The Role of Foundational Ontologies in Deep Modeling

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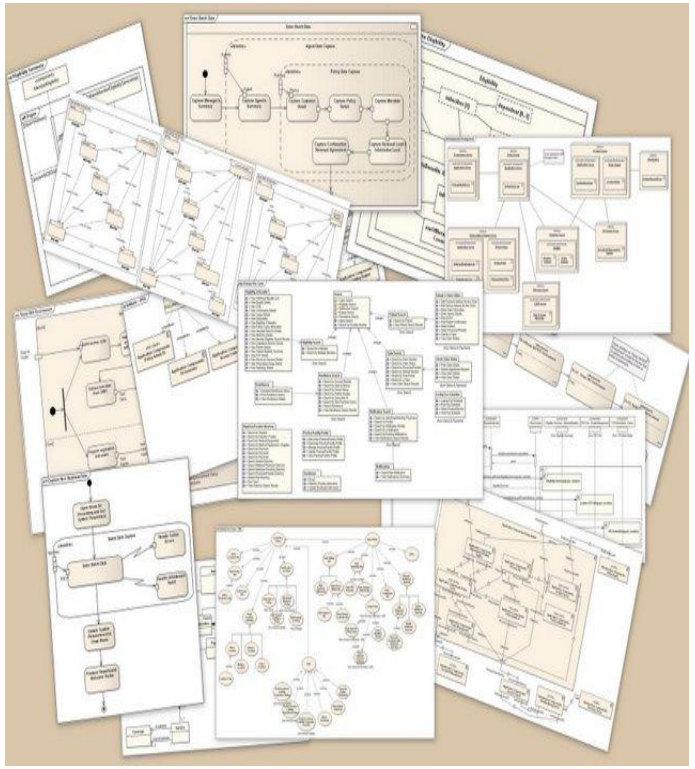
Modeling Everywhere ...

- Modeling is a now key activity in virtually all IT projects
  - today is performed in may different languages

- General-purpose structural languages
  - UML, OWL, ERA, RDF ...
- General-purpose behavioural languages
  - UML activity diagrams, Petri nets, ...
- Associated textual languages
  - OCL, ATL, QVT, Xtext
- Domain specific language
  - ……



Wikipedia 2012

Basic Tension in Language Design

- Since models are used to communicate properties of the real world between humans they should be able to -
  - accurately and unambiguously represent the real world (representational adequacy [GGO5])
  - at any desired level of detail
  - in the simplest and most concise way possible (lucidity, ontological clarity, construct redundancy [GGO5])
- There is a basic tension between expressive power and simplicity
  - rich, expressive languages often complex and verbose
  - simple, concise languages often lack expressive power
- Related to the question
  - General-purpose versus domain specific?

UML 1.x Four Layer Model Architecture

Layer	Description	Example	
meta-metamodel	The infrastructure for a metamodeling architecture. Defines the language for specifying metamodels.	*MetaClass, MetaAttribute, MetaOperation*	M_3
metamodel	An instance of a meta-metamodel. Defines the language for specifying a model.	*Class, Attribute, Operation, Component*	M_2
model	An instance of a metamodel. Defines a language to describe an information domain.	*StockShare, askPrice, sellLimitOrder, StockQuoteServer*	M_1
user objects (user data)	An instance of a model. Defines a specific information domain.	*<Acme_Software_Share_98789>, 654.56, sell_limit_order, <Stock_Quote_Svr_32123>*	M_0

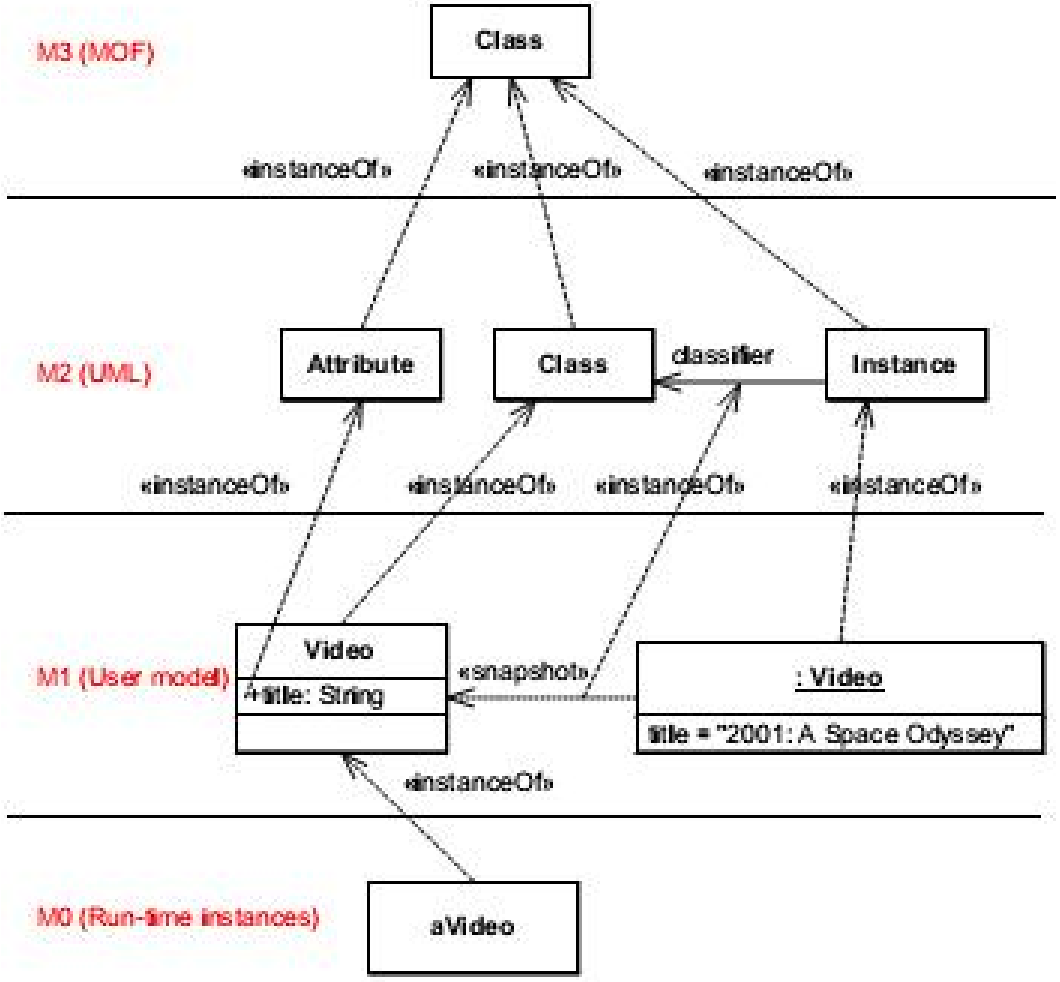
(from UML Semantics Version 1.1)

Strict Metamodeling (Classic Definition)

In an n-level modeling architecture, M_0, M_1 ... M_{n-1}, every element of an M_m level model must be an instance-of exactly one element of an M_{m+1} level model, for all m<n-1 and any relationship other than the instance-of relationship between two elements X and Y implies that level(X)=level(Y).

- every element has exactly one type, except those elements in the top level
- instance-of relationship used to define levels
- model elements allocated to levels according to their location in the type hierarchy

UML 2.x Infrastructure

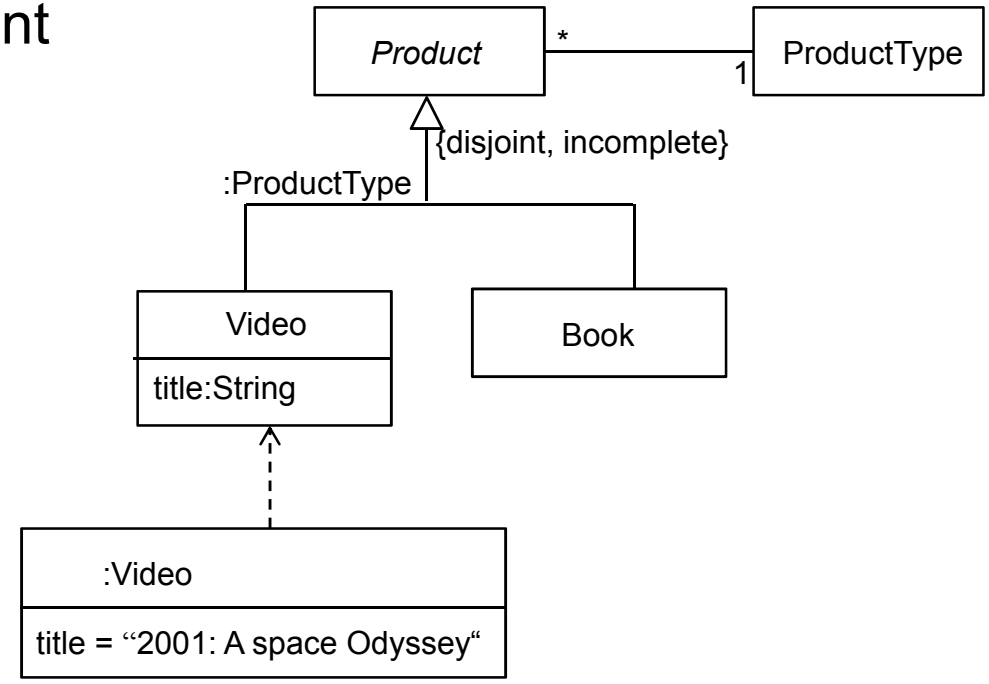


(from UML Infrastructure Specification v2.4.1)

- M_0 level contains the real-world elements (the subject of the model)
- M_1 level contains model representation of types and instances
- M_2 level contains linguistic types of the M_1 elements
- M_3 level contains the linguistic types of the M_2 level concepts

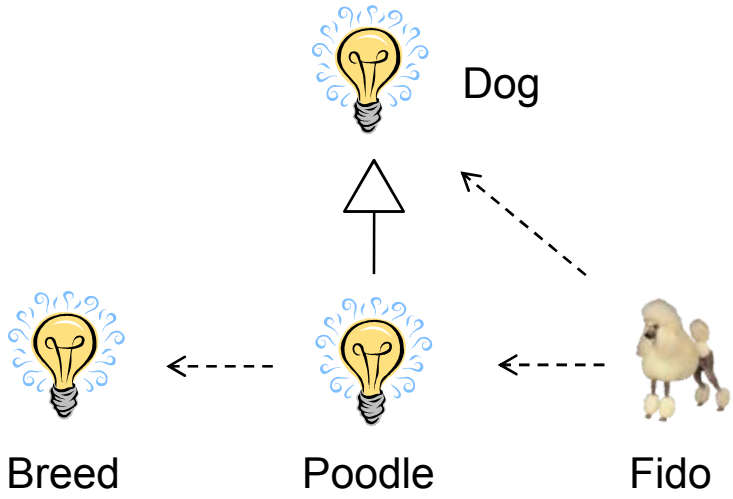
The Powertype Problem

- X is a power type of Y, if the instances of X are subclasses of Y
  - power types are classes whose instances are also subclasses
- therefore, according to the strict modeling tenet, powertypes must be at the M2 level
  - but they are represent domain concepts
  - the *isPowerTypeOf* relationship crosses level boundaries
- occur very frequently in practice



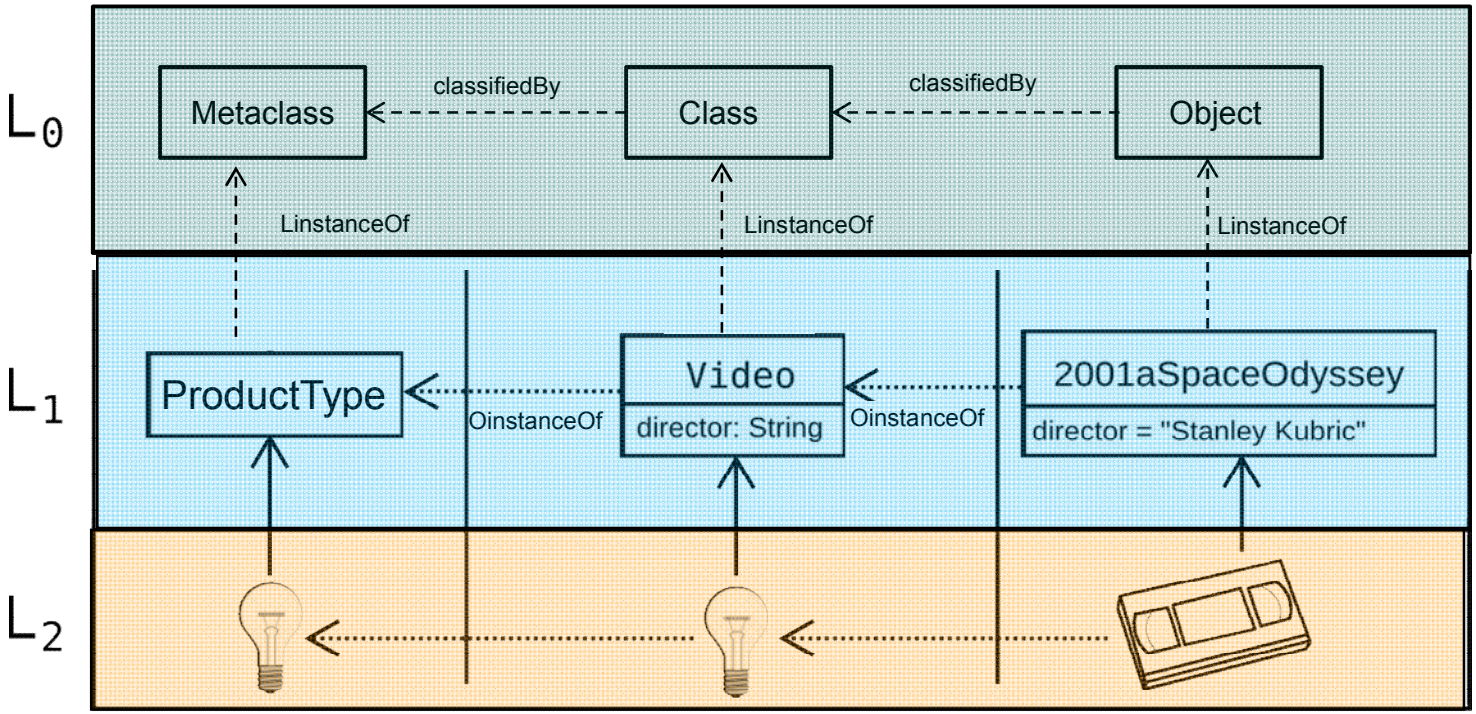
Deep Characterization

- usually a type only describes its instances
  - e.g., every dog has an age
- sometimes, however, a type needs to define constraints on the properties of the instances of its instances
  - e.g. every instance, of a breed instance, has an age
- such transitive influences cannot be directly expressed using traditional instanceOf relationships
- with UML must resort to -
  - constraints
  - powertypes
  - stereotypes
  - …..



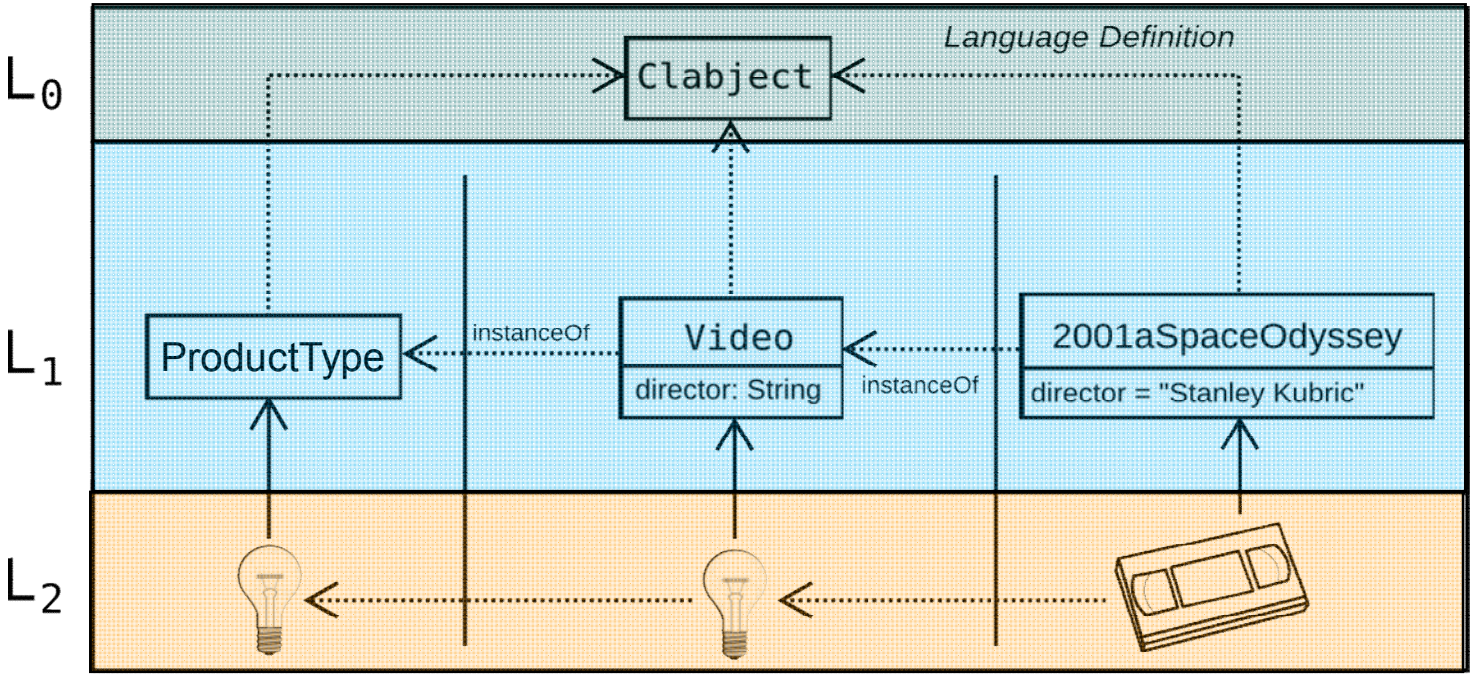
Orthogonal Classification Architecture

- two distinct forms of classification organized in different, dimensions
  - linguistic and ontological
- Strict (meta)-modeling in each dimension
- **So called "linguistic/ontological metamodeling paradox" [EHA13]**

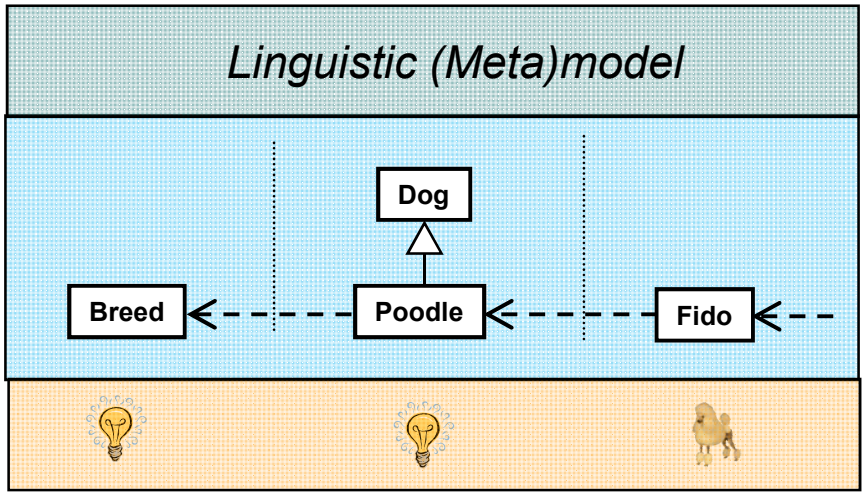


Deep (Multi-Level)Modeling

- Orthogonal classification architecture
- Unified class/object model element
  - Clabject
- Level-agnostic mechanisms for representing “typeness” of clabjects
  - Potency (deep instantiation)



Different Views of the Infrastructure



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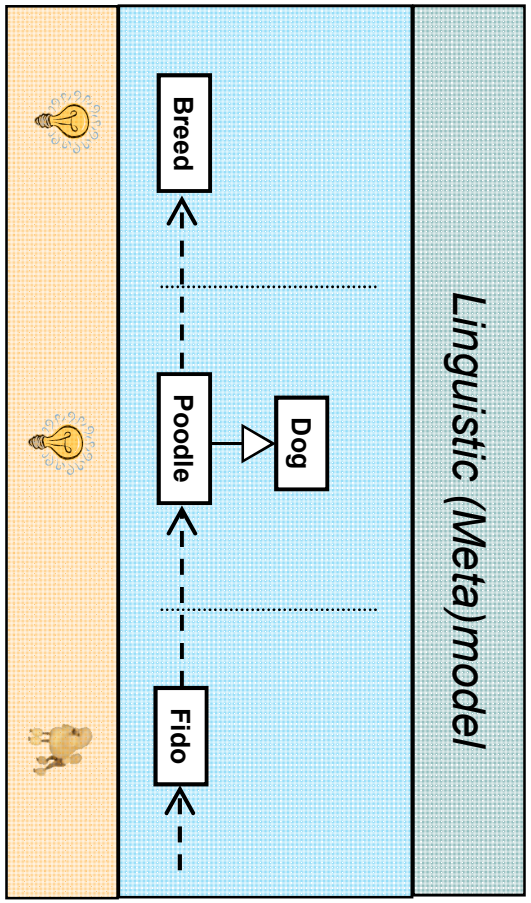
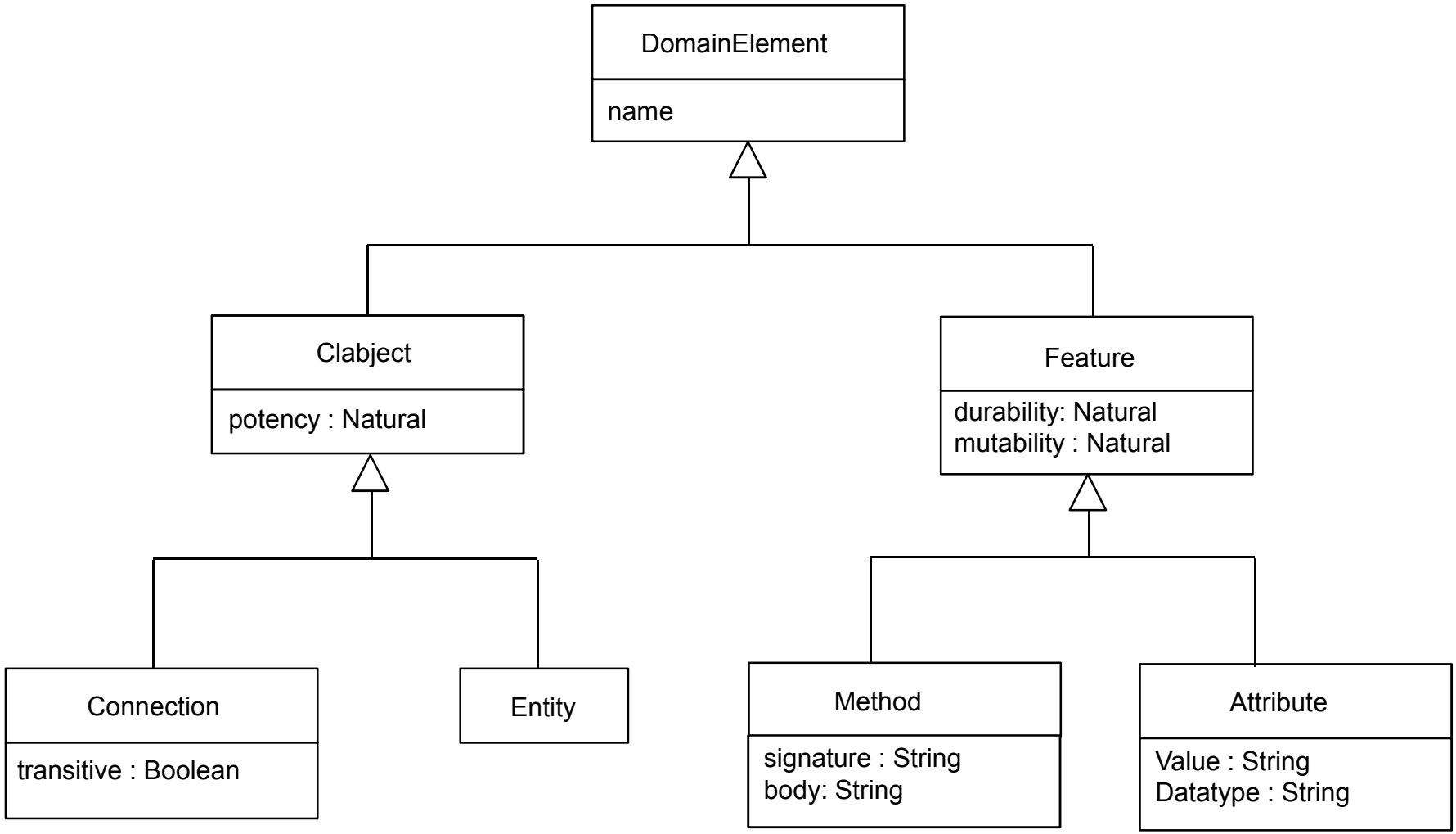


Tool Developer's View

Modeler's View

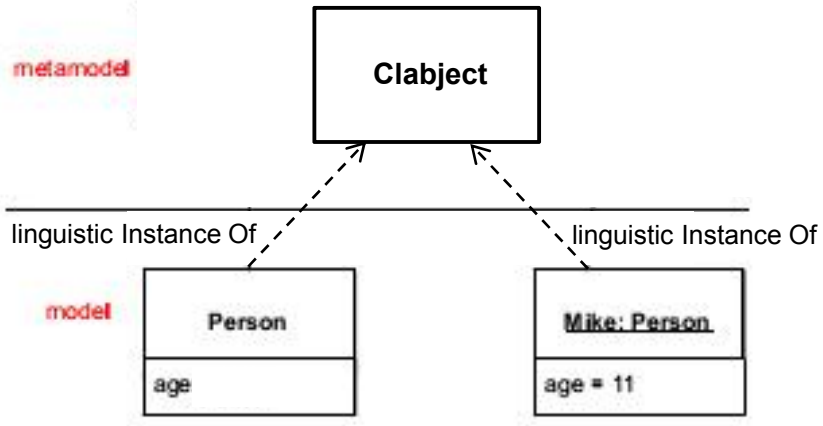
Essence of a Deep Linguistic Metamodel



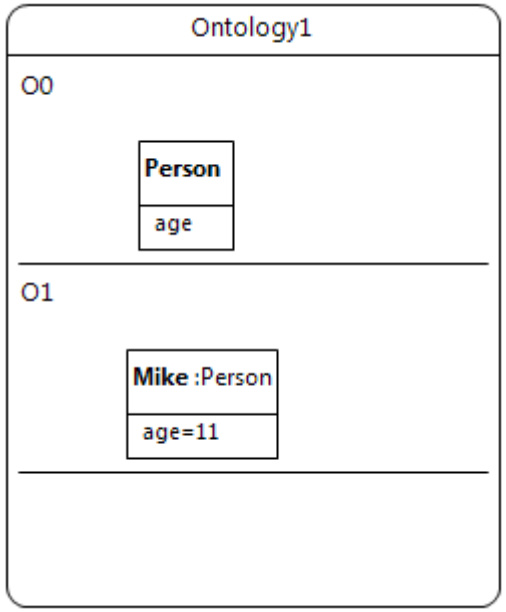
- abstract syntax for a Level-Agnostic Modeling language (LML)

Classes and Objects

- In LML classes and objects are unfied into the notion of “clabjects“
  - clabjects can have ontological attributes that play the role of UML attributes / slots
- ontological attributes must always have a name
  - can also, optionally, have a type and /or a value



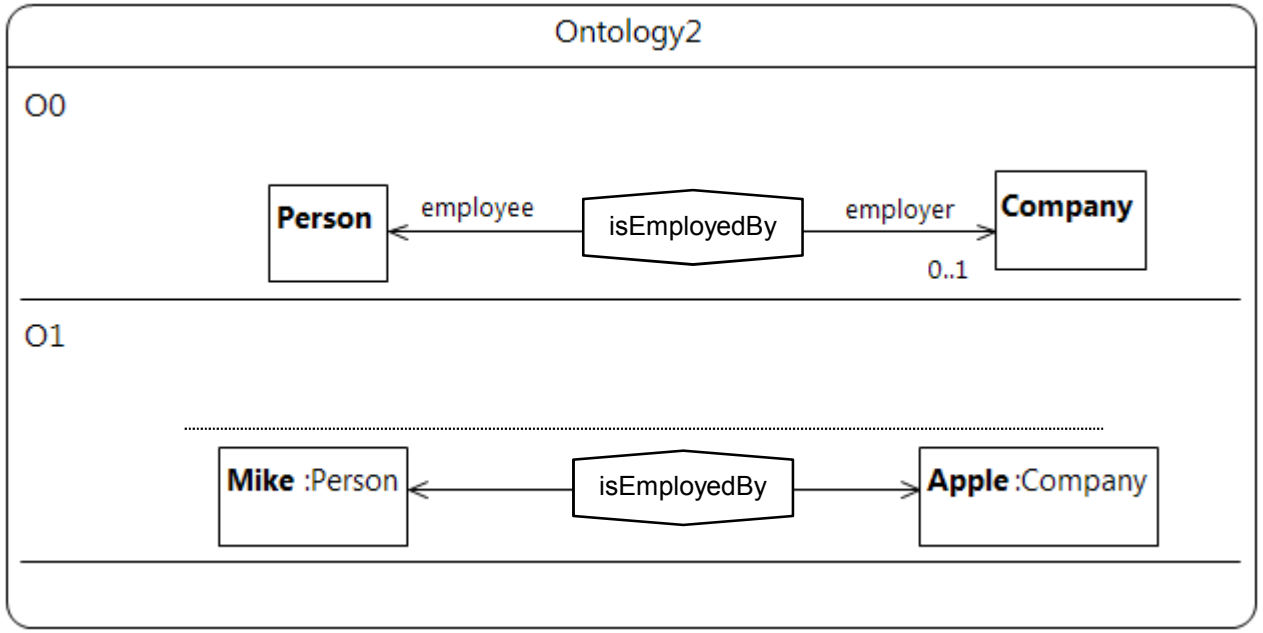
UML



LML

Associations and Links

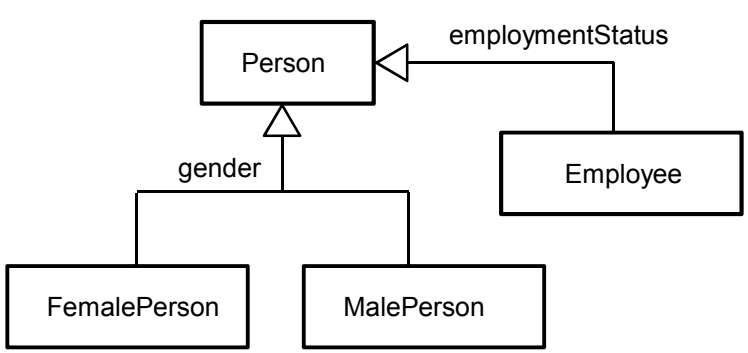
- Associations / links are also represented by a unified concept in LML – Connections
- conection are also clabjects
  - can have attributes and particpate in generalizations
  - can be visualized in an exploded or “dotted“ form



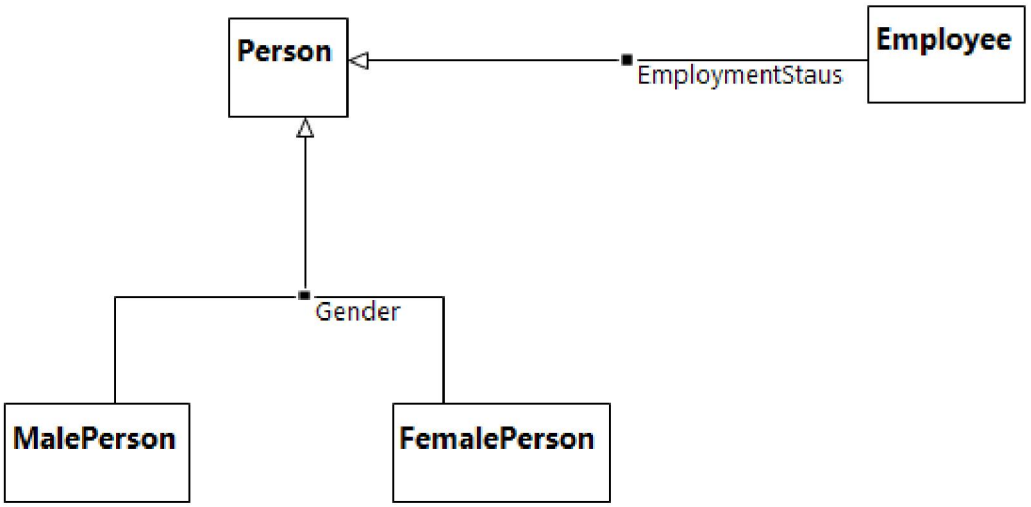
ULML

Generalization

- Generalizations are another first class citizen of LML
  - can also be view in an exploded or visually “insignificant“ form
- The name of the generalization usually identifies the discriminant
- Usual constraints such as disjoint and complete also supported



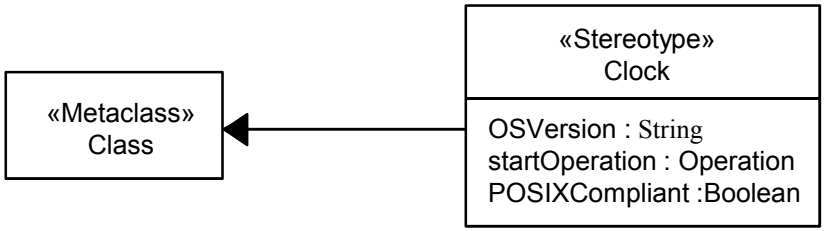
UML



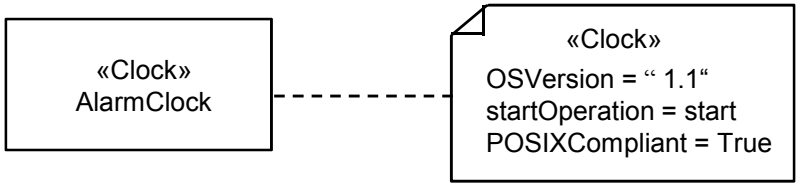
LML

Stereotypes

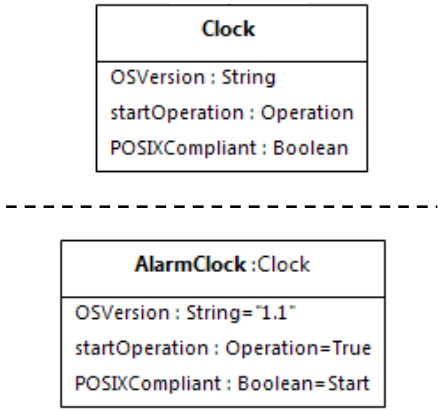
- Stereotypes and stereotyping supported by metamodeling



Stereotype



Stereotyped Element

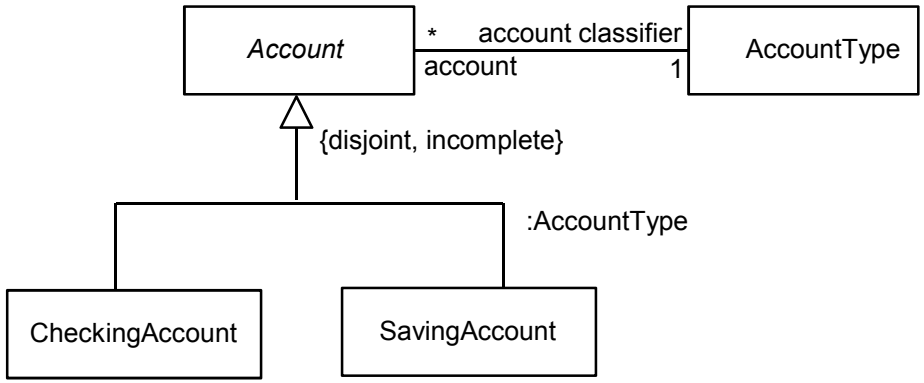


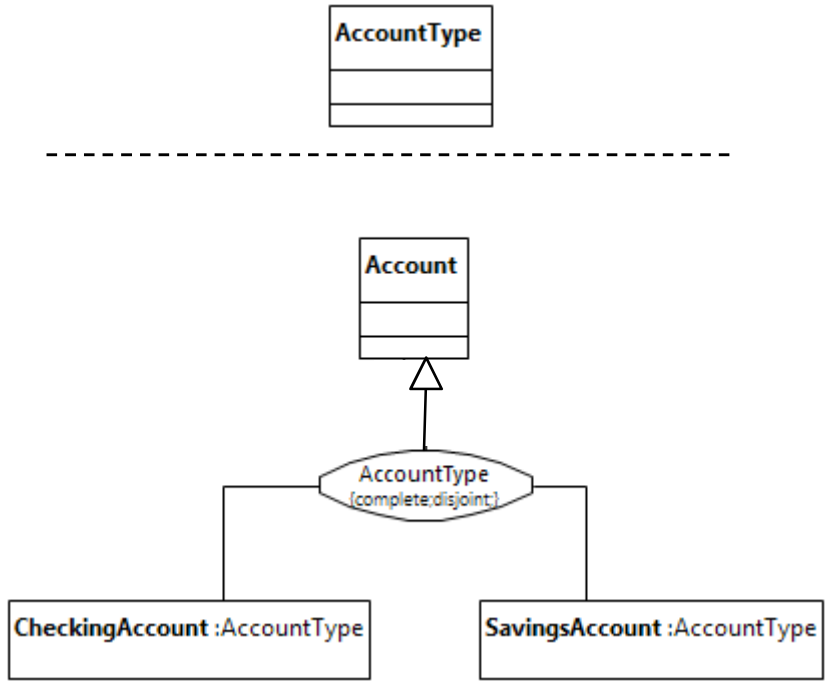
UML

LML

Powertypes

- LML also provides natural support for powertypes
- power types are metaclasses whose instances are also subclasses.
  - X is a power type of Y, if the instances of X are subclasses of Y



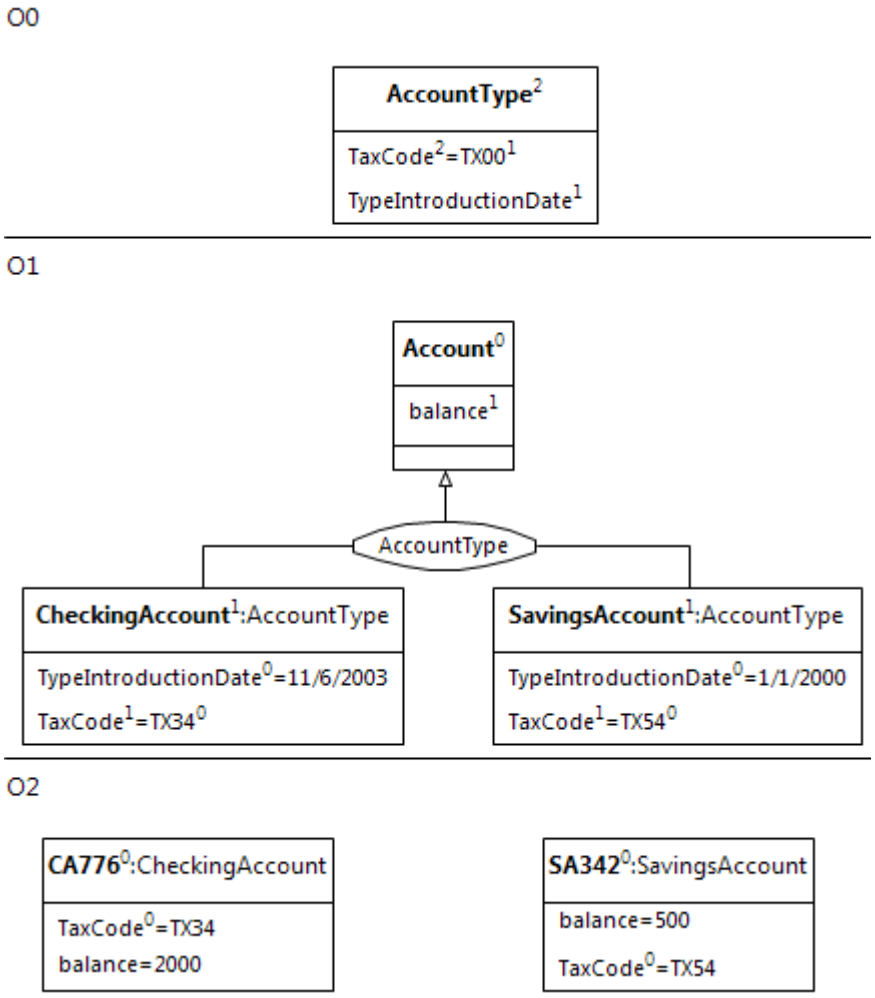


UML LML

Deep Instantiation

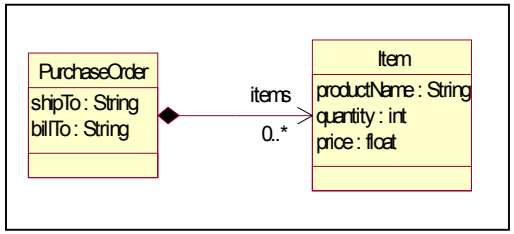
- a simple mechanism supporting deep characterization
- allows feature properties to be exactly specified using the notion of
  - ⇒ potency
- provides a simple but precise definition of instanceOf relationships (principle of application) over multiple classification levels
  - potency takes non-negative integer values
  - an instance of a type always has a potency that is one lower than the type
- although instantiation also lowers the level of a clabject by one,
  - the potency and level of a clabject do not have to be the same

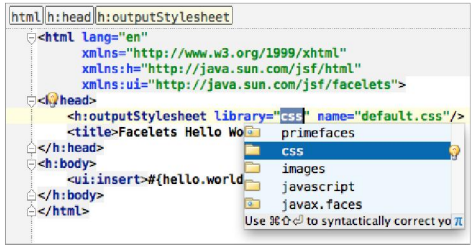
The Power Type Example Revisited

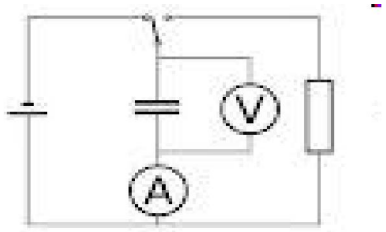


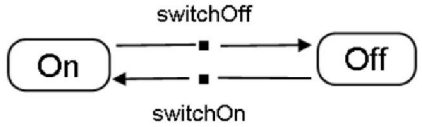
LML

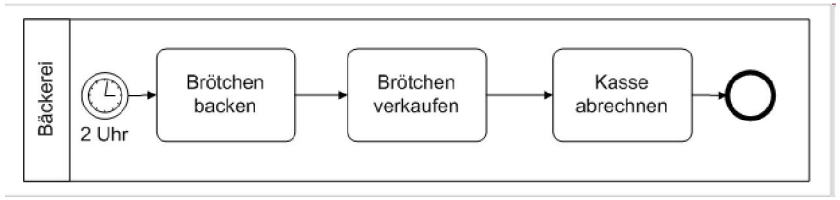
Domain Specific v General Purpose?











GPLs

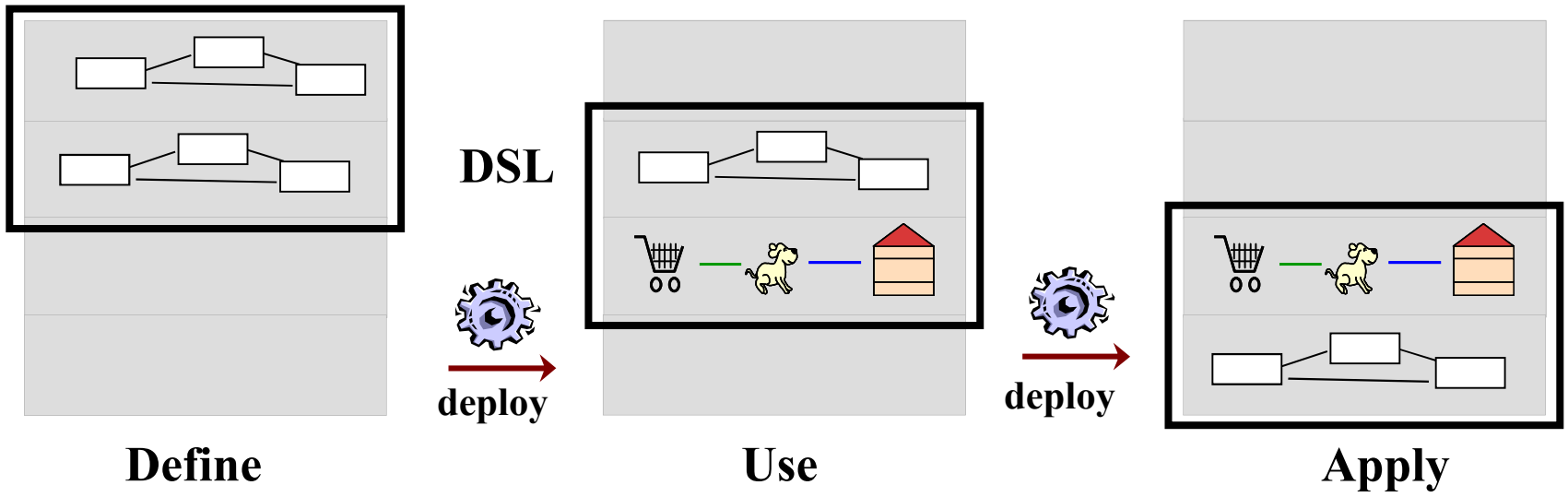
- E.g UML, Java, XML etc.
- Lingua Franca
- less concise and efficient
- facilitate inter-domain communication

DSLs

- E.g. BPMN, Circuit Diagrams etc
- optimized for special tasks
- more concise and efficient
- “Tower of Babel“ problem

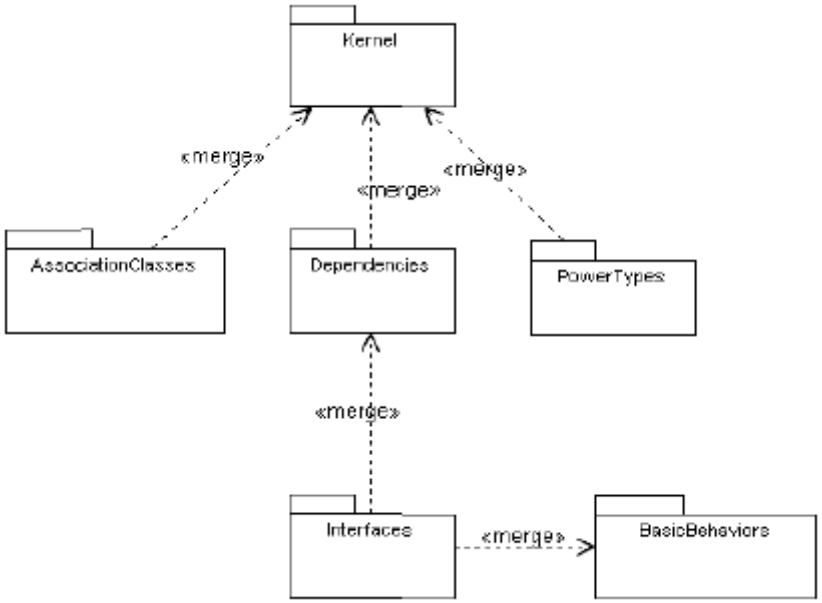
DSL State-of-the-Art

- DSLs defined in rigid, disjoint phases and environments
- result of one phase has to be “deployed” in a major compilation step to enable the second phase
- in each phase/environment only one classification level is “soft”
- only one concrete syntax is available in a given phase.

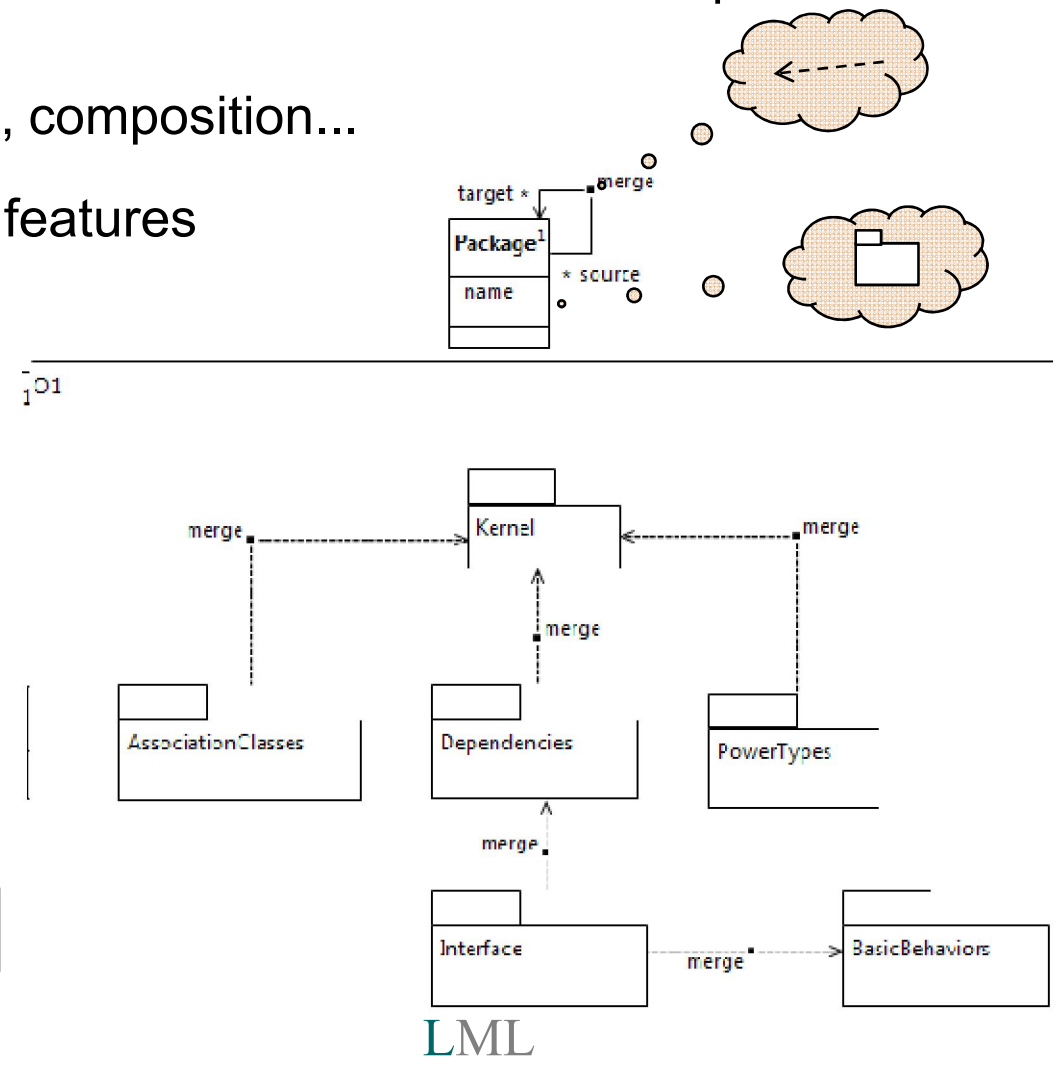


Package Diagrams as a DSL

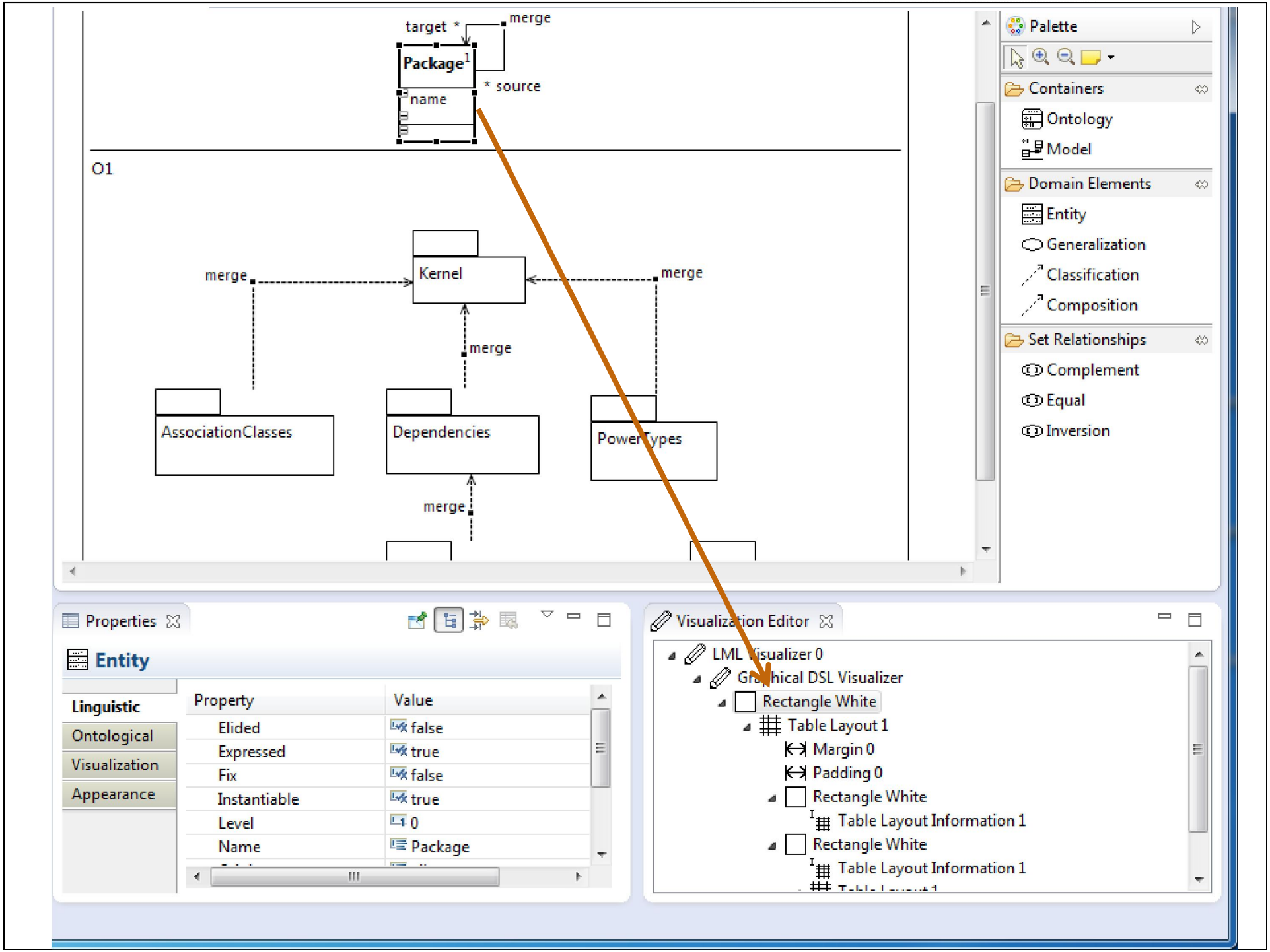
- Many features of UML were not included in the earlier comparison of UML and LML
  - packages, components, composition...
- these can be added as DSL features



UML



LML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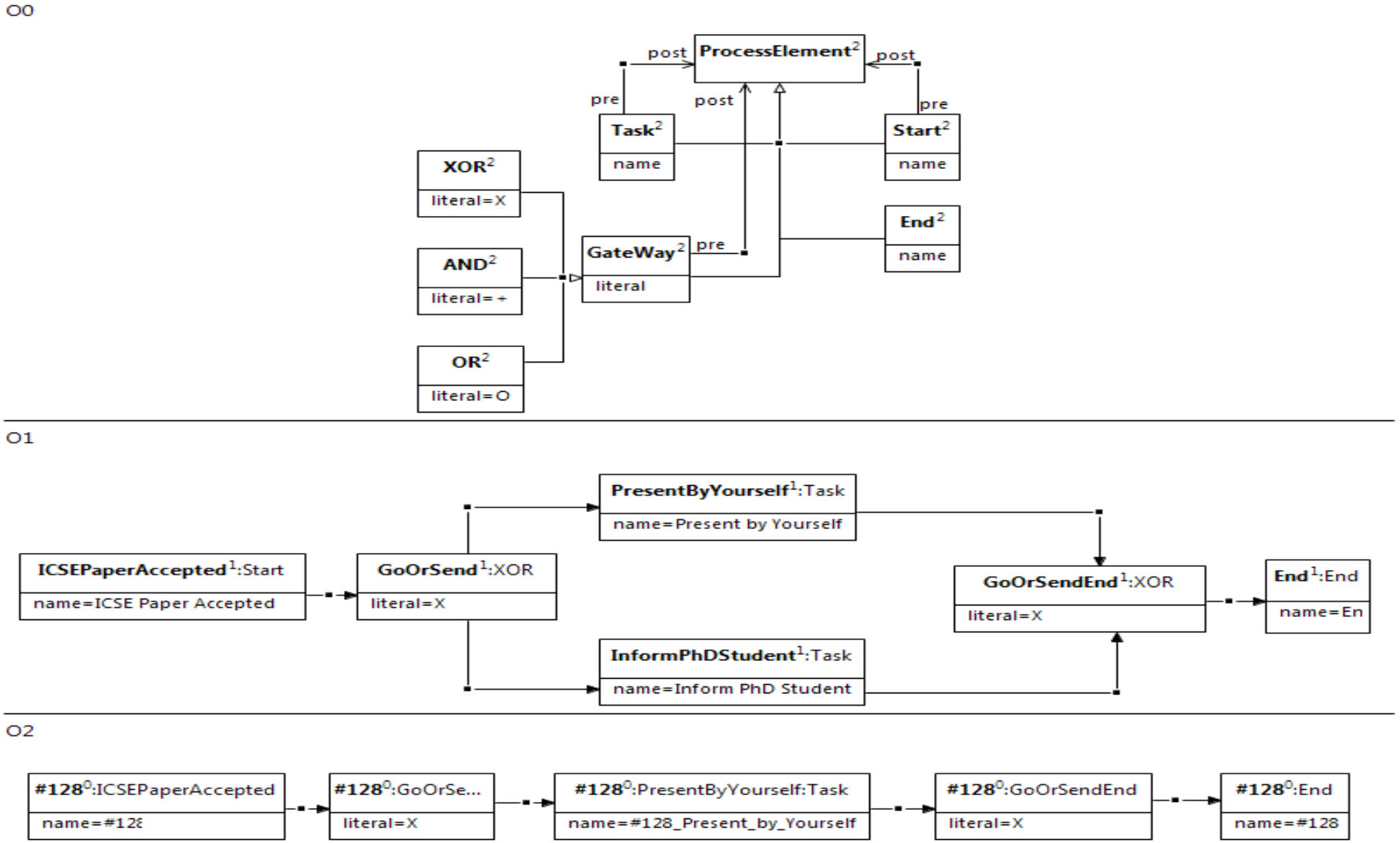
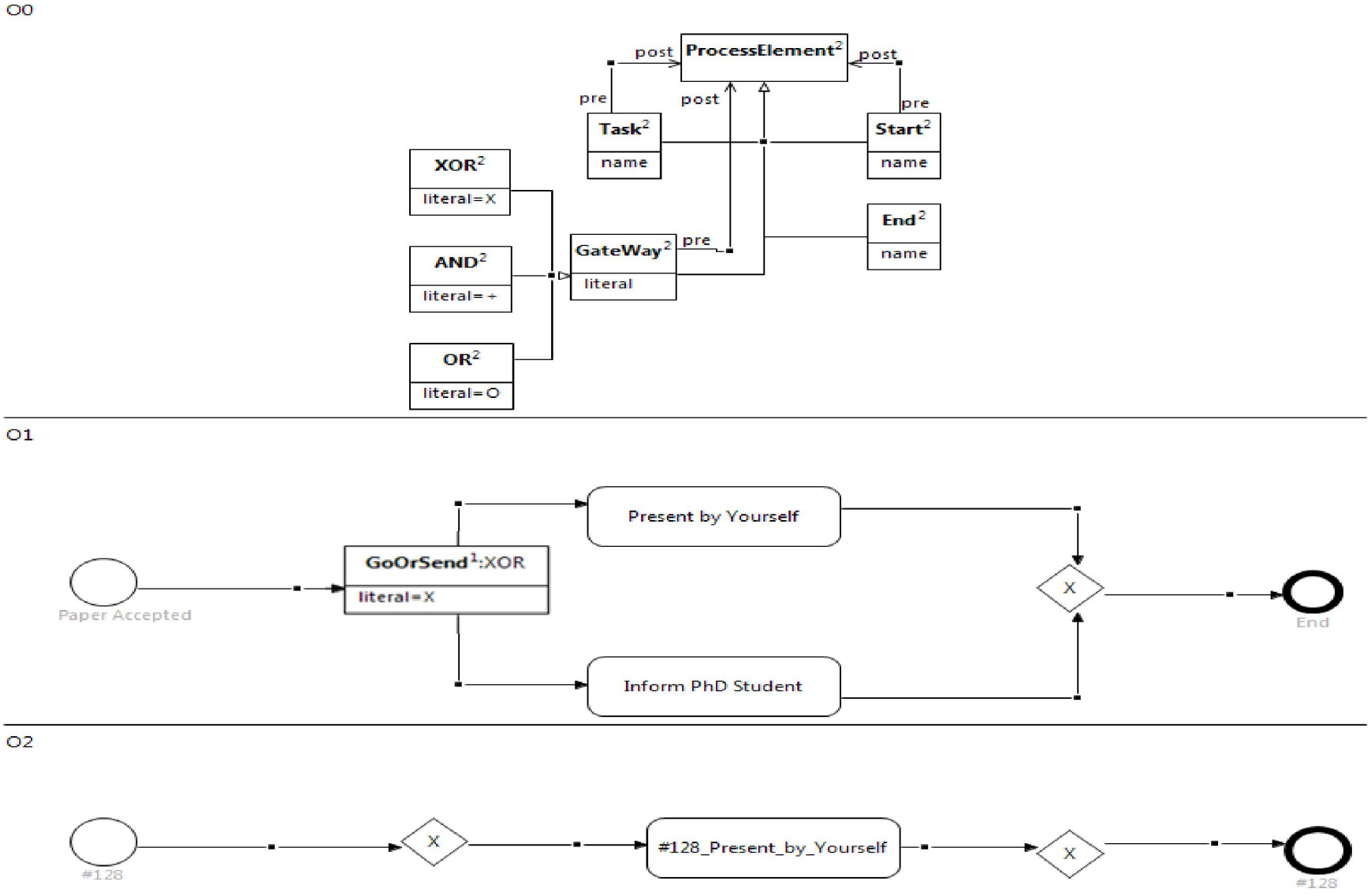
Symbiotic Languages

- Symbiosis – a relationship in which two things compenstate for each other‘s weaknesses and reinforce each other‘s strengths
- Symbiotic languages
  - coexists and can be mixed in arbitrary ways
  - Melanie supports a symbiosis between general purpose and domain specific visualizations
- Key features –
  - choice between purely general purpose or domain specific representations of the same model
  - symbols can be arbitrarily mixed
    - any symbol can be dynamically toggled from domain-specific to general purpose and back
  - can be applied at multiple classification level (i.e. models) simultaneously

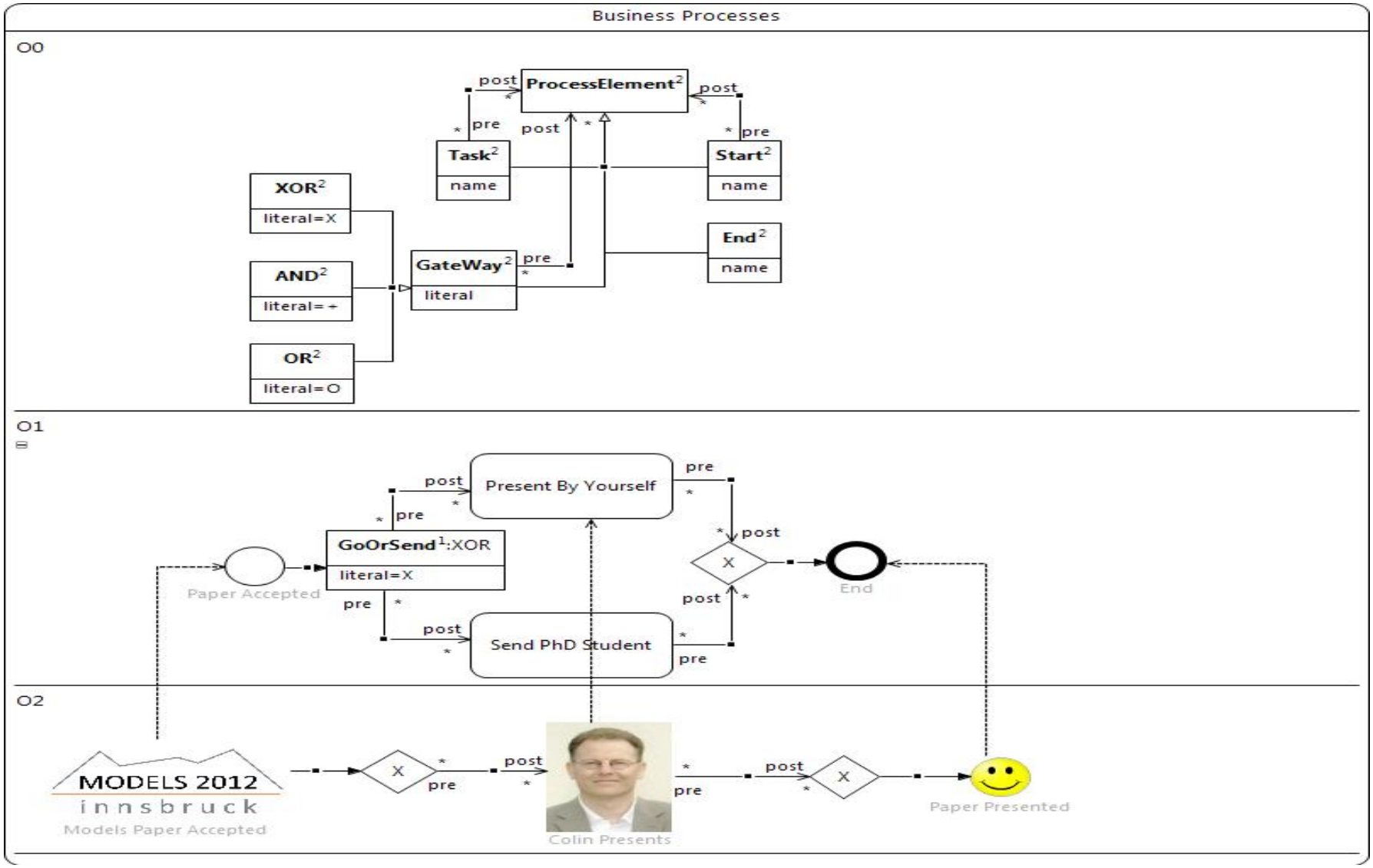
Symbiotic Language Example (1/3)



Symbiotic Language Example (2/3)



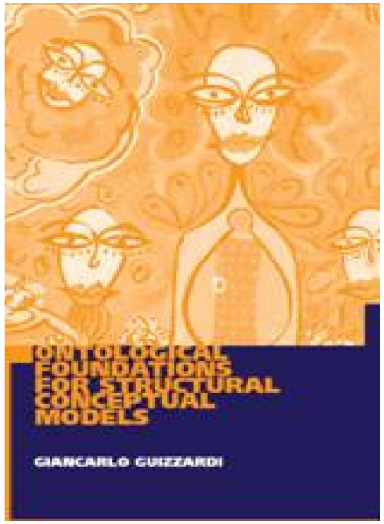
Symbiotic Language Example (3/3)



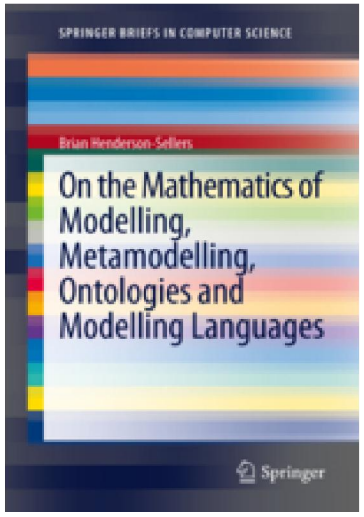
Foundation Ontologies

- a foundation ontology (also known as a top-level ontology or upper ontology) describes very general concepts that are common across all knowledge domains
- meet the following basic needs [EHA13]
  - promote reuse in a higher level of abstraction aimed at maximising the reuse of domain models
  - produce domain specifications that are truthful to reality
  - theoretical foundations for conceptual modelling languages
- Examples
  - Bunge-Ward-Weber (BWW), Basic Formal Ontology (BFO), General Formal Ontology (GFO), Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE), Suggested Upper Merged Ontology (SUMO),
  - Unified Foundation Ontology (UFO) [GG05]

References



- [GG05] Guizzardi, G. Ontological Foundations for Structural Conceptual Models, PhD Thesis, University of Twente, The Netherlands.
  - published as the book “Ontological Foundations for Structural Conceptual Models”, Telematica Instituut Fundamental Research Series No. 15, ISBN 90-75176-81-3 ISSN 1388-1795

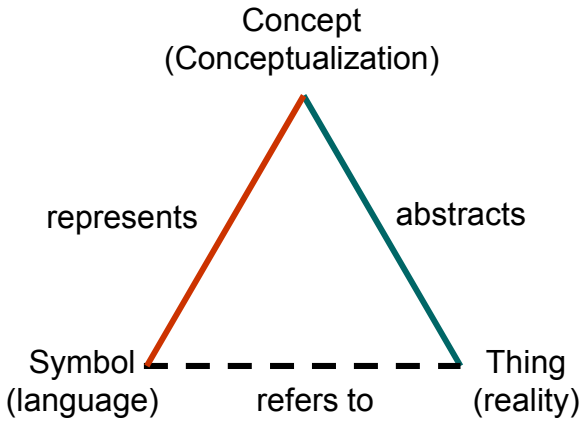


- [EHG13] Owen Eriksson, Brian Henderson-Sellers, and Pär J. Agerfalk. 2013. Ontological and linguistic metamodelling revisited: A language use approach. Inf. Softw. Technol. 55, 12, December 2013.
- B. Henderson-Sellers, On the Mathematics of Modelling, Metamodelling,Ontologies and Modelling Languages, SpringerBriefs in Computer Science, Springer-Verlag, Heidelberg, 2012.

Semantics of Models

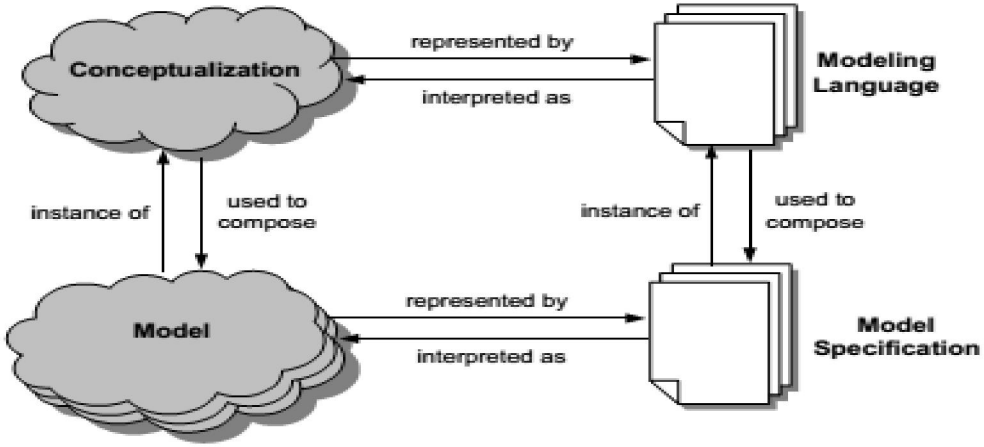
Ullmann's Triangle

- basis for understanding how symbols represent concepts in a language
- "the relation between language and reality is always intermediated by a certain conceptualization" (Baldinger)



Guizzardi's Square

- characterizes relationship between conceptualizations models, languages and specializations [GG05]

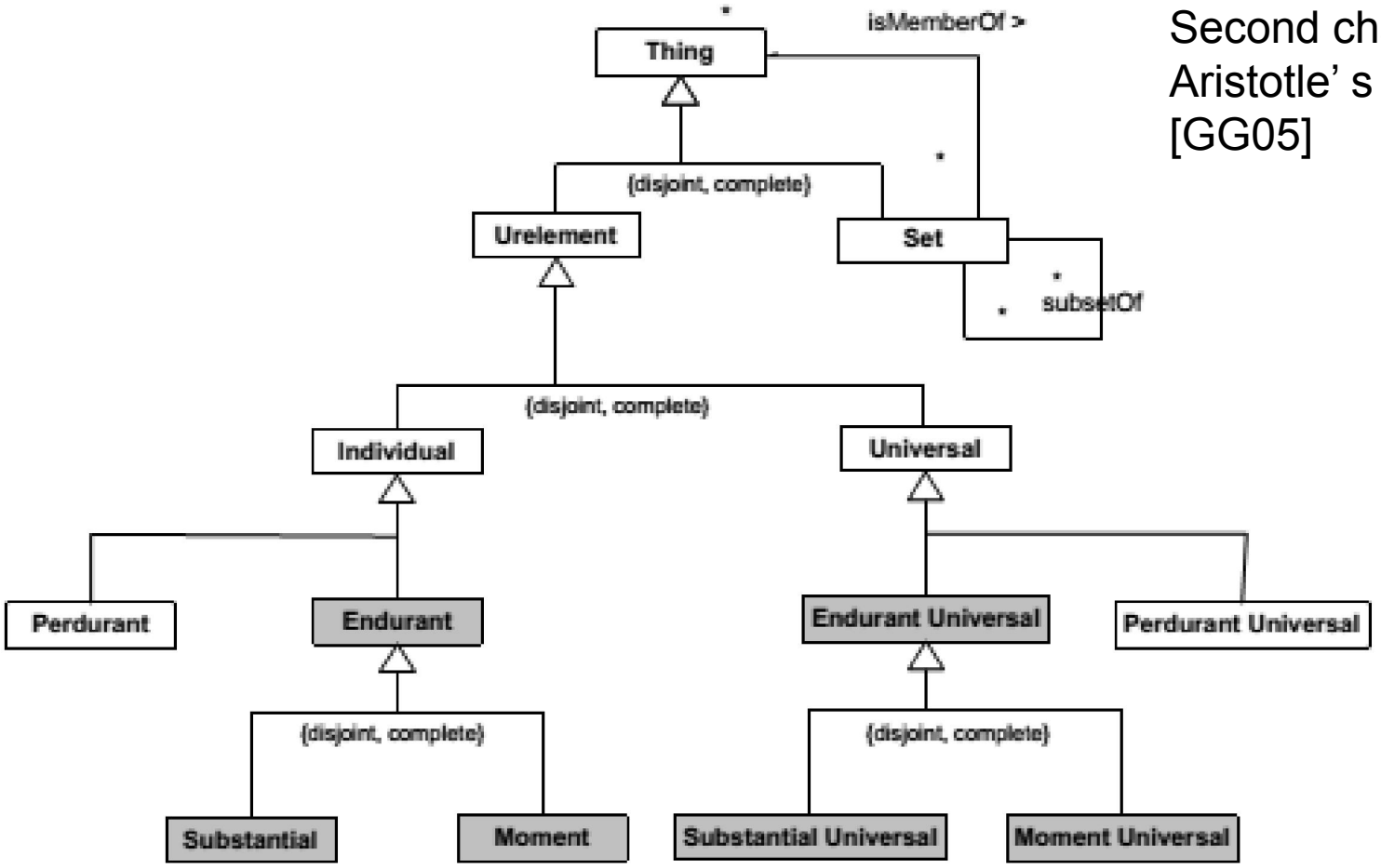


Concrete Incarnation

- In practice, boils down to a detailed taxonomy of modelling constructs capturing and philosophically well-founded concepts
- Based on a traditional (two-level) class / object dichotomy
  - Aristotle's four category ontology
- Most widely used and practical incarnation is OntoUML
  - a UML profile capturing the UFO taxonomy
  - supported by a tool developed by NEMO (Ontology & Conceptual Modeling Research Group) in Vitoria, Brazil
- Arguments for validity and utility are philosophical
  - the necessity or correctness of modelling features can not be proven per se
  - often the information they convey can be modelling in another way (albeit perhaps less elegant)
    - phases can be modelled by attributes of enumeration types

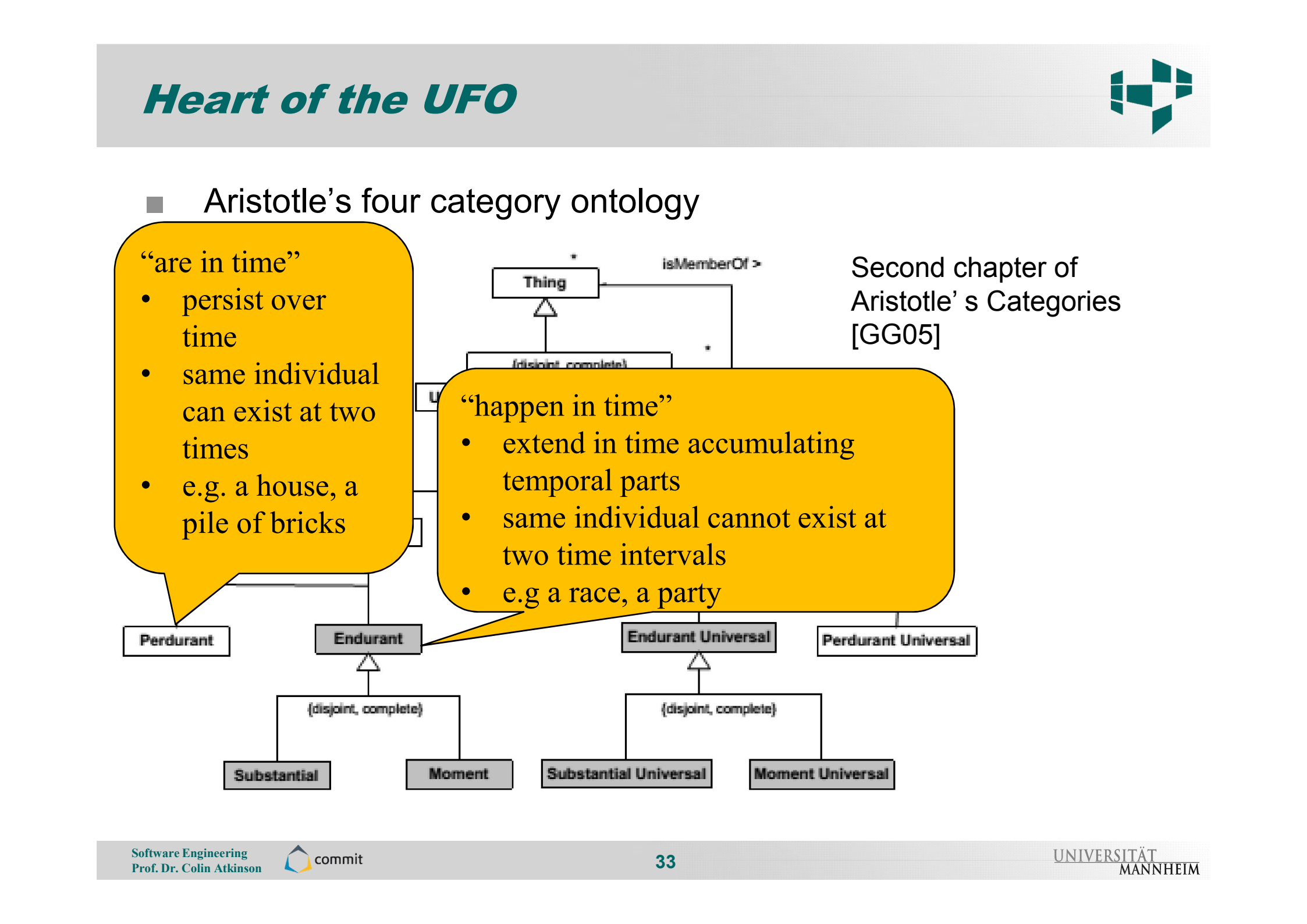
Heart of the UFO

- Aristotle's four category ontology



Second chapter of Aristotle' s Categories [GG05]

Heart of the UFO



- Aristotle's four category ontology

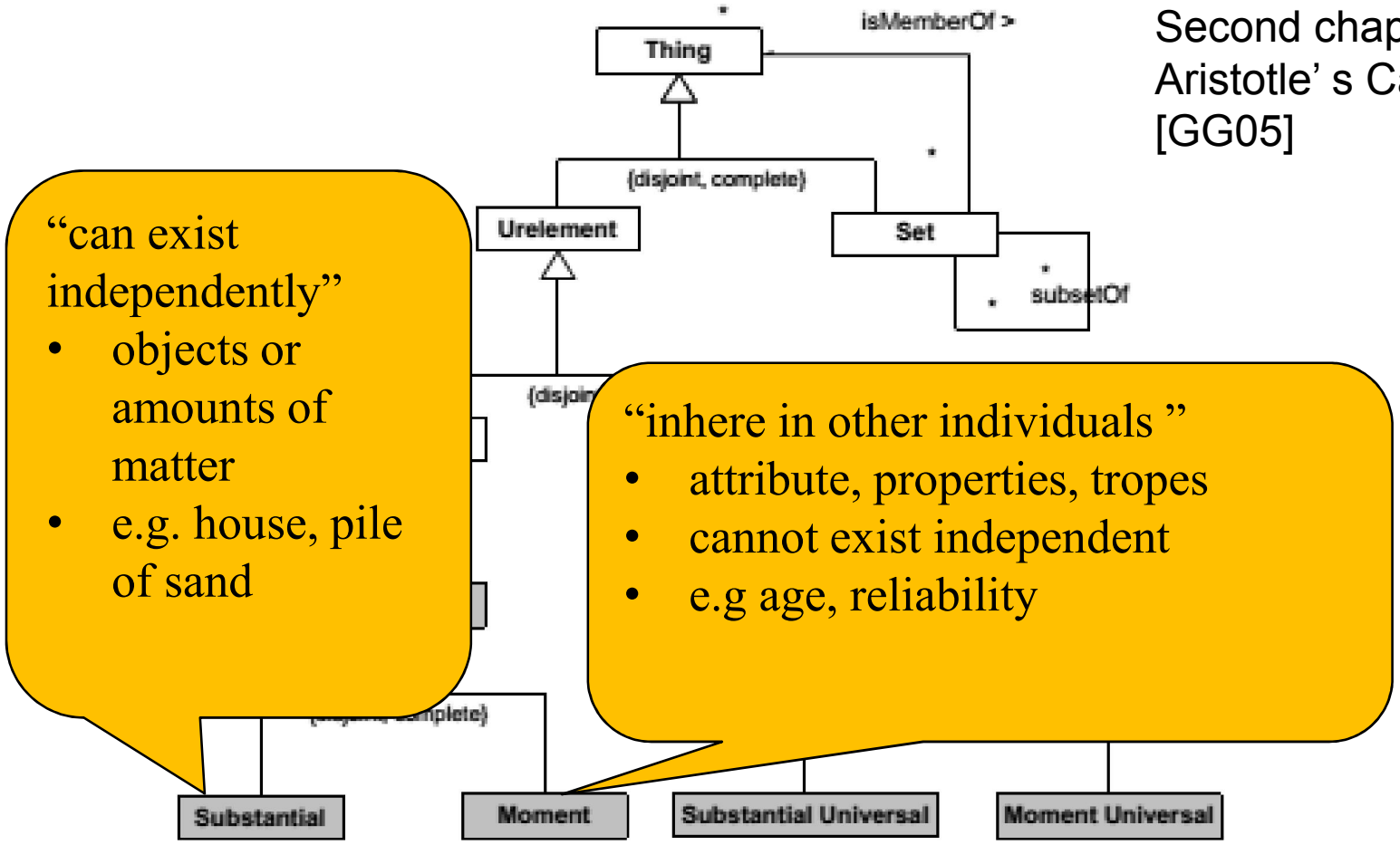
"are in time"
- persist over time
- same individual can exist at two times
- e.g. a house, a pile of bricks

"happen in time"
- extend in time accumulating temporal parts
- same individual cannot exist at two time intervals
- e.g a race, a party

Second chapter of Aristotle' s Categories [GG05]

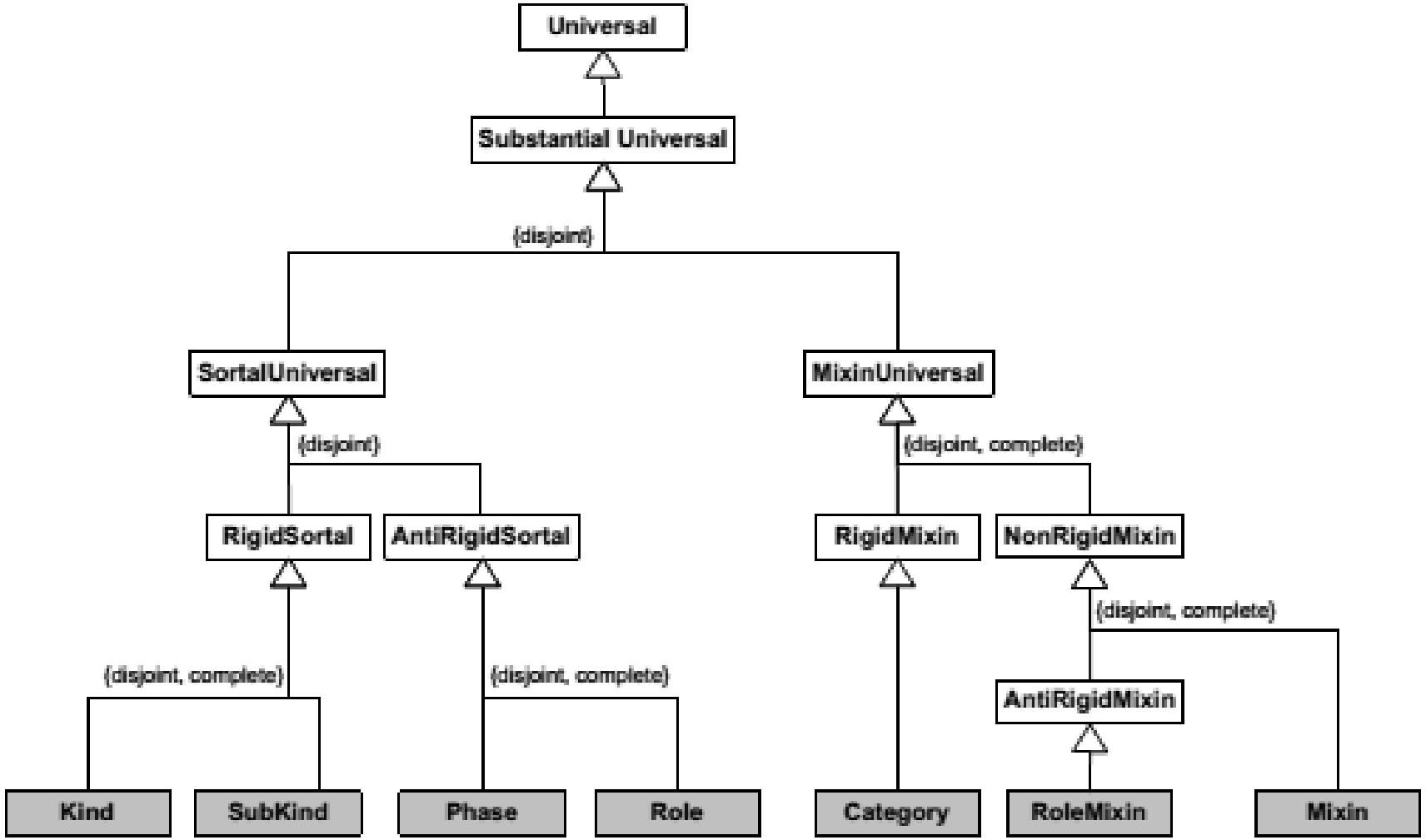
Heart of the UFO

- Aristotle's four category ontology

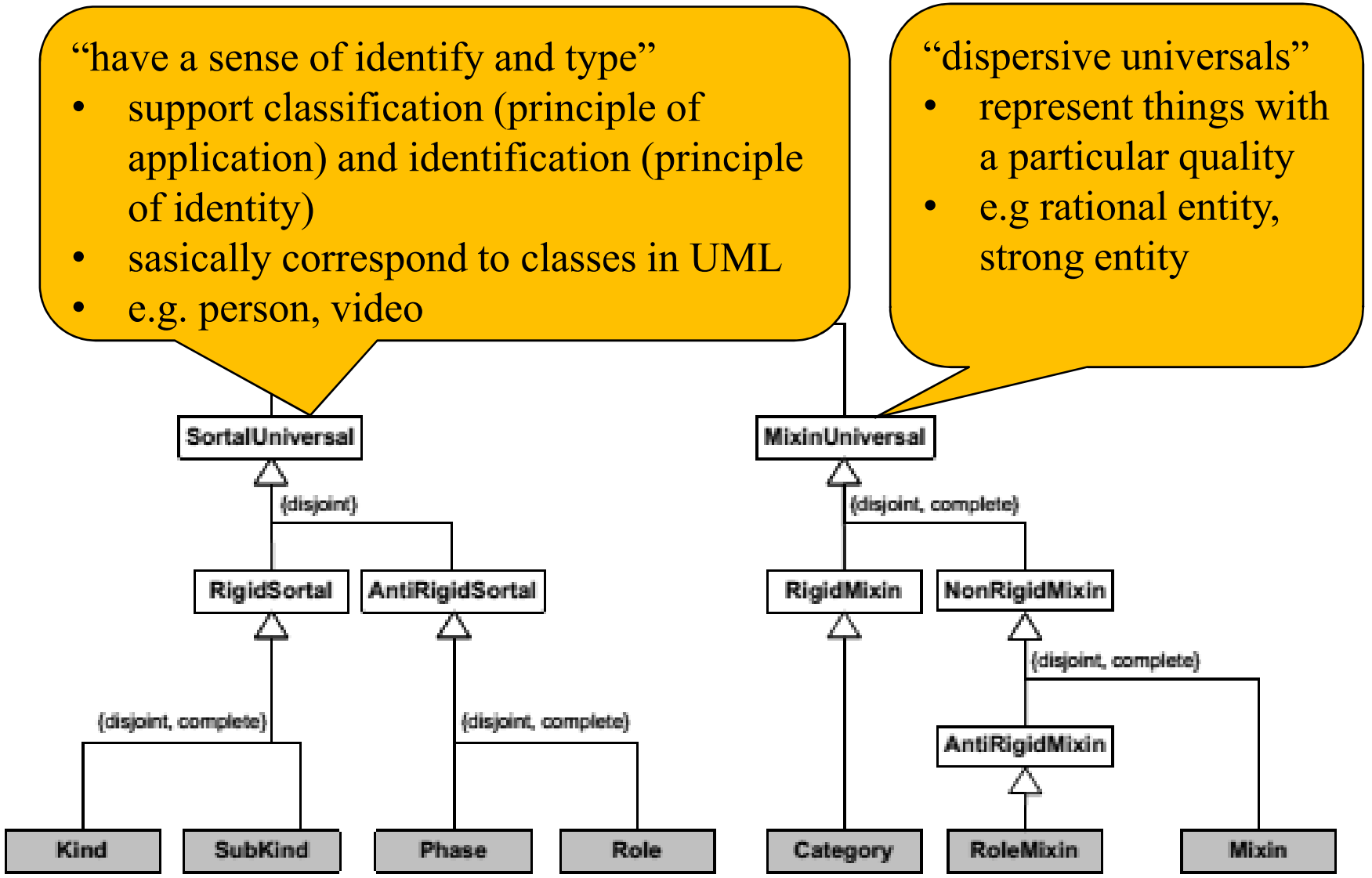


Second chapter of Aristotle' s Categories [GG05]

Taxonomy of Substantial Universals



Taxonomy of Substantial Universals



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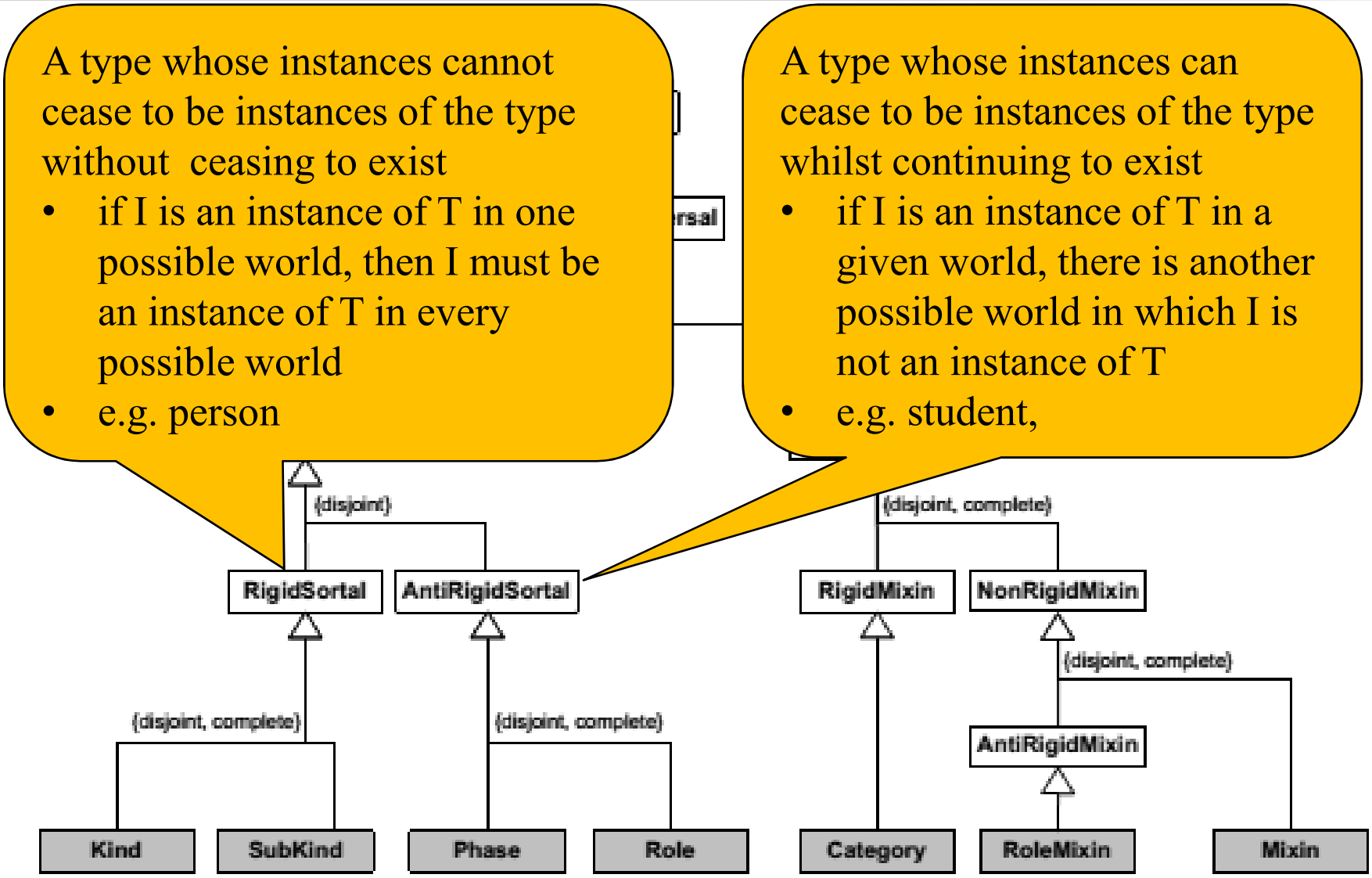
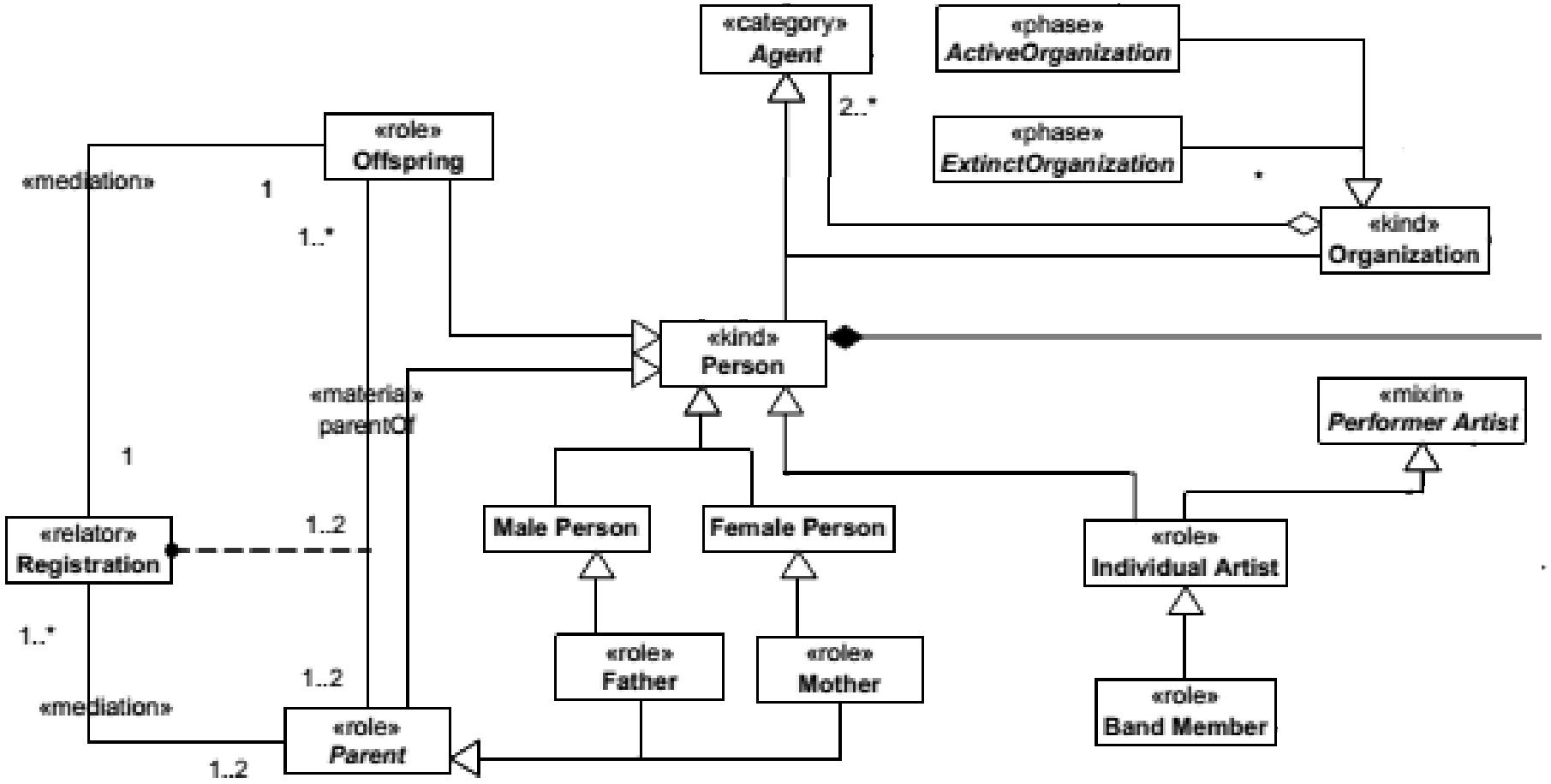


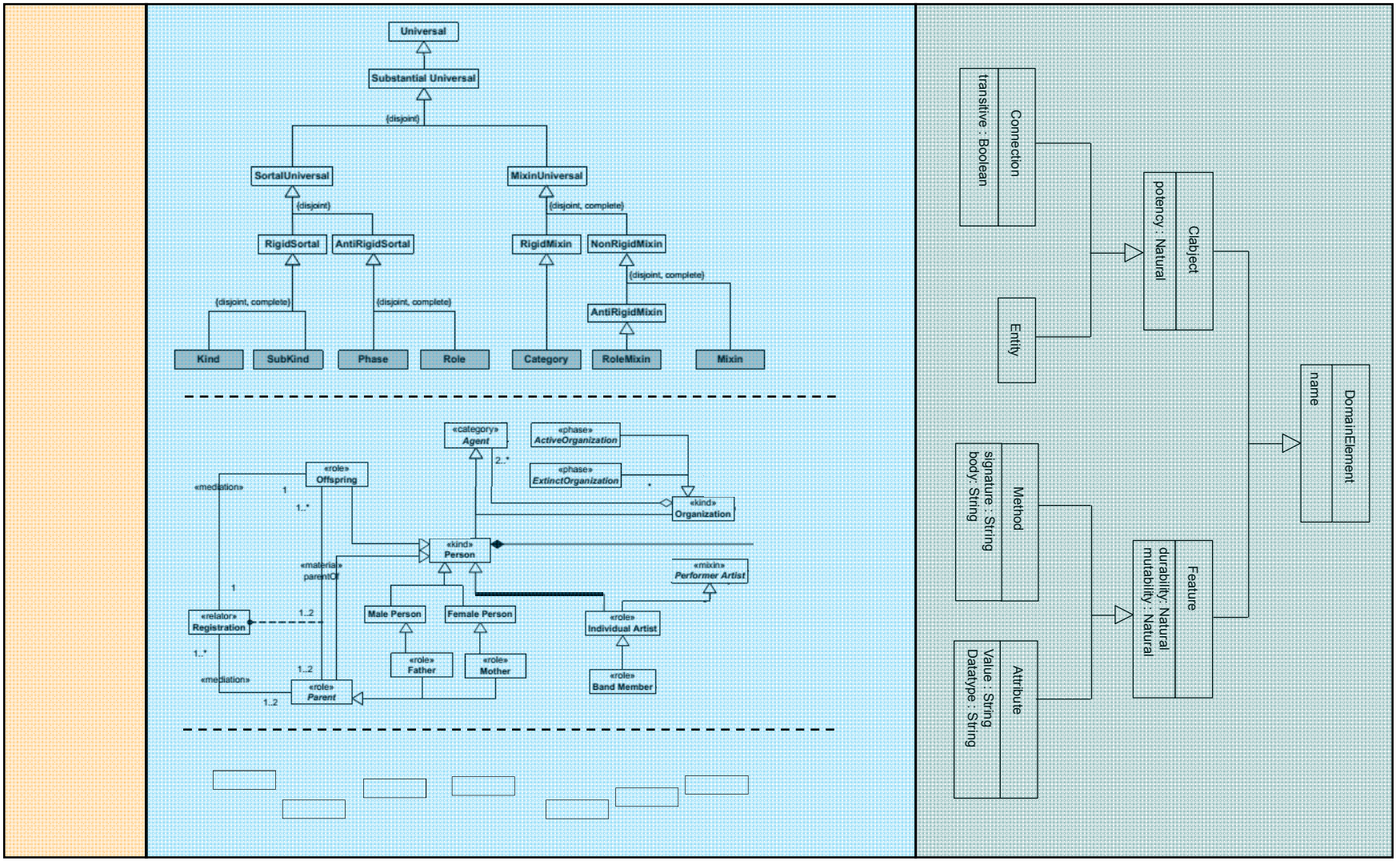
Example (OntoUML) [GG05]



Compatability of FOs and Deep Modeling

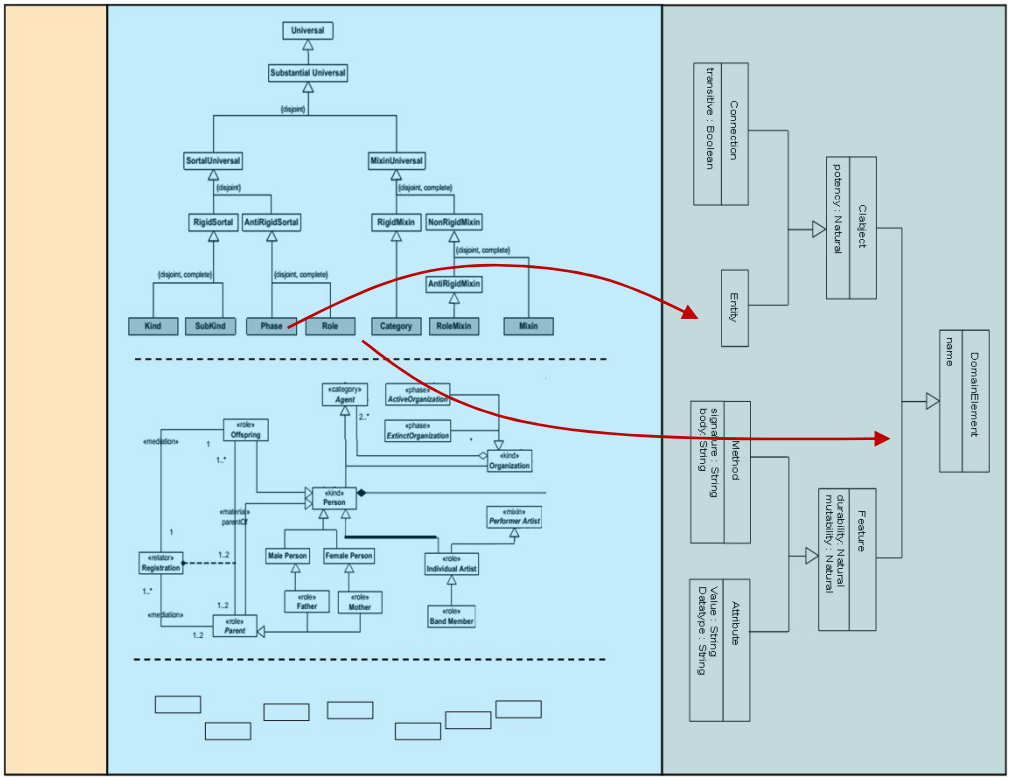
- At first sight FOs and deep modelling are fundamentally incompatible
  - UFO based on the fundamental universal / instance dichotomy
  - deep modelling exists to precisely to overcome this limitation
- UFO does not explain some concepts that are important in IT
  - abstract classes
  - interfaces
  - power types
  - stereotypes?
- but UFO can be regarded as a DSL in deep modelling
  - provides exactly the same expressive power as OntoUML

UFO as DSL

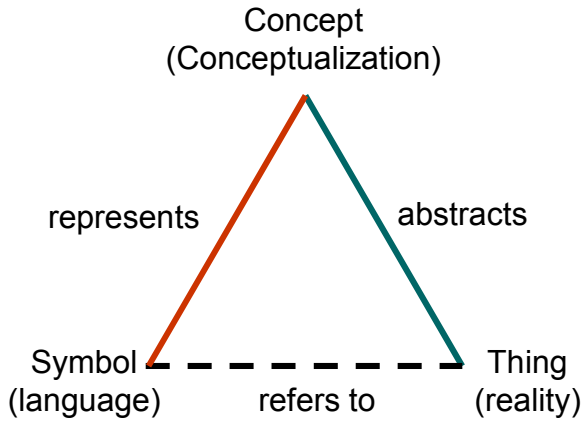

Universal
Substantial Universal
{disjoint}
SortalUniversal
MixinUniversal
{disjoint}
{disjoint, complete}
RigidSortal
AntiRigidSortal
RigidMixin
NonRigidMixin
{disjoint, complete}
{disjoint, complete}
{disjoint, complete}
{disjoint, complete}
AntiRigidMixin
Kind
SubKind
Phase
Role
Category
RoleMixin
Mixin
«category» Agent
«phase» ActiveOrganization
«phase» ExtinctOrganization
«role» Offspring
«mediation»
1
1..*
2..*
*
«kind» Organization
«kind» Person
«material» parentOf
«mixin» Performer Artist
1
«relator» Registration
1..2
Male Person
Female Person
«role» Individual Artist
1..*
«mediation»
1..2
«role» Father
«role» Mother
«role» Band Member
«role» Parent
1..2
Connection
transitive : Boolean
Entity
Clabject
potency : Natural
DomainElement
name
Method
signature : String
body: String
Feature
durability: Natural
mutability : Natural
Attribute
Value : String
Datatype : String

Big Question

- In an optimal deep modelling environment, what features in (e.g.) UFO be moved to the linguistic (meta)model ?
  - would the notion of rigid or antirigid clabjects be useful?
  - would it be useful to introduce the notion of role clabjects?
- For example EHA13 argue that Dog is a substantial class while Breed is a moment type
  - but what if Dog were not in the model?
- The top ontological model and the linguistic model need to be aligned and optimized to support deep, FO based modeling

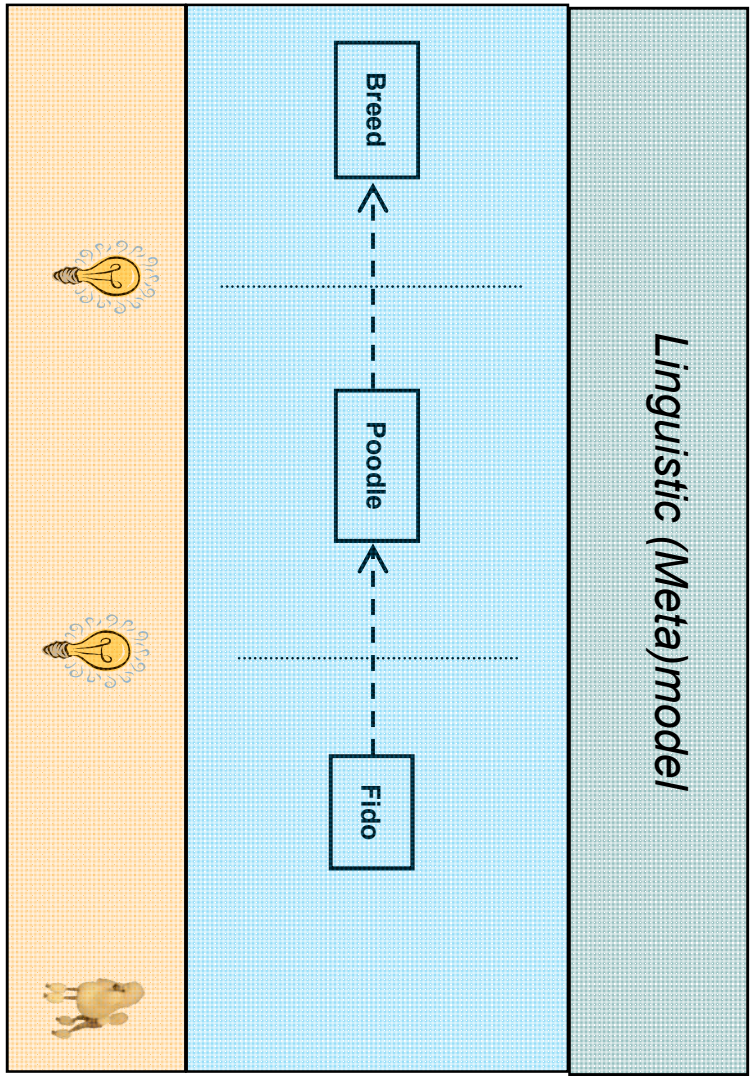


Deep Interpretation of Ullman's Triangle



- ontological model elements are symbols
- real world entities, including concepts, are things
- higher level model elements are concepts

a concept can be an instance of another concept (counter to [EHA13])



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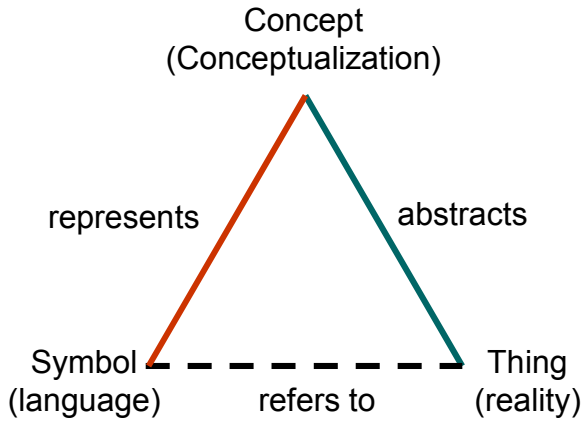

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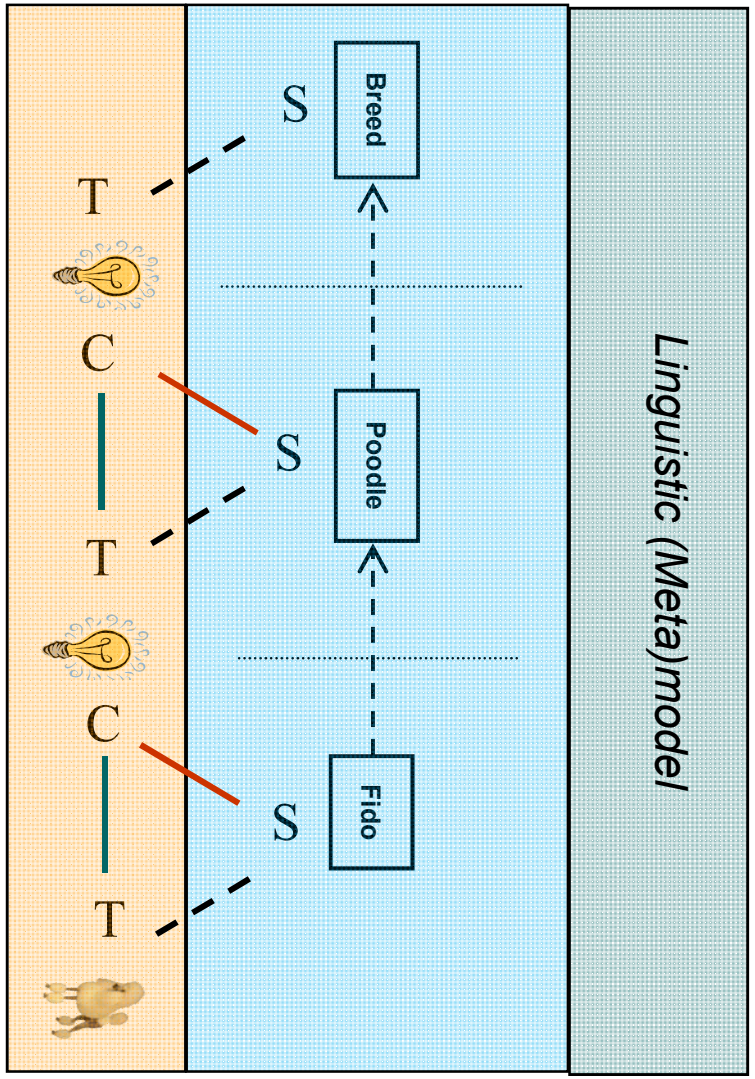
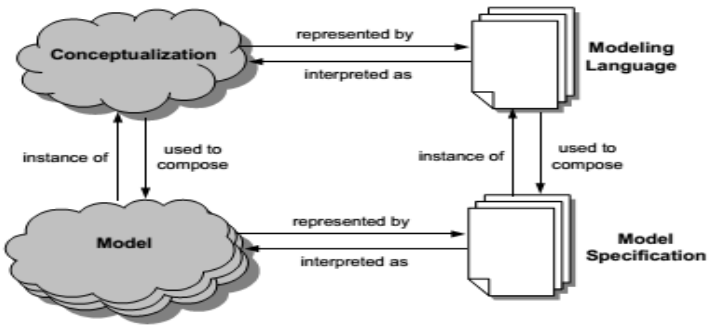
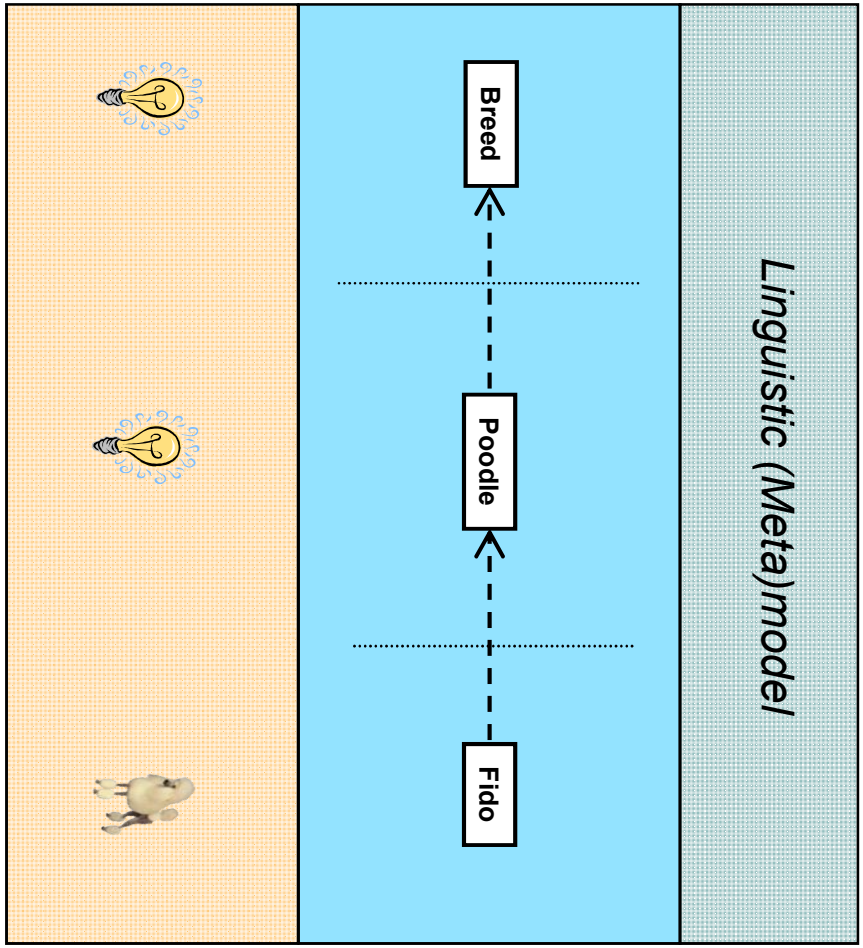


Deep Interpretation of Guizzardi's Square



- model elements at one level are a language for the model specification at the level below
- a model language represents a conceptualization
- a model, a an instance of a conceptualization, is a model specification



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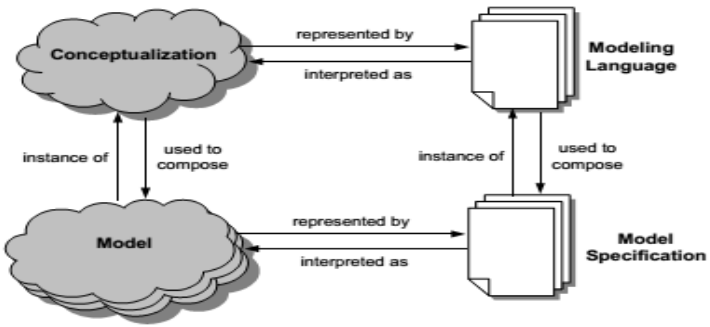

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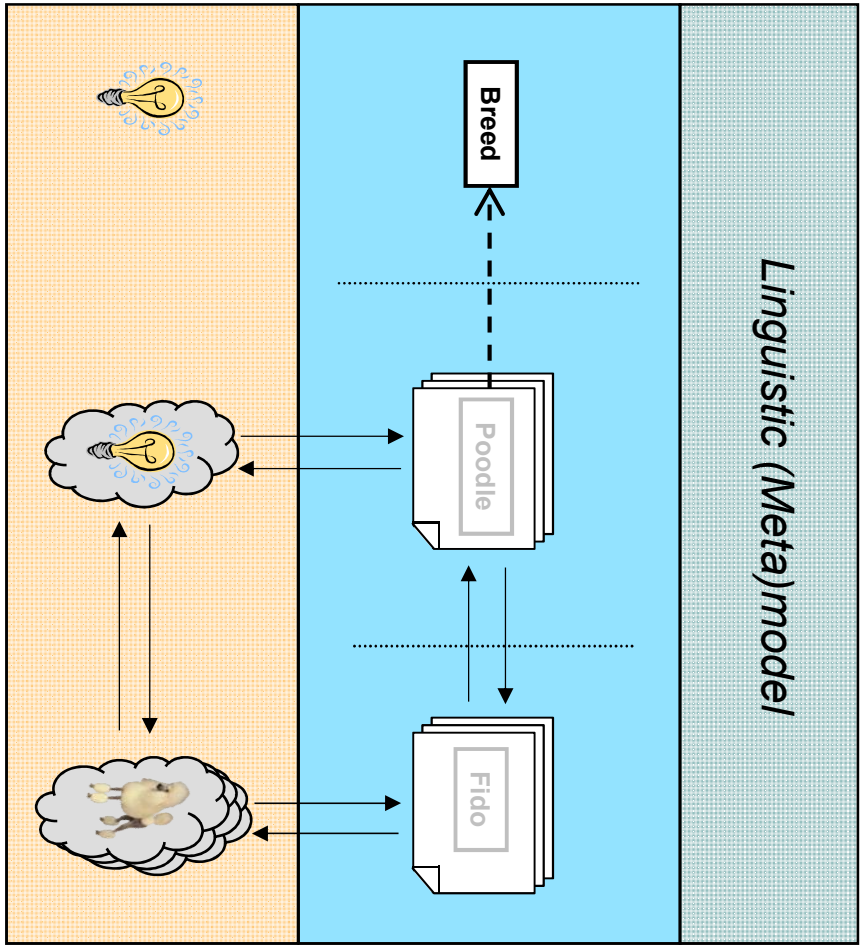

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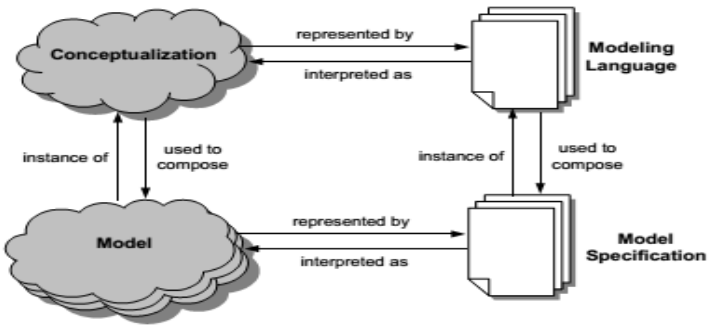

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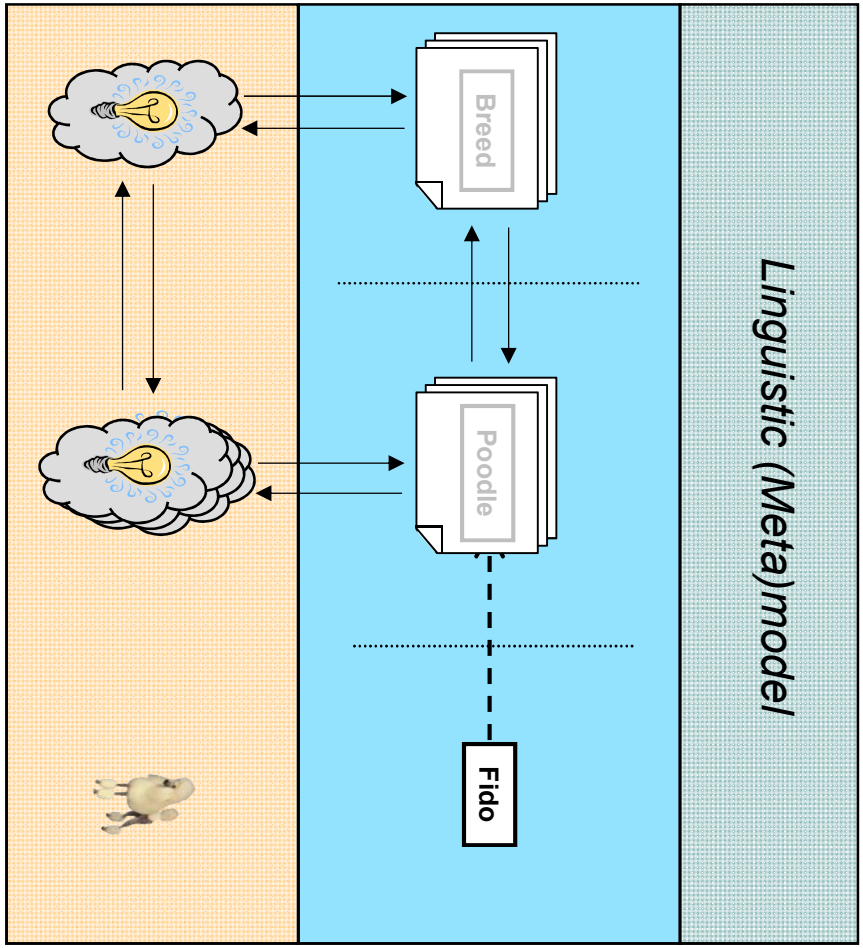

Conclusion

- FOs and deep modelling are at one level fundamentally incompatible, but at another level they are synergetic
  - an FO can be supported as a DSL in deep modelling
  - FO semantic models map well to a potency-based OCA (Ullmans's triangle, Guizzardi's square)
- "Linguistic" and "ontological" are highly misleading labels for the different forms of classification
  - infrastructural versus conceptual or domain
- The modeling community would benefit from a fundamental unification of FO and deep modelling
  - FOs needs to move beyond the two-level world view
  - Infrastructural model needs to be enhanced with FO concepts
- Deep modelling environment from Uni. Mannheim
  - www.melanee.org

Deep, SUM-based Environments