Meta-Modelling

Model vs. System

René Magritte. La trahison des images. 1928–29.

Model of a model — The correspondence continuum

Meaning is rarely a simple mapping from a symbol to an object; instead it often involves a ***continuum of (semantic) correspondences*** *from symbol to (symbol to)* object.* [Barry Smith. The correspondence continuum. 1987]

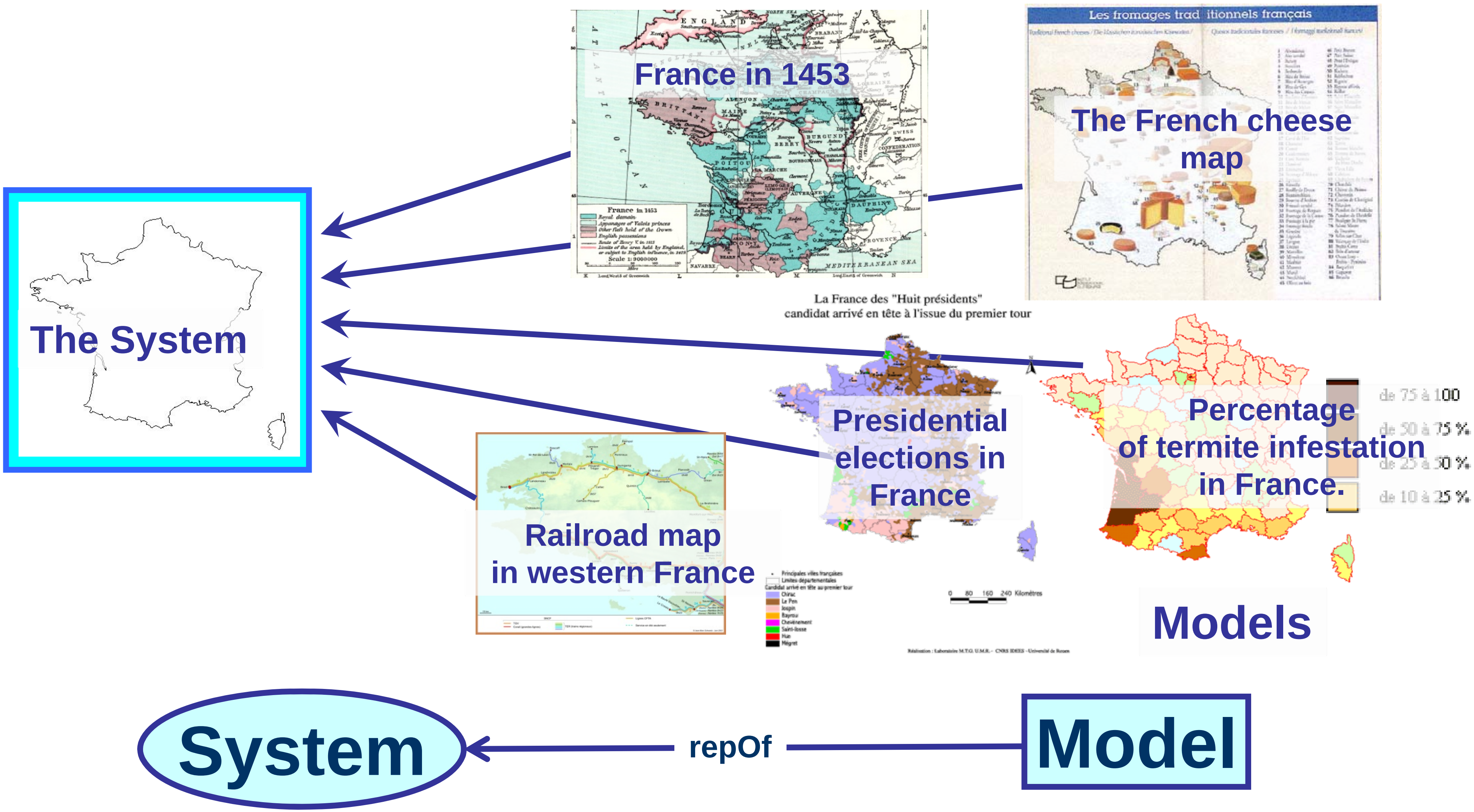
- Example
  - A photo of a landscape is a model of the landscape.
  - A photocopy of the photo is model of a model of the landscape.
  - A digitalization of the photocopy is a model of the model of the model of the landscape.
  - etc.

Basic entities of MDE and MDSD

***System*: a group of interacting, interrelated, or interdependent elements forming a complex whole.**

***Model*: an abstract representation of a system created for a specific purpose.**

A very popular model: Geographical maps



Limited substitutability principle

- The purpose of a model is always to be able to answer some specific sets of questions in place of the system, exactly in the same way the system itself would have answered similar questions.

- A model represents certain specific aspects of a system and only these aspects, for a specific purpose.

Lewis Carroll and the 1:1 map

“That’s another thing we’ve learned from your Nation” said Mein Herr, “map-making. But we’ve carried it much further than you. What do you consider the ***largest*** map that would be really useful?”

“About six inches to the mile.”

“Only *six inches*!” exclaimed Mein Herr. “We very soon got to *six yards* to *the mile*. Then we tried a hundred yards to the mile. And then came the grandest idea of all! We actually made a map of the country, on the scale of ***a mile to the mile***!”

”***Have you used it much***?” I enquired.

“***It has never been spread out***, yet” said Mein Herr: “the farmers objected: they said it would cover the whole country, and shut out the sunlight! So we now use the country itself, as its own map, and I assure you it does nearly as well.“

Lewis Carroll. Sylvie and Bruno concluded.

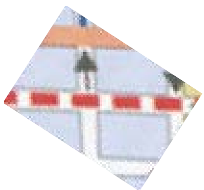
Lewis Carroll and the blank map

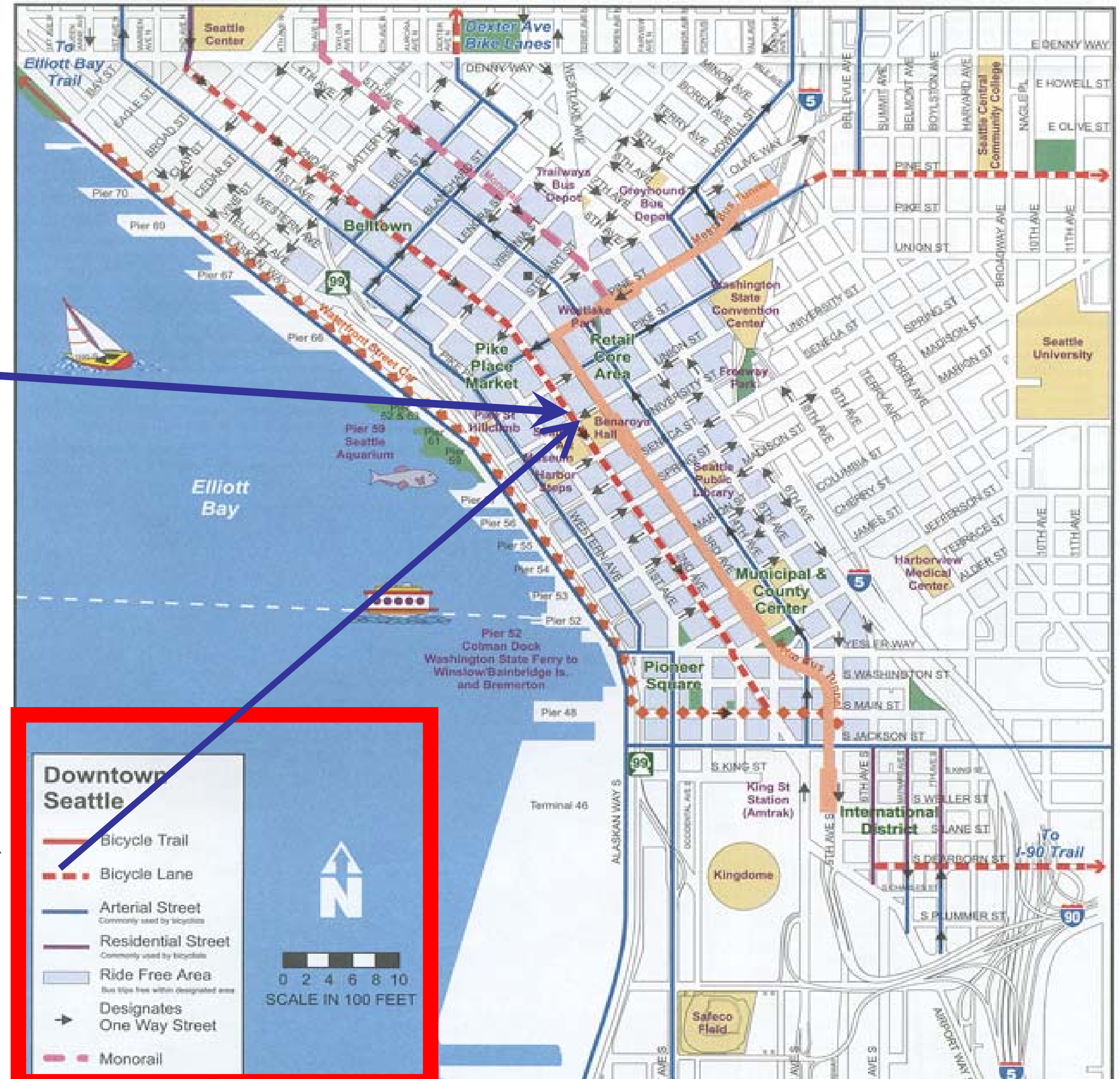
He had bought a large map representing the sea,
Without the least vestige of land:
And the crew were much pleased when they found it to be
A map they could all understand.
“What's the good of Mercator's North Poles and Equators,
Tropics, Zones, and Meridian Lines?”
So the Bellman would cry: and the crew would reply
“They are merely conventional signs!
Other maps are such shapes, with their islands and capes!
But we've got our brave Captain to thank:”
(So the crew would protest) “that he's bought us the best—
A perfect and absolute blank!”

Lewis Carroll. The Hunting Of The Snark — An Agony in Eight Fits.

Every map has a legend (implicit or explicit)

Same visual notation, different context, different meaning



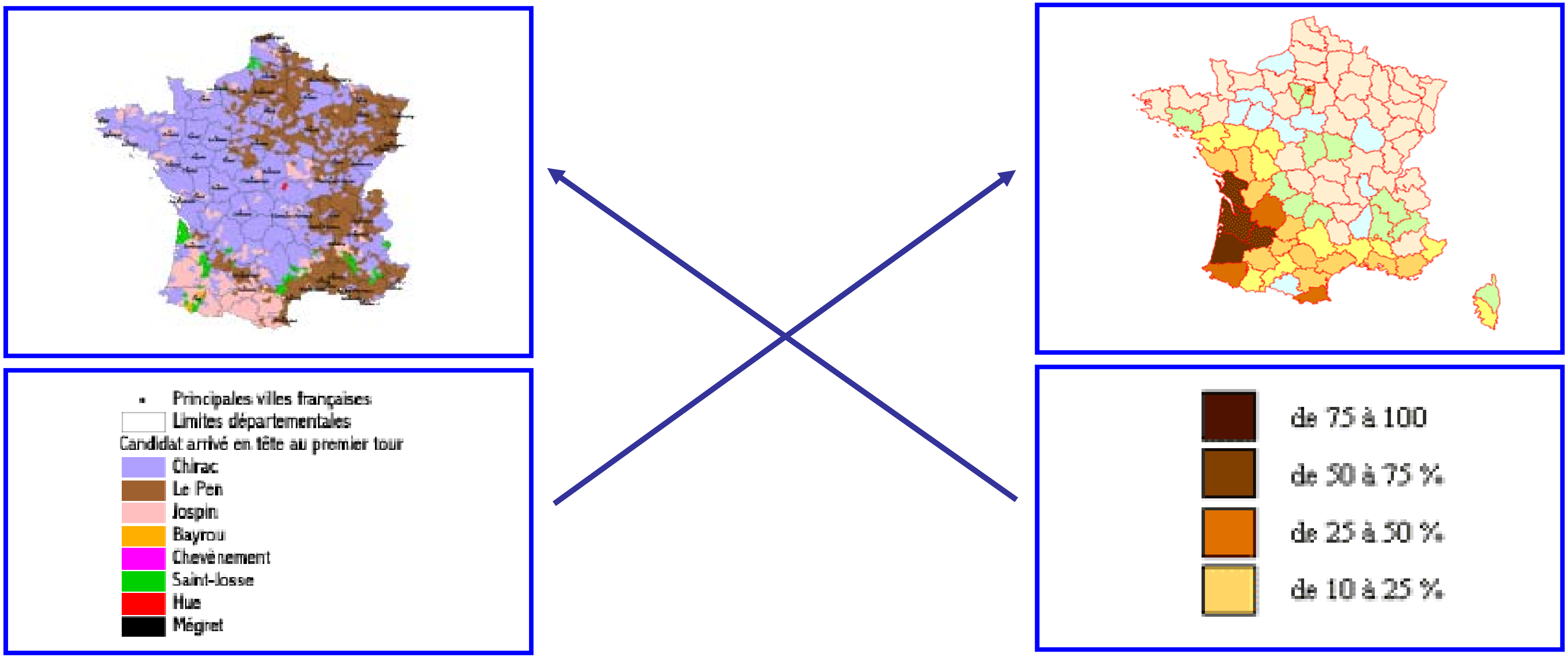


The legend is the metamodel

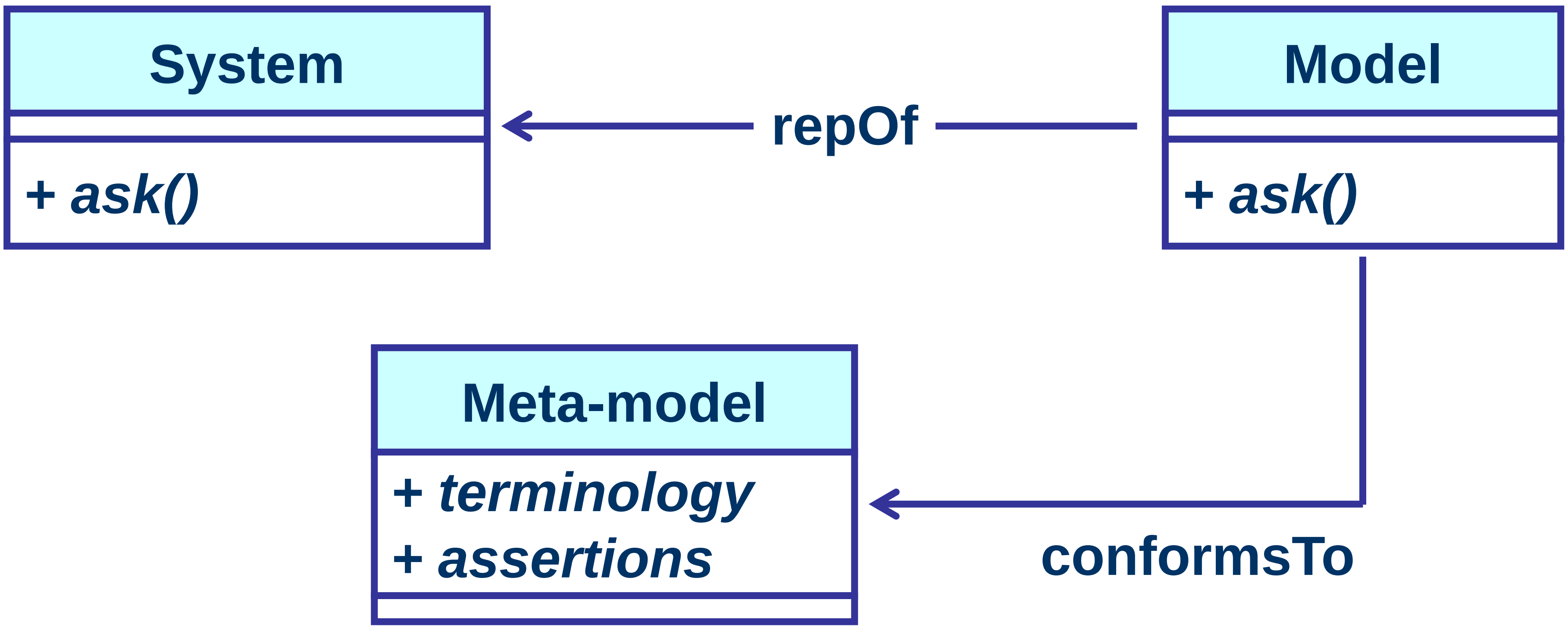
Maps without legends are meaningless

First round of political election in France in 2002

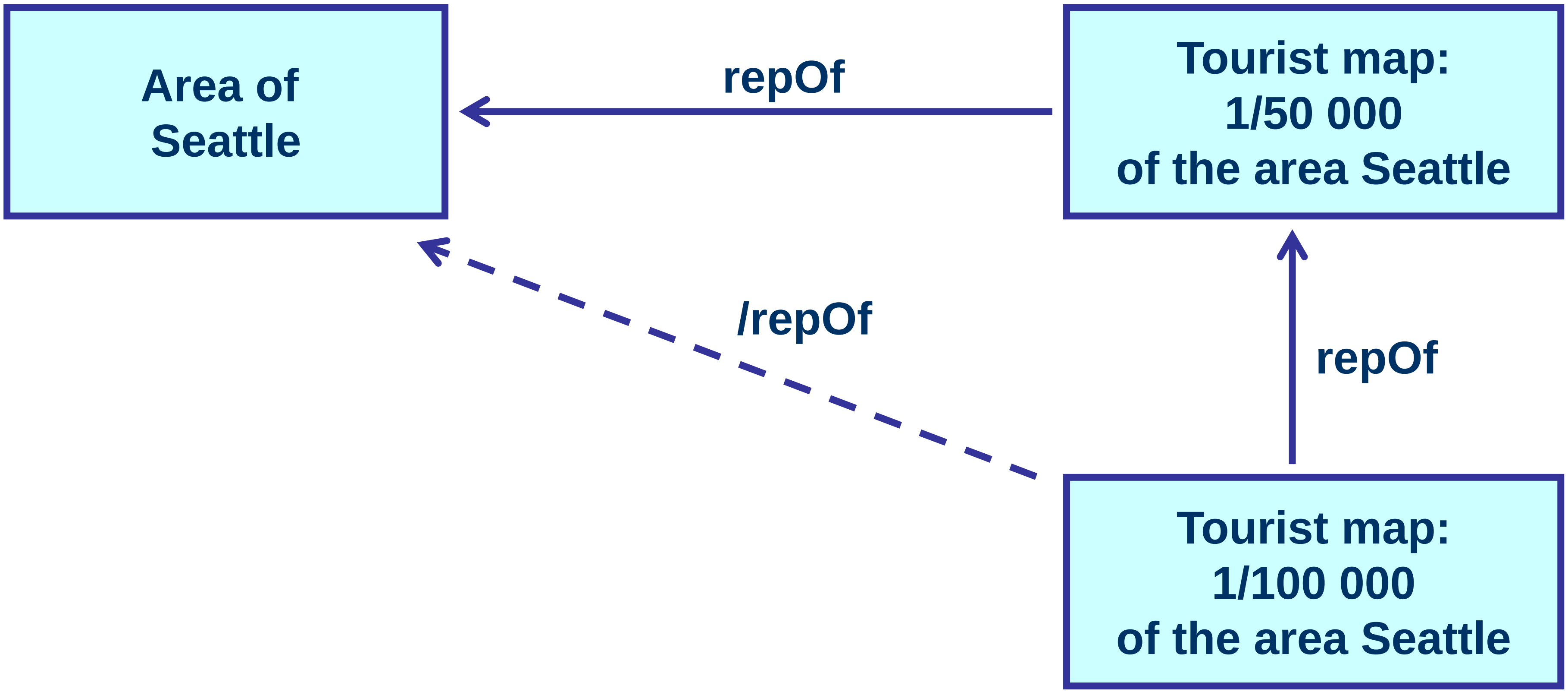
Percentage of places infested by termites in France



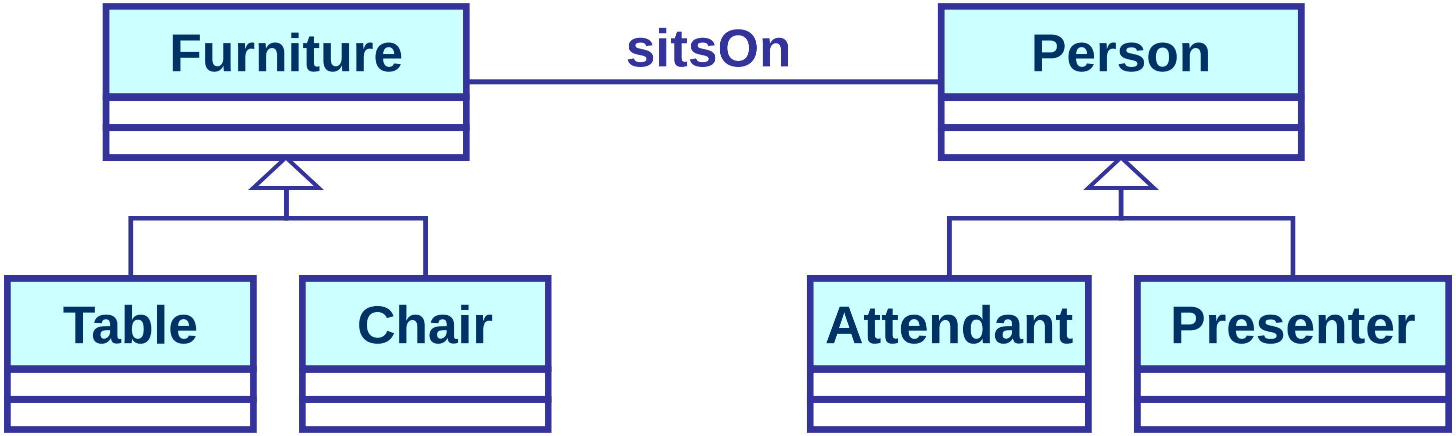
The legend is a meta-model



The model of a model is not a meta-model



Meta-models act as filters



A system

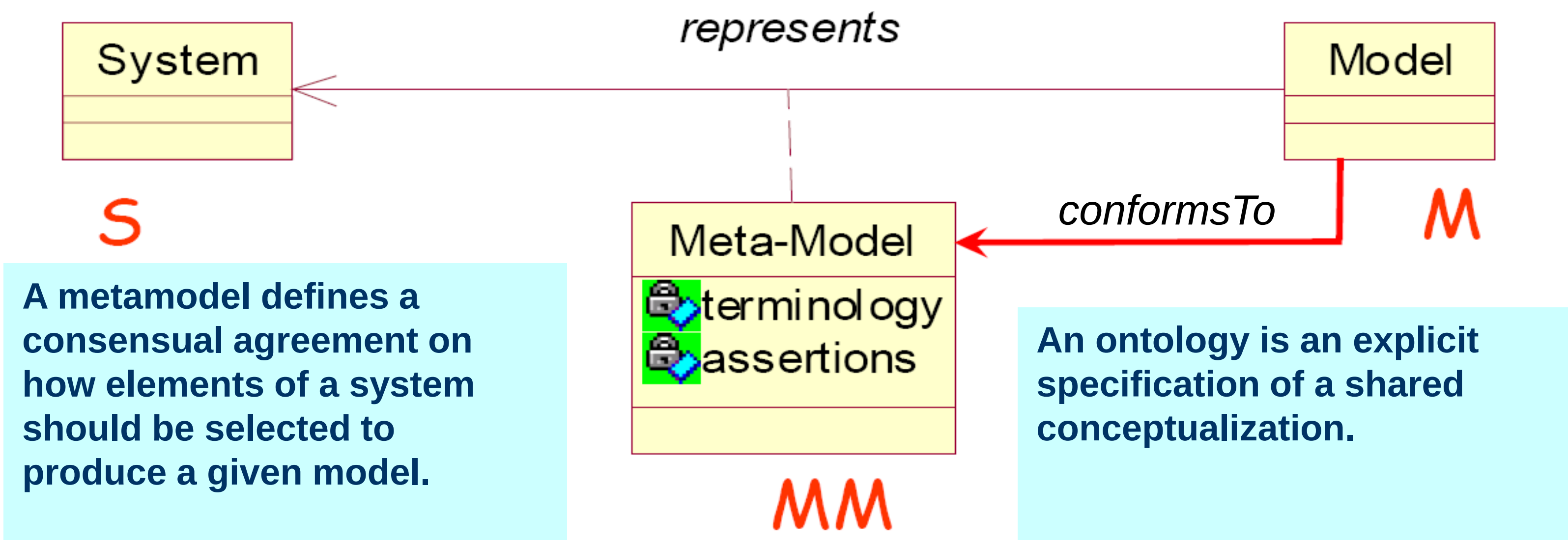
The metamodel

Mary
Table 237
Chair 34
Paul
Victor
Emily

A model

Meta-models as simple ontologies

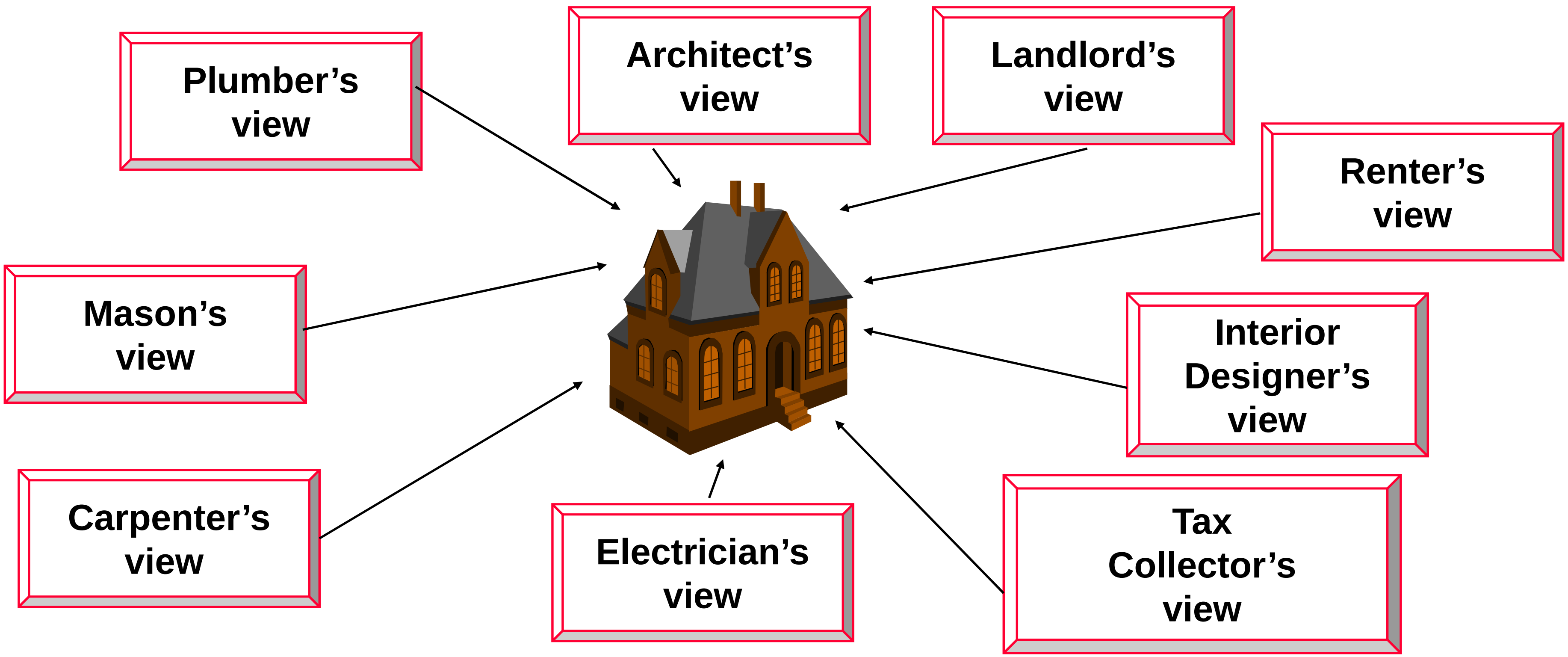
- Meta-models are precise abstraction filters.
- Each meta-model defines a domain-specific language.
- Each meta-model is used to specify which particular “aspect” of a system should be considered to constitute the model.



- The correspondence between a system and a model is precisely and computationally defined by a meta-model.

Multiple views and coordinated DSLs

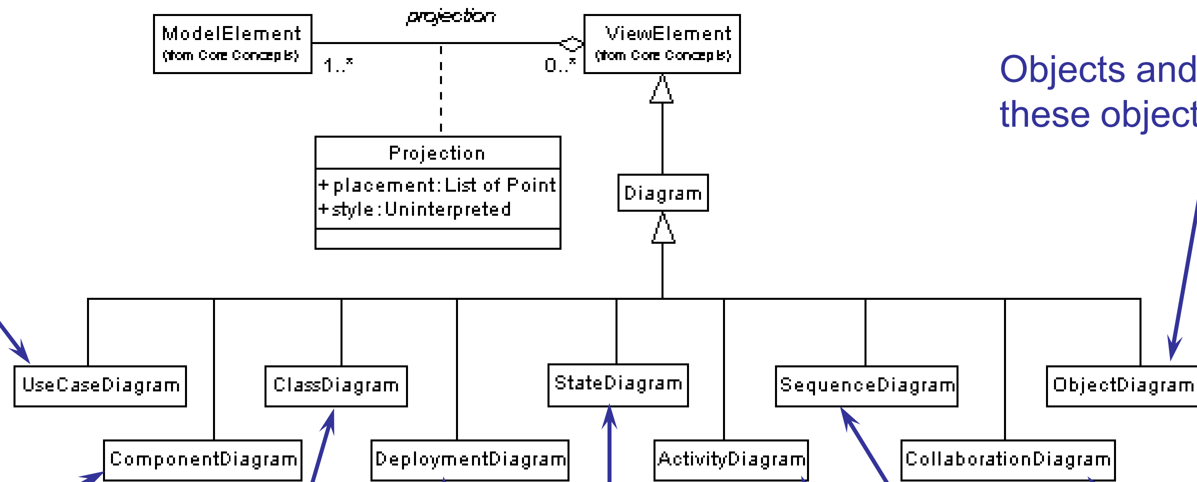
- 1:1 map vs. blank map
- Limited substitutability principle
- A model has no meaning when separated from its meta-model.



Multiple views and aspects of a software system

System functions
from the user view

Objects and basic relations between
these objects



Physical components
of an application

Representation
of behavior
in term of states

Representation of objects,
of their mutual links and
potential interactions

Schemas of component
installation
on hardware devices

Representation of
objects and their
temporal interactions

Representation
of operation behavior
in terms of actions

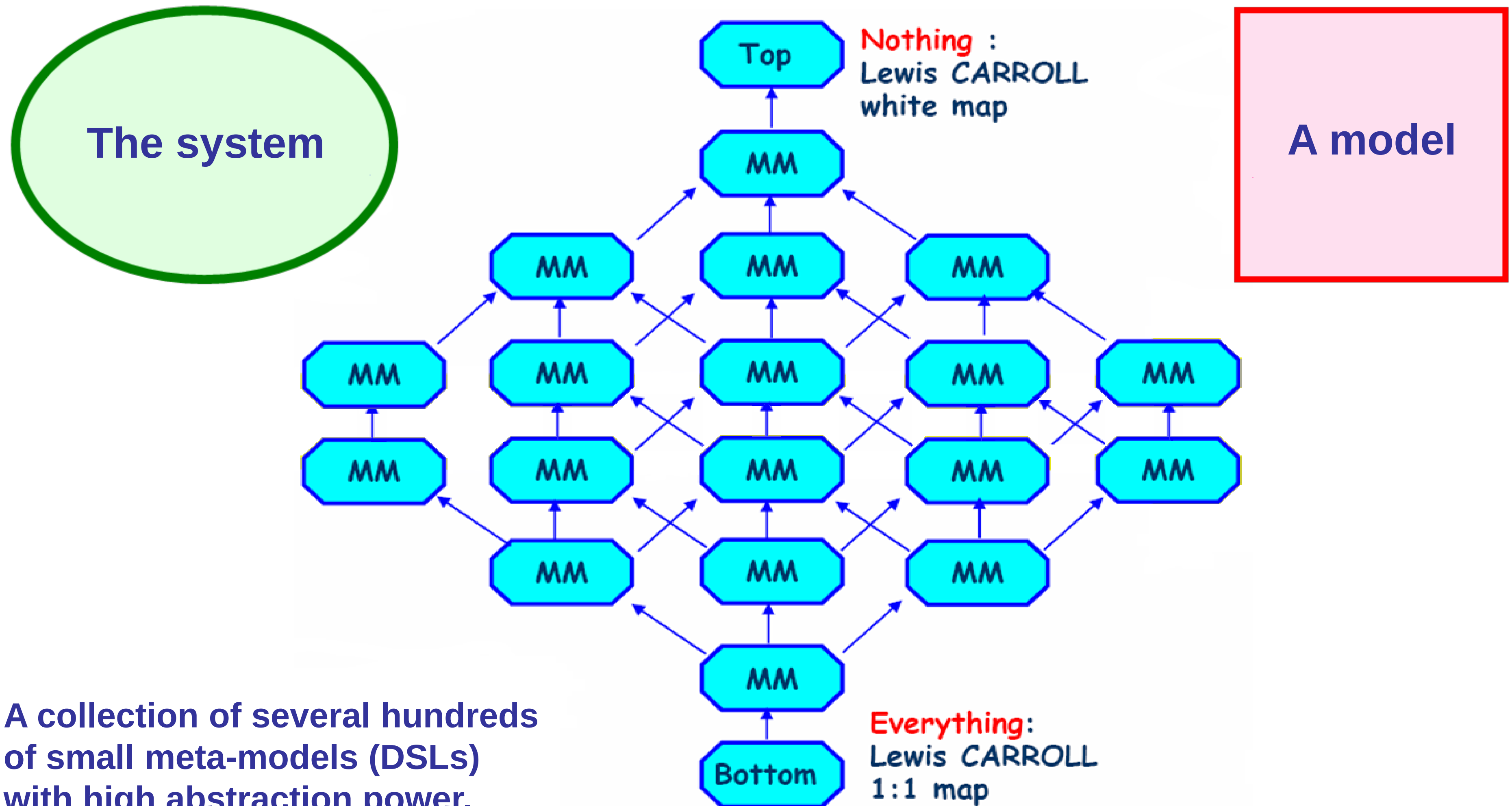
Class static structure
and relations between these classes

Meta-models

- A meta-model is just another model.
  - **Model of a set of models**
- Meta-models are specifications.
  - Models are valid if no false statements according to meta-model (e.g. well-formed)
  - Meta-models typically represent domain-specific models (real-time systems, safety critical systems, e-business)
- The domain of meta-modelling is language definition.
  - A meta-model is a model of some part of a language
  - Which part depends on how the meta-model is to be used
  - Parts: syntax, semantics, views/diagrams, ...

- **Meta-meta-model**
  - Model of meta-models
  - Reflexive meta-models expressed using itself

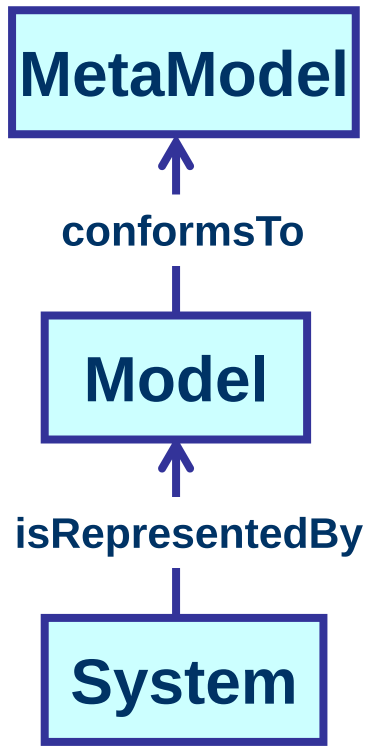
A “lattice” of meta-models



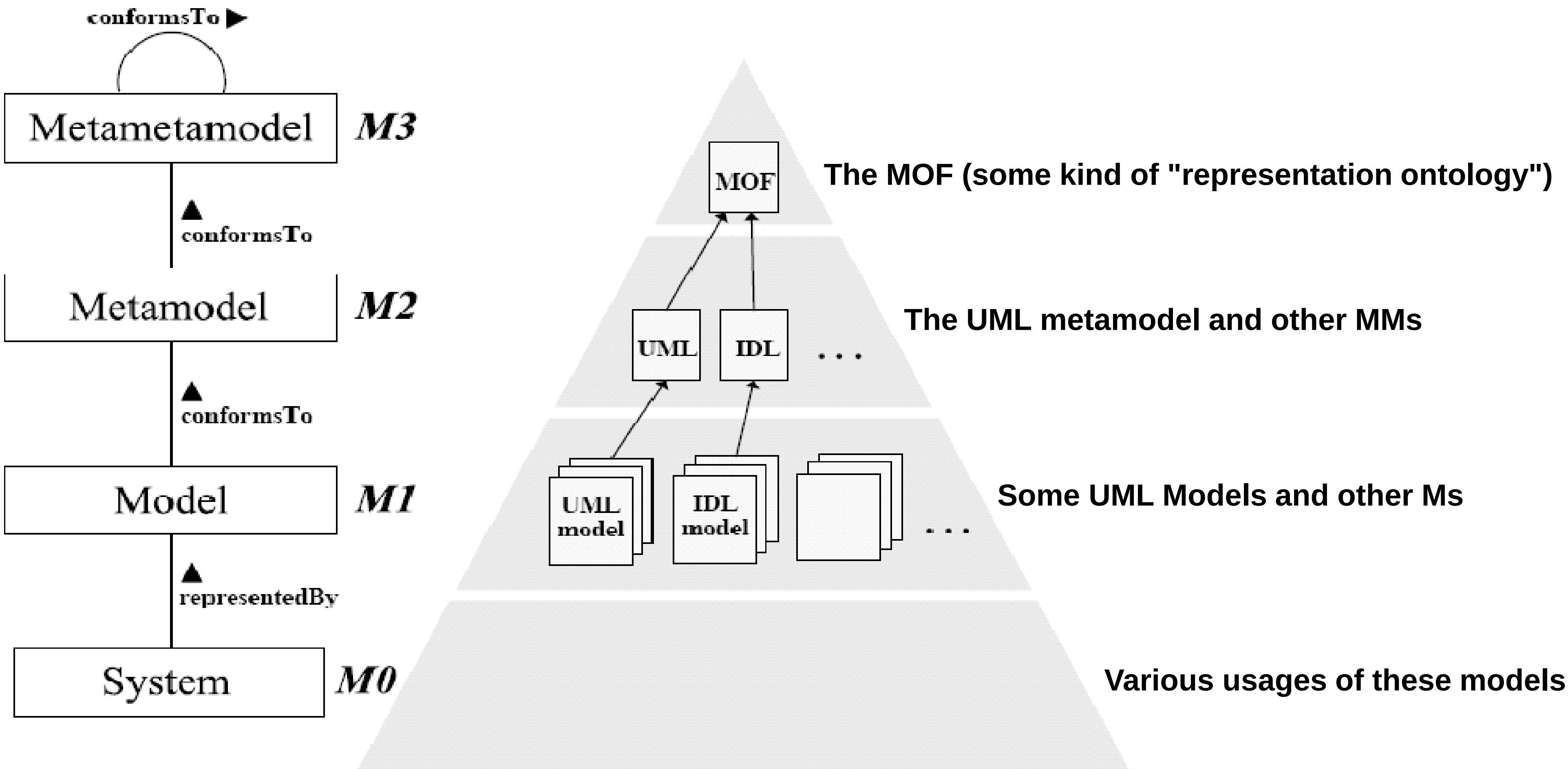
A collection of several hundreds of small meta-models (DSLs) with high abstraction power.

The basic assumptions of MDE and MDSD

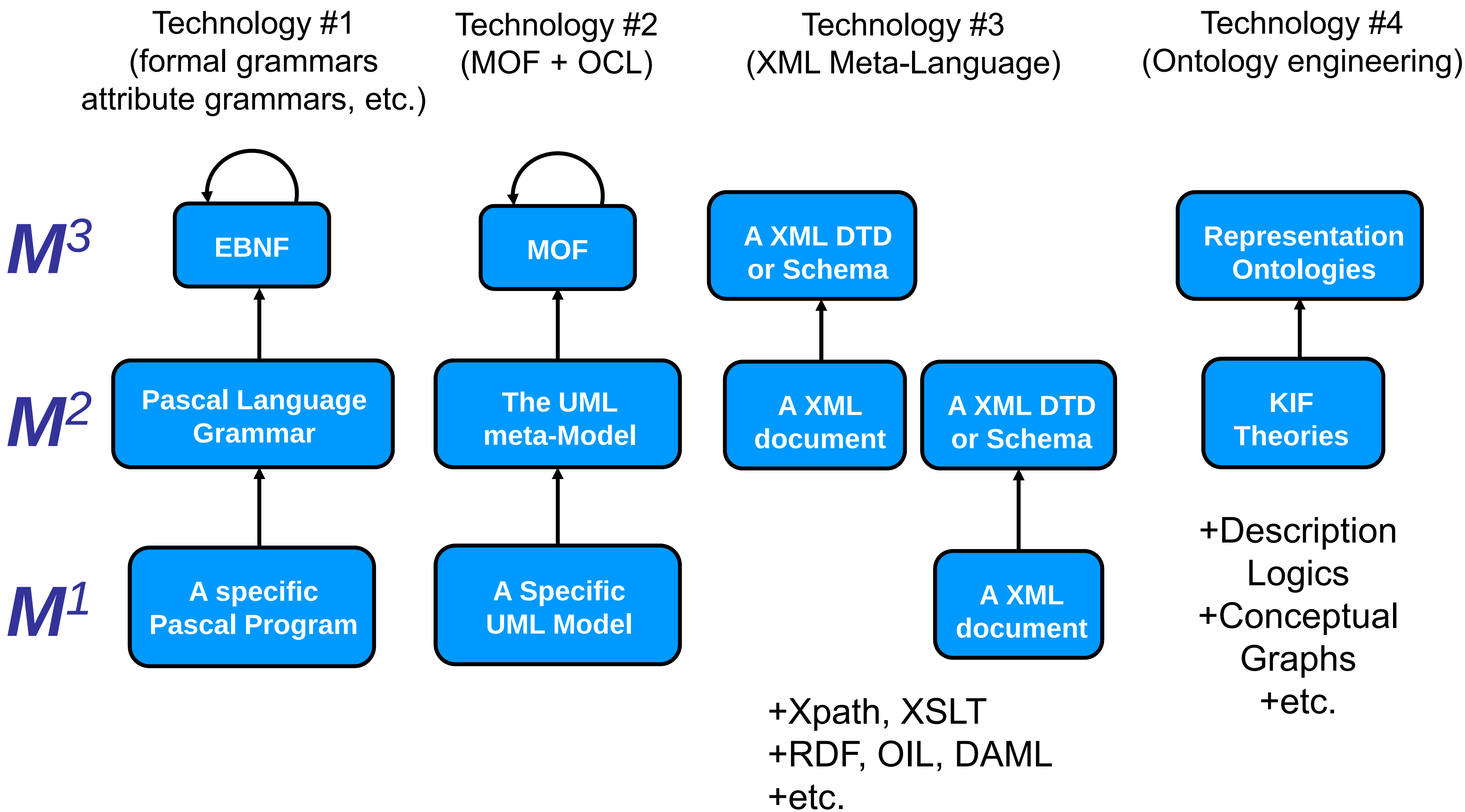
- Models as first class entities
- ***Conformance*** and ***Representation*** as kernel relations central to MDE
  - MDSD as a special case of MDE



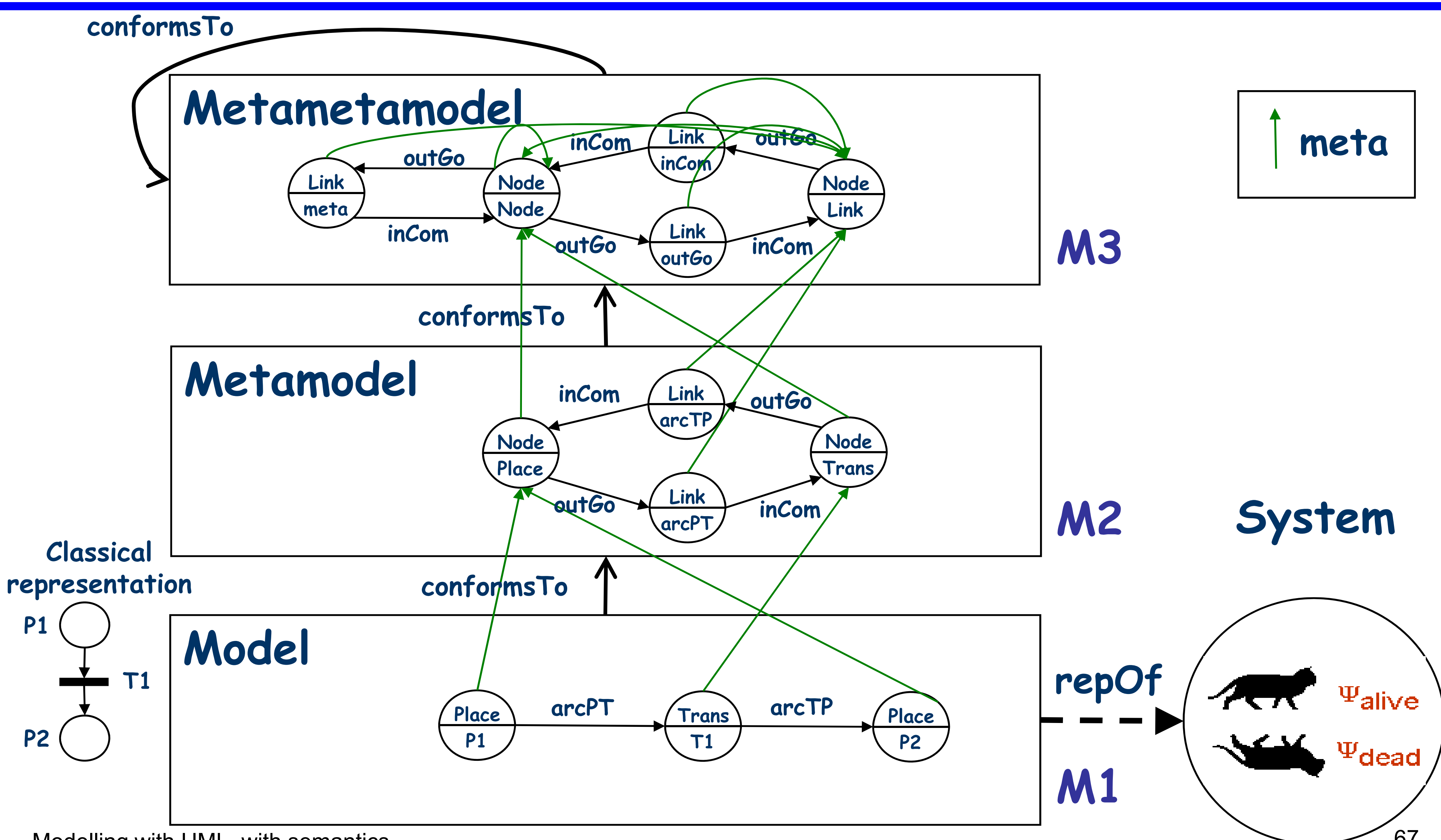
Meta-modelling hierarchy or the meta-modelling stack

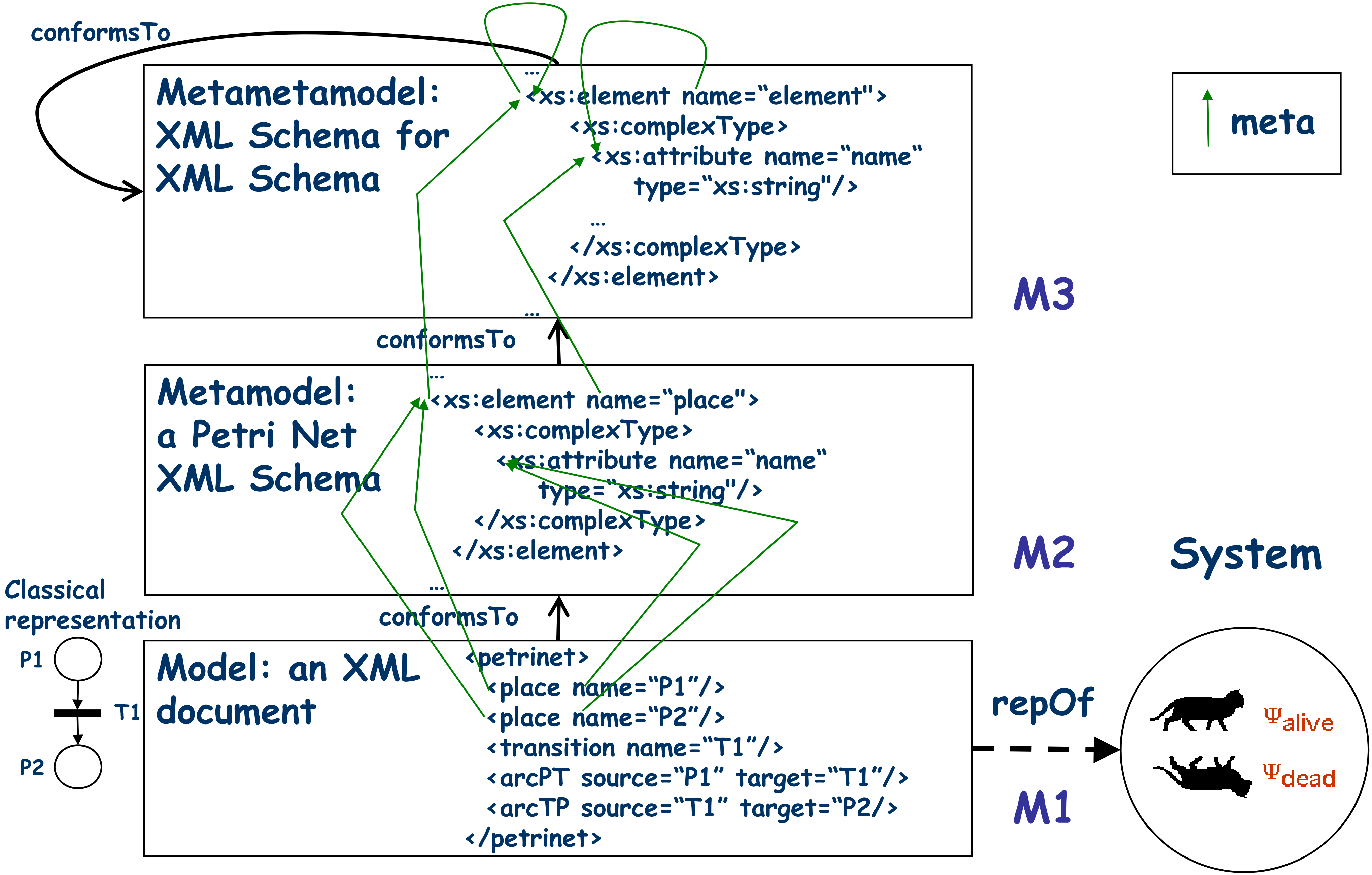


Abstract Syntax Systems Compared



Three-level hierarchy: Example — Petri-nets




conformsTo
Metametamodel:
XML Schema for
XML Schema
…
<xs:element name="element">
<xs:complexType>
<xs:attribute name="name"
type="xs:string"/>
…
</xs:complexType>
</xs:element>
…
meta
M3
conformsTo
Metamodel:
a Petri Net
XML Schema
…
<xs:element name="place">
<xs:complexType>
<xs:attribute name="name"
type="xs:string"/>
</xs:complexType>
</xs:element>
…
M2
System
Classical
representation
P1
T1
P2
conformsTo
Model: an XML
document
<petrinet>
<place name="P1"/>
<place name="P2"/>
<transition name="T1"/>
<arcPT source="P1" target="T1"/>
<arcTP source="T1" target="P2/>
</petrinet>
repOf
M1
Ψalive
Ψdead

conformsTo

Metametamodel: EBNF grammar of EBNF

```
productionRule := IDENT ":=" seq ";";
seq := alternative seq?;
alternative := rep ("|"alternative)?;
rep := atom ("?" | "*")?;
atom := terminal | "(" seq ")";
terminal := STRING | IDENT;
```

M3

meta

conformsTo

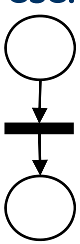
Metamodel: a Petri Net Grammar

```
petrinet := "petrinet" "{"
            place* transition*
            arcPT* arcTP* "}";
place := "place" IDENT ";";
transition := "transition" IDENT ";";
arcPT := "arcPT" IDENT "->" IDENT;
arcTP := "arcTP" IDENT "->" IDENT;
```

M2

System

Classical representation



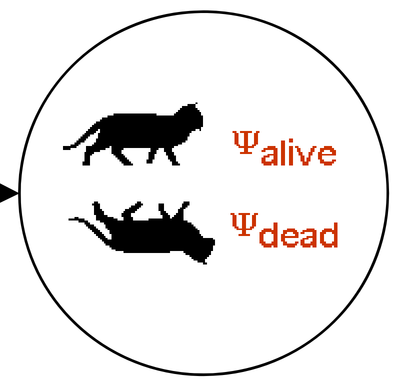
conformsTo

Model: a string

```
petrinet {
  place P1;
  place P2;
  transition T1;
  arcPT P1 -> T1;
  arcTP T1 -> P2;
}
```

repOf

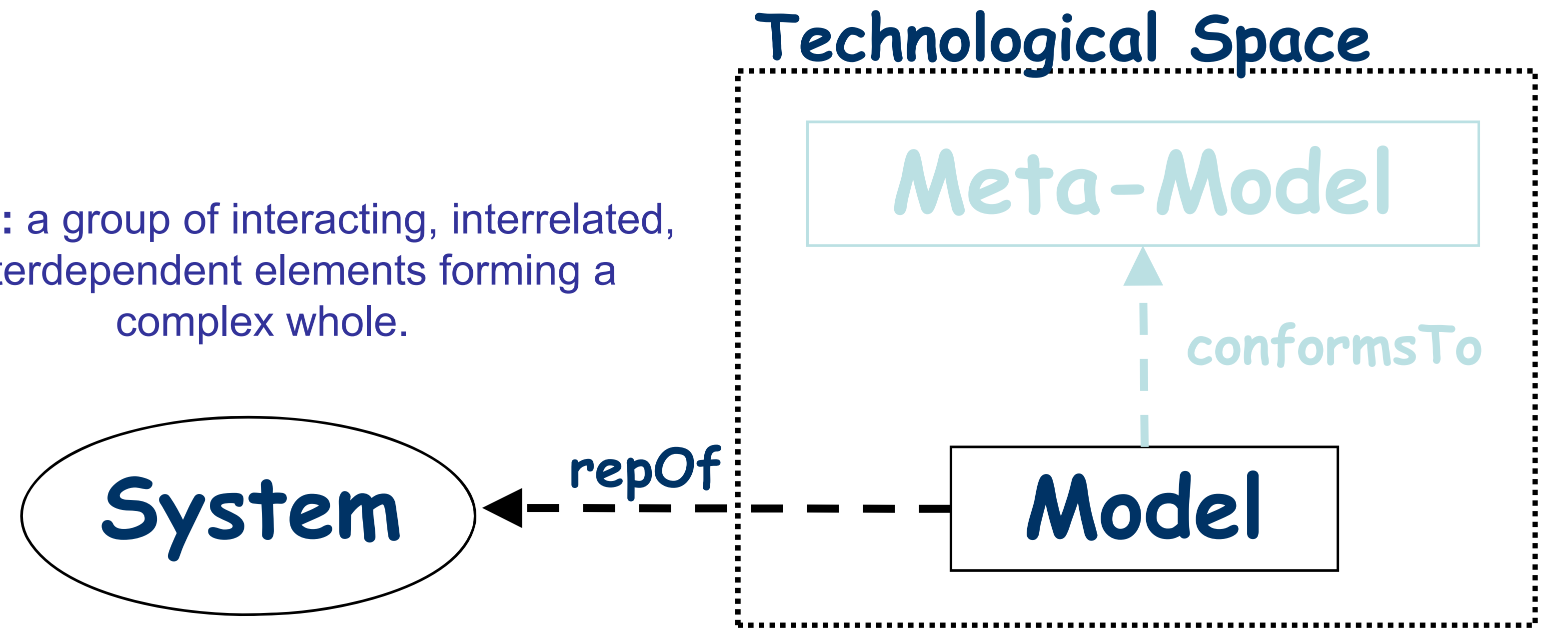
M1



Basic entities of MDE and MDSD

***Technological Space*: a model management framework usually based on some algebraic structures (trees, graphs, hypergraphs, etc.).**

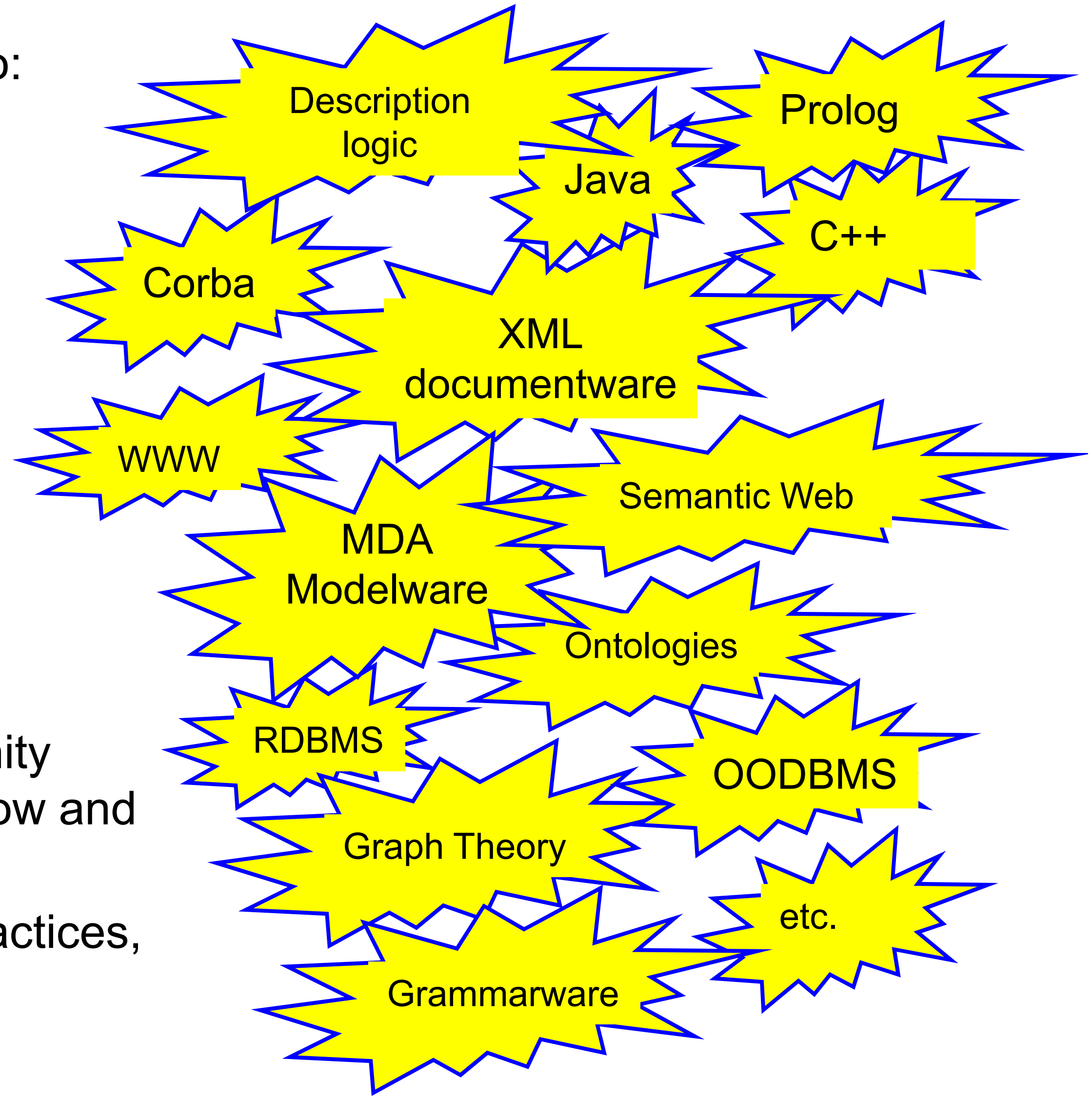
***System*: a group of interacting, interrelated, or interdependent elements forming a complex whole.**



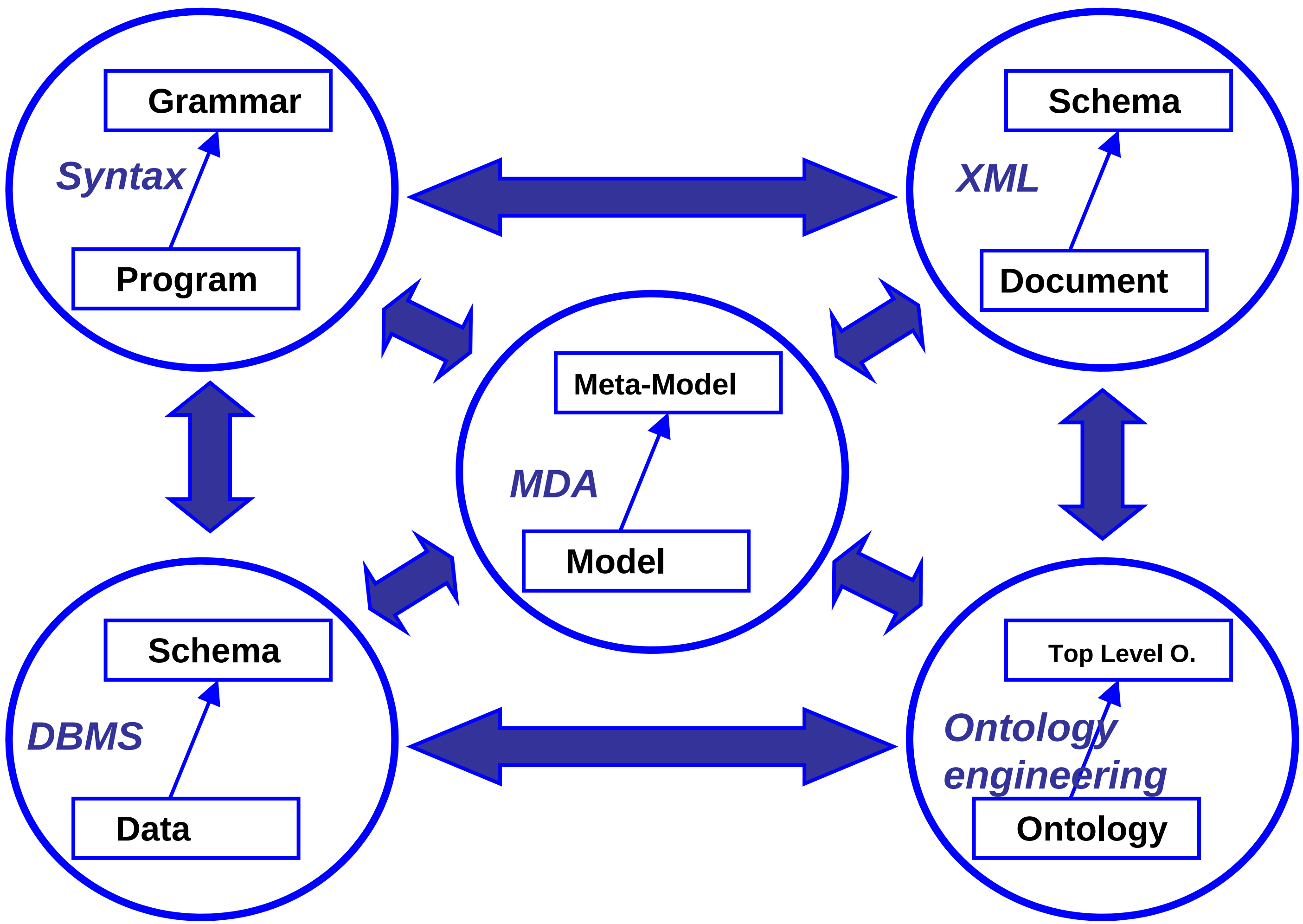
***Model*: an abstract representation of a system created for a specific purpose.**

The notion of Technological Space (TS)

- A Technological Space corresponds to:
  - A **uniform representation system**
    - Syntactic trees
    - XML trees
    - Sowa graphs
    - UML graphs
    - MOF graphs
  - A **working context**
  - A **set of concepts**
  - A **set of methods**
  - A **shared knowledge and know-how**
  - etc.
- It is usually related to a given community with an established expertise, know-how and research problems.
- It has a set of associated tools and practices, etc.
  - Protégé, Rational Rose, …



Main Technological Spaces

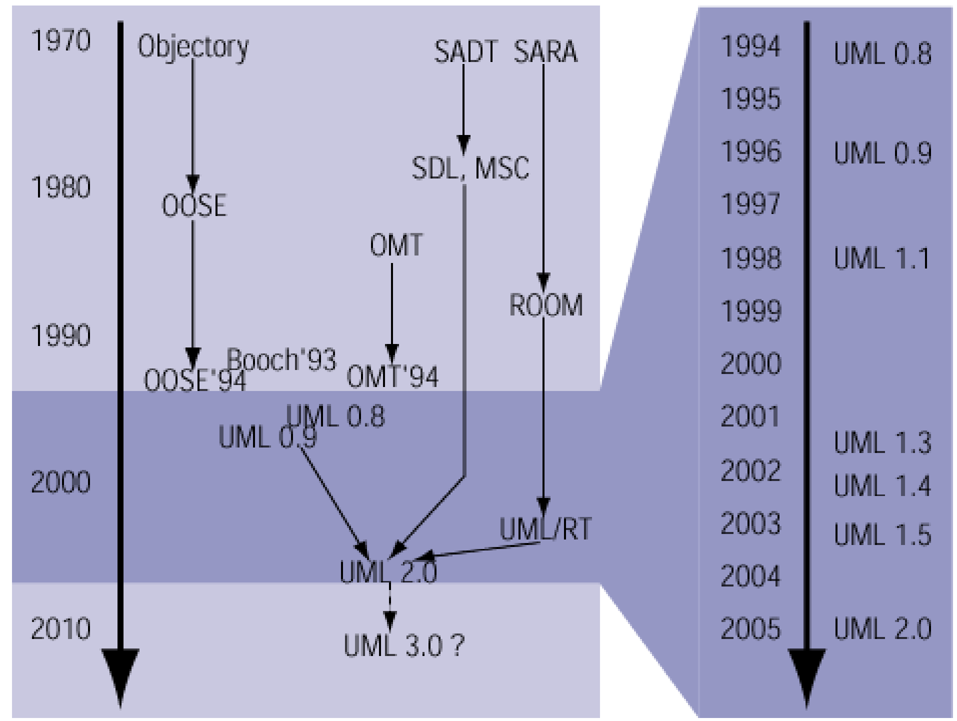


TS's may be connected via **bridges**

Unified Modeling Language 2

History and Predecessors

- The UML is the "lingua franca" of software engineering.
- It subsumes, integrates and consolidates most predecessors.
- Through the network effect, UML has a much broader spread and much better support (tools, books, trainings etc.) than other notations.
- The transition from UML 1.x to UML 2.0 has
  - resolved a great number of issues;
  - introduced many new concepts and notations (often feebly defined);
  - overhauled and improved the internal structure completely.
- While UML 2 still has many problems, it is much better than what we ever had before.

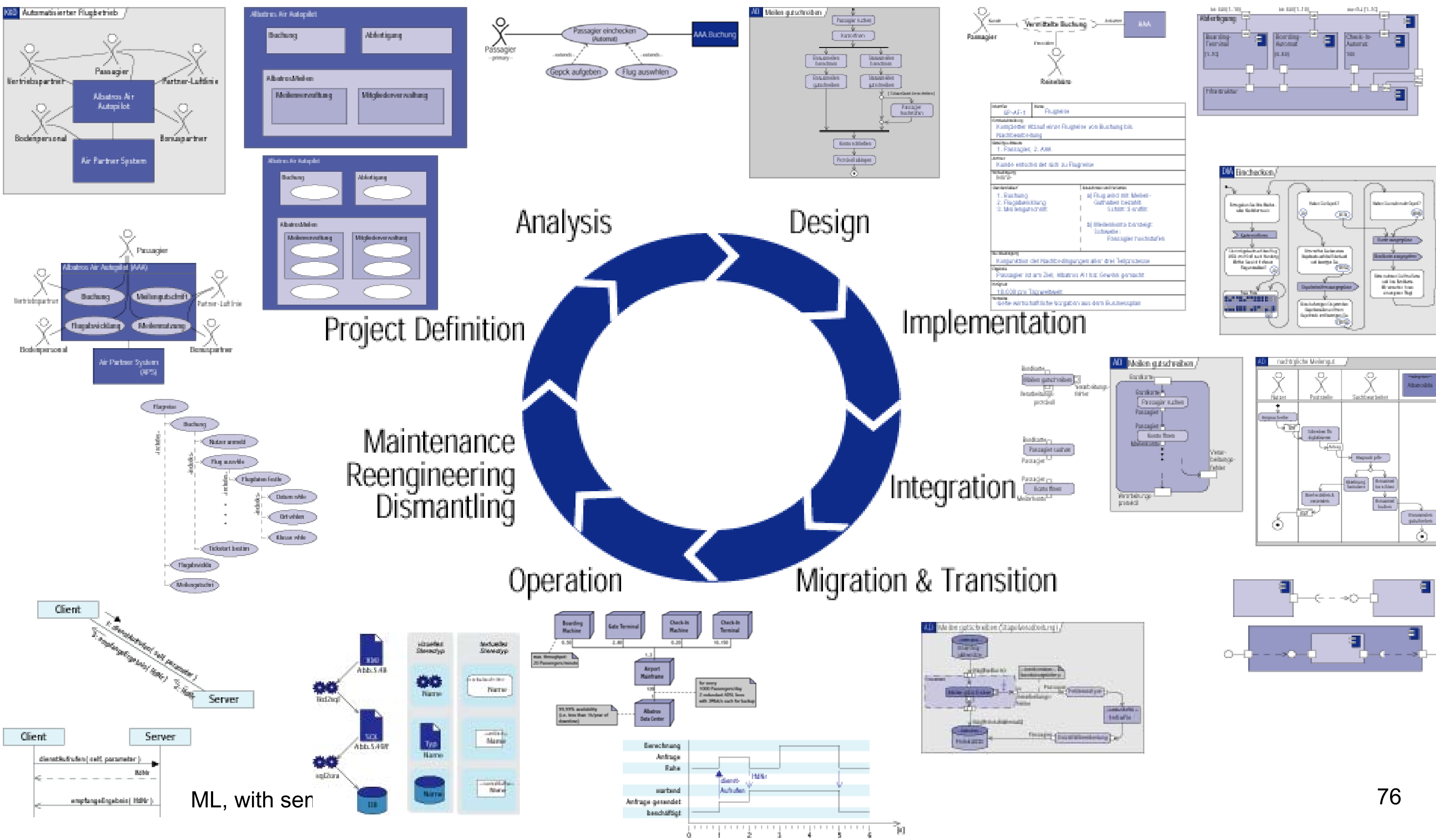


current version ("the standard") UML 2.4.1
formal/2011-08-06 of August '11

Usage Scenarios

- UML has not been designed for specific, limited usages.
- There is currently no consensus on the rôle of the UML:
  - Some see UML only as tool for sketching class diagrams representing Java programs.
  - Some believe that UML is “*the prototype of the next generation of programming languages*”.
- UML is a really a system of languages (“notations”, “diagram types”) each of which may be used in a number of different situations.
- UML is applicable for a multitude of purposes and during all phases of the software lifecycle – to varying degrees.

Usage Scenarios



ML, with ser

Diagram types in UML 2

UML is a coherent system of languages rather than a single language.
Each language has its particular focus.

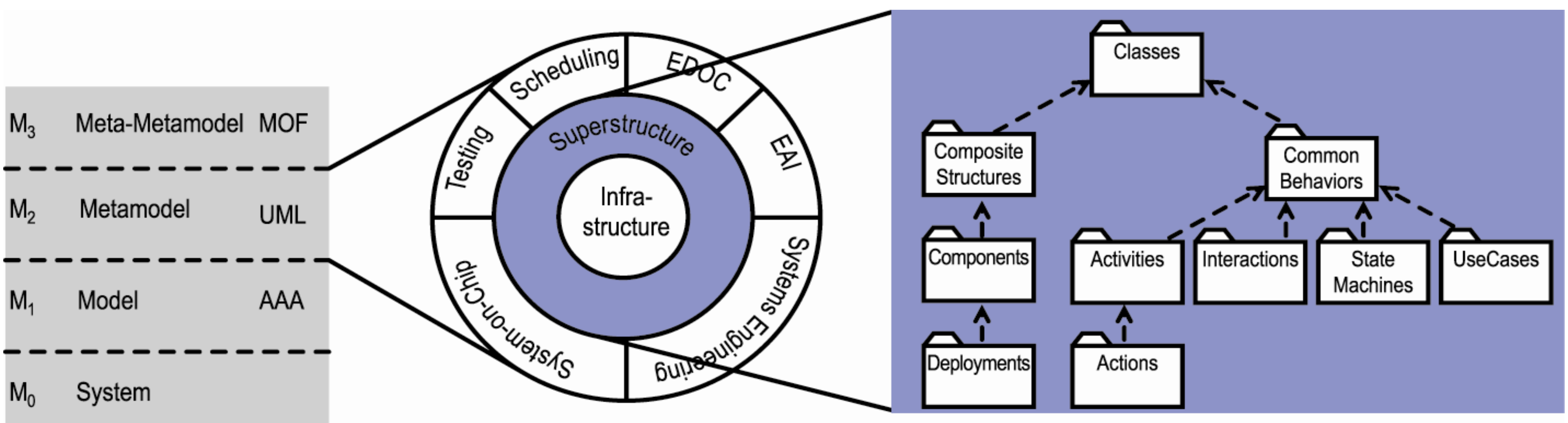
Structure		Class Diagram		static structure (generic/snapshot)
		Composite Structure Diagram		logical system structure
		Component Diagram		physical system structure
		Deployment Diagram		computing infrastructure / deployment
		Package Diagram		containment hierarchy
Behavior		Use Case Diagram		abstract functionality
		Activity Diagram		controlflow and dataflow
	Interaction	Sequence Diagram	interactions by message exchange	message exchange over time
		Communication Diagram		structure of interacting elements
		Timing Diagram		coordinated state change over time
		Interaction Overview Diagram		flows of interactions
		State Machine Diagram		event-triggered state change

Internal Structure: Overview

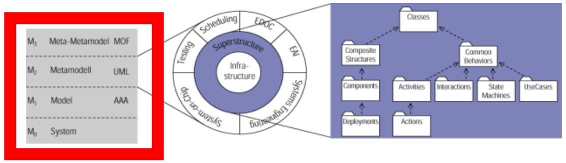
- The UML is structured using a metamodeling approach with four *layers*.
- The M_2-layer is called metamodel.

- The metamodel is again structured into *rings*, one of which is called superstructure, this is the place where concepts are defined (“the metamodel” proper).

- The Superstructure is structured into a tree of *packages* in turn.

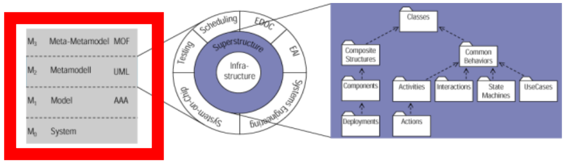


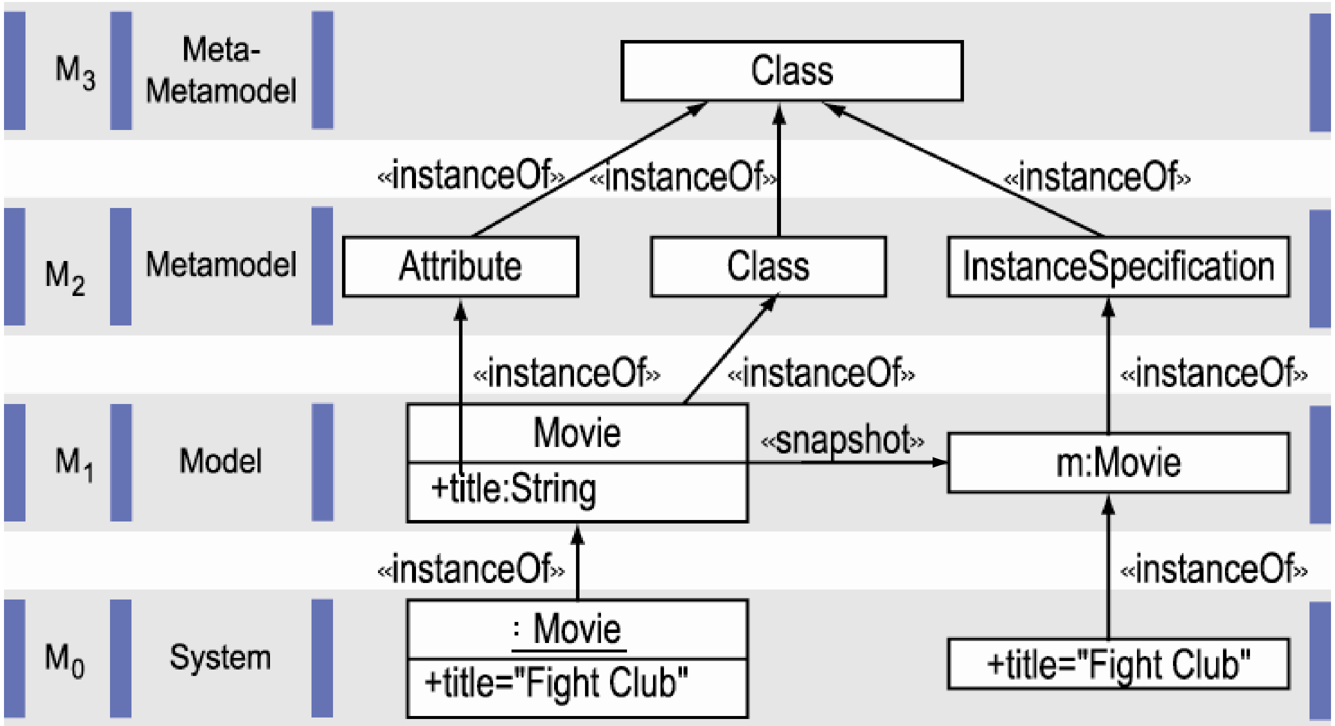
Internal Structure: Layers



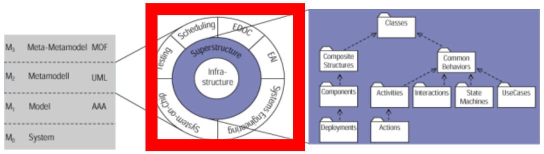
M_3	Meta-Metamodel	EBNF	Meta Object Facility (MOF)
M_2	Metamodel	Java grammar	Unified Modeling Language (UML) Common Warehouse Metamodel (CWM)
M_1	Model	a Java program	Albatros Air Autopilot
M_0	System	an execution of a Java program	a runtime state in a deployment of Albatros Air Autopilot

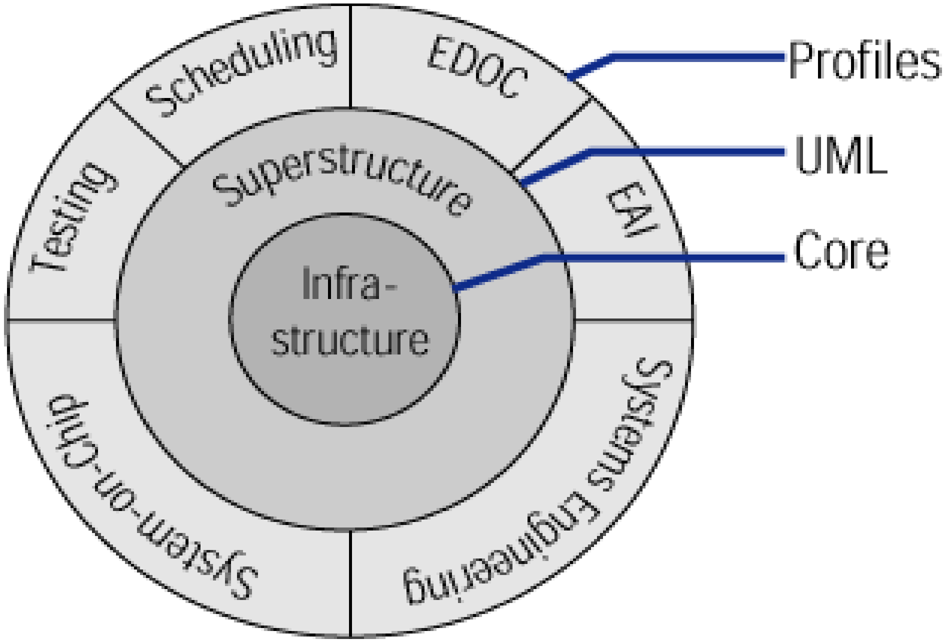
Internal Structure: Layers



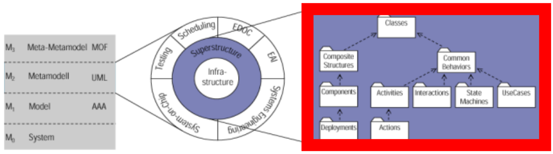


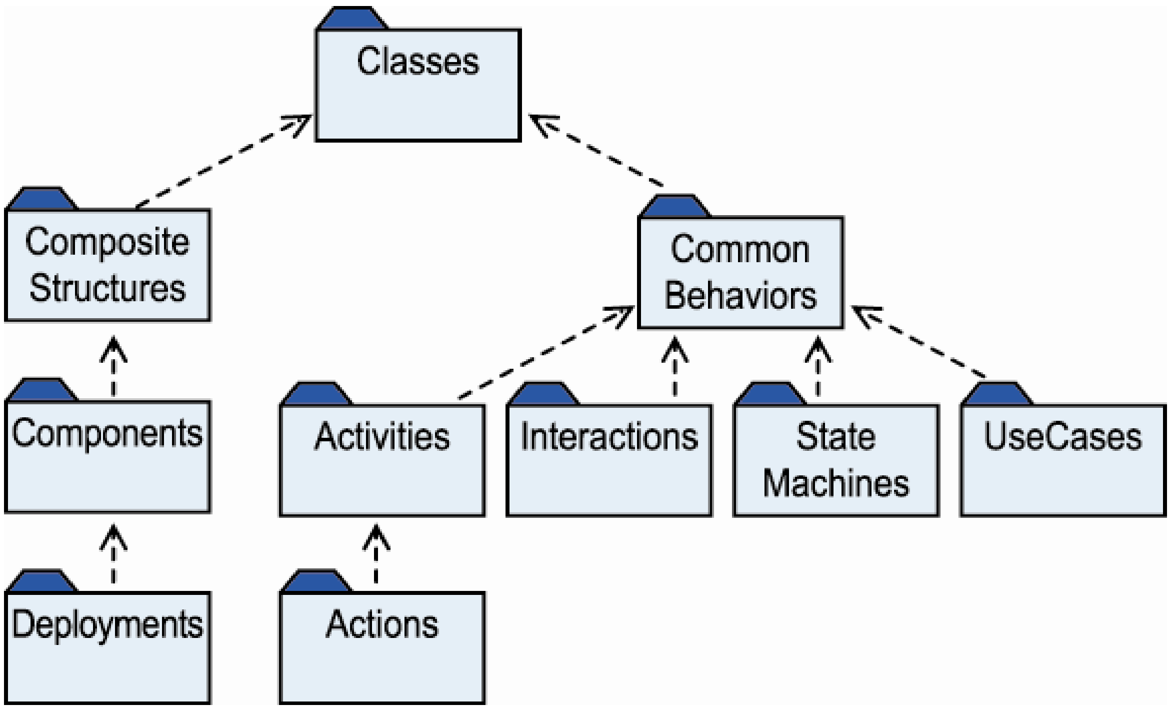
Internal Structure: Rings





Internal Structure: Packages





UML is not (only) object oriented

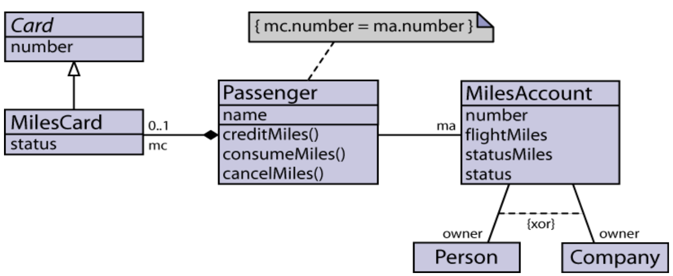
- A popular misconception about UML is that it is “object oriented” by heart – whatever that means.

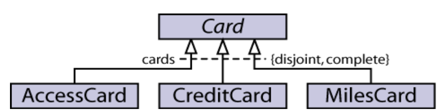
- It is true that
  - UML defines concepts like class and generalization;
  - UML is defined using (mainly) a set of class models;
  - UML 2 rediscovers the idea of behaviour embodied in objects.

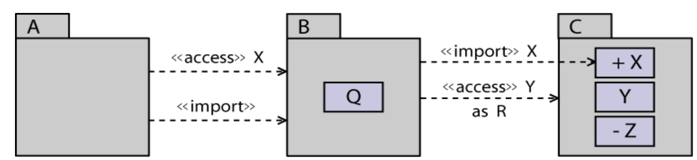
- However, UML 2
  - also encompasses many other concepts of non- or pre-OO origin (Activities, StateMachines, Interactions, CompositeStructure, …);
  - may be used in development projects completely independent of their implementation languages (Java, Cobol, Assembler, …);
  - is not tied to any language or language paradigm, neither by accident nor purpose.

Unified Modeling Language 2

Classes and packages







History and predecessors

- **Structured analysis and design**
  - Entity-Relationship (ER) diagrams (Chen 1976)
- **Semantic nets**
  - Conceptual structures in AI (Sowa 1984)
- **Object-oriented analysis and design**
  - Shlaer/Mellor (1988)
  - Coad/Yourdon (1990)
  - Wirfs-Brock/Wilkerson/Wiener (1990)
  - OMT (Rumbaugh 1991)
  - Booch (1991)
  - OOSE (Jacobson 1992)

Usage scenarios

- Classes and their relationships describe the vocabulary of a system.
  - **Analysis**: Ontology, taxonomy, data dictionary, …
  - **Design**: Static structure, patterns, …
  - **Implementation**: Code containers, database tables, …

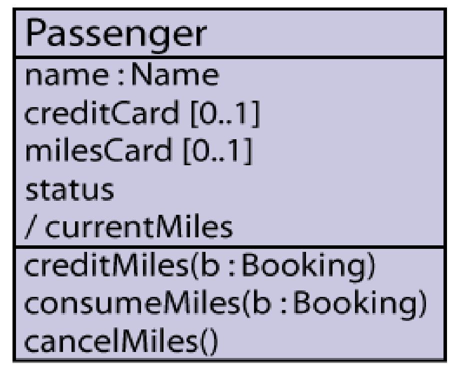
- Classes may be used with different meaning in different software development phases.
  - meaning of generalizations varies with meaning of classes

	Analysis	Design	Implementation
Concept	√		×
Type		√	√
Set of objects		√	√
Code	×		√

Classes

- Classes describe a set of instances with common features (and semantics).
  - Classes induce types (representing a set of values).
  - Classes are namespaces (containing named elements).

- **Structural features** (are typed elements)
  - properties
    - commonly known as attributes
    - describe the structure or state of class instances
    - may have multiplicities (e.g. **1, 0..1, 0..*, *, 2..5**)

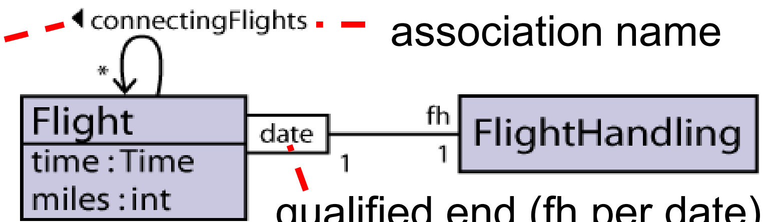


- **Behavioral features** (have formal parameters)
  - operations
    - services which may be called
    - need not be backed by a method, but may be implemented otherwise

Associations

- **Associations** describe sets of tuples whose values refer to typed instances.
  - In particular, structural relationship between classes
  - Instances of associations are called links.

reading direction



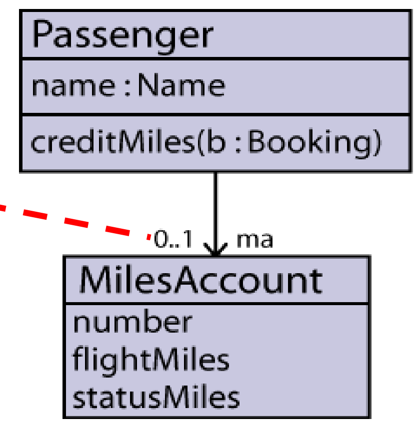
association name

qualified end (fh per date)

ternary association

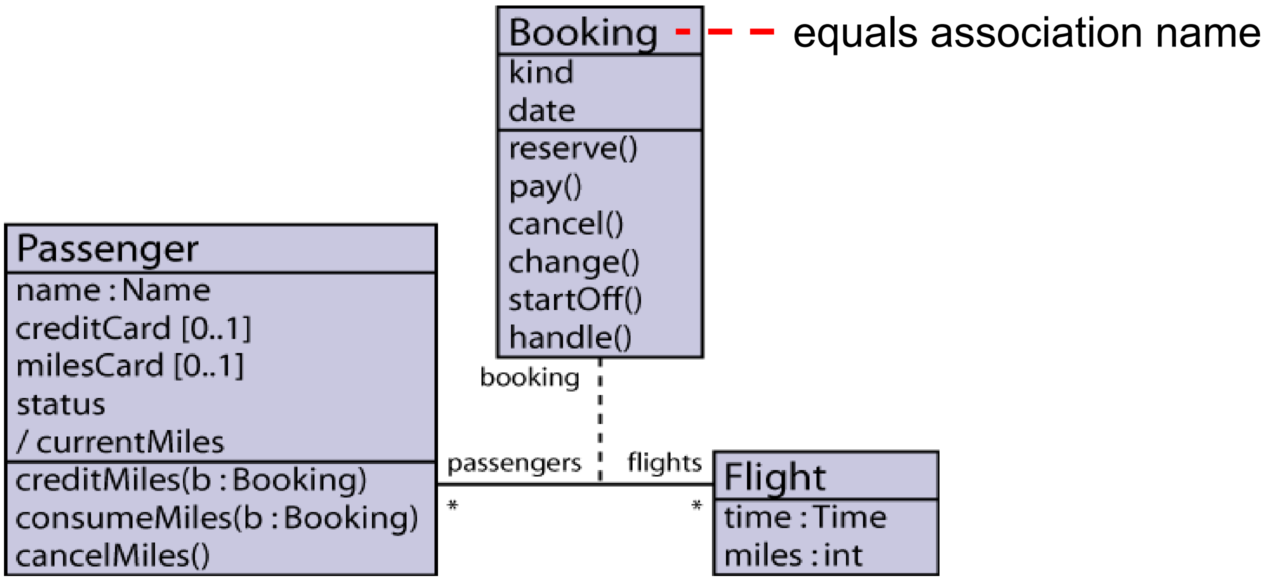
- **Association ends** are properties.
  - correspond to properties of the opposite class (default multiplicity is 0..1)
- Association ends may be navigable.
  - in contrast to general properties

navigable not navigable
association end



Association classes

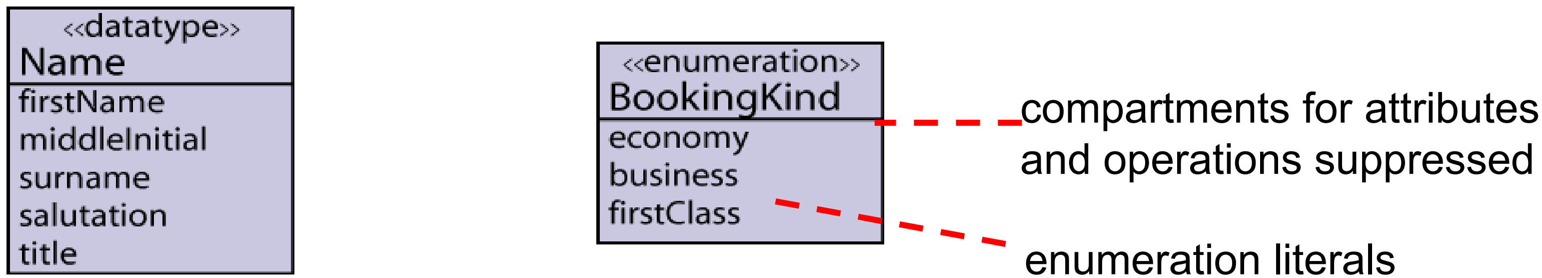
- **Association classes** combine classes with associations.
  - not only connect a set of classifiers but also define a set of features that belong to the relationship itself and not to any of the classifiers



- each instance of Booking has one passenger and one flight
- each link of Booking is one instance of Booking

Data types and enumerations

- **Data types** are types whose instances are identified by their value.
  - Instances of classes have an identity.
  - may show structural and behavioural features

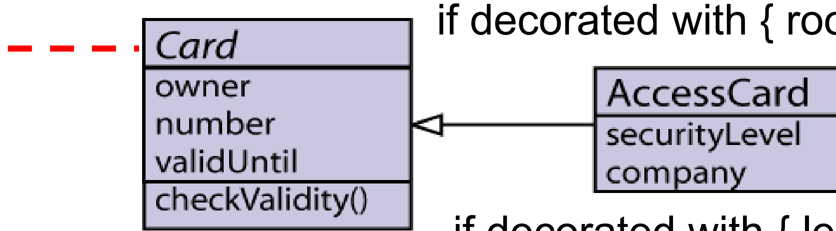


- **Enumerations** are special data types.
  - instances defined by enumeration literals
    - denoted by *Enumeration*::*EnumerationLiteral* or *#EnumerationLiteral*
  - may show structural and behavioural features

Inheritance (1)

- **Generalizations** relate specific classes to more general classes.
  - instances of specific class also instances of the general class
  - features of general class also implicitly specified for specific class

{ abstract } class (no direct instances, only specializations may have instances)

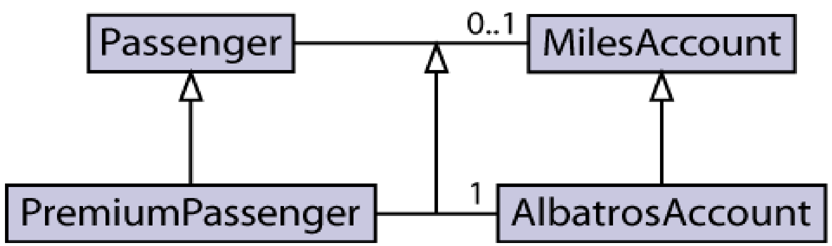


if decorated with { root }: no superclass

if decorated with { leaf }: no subclass

  - implies substitutability (in the sense of Liskov & Wing)
    - must be specified on specific class separately by { substitutable }

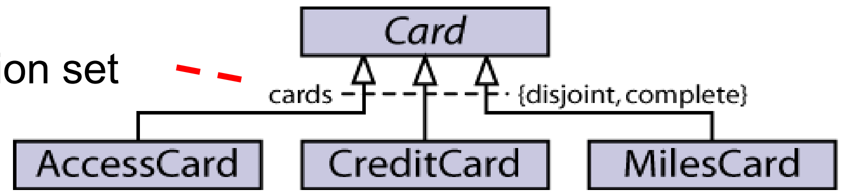
- Generalizations also apply to associations.
  - as both are Classifiers



Inheritance (2)

- **Generalization sets** detail the relation between a general and more specific classifiers.
  - { complete }   (opposite: { incomplete })
    - all instances of general classifier are instances of one of the specific classifiers in the generalization set
  - { disjoint }   (opposite: { overlapping })
    - no instance of general classifier belongs to more than one specific classifier in the generalization set
  - default: { disjoint, incomplete }

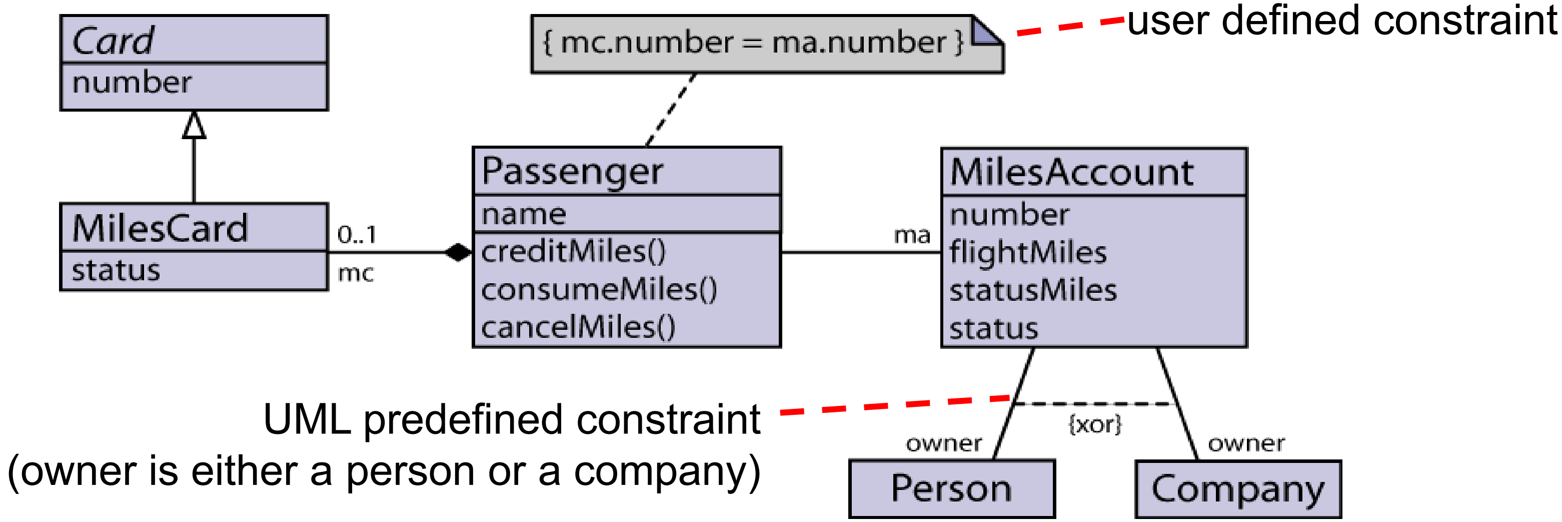
name of generalization set



  - several generalization sets may be applied to a classifier
    - useful for taxonomies

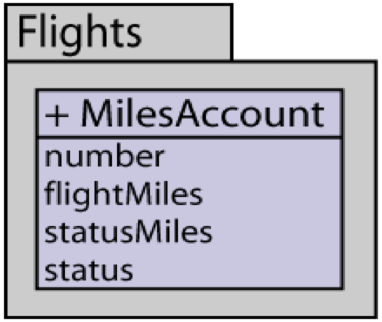
Constraints

- **Constraints** restrict the semantics of model elements.
  - constraints may apply to one or more elements
  - no prescribed language
    - OCL is used in the UML 2 specification
    - also natural language may be used

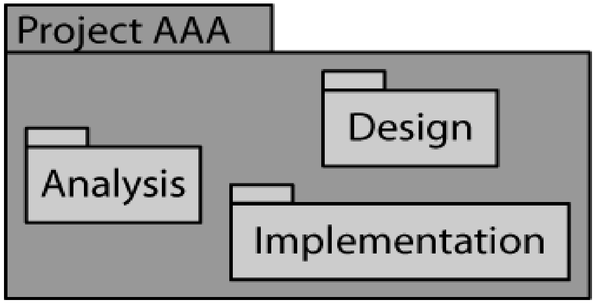


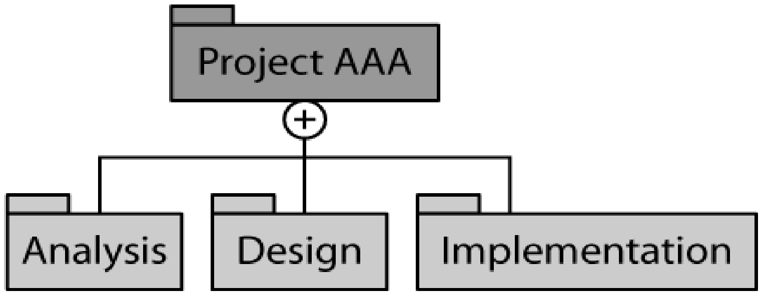
Packages (1)

- **Packages** group elements.
  - Packages provide a **namespace** for its grouped elements.
  - Elements in a package may be
    - public (+, visible from outside; default)
    - private (-, not visible from outside)
  - Access to public elements by qualified names
    - e.g., Flights::MilesAccount



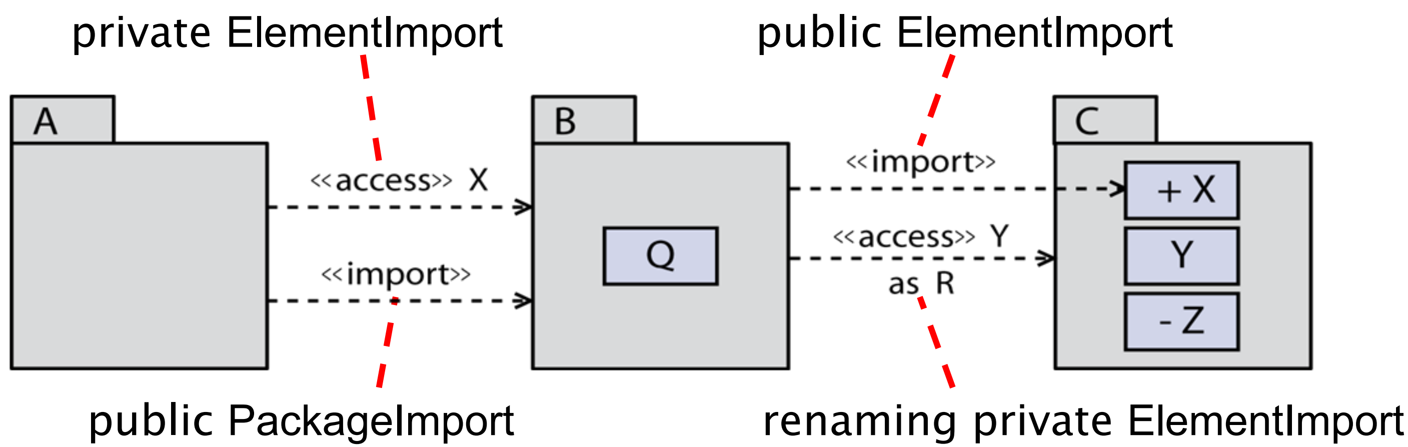
Notational variants





Packages (2)

- **Package imports** simplify qualified names.

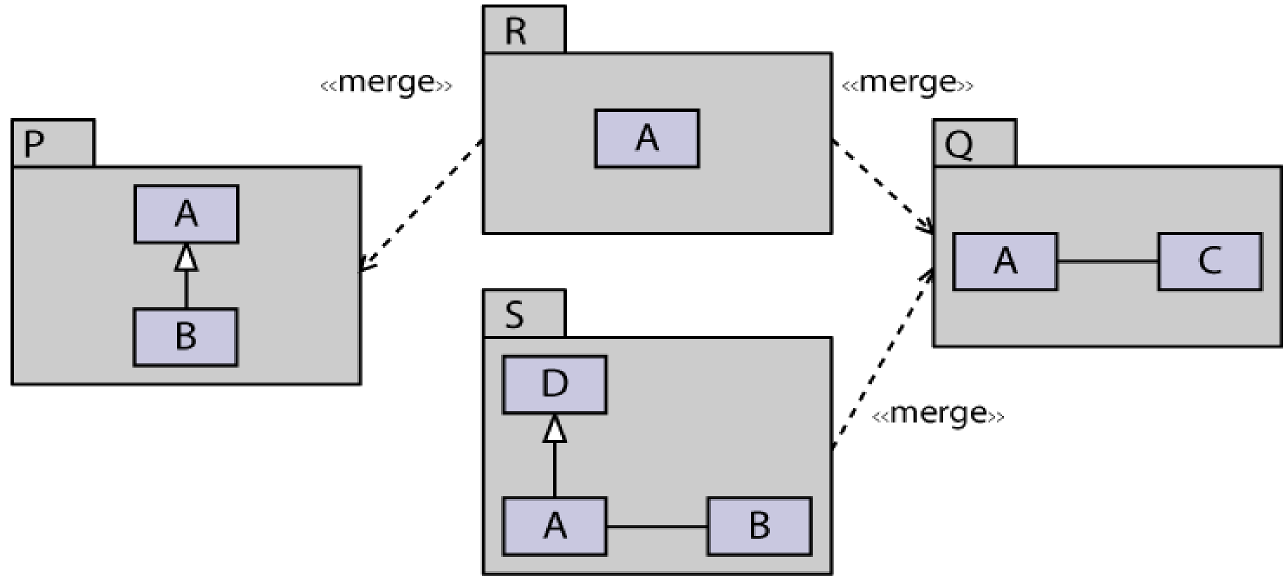


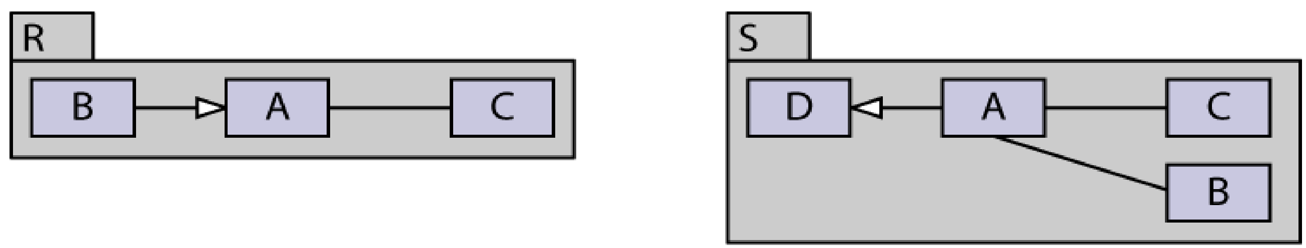
Package	Element	Visibility	
A	X	private	separate private element import (otherwise public overrides private)
A	Q	public	all remaining visible elements of B
B	X	public	public import
B	Q	public	default visibility
B	R	private	private import, renaming

Packages (3)

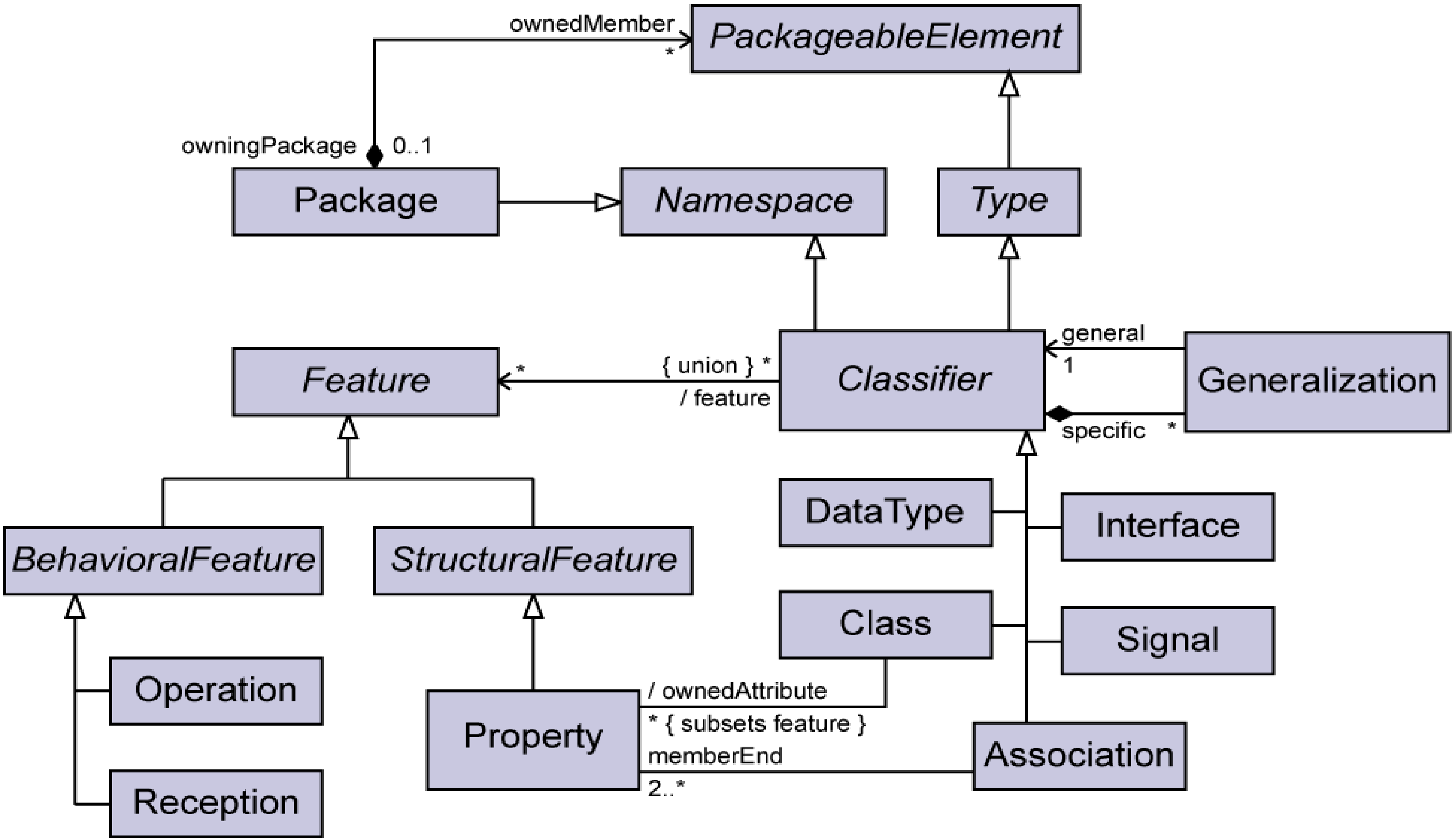
- **Package mergings** combine concepts incrementally.
  - … but use with care

- The receiving package defines the increment.
- The receiving package is simultaneously the resulting package.
- Merging is achieved by (lengthy) transformation rules (not defined for behaviour).
- Package merging is used extensively in the UML 2 specification.





Metamodel



ownedMember
*
PackageableElement
owningPackage
0..1
Package
Namespace
Type
general
1
Feature
*
{ union } *
/ feature
Classifier
Generalization
specific
*
BehavioralFeature
StructuralFeature
DataType
Interface
Class
Signal
Operation
Property
/ ownedAttribute
* { subsets feature }
memberEnd
2..*
Association
Reception