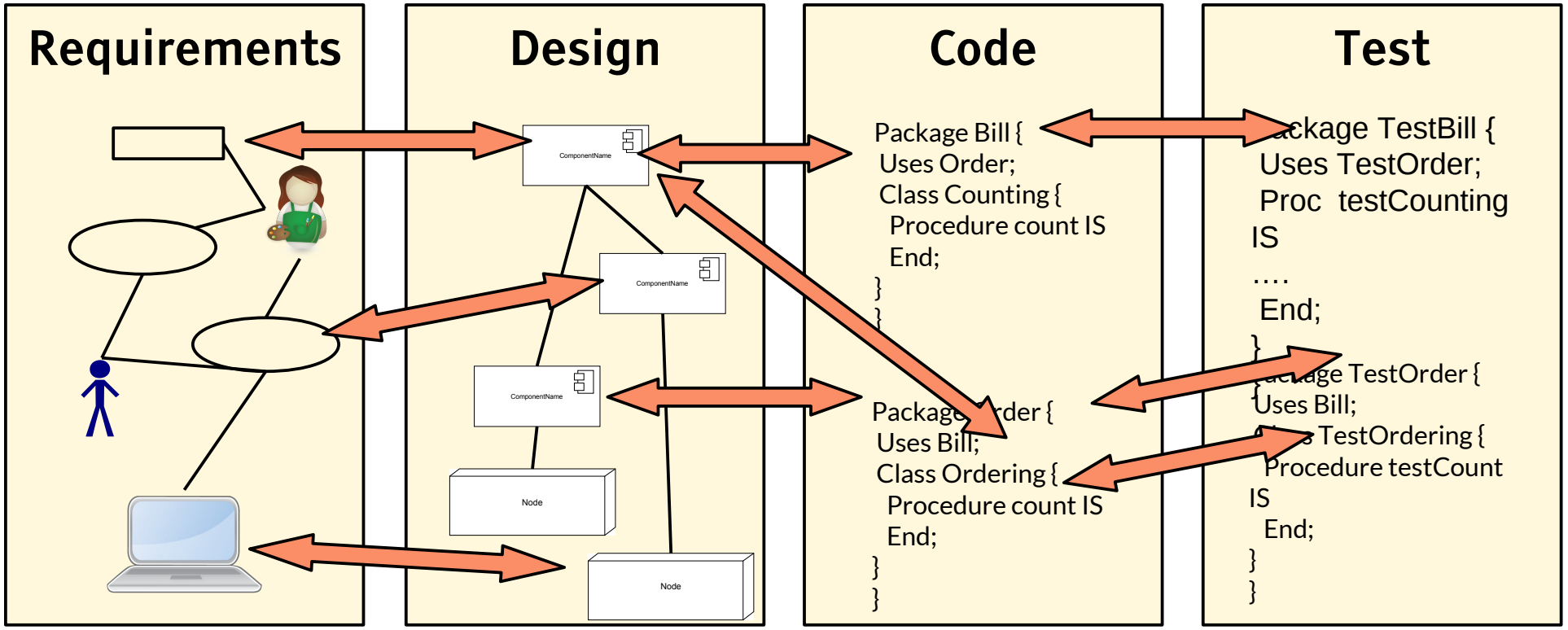
- But always performs model synchronization as a basic step





Q12: The ReDeCT Problem and its Macromodel

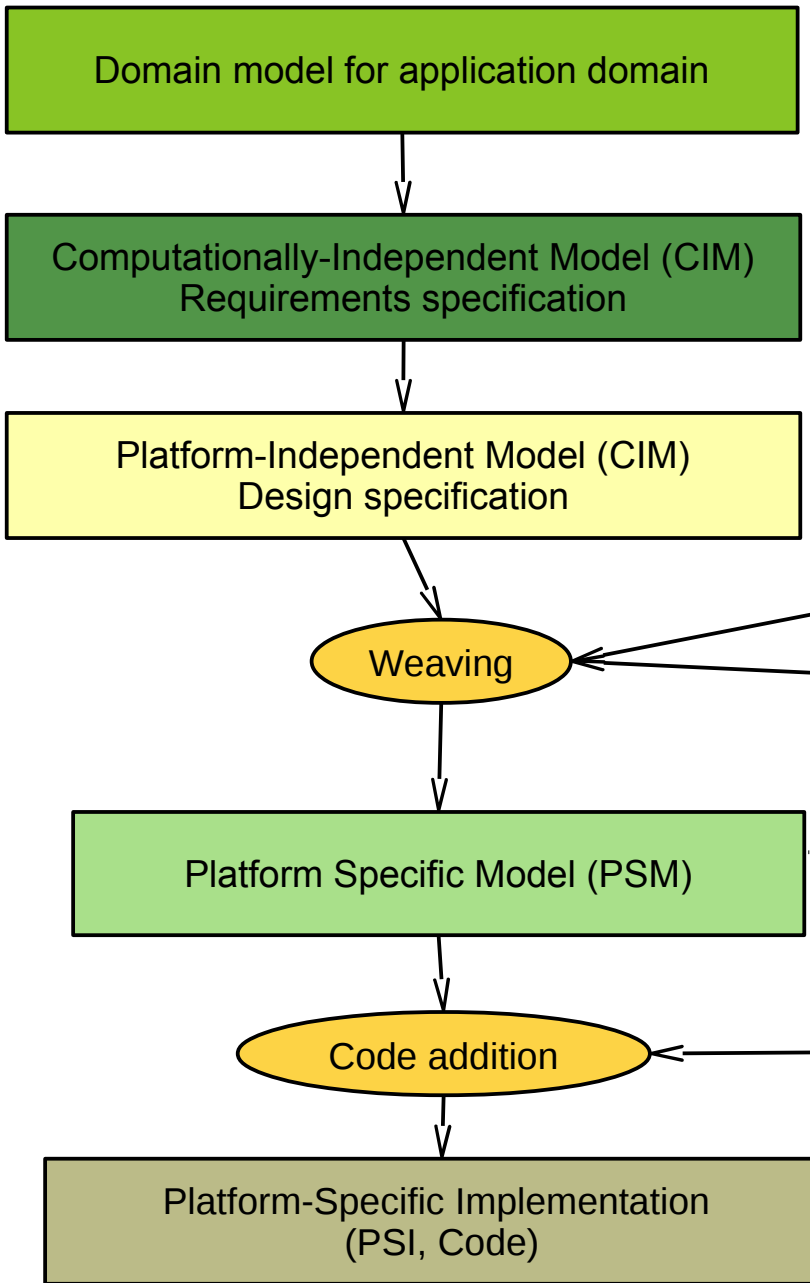
- The **ReDeCT problem** is the problem how requirements, design, code and tests are related (⍰ V model)
- Mappings between the Requirements model, Design model, Code, Test cases
- A **ReDeCT macromodel** has maintained mappings between all 4 models



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 Macromodel



- **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 extensions (model merges, aadditions)** extend an input model by an extension (often done by hand)
  - Usually, some parts are still hand-written code

Platform-Specific Extension (PSE)

Platform Description Model (PDM)

- **Model weavings** weave two input models to an output model, based on a crosscut specification
- **Model2Text expansion** (code generation by template expansion)

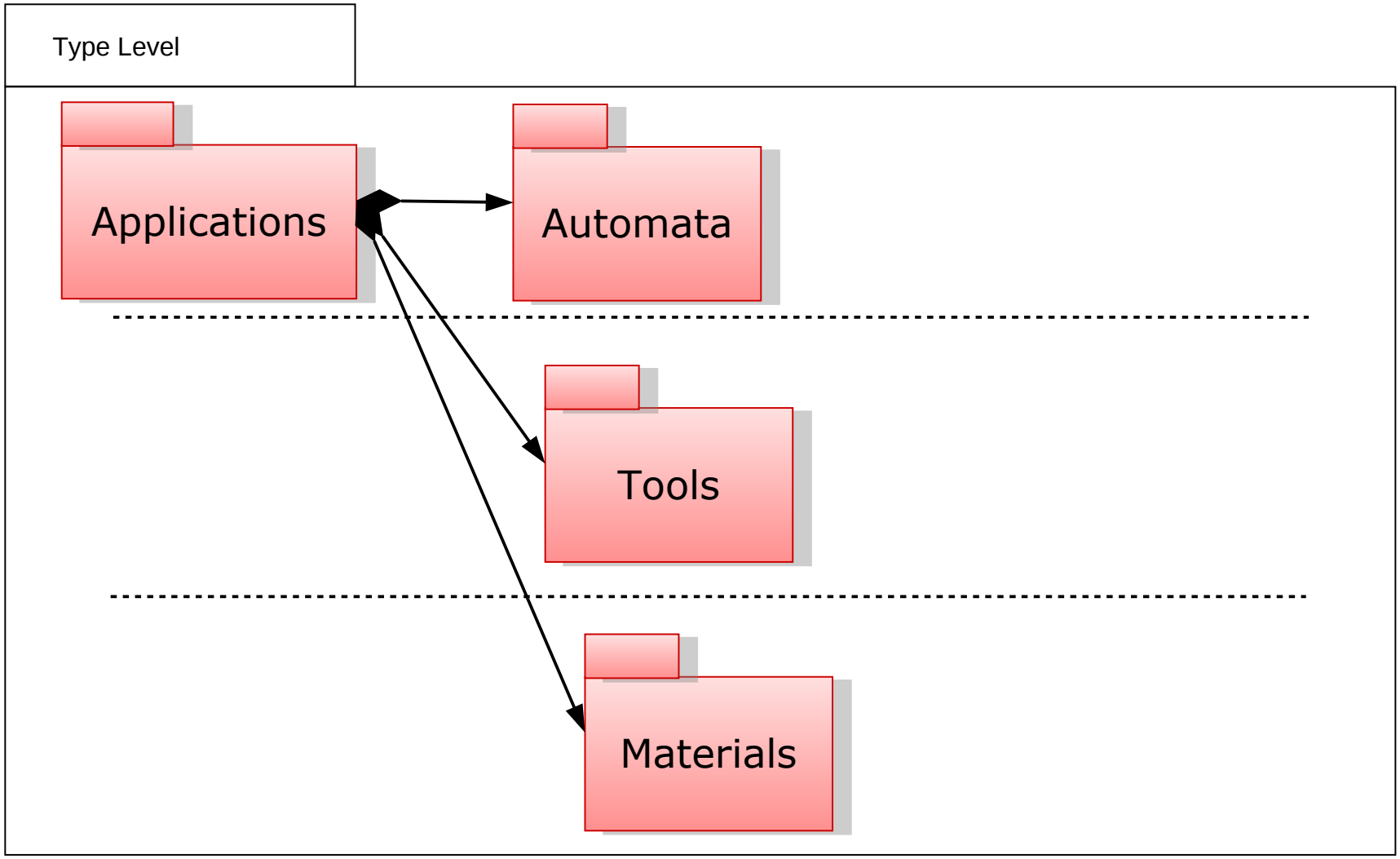
Handwritten code

12.5. Pattern Languages in a Technical Space

- In a TS, several pattern languages may be used to structure the relationship of models and metamodels
- TAM can be used as Pattern Language on all levels in the metahierarchy
- However, there may be more pattern languages associated to a technical space
- Pattern languages can be expressed as stereotypes

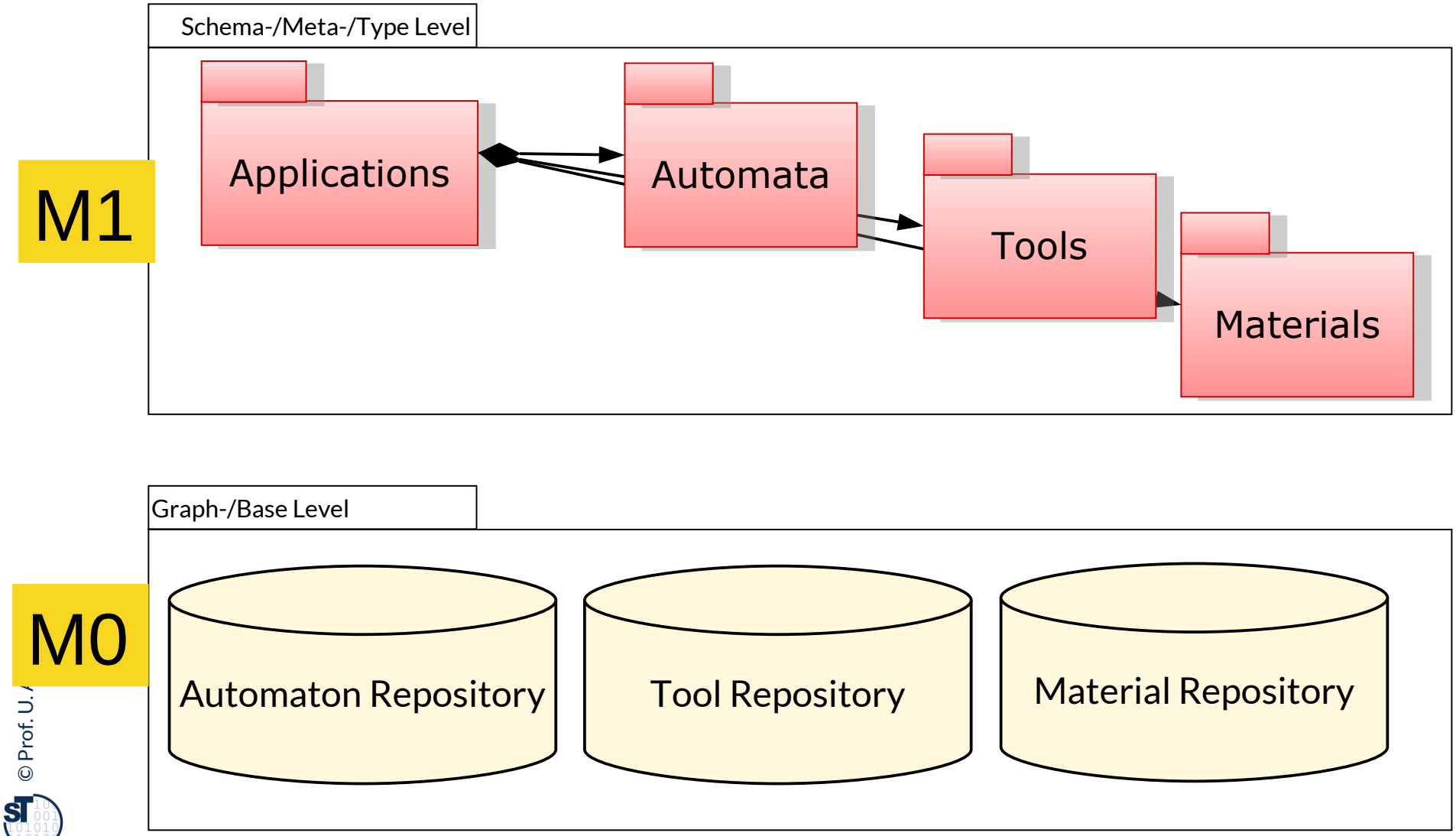
A Pattern Language Useful for all Technical Spaces
TAM Structures on M1

- On M1, application class models need to define (stereotype) tools, automata, and materials.



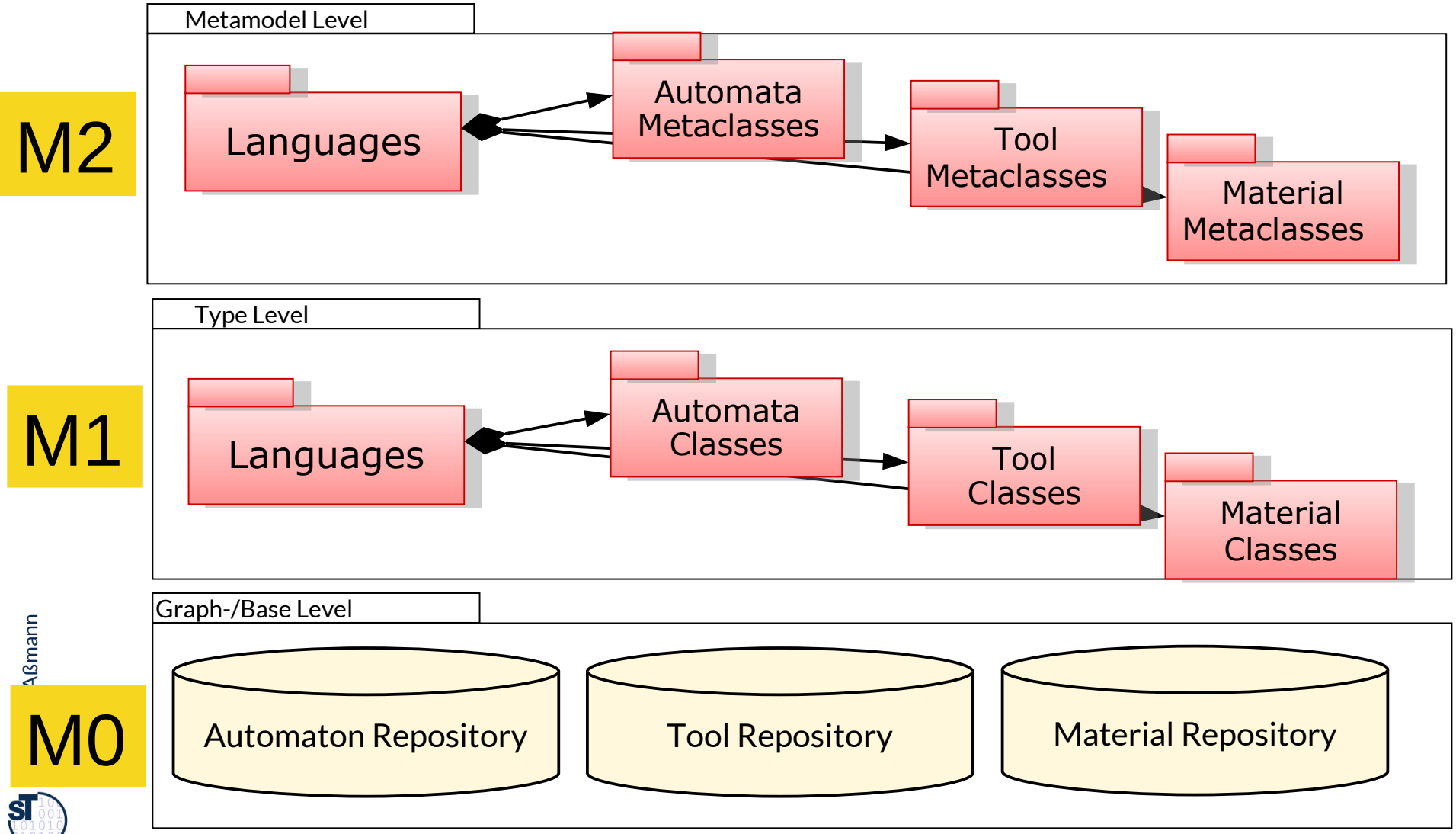
TAM Structures on M1 Provide Types for Objects in Repositories on M0

- On M1, application class models need to define (stereotype) tools, automata, and materials.



TAM Structures on M2 Provide Language Concepts for Stereotypes for Classes in M1

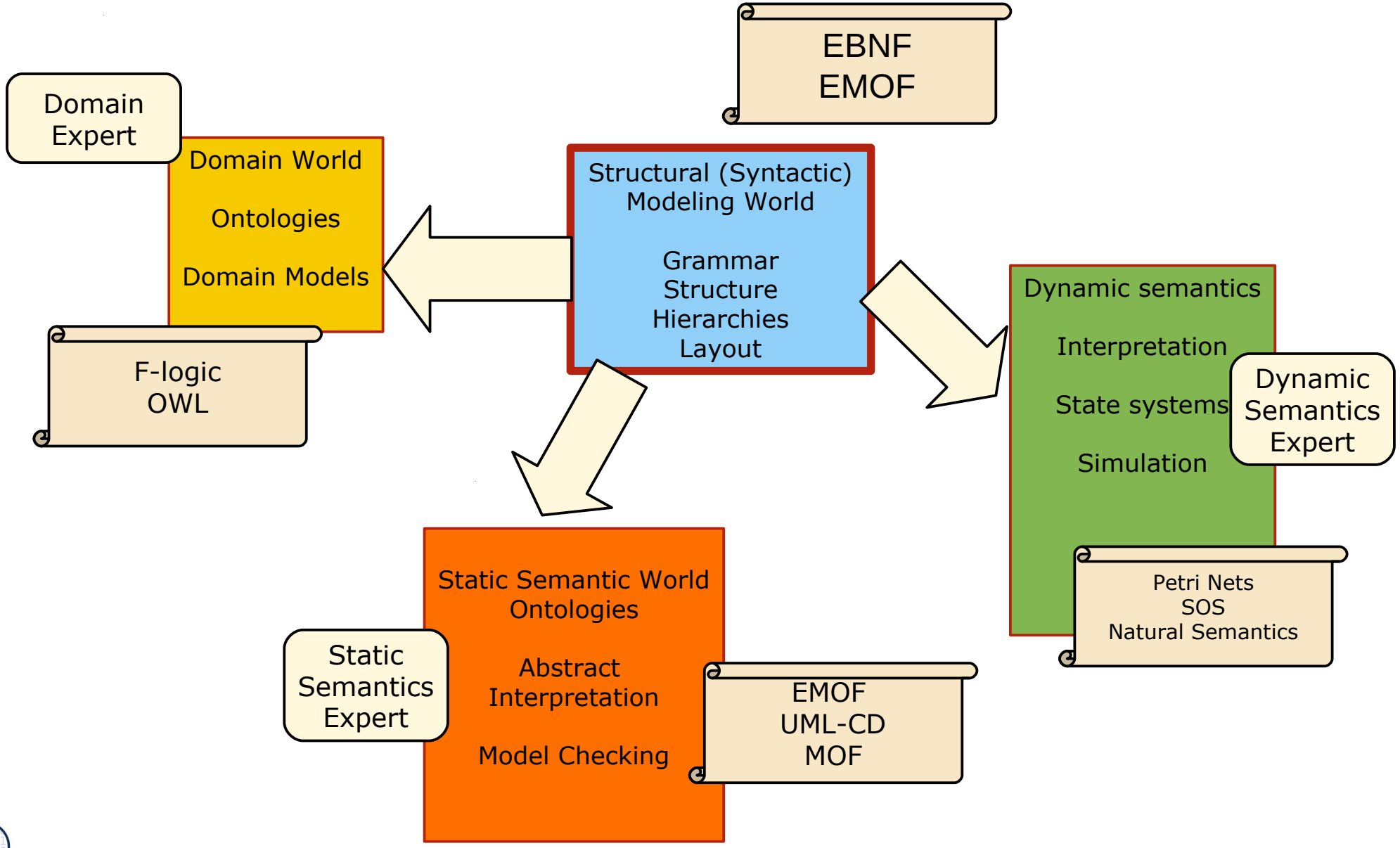
- On M2, TAM forms a DSL for stereotypes on M1
- Other pattern languages can use the same principle



12.6. Briding Technical Spaces

- 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

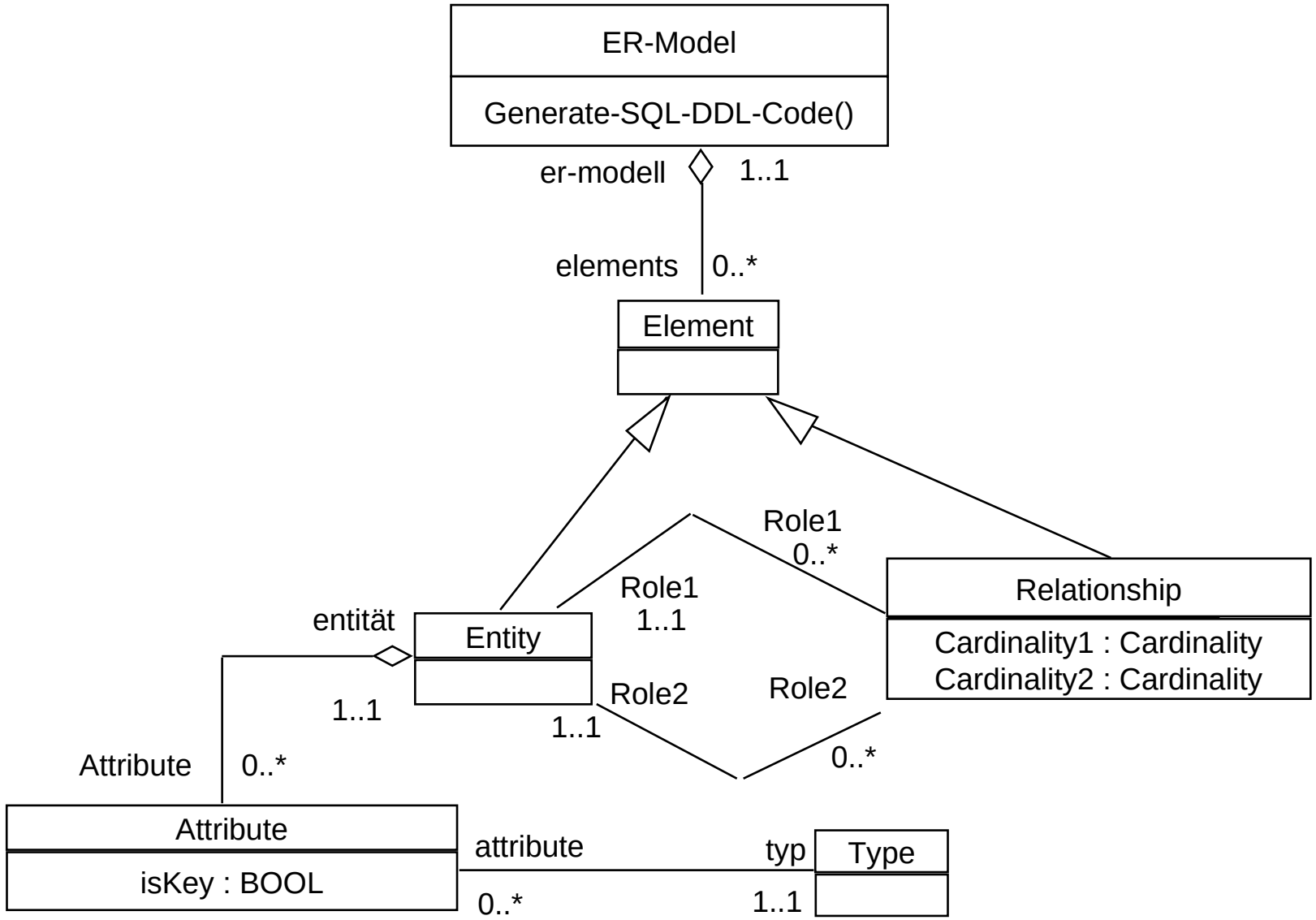


The End

12.A.1 Other Metalanguages

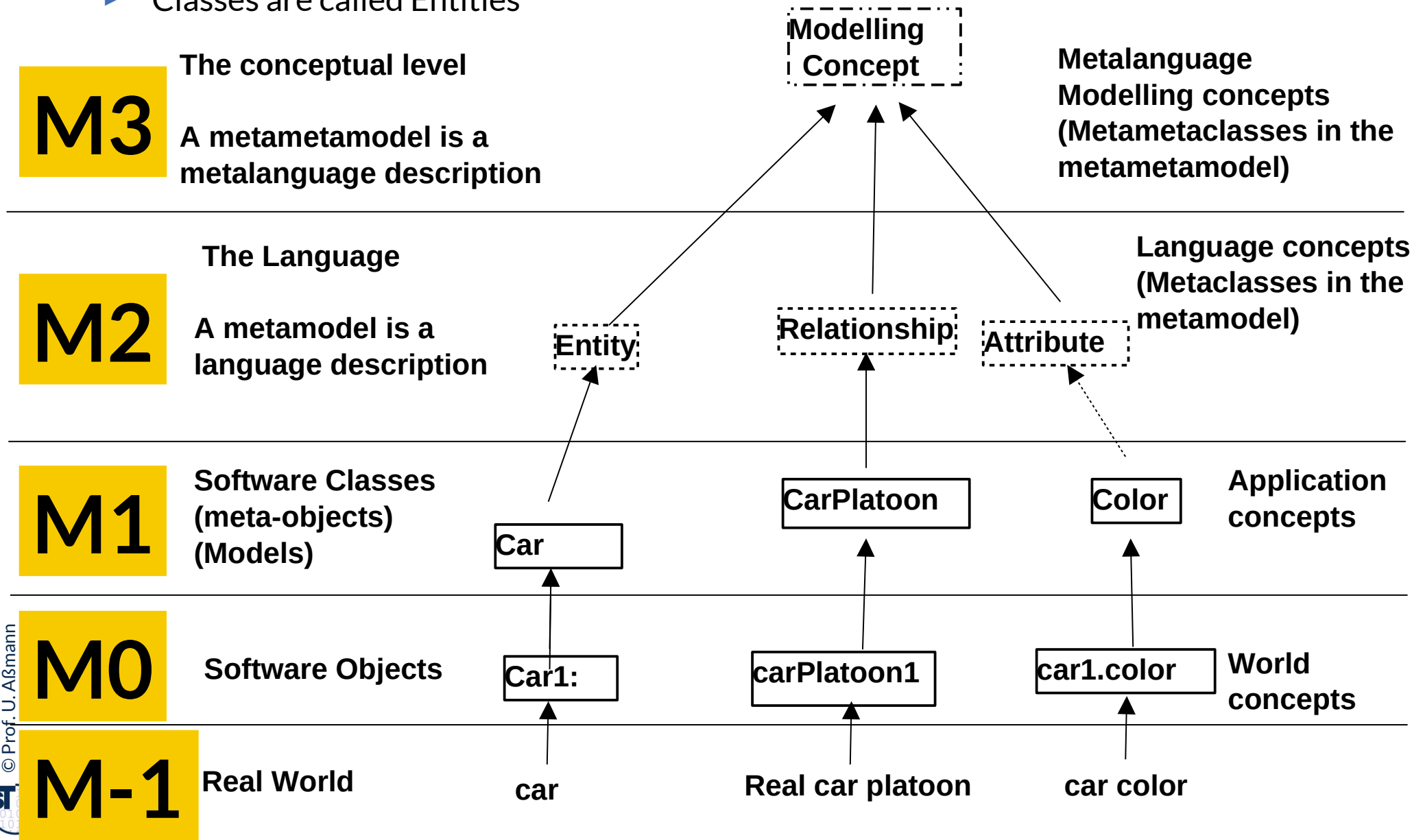
Metamodel of EntityRelationship Diagrams (ERD-ML) in MOF

- ERD is like MOF without inheritance



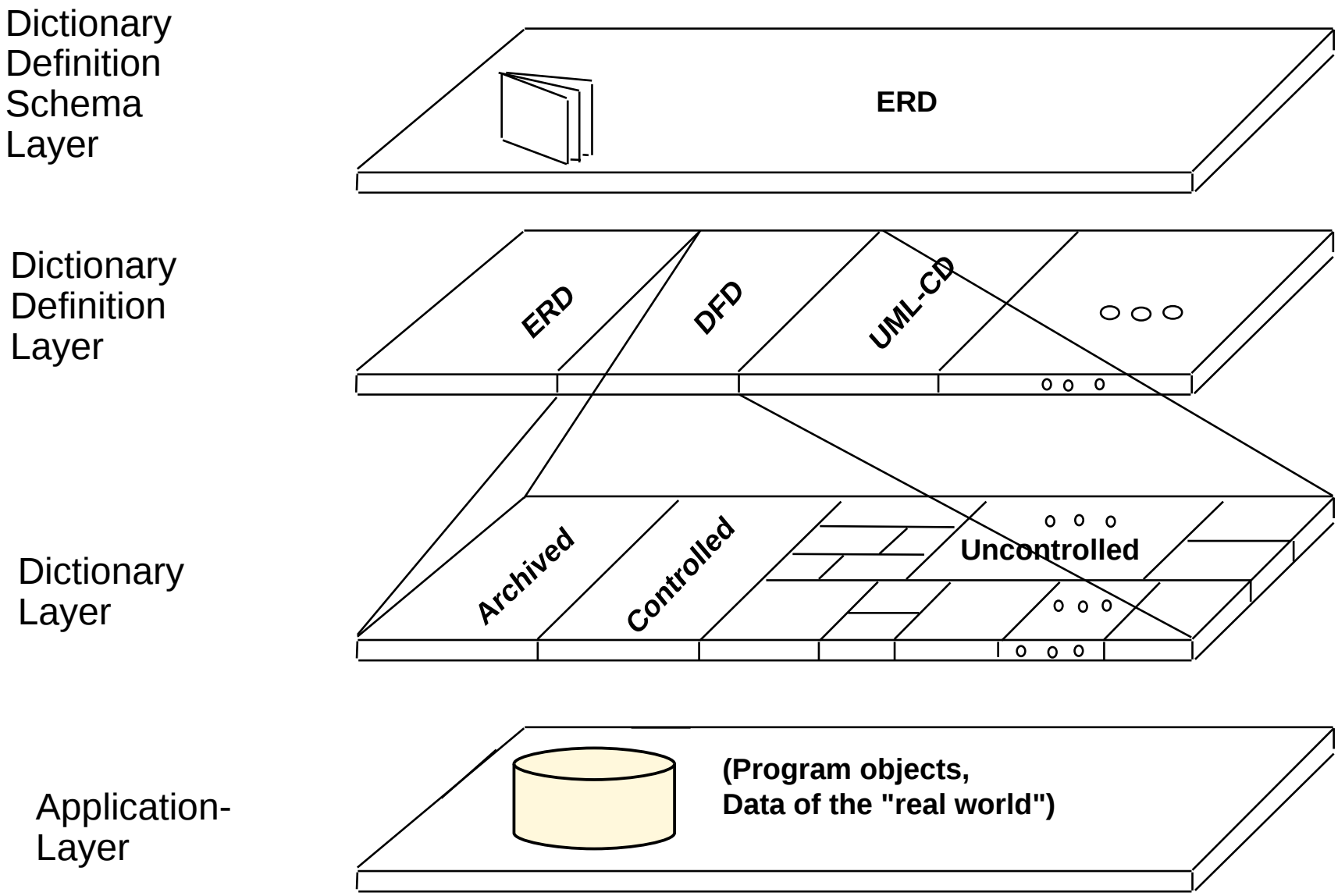
Metalevels in ERD

- Classes are called Entities



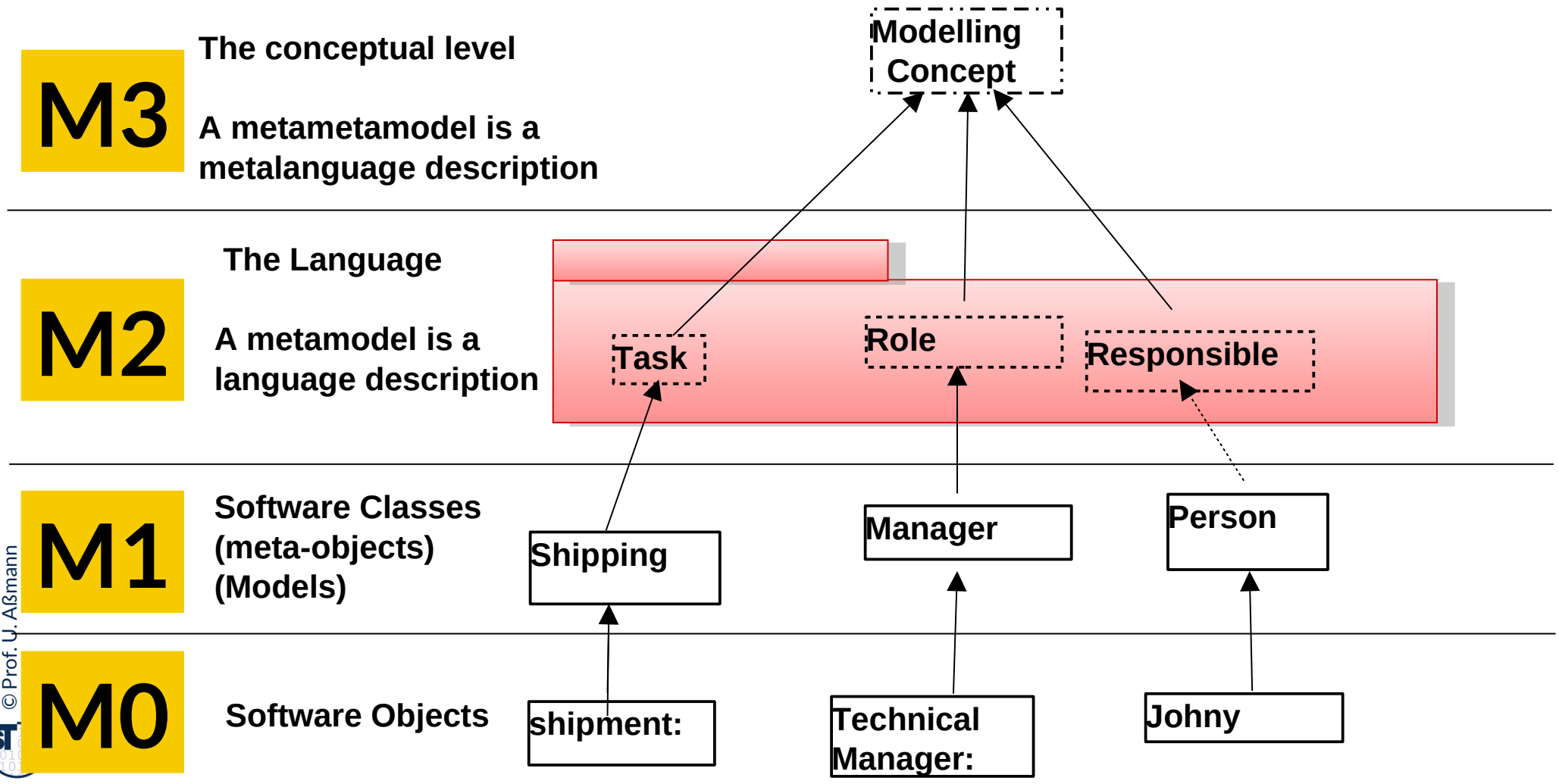
Ex.: IRDS/MOF Metahierarchy for Data Dictionaries in the Structured Analyse (SA)

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



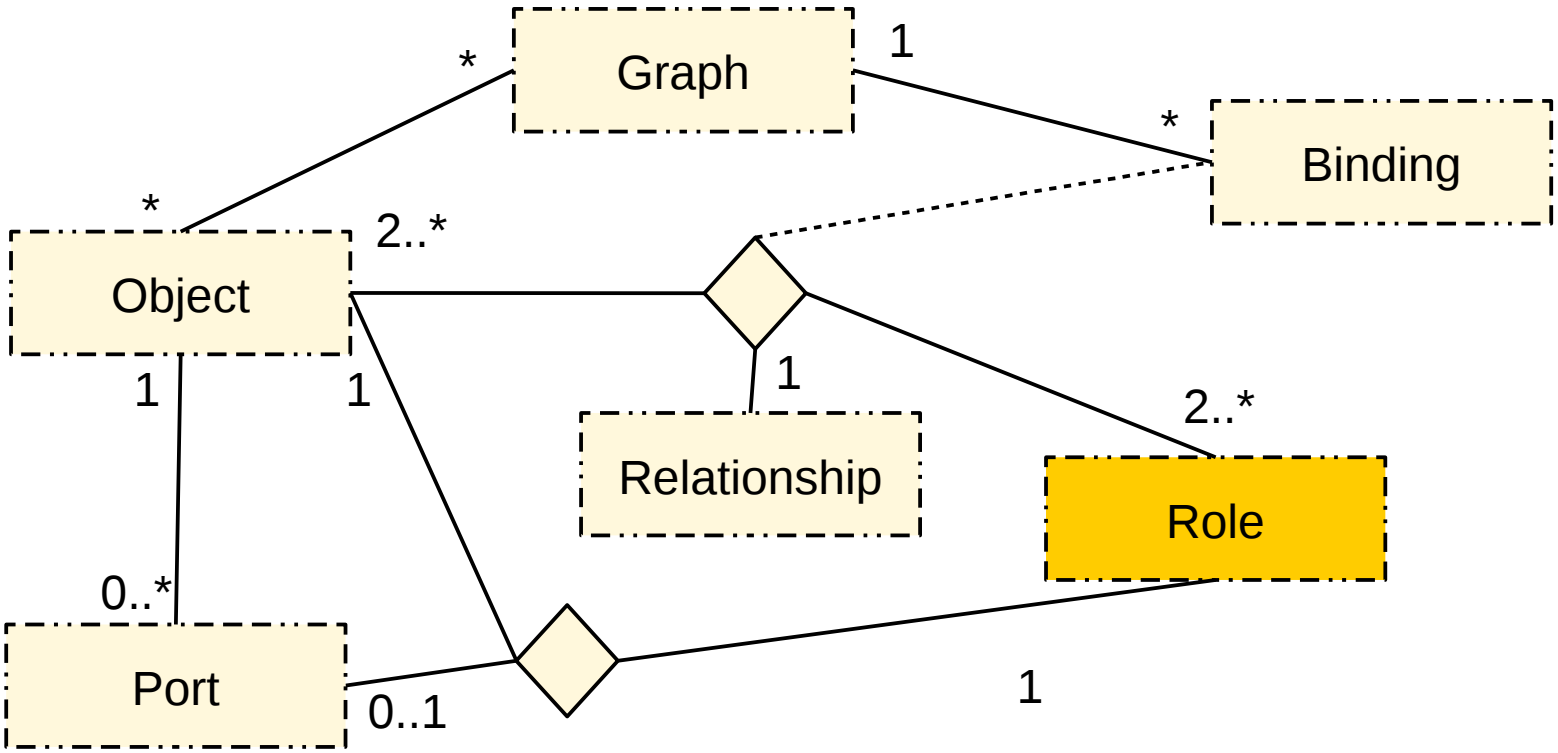
Ex.: Metahierarchy in Workflow Systems and Web Services (e.g., BPEL, BPMN, ARIS-EPK)

- 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**



Role-Based Graph Types in MetaEdit+

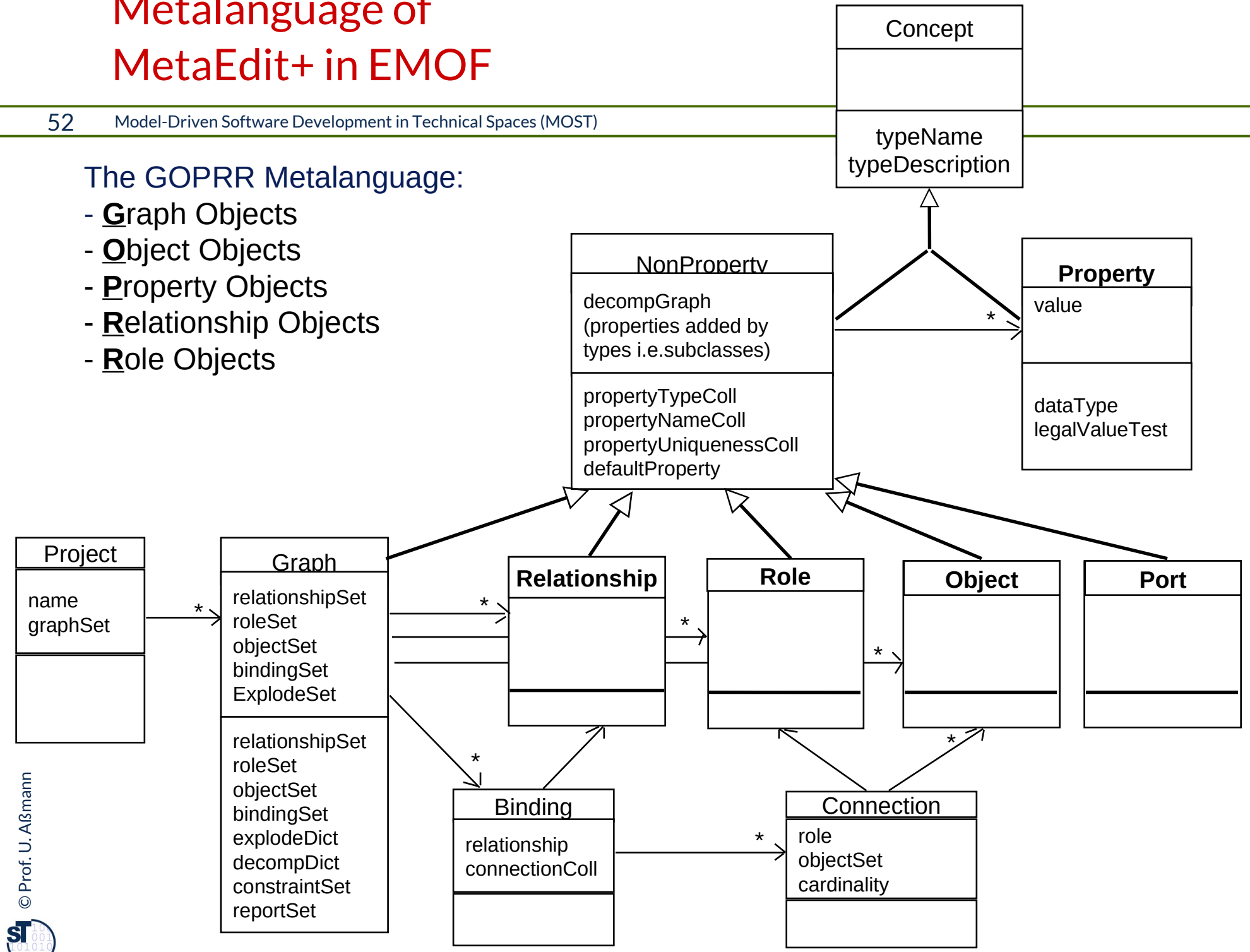
- [www.metacase.com]
- The tool MetaEdit+ uses the **graph schema (metalanguage) GOPRR**:
  - Objects and their Roles; Relationships
  - Allowed Bindings between all entities:
    - a binding consists of a relationship with roles and playing objects



Metalanguage of MetaEdit+ in EMOF

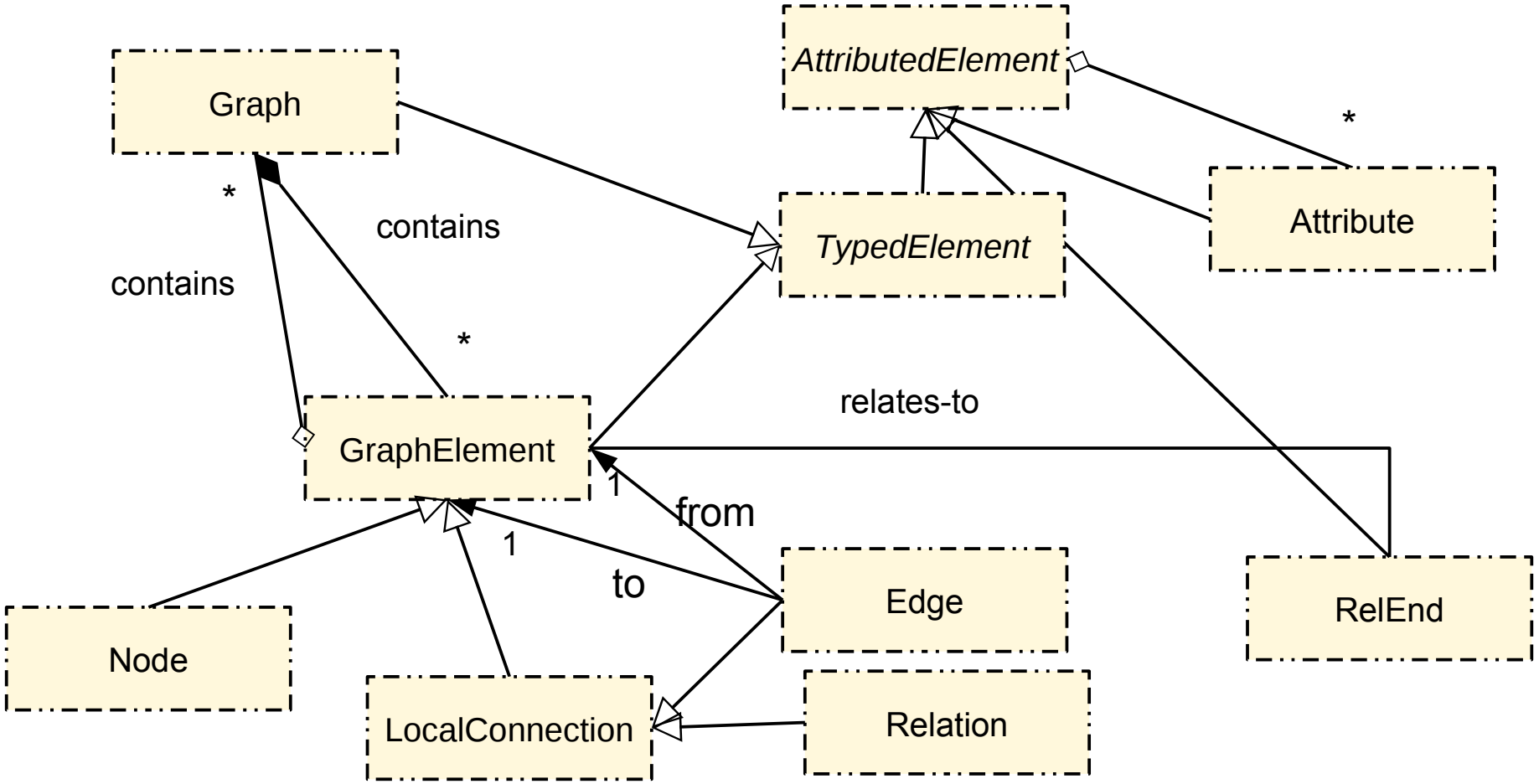
The GOPRR Metalanguage:

- **G**raph Objects
- **O**bject Objects
- **P**roperty Objects
- **R**elationship Objects
- **R**ole Objects



GXL Graph eXchange Language – a Technical Metametamodel

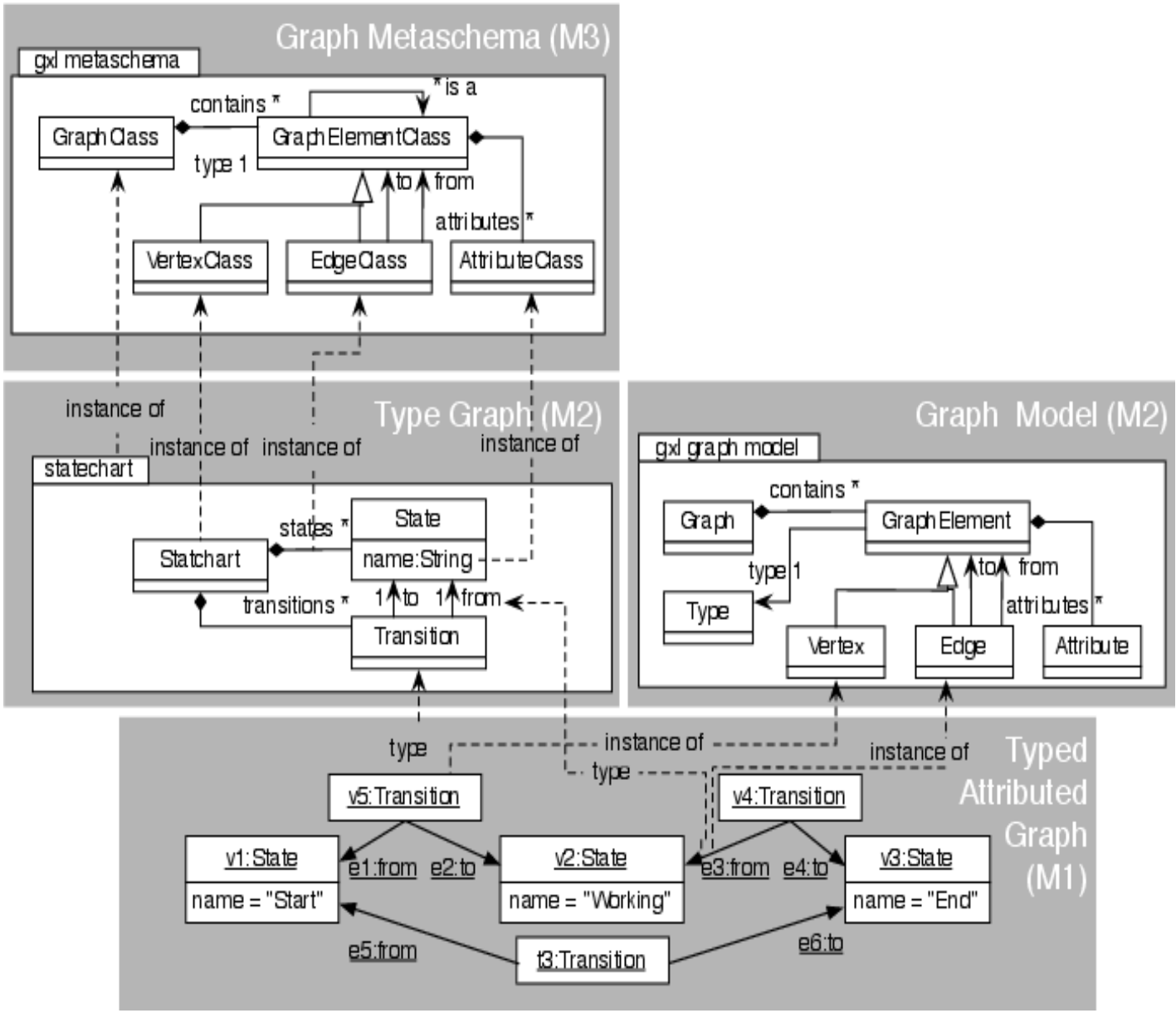
- GXL is a modern graph-language (graph-exchange format)
- Contains abstractions for elements of graphs usable for generic algorithms (e.g., flexible navigation)



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

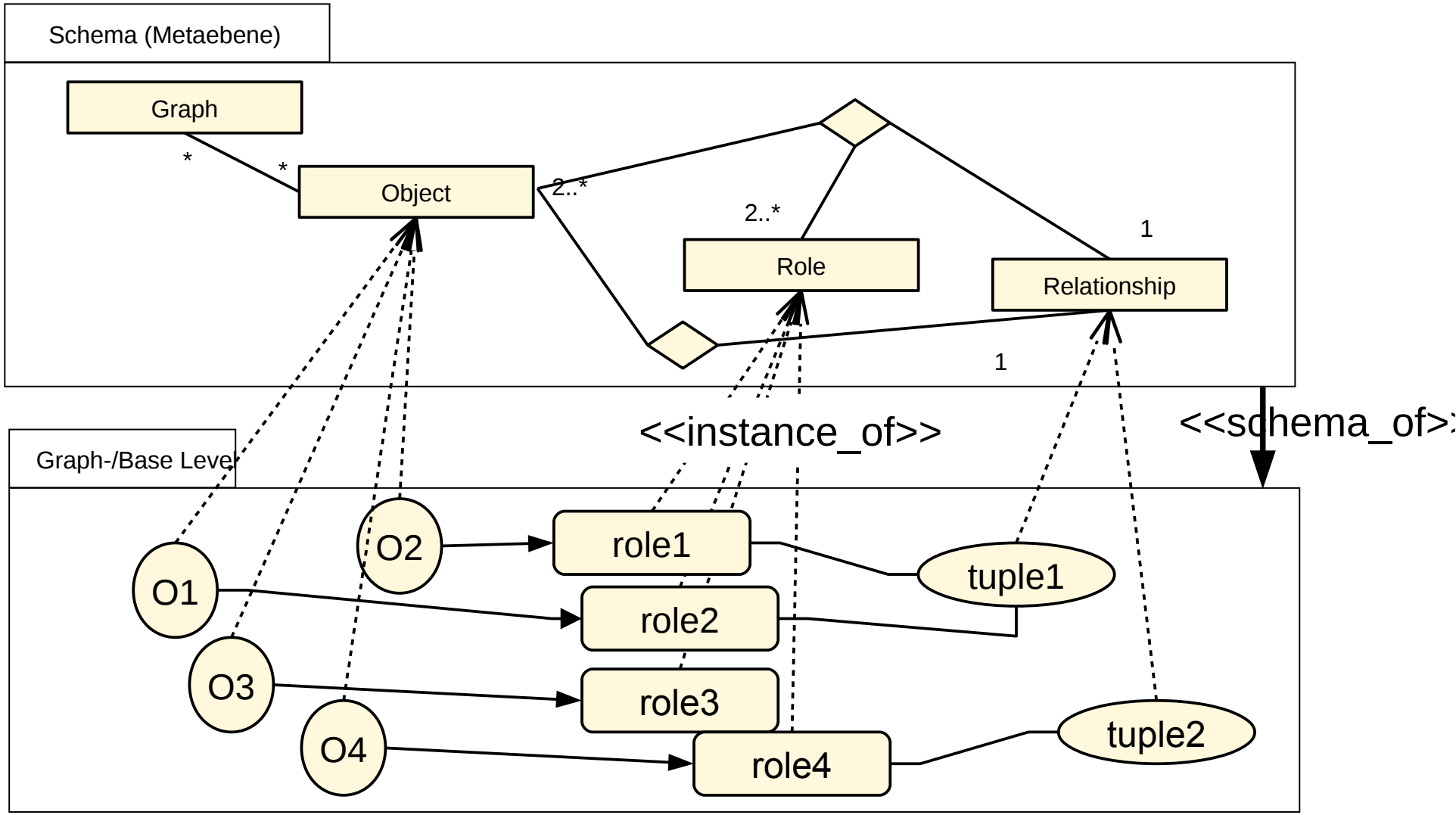
GXL-based Metamodel of Typed Attributed Graph

- 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)



Typed Graphs (Models and Metamodels)

- Graphs can be typed, but the schemata may look differently
- Here: object-role model



Different Types of Semantics and their Metalanguages (Description Languages)

- **Structure**
  - Described by a *context-free grammar* or a *metamodel*
  - Does not regard context
- **Static Semantics** (context conditions on structure), **Wellformedness**
  - Described by *context-sensitive grammar (attribute grammar, denotational semantics, logic constraints)*, or a *metamodel with context constraints*
  - Describes context constraints, context conditions, meaning of names
  - Can describe consistency conditions on the specifications
    - "If I use a variable here, it must be defined elsewhere"
    - "If I use a component here, it must be alive"
- **Dynamic Semantics (Behavior)**
  - Interpreter in an *interpreter language (e.g., lambda calculus)*, or a *metaobject protocol*
  - A dynamic semantics consists of sets of run-time states or run-time terms
  - In an object-oriented language, the dynamic semantics can be specified in the language itself. Then it is called a *meta-object protocol (MOP).*

Metamodelle für CASE

Metamodelle für CASE basieren auf textuellen oder graphischen **Beschreibungen einer Methode** oder einer **Notation**, aus deren Interpretation, Compilier und CASE-Werkzeuge **generiert, konf iguriert** oder **parametrisiert** werden können.

- Die auf Metamodellen beruhenden SEU werden oftmals auch als **Meta-CASE** bezeichnet.
  - Die Sprache, in der die Metamodelle erstellt werden, wird Metasprache genannt (Auf Ebene M3)
  - Sie beinhalten im Allgemeinen eine Technologie zum Entwickeln und zum Erzeugen von CASE.
  - unterstützen eine oder mehrere Entwicklungsmethoden
  - unterstützen automatisch (Generierung,funktionaler Aspekt) oder halbautomatisch (Modellierung, statischer Aspekt) die Entwicklung von CASE-Tools

Fromn: http://www.uni-koblenz.de/FB4/Institutes/IST/AGEbert/MainResearch/MetaTechnology/Kogge
http://www.cs.usask.ca/grads/vsk719/academic/856/project/node8.html
http://www.cs.ualberta.ca/~softeng/Theses/zhu.shtml
http://www.metacase.com/de/index.html

Benefits of the Metahierarchy

- With **Metametamodels (Metasprachen)** arbitrary metamodels of languages can be defined for their context-free and context-sensitive structure

- Auf Basis von Metaebenen können verschiedene Beschreibungssprachen ineinander **überführt** werden *(Model-driven Architecture; MDA)*
  - Hierarchische Anordnung der einzelnen Modellebenen ermöglicht schrittweise Verfeinerung der semantischen Konzepte
  - **Transformationsbrücken** (z.B. Transformation eines ER-Diagrams in ein UML-Diagram, wenn beide Diagram-Sprachen als Instanz von Ecore erstellt wurden)
- Metamodelle bieten:
  - prägnante, präzise Definition von Softwareobjekten und -dokumenten
  - Vertiefung semantischer Beziehungen und Regeln (Konsistenzprüfung)
  - automatisierte Implementation von Werkzeugen für zu unterstützende Methoden
  - Fähigkeit der Selbstbeschreibung und Überprüfbarkeit mit eigenen Mitteln

Metamodeling - Summary

- Discussed metametamodels are
  - Complete MOF and Essential MOF (EMOF/CMOF)
    - Ecore as Eclipse's implementation of EMOF
    - UML core – a subset of CMOF
  - GXL – Graph eXchange Language
  - GOPRR – Graph, Object, Property, Role, Relation
- Meta-Hierarchy
  - M3 to M0
- Example metamodels (Statecharts, ER, Class Diagrams)