

Formal Ontology, Patterns and Anti-Patterns for Next-Generation Conceptual Modeling

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Acknowledgements

I am grateful to Gerd Wagner, Nicola Guarino, Ricardo Falbo, Renata Guizzardi, João Paulo Almeida, John Mylopoulos and the members of NEMO for many years of fruitful collaboration.

*“**Conceptual Modeling** is the activity of describing aspects of the **physical and social world** for the purpose of **understanding and communication...** the adequacy of a conceptual modeling notation rests in its ability to **promote understanding** about that world **among its human users**”*

(John Mylopoulos, Conceptual Modeling and Telos, 1992)

Why now?

1

Much larger degrees of
automation producing
information in all forms

The **Taxonomy** of Animals in *The Celestial Emporium of Benevolent Knowledge* (Borges)

- Those that belong to the emperor
- Those that resemble flies from a distance
- Those that have just broken a flower vase
- Embalmed ones
- Fabulous ones

“Those that resemble flies from a distance”

is a logically possible way to group objects, but it's not how we naturally make sense of the world. No real language would have a noun for such a category...Real nouns capture something deep; they refer to **kinds** of things that are thought to share deep properties...”

(Paul Bloom, *How Pleasure Works*, 2010)

“...As the evolutionary theorist Stephen Jay Gould put it, our classifications don't just exist to avoid chaos, they are ***“theories about the basis of natural order.”***”

(Paul Bloom, How Pleasure Works, 2010)

Carving reality at its joints [Plato]:

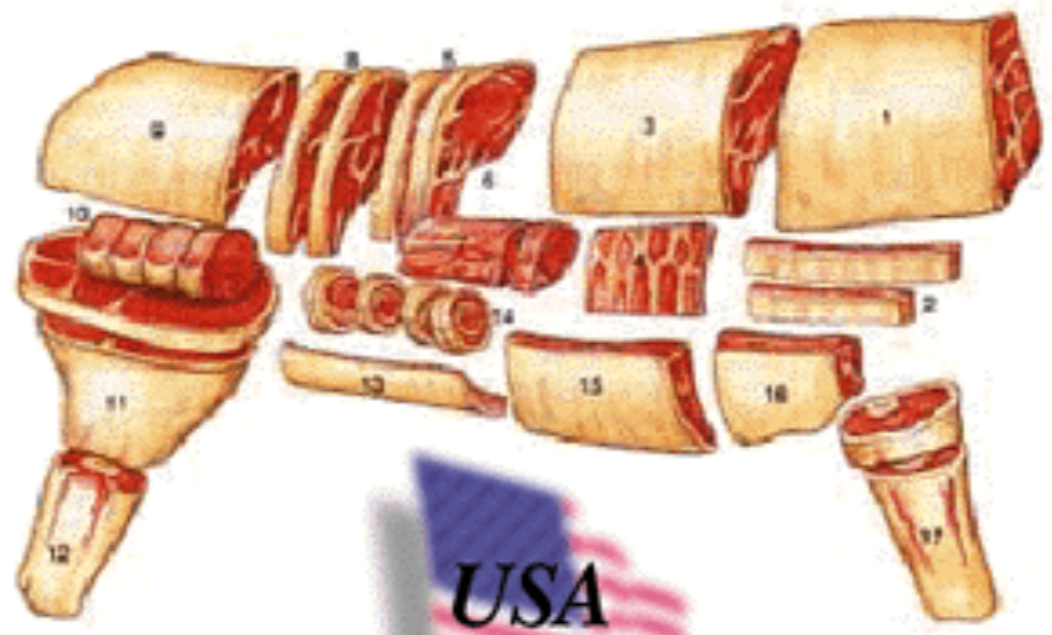




British



French



USA

“Carving up Reality”

We need to guarantee

Intra-worldview Consistency

and

Inter-worldview Interoperability

Why now?

2

The increasing need to
answer Cross-Silo
Questions

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World Trade Centre insurance

Bad forms

After a rancorous trial, relief for many insurers of the twin towers

May 6th 2004 | From the print edition



IT WAS a \$3.5 billion question: was the crashing of two aeroplanes into New York's twin towers in September 2001 one event or two? One, many insurers are relieved to know. On May 3rd a jury ruled that Swiss Re, the world's second-largest reinsurer, which wrote about a quarter of the coverage for the World Trade Centre, was bound by a form that classed such attacks as a single occurrence. Last week the same jury had reached a similar verdict for several Lloyd's of London syndicates and seven other insurers. The loser was Larry Silverstein, the centre's leaseholder. He had argued that another form was valid, in the hope of claiming around \$7 billion for two events. Now he may get only half that.

In most disaster insurance, "occurrence" is carefully defined. Earthquake coverage typically treats all shaking

AP



Silverstein's the loser

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World Trade Centre insurance

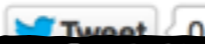
Bad forms

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World Trade Centre insurance

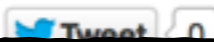
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World Trade Centre insurance

One into two

Having lost one legal case to insurers, the towers' leaseholder wins a second

Dec 9th 2004 | NEW YORK | From the print edition



SEVEN months ago, a jury in lower Manhattan ruled that under the forms covering insurance of the World Trade Centre, the striking of the twin towers by two aeroplanes constituted only one "occurrence". Consequently, Larry Silverstein, who had recently leased the Trade Centre complex, was entitled to one payment, not two—a difference of \$3.5 billion. On December 6th, in the same courtroom with the same judge presiding, another jury decided that under the documents used by nine other insurers the attacks were two events, thus qualifying for two payments. The verdict will provide Mr Silverstein with as much as \$1.1 billion extra for rebuilding the Trade Centre. It will also ensure that he remains in control of the project.

Why, after two weeks of deliberation, did the second jury come to a different conclusion from the first? The main reason lay in the preliminary paperwork signed by the underwriters. Because the Trade Centre had been leased to Mr Silverstein only weeks before the attack, the final insurance contracts had yet to be signed. The insurers in the first trial had signed a form with a much tighter definition of an "occurrence" than in the form signed by the nine insurers in the second trial. In addition, the insurance companies' claim that they always define "occurrence" precisely may have been undermined by testimony that they had been flexible in other cases—for example, involving sequences of

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Why now?

3

The Criticality of the
Domains Involved and
Complexity of the
Concepts at hand

“Carving up Reality”

- There is not doubt about the brute reality. The issue is interpreting that part of reality according to a certain **system of categories**
- These categorization operations are in a sense **a prioristic**

Ontology

- For that we need a *a prioristic* system of categories and their ties addressing issues of Identity, Unity (Parts and Wholes), Individuation, Change, Classification and Taxonomic Structures, Dependence (Existential, Historical, Relational, Notional), Causality, Essential and Accidental Characterization
- We need **Formal Ontology** and **Ontological Analysis**

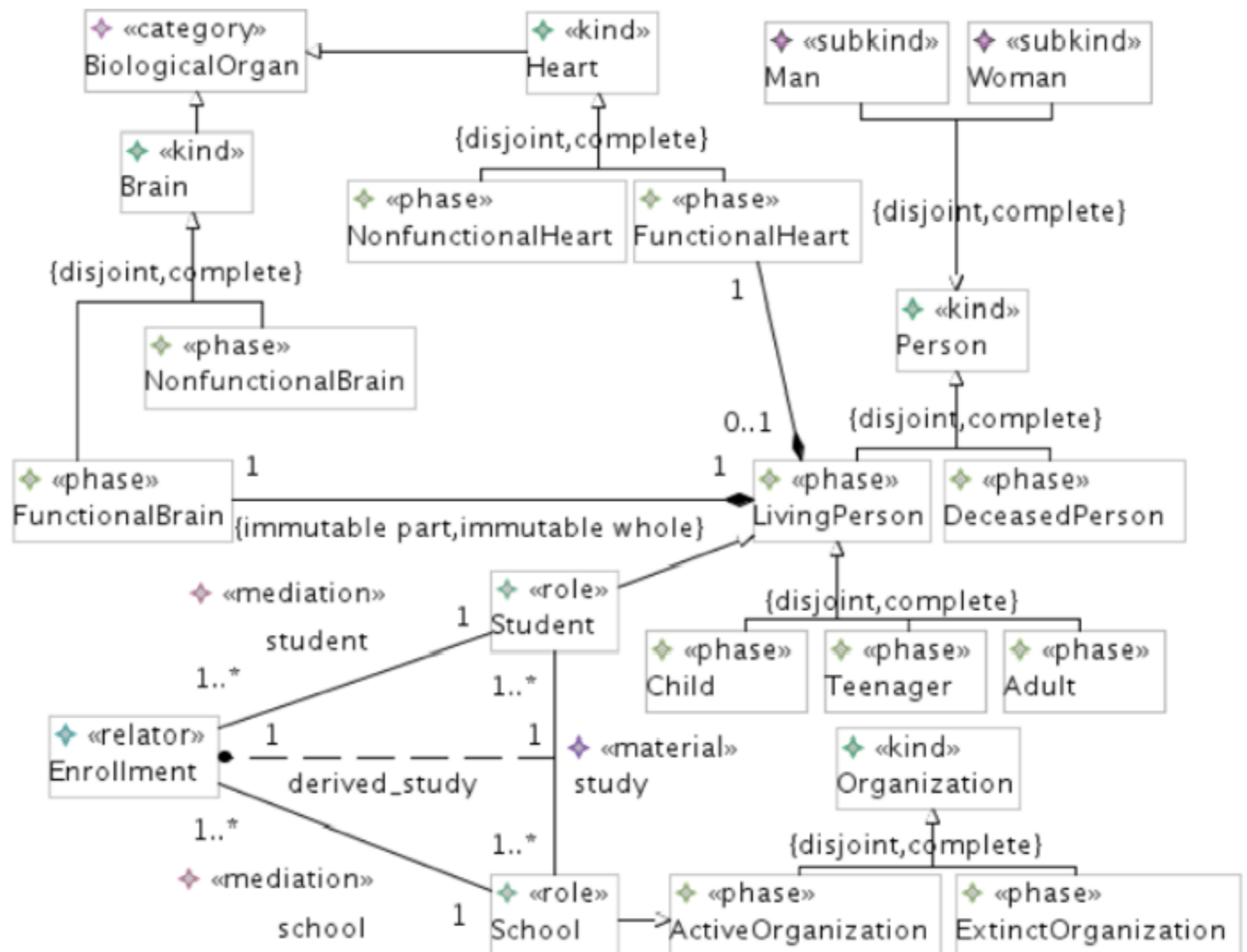
Ontology-Driven Conceptual Modeling

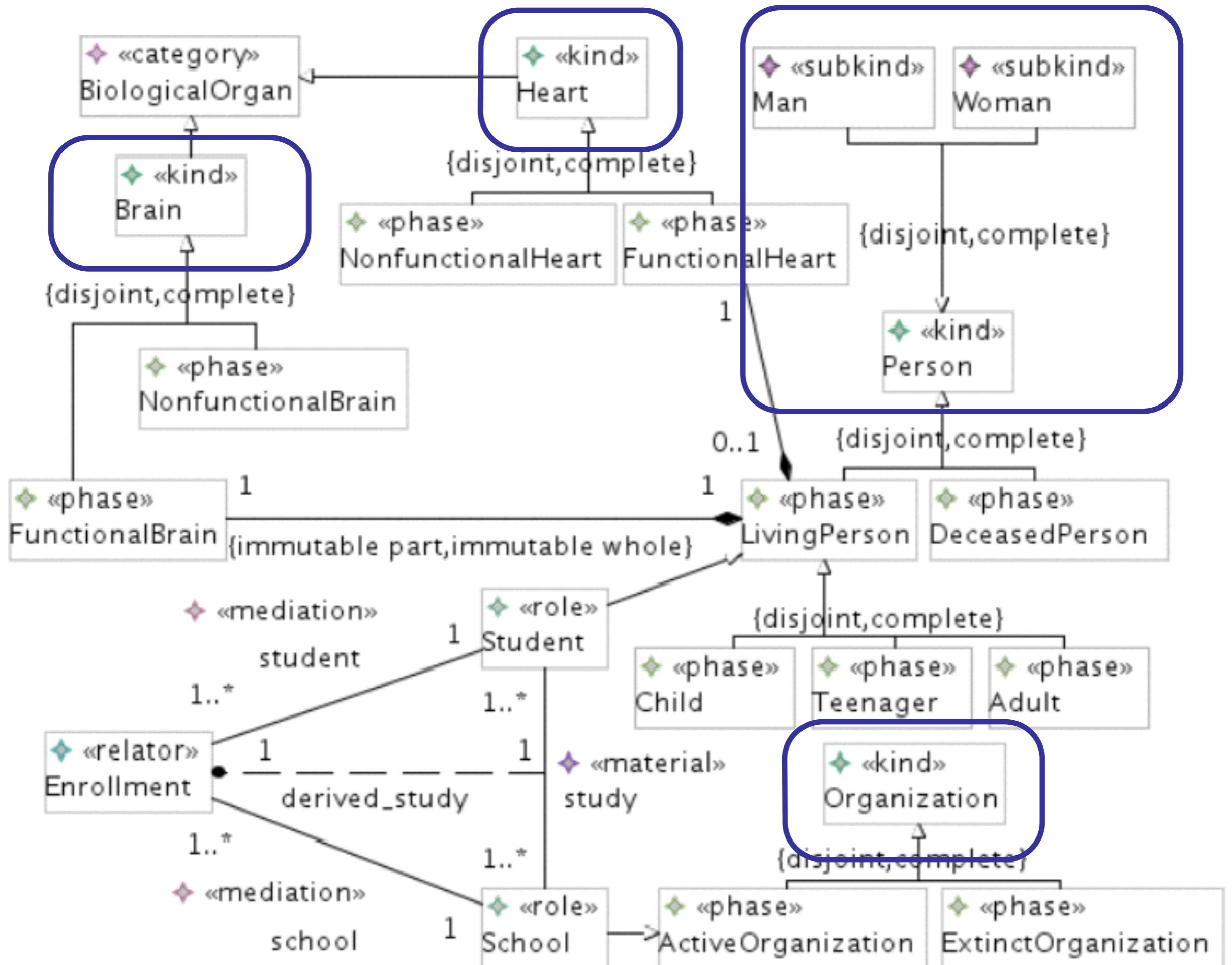
A discipline aiming at developing ontology-based methodologies, computational tools and **modeling languages** for the area of Conceptual Modeling

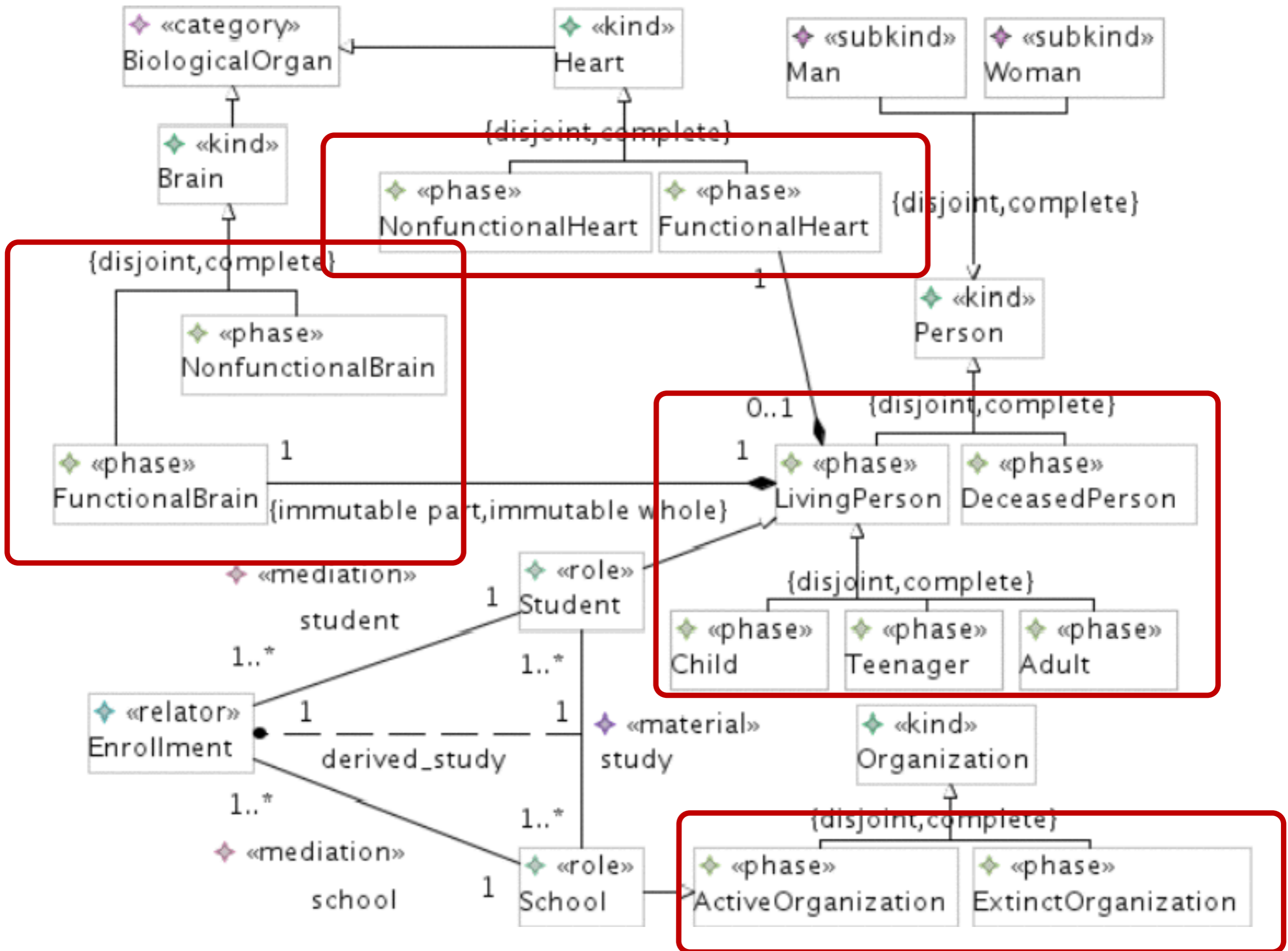
UFO

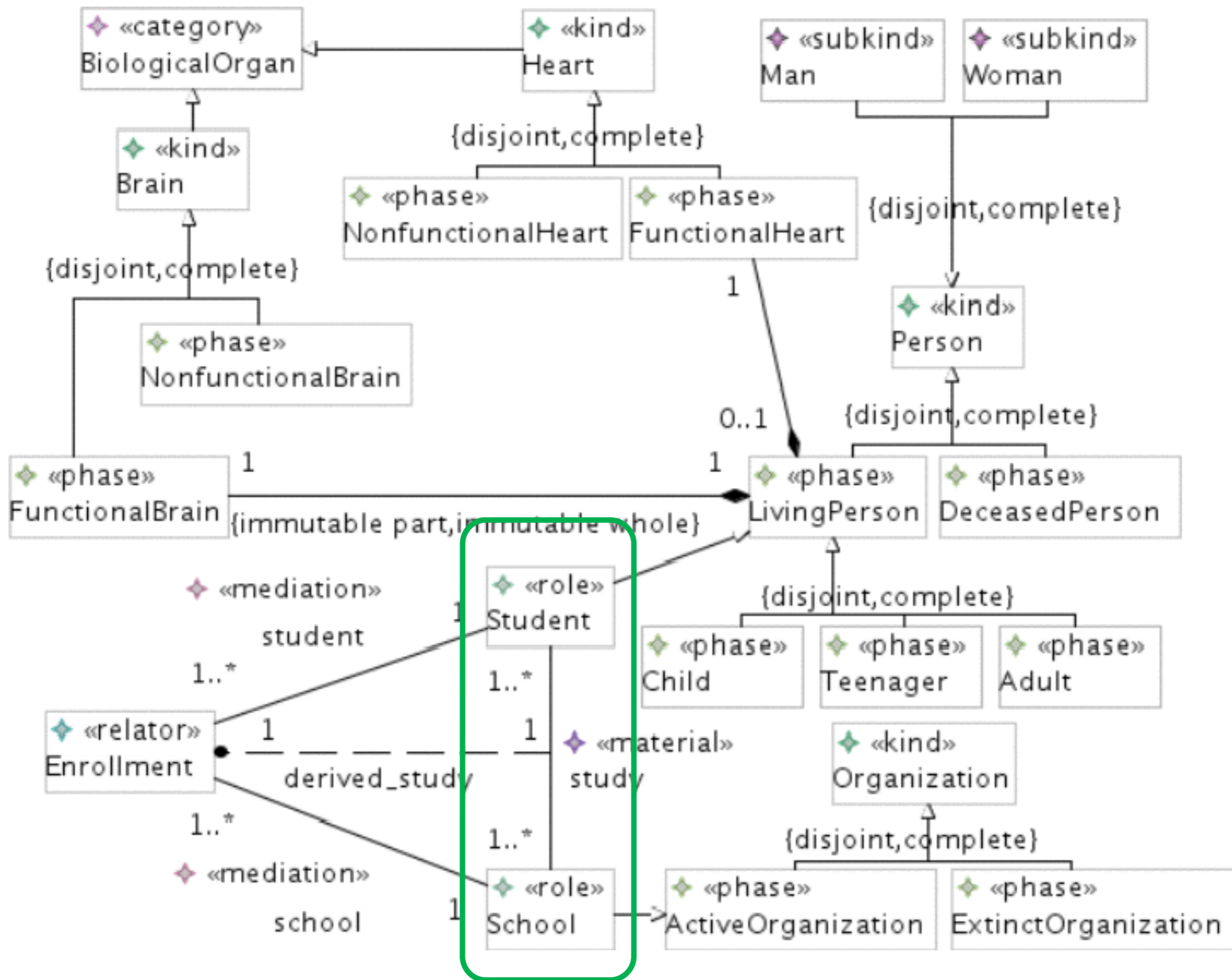
(Unified Foundational Ontology)

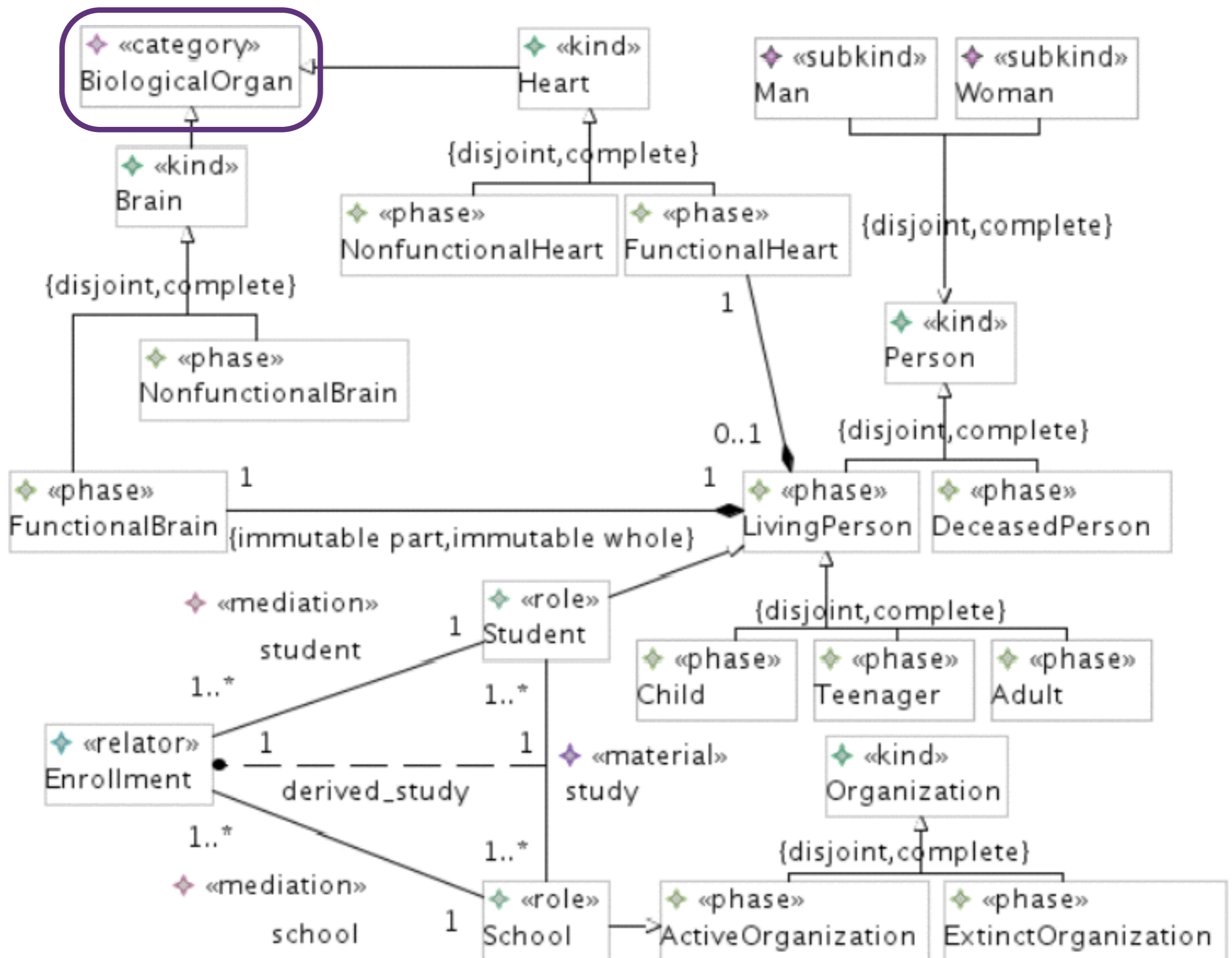
- Over the years, we have built a Philosophically and Cognitively well-founded Ontology to contribute to the general goal of serving as a Foundation for Conceptual Modeling
- This Ontology has been used to as a theory for addressing many classical conceptual modeling constructs such as Object Types and Taxonomic Structures (CAISE 2004, CAISE 2007, CAISE 2012), Part-Whole Relations (CAISE 2007, CAISE 2009, FOIS2010, CAISE 2011), Intrinsic and Relational Properties (ER 2006, ER 2008, ER 2011, CAISE 2015), Weak Entities, Attributes and Datatypes (ER 2006), Events (ER 2013), Services (EDOC 2013), Capabilities (EDOC 2013), Goals, Communities, Organizational Structures, etc...



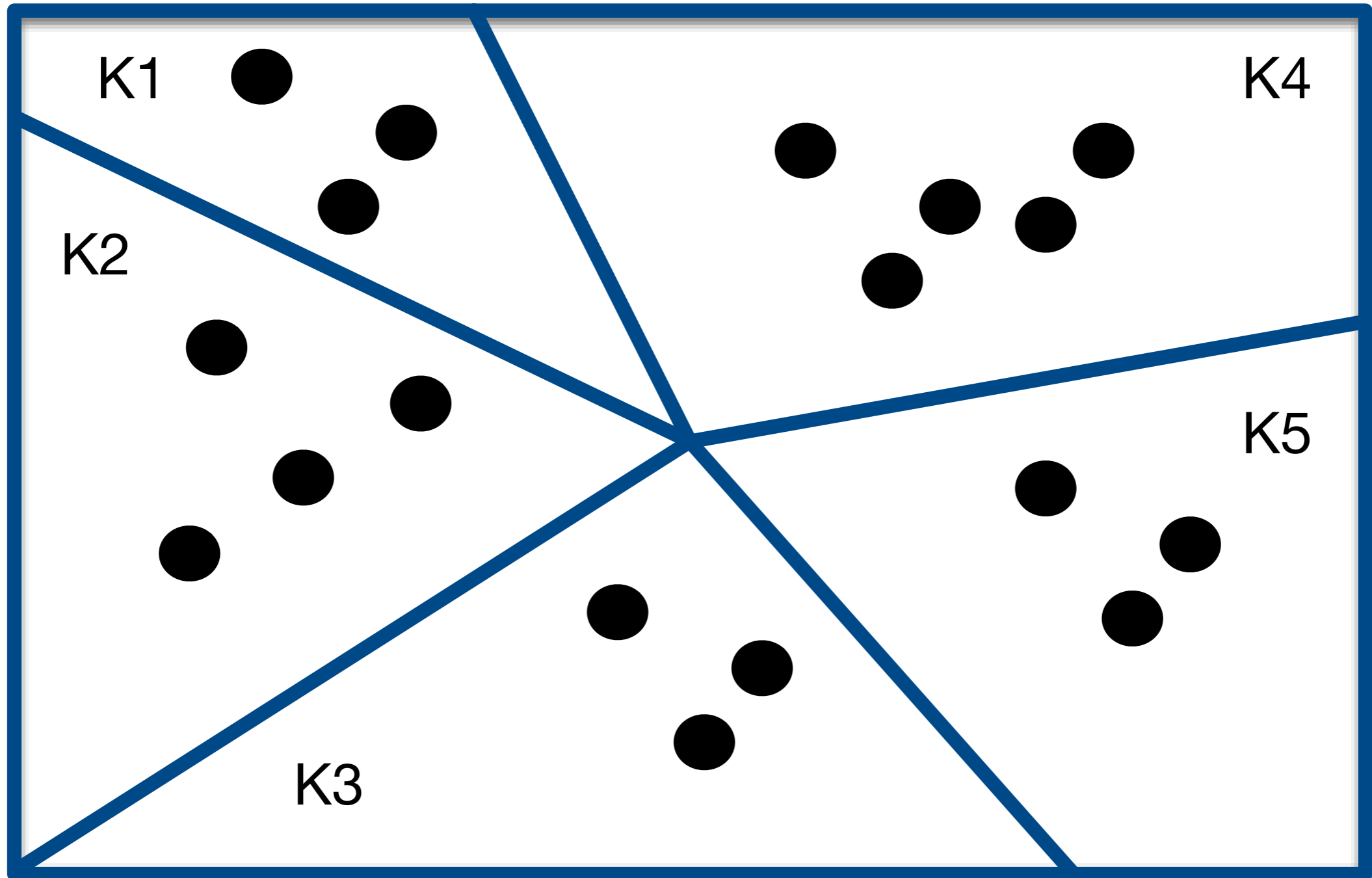




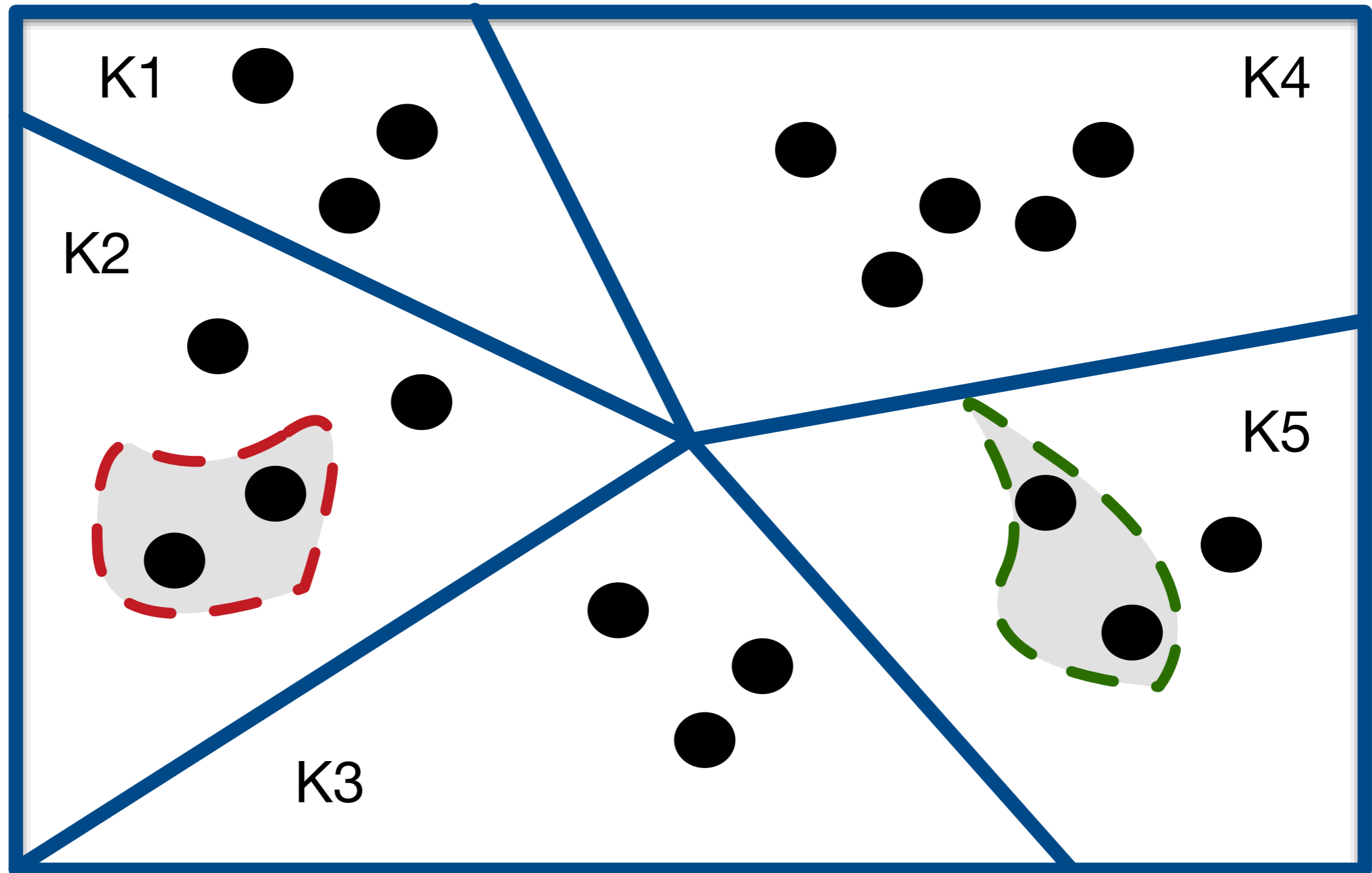




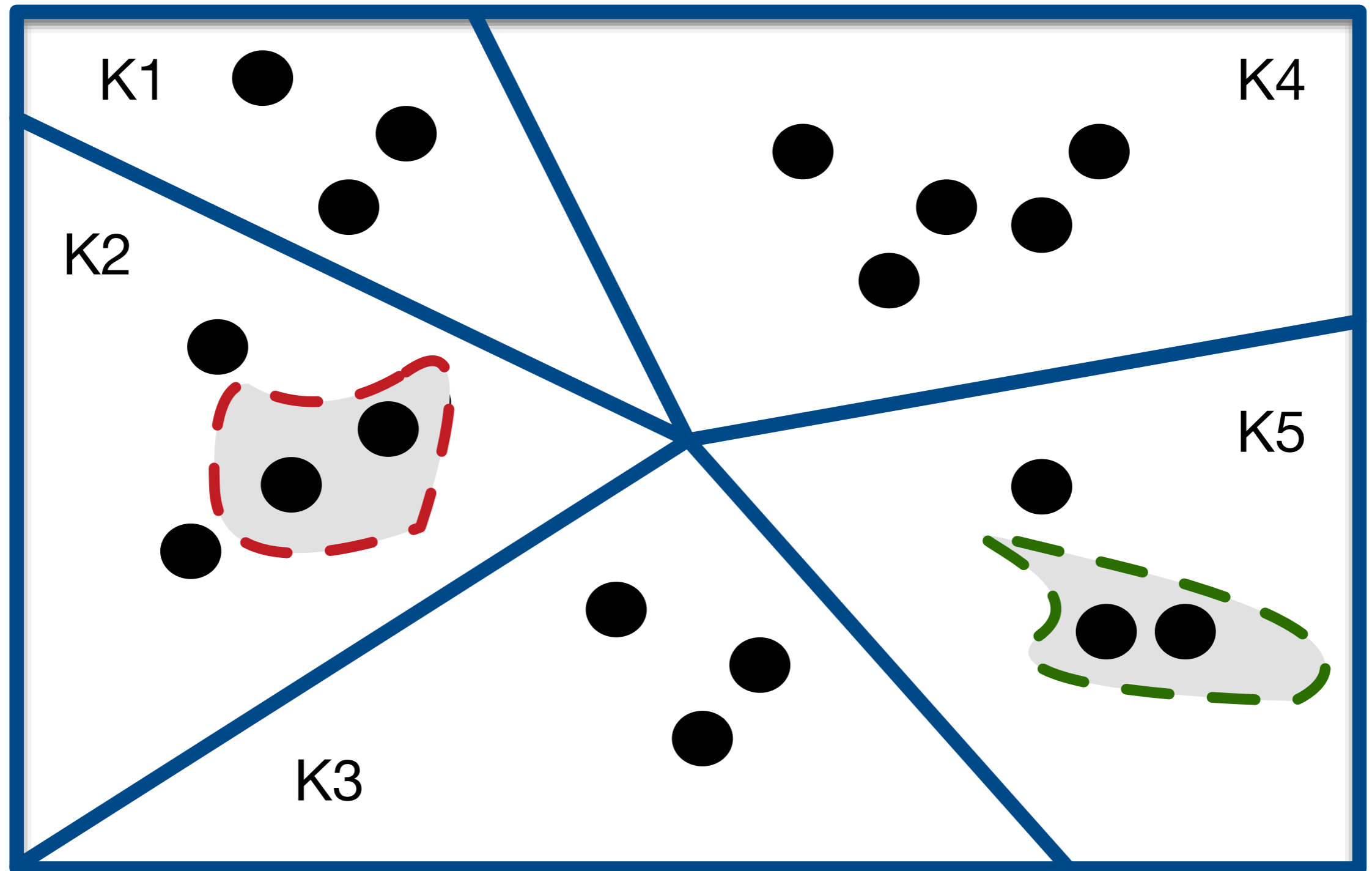
Kinds



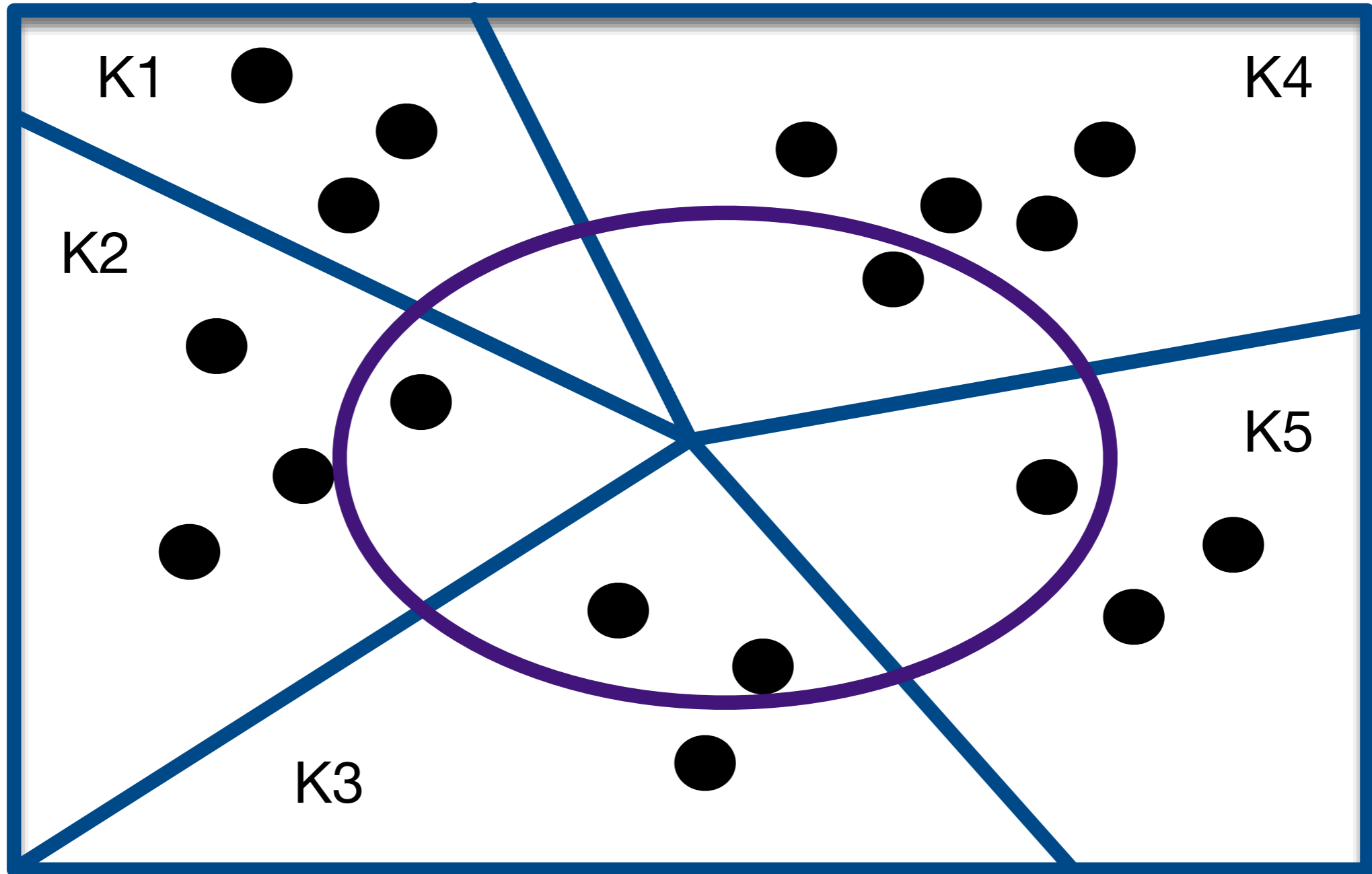
Anti-Rigid Sortals (**Roles** and **Phases**)



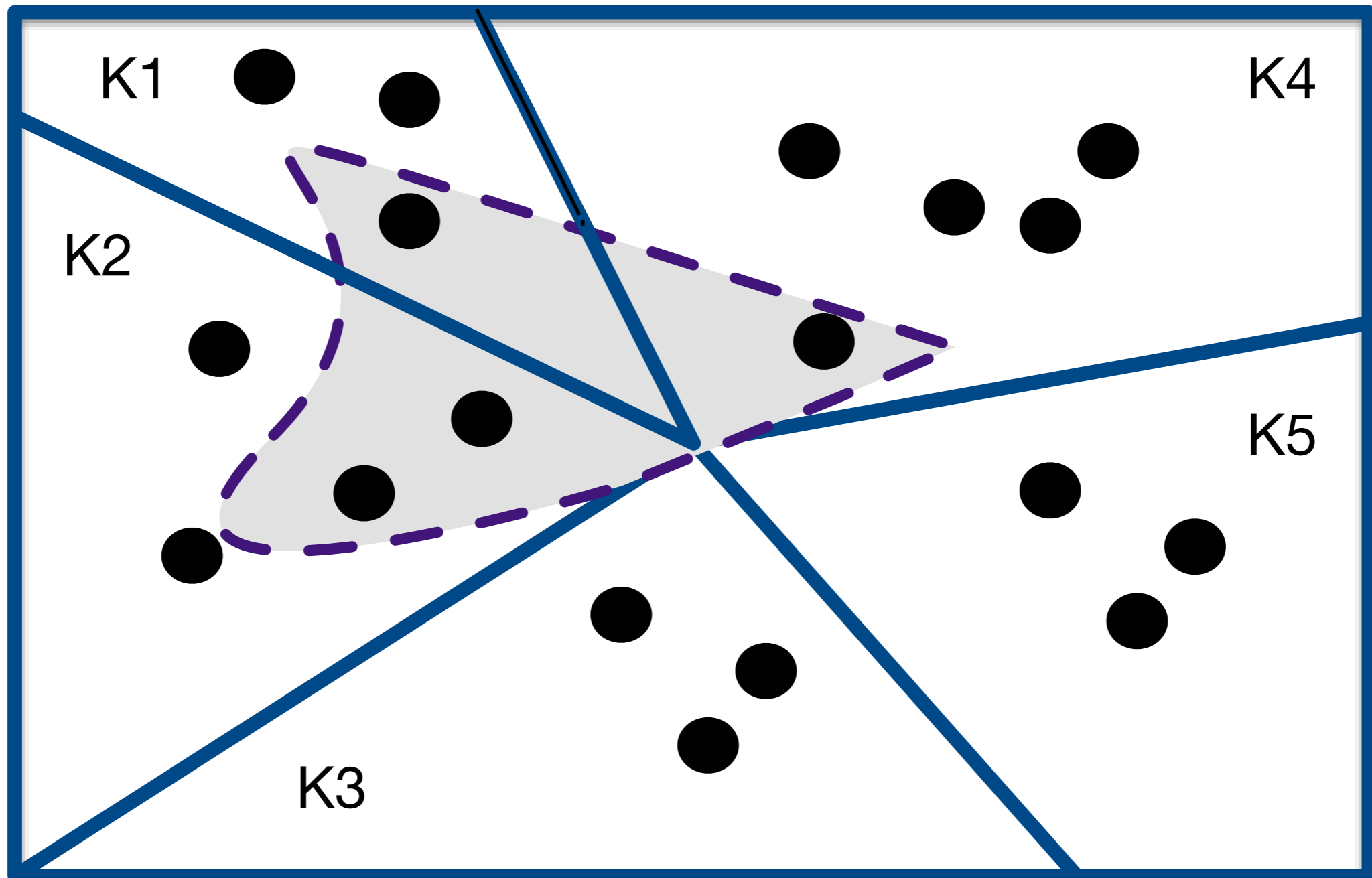
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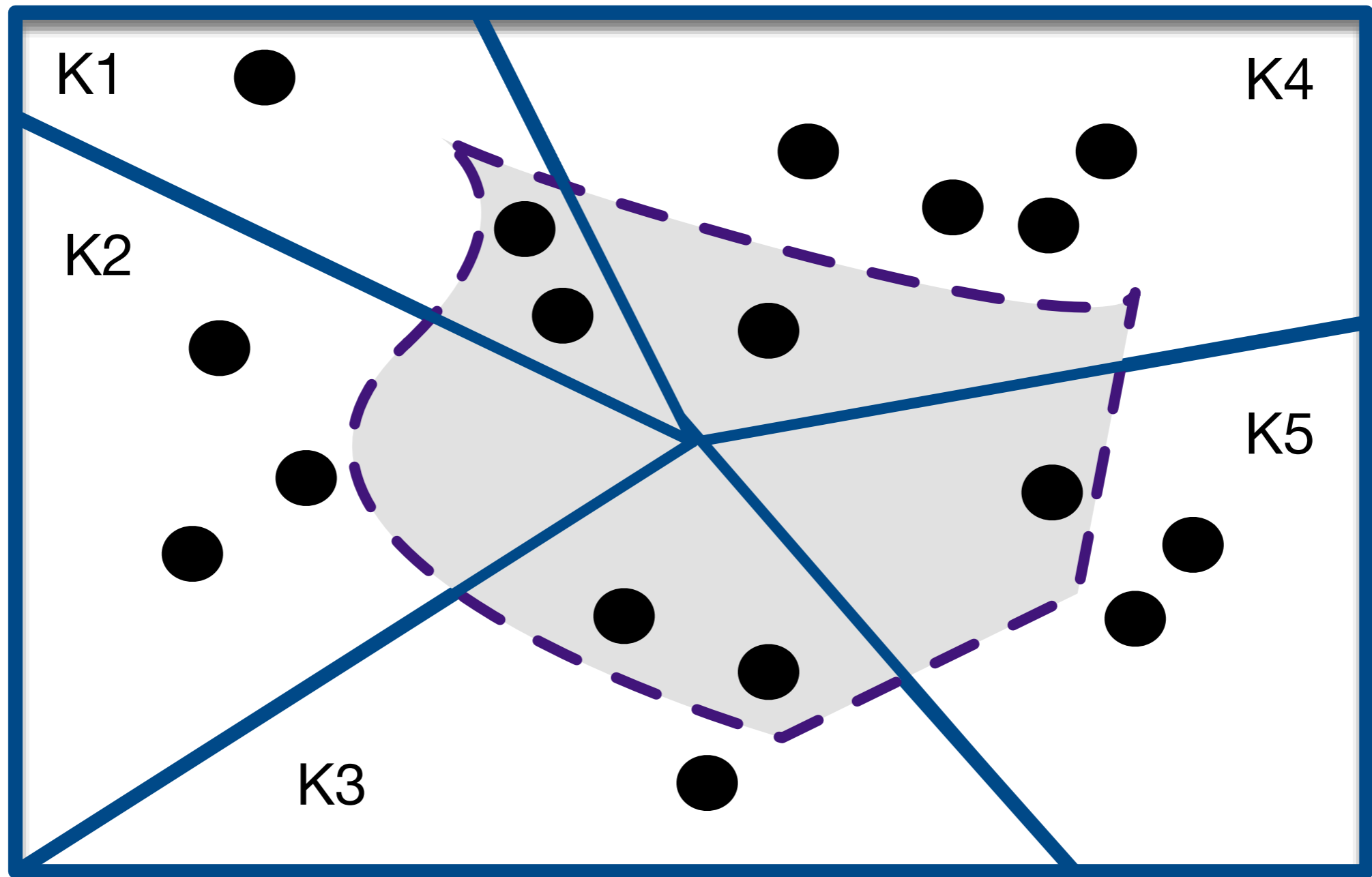
Rigid Mixins

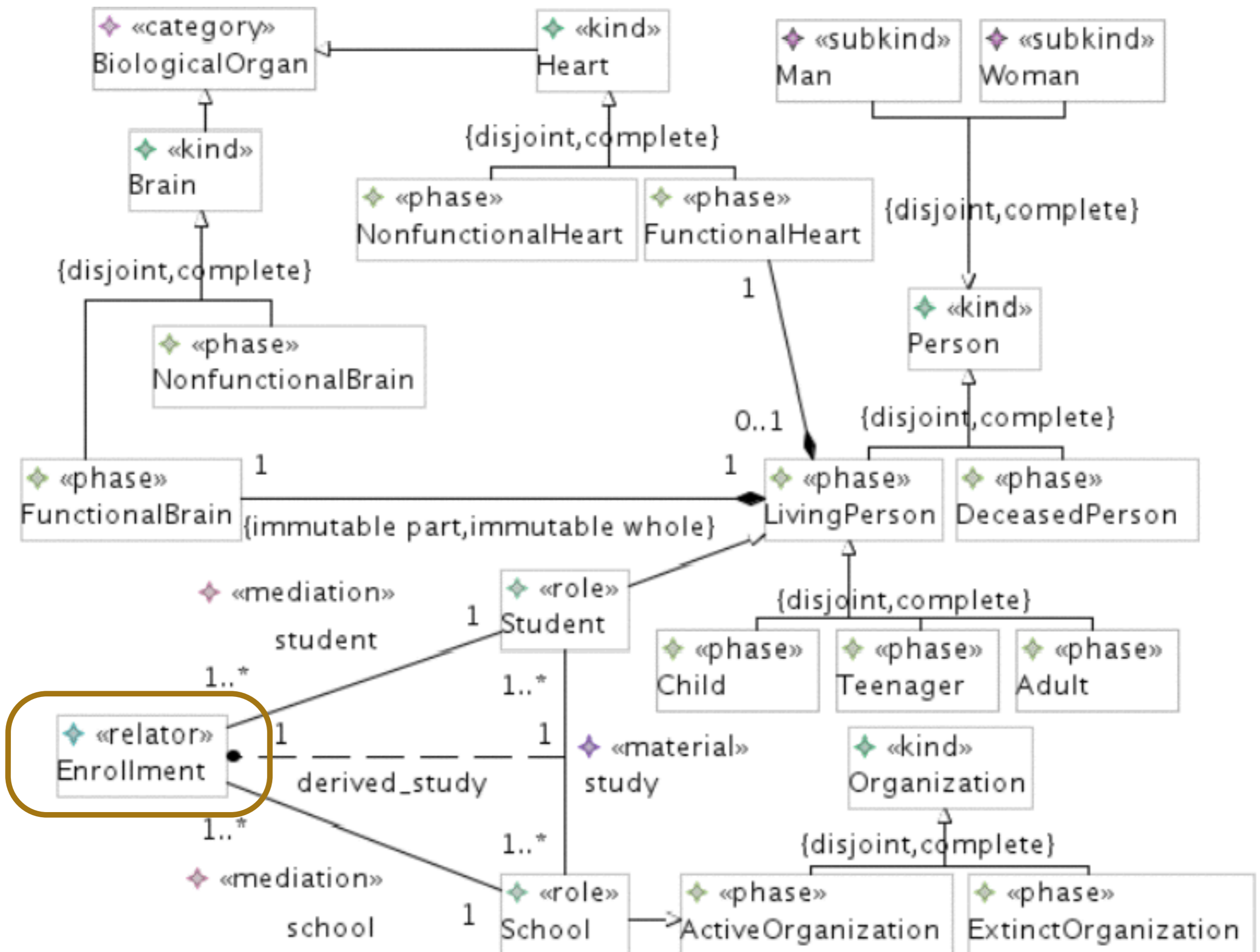


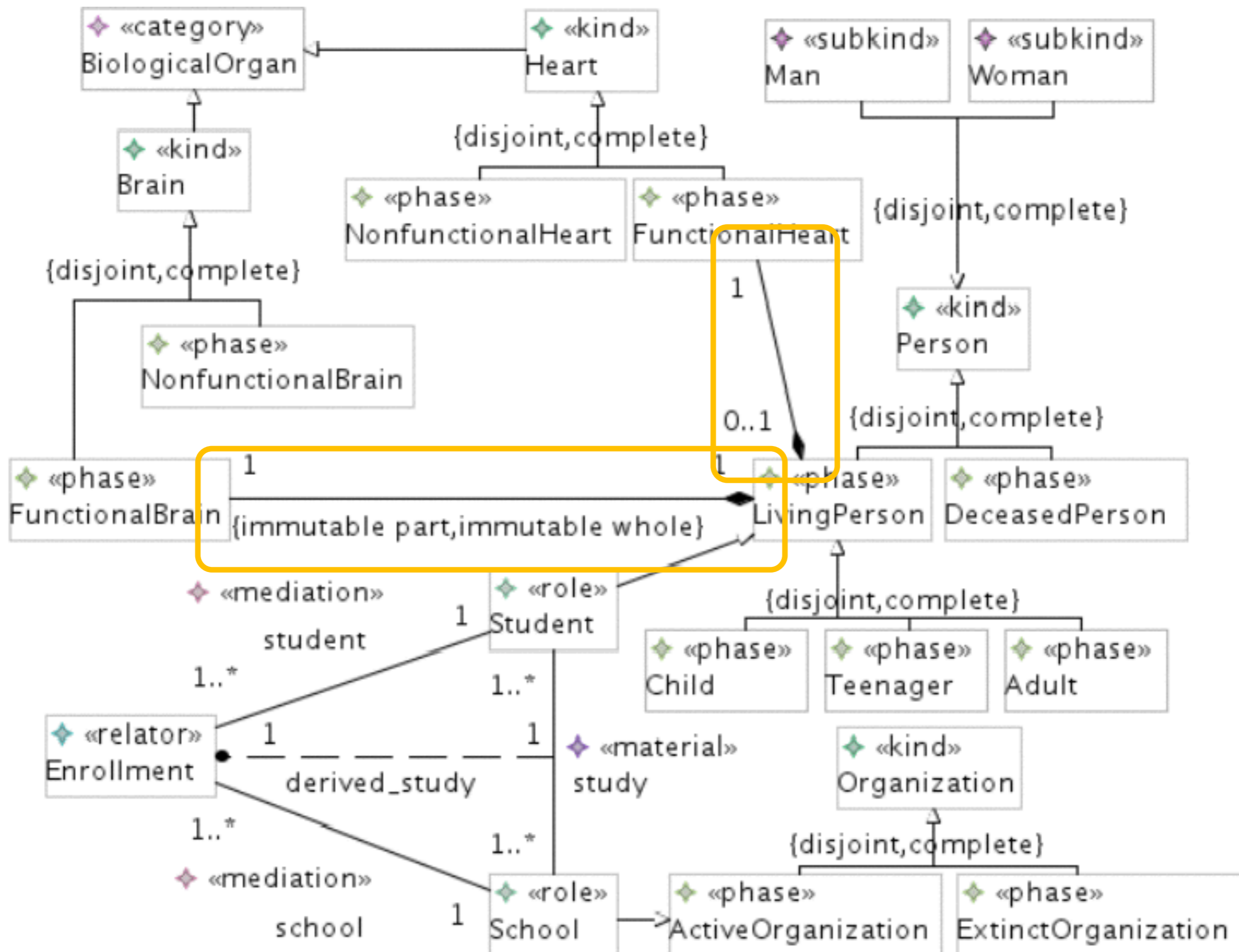
Anti-Rigid Mixins

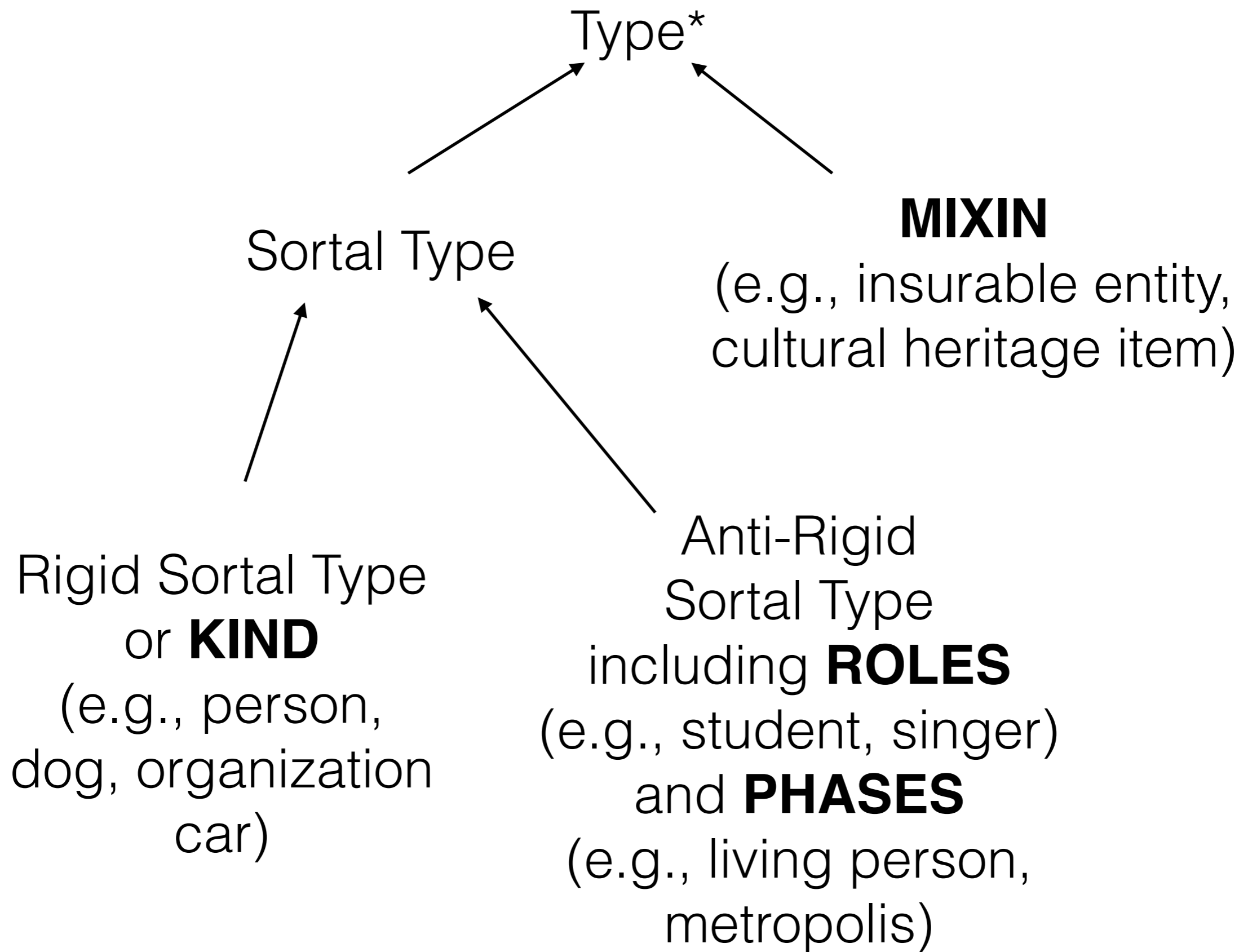


Anti-Rigid Mixins









* (these ontological distinctions with the meaning they have in OntoUML were first presented at Guizzardi, Wagner, Guarino & van Sinderen in CAISE, 2004 and are strongly based on the ontological distinctions underlying the OntoClean methodology, see Guarino & Welty, 2002, 2004)

Why is this important?

1

Ontologically well-defined,
formally characterized and
cognitively sound
systems of types

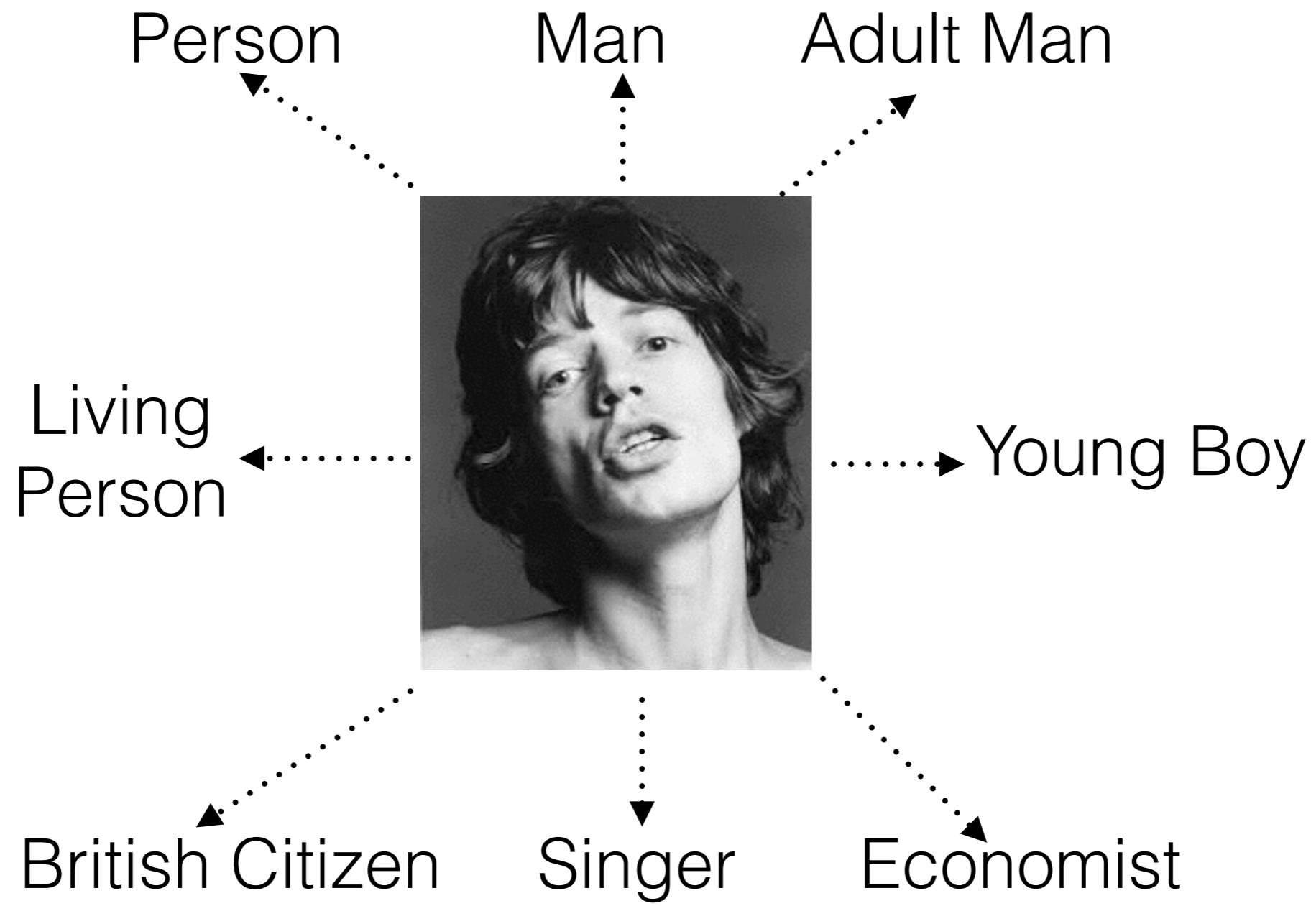
Why is this important?

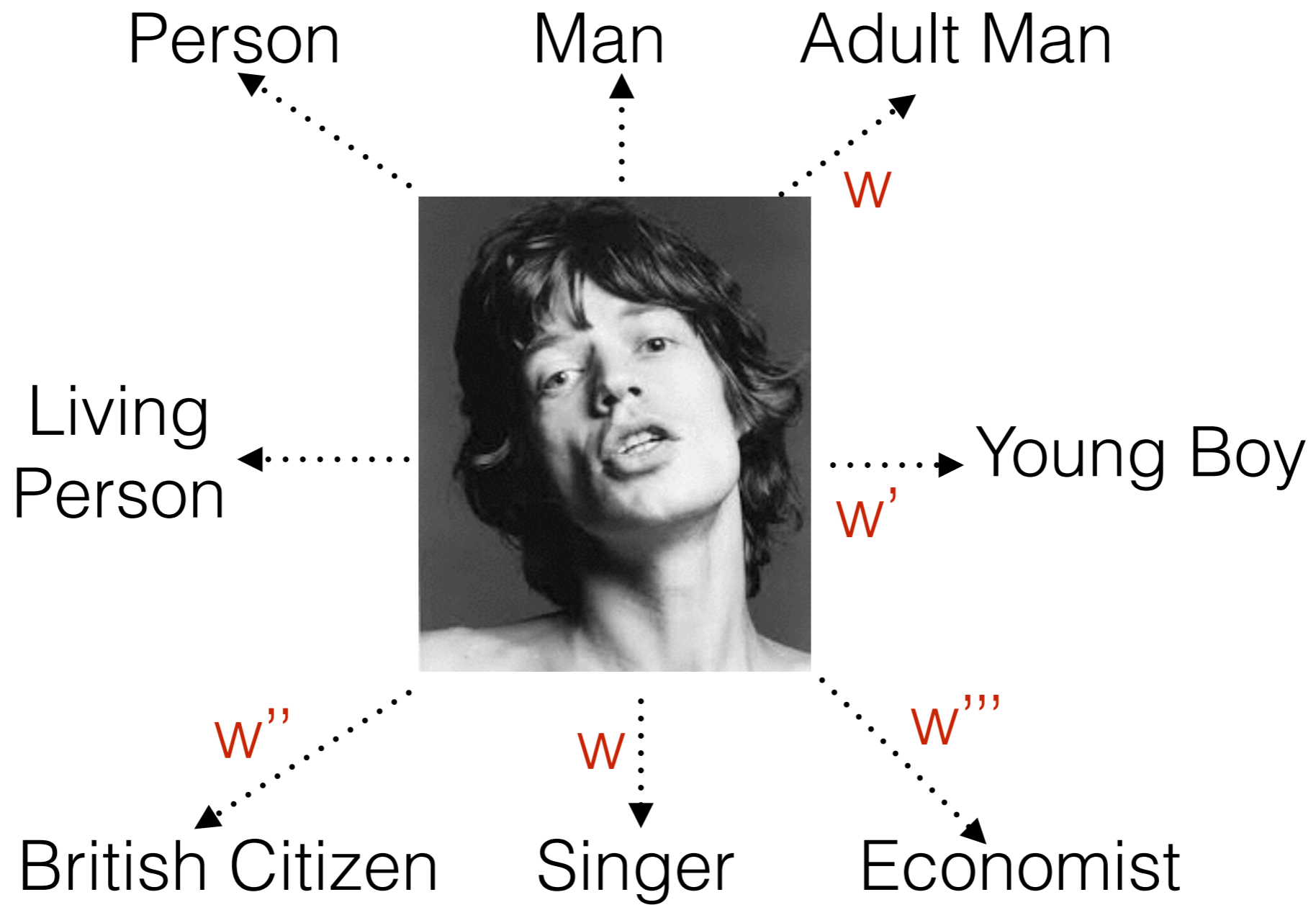
2

Precise methodological
guidelines for choosing how to
model different elements in
the universe of discourse

Problem (1)

1. Characterize the difference between the following types:
 - Person, Apple, Car, Dog, Organization
 - Student, Singer, President, Employee
 - Adult, Puppy, Metropolis
 - Crime Weapon, Insurable Item, Sharp Object, Rational Agent, Cultural Heritage Item





Solution

1. Characterizing the difference between:

- NATURAL TYPE/KIND (e.g., Person, Apple, Car) = **RIGID SORTAL**
- ROLE (e.g., Student, President, Employee) = **ANTI-RIGID + RELATIONALLY DEPENDENT SORTAL**
- PHASE (e.g., Living Person, President, Employee) = **ANTI-RIGID + RELATIONALLY INDEPENDENT SORTAL**
- MIXIN (e.g., Crime Weapon, Insurable Item, Sharp Object, Rational Agent, Cultural Heritage Item)? = **MIXIN**

Why is this important?

3

Incorporation of ontological constraints in the language metamodel to guarantee *ontological consistency by design*

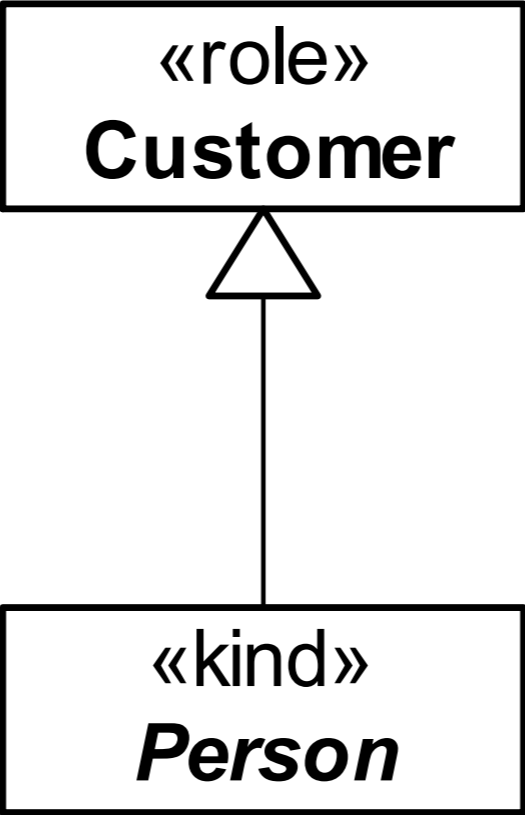
Role

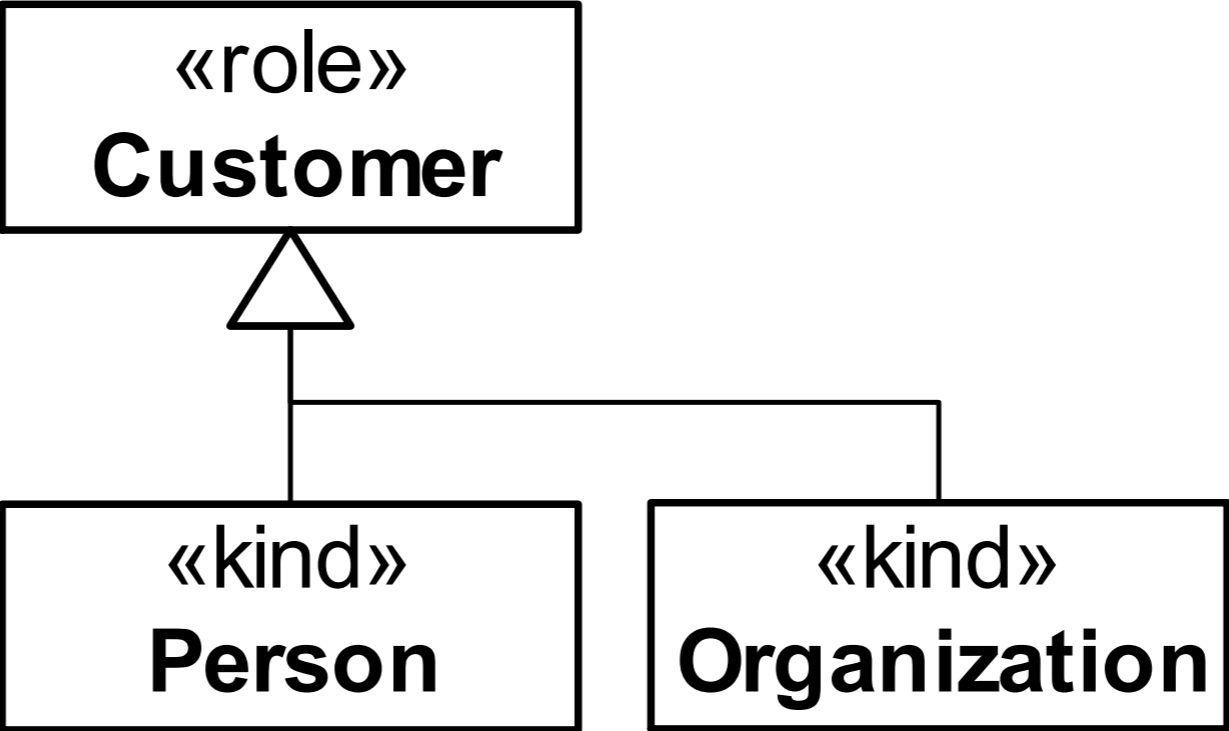
- All instances of a given ROLE are of the same KIND (e.g., all Students are Person)
- All instances of a ROLE instantiate that type only contingently (e.g., no Student is necessarily a Student)
- Instances of a KIND instantiate that ROLE when participating in a certain RELATIONAL CONTEXT (e.g., instances of Person instantiate the Role Student when enrolled in an Educational Institution)
- **A ROLE cannot be a supertype of a Rigid Type**

«role»
Customer

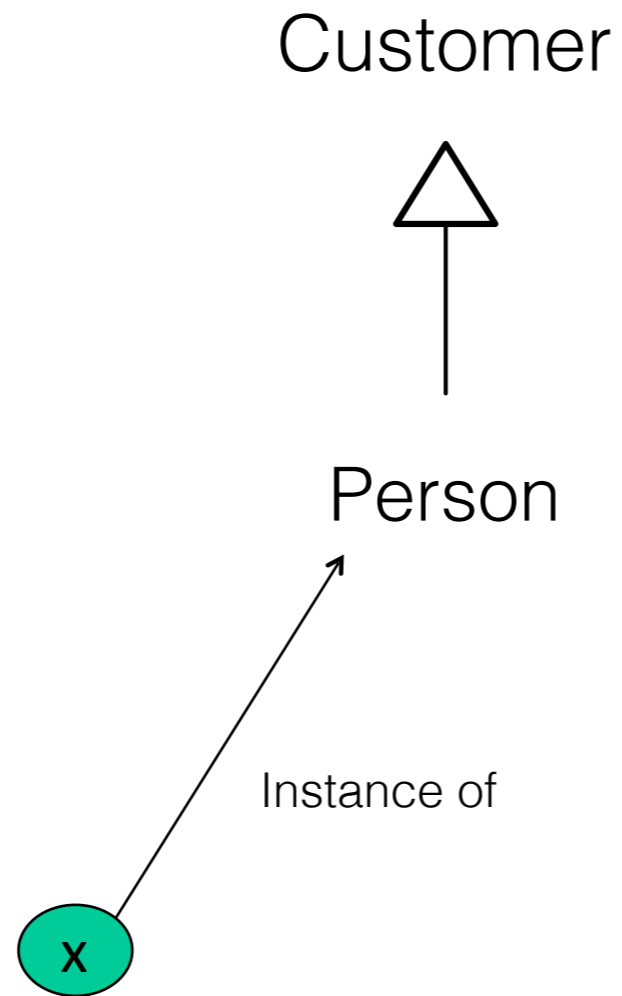


«kind»
Person

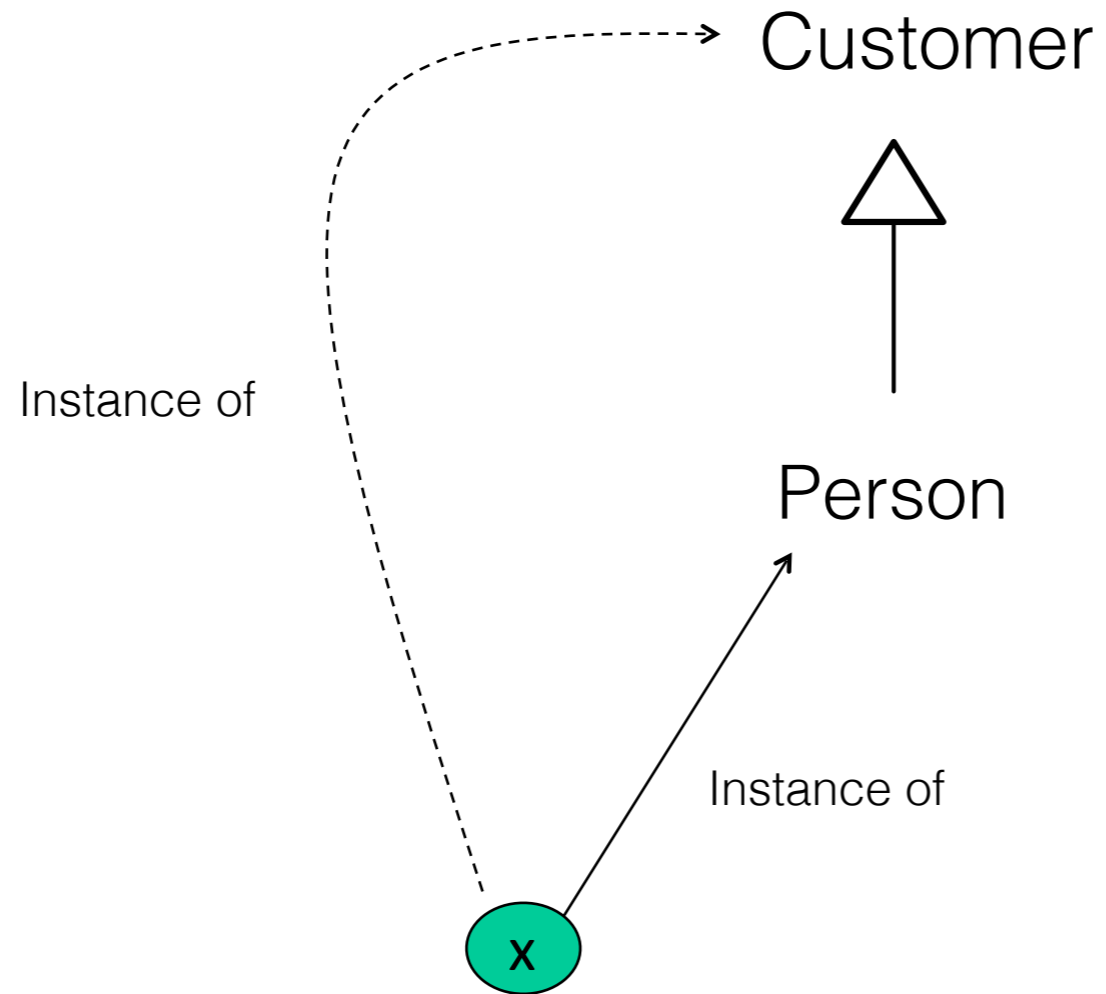




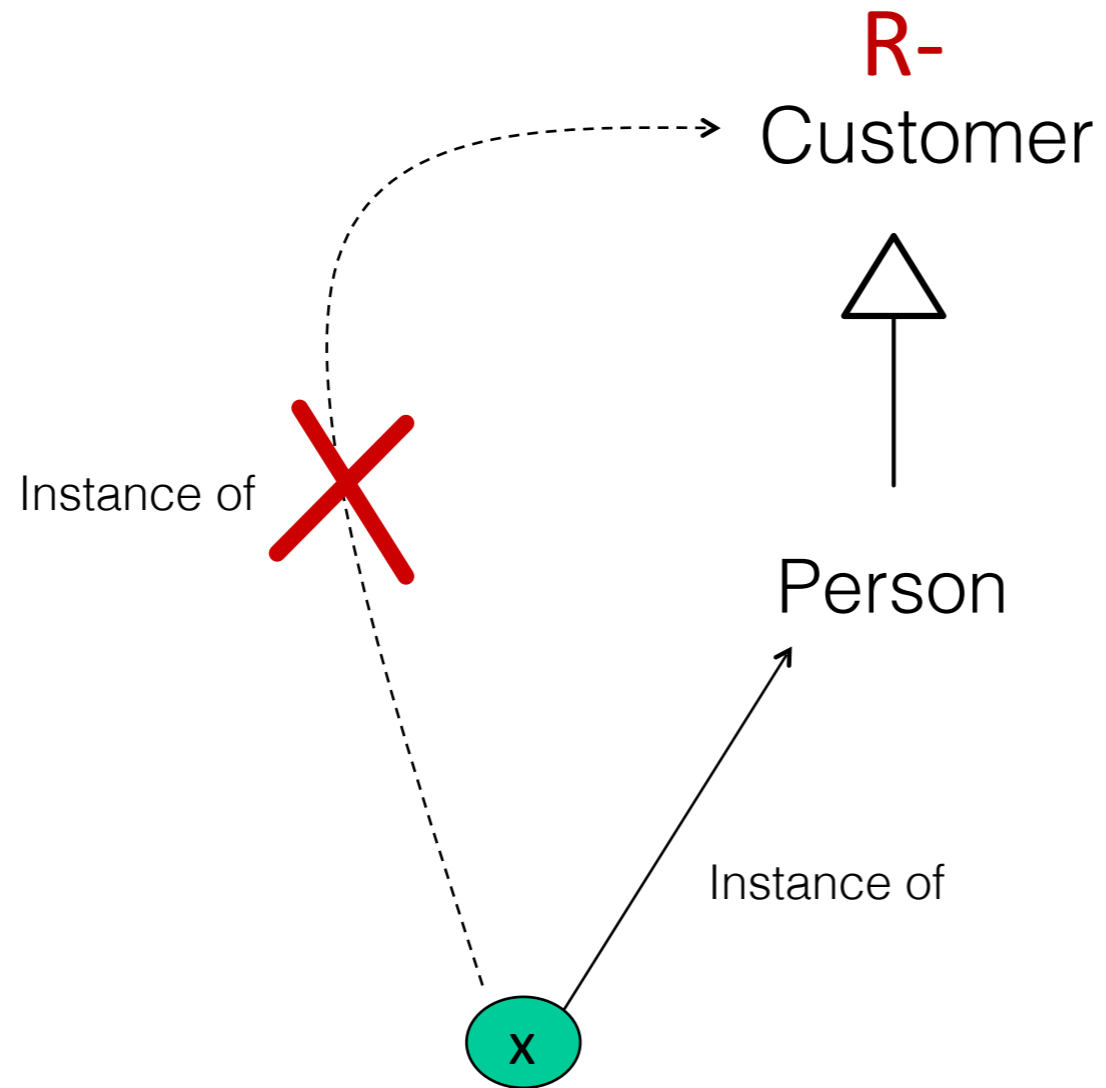
WORLD W



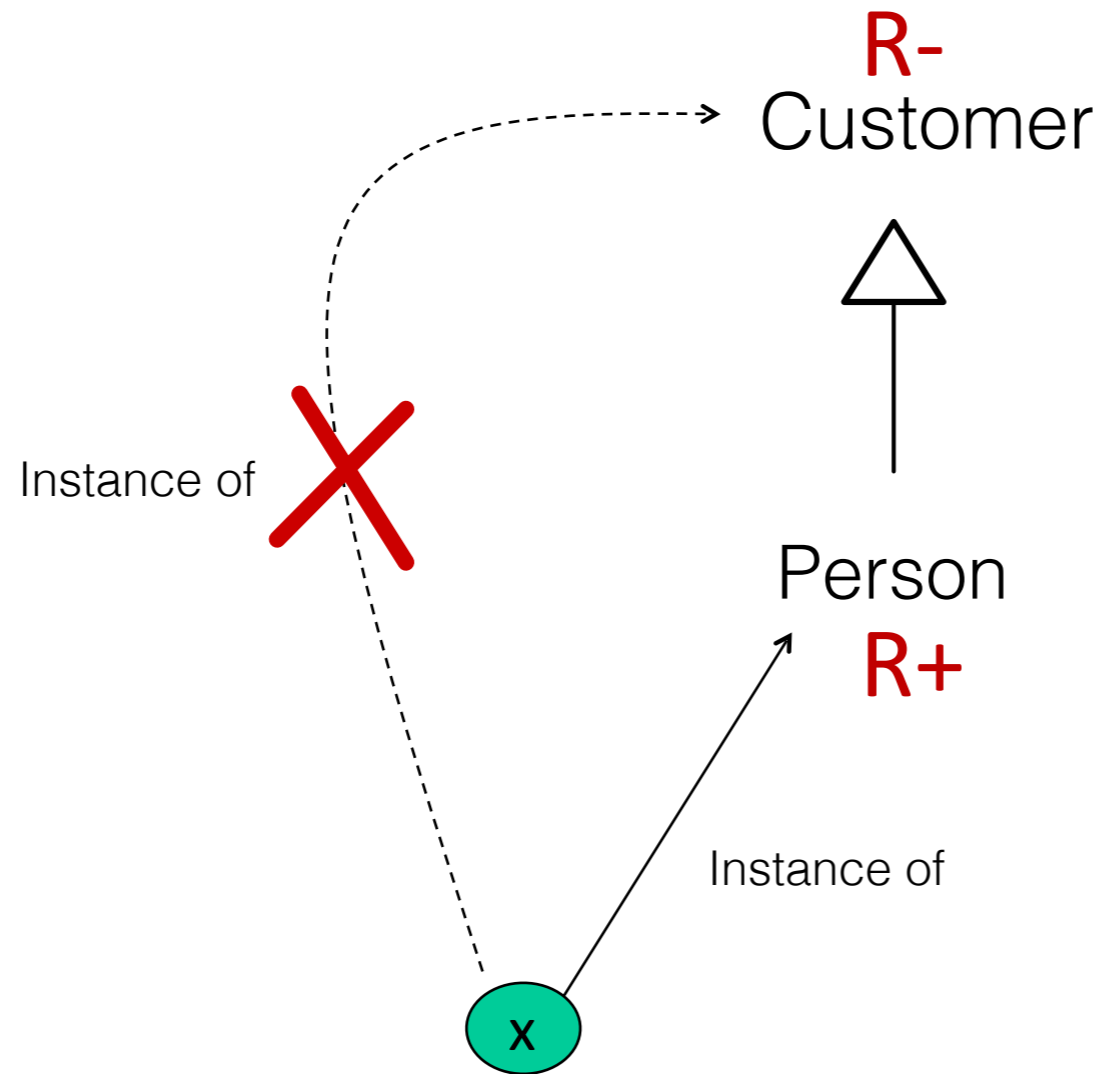
WORLD W



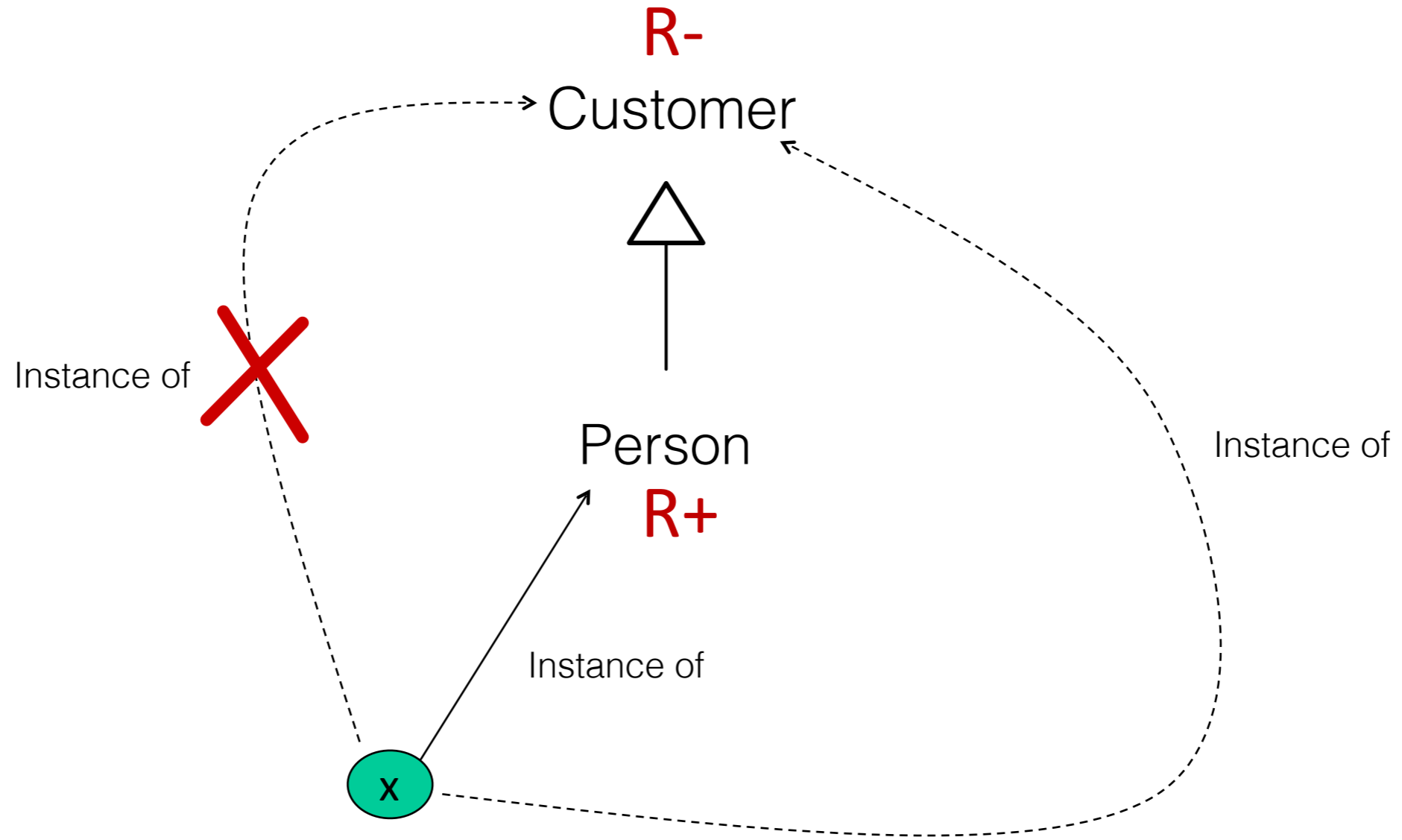
WORLD W'



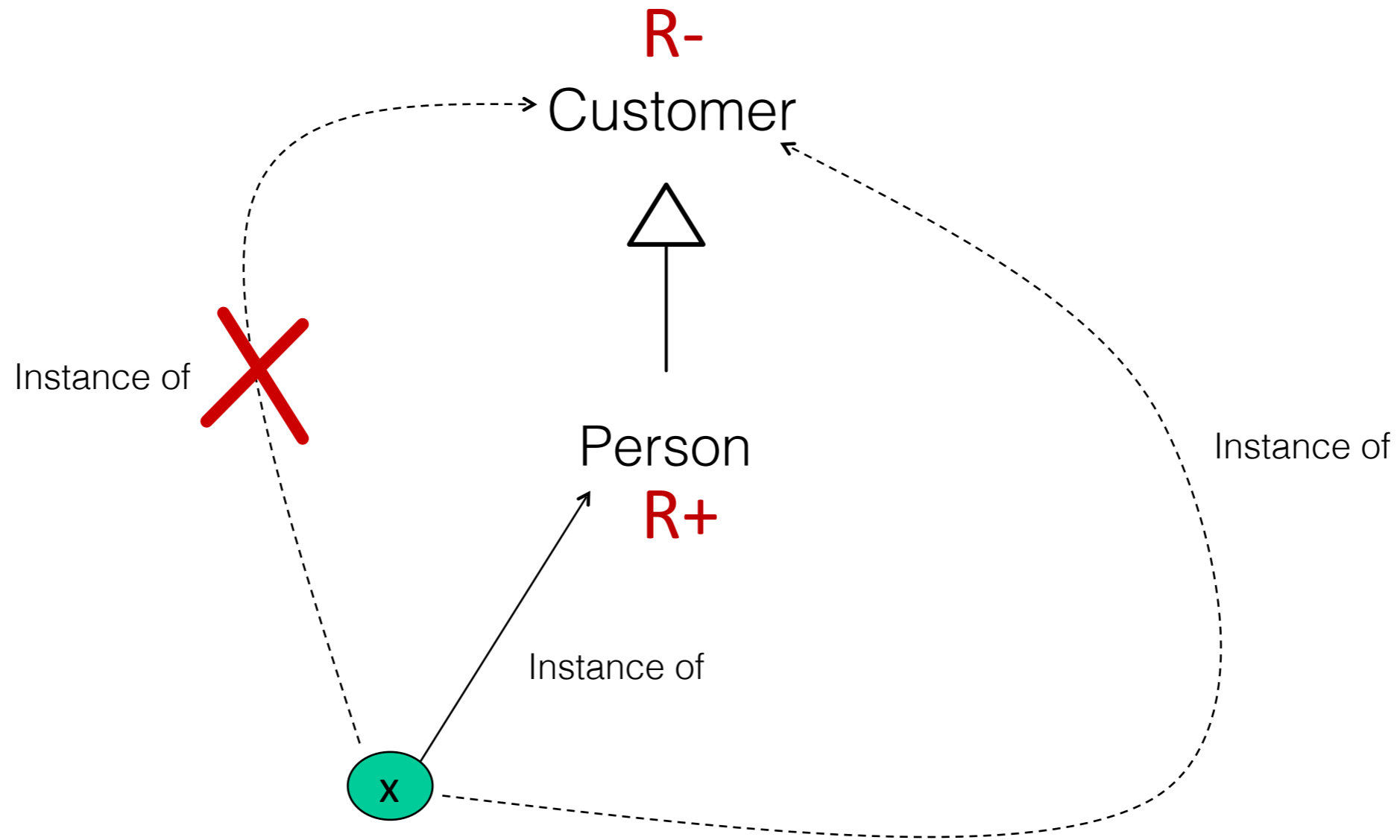
WORLD W'



WORLD W'



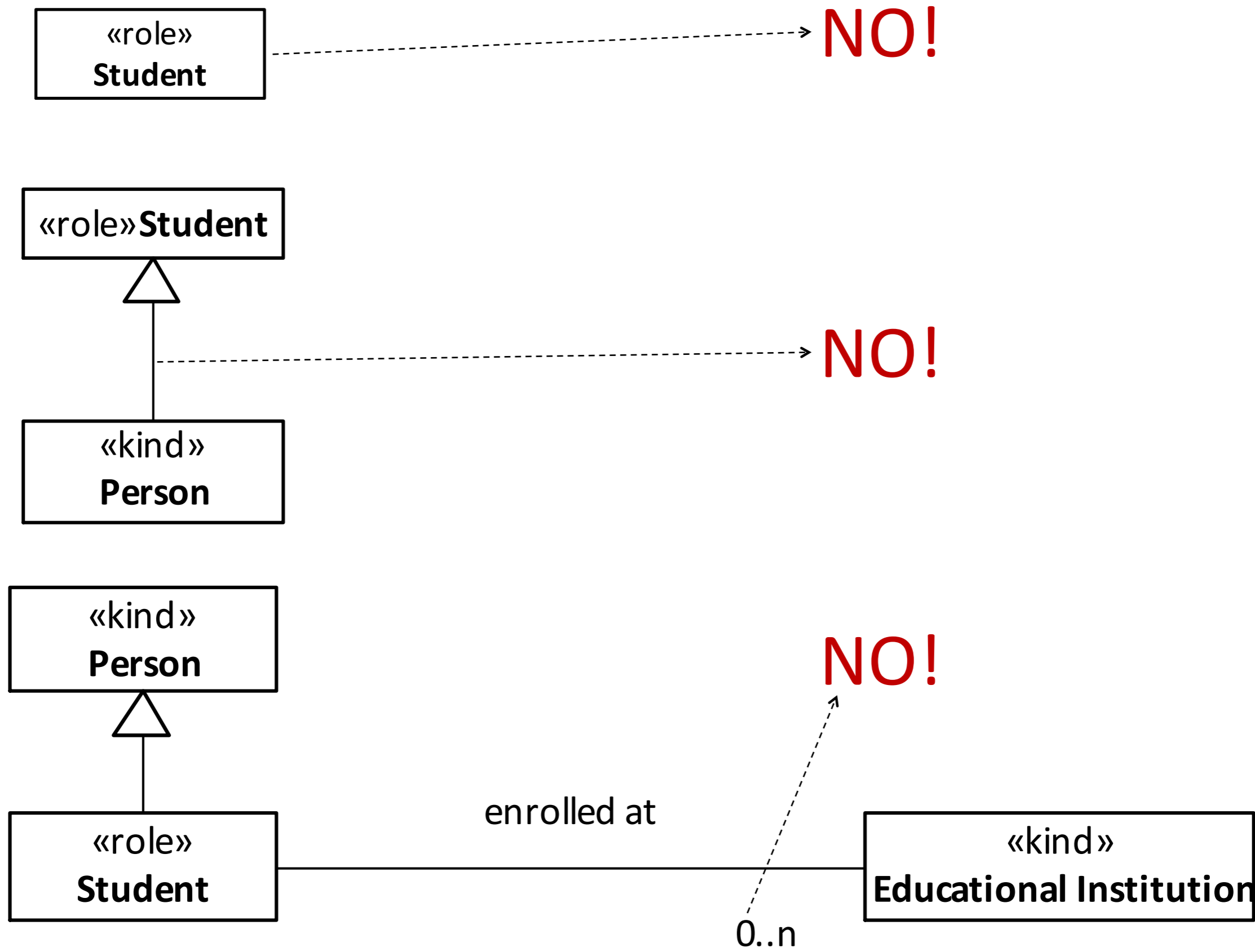
WORLD W'



We run into a logical contradiction!

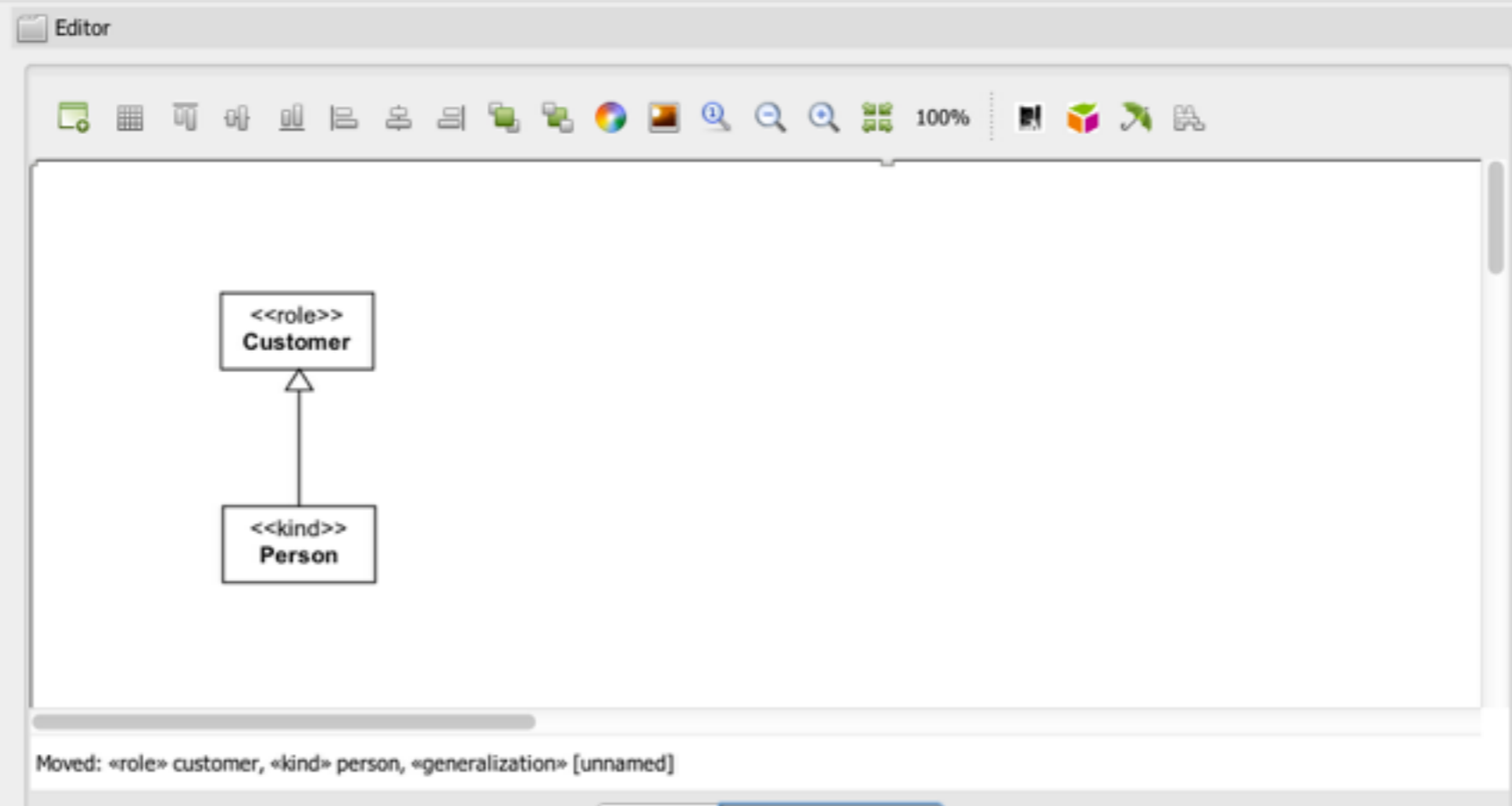
Role

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- Toolbox
- Elements
 - Nominal Quality
 - Non Perceivable Quality
 - Perceivable Quality
 - Phase
 - Primitive Type
 - Quantity
 - Relator
 - Role
 - Role Mixin
 - SubKind
 - Association
 - Characterization
 - ComponentOf
 - Derivation
 - Formal
 - Generalization
 - Material
 - Mediation
 - MemberOf
 - Structuration
 - SubCollectionOf
 - SubQuantityOf
- Patterns
- Derived Patterns



- Project Browser
- OLED Project
 - Diagrams
 - Constraints
 - Model
 - «Role» Customer
 - «Kind» Person
 - Generalization Customer

Welcome Diagram0* x

Information Footer

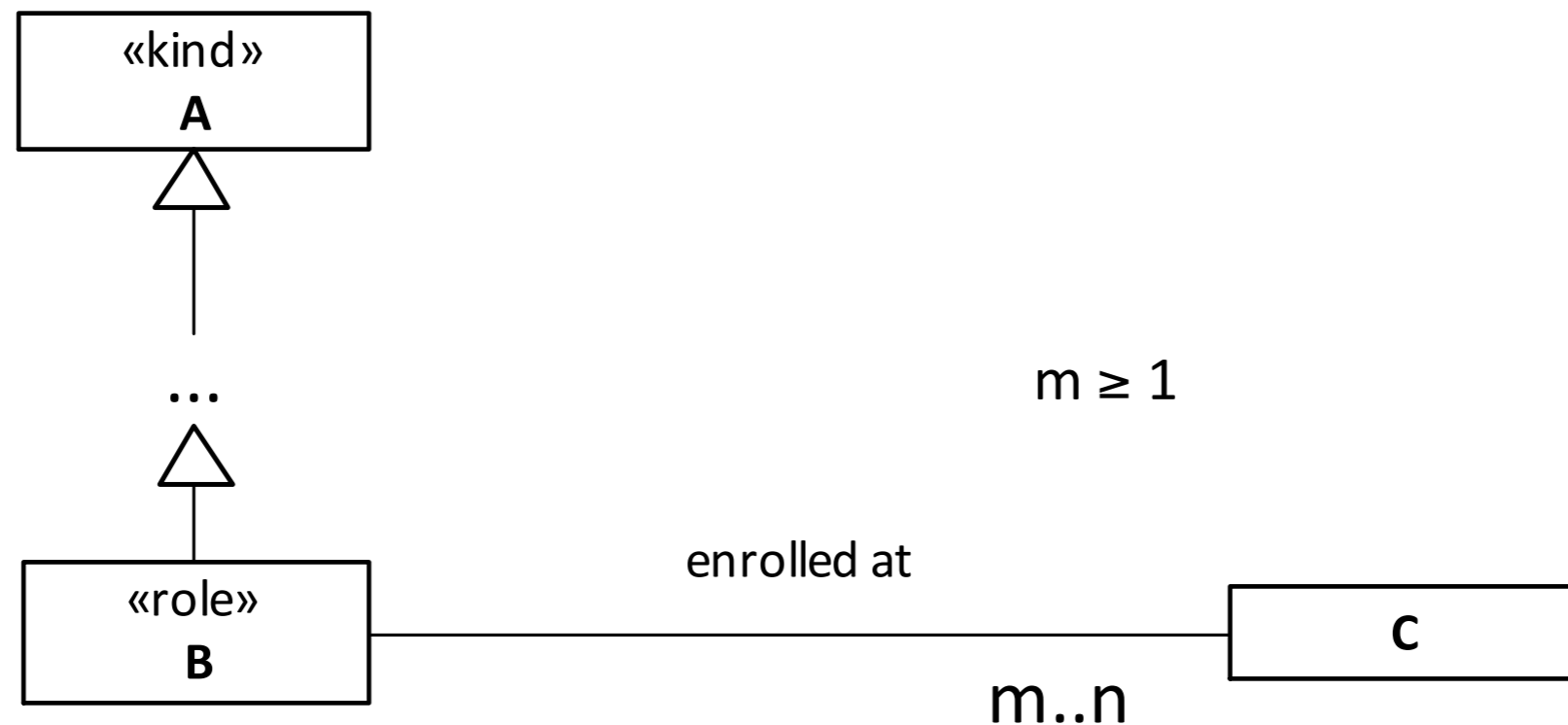
Type	Description	Stereotype	Element	Location
Syntactical	01. A RigidSortalClass cannot have an Anti-Rigid parent (role, phase, role...	Kind	Person	Model::Person
Syntactical	02. A Role must be connected (directly or indirectly) to a Mediation	Role	Customer	Model::Customer
Syntactical	03. Every non abstract Sortal must have a Substance Sortal ancestor (or be...	Role	Customer	Model::Customer

Model verified in 1,874 ms, 3 error(s) found

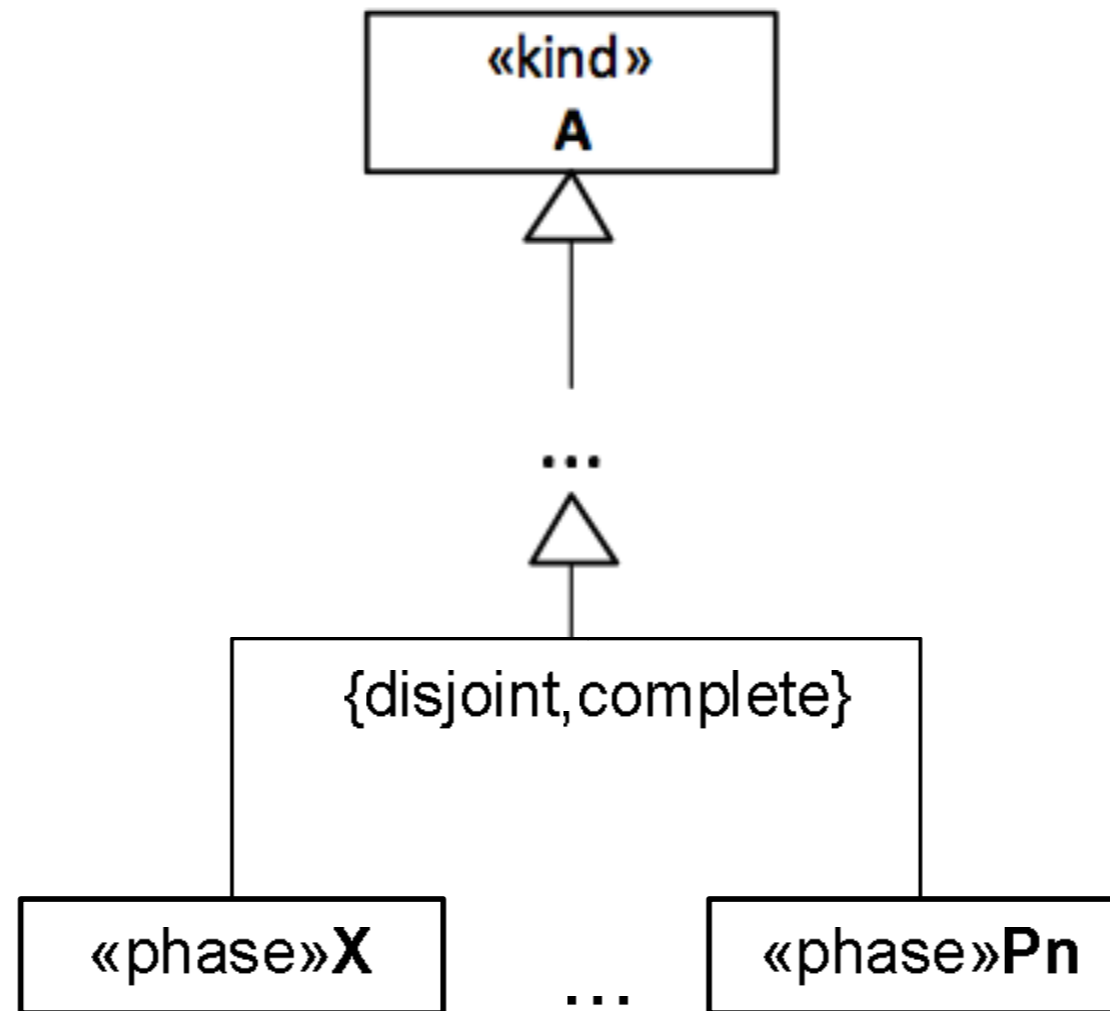
Messages Console Problems x Warnings x



The Emerging **Role** Pattern



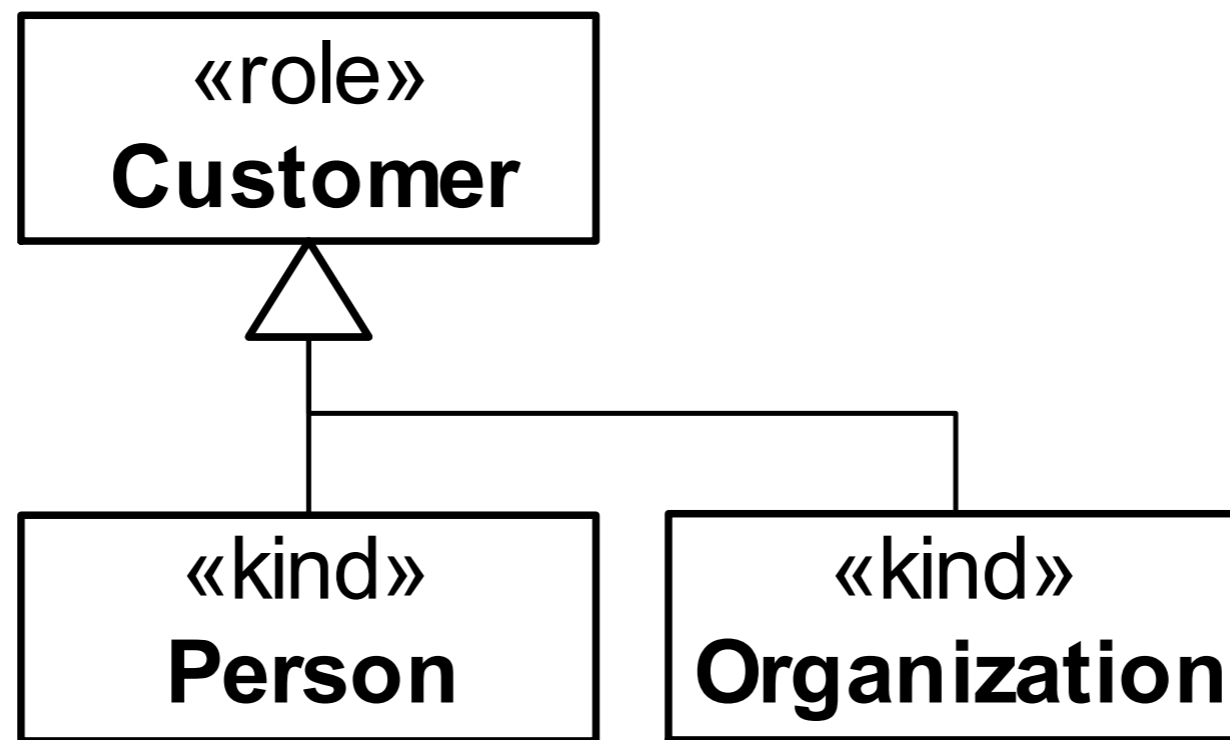
The Emerging **Phase** Pattern

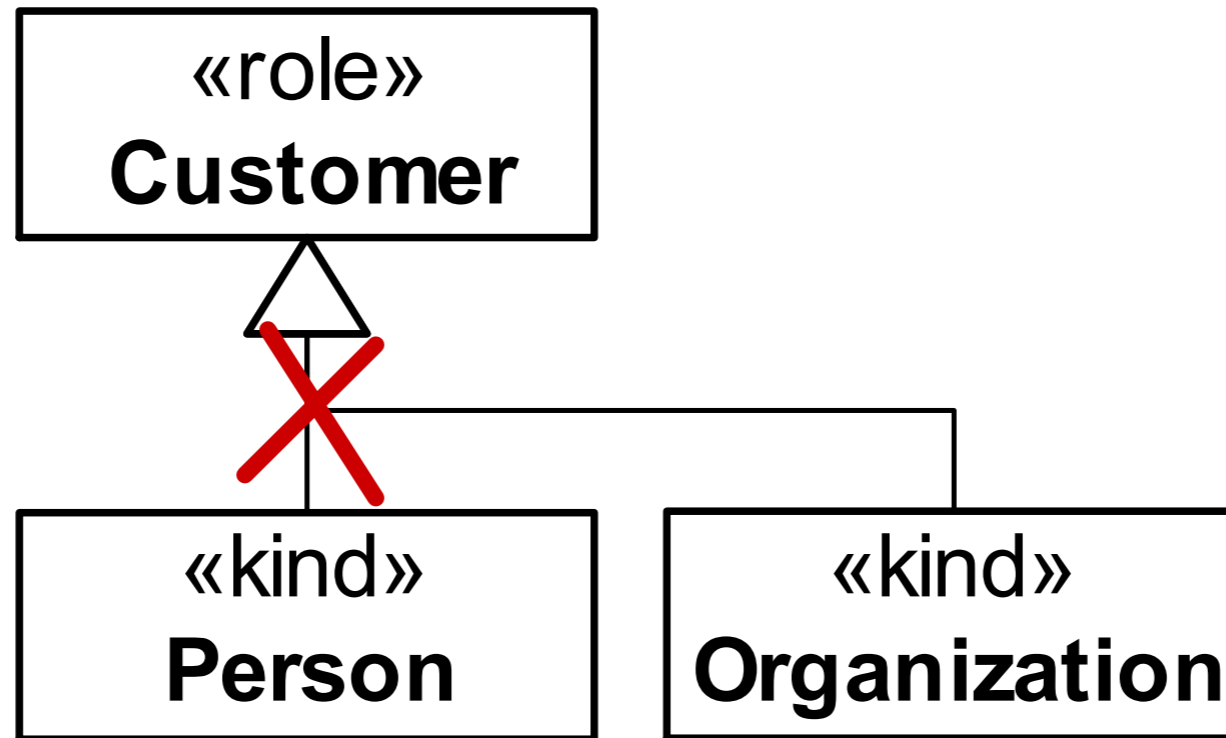


Problem (2)

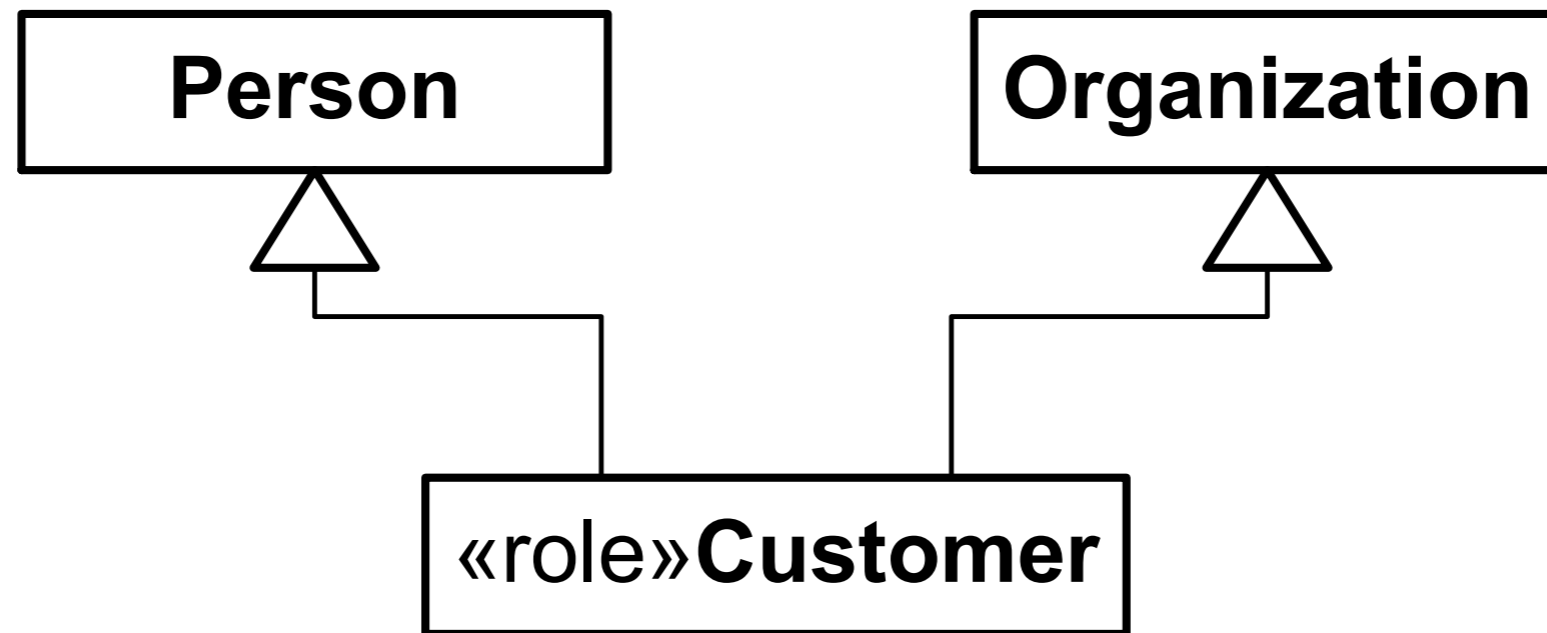
1. Suppose that I want to represent that the ROLE Customer can be played by entities of different KINDS, namely, People and Organizations. How to relate the ROLE and its *allowed types* using subtyping relations?

A Classic Problem

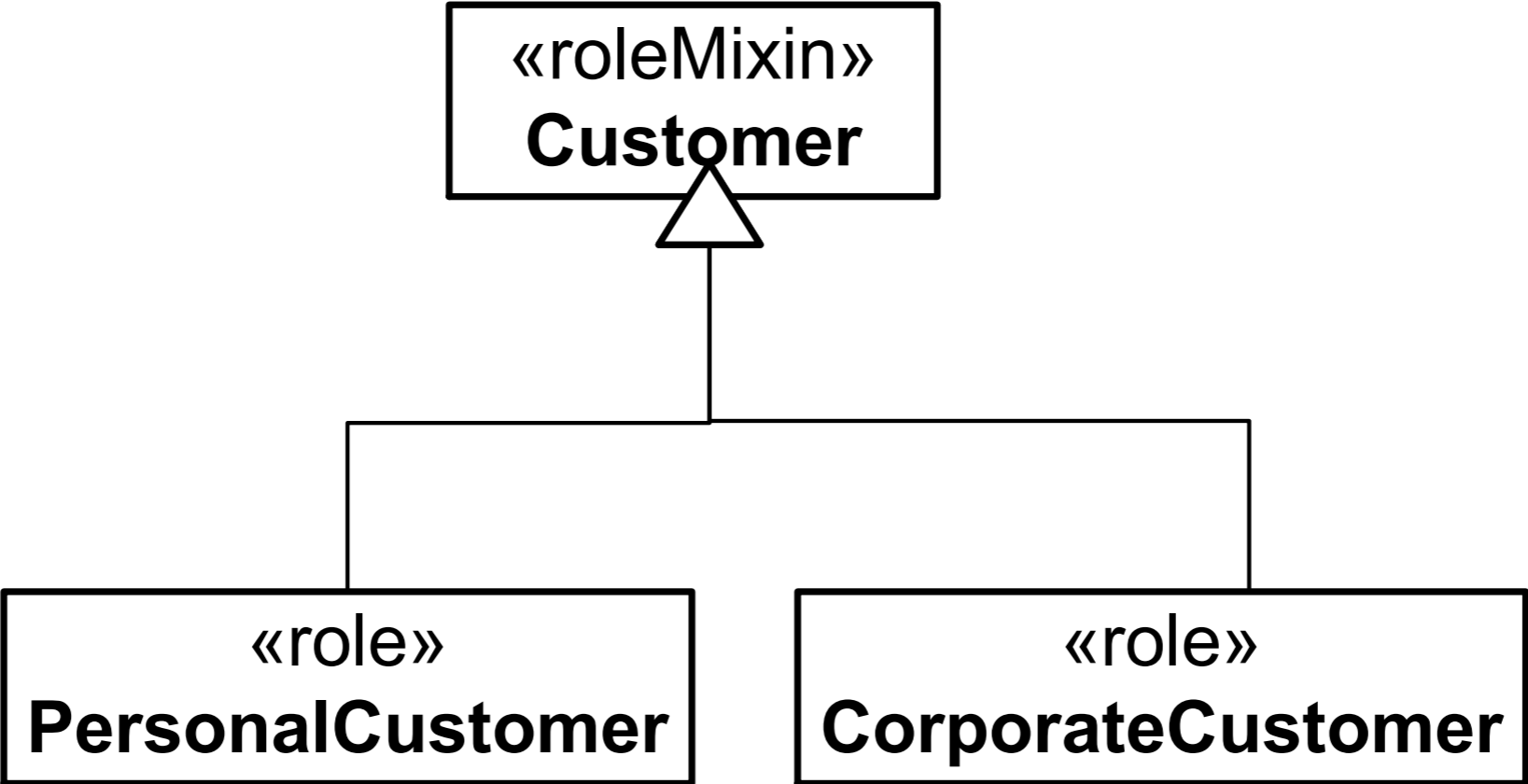


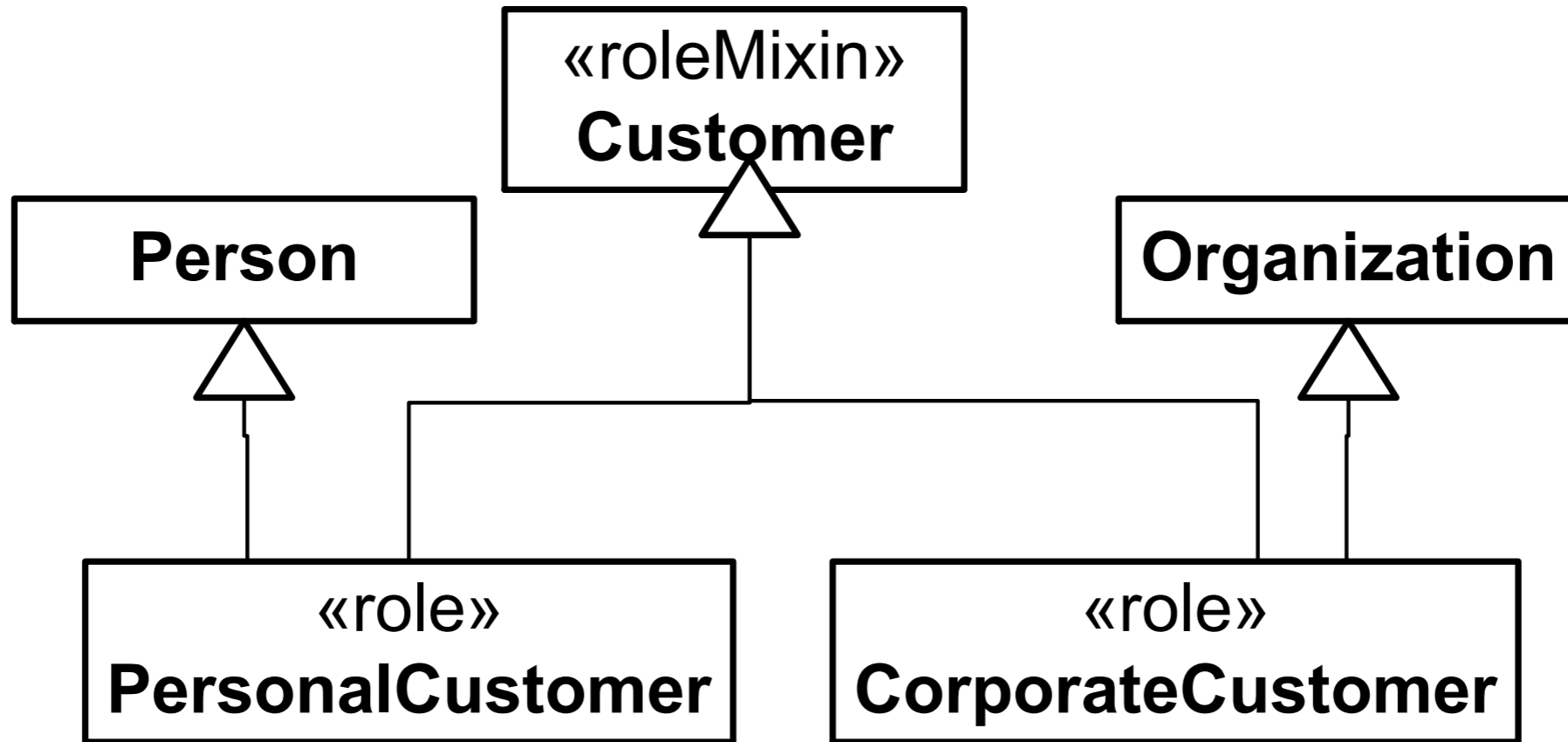


A Possible Alternative?

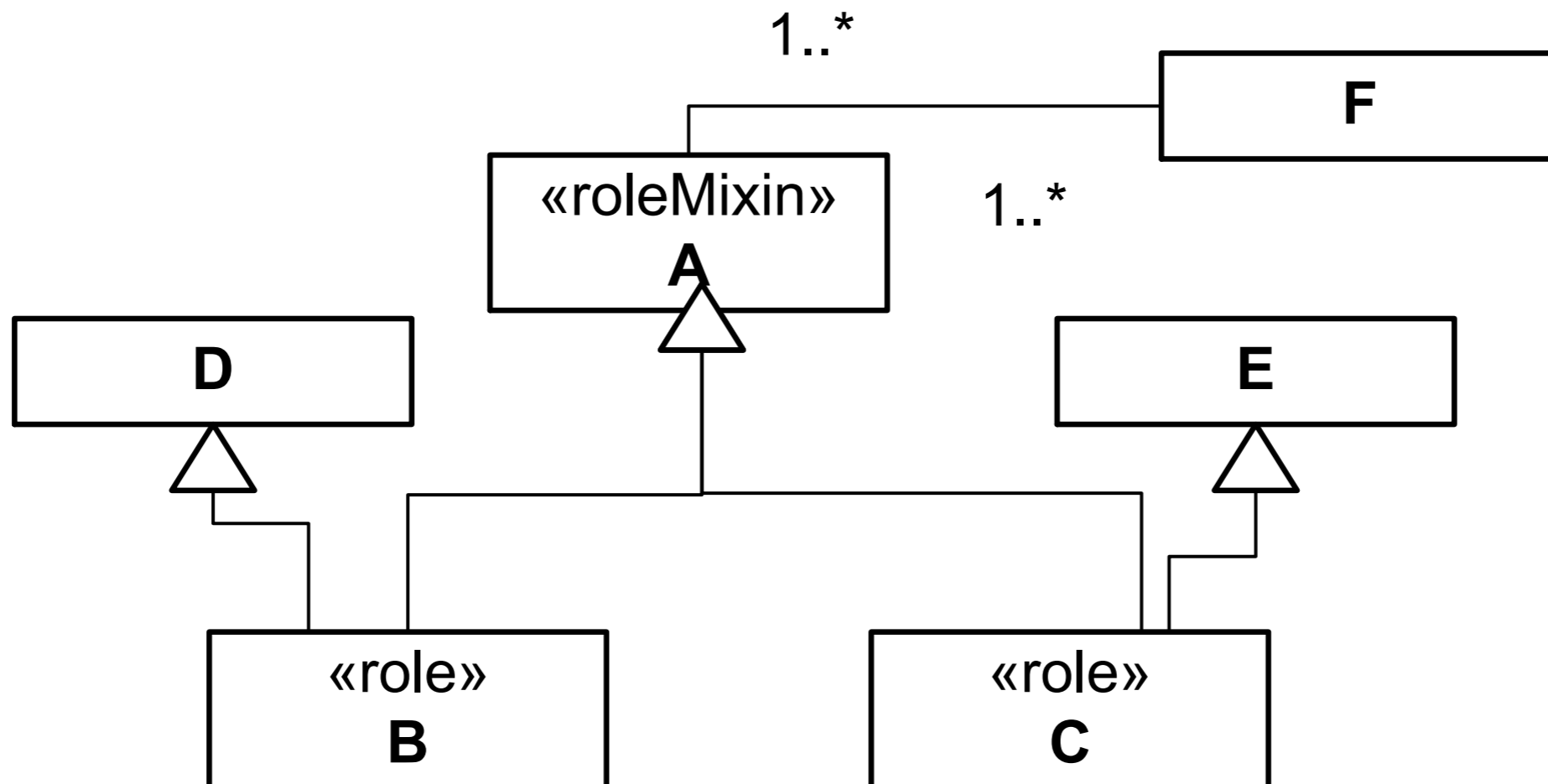


«roleMixin»
Customer

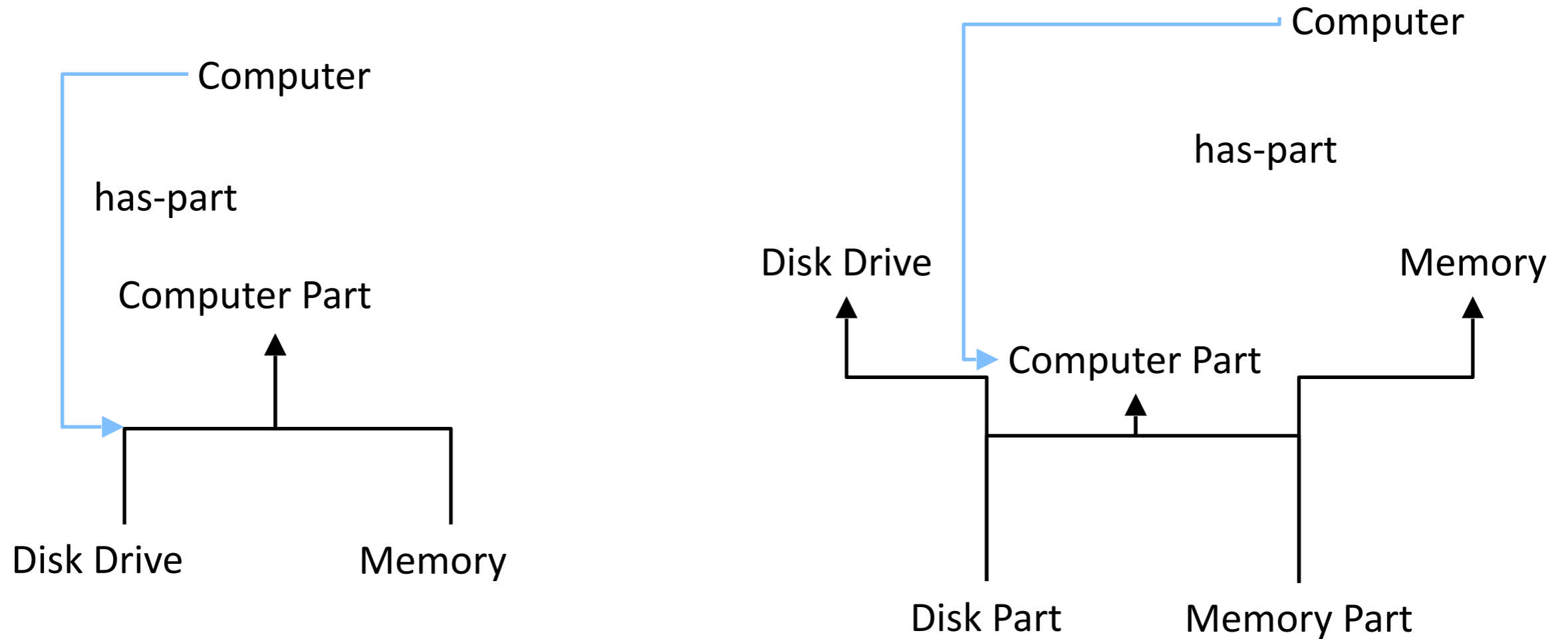




The emerging **RoleMixin** Pattern

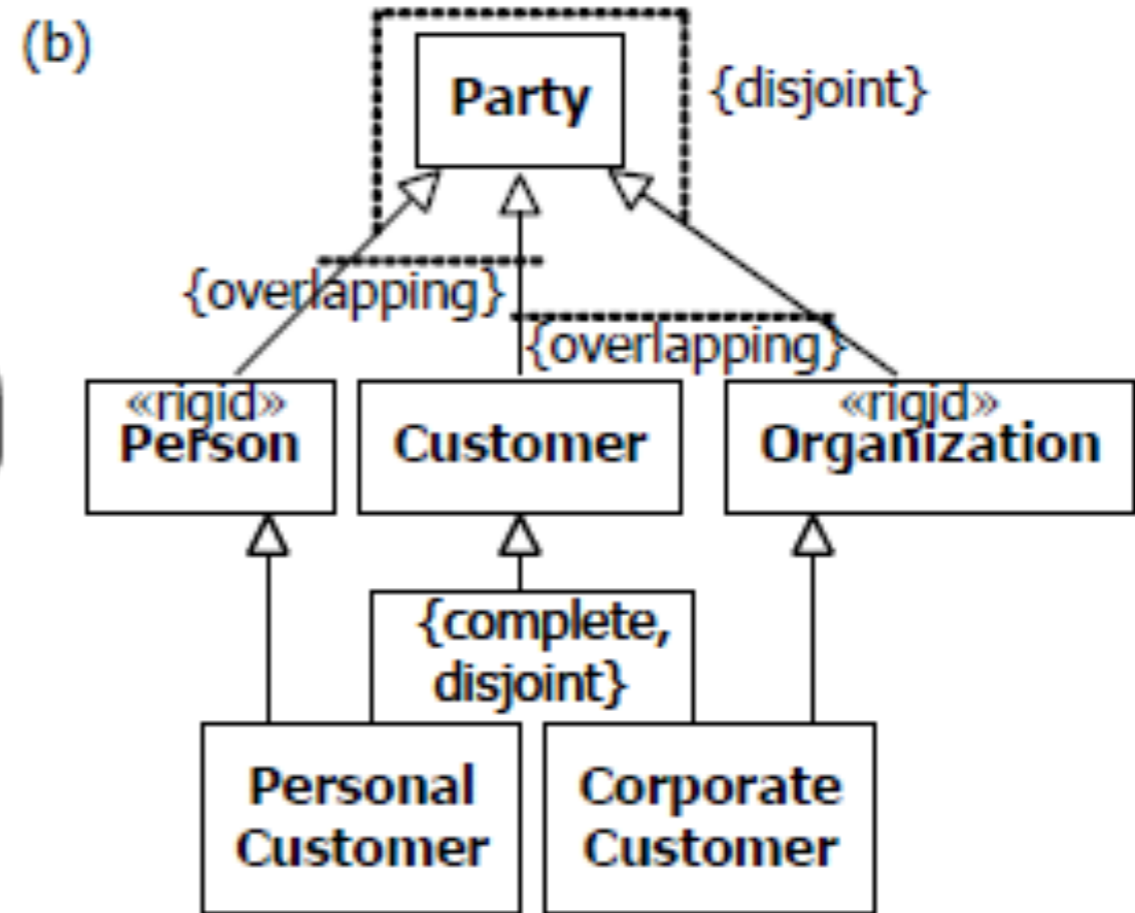
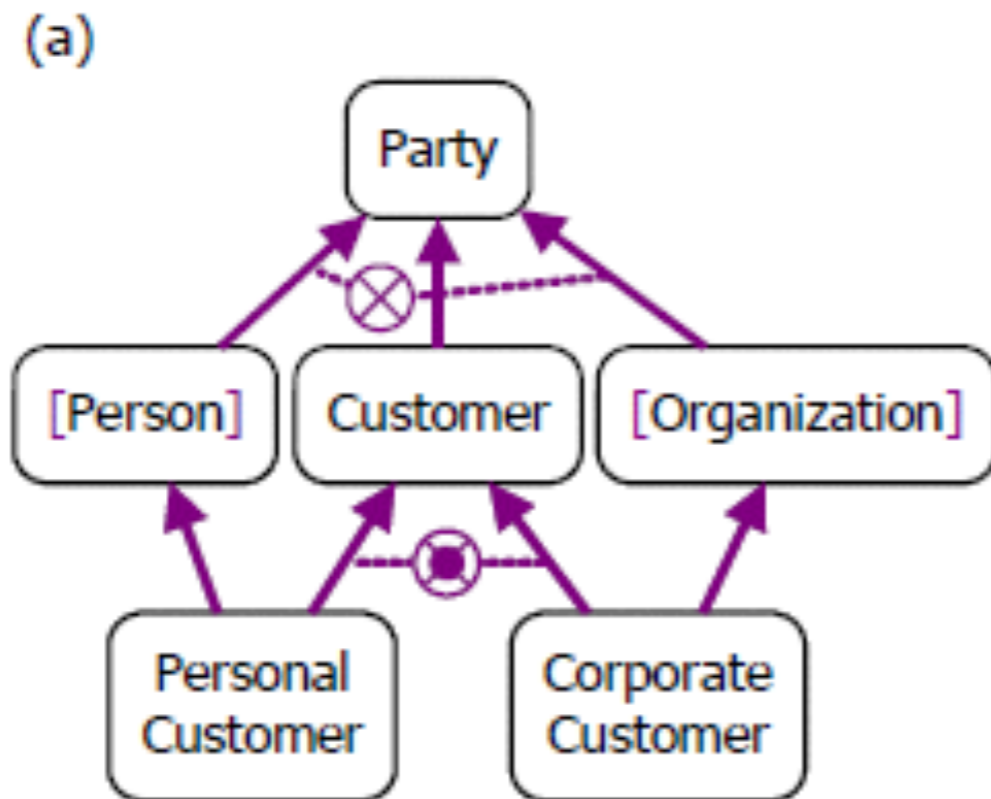


Which one is better?



by Chris Welty

The RoleMixin Pattern in ORM

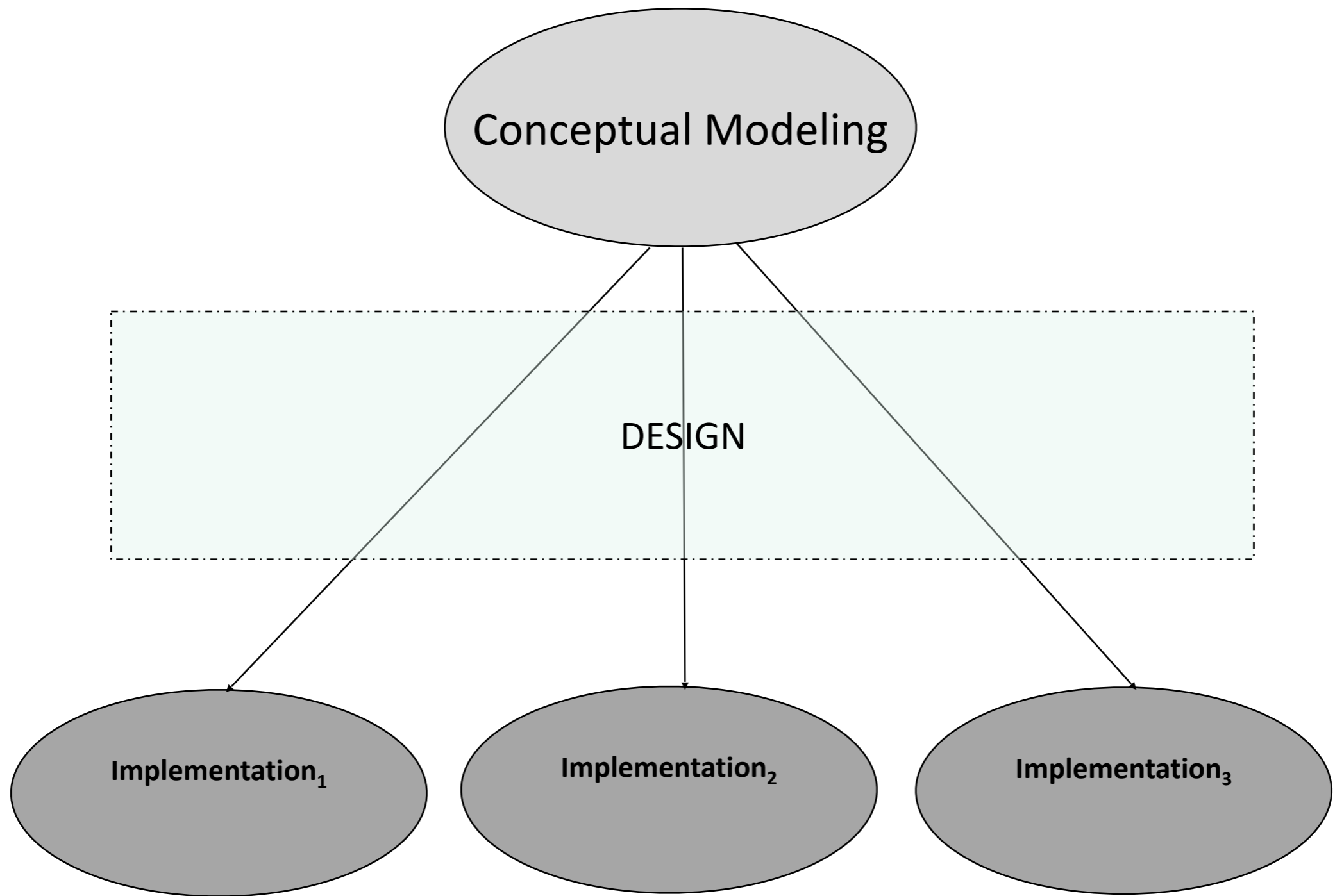


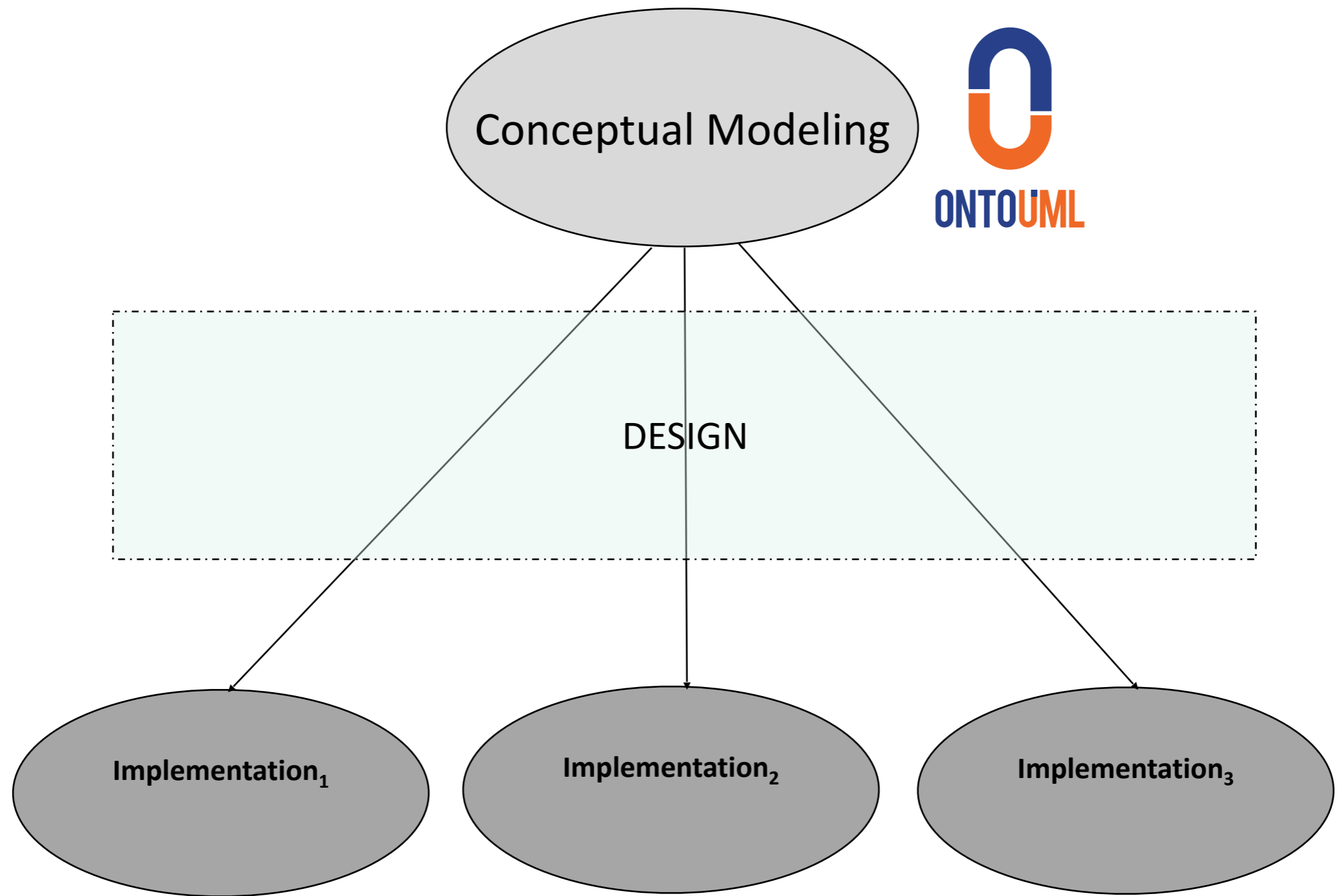
by Terry Halpin

Why is this important?

4

Precise methodological
guidelines for mapping into
different implementation
environments

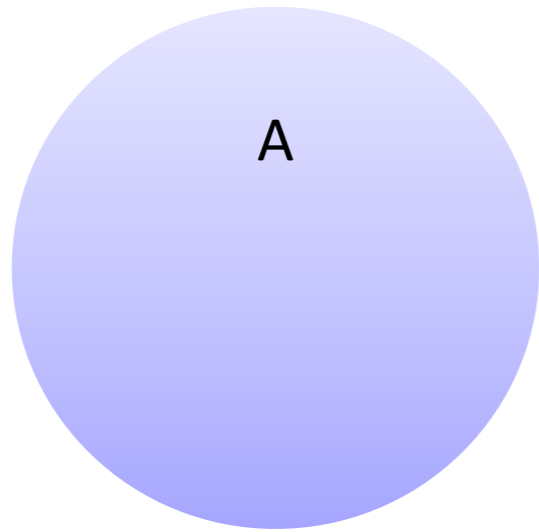




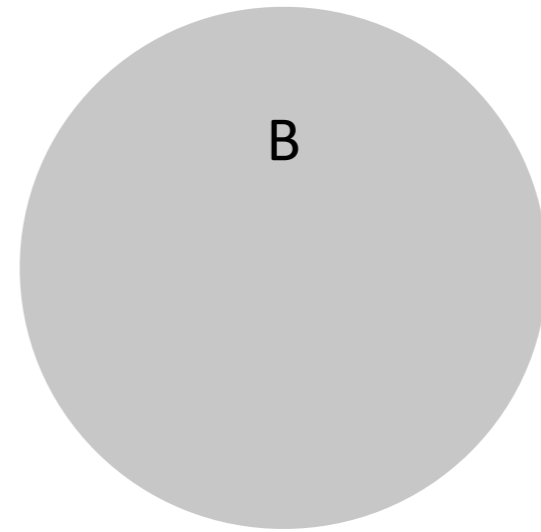
Why is this important?

5

Precise modal semantics with
implications for validation

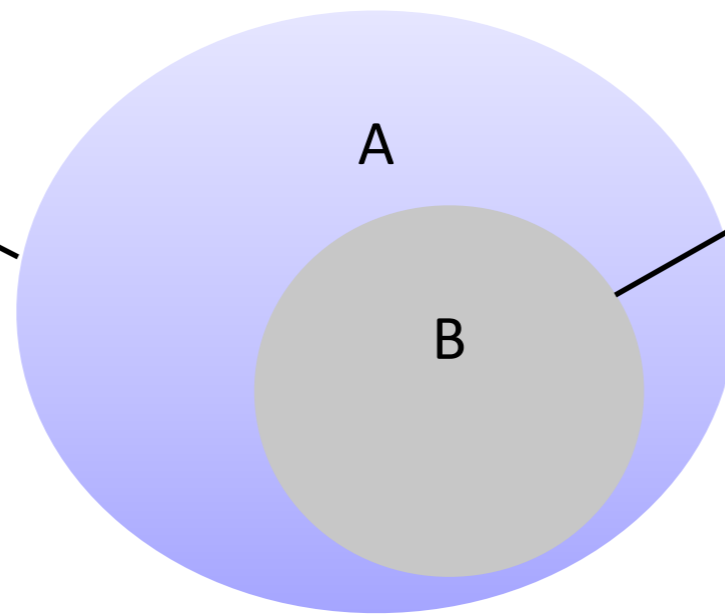


Valid state of affairs
according to the representation



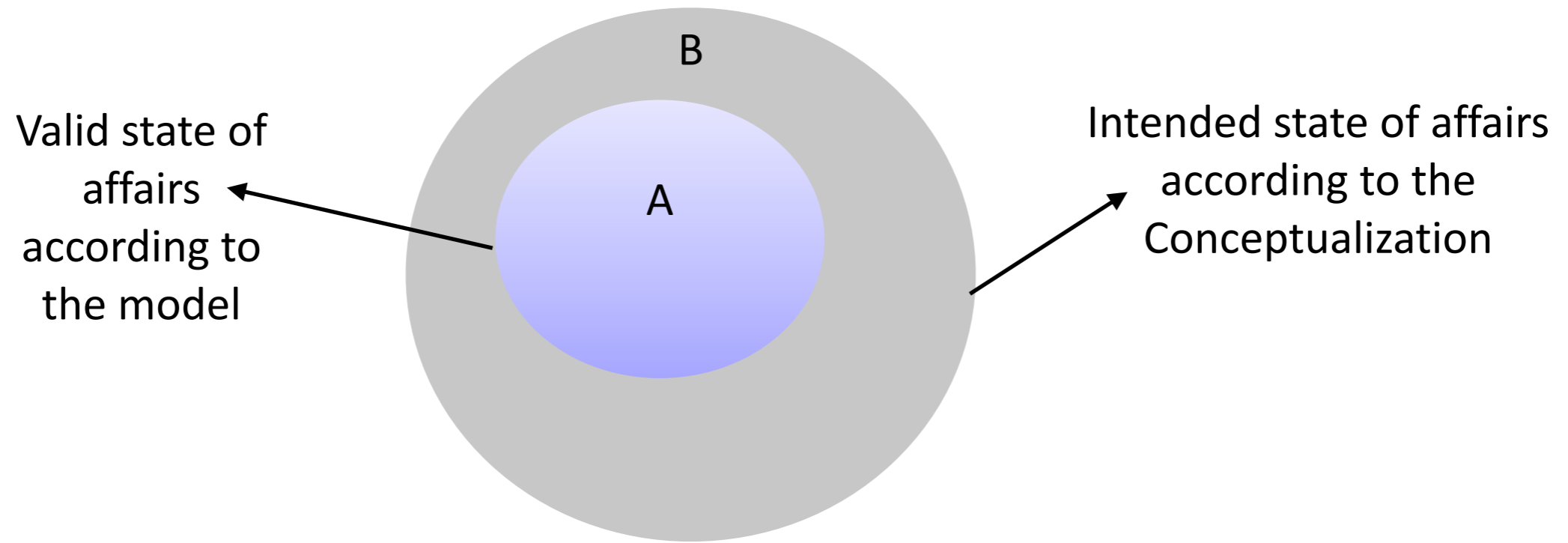
Intended state of affairs
according to the Conceptualization

Valid state of affairs according to the model

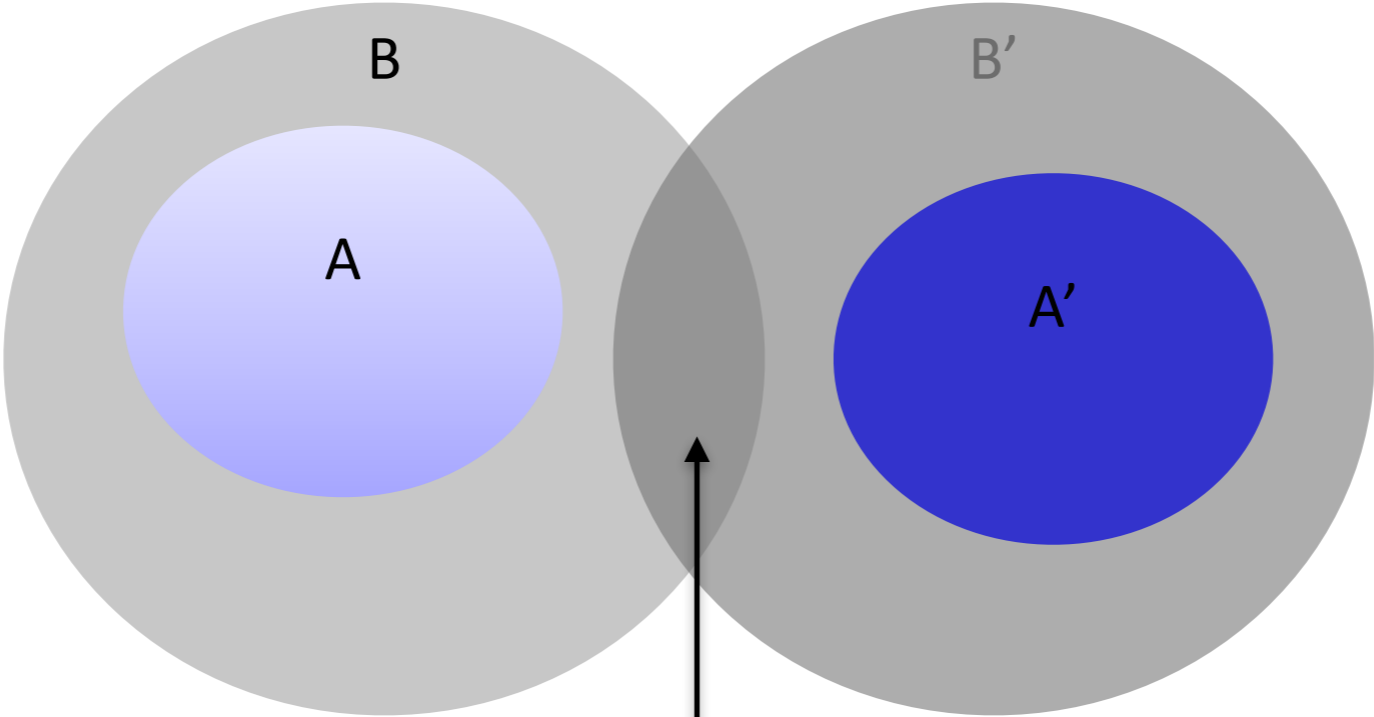


Intended state of affairs according to the Conceptualization

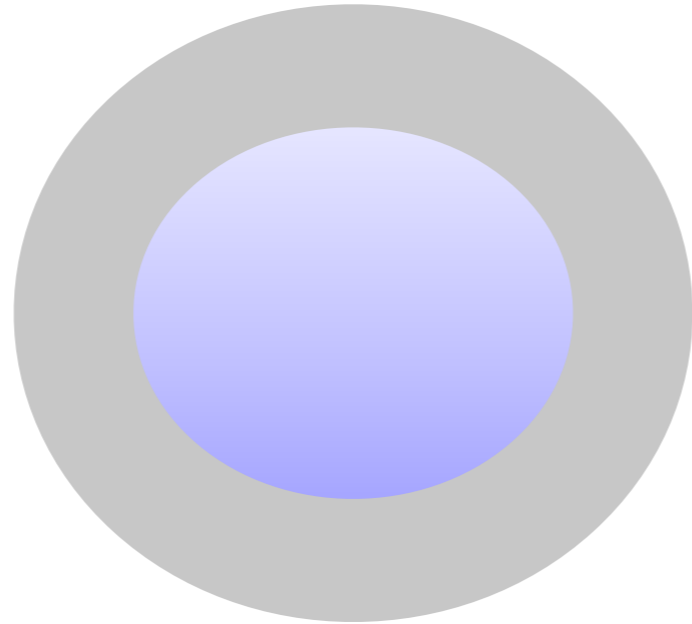
Under-constraining



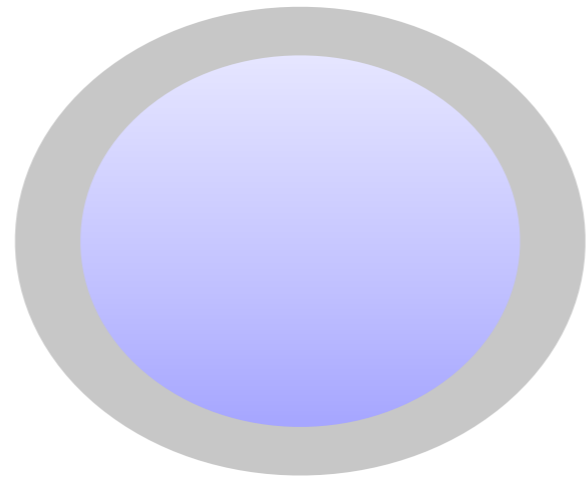
Over-constraining



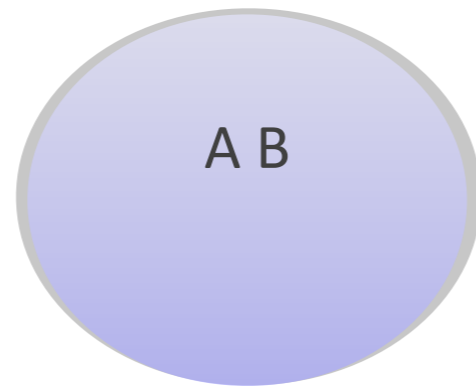
False Agreement



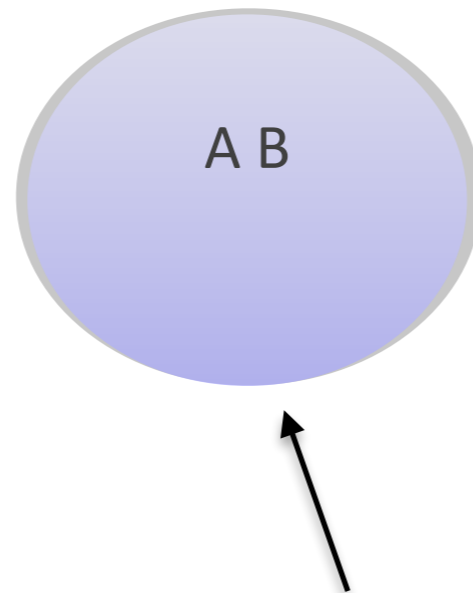
Constraints



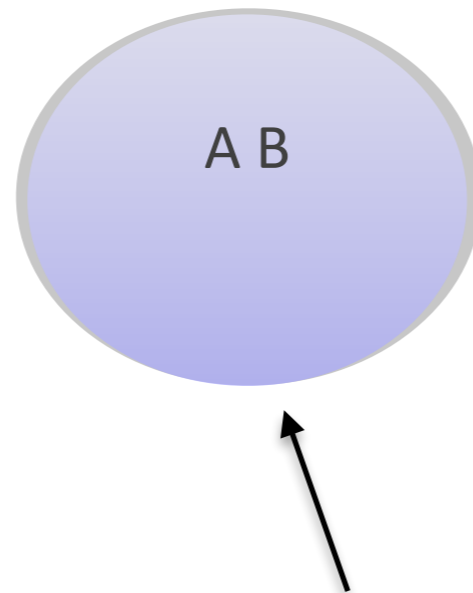
Constraints



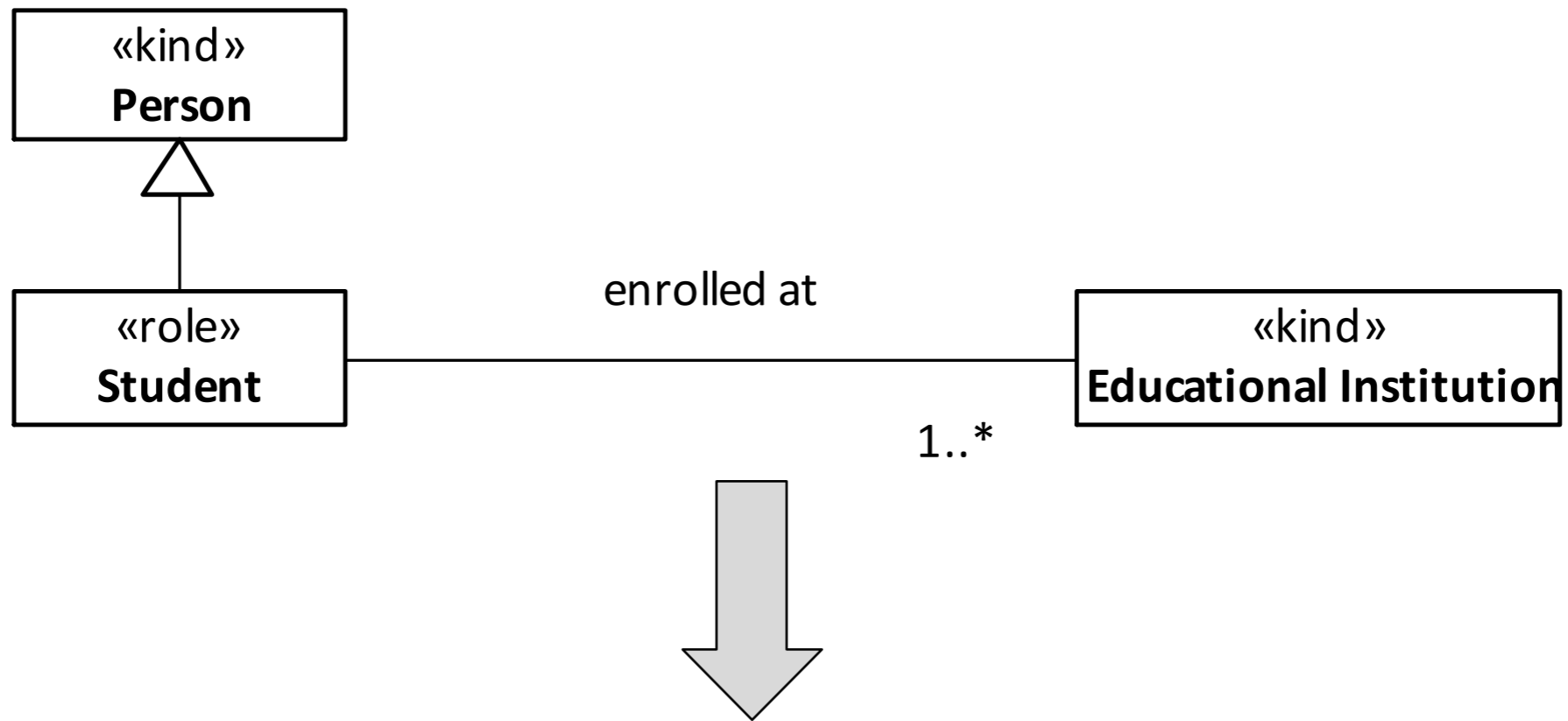
Constraints



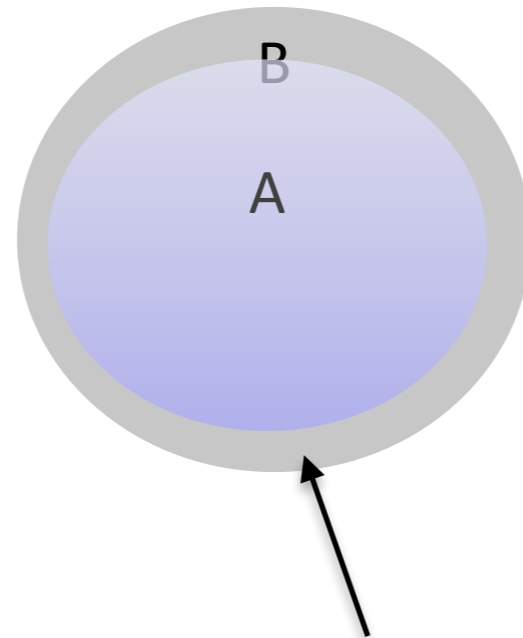
Conceptual Model = Structure + Axiomatization



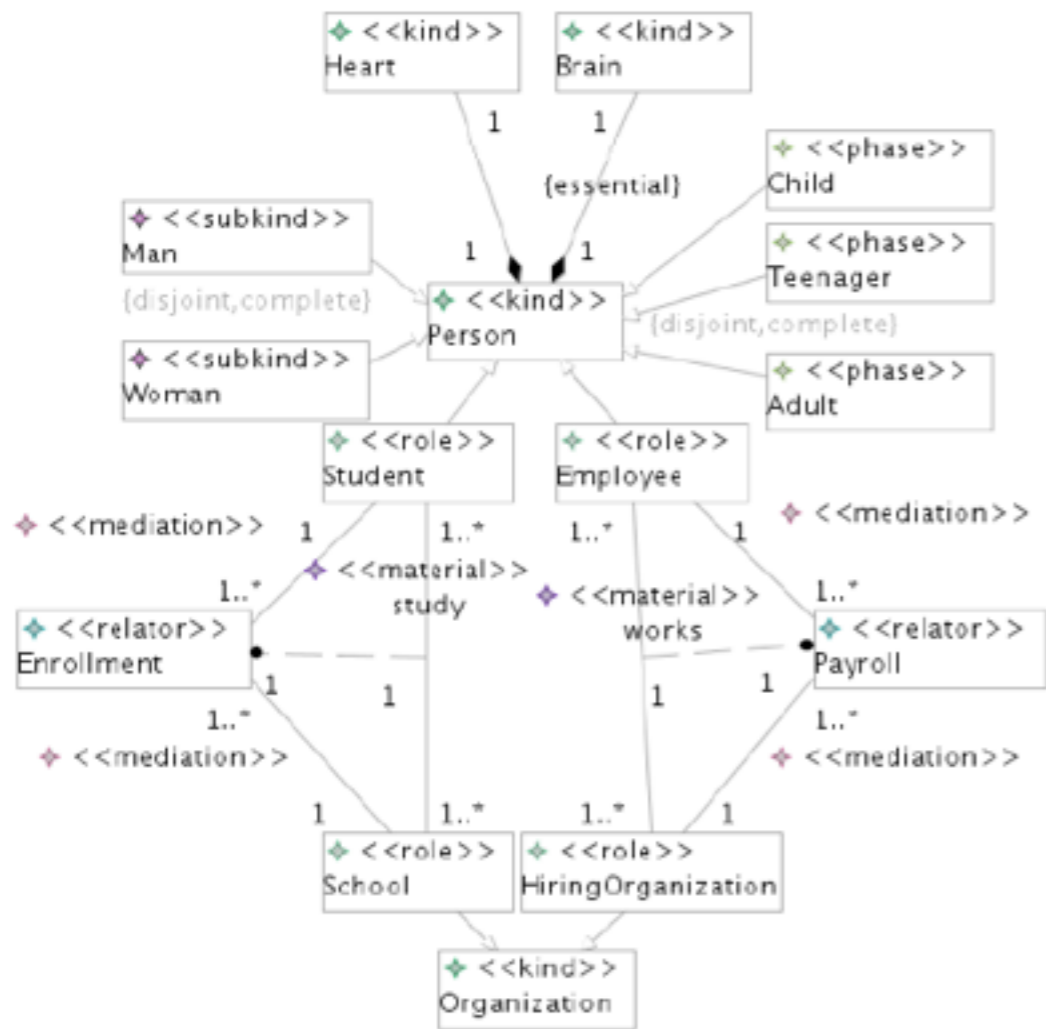
Conceptual Model = Structure + Axiomatization
(Ontological Commitment)



- (∀x **Person(x)** → □(**Person(x)**))
- (∀x **Student(x)** → ◇(¬**Student(x)**))
- (∀x **Student(x)** → **Person(x)**)
- (∀x **Student(x)** → ∃y **Educational Institution(y)** ∧ **Enrolled-at(x,y)**)
- ...



Conceptual Model =
Structure + Domain-Independent Axioms +
Domain-Specific Axioms



ATL Transformation

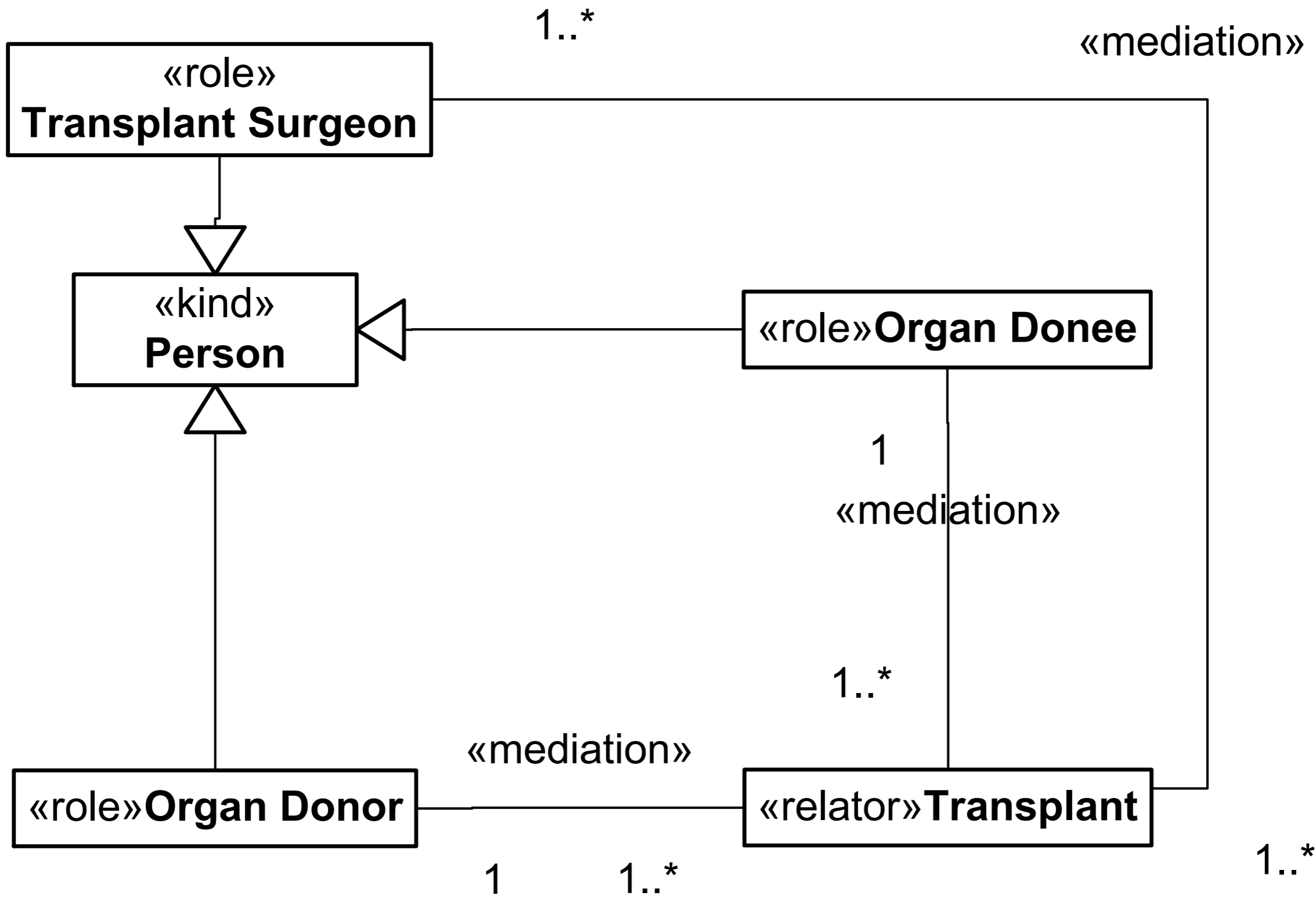
```

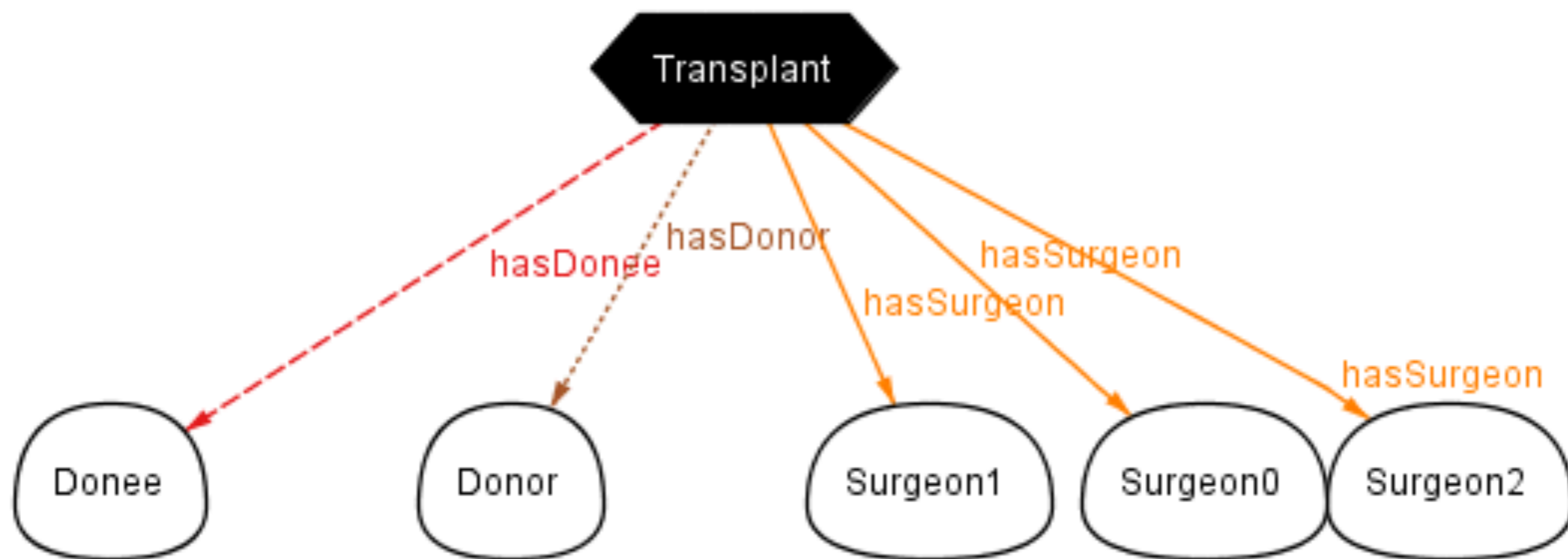
1 sig Person_Set in Concept { Person: some World }
2 {
3   Person in existsIn
4   all w1: World | w1 in Person => (all w2:
5     w1.access | (w2 in existsIn) => (w2 in
6     Person)) -- Rigidity
7   some w: World | w in this.Child -- Phase
8   some w: World | w in this.Teenager -- Phase
9   some w: World | w in this.Adult -- Phase
8   :
9 }

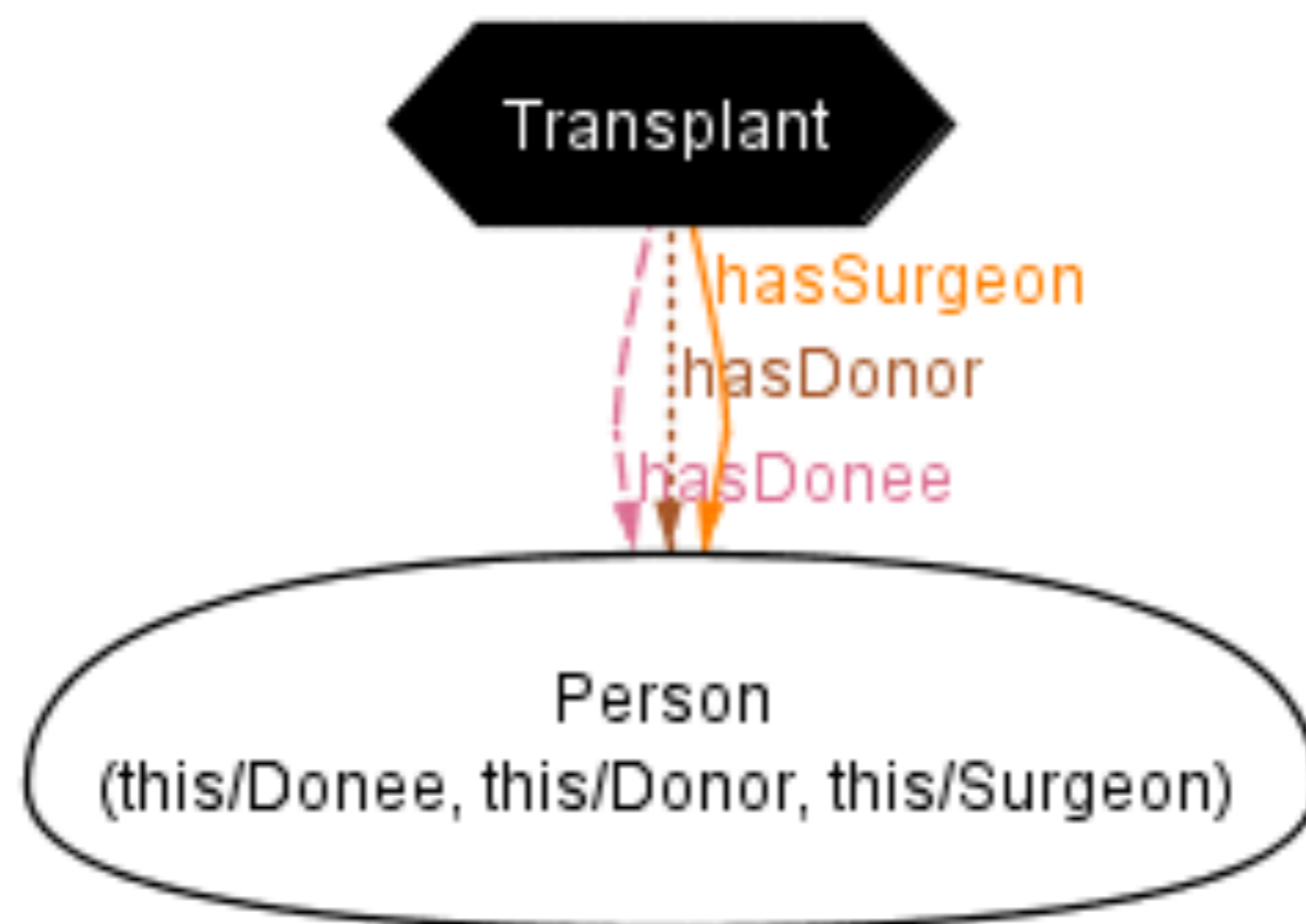
```

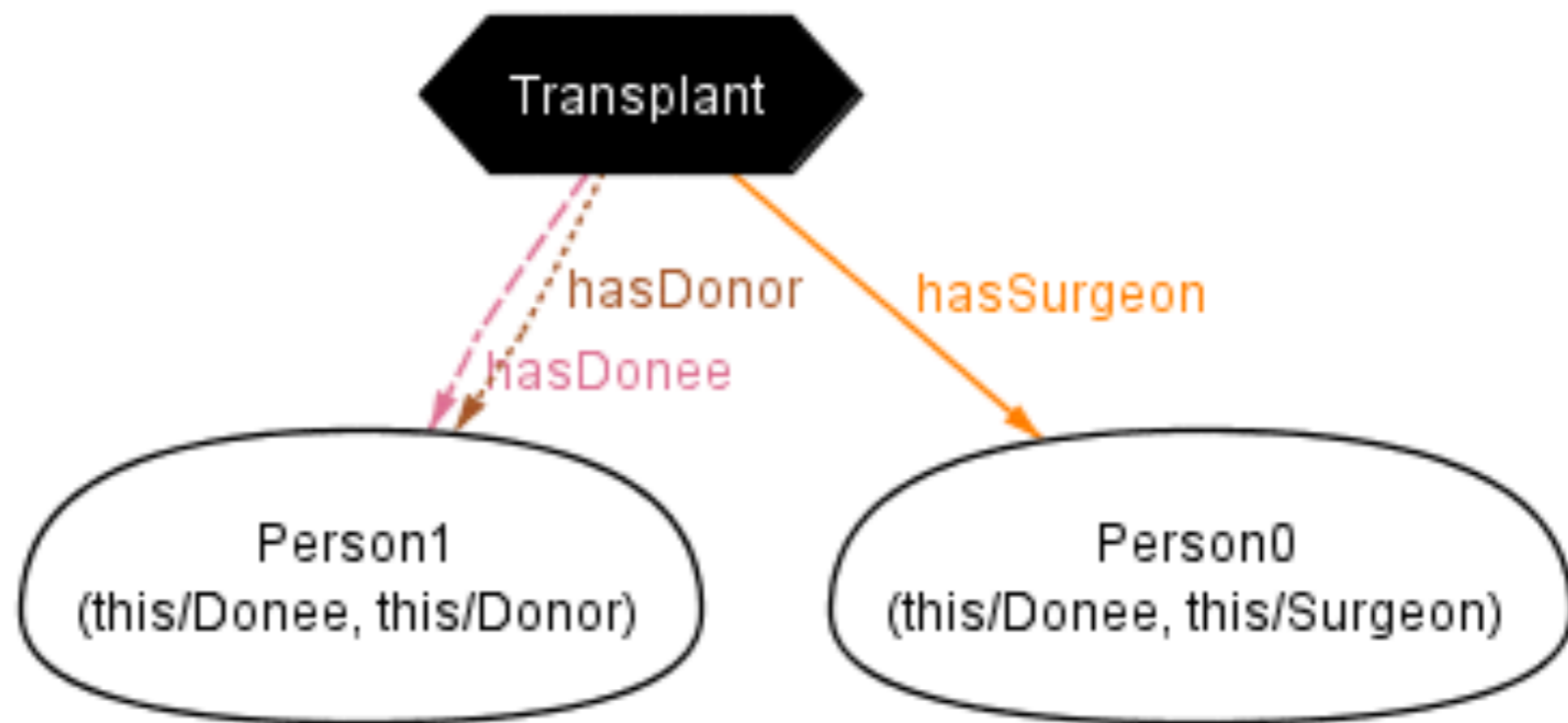
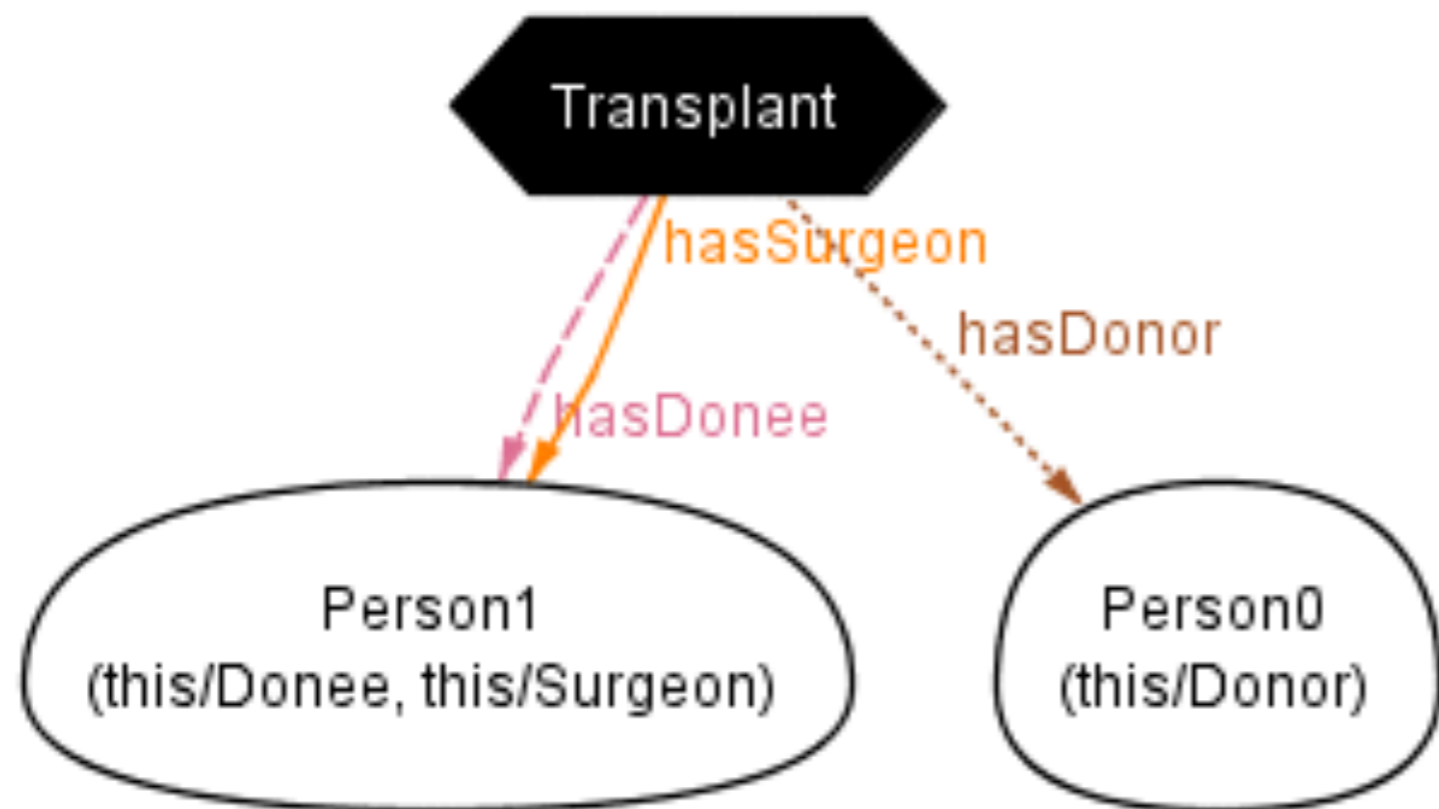
Simulation and Visualization

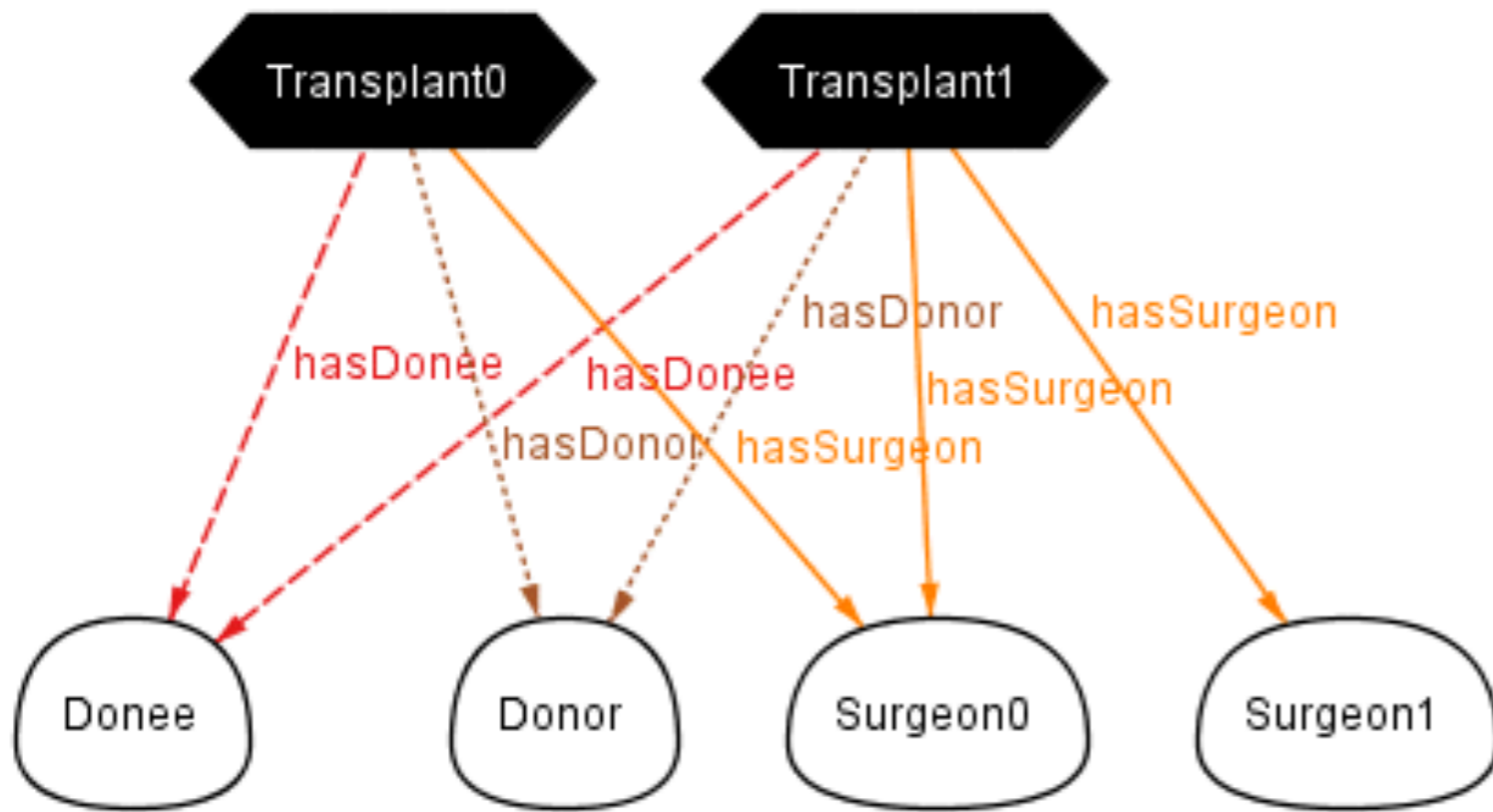
Alloy Analyzer + OntoUML visual Plugin



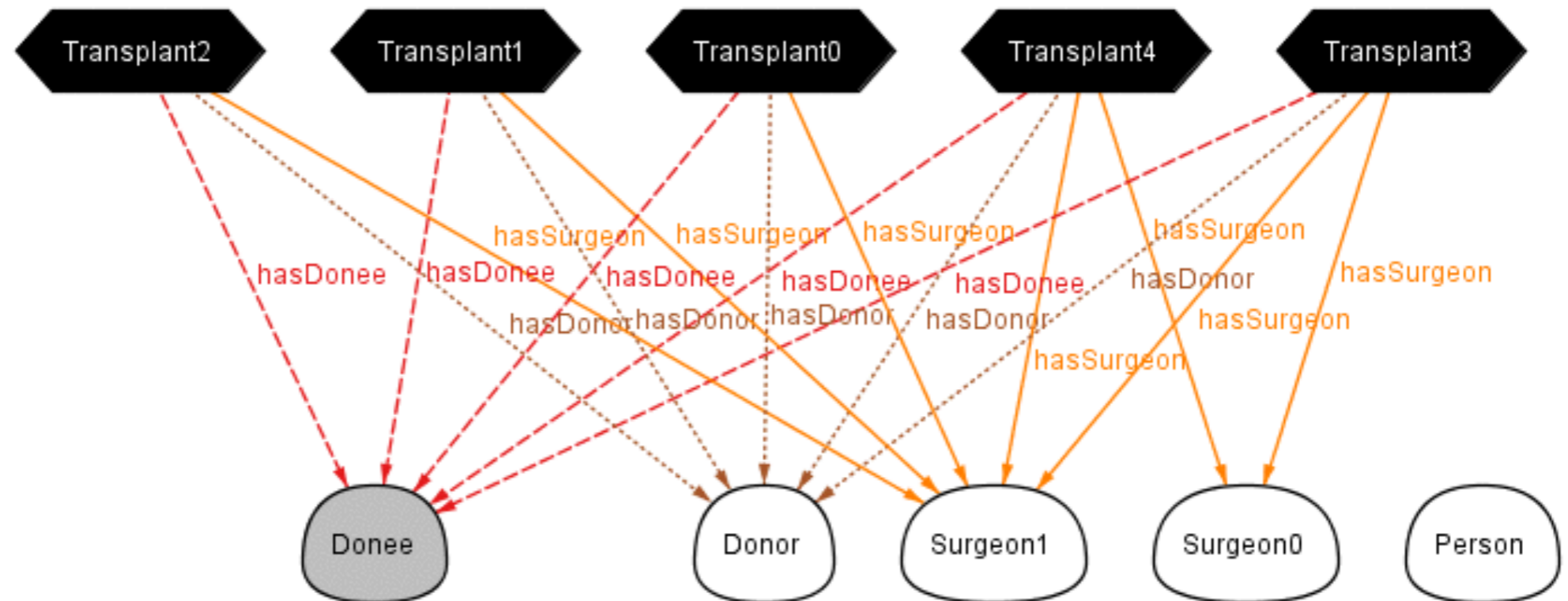








Real-Word Semantics





Data Modeling Guide (DMG) For An Enterprise Logical Data Model (ELDM)

Version 2.3

March 15, 2011

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under contract number H98230-09-C-1180.**

Data Modeling Guide (DMG) For An Enterprise Logical Data Model, V2.3; 15 March 2011

Preface

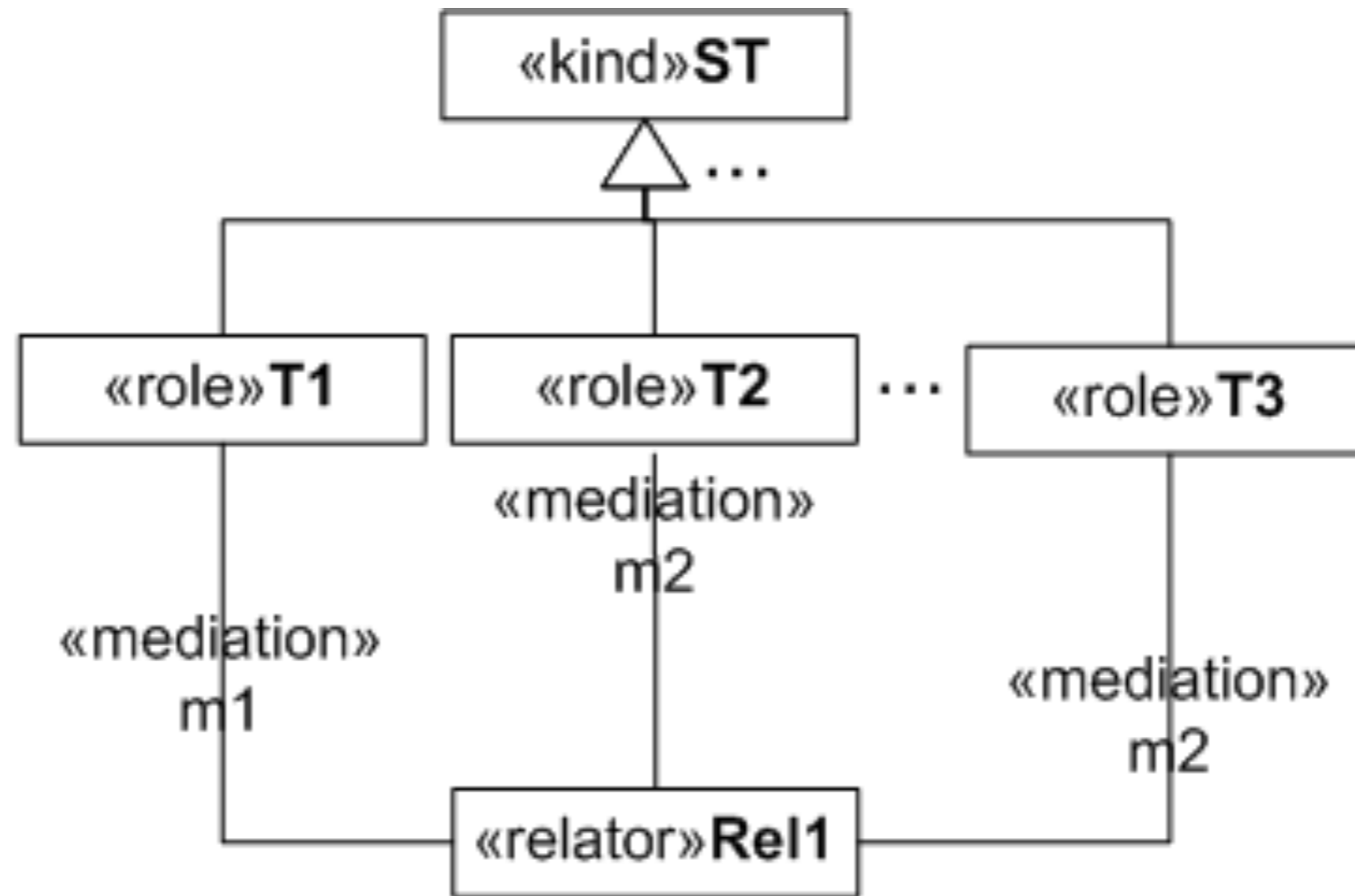
The success of this Data Modeling Guide for an Enterprise Logical Data Model could not have been possible without the inspired and exhaustive research of Giancarlo Guizzardi, notably his “Ontological Foundations for Structural Conceptual Models,” published in 2005 in association with the Centre for Telemetrics and Information Technology, which provided the theoretical foundation for the methodologies describe within, and from which real world, practical implementations have already ensued.

At the core of Guizzardi’s modeling paradigm are the principles of Rigidity, Uniform Identity and Existential Dependence. From those foundational tenets he extrapolates the concepts of SortalUniversal (Unified Principle of Identity), MixinUniversal (Disparate Set of Concepts), and finally the constructs of SubstanceSortal (Kind, Quantity, and Collective), Subkind, Phase, Role, Category, RoleMixin and Mixin. In short, the total package offered to us by Guizzardi contained a complete and fully integrated set of concepts and constructs that left us wanting for nothing.

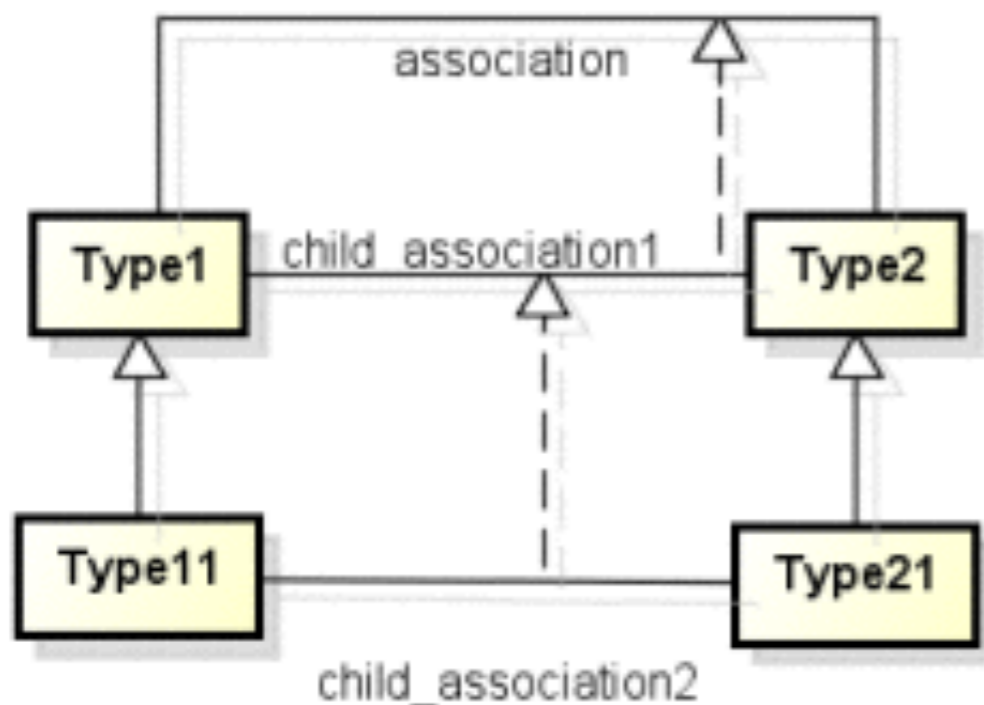
OntoUML Model Benchmark

- Model benchmark with 56 models
- Models in domains such as Provenance in Scientific Workflow, Public Cloud Vulnerability, Software Configuration Management, Emergency Management, Services, IT Governance, Organizational Structures, Software Requirements, Heart Electrophysiology, Amazonian Biodiversity Management, Human Genome, Optical Transport Networks, Federal Government Organizational Structures, Normative Acts, and Ground Transportation Regulation

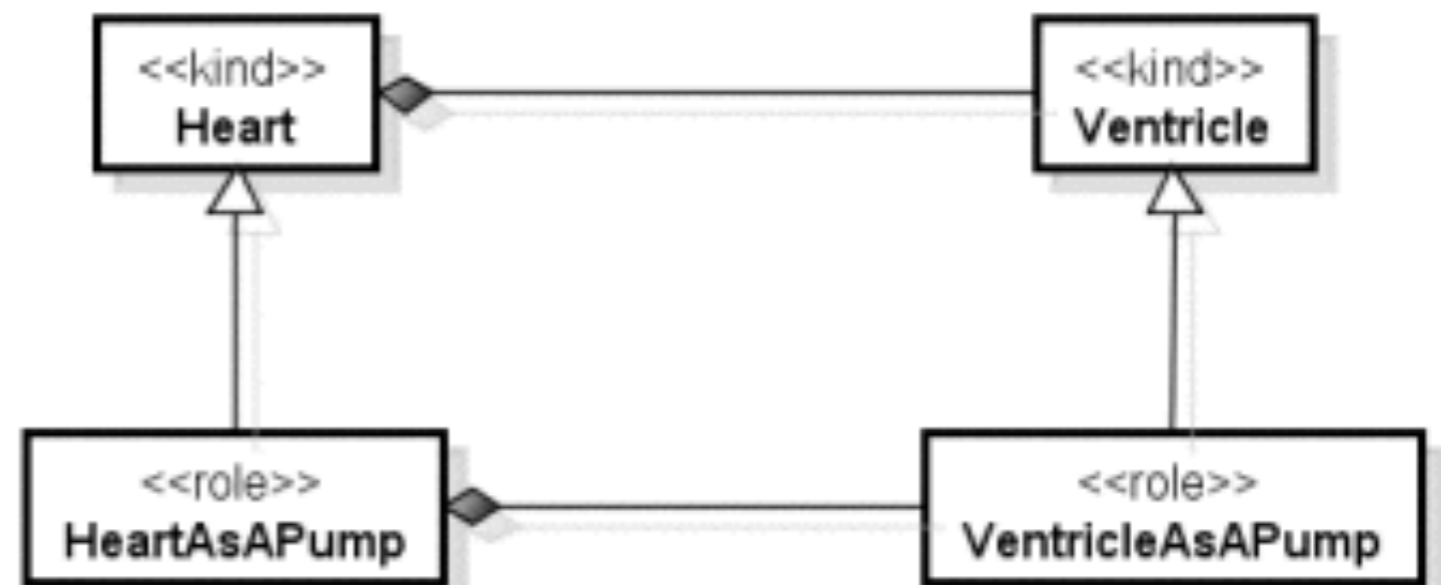
The Emerging Anti-Pattern: Relation Between Overlapping Types (**RelOver**)



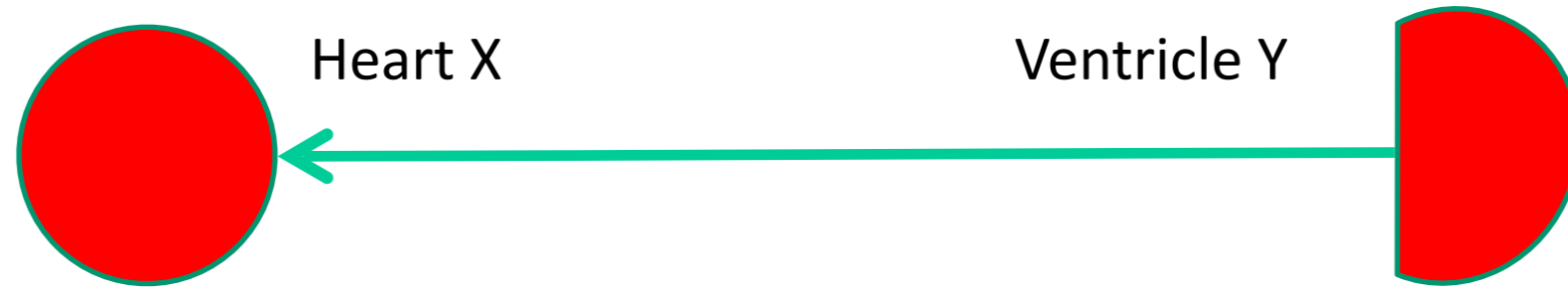
The Emerging Anti-Pattern: Relation Specialization (**RelSpec**)

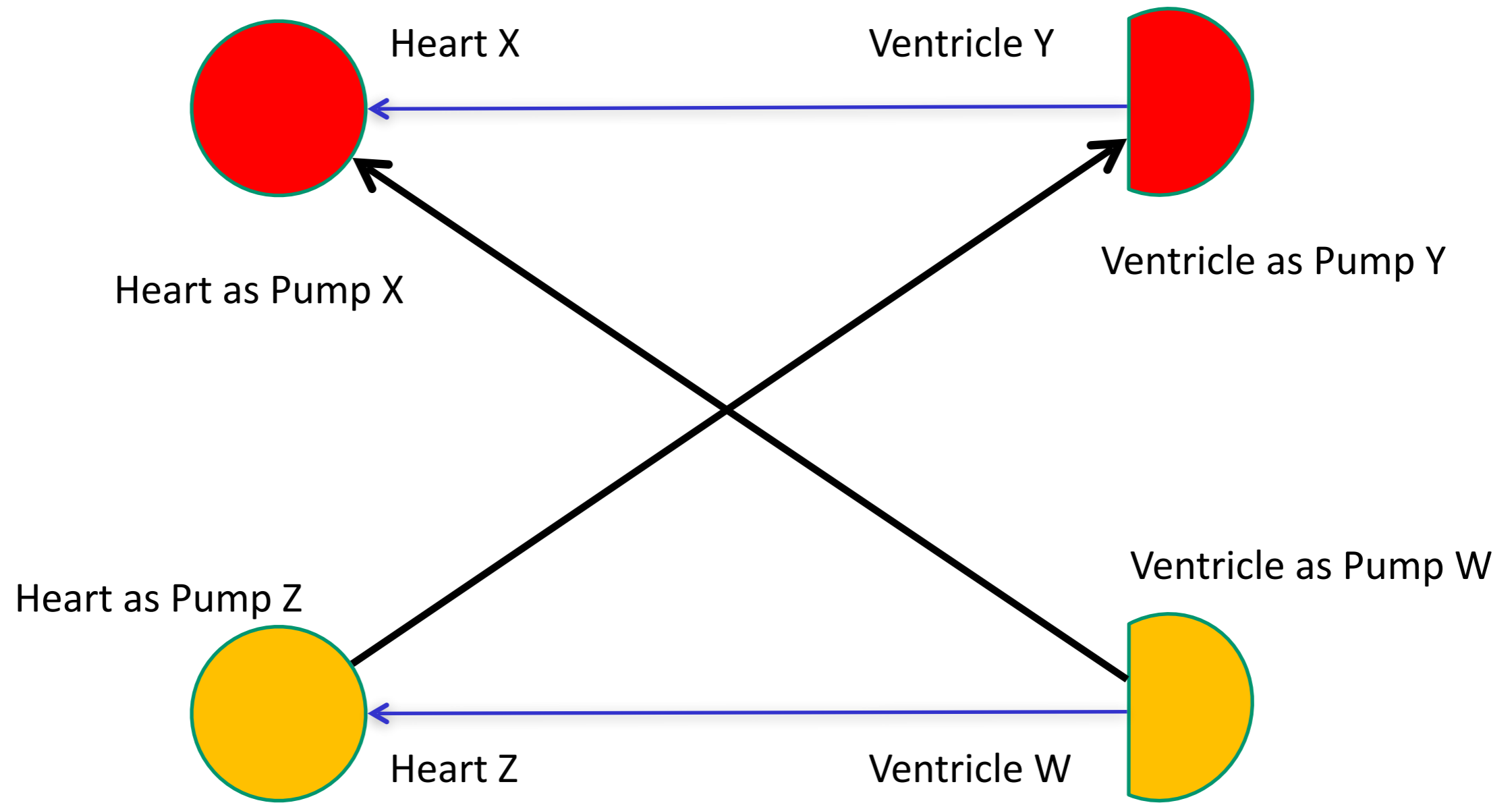


(a)



(b)





Anti-Pattern Catalogue

- Association Cycle
- Binary Relation Between Over. Types
- Deceiving Intersection
- Free Role Specialization
- Imprecise Abstraction
- Multiple Relational Dependency
- Part Composing Over. Roles
- Whole Composed by Over. Parts
- Relator Mediating Over. Types
- Relation Composition
- Relator Mediating Rigid Types
- Relation Specialization
- Repeatable Relator Instances
- Relationally Dependent Phase
- Generalization Set With Mixed Rigidity
- Heterogeneous Collective
- Homogeneous Functional Complex
- Mixin With Same Identity
- Mixin With Same Rigidity
- Undefined Formal Association
- Undefined Phase Partition

Anti-Patterns (AP)	AP Occurrences	Relevant Model Construct (RMC)	RMC /AP Ratio	% of Qualified Models with AP Occurrence
RelSpec	817	Association	4.92	48.15%
ImpAbs	758	Association	5.30	72.22%
AssCyc	1809	Association	2.22	92.59%
RelOver	149	Relator	8.08	25%
RepRel	319	Relator	3.77	64.58%
BinOver	224	Association	17.93	48.15%

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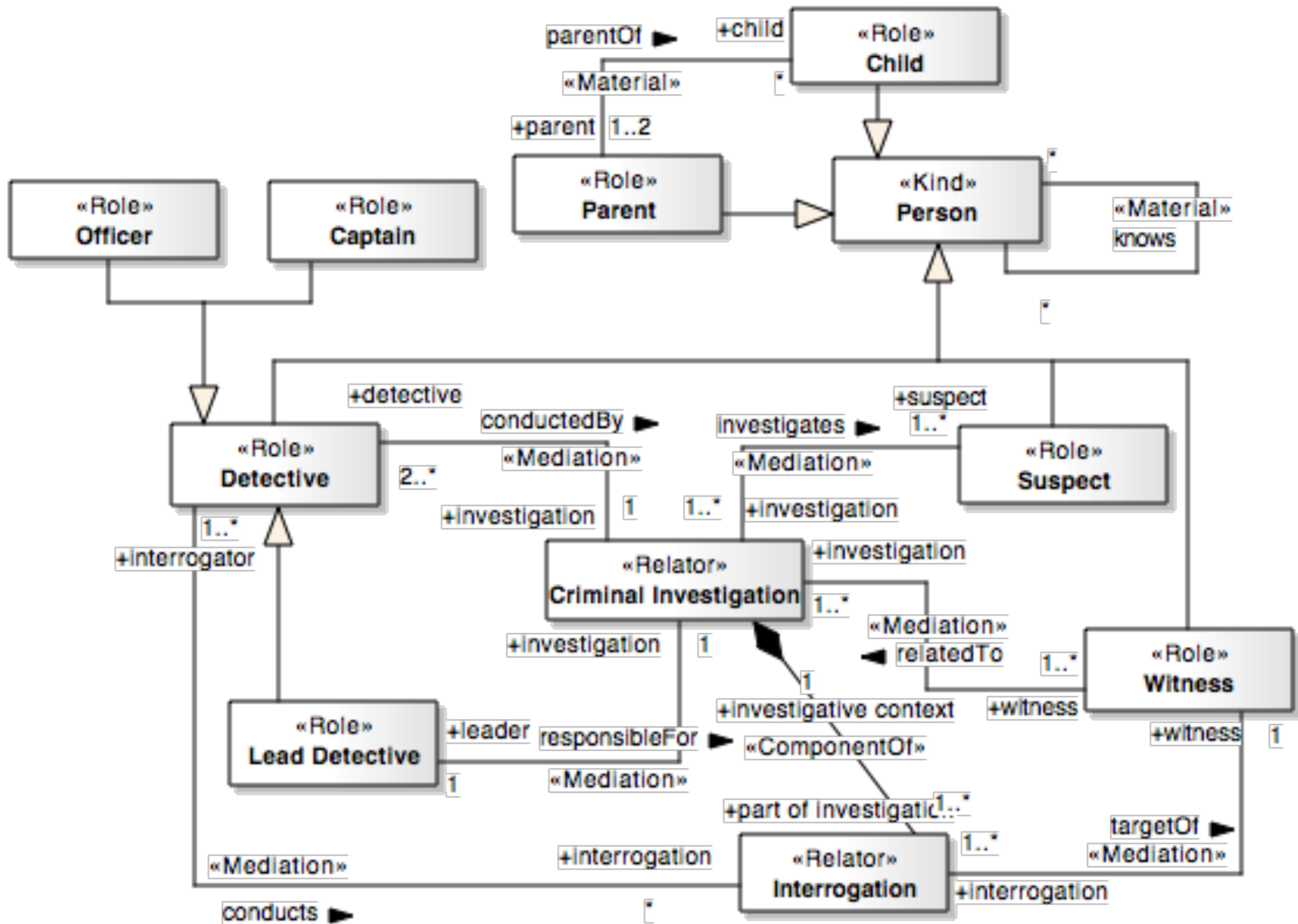
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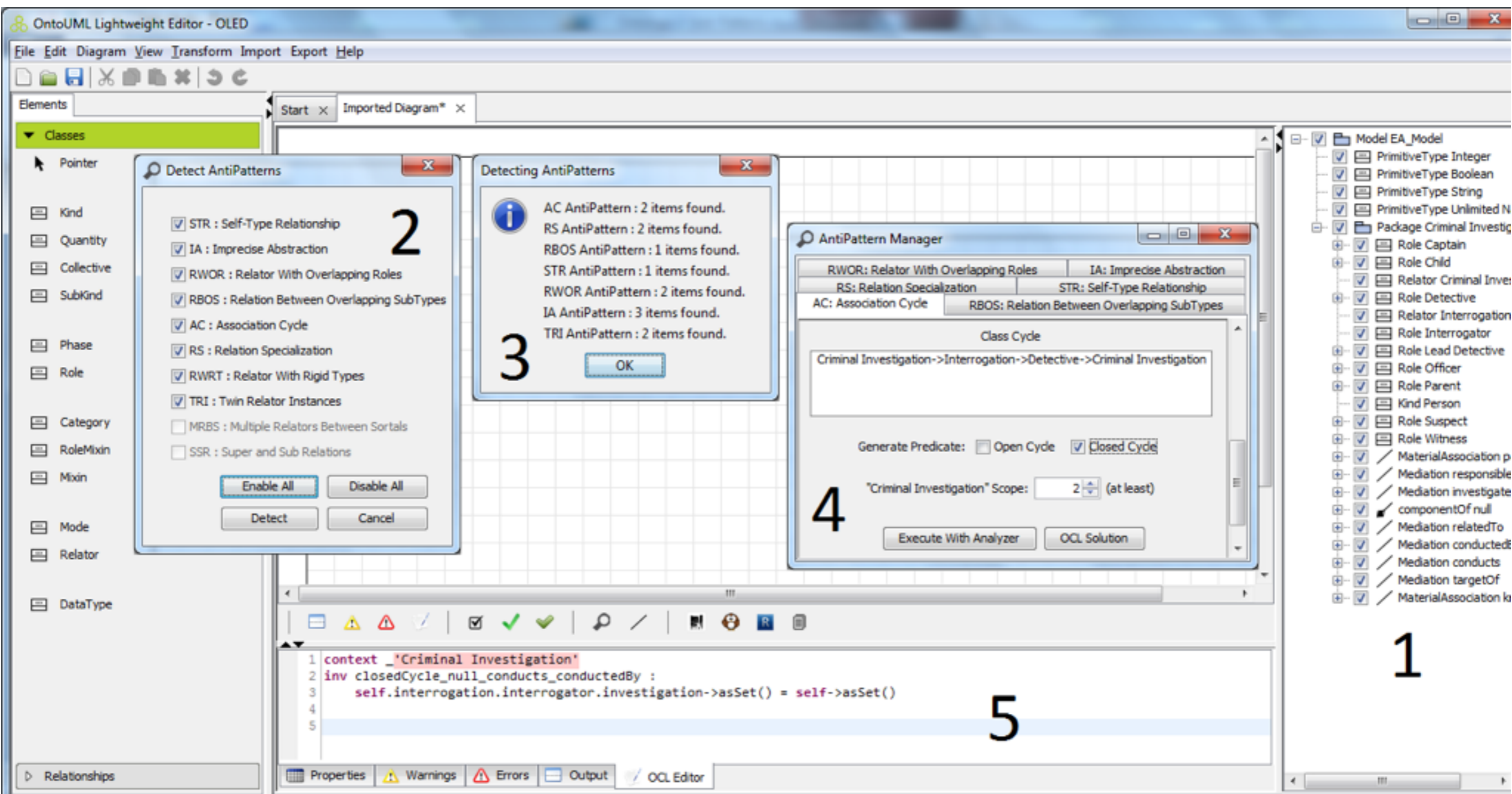
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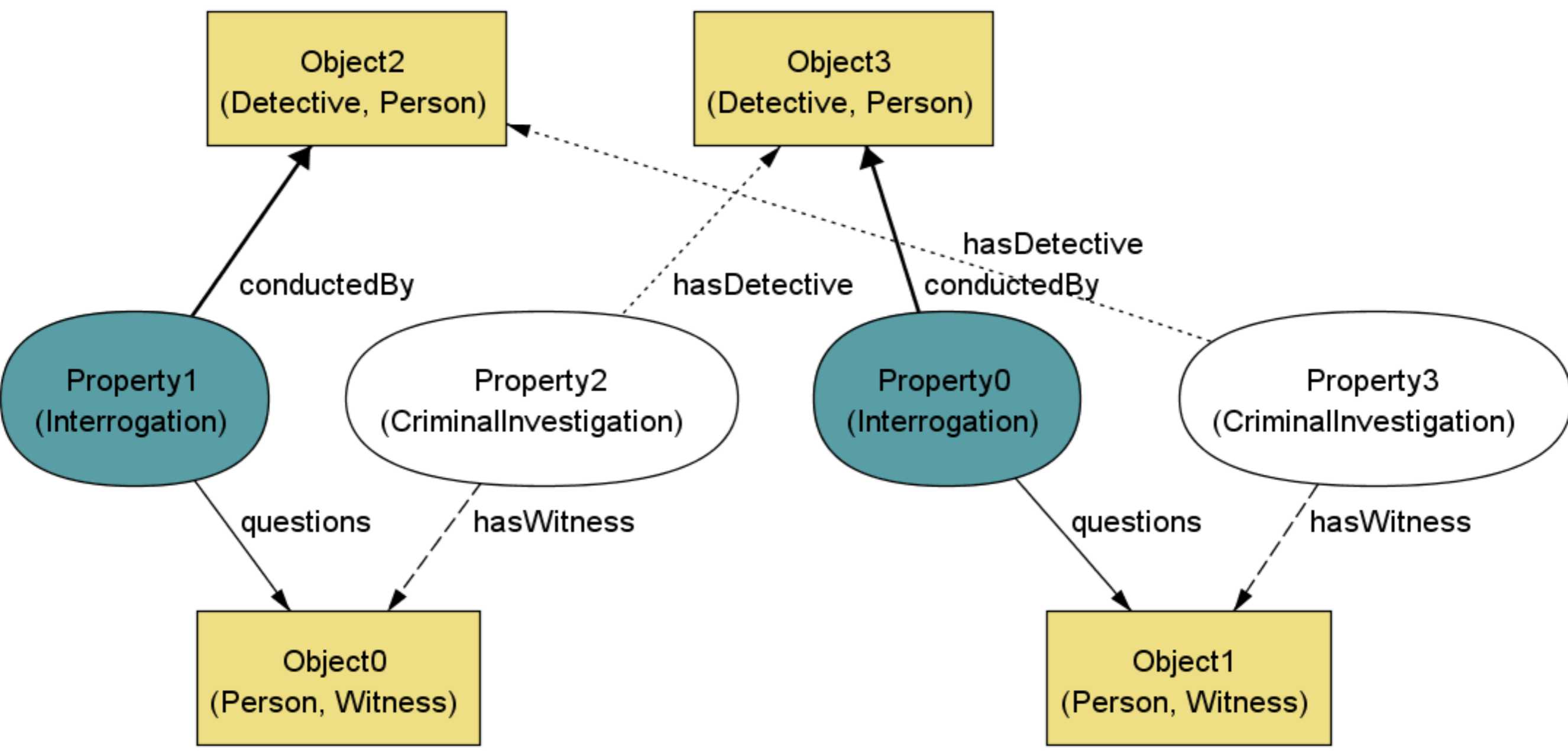
Anti-Pattern	#Occ.	#Error	#Error / #Occ.	#Refac. /#Error
RelSpec	315	279	88.6%	97.1%
RepRel	221	57	25.8%	84.2%
RelOver	124	70	56.5%	77.1%
BinOver	74	31	41.9%	74.2%
AssCyc	20	14	70.0%	71.4%
ImpAbs	125	11	8.8%	27.3%
Total	879	462	52.56%	88.53%

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Total	879	462	52.56%	88.53%

OntoUML Criminal Investigation







Relator With Overlapping Roles

Relator:

Customizing Disjoints Roles:

Add

Lead Detective	Witness	Detective	Suspect
<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

Exclusive

Exclusive from Table

Overlapping

Disjoint

Disjoint from Table

"Criminal Investigation" Scope: (at least)

Execute With Analyzer

OCL Solution



```

1 context _'Criminal Investigation'
2 inv: self.witness.oclAsType(Person)->asSet()->intersection(self.detective.oclAsType(Person)->asSet()->size())=0
3
4 context _'Criminal Investigation'
5 inv: self.witness.oclAsType(Person)->asSet()->intersection(self.suspect.oclAsType(Person)->asSet()->size())=0
6
7 context _'Detective'
8 inv: not self.oclIsTypeOf(Suspect)
9

```

“Few modelers, however, have had the experience of subjecting their models to continual, automatic review. Building a model incrementally with an analyzer, **simulating** and checking as you go along, is a very different experience from using pencil and paper alone. The first reaction tends to be amazement: modeling is much more fun when you get instant, **visual feedback**. Then the sense of **humiliation** sets in, as you discover that **there’s almost nothing you can do right.**”

(Daniel Jackson, Software Abstractions : Logic, Language, and Analysis, 2006)

The Humble **Ontologist**

[What] I have chosen to stress in this talk is the following. We shall do a much better **ontology** job in the future, provided that we approach the task with a full appreciation of its tremendous complexity, ..., provided we respect the intrinsic limitations of the human mind and approach the task a Very Humble **Ontologist**

(paraphrasing Dijkstra's Humble Programmer, 1972)

Demos, Tools and Model Repository

Demos

[https://www.youtube.com/channel/
UC9pKWYDVEevmDHaGQybAB1g](https://www.youtube.com/channel/UC9pKWYDVEevmDHaGQybAB1g)

Tools

[https://www.facebook.com/
ontoumleditor](https://www.facebook.com/ontoumleditor)

[https://code.google.com/p/ontouml-
lightweight-editor/](https://code.google.com/p/ontouml-lightweight-editor/)

<http://www.menthor.net>

Model Repository

<http://www.menthor.net/model-repository.html>

Reading Material



**ONTOLOGICAL
FOUNDATIONS
FOR STRUCTURAL
CONCEPTUAL
MODELS**

GIANCARLO GUIZZARDI

Reading Material

- SALLES, T.P., GUIZZARDI, G., Ontological Anti-Patterns: Empirically Uncovered Error-Prone Structures in Ontology-Driven Conceptual Models, *Data & Knowledge Engineering (DKE) Journal*, Volume 99, September 2015, Pages 72–104.
- RUY, F., REGINATO, C.C., SANTOS, V.A., FALBO, R., GUIZZARDI, G., Ontology Engineering by Combining Ontology Patterns, 35th International Conference on Conceptual Modeling (ER 2015) Stockholm, 2015.
- GUIZZARDI, G., Ontological Patterns, Anti-Patterns and Pattern Languages for Next-Generation Conceptual Modeling, invited companion paper to the Keynote Speech delivered at the 33rd International Conference on Conceptual Modeling (ER 2014), Atlanta, USA.

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- NARDI, J., FALBO, R., ALMEIDA, J.P., GUIZZARDI, G., PIRES, L.F., VAN SINDEREN, M., GUARINO, N., FONSECA, C. M., A Commitment-Based Reference Ontology for Services, Information Systems, Oxford University Press, Volume 54, December 2015, Pages 263–288
- GUIZZARDI, G.; GRAÇAS, A.P., GUIZZARDI, R.S.S., Design Patterns and Inductive Modeling Rules to Support the Construction of Ontologically Well-Founded Conceptual Models in OntoUML, 3rd International Workshop on Ontology-Driven Information Systems (ODISE 2011), together with the 23rd International Conference on Advanced Information System Engineering (CAiSE'11), London, UK.
- BENEVIDES, A.B.; GUIZZARDI, G.; BRAGA, B.F.B.; ALMEIDA, J.P.A., Validating modal aspects of OntoUML conceptual models using automatically generated visual world structures, Journal of Universal Computer Science, Special Issue on Evolving Theories of Conceptual Modeling, Editors: Klaus-Dieter Schewe and Markus Kirchberg, 2010.

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- GUIZZARDI, G., ZAMBORLINI, V., Using a Trope-Based Foundational Ontology for Bridging different areas of concern in Ontology-Driven Conceptual Modeling, Science of Computer Programming, Elsevier, 2014, DOI:10.1016/j.scico.2014.02.022.
- ZAMBORLINI, V.; GUIZZARDI, G., On the representation of temporally changing information in OWL, IEEE 5th Joint International Workshop on Vocabularies, Ontologies and Rules for The Enterprise (VORTE) – Metamodels, Ontologies and Semantic Technologies (MOST), together with 15th International Enterprise Computing Conference (EDOC 2010), Vitória, Brazil, 2010.
- GUIZZARDI, G.; WAGNER, G.; GUARINO, N.; VAN SINDEREN, M., An Ontologically Well-Founded Profile for UML Conceptual Models, 16th International Conference on Advances in Information Systems Engineering (CAiSE), Latvia, 2004. Springer-Verlag , Berlin, Lecture Notes in Computer Science 3084, ISBN 3-540-22151-4

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- GUARINO, N., The Ontological Level: Revisiting 30 Years of Knowledge Representation. *Conceptual Modeling: Foundations and Applications 2009*: 52-67
- GUARINO, N. WELTY, C., An Overview of OntoClean. *Handbook on Ontologies 2004*: 151-172
- GUARINO, N. WELTY, C., Evaluating ontological decisions with OntoClean. *Commun. ACM* 45(2): 61-65 (2002).
- Jackson, D.: *Software Abstractions: Logic, Language, and Analysis*. The MIT Press, Cambridge, Massachusetts (2012).

Reading Material

- Bauman, B. T., Prying Apart Semantics and Implementation: Generating XML Schemata directly from ontologically sound conceptual models, Balisage Markup Conference, 2009.
- U.S. Department of Defense, Data Modeling Guide (DMG) for an Enterprise Logical Data Model (ELDM), available online: http://www.omgwiki.org/architecture-ecosystem/lib/exe/fetch.php?media=dmg_for_enterprise_ldm_v2_3.pdf.
- Dijkstra, E.W., The Humble Programmer, Communications of the ACM, 15:10, Oct. 1972.
- Mylopoulos, J., Conceptual modeling and Telos. In P. Loucopoulos & R. Zicari (eds.), Conceptual Modeling, Databases, and CASE (Chapter 2, pp. 49–68). Wiley, 1992.



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