# 12. An Overview of Technical Spaces

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Version 21-0.1, 20.11.21

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

# Literature




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  - https://journal.ub.tu-berlin.de/eceasst/article/viewFile/704/713
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- Rick Salay, Shige Wang, and Vivien Suen. Managing related models in vehicle control software development. In Robert B. France, Jürgen Kazmeier, Ruth Breu, and Colin Atkinson, editors, Model Driven Engineering Languages and Systems - 15th International Conference, MODELS 2012, Innsbruck, Austria, September 30-October 5, 2012. Proceedings, volume 7590 of Lecture Notes in Computer Science, pages 383--398. Springer, 2012.

# 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

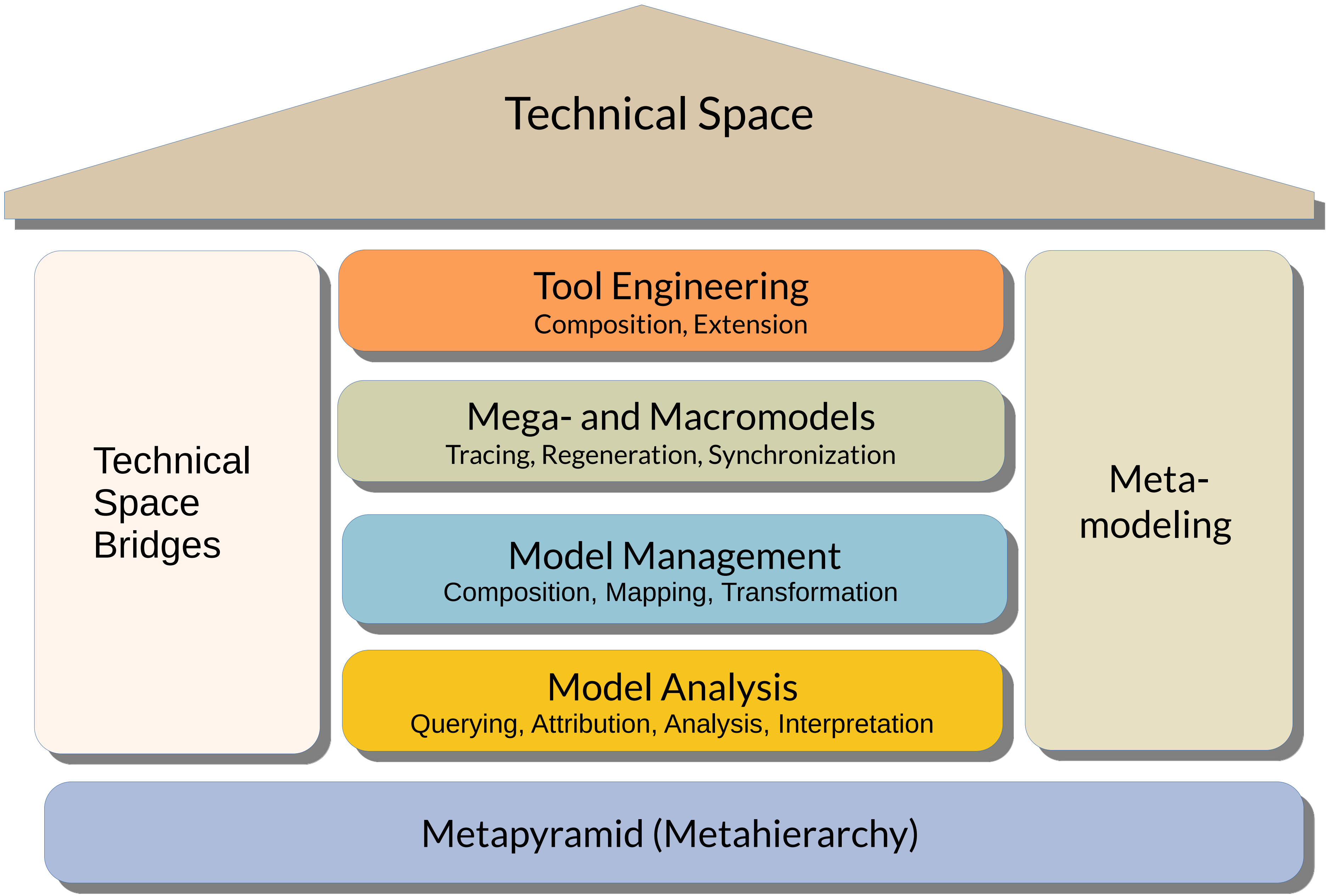


Multimodeling is the act of combining diverse models.
[Brooks-Lee-Hanxleden]

- 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)



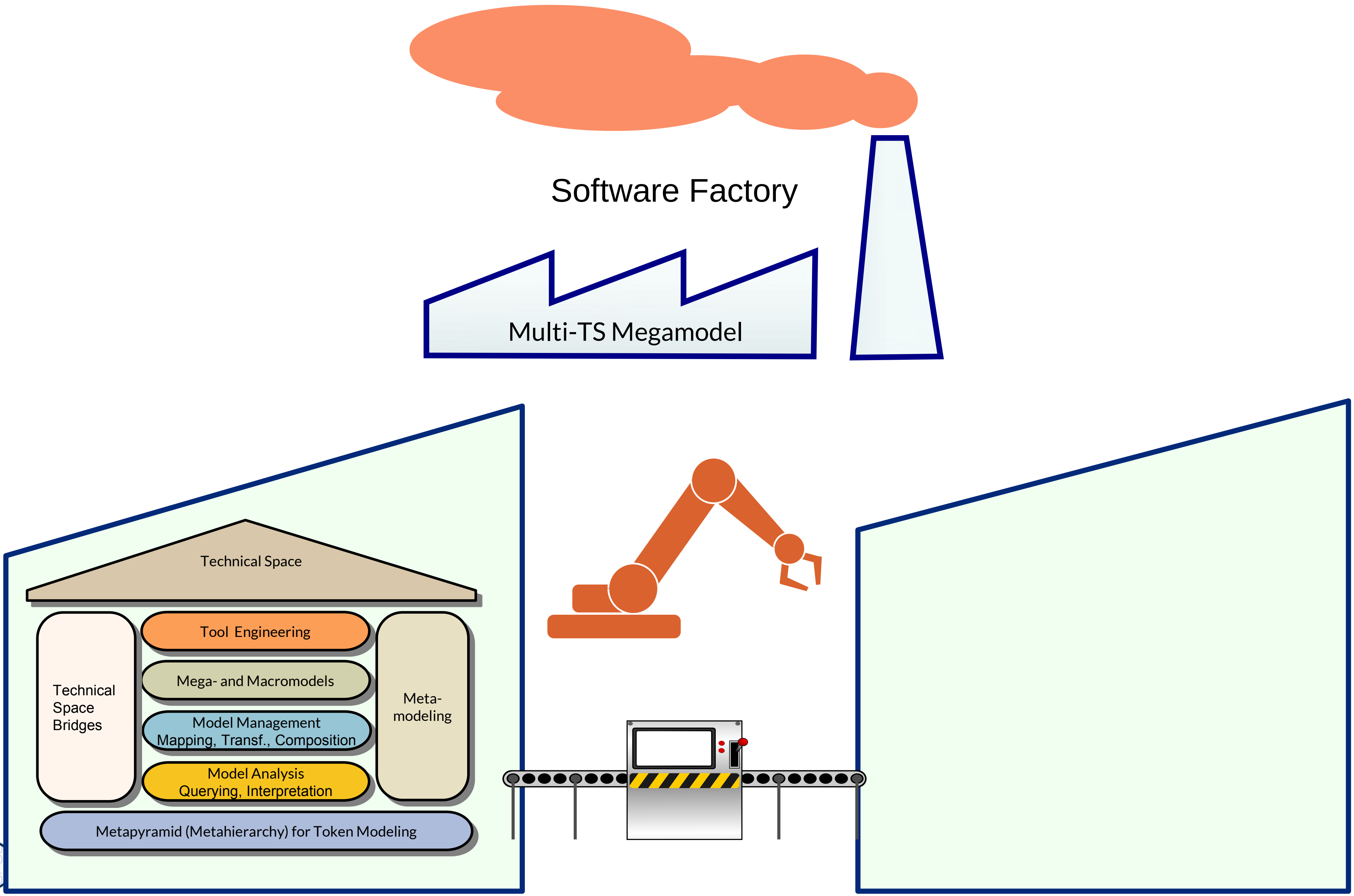
A **software factory** schema essentially defines a recipe for building members of a software product family.

Jack Greenfield

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

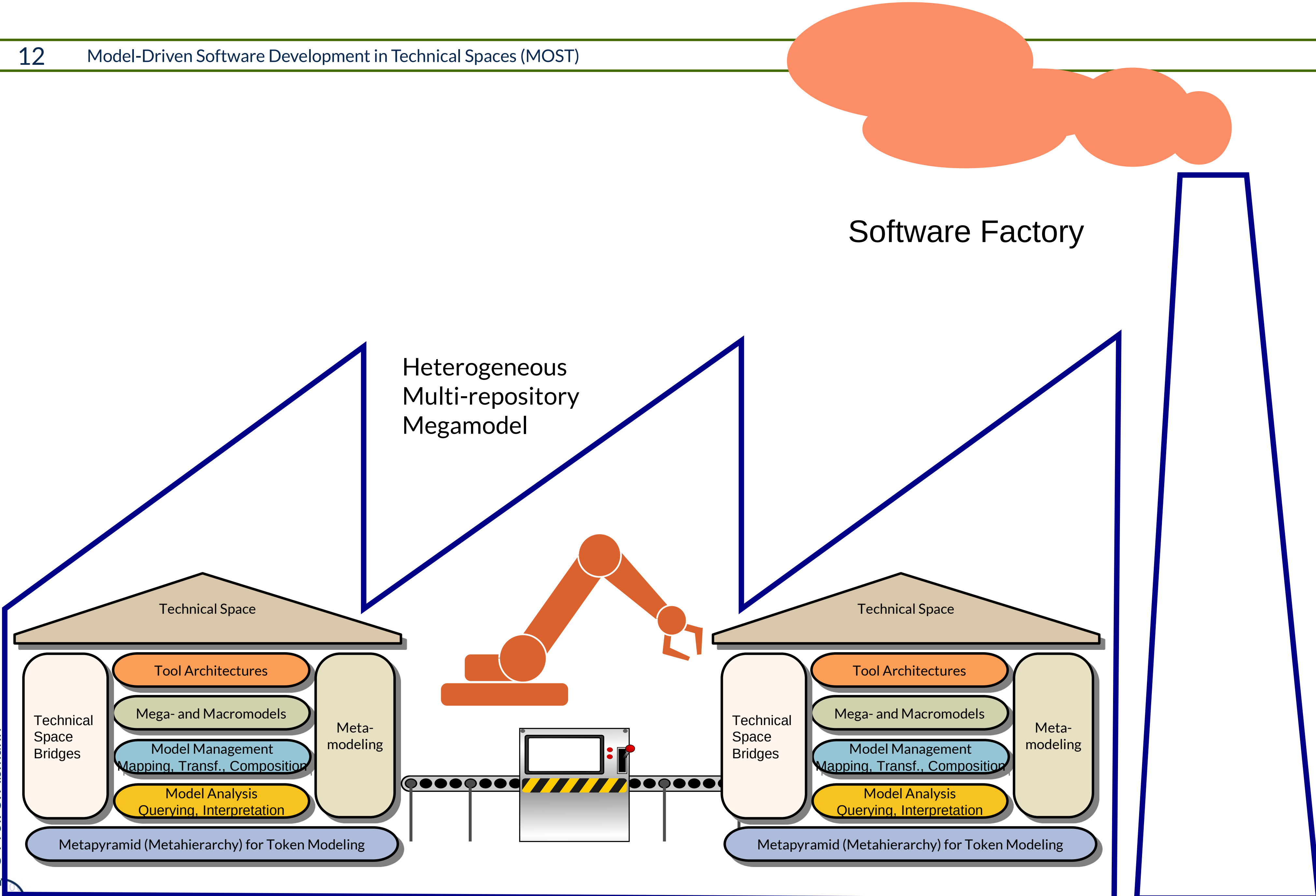
# Software Factories with Only 1 Technical Space





# 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

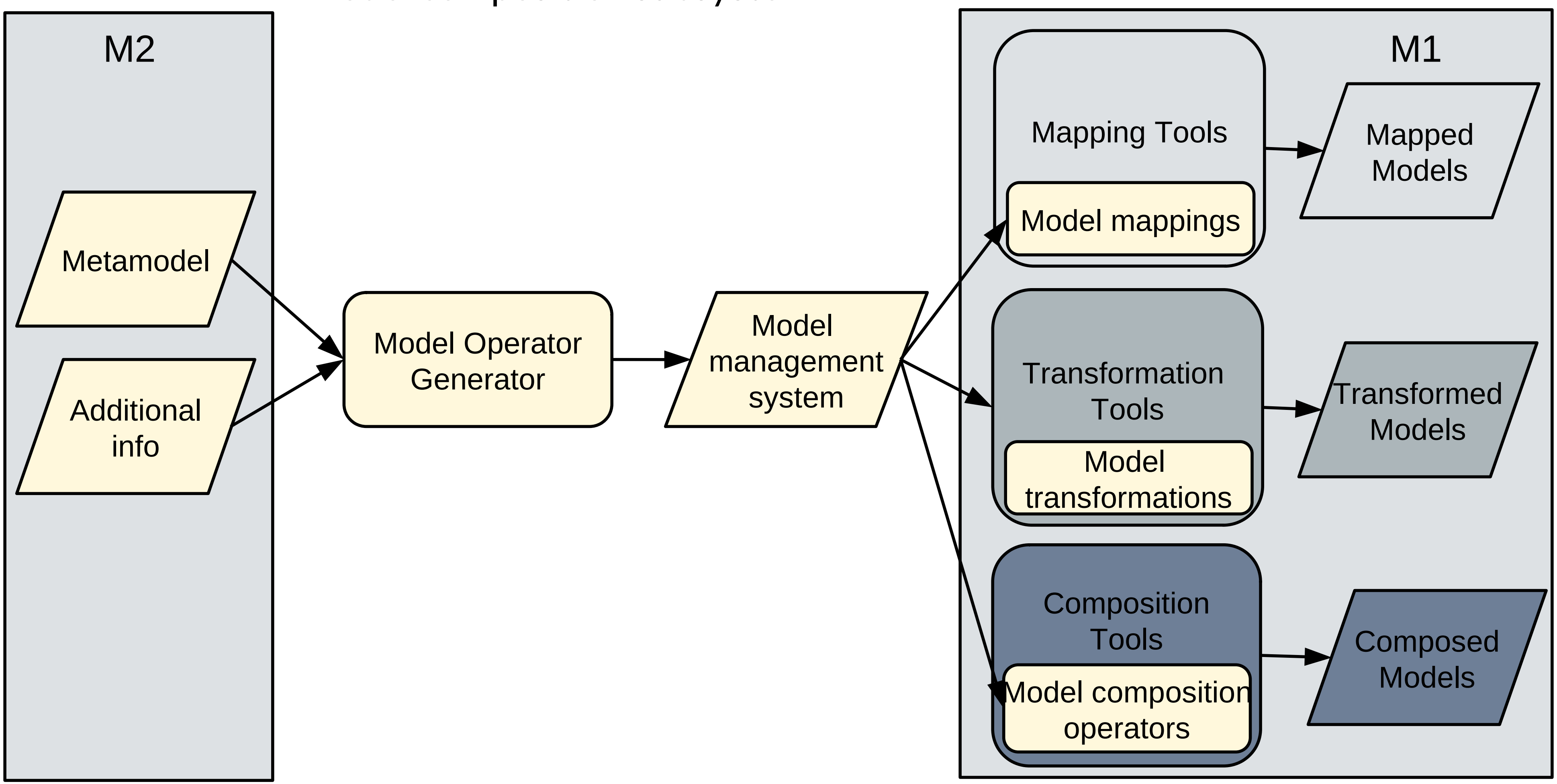
# 12.3. Model Management in a Technical Space with Model Mapping, Transformation and Composition

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



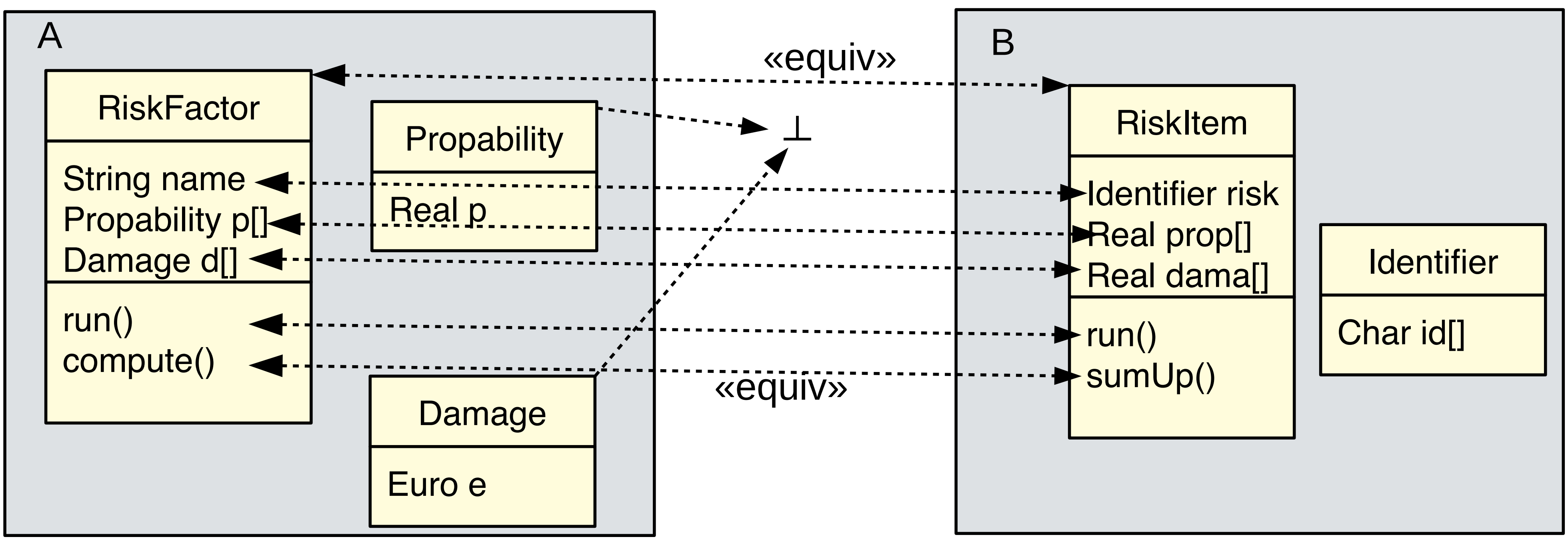
# 12.3.1. Model Mapping

# 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.



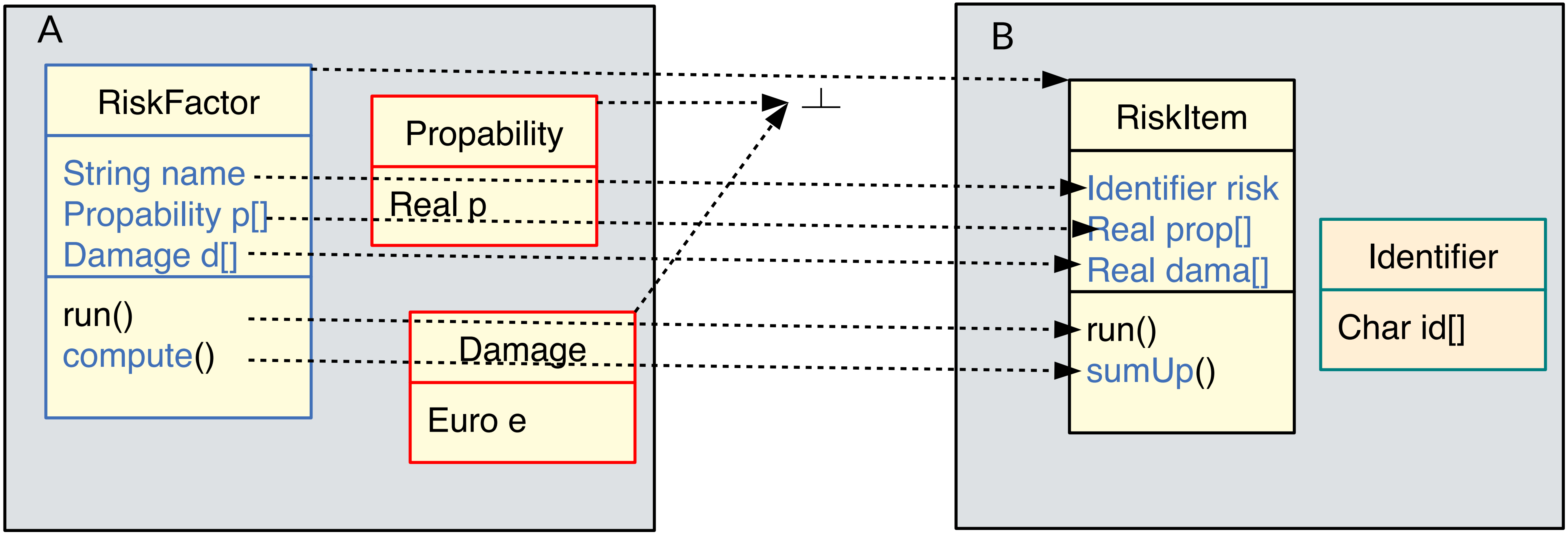
# 12.3.2. Model Transformation

# 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



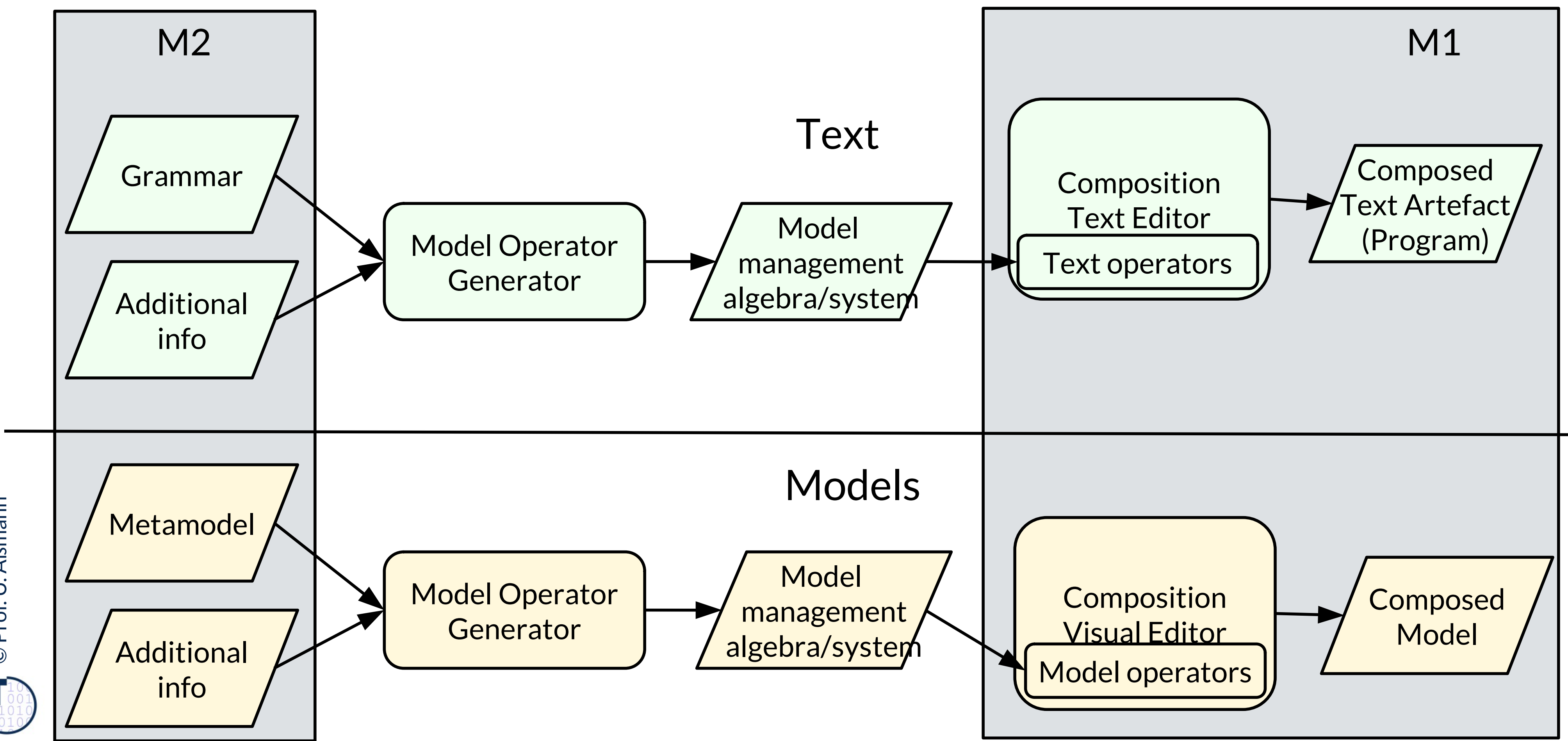
# 12.3.3. Model Composition with Model Algebrae and Composition Systems

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



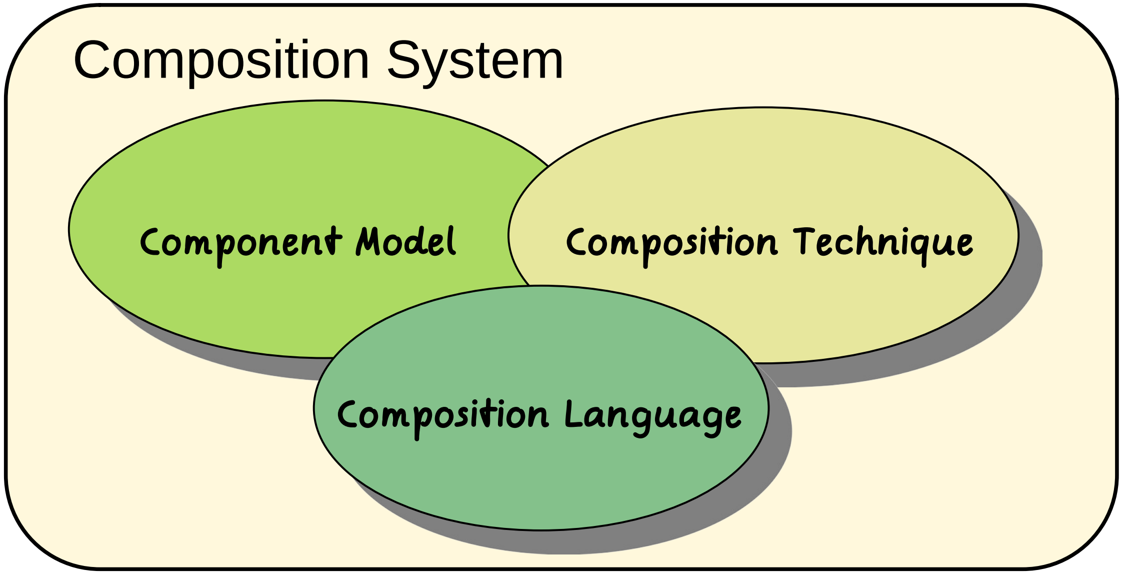
# Simple Algebra for Models (on M1) and Metamodels (on M2)



- 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

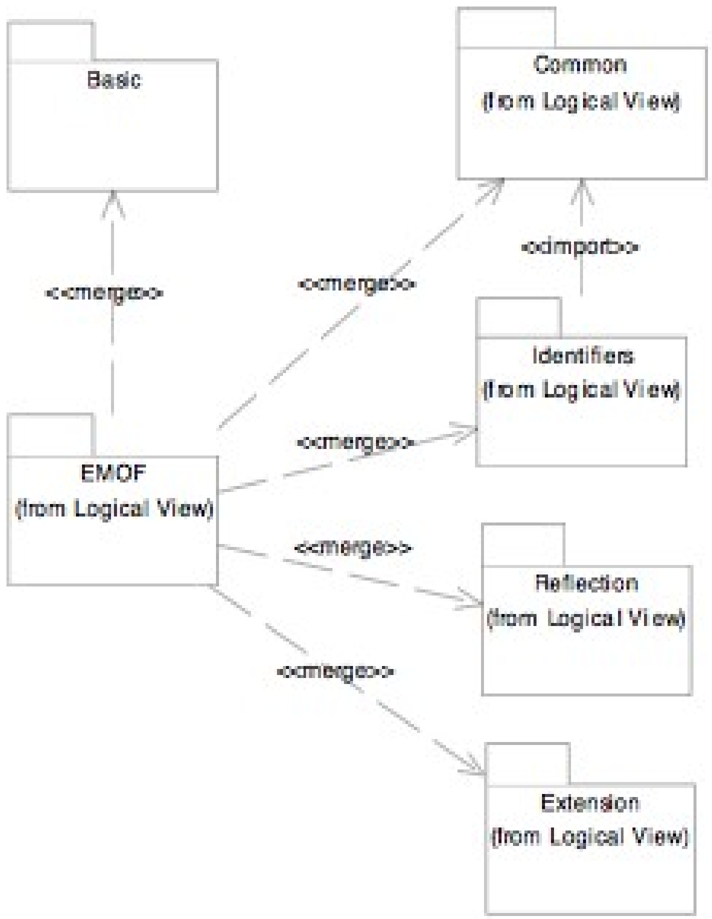
→ Metamodels can be composed from packages

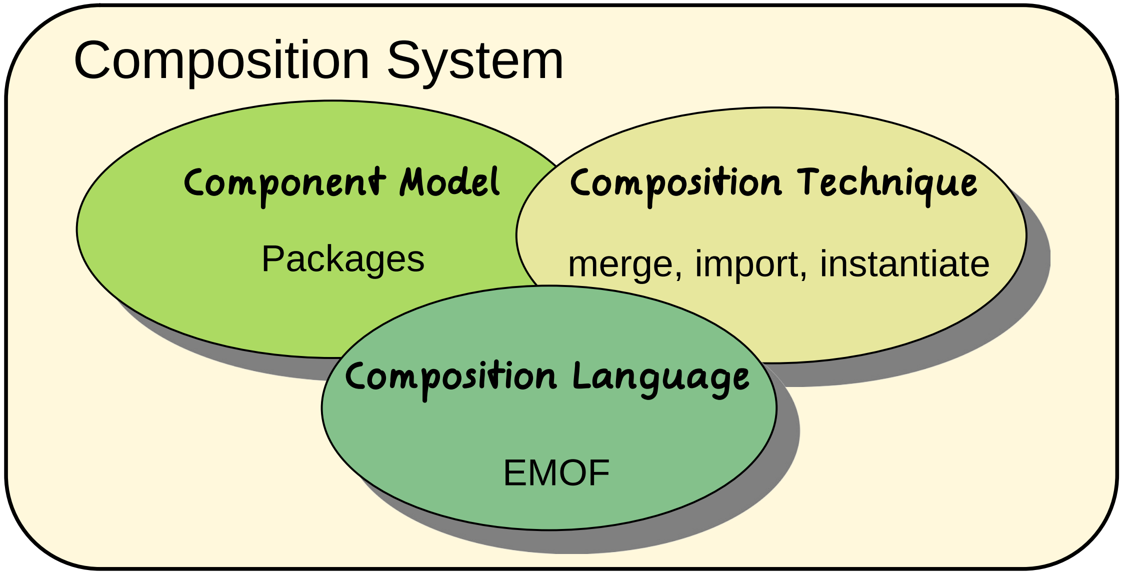


# Ex.: EMOF Class Composition by EMOF Package Merge



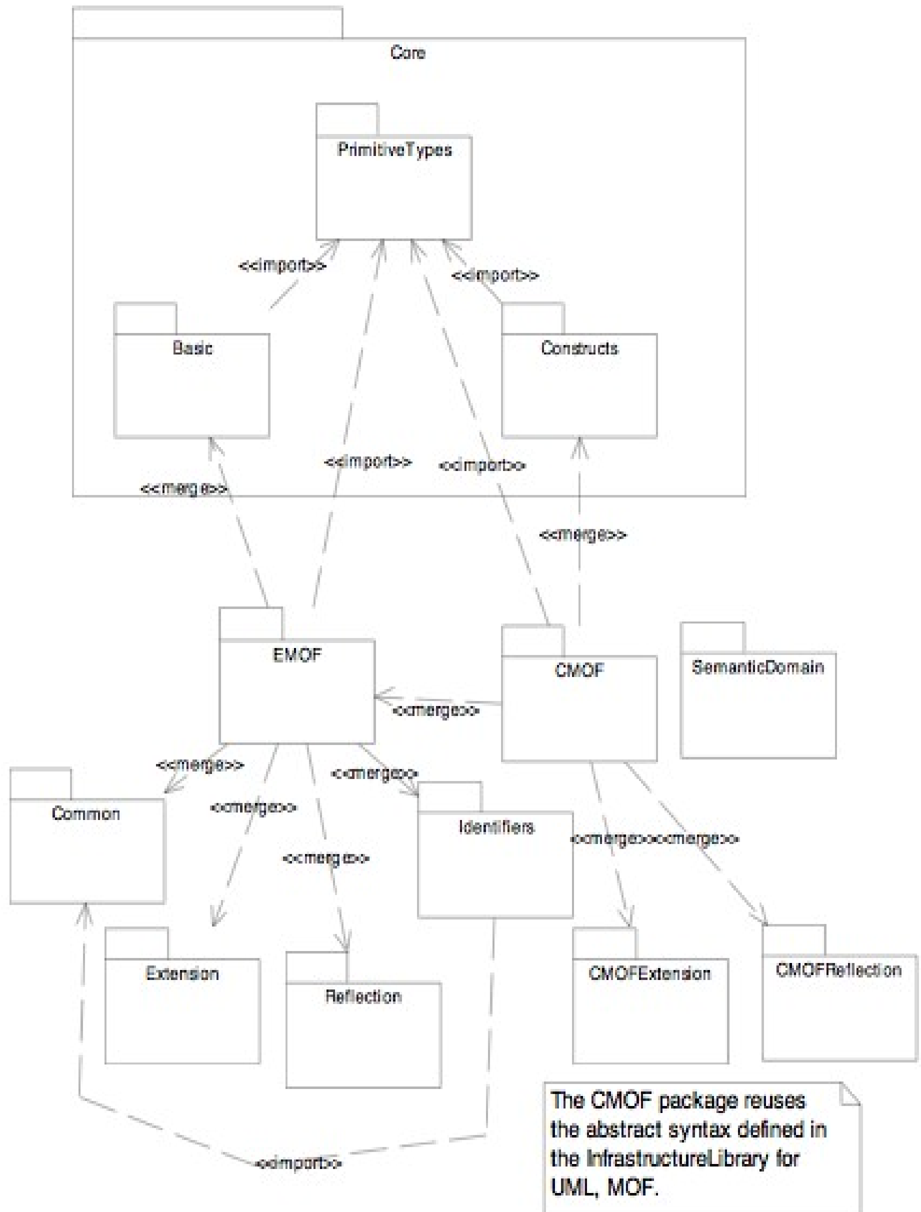
[MOF]



# 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.

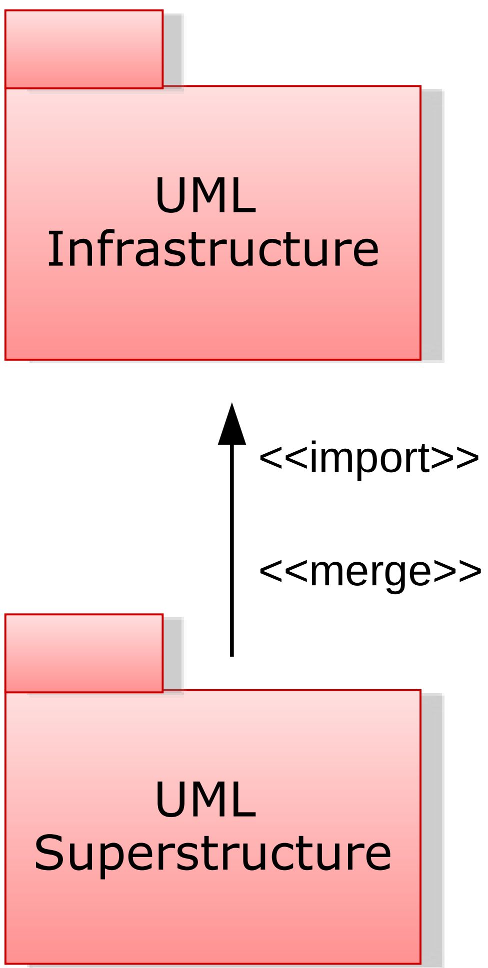
The UML-metamodel is a “logic” metamodel, because it is *composed:*

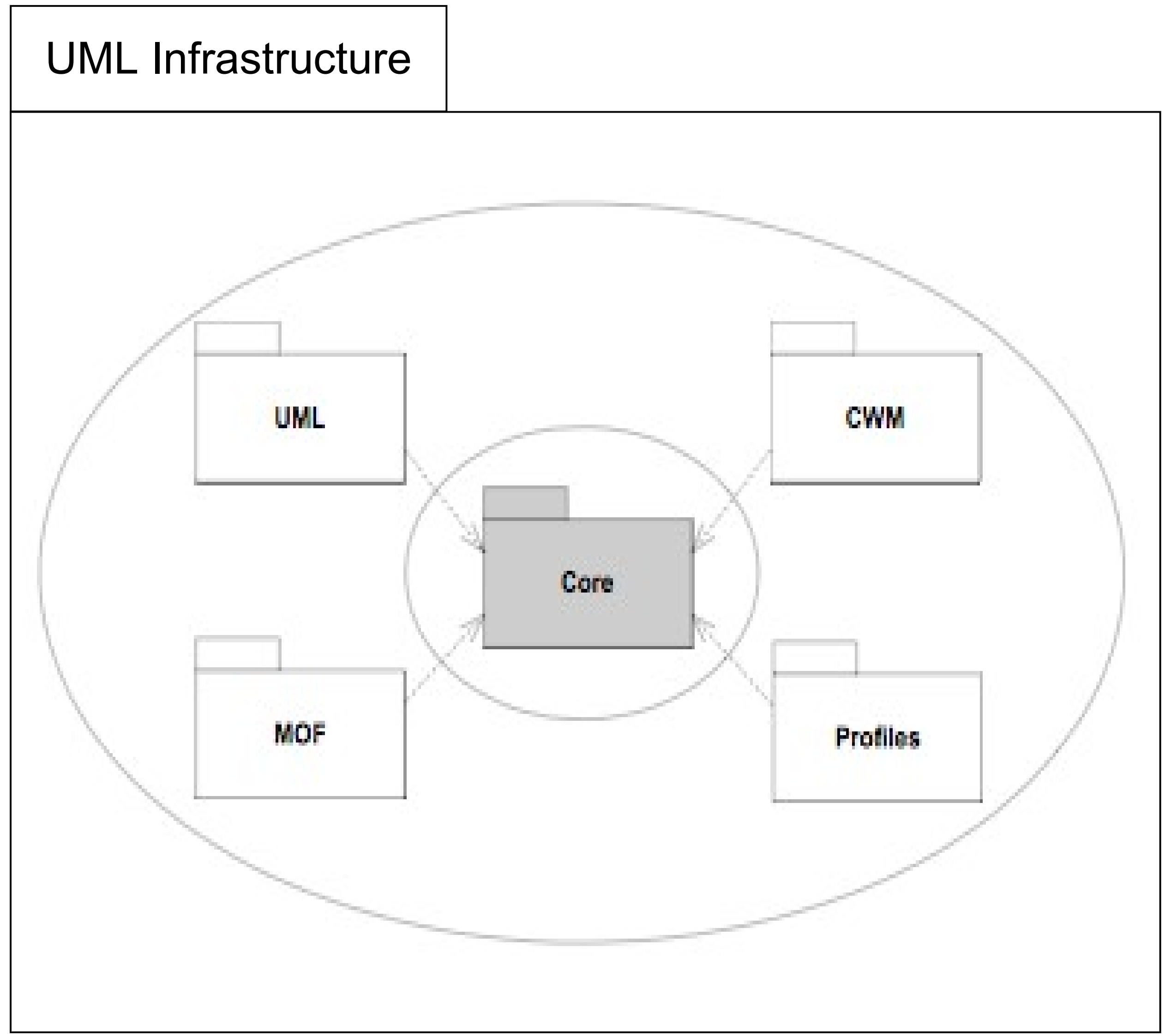
- Definition of merge operator composing metaclasses and metaclass-packages
- Defined in composable **packages**
  - With a clear **CMOF**-package architecture
  - uniform **package structure** and context-sensitive semantics for all diagrams such as Statecharts (UML-SC), Sequence Diagrams (UML-SD), 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

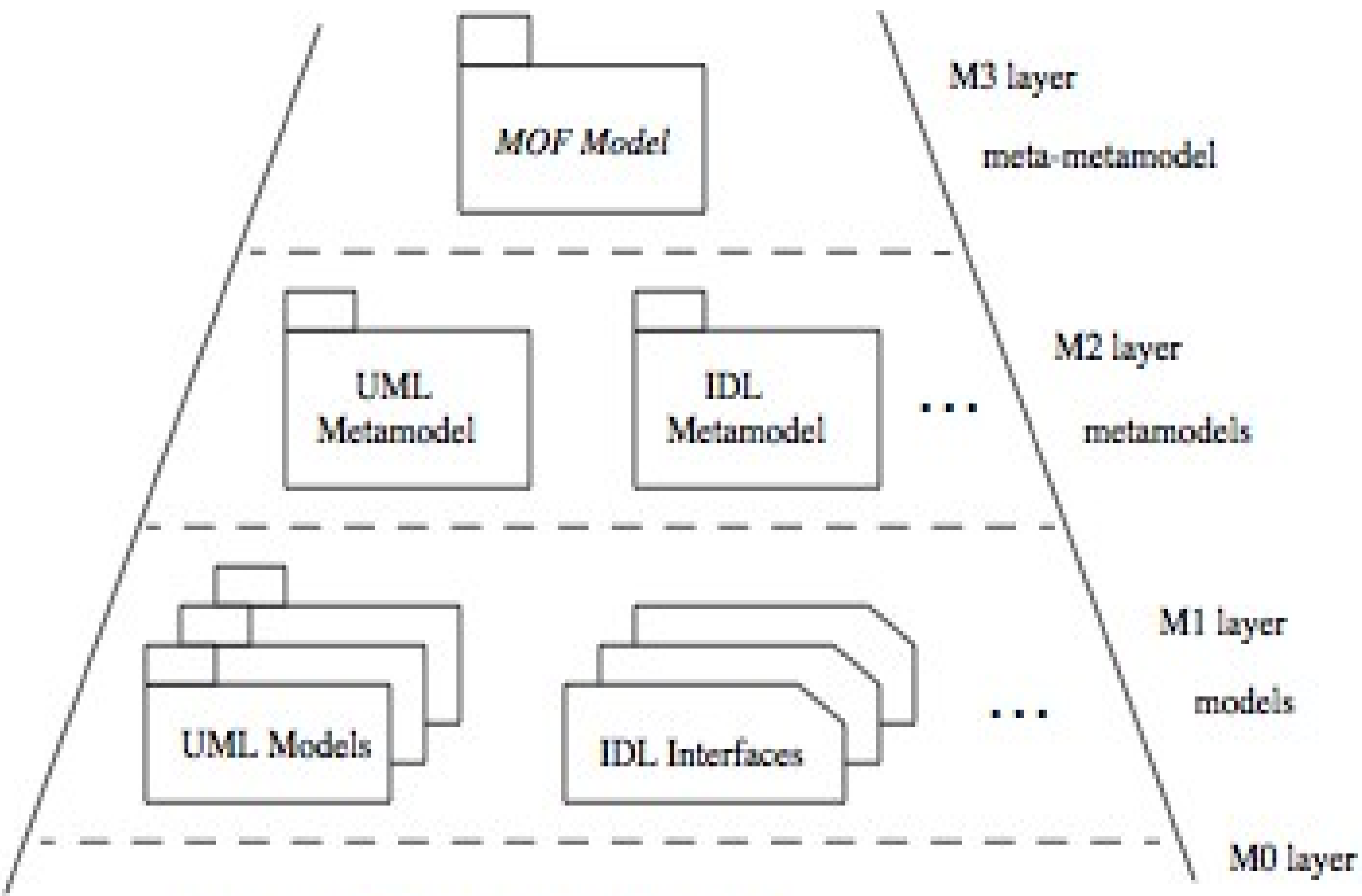
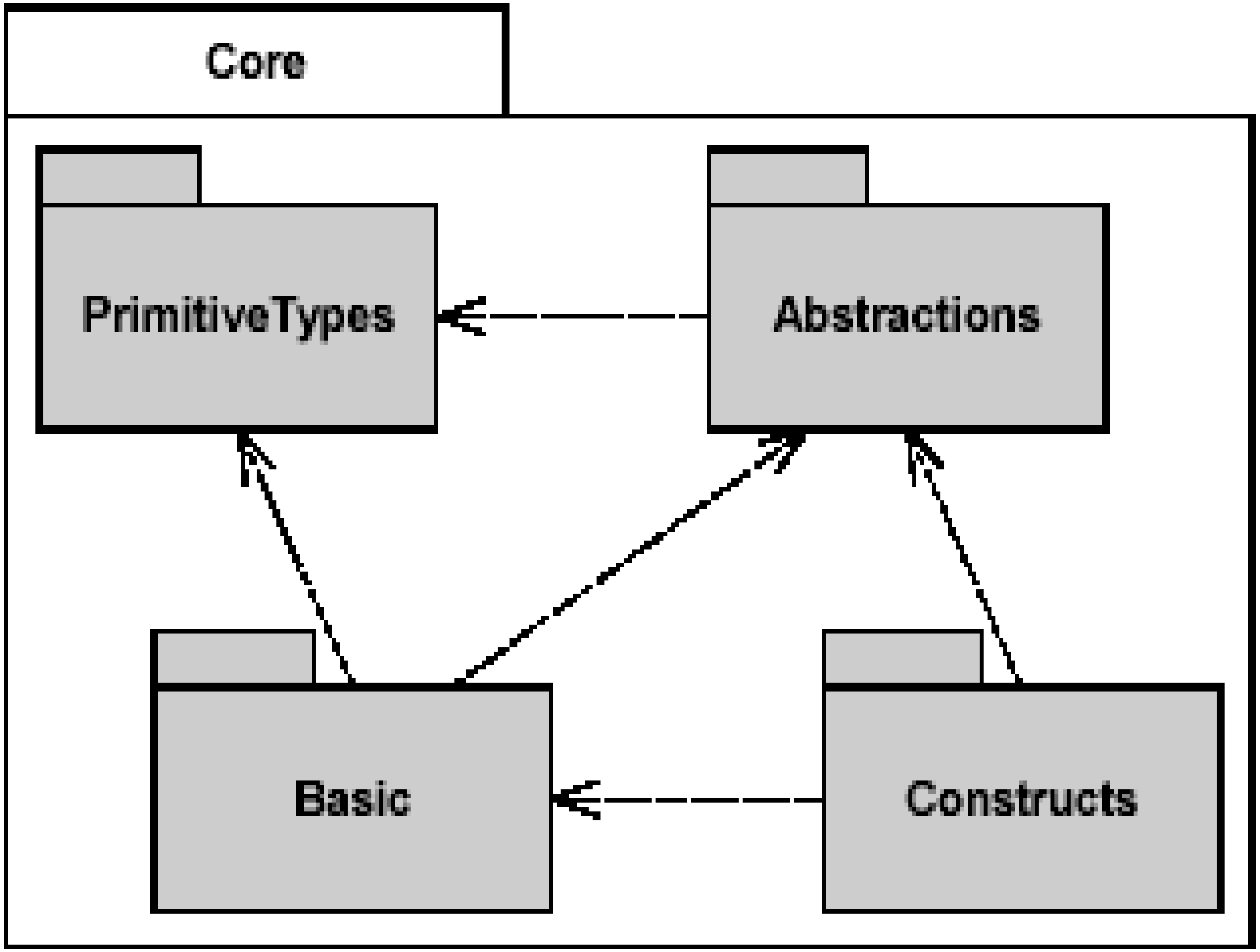



*Figure 2-2* MOF Metadata Architecture

[MOF]

# Core Package of the UML-Infrastructure Metamodel (M2)





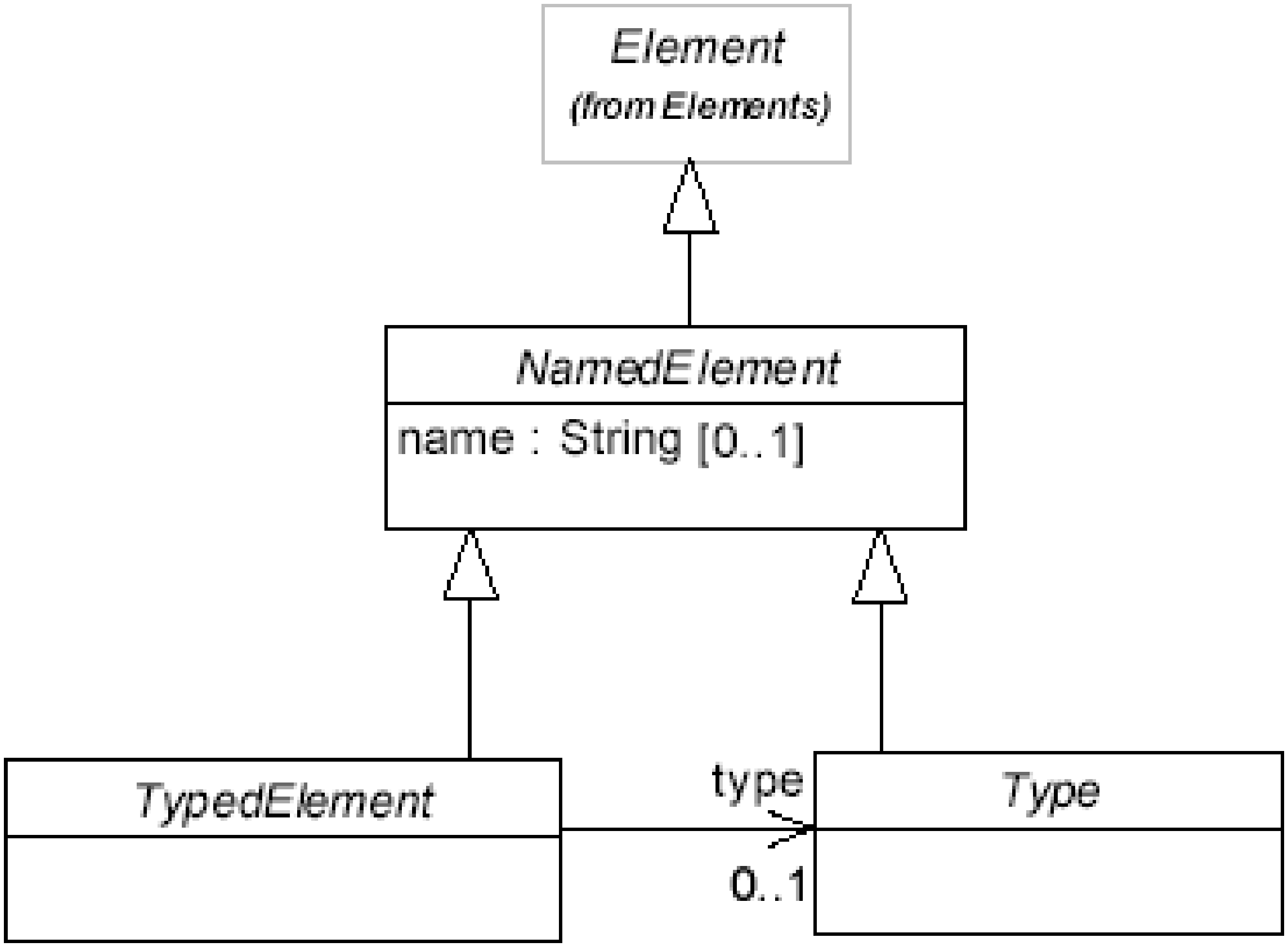

**Basic:** basic constructs for XMI
**Constructs:** Metaclasses for modeling

**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

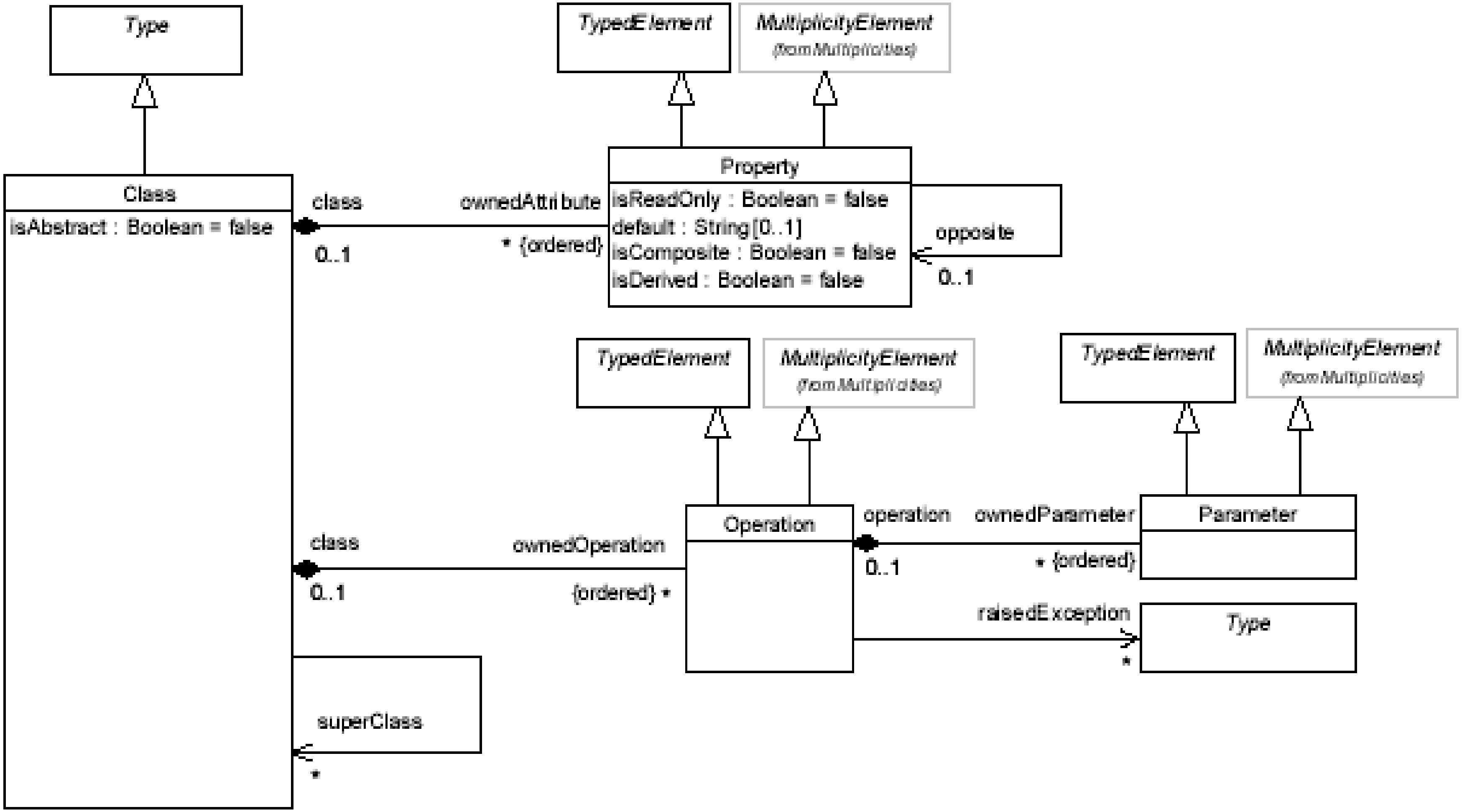





**From:** UML 2.0 Infrastructure Specification; OMG Adopted Specification ptc/03-09-15

# Package Basic: Classes

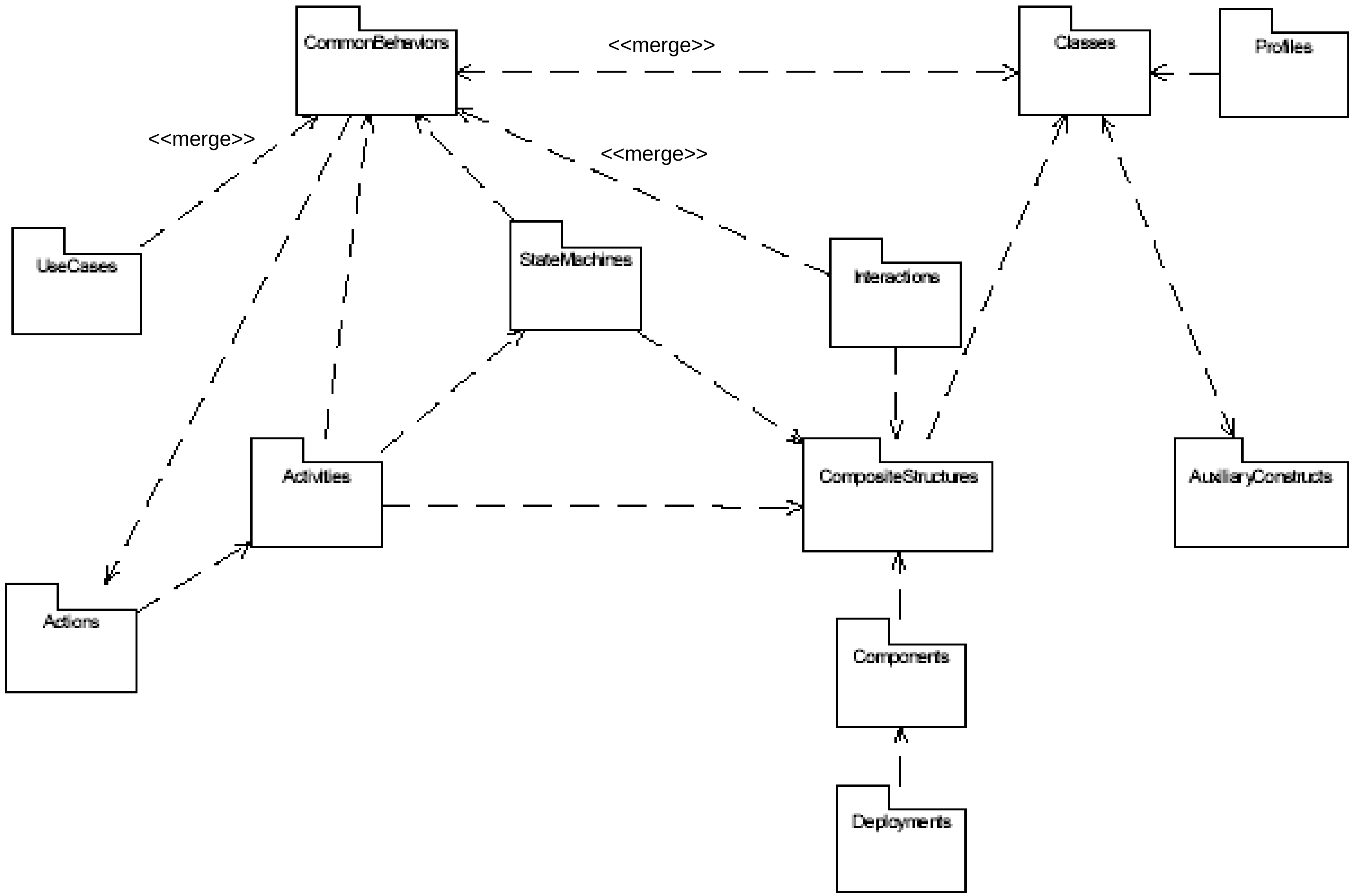





**From:** UML 2.0 Infrastructure Specification; OMG Adopted Specification ptc/03-09-15

# Package Composition Architecture UML 2.0 (M2)

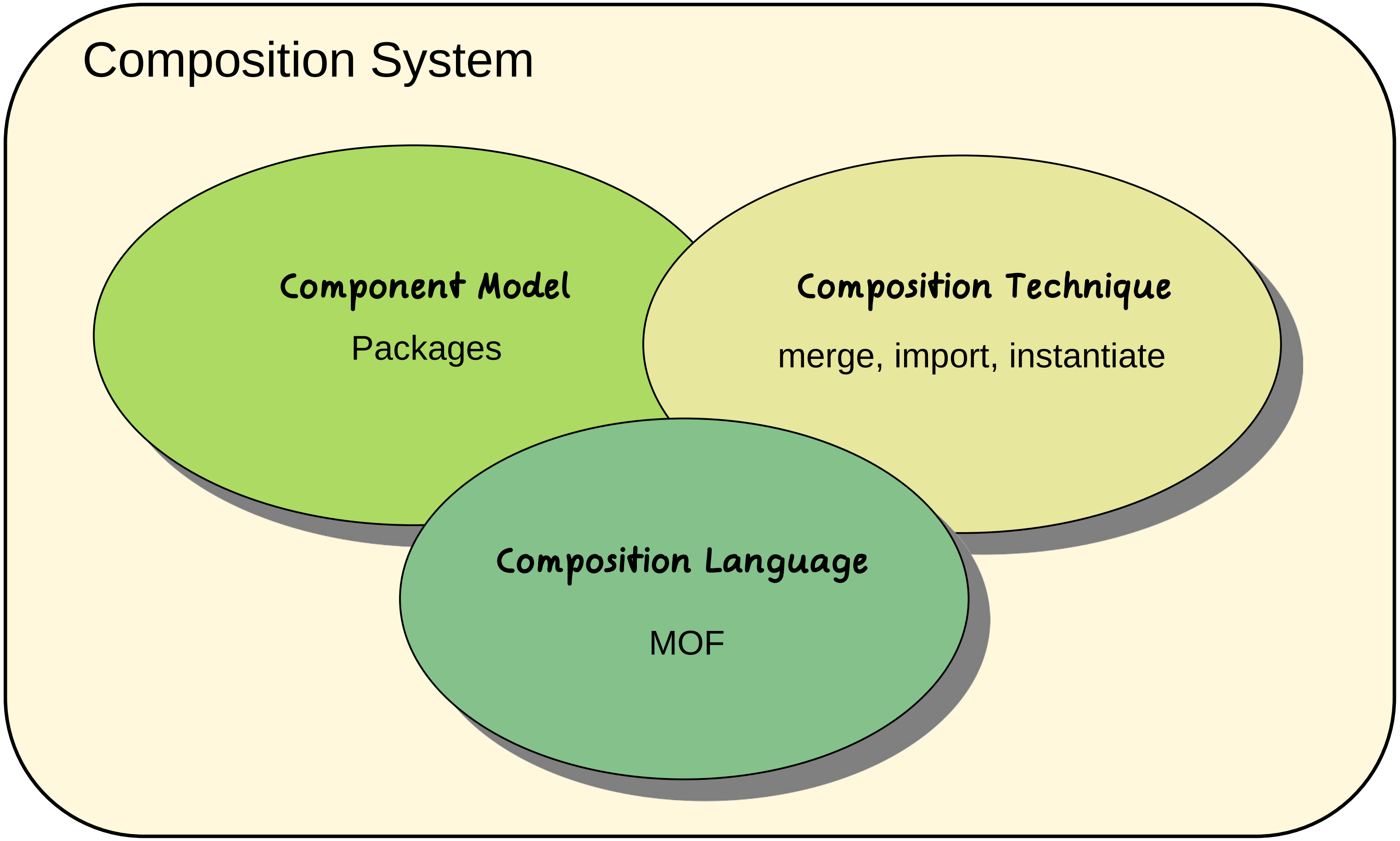





**From:** UML 2.0 Infrastructure Specification; OMG Adopted Specification ptc/03-09-15

# Metamodel Composition – the Composition System of the UML Language Report





# 12.4 Mega- and Macromodels – Models about Models

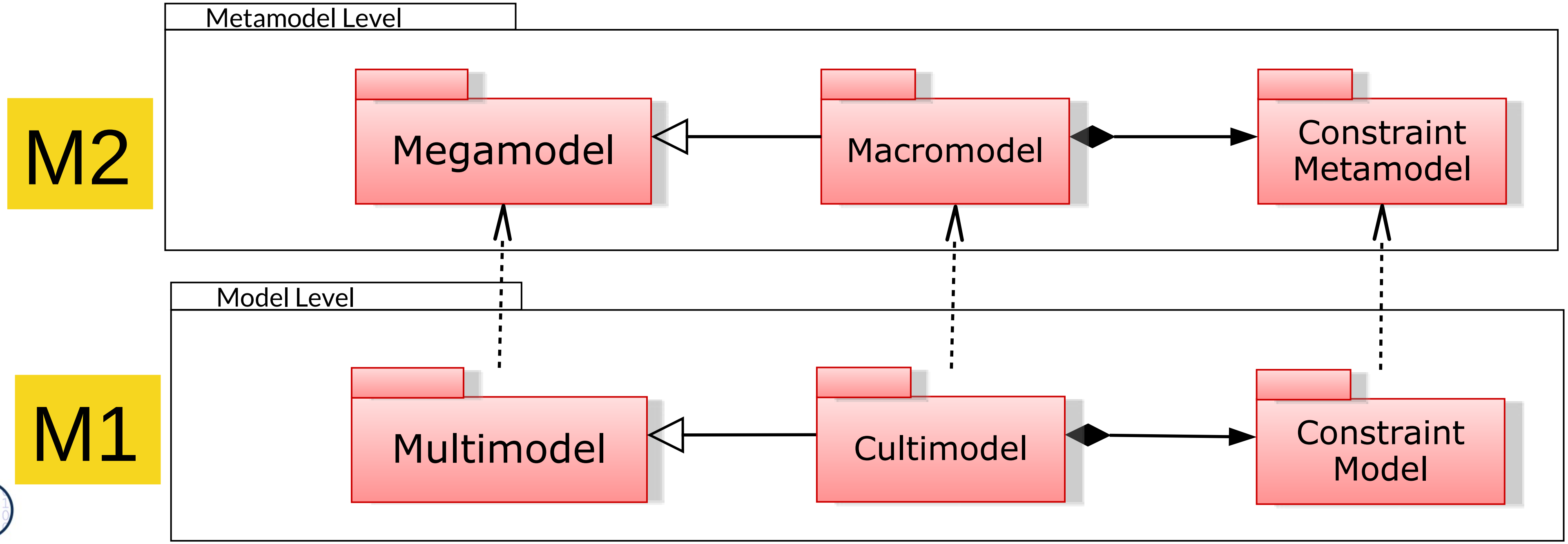
In a technical space, a ***megamodel*** is an infrastructure for models and metamodels, systematically linking a set of models

# 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

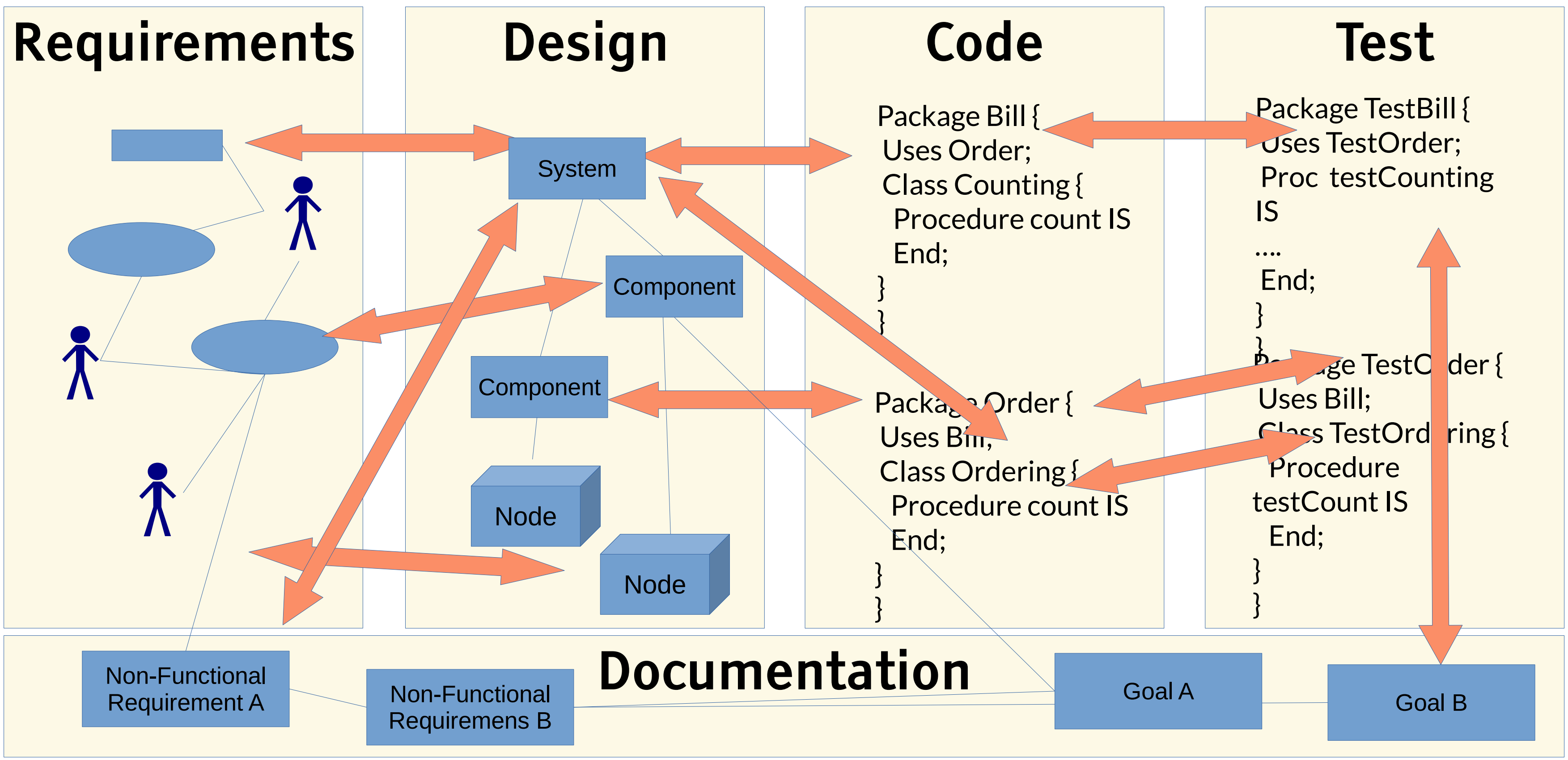


- A ***cultimodel*** is an instance of a macromodel, i.e., a multimodel *fulfilling some consistency constraints over the models and their elements.*
  - The schema, the macromodel is adorned with a constraint metamodel
  - The graph of models in the multimodel obeys wellformedness constraints
  - There 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



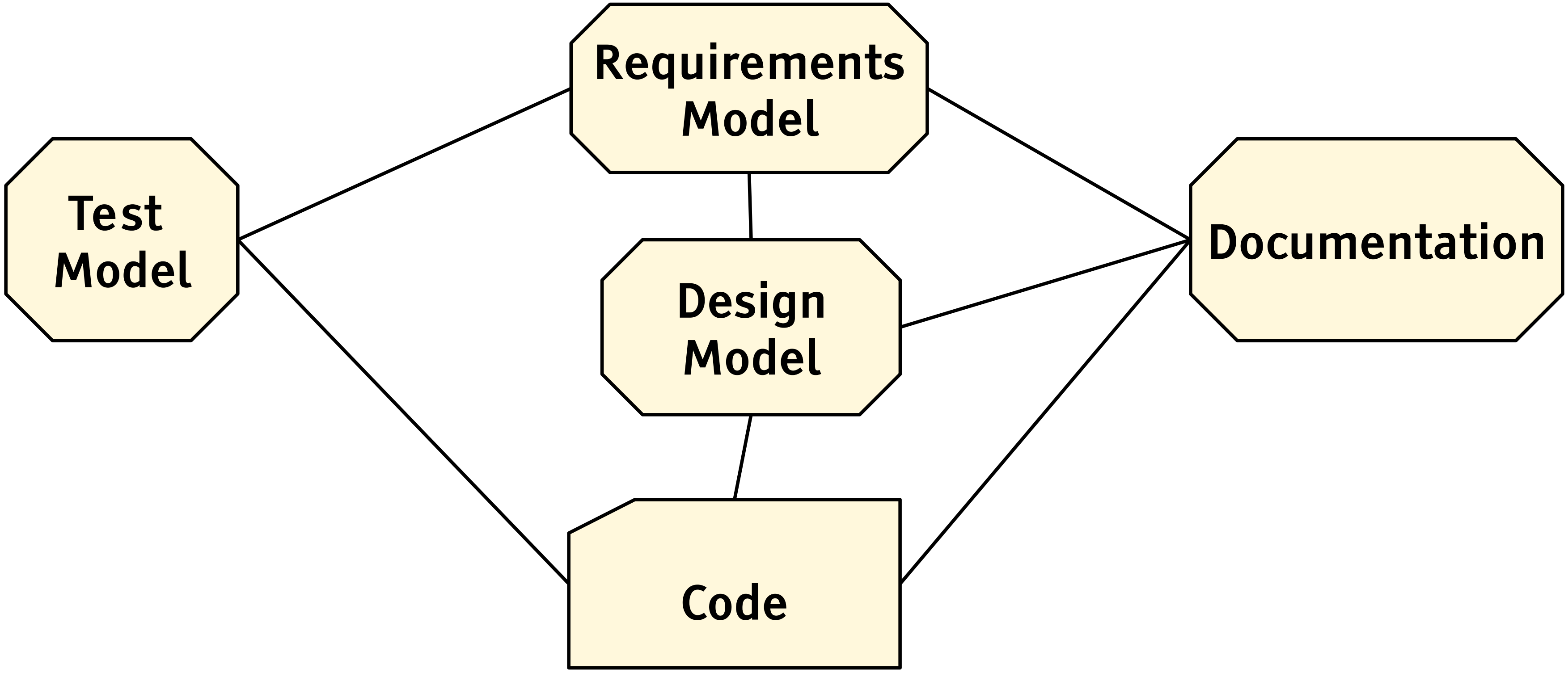
- The **ReDoDeCT problem** is the problem how requirements, documentation, design, code, and tests are related (→ V model)
- Mappings between the Requirements model, Documentation files, Design model, Code, Test cases
- A **ReDoDeCT macromodel** has maintained mappings between all 5 models



# Model Synchronization in Macromodels



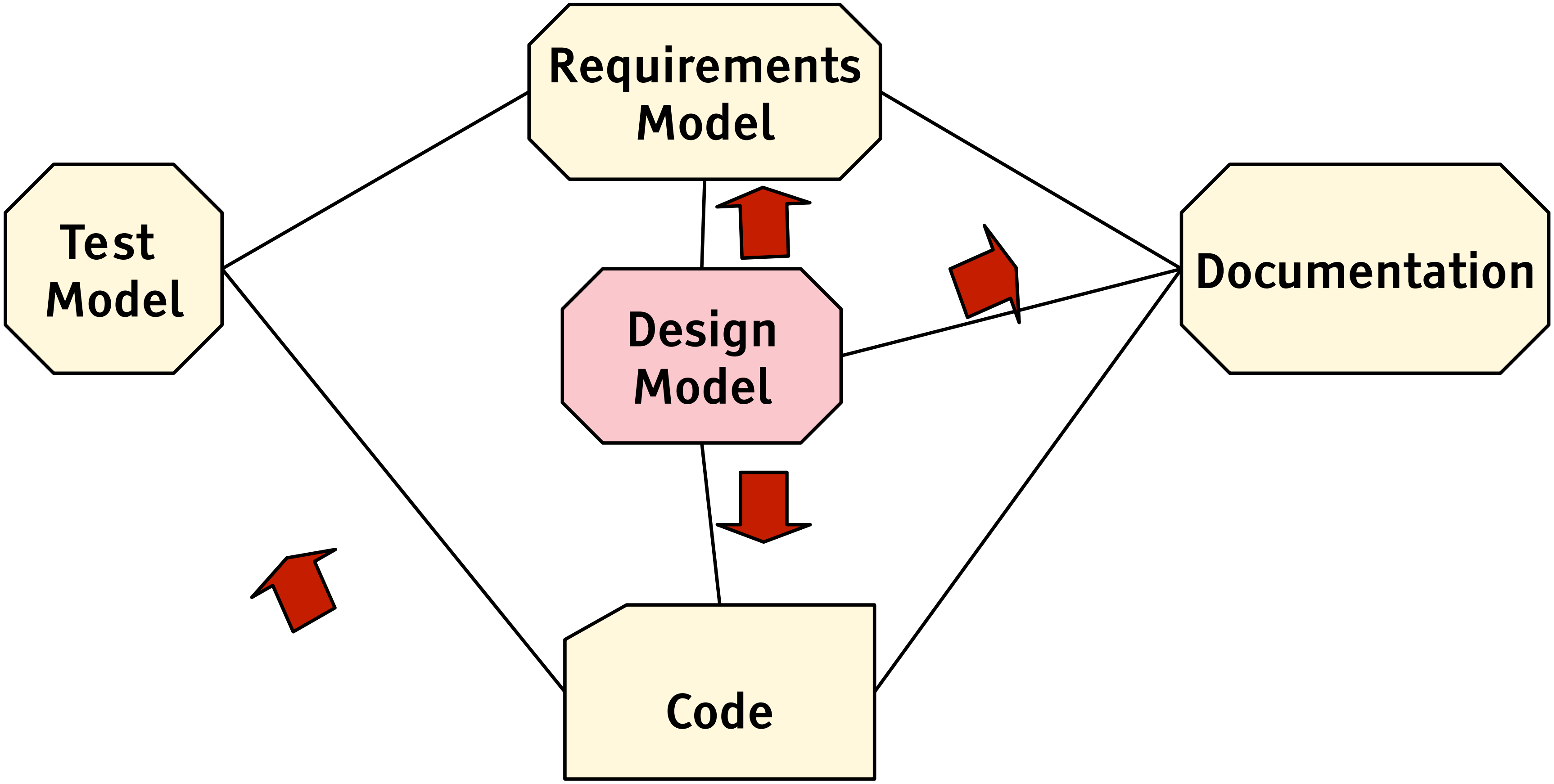
- ***Model synchronization*** keeps a set of connected models (the ***crowd***) *in* sync, i.e., consistent



# Model Synchronization in Macromodels



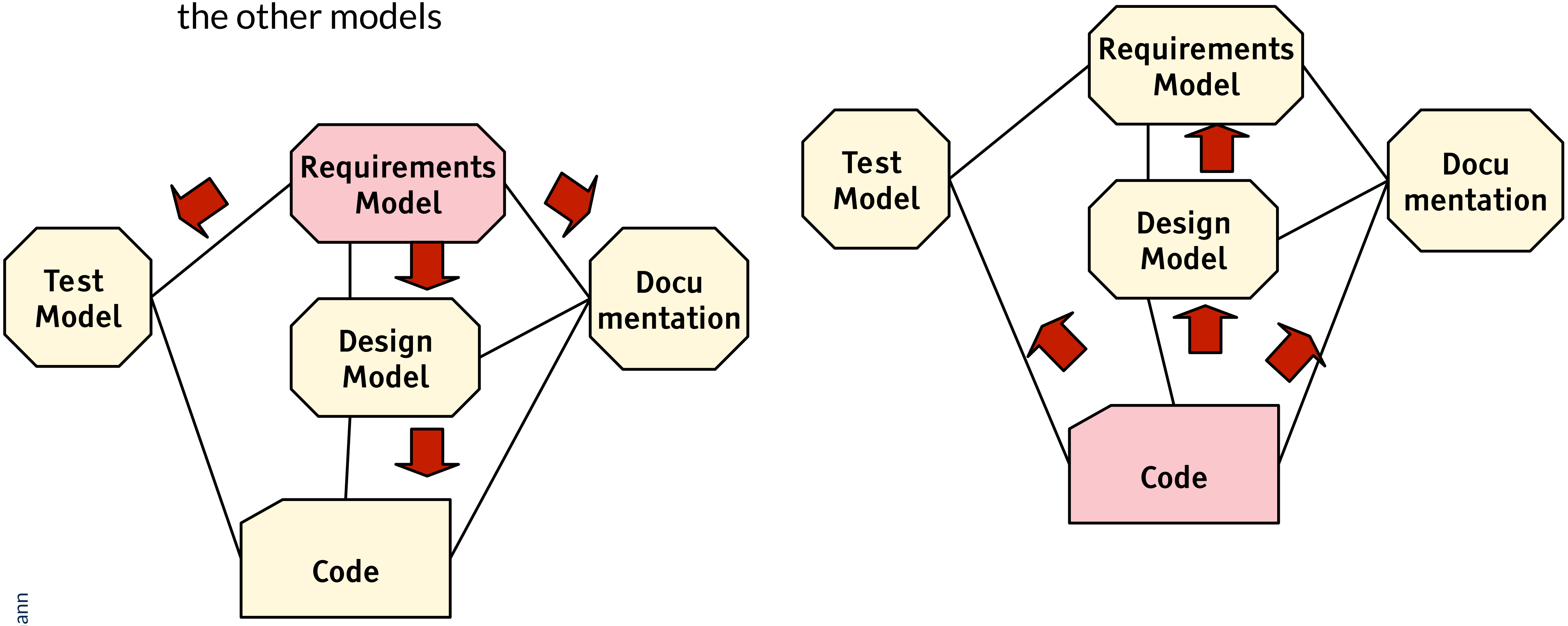
- In model synchronization, if an edit has occurred in a ***origin model***, all other connected models of a crowd (***dependent models***) are updated instantaneously, when one focus model changes



# 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



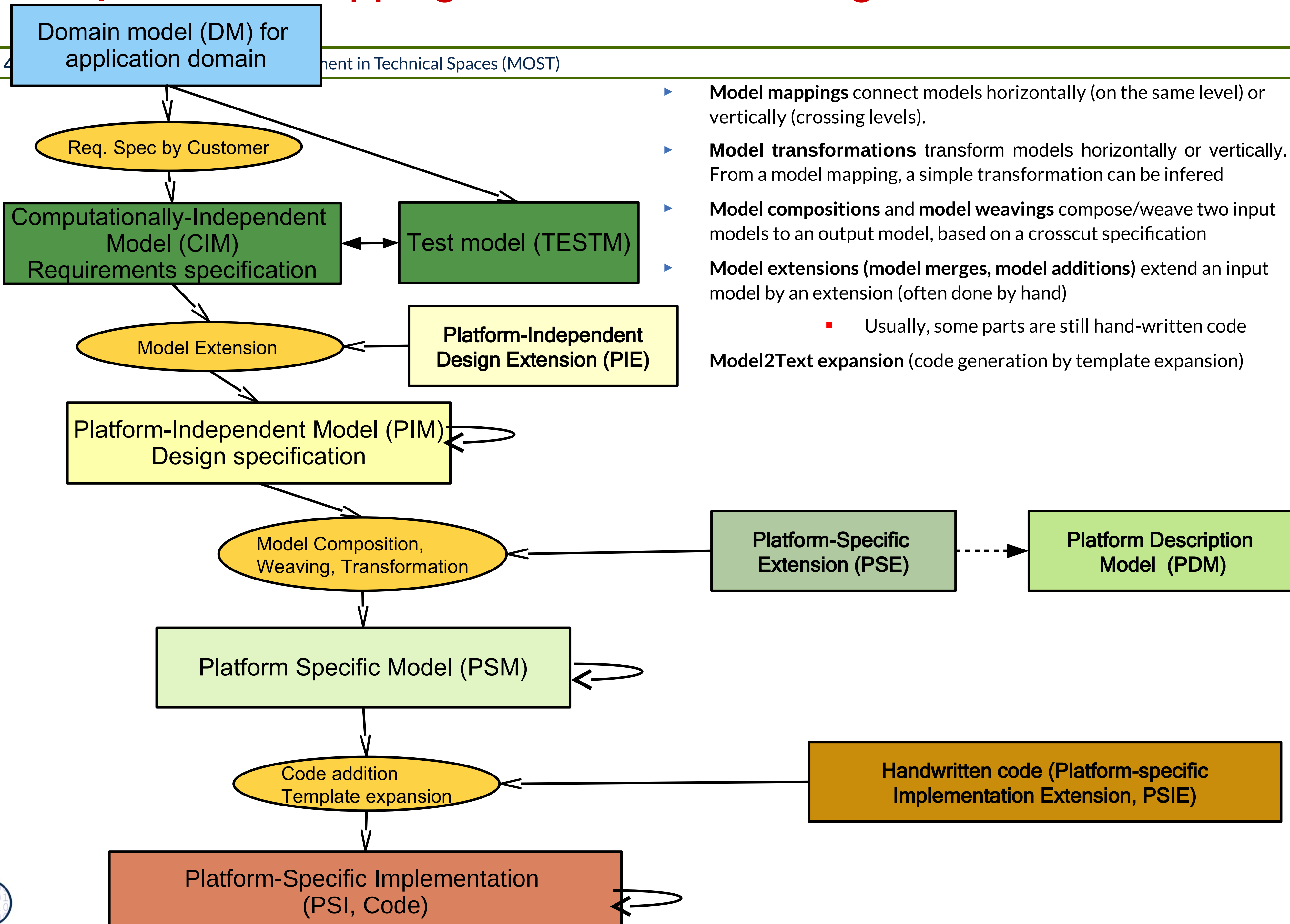
# Advantages of Model Mappings in Macromodels



- **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



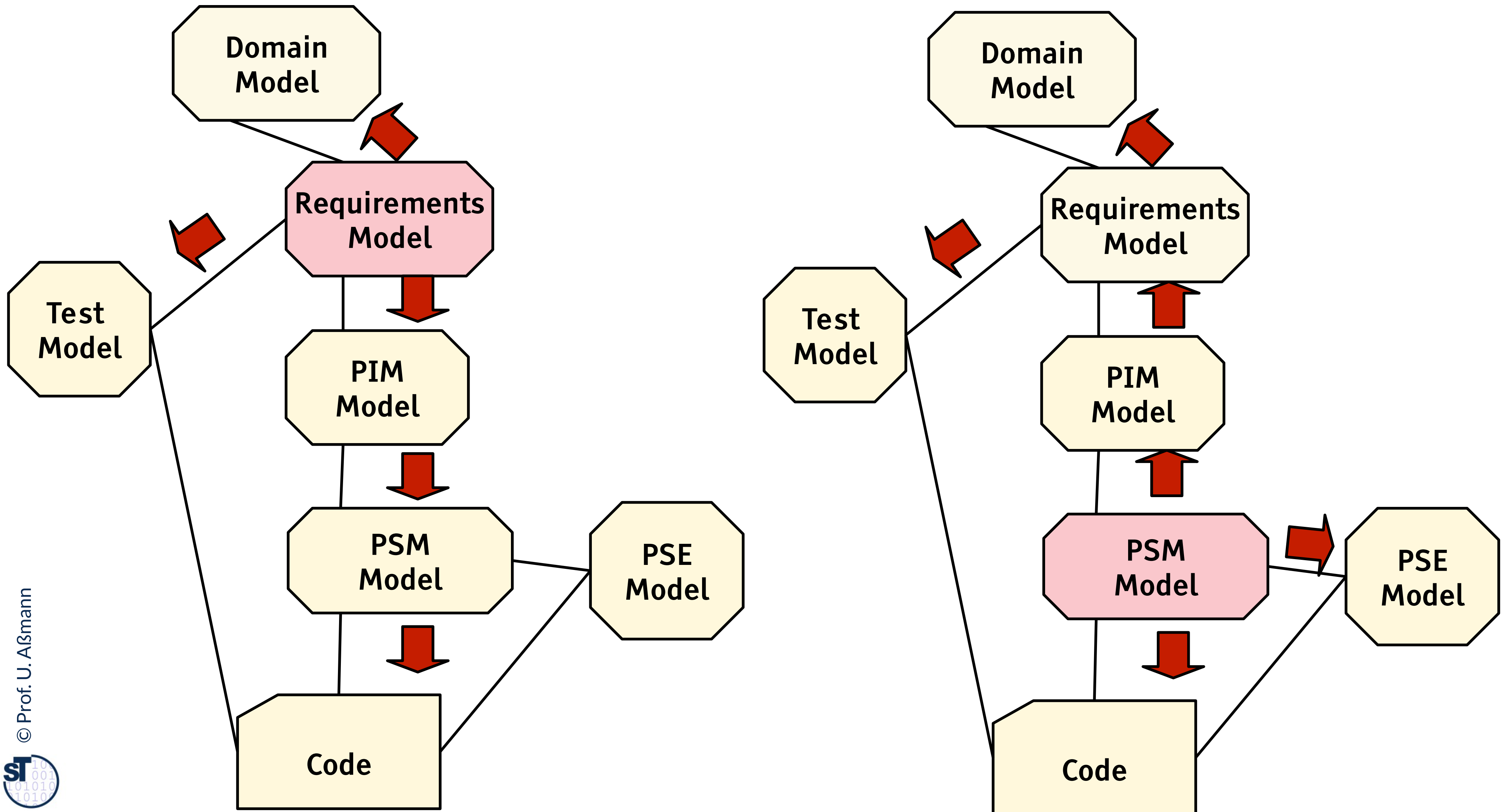



- **Model mappings** connect models horizontally (on the same level) or vertically (crossing levels).
- **Model transformations** transform models horizontally or vertically. From a model mapping, a simple transformation can be infered
- **Model compositions** and **model weavings** compose/weave two 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



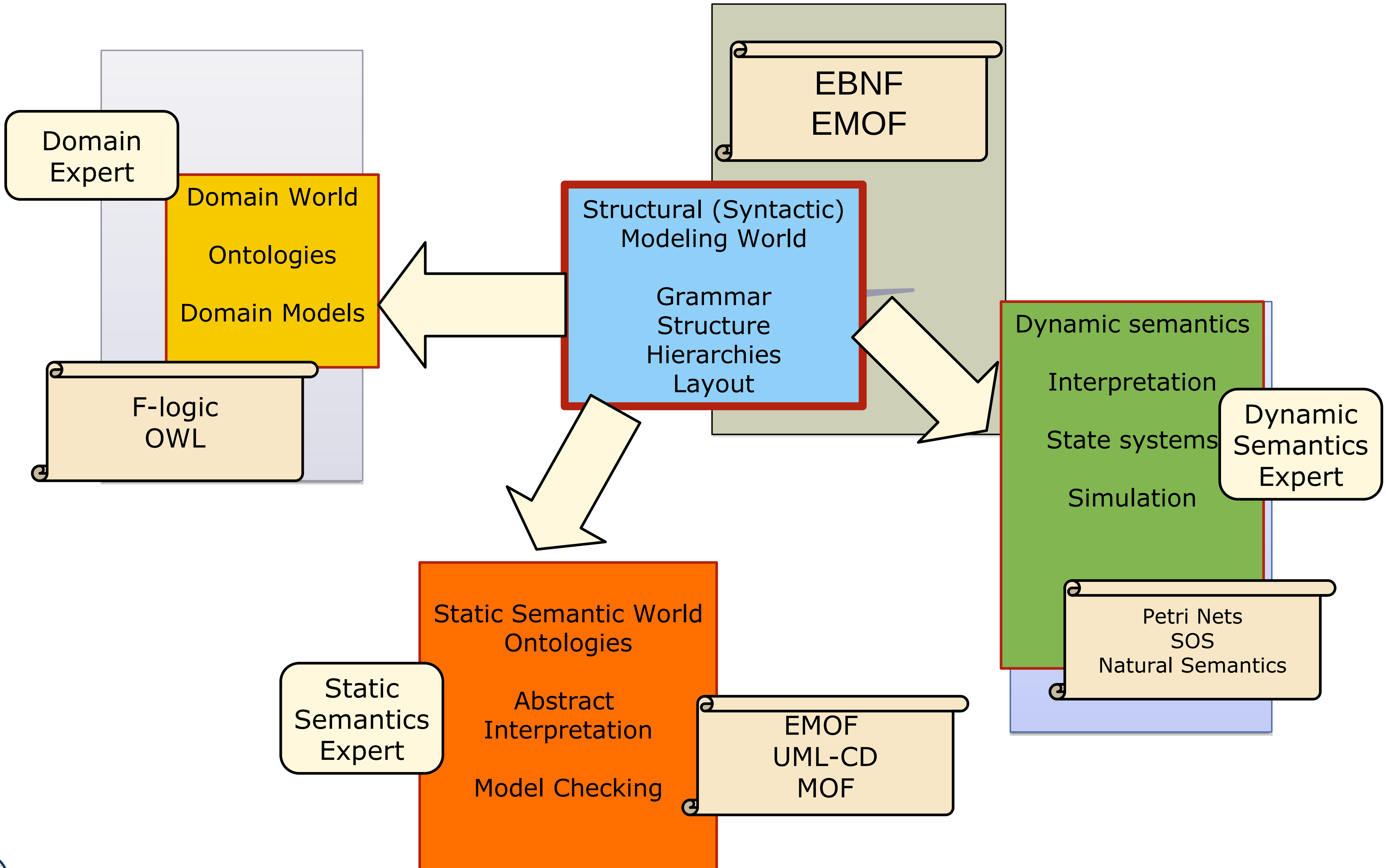


# 12.5. Briding Technical Spaces and Software Factories

- 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



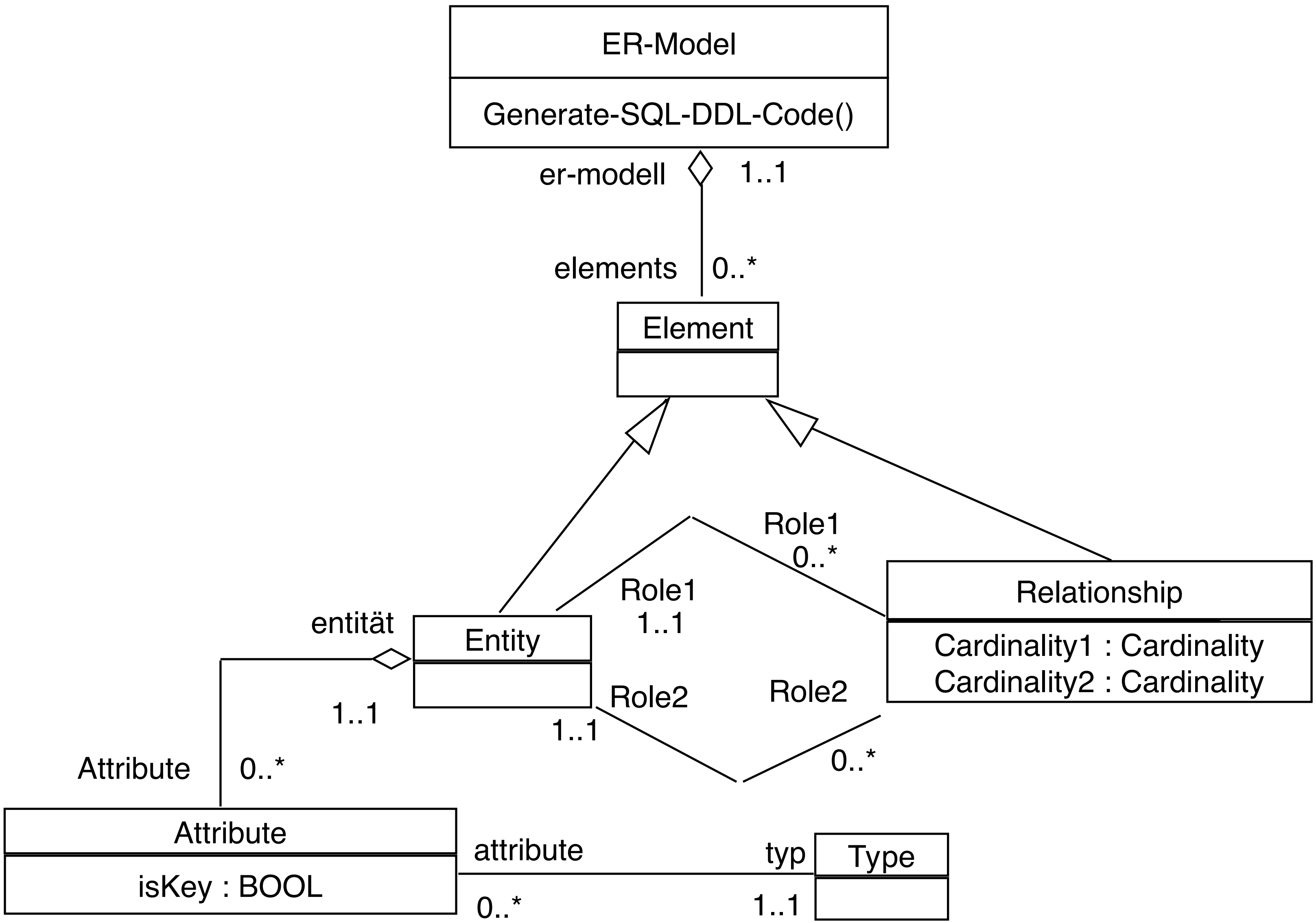
- Why do different technical spaces exist?
- What is the difference between a technological and a technical space?
- Explain round-trip engineering and model synchronization.
- What is model mapping vs model transformation?
- Explain the different forms of model mappings.

# 12.A.1 Other Metalanguages and Technical Spaces

# Metamodel of EntityRelationship Diagrams (ERD-ML) in MOF



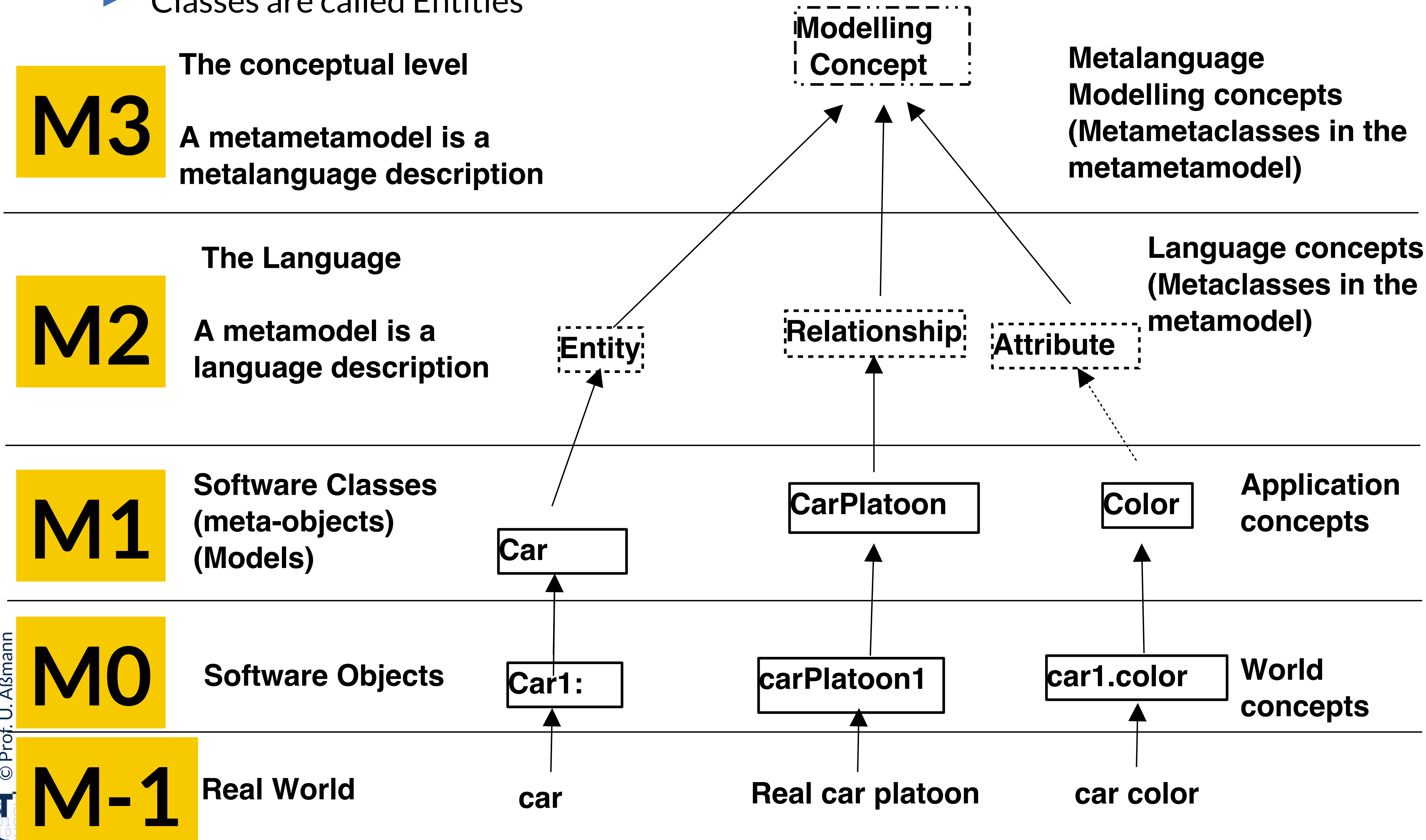
- ERD is like MOF without inheritance



# Metalevels in ERD



- Classes are called Entities



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



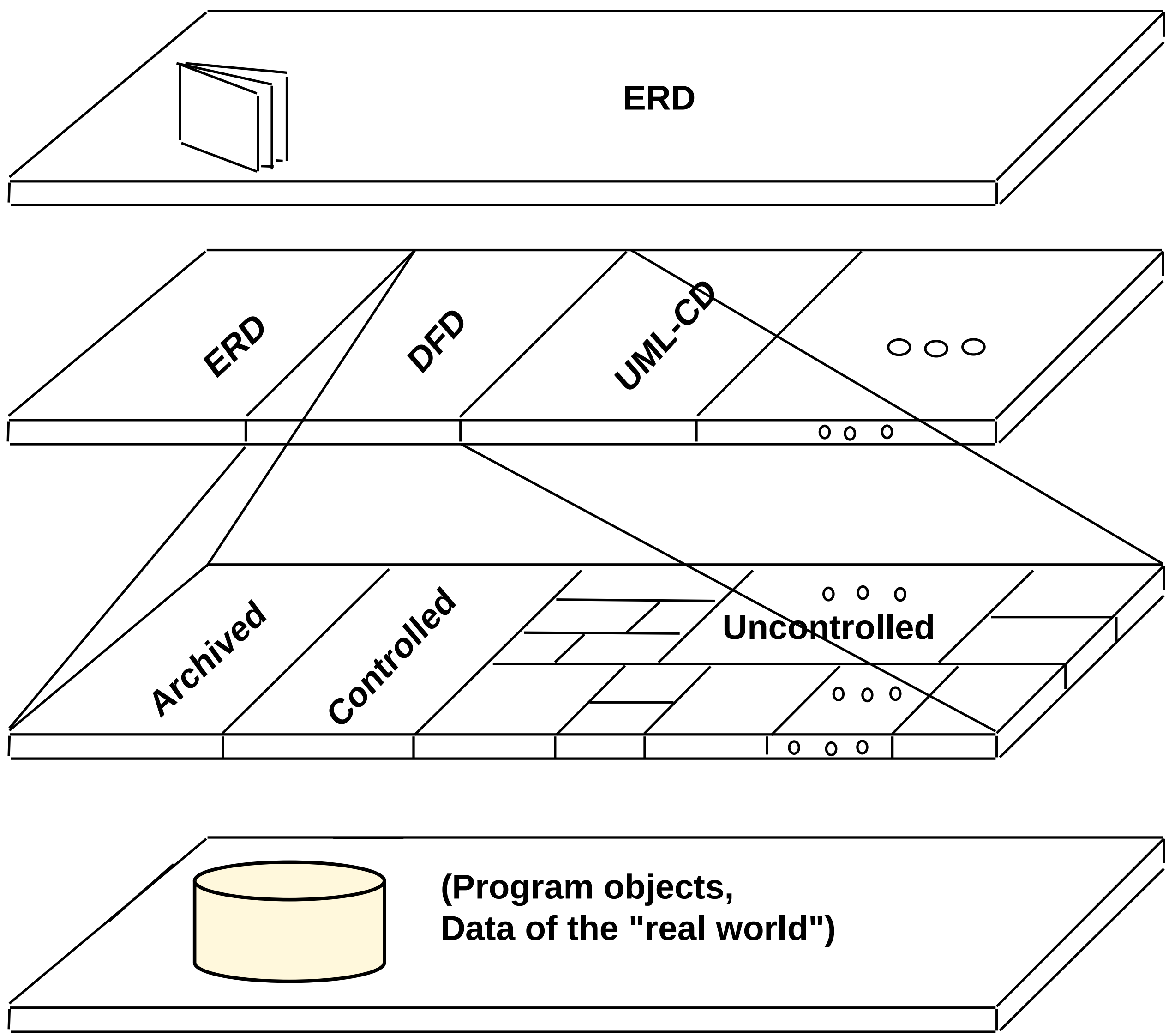
- IRDS was defined in the 70s to model (persistent) data structures of applications

**M3** Dictionary Definition Schema Layer

**M2** Dictionary Definition Layer

**M1** Dictionary Layer

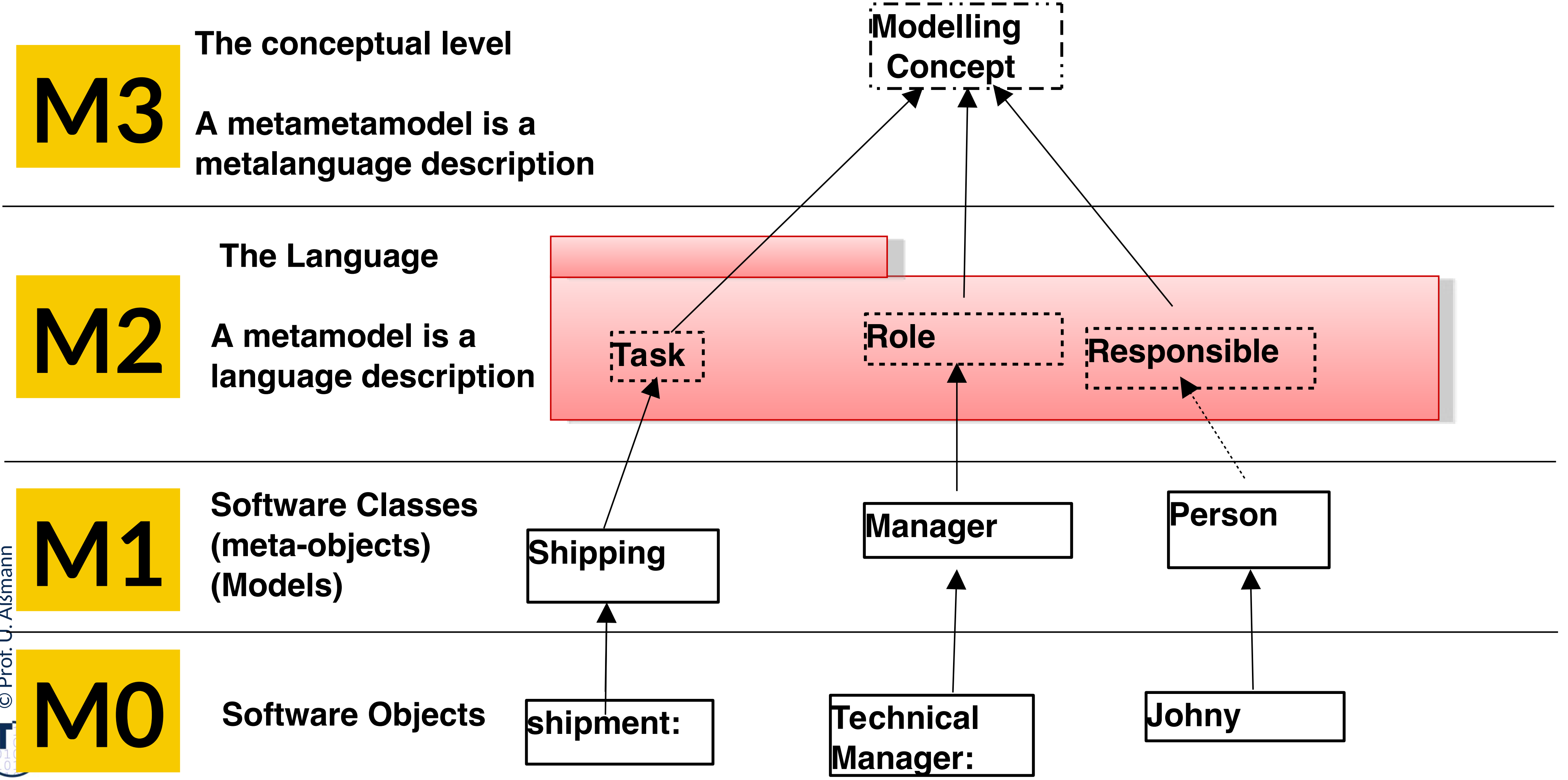
**M0** Application-Layer



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



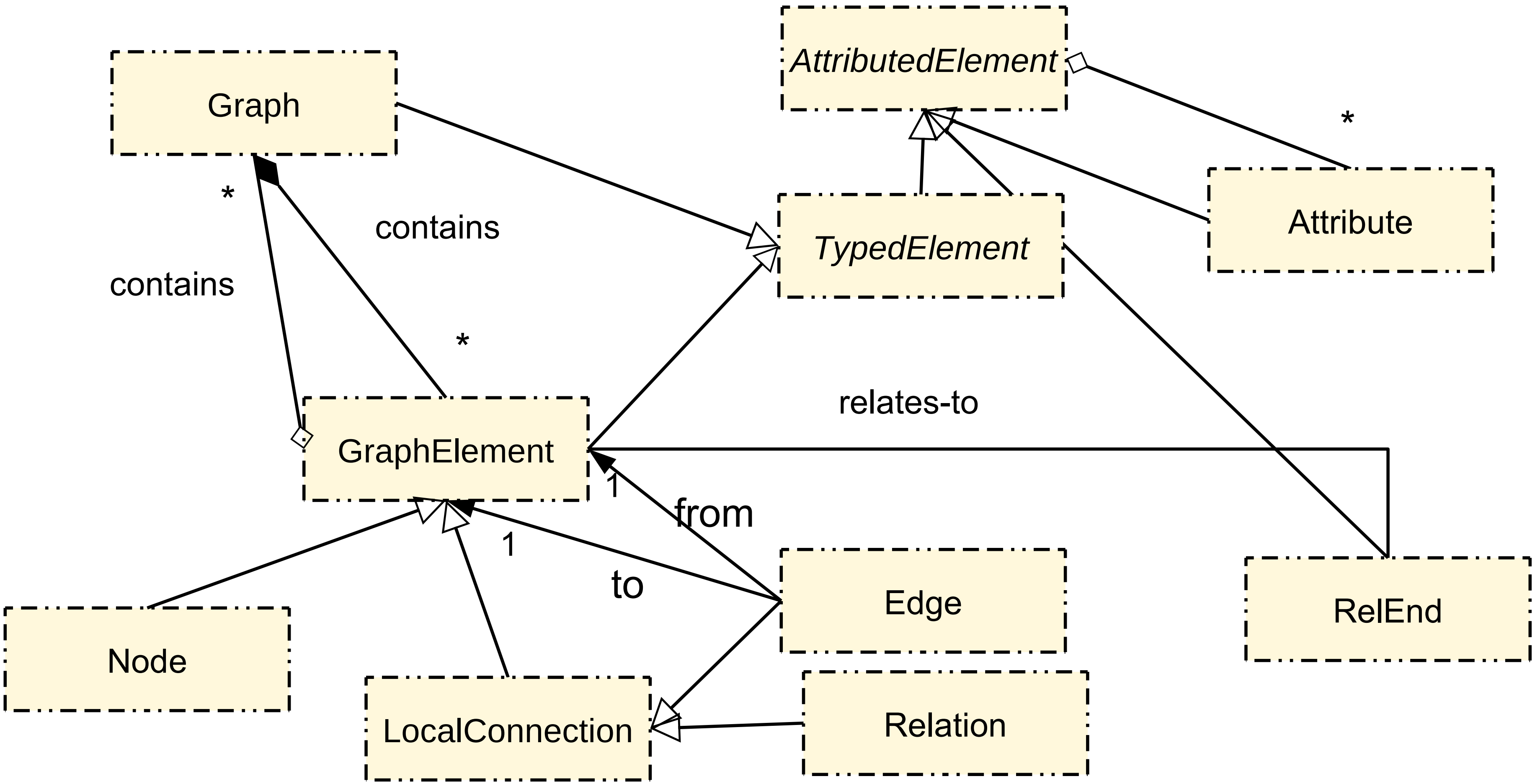
- It is possible to specify workflow languages with the metamodelling hierarchy
- BPEL and other workflow languages can be metamodeled
- **BPEL is metamodeled with the metalanguage XSD**



# 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)



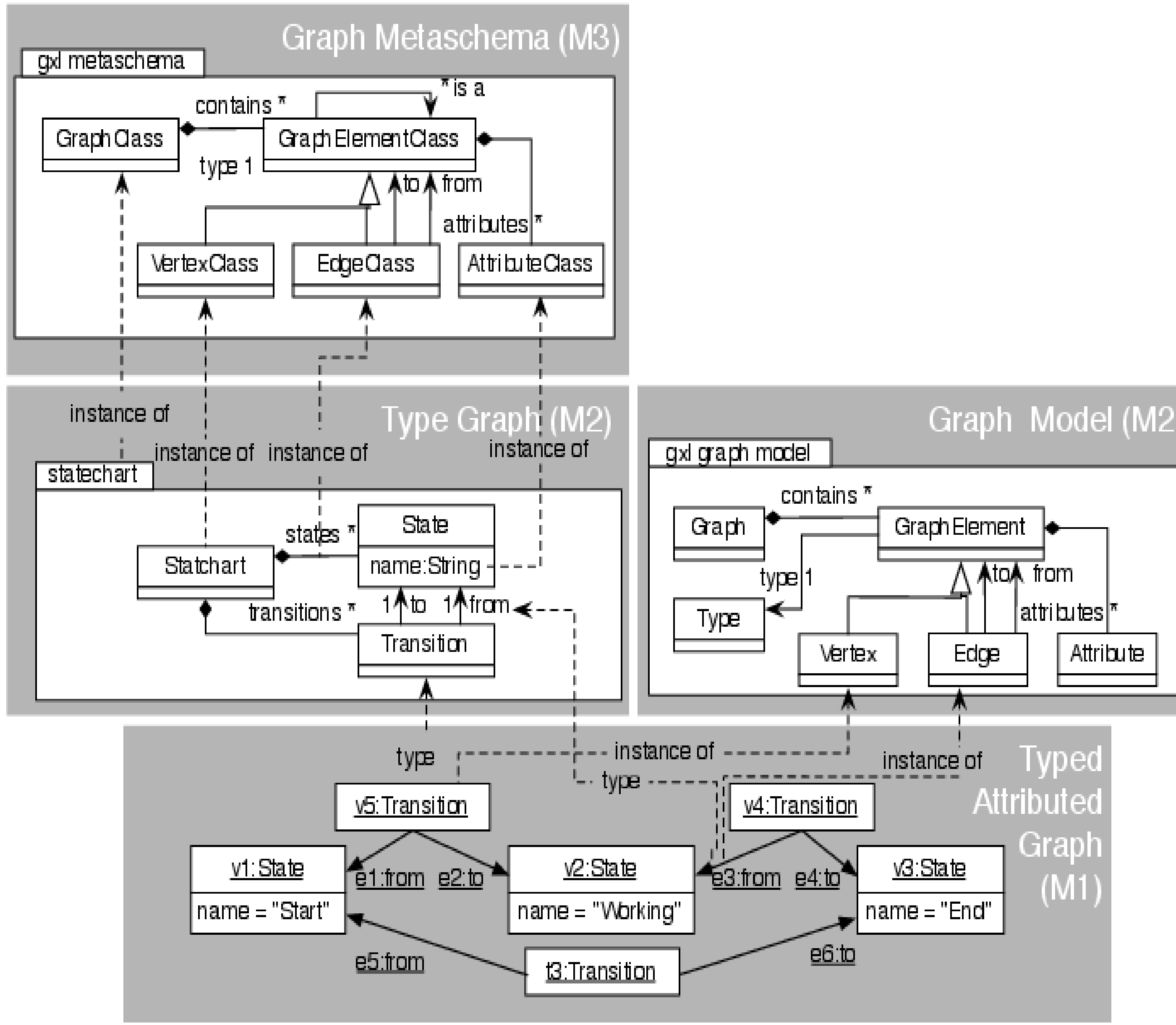



Richard C. Holt, Andy Schürr,Susan Elliott Sim, Andreas Winter. GXL: A graph-based standard exchange format for reengineering. Science of Computer ProgrammingVolume 60, Issue 2, April 2006, Pages 149-170

# 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)



# 12. An Overview of Technical Spaces

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Version 21-0.1, 20.11.21

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

# Literature




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  - https://journal.ub.tu-berlin.de/eceasst/article/viewFile/704/713
- Christopher Brooks, Chihhong Patrick Cheng, Thomas Huining Feng, Edward A. Lee, Reinhard von Hanxleden. Model Engineering using Multimodeling. Electrical Engineering and Computer Sciences University of California at Berkeley.
  - Technical Report No. UCB/EECS-2008-39 http://www.eecs.berkeley.edu/Pubs/TechRpts/2008/EECS-2008-39.html
- Rick Salay, John Mylopoulos, and Steve M. Easterbrook. Using macromodels to manage collections of related models. In Pascal van Eck, Jaap Gordijn, and Roel Wieringa, editors, Advanced Information Systems Engineering, 21st International Conference, CAiSE 2009, Amsterdam, The Netherlands, June 8-12, 2009. Proceedings, volume 5565 of Lecture Notes in Computer Science, pages 141--155. Springer, 2009. [ bib ]
- Rick Salay, Shige Wang, and Vivien Suen. Managing related models in vehicle control software development. In Robert B. France, Jürgen Kazmeier, Ruth Breu, and Colin Atkinson, editors, Model Driven Engineering Languages and Systems - 15th International Conference, MODELS 2012, Innsbruck, Austria, September 30-October 5, 2012. Proceedings, volume 7590 of Lecture Notes in Computer Science, pages 383--398. Springer, 2012.

# Secondary Literature




- Christopher Brooks, Thomas H. Feng, Edward A. Lee, Reinhard von Hanxleden. Multimodeling: A Preliminary Case Study. Berkeley University, Dept of Electrical Engineering and Computer Science. Accession Number : ADA519171. 2008
  - https://apps.dtic.mil/docs/citations/ADA519171
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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

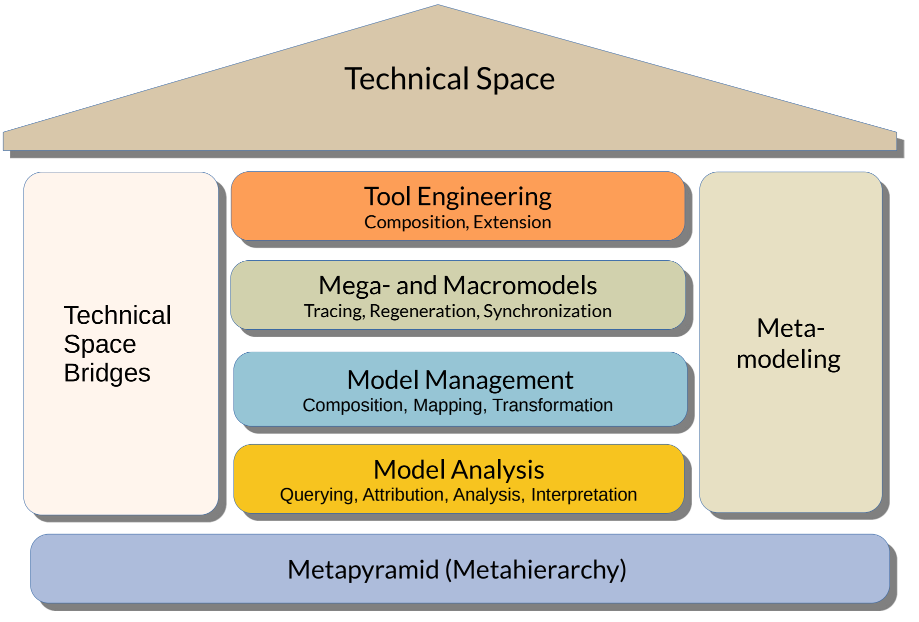


Multimodeling is the act of combining diverse models.
[Brooks-Lee-Hanxleden]

- 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)



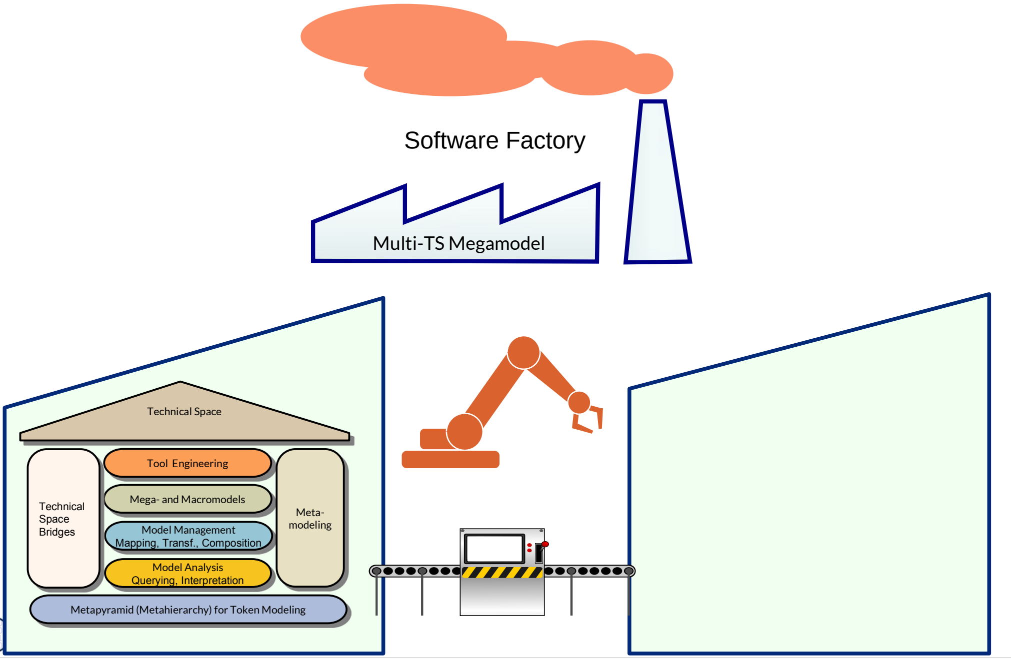
A **software factory** schema essentially defines a recipe for building members of a software product family.

Jack Greenfield

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

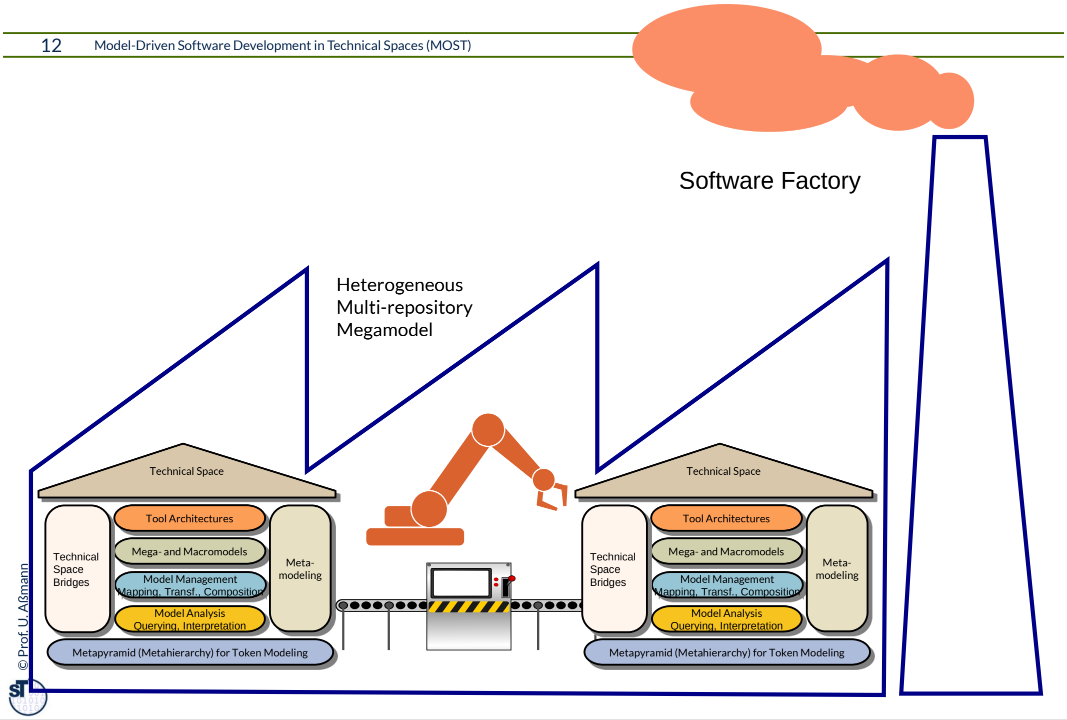
# Software Factories with Only 1 Technical Space





# 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

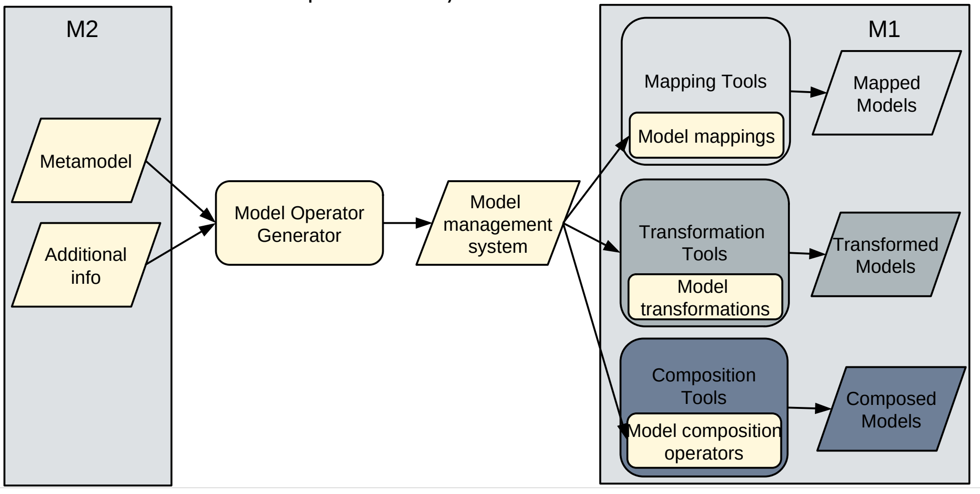
# 12.3. Model Management in a Technical Space with Model Mapping, Transformation and Composition

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



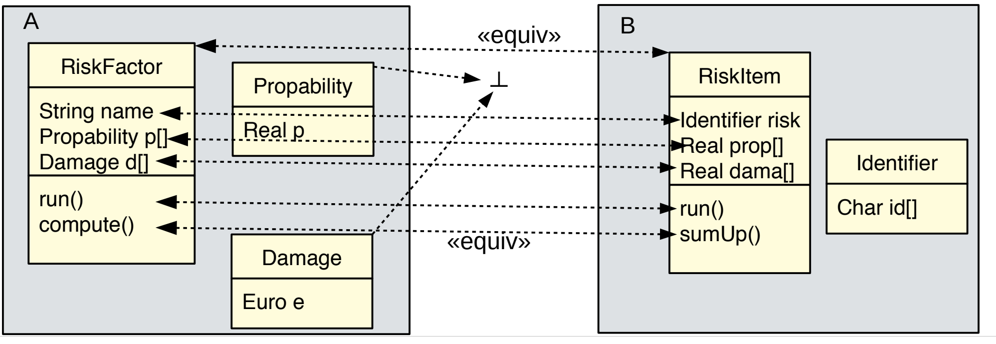
# 12.3.1. Model Mapping

# 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.

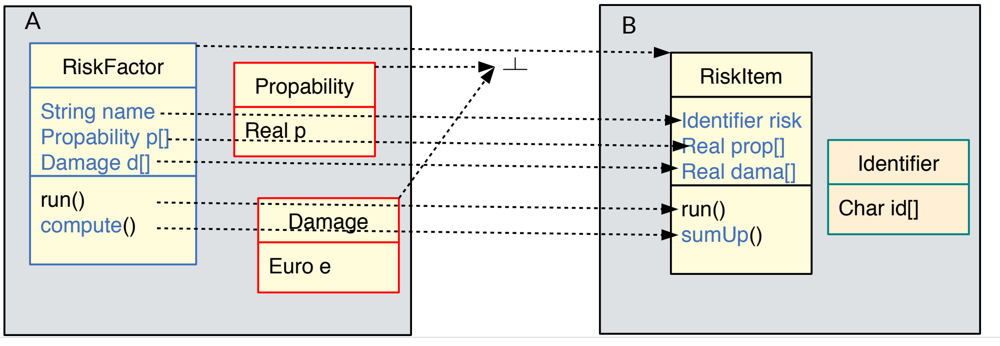


# 12.3.2. Model Transformation

# 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



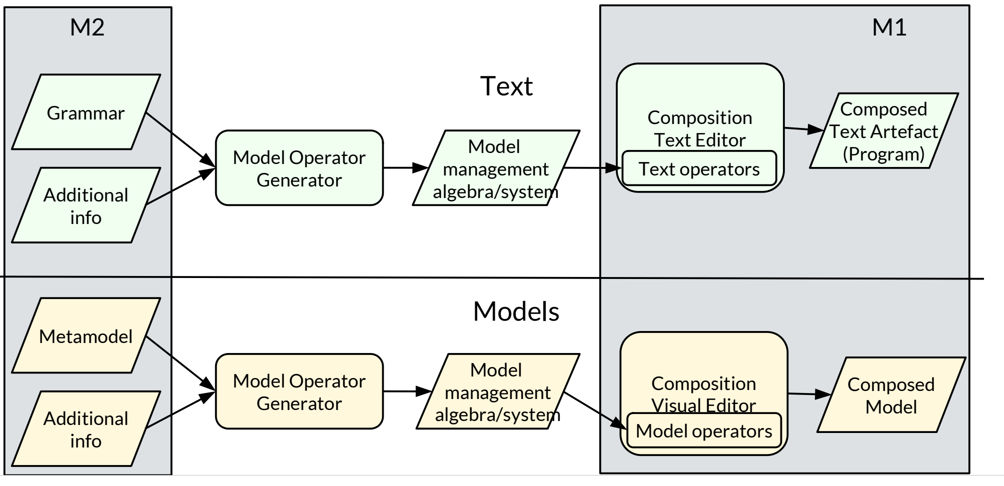
# 12.3.3. Model Composition with Model Algebrae and Composition Systems

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



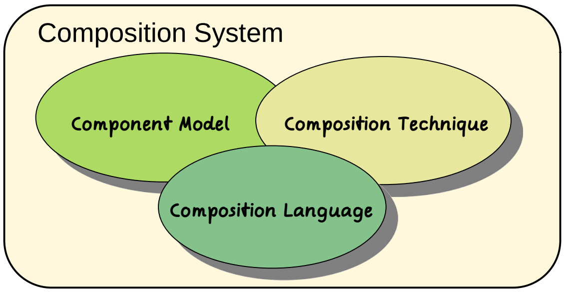
# Simple Algebra for Models (on M1) and Metamodels (on M2)



- 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

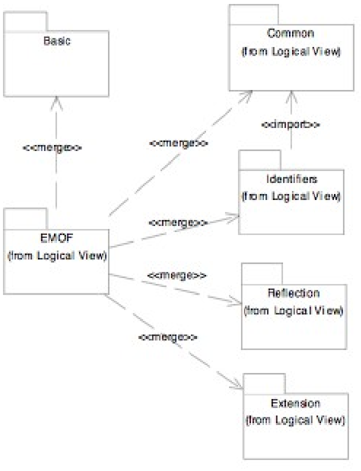
→ Metamodels can be composed from packages

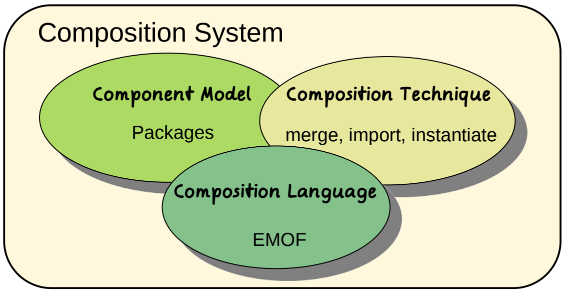


# Ex.: EMOF Class Composition by EMOF Package Merge



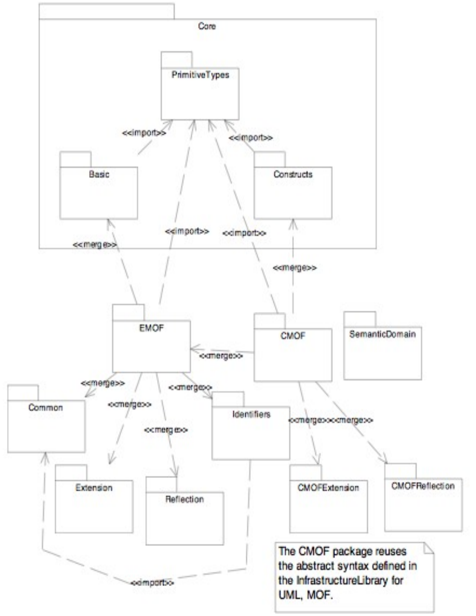
[MOF]



# 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.

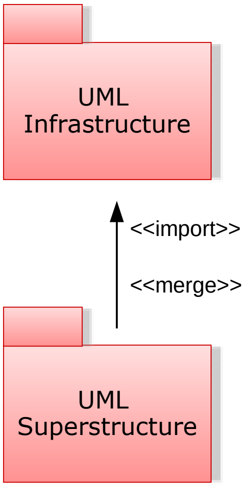
The UML-metamodel is a "logic" metamodel, because it is *composed:*

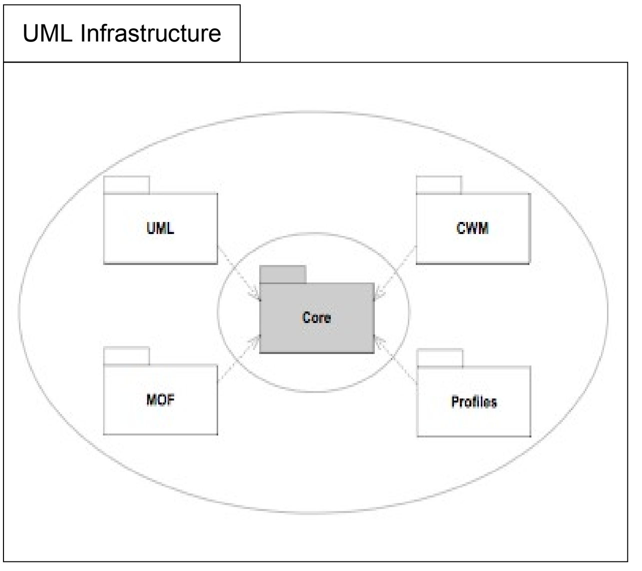
- Definition of merge operator composing metaclasses and metaclass-packages
- Defined in composable **packages**
  - With a clear **CMOF**-package architecture
  - uniform **package structure** and context-sensitive semantics for all diagrams such as Statecharts (UML-SC), Sequence Diagrams (UML-SD), 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

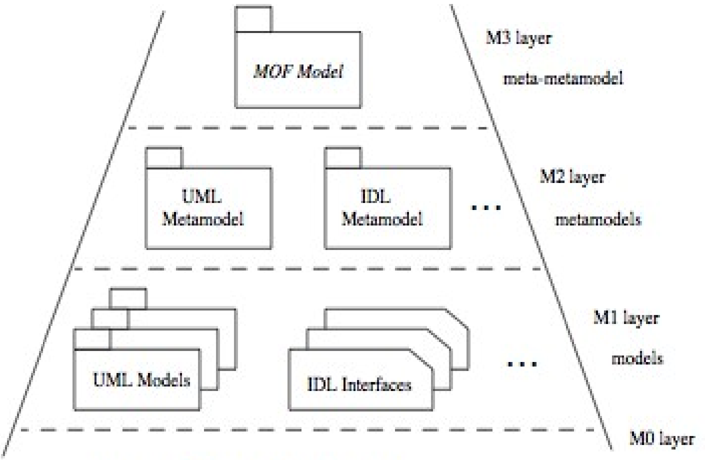



*Figure 2-2* MOF Metadata Architecture

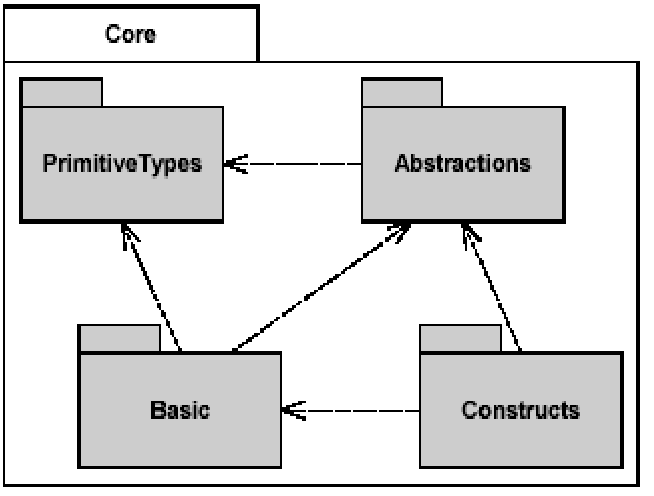


[MOF]

# MOF doc

# Core Package of the UML-Infrastructure Metamodel (M2)



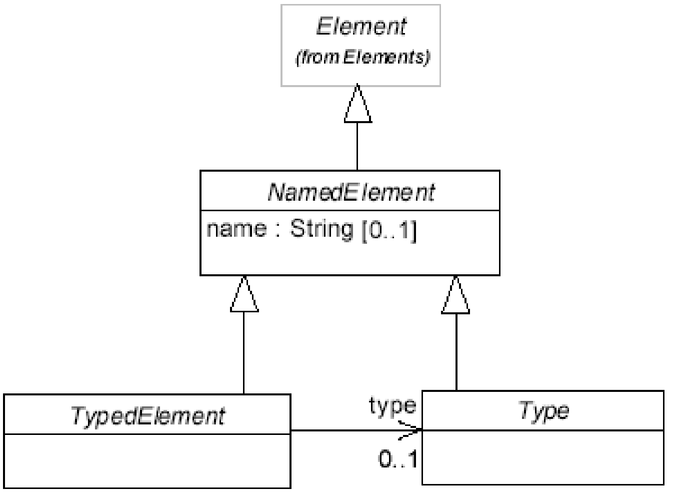



**Basic:** basic constructs for XMI
**Constructs:** Metaclasses for modeling
**Abstractions:** abstract metaclasses
**Primitive Types:** basic types

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

# Package Basic: Uses Types from CMOF



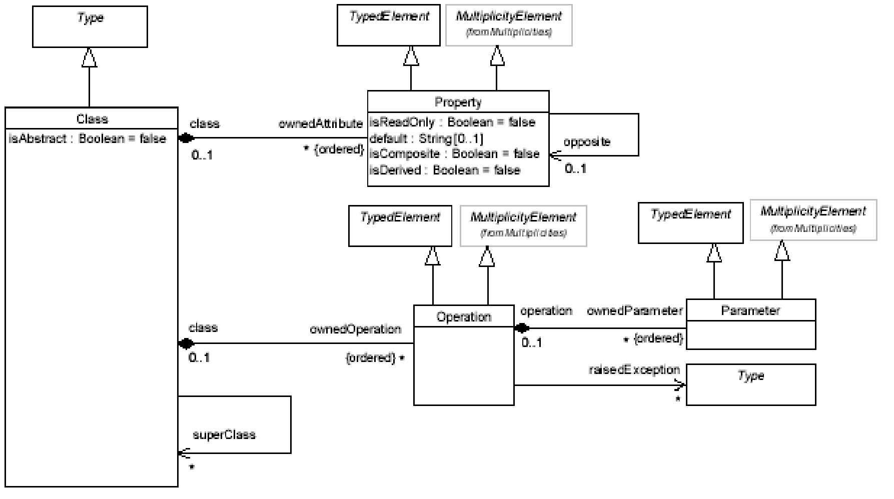





**From:** UML 2.0 Infrastructure Specification; OMG Adopted Specification ptc/03-09-15

# Package Basic: Classes

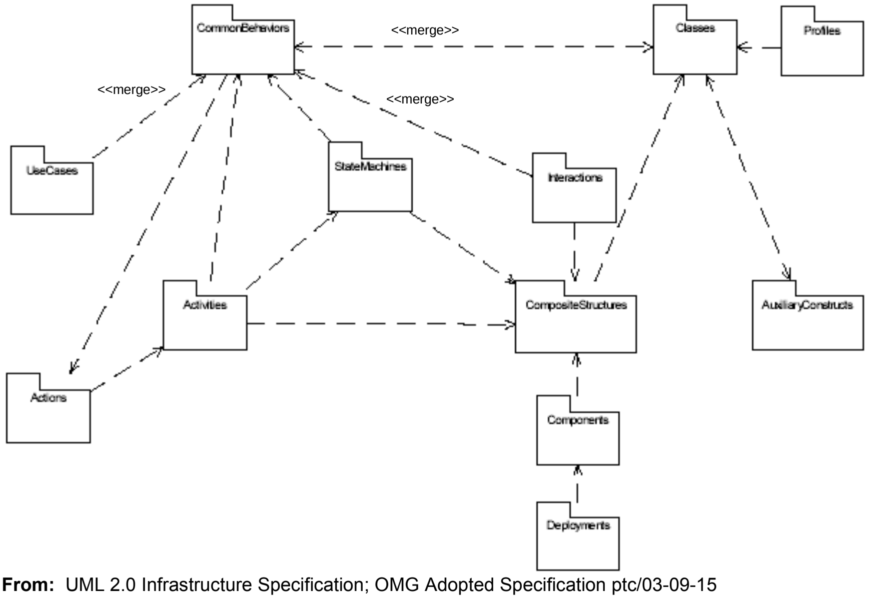





**From:** UML 2.0 Infrastructure Specification; OMG Adopted Specification ptc/03-09-15

# Package Composition Architecture UML 2.0 (M2)



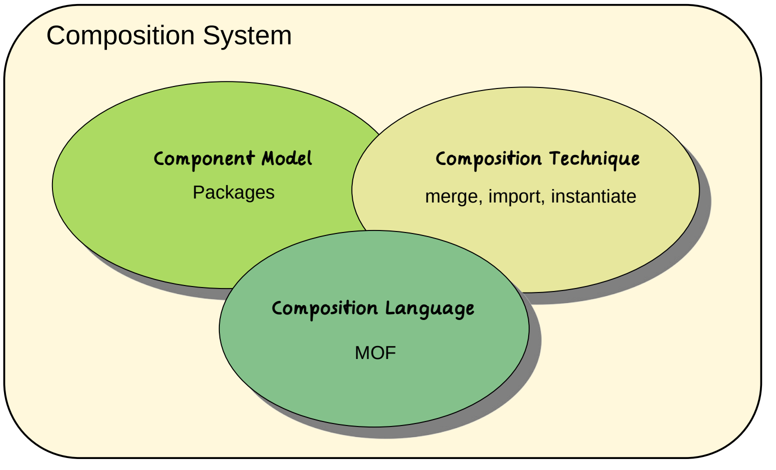





**From:** UML 2.0 Infrastructure Specification; OMG Adopted Specification ptc/03-09-15

# Metamodel Composition – the Composition System of the UML Language Report





# 12.4 Mega- and Macromodels – Models about Models

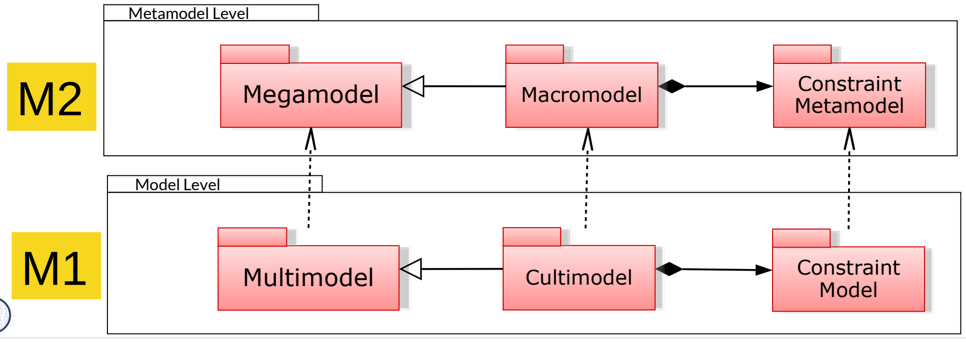
In a technical space, a ***megamodel*** is an infrastructure for models and metamodels, systematically linking a set of models

# 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






•A macromodel consists of elements denoting models and links denoting intended relationships between these models with their internal details abstracted away" [SME09].

# Cultimodels – Multimodels with Consistency Rules

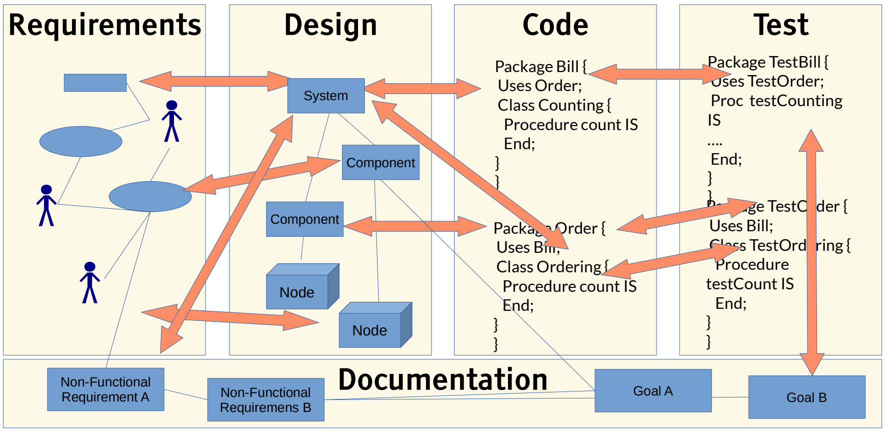


- A ***cultimodel*** is an instance of a macromodel, i.e., a multimodel *fulfilling some consistency constraints over the models and their elements.*
  - The schema, the macromodel is adorned with a constraint metamodel
  - The graph of models in the multimodel obeys wellformedness constraints
  - There 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



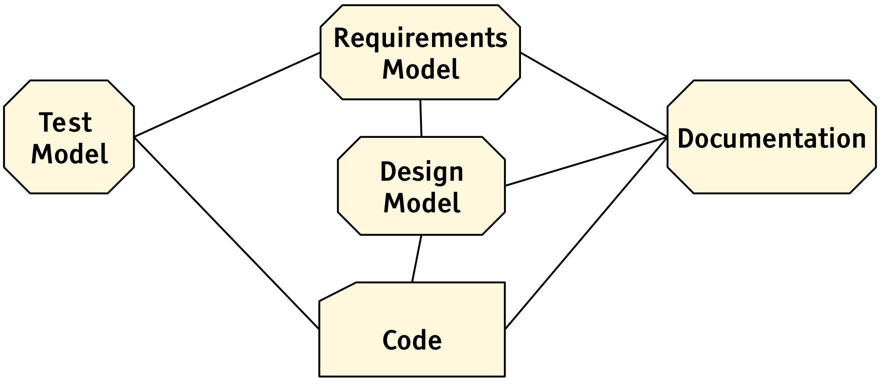
- The **ReDoDeCT problem** is the problem how requirements, documentation, design, code, and tests are related (→ V model)
- Mappings between the Requirements model, Documentation files, Design model, Code, Test cases
- A **ReDoDeCT macromodel** has maintained mappings between all 5 models



# Model Synchronization in Macromodels



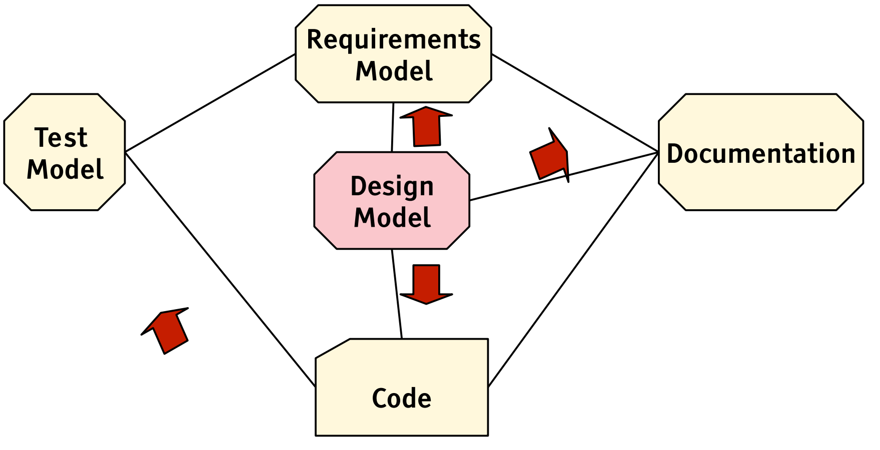
- ***Model synchronization*** keeps a set of connected models (the ***crowd***) *in* sync, i.e., consistent



# Model Synchronization in Macromodels



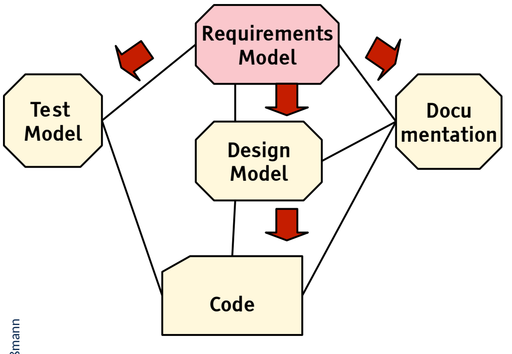
- In model synchronization, if an edit has occurred in a ***origin model***, all other connected models of a crowd (***dependent models***) are updated instantaneously, when one focus model changes

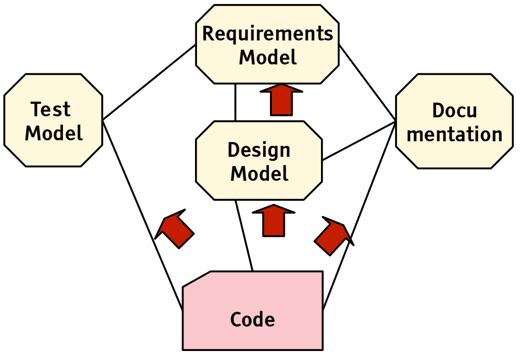


# Round-Trip Engineering (RTE) Changes the Model-in-Focus of the Crowd



- 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



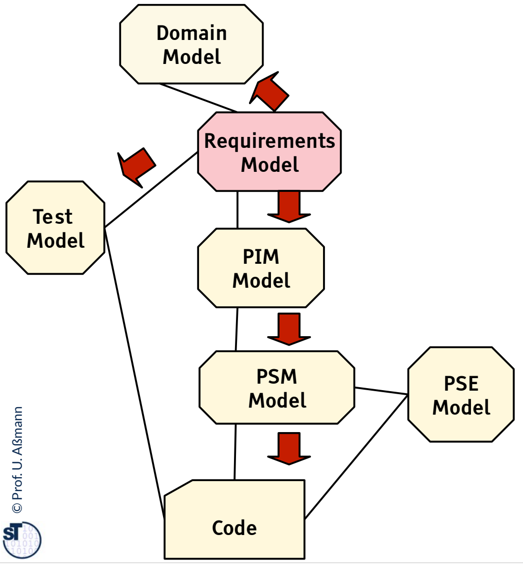
- **Error tracing**
  - When an error occurs during testing or runtime, we want to trace back the error to a design element or requirements element
- **Traceability**
  - We want to know which requirement (feature) influences which design, code, and test elements, so that we can demarcate modules in 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

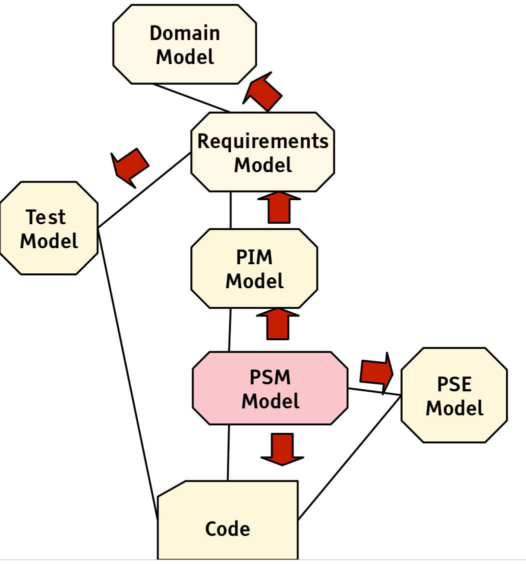
describing the situation in which the system will be used

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.

# Round-Trip Engineering in MDA Multimodels





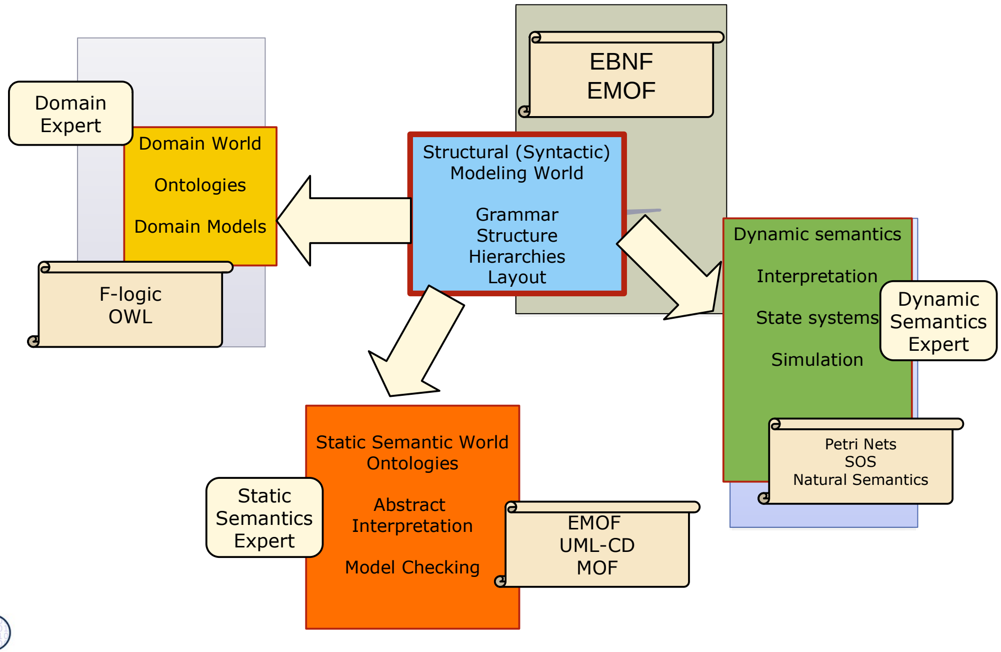



# 12.5. Briding Technical Spaces and Software Factories

- 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








Bridging.all-the-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

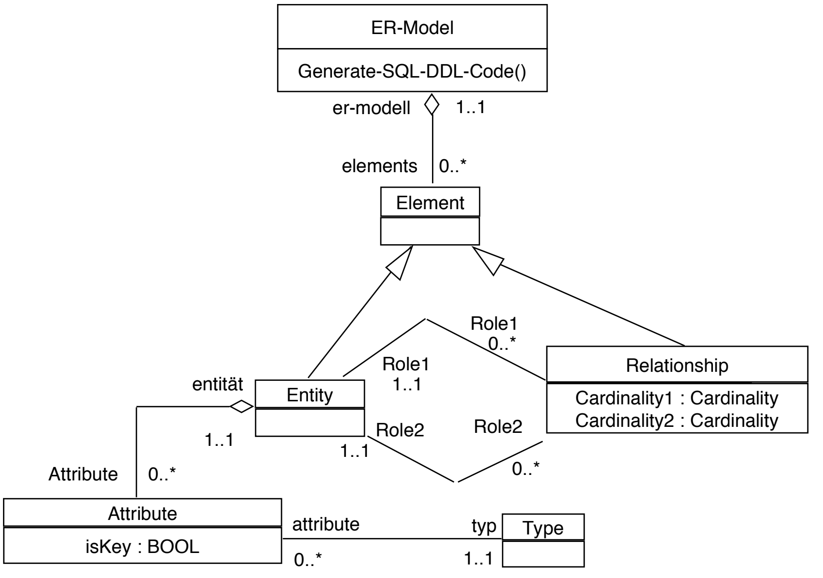


- Why do different technical spaces exist?
- What is the difference between a technological and a technical space?
- Explain round-trip engineering and model synchronization.
- What is model mapping vs model transformation?
- Explain the different forms of model mappings.

# 12.A.1 Other Metalanguages and Technical Spaces

# Metamodel of EntityRelationship Diagrams (ERD-ML) in MOF

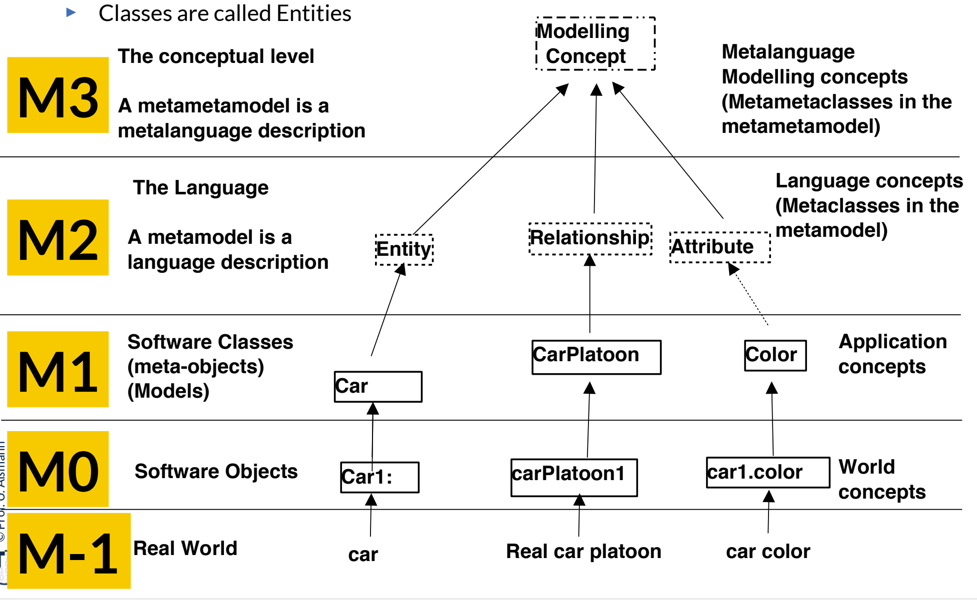
- ERD is like MOF without inheritance



# Metalevels in ERD



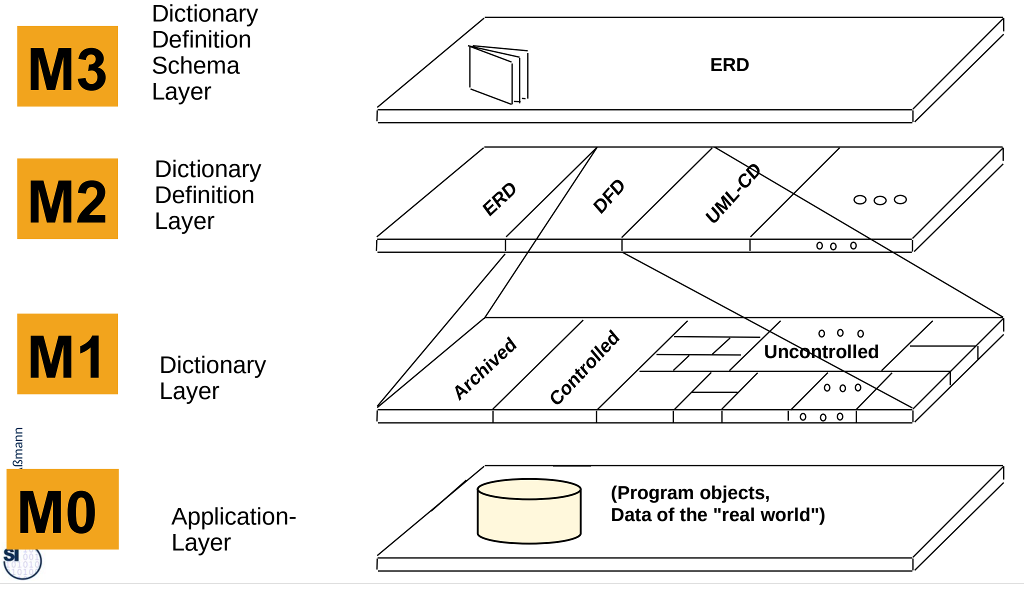
- Classes are called Entities



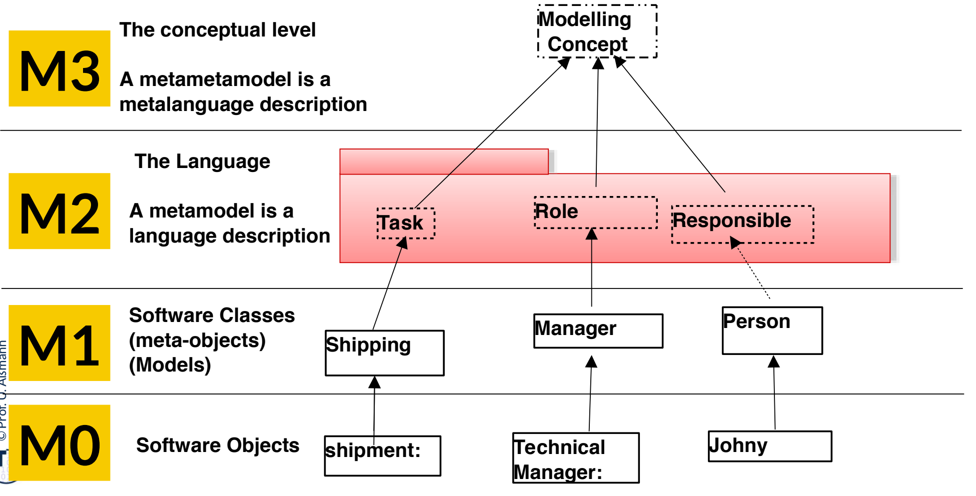
# Ex.: IRDS/MOF Metahierarchy for Data Dictionaries in the Structured Analyse (SA)



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



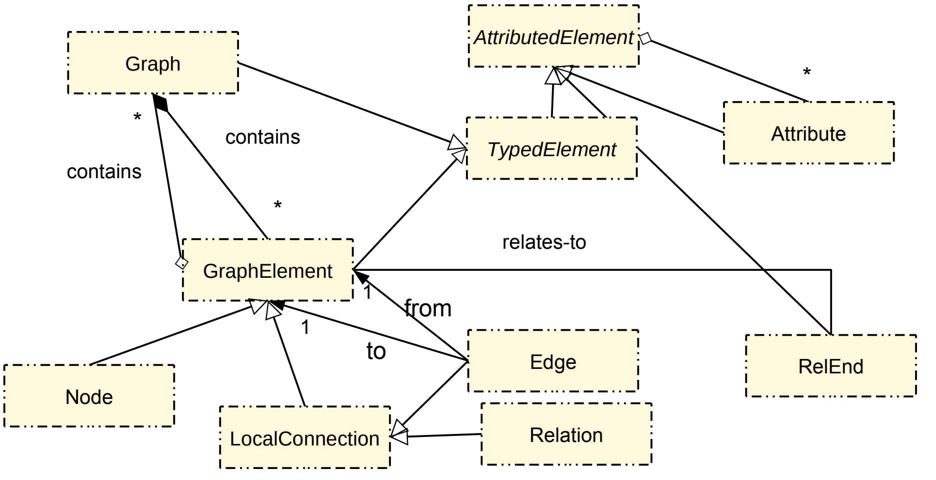
- It is possible to specify workflow languages with the metamodelling hierarchy
- BPEL and other workflow languages can be metamodeled
- **BPEL is metamodeled with the metalanguage XSD**



# 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)