

An Ontological View on Types



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Giancarlo Guizzardi
Semantics,
Cybersecurity
& Services

UNIVERSITEIT
TWENTE.



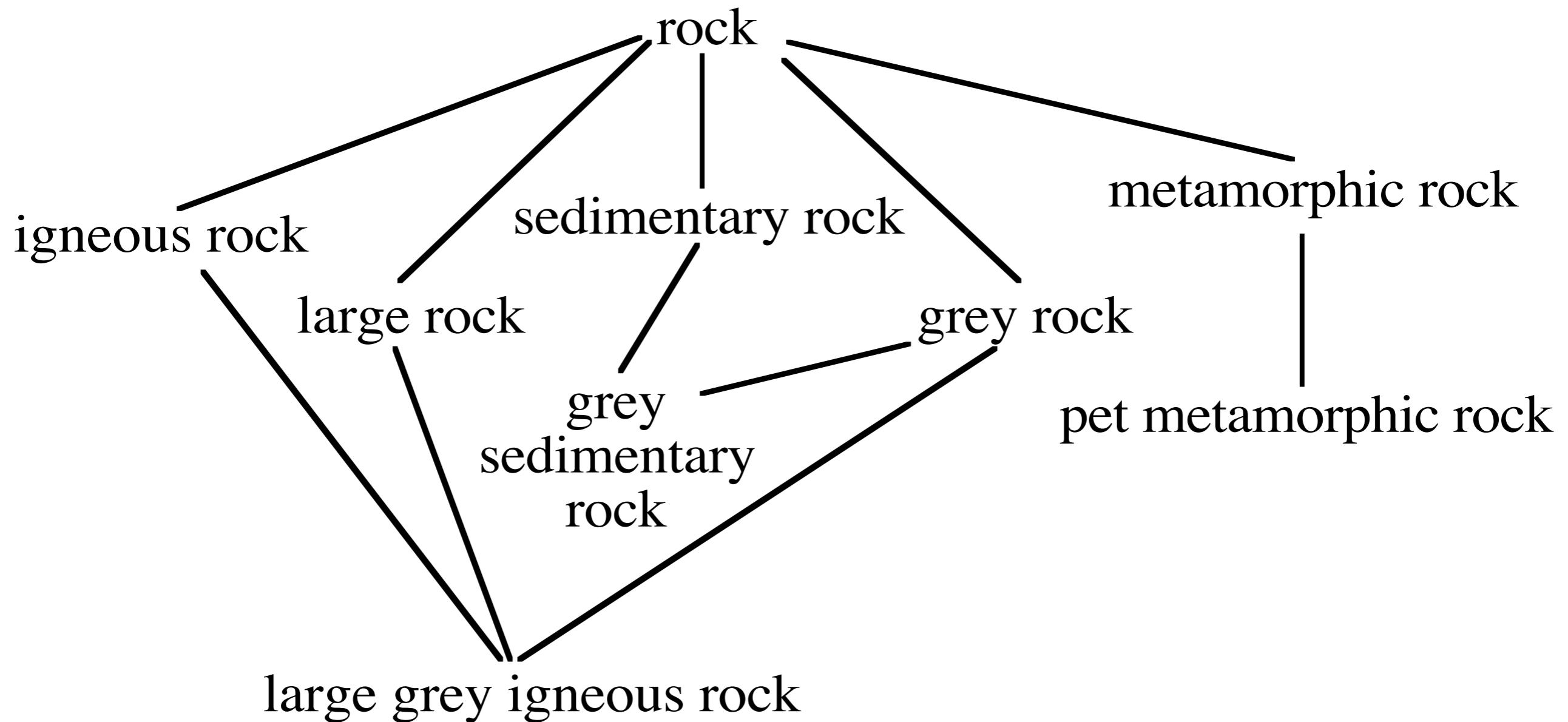
Acknowledgements

- João Paulo Almeida
- Victorio Carvalho
- Claudenir Fonseca
- Nicola Guarino

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Ontological Aspects of Types

How many kinds of rock?



Competence in Knowledge Representation

Ronald J. Brachman

Hector J. Levesque

Fairchild Laboratory for Artificial Intelligence Research

Palo Alto, CA

§1 Introduction

The range of domains and tasks for “knowledge-based systems” has been expanding at a furious pace. As we move away from trivial domains, such as the “blocks world”, the demands on knowledge representation systems used by expert programs are becoming more extreme. For one thing, the domains themselves are getting so complex that specialized technical vocabularies are unavoidable; consequently, the issue of a system *talking with an expert in his own language* cannot be ignored. For another, tasks such as medical diagnosis, scene analysis, speech understanding, and game playing all have as a central feature an *incrementally evolving model* representing probably incomplete knowledge of part of the task domain. In this paper, we explore some of the impact of these two critical issues—complexity and incompleteness—on knowledge representation systems. We review some aspects of current representation research that offer a foundation for coping with these problems, and finally suggest a way of integrating these ideas into a powerful, practical knowledge representation paradigm.

- ▶ an “*enhancement mode transistor*” is a *kind* of transistor with specific electrical properties.
- ▶ a “*pass transistor*” is any transistor that plays a certain *role* in a larger circuit.
- ▶ a “*barrel shifter*” is a *structured configuration* of components with a certain functionality.
- ▶ “*two-phase nonoverlapping clocking*” is a *method* of organizing the timing in a circuit.

In order to behave knowledgeably in a real domain, a system will have to interact with experts using specialized terms like the above. Therefore, the application of knowledge representation to expert problems demands of a representation system the ability to *develop, augment, and maintain* this kind of technical vocabulary. As the above examples suggest, a representation scheme must allow the introduction of terms that deal with different aspects of the domain: objects, properties, methods, rules, heuristics, and so on. Moreover, it must be possible to specify terms that are related to each other in several different and complex ways.

- (1) Kind = Type
- (2) Type = Predicate

Fundamental Problems

1. **Ontological Extravagance:** Allow for types that are not ontologically genuine
2. **Ontological Incompleteness** :no differentiation between types of types, which leads to a **semantic overload** of the corresponding construct in language

$C(a)$ 

a

A blue circular button with the letter 'a' in white, centered at the bottom of the diagram.

$C(a)$ 

A blue circular node containing the white text 'a'.

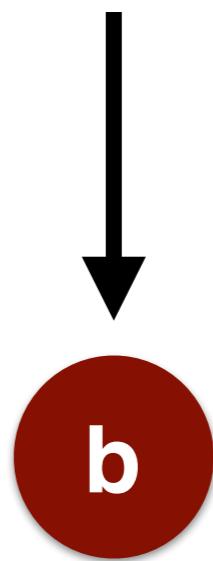
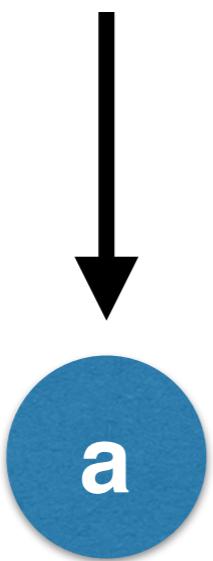
 $M(b)$ 

A red circular node containing the white text 'b'.

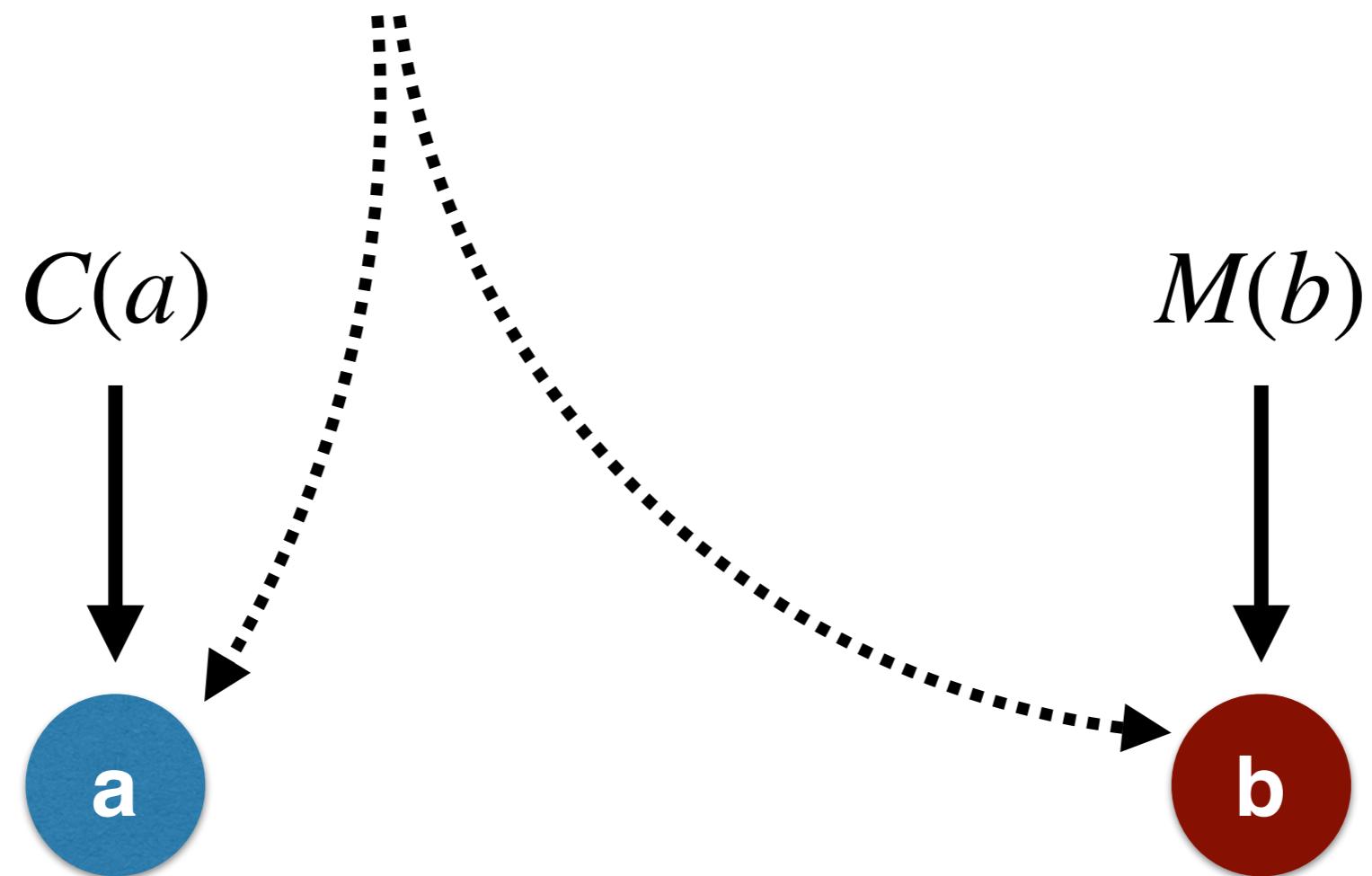
$$P(x) \triangleq C(x) \vee M(x)$$

$C(a)$

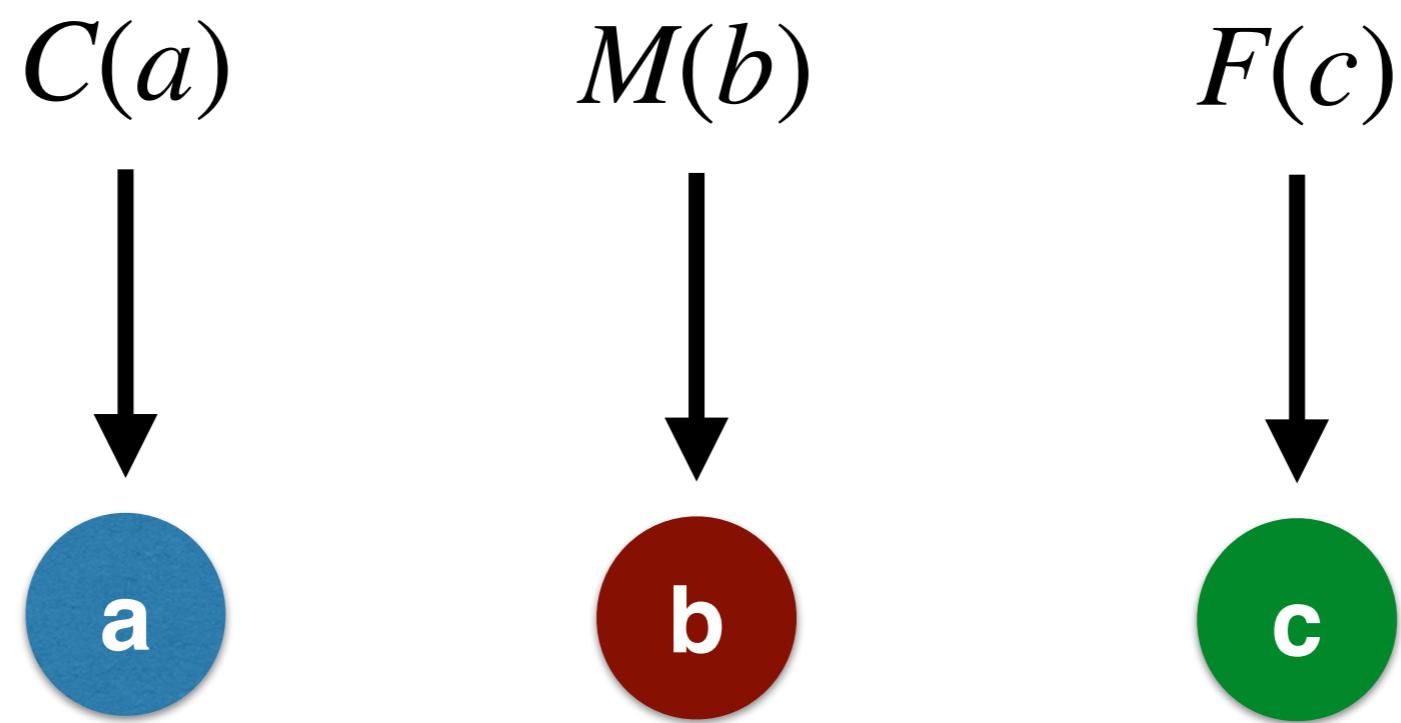
$M(b)$

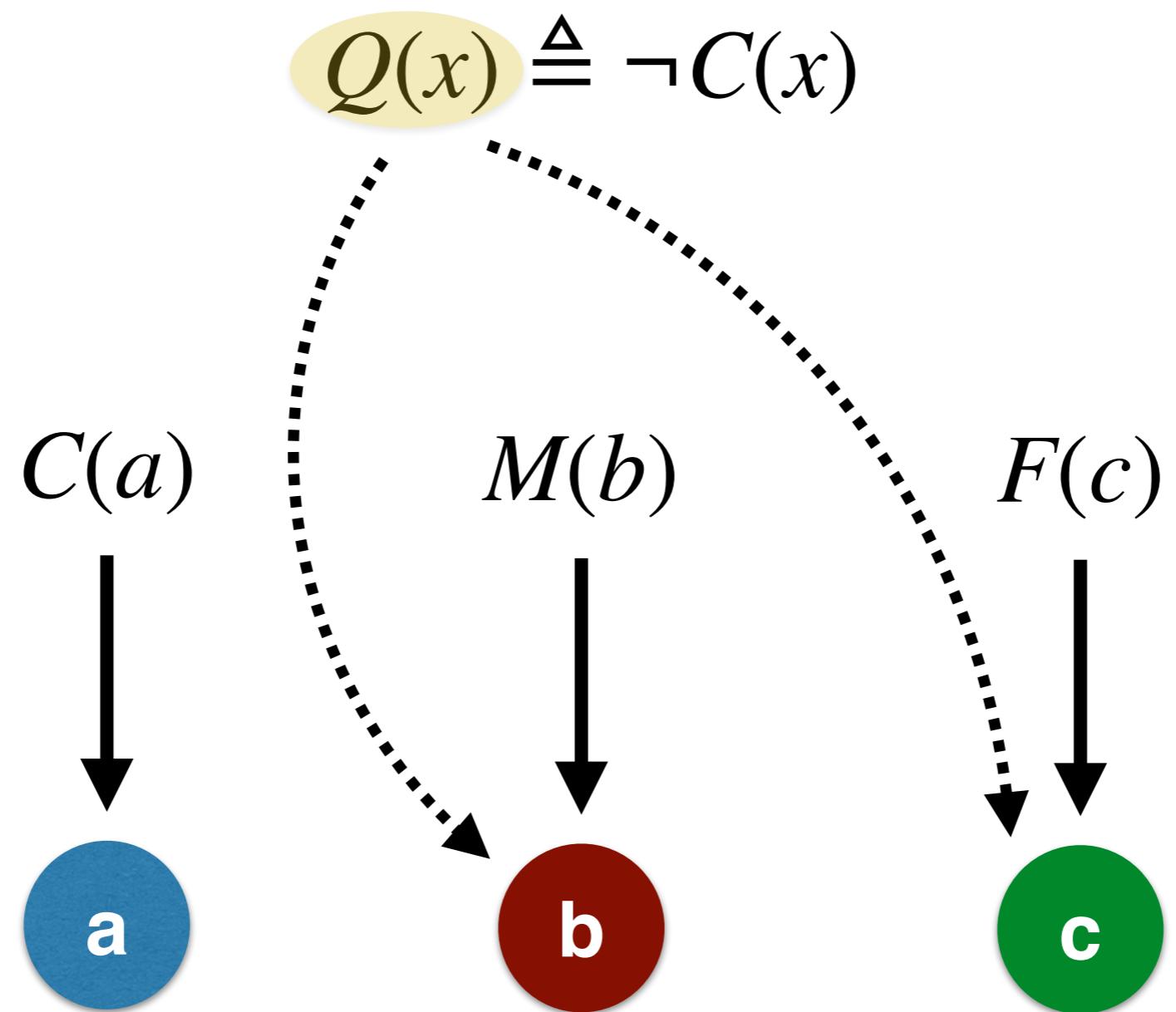


$$P(x) \triangleq C(x) \vee M(x)$$



$$Q(x) \triangleq \neg C(x)$$





The Logical Level

$$\exists x \text{ Apple}(x) \wedge \text{Red}(x)$$

The **Espistemological** Level

Apple

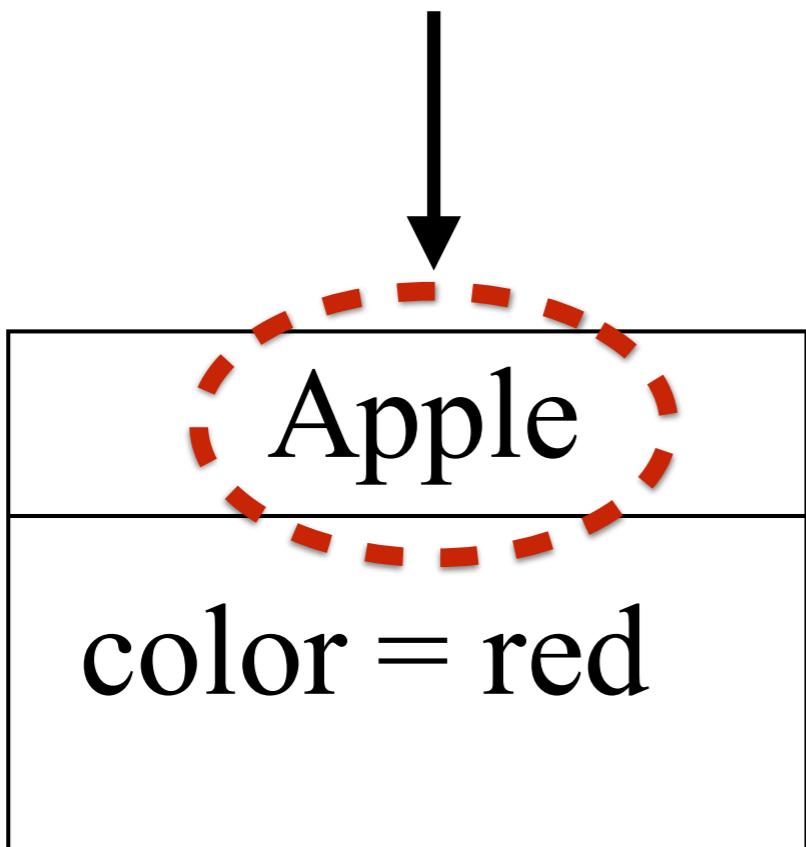
color = red

Red

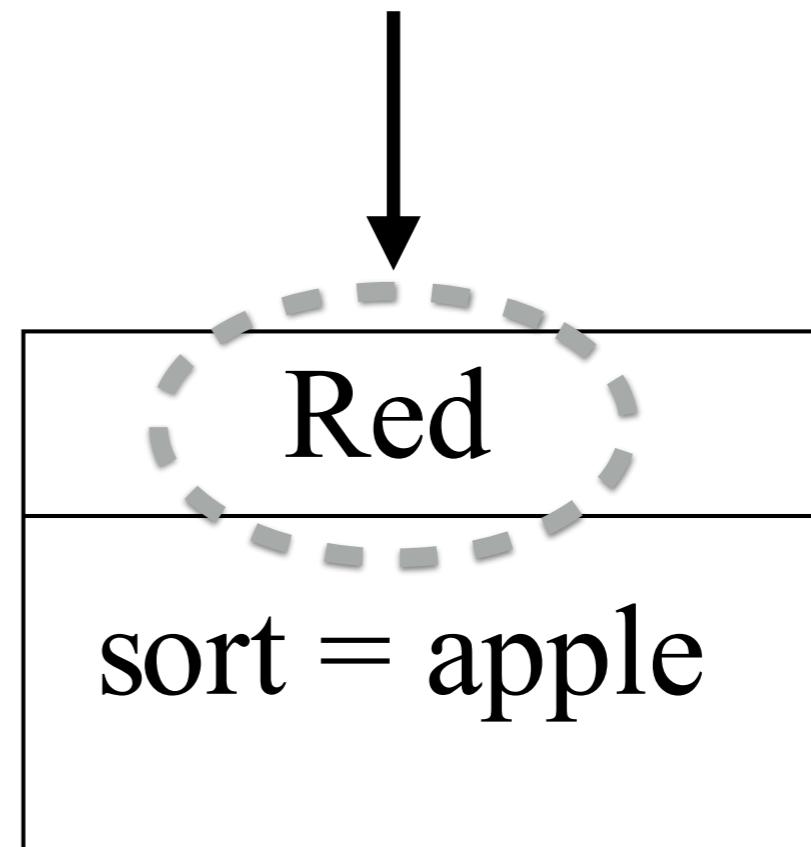
sort = apple

The Ontological Level

SORTAL



MIXIN



General Terms and Common Nouns

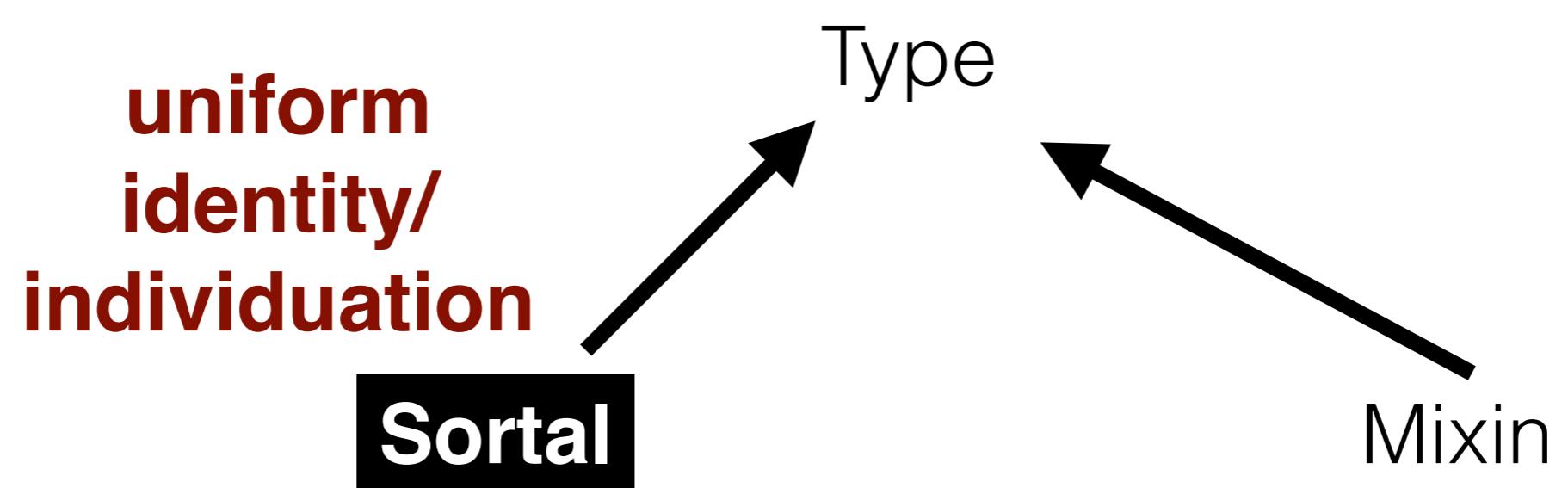
- (i) exactly five mice were in the kitchen last night
- (ii) the mouse which has eaten the cheese, has been in turn eaten by the cat

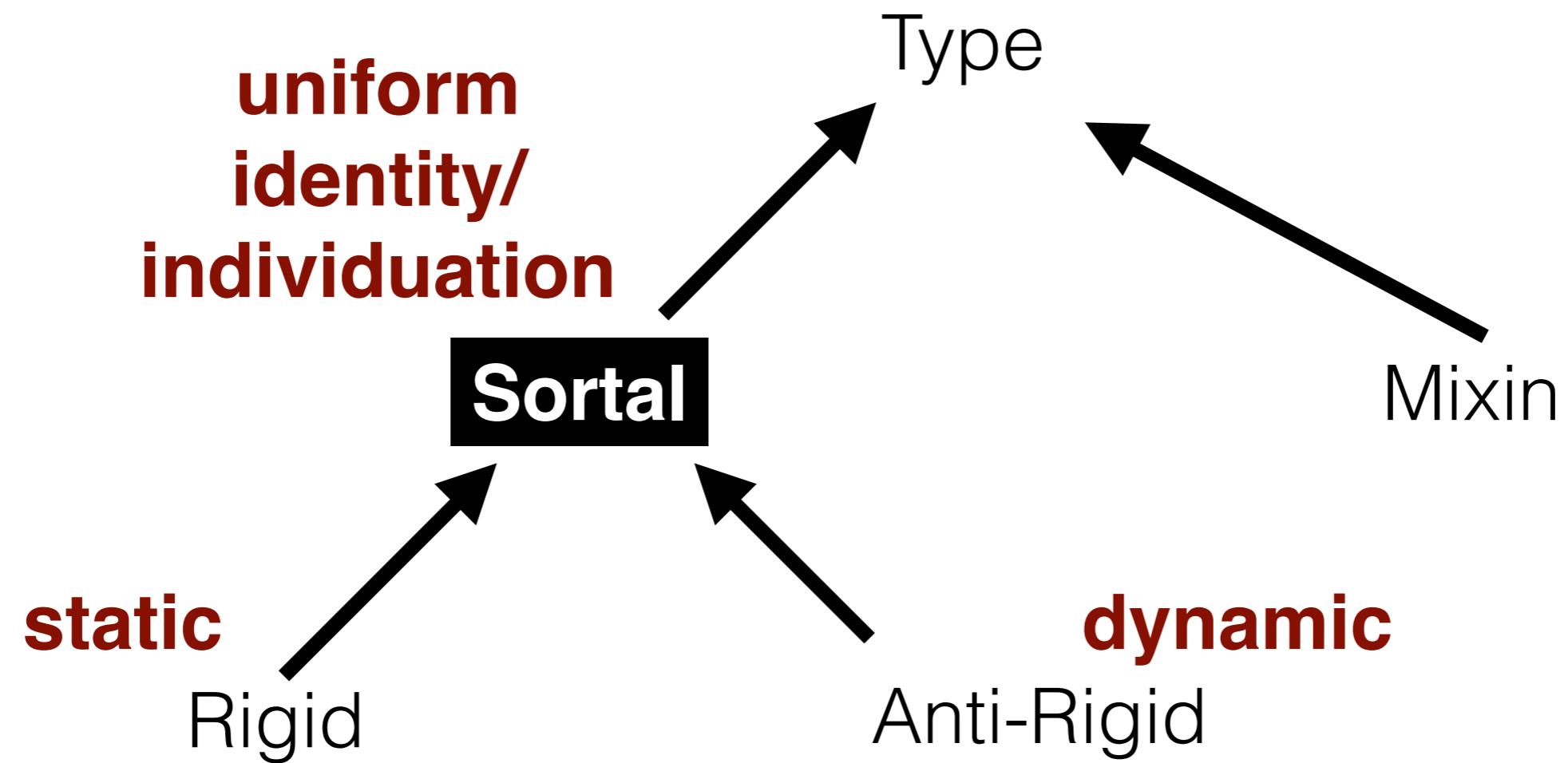
General Terms and Common Nouns

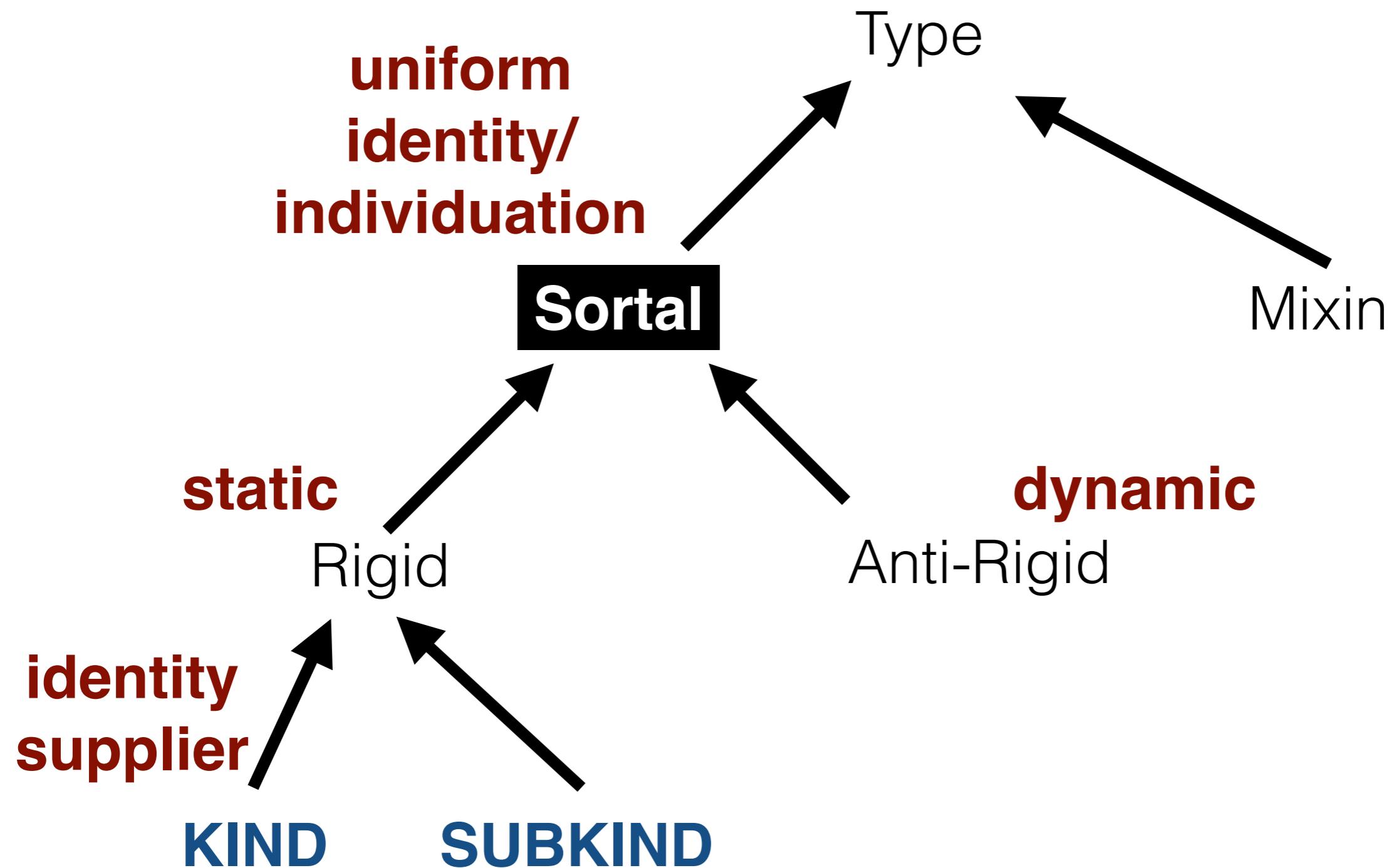
- (i) exactly five X ...
- (ii) the Y which is Z...

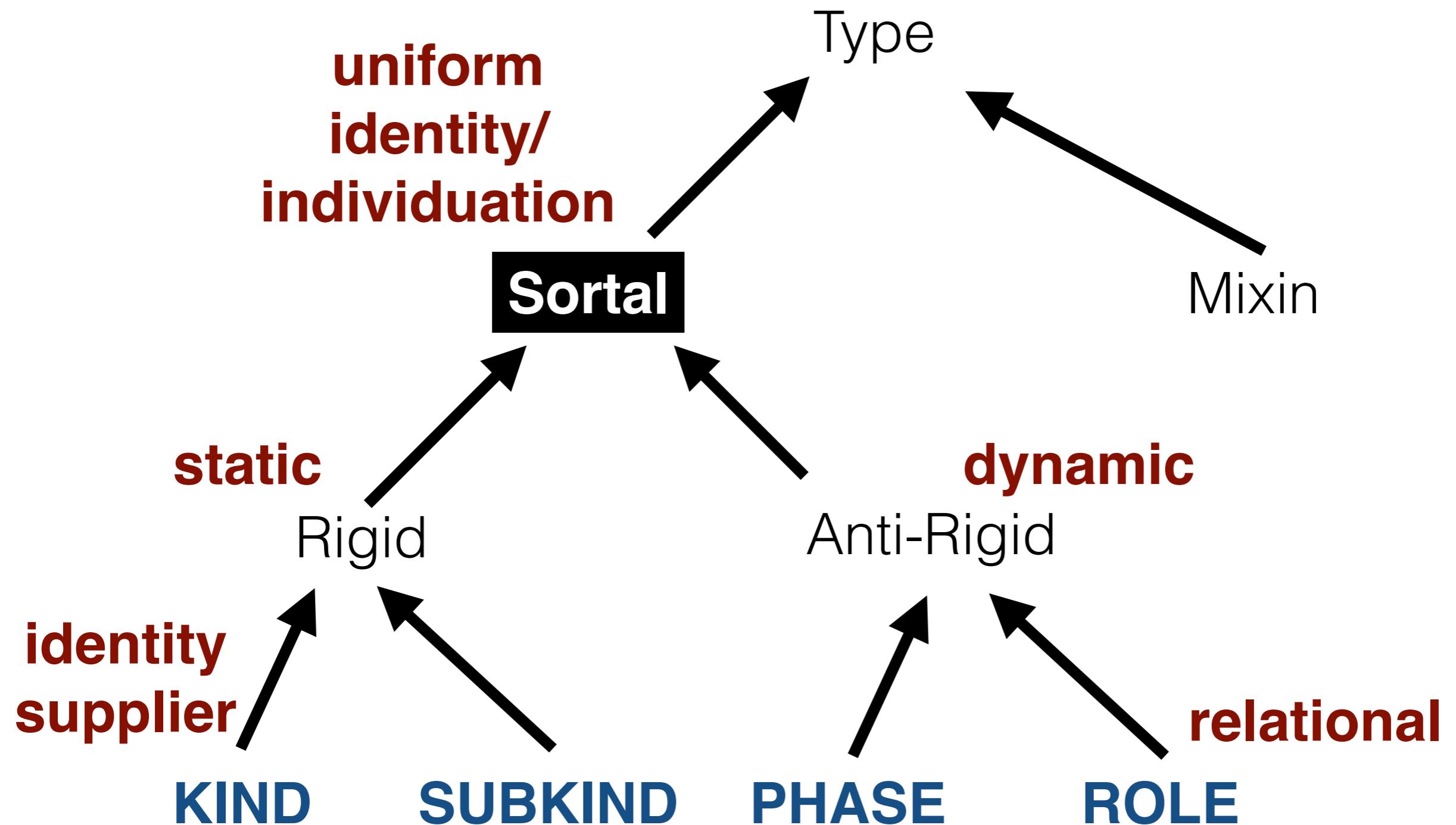
General Terms and Common Nouns

- (i) exactly five *reds* were in the kitchen last night
- (ii) the *red* which has ..., has been in turn ...

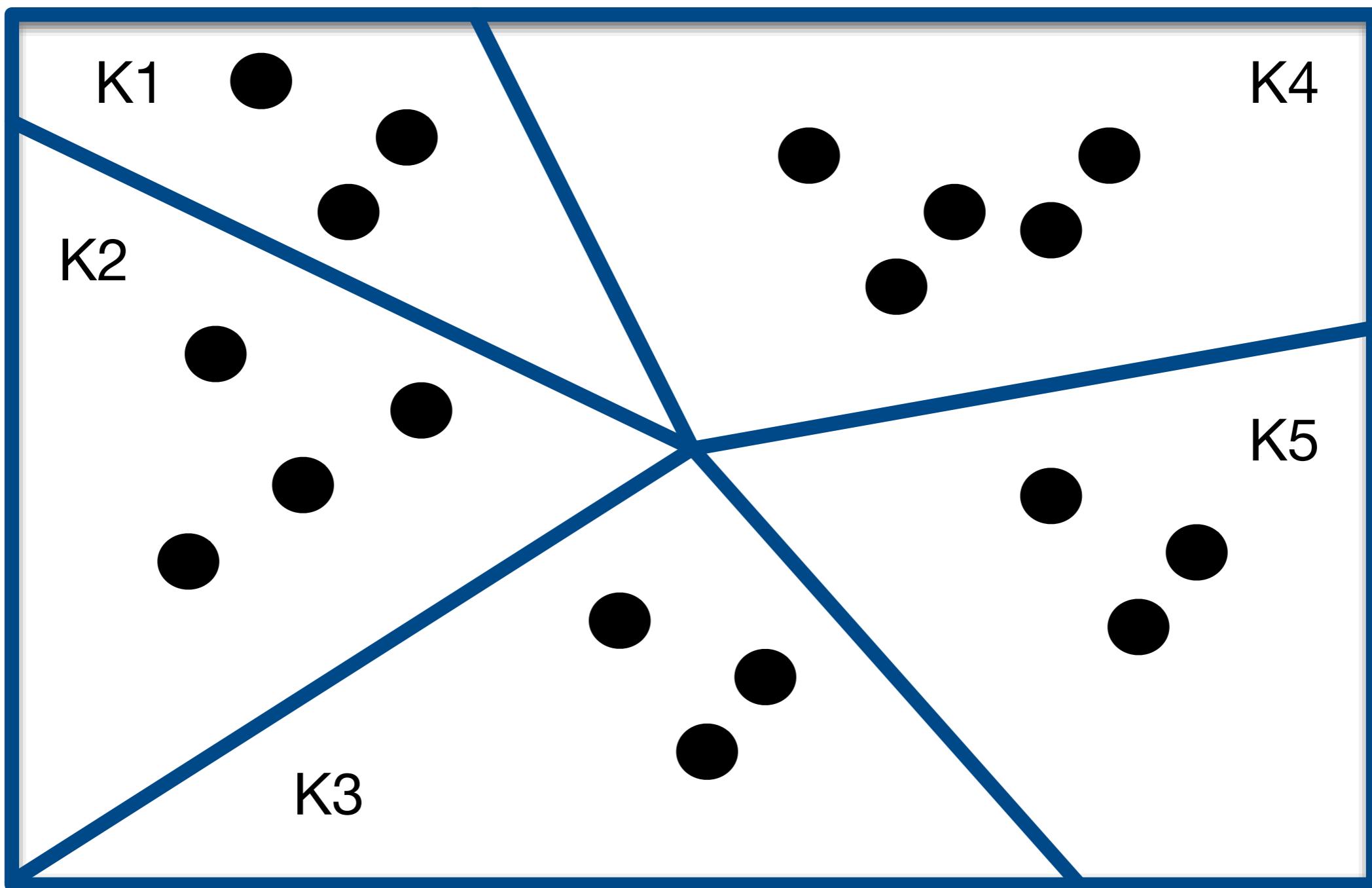




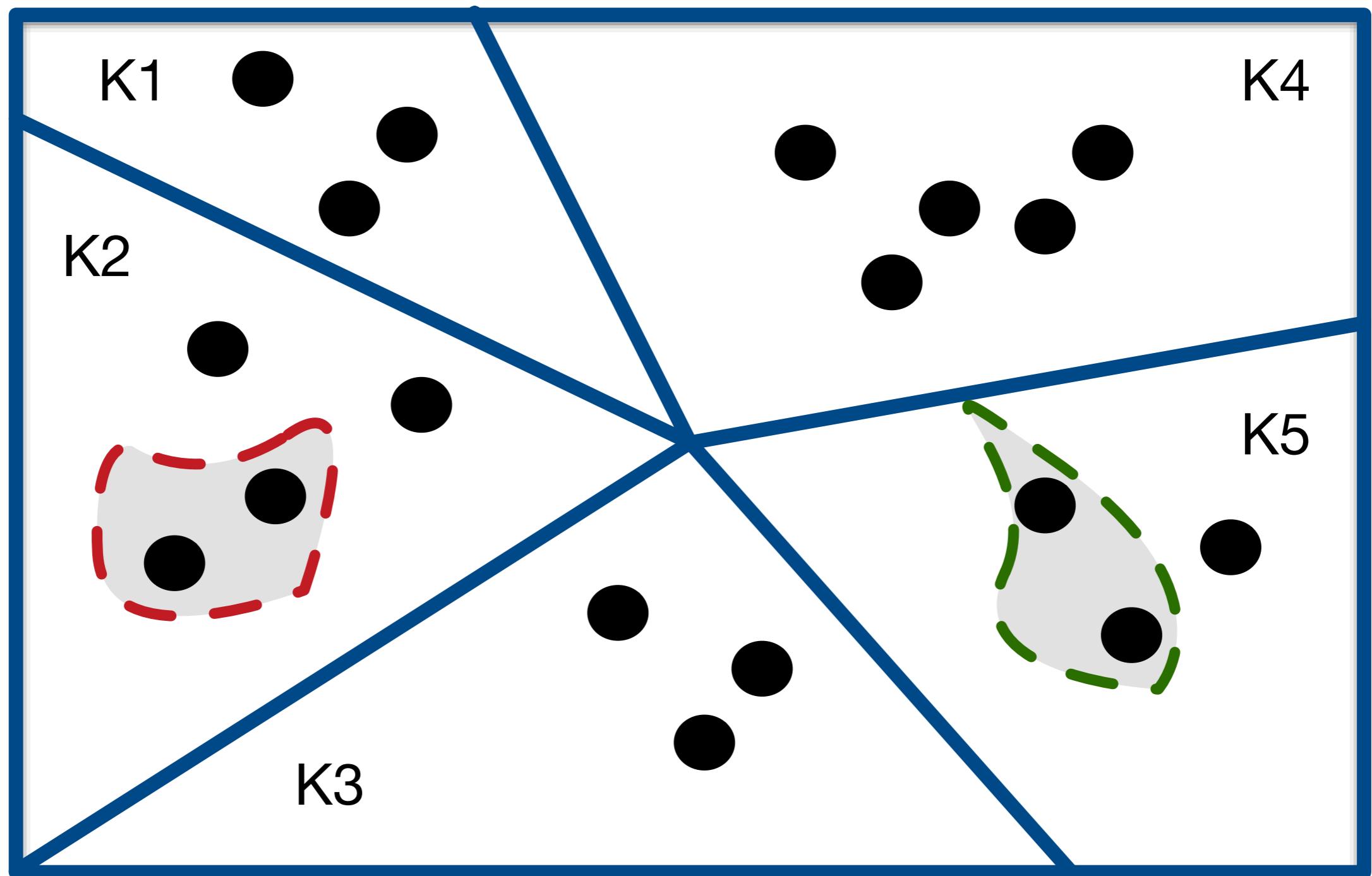




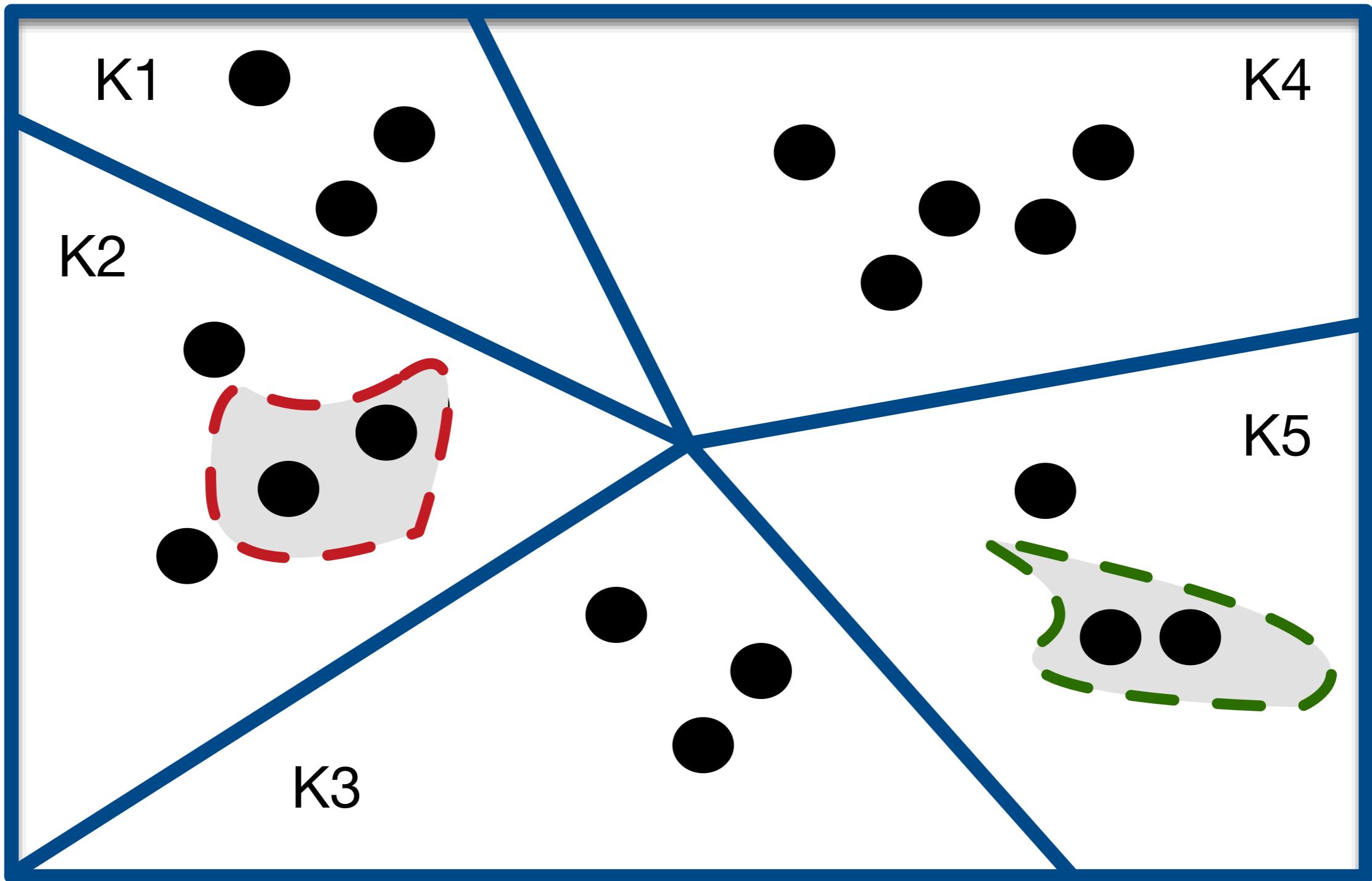
Kinds

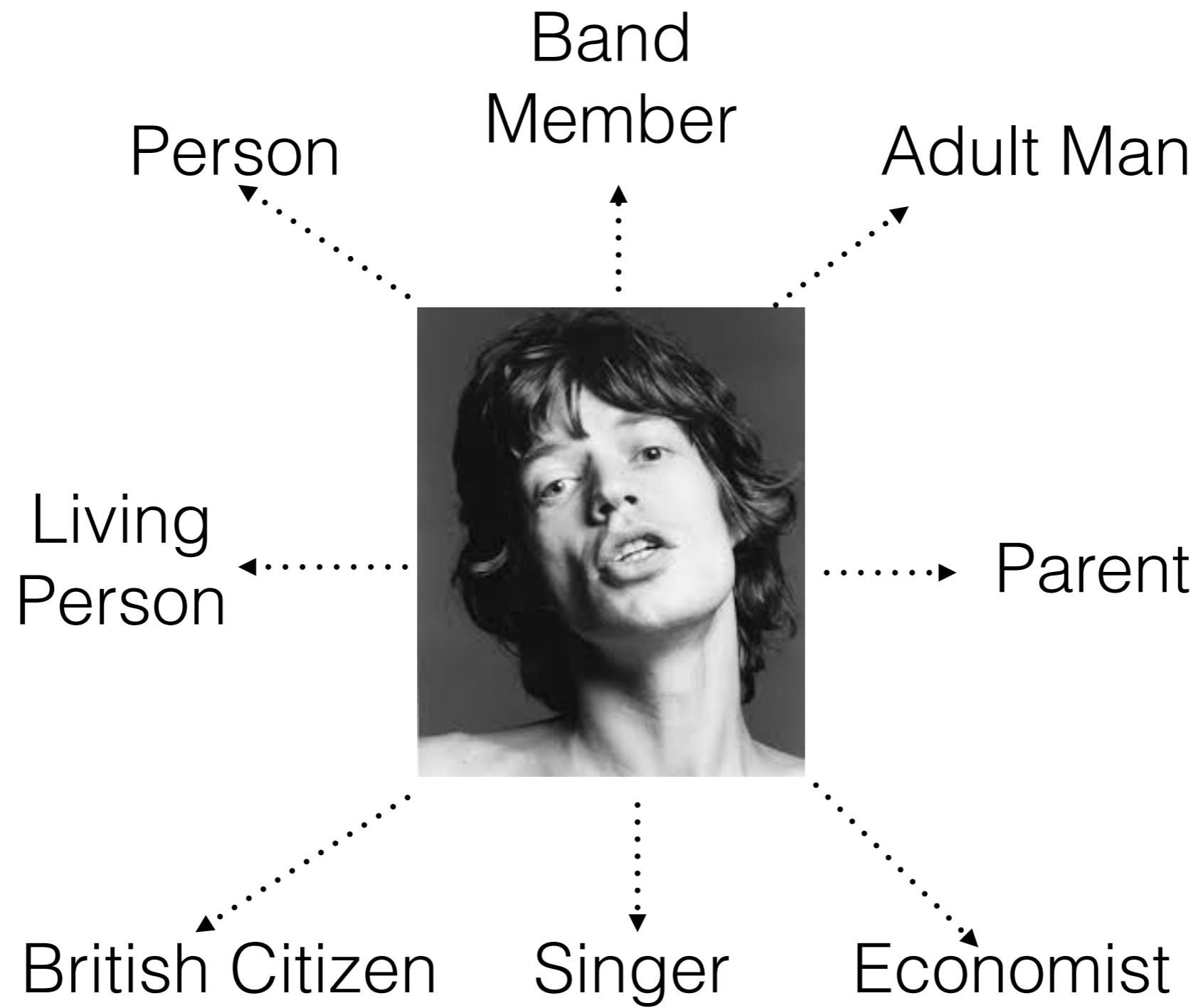


Anti-Rigid Sortals



Anti-Rigid Sortals



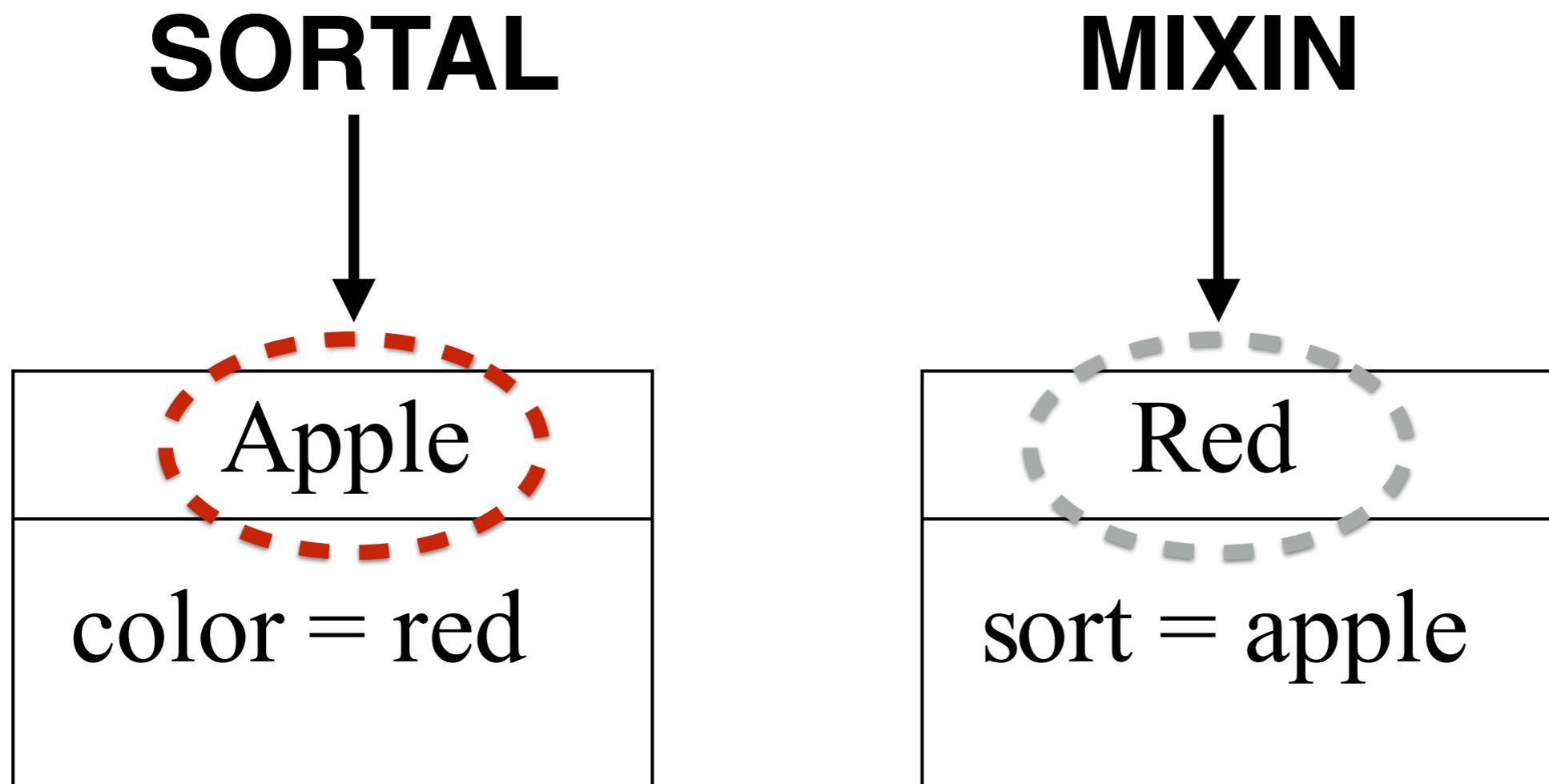


KIND = IDENTITY PROVIDER DEFINING
ESSENTIAL PROPERTIES (e.g., **PERSON**)

ROLE = DYNAMIC + RELATIONAL
(e.g., **SINGER, ECONOMIST, BRITISH CITIZEN,**
KNIGHT OF THE BRITISH EMPIRE, PARENT)

PHASE = DYNAMIC BUT NON-RELATIONAL
(e.g., **LIVING PERSON, ADULT MAN**)

The Ontological Level



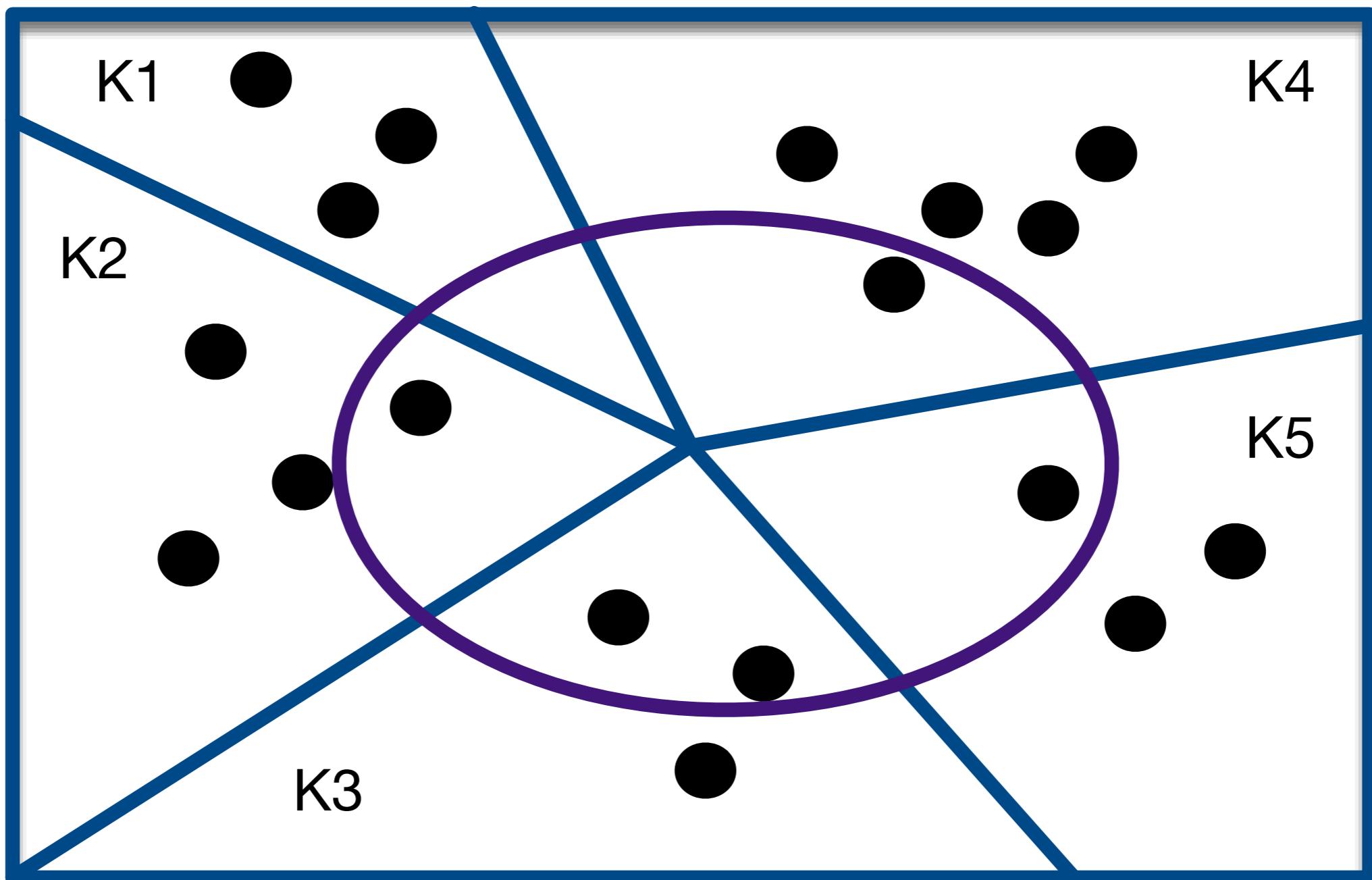
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ROLE = DYNAMIC + RELATIONAL
(e.g., **SINGER, ECONOMIST, BRITISH CITIZEN, KNIGHT OF THE BRITISH EMPIRE**)

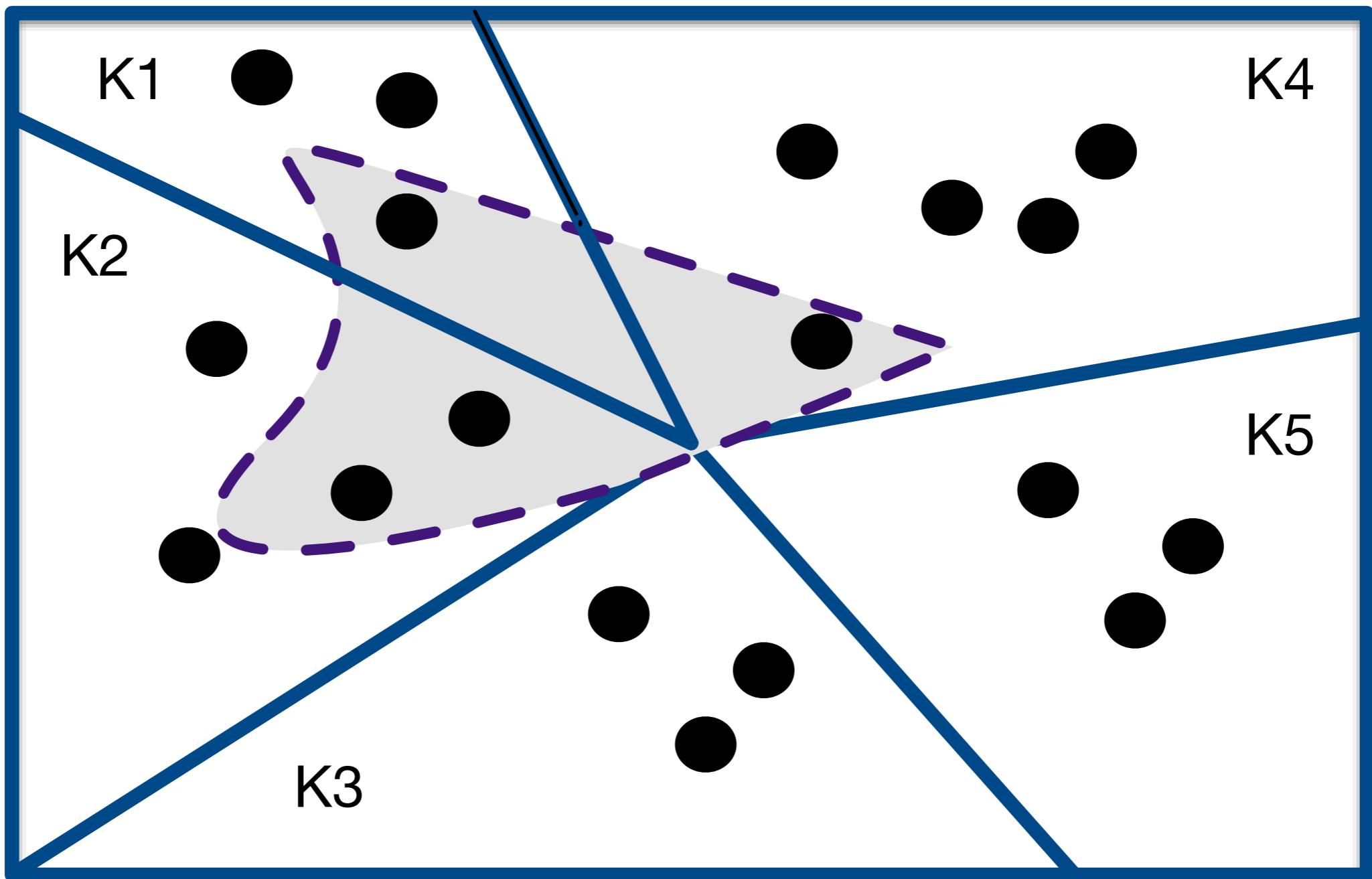
PHASE = DYNAMIC BUT NON-RELATIONAL
(e.g., **LIVING PERSON, ADULT MAN**)

MIXIN = CLASSIFYING ENTITIES OF SEVERAL
KINDS (e.g., **CULTURAL HERITAGE ENTITY, PHYSICAL ENTITY, INSURABLE ITEM**)

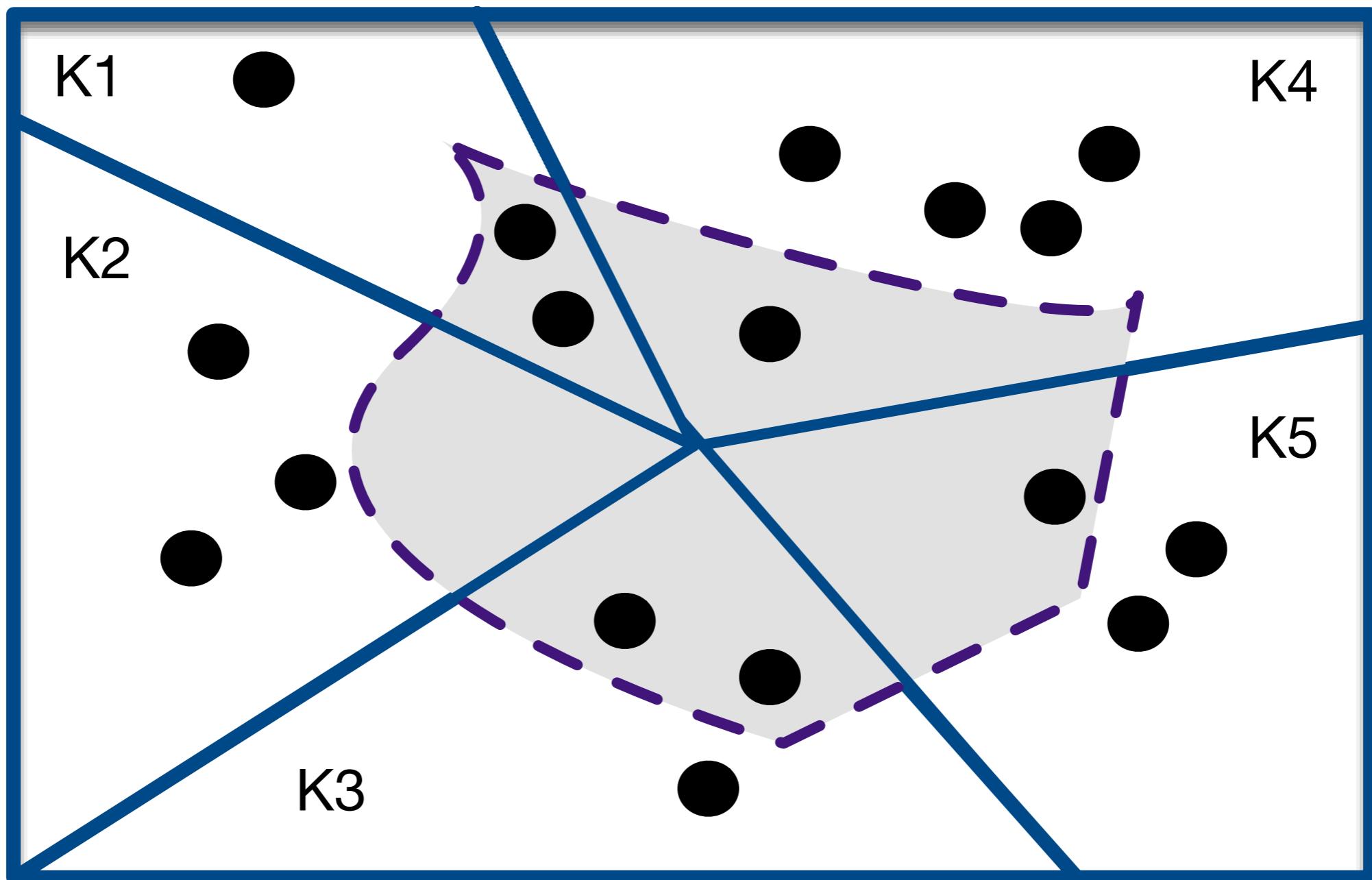
Mixin

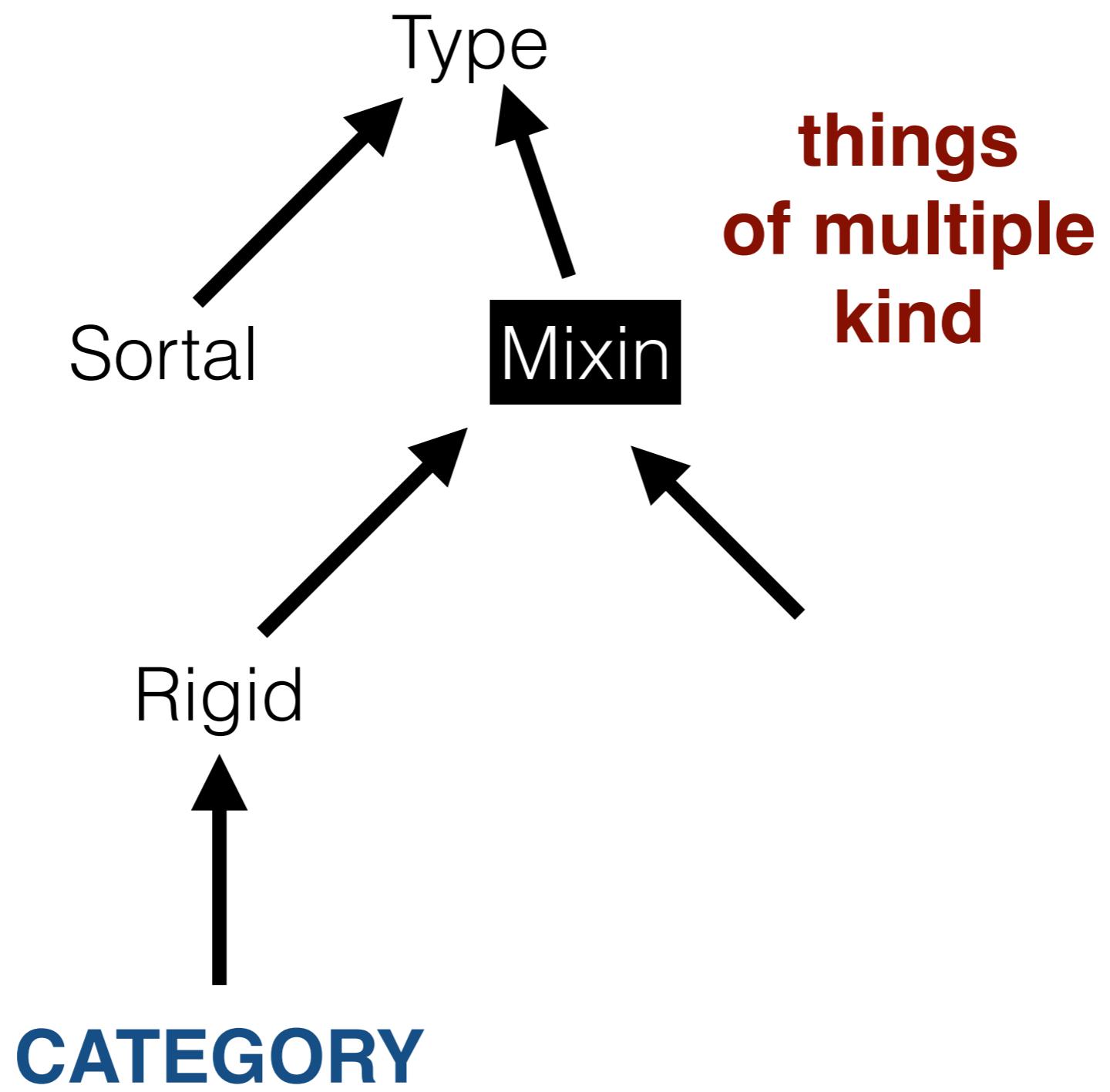


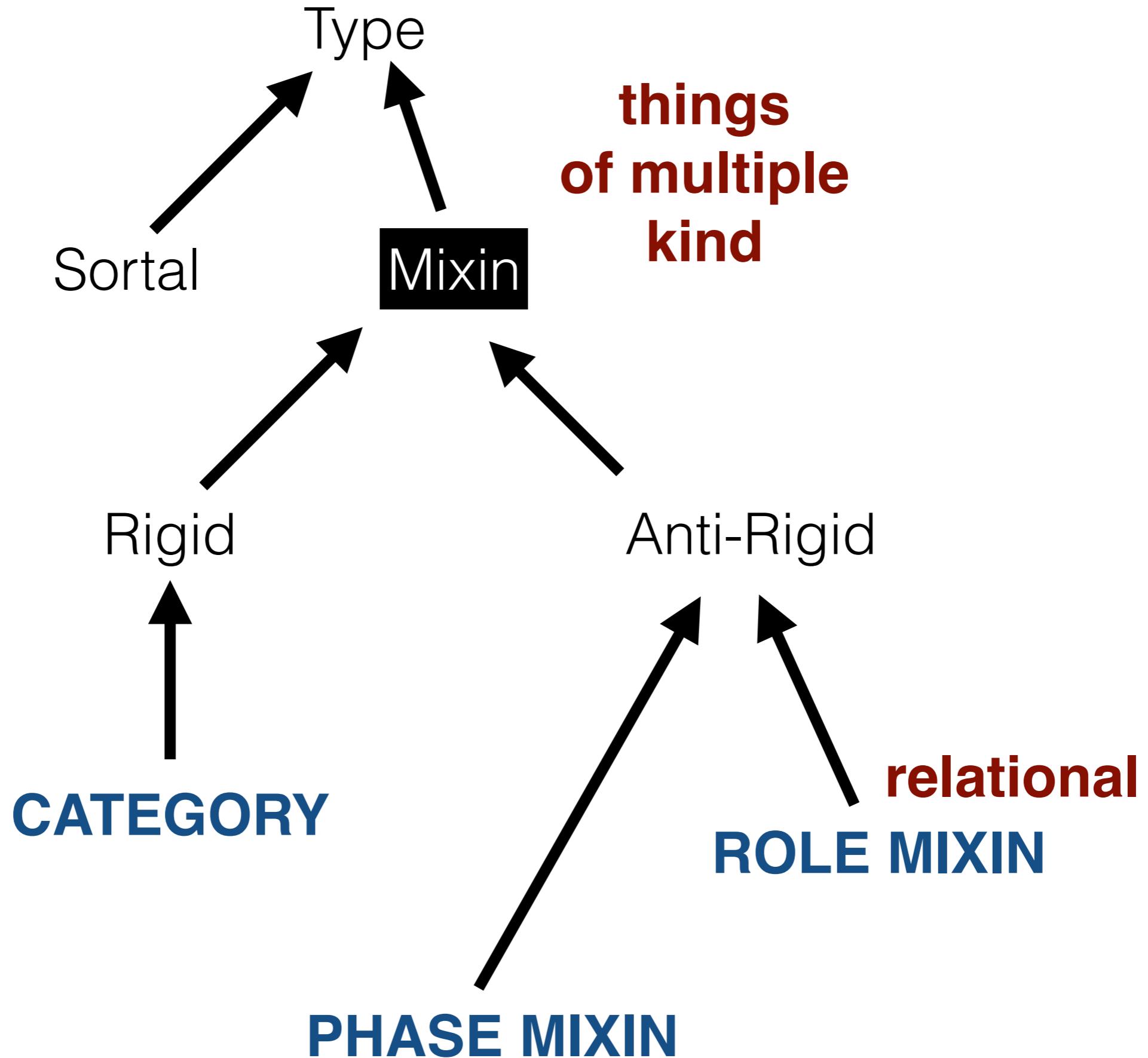
Anti-Rigid Mixin



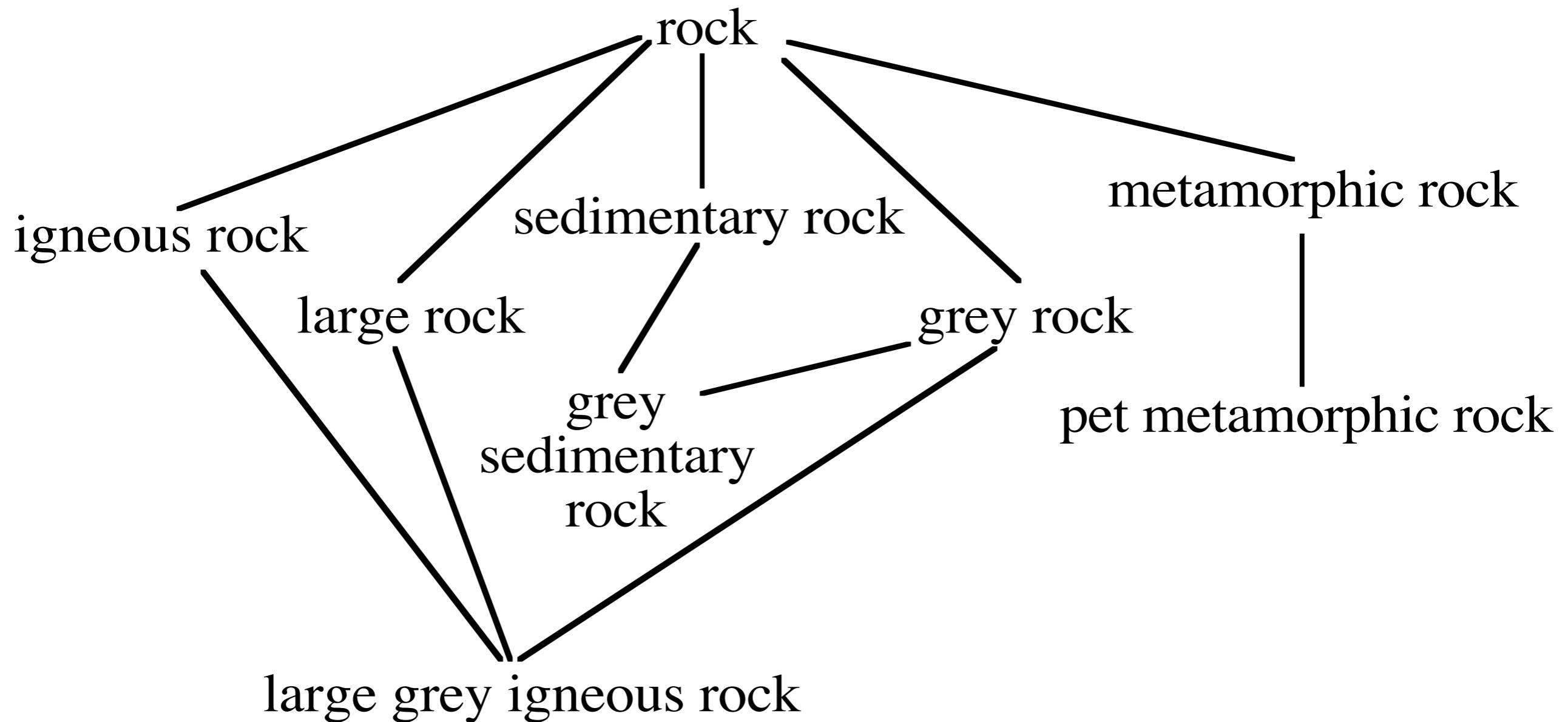
Anti-Rigid Mixin



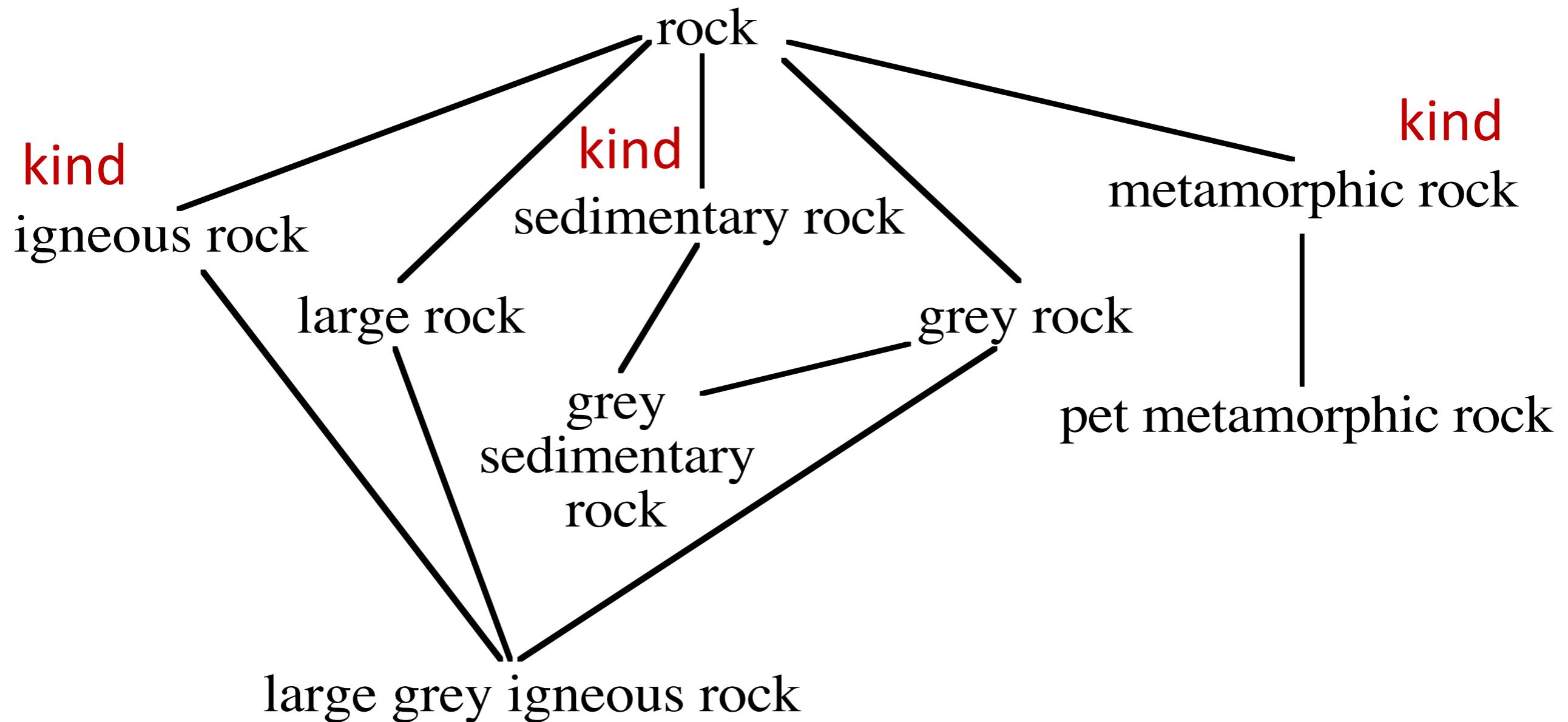




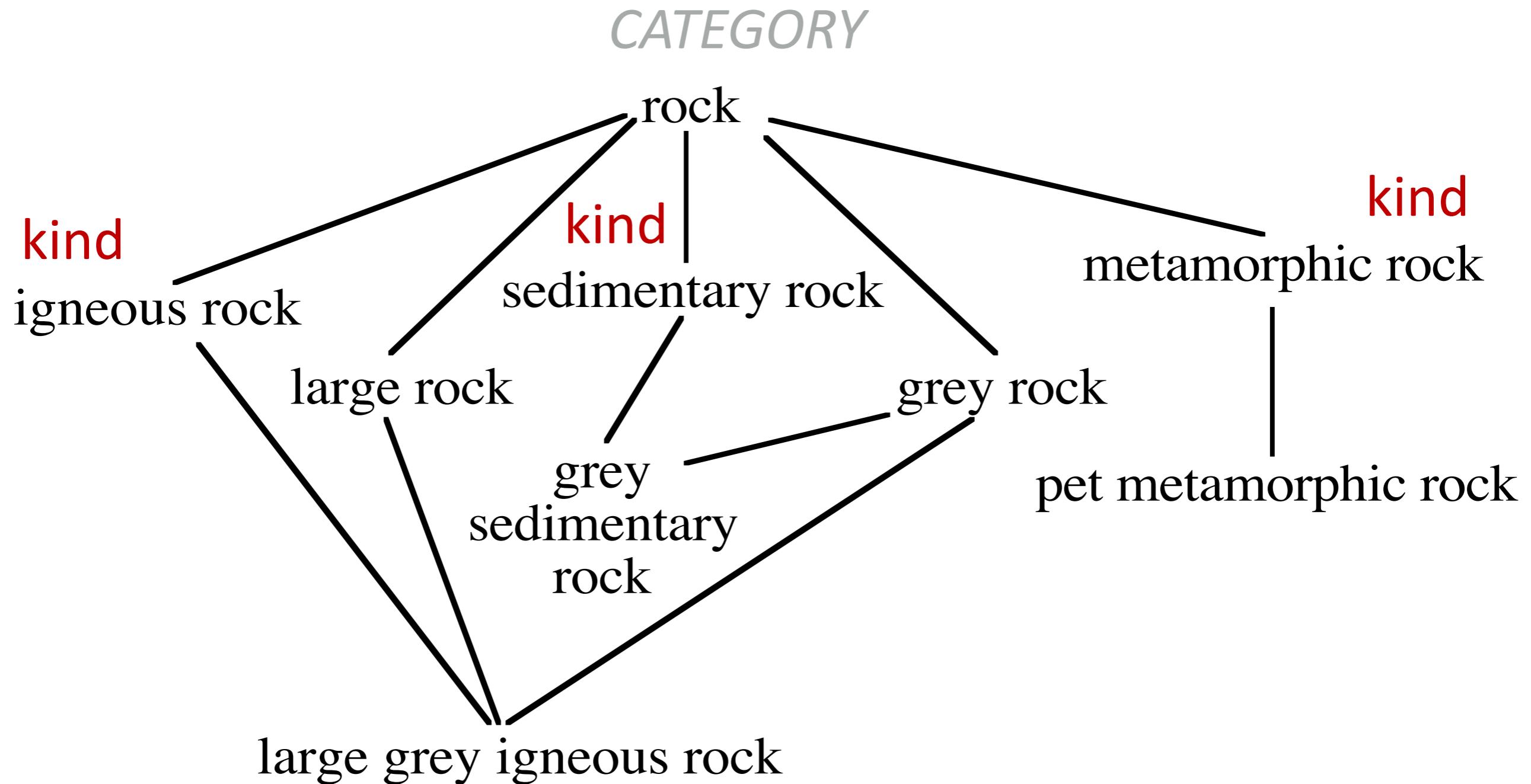
How many kinds of rock?



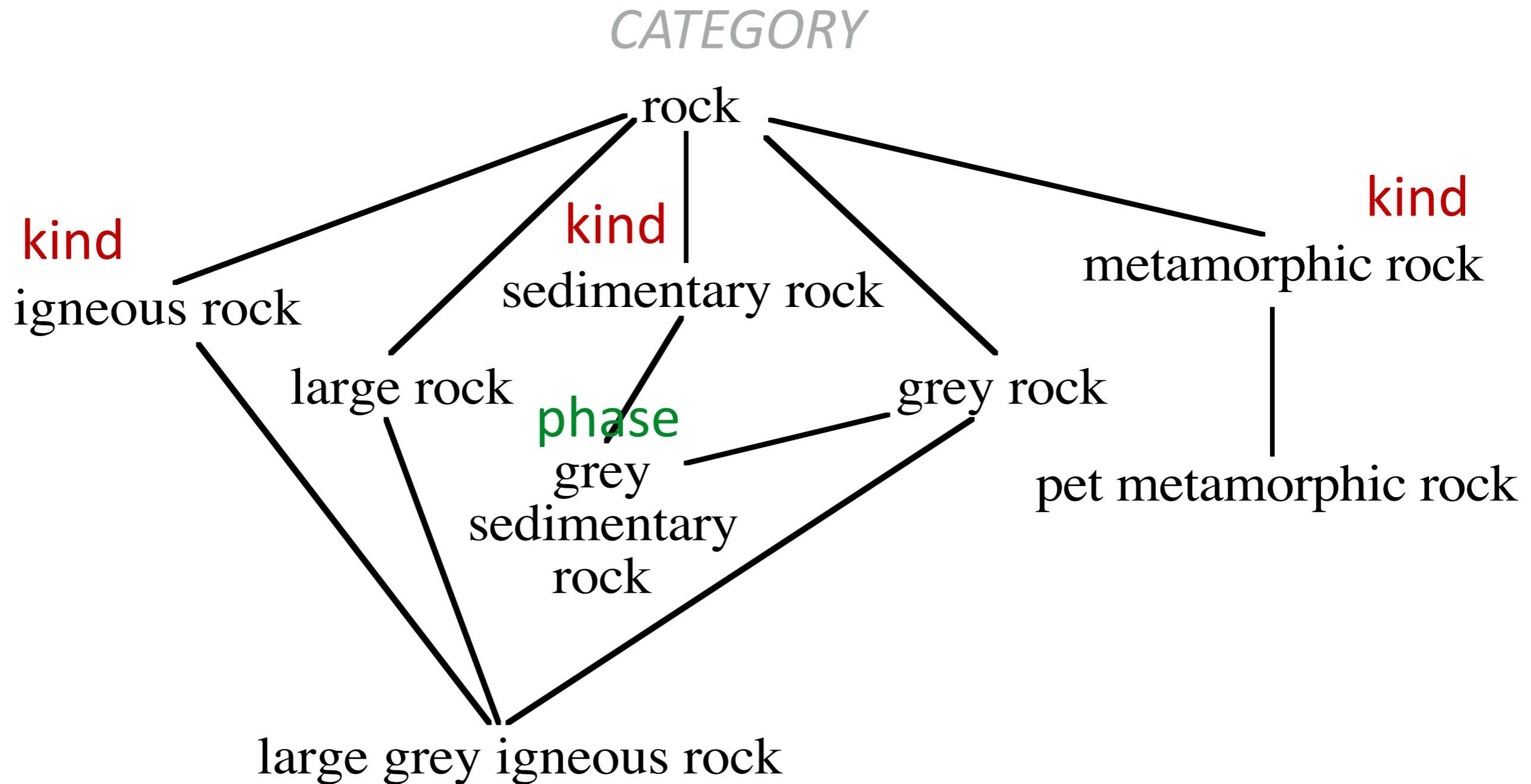
How many kinds of rock?



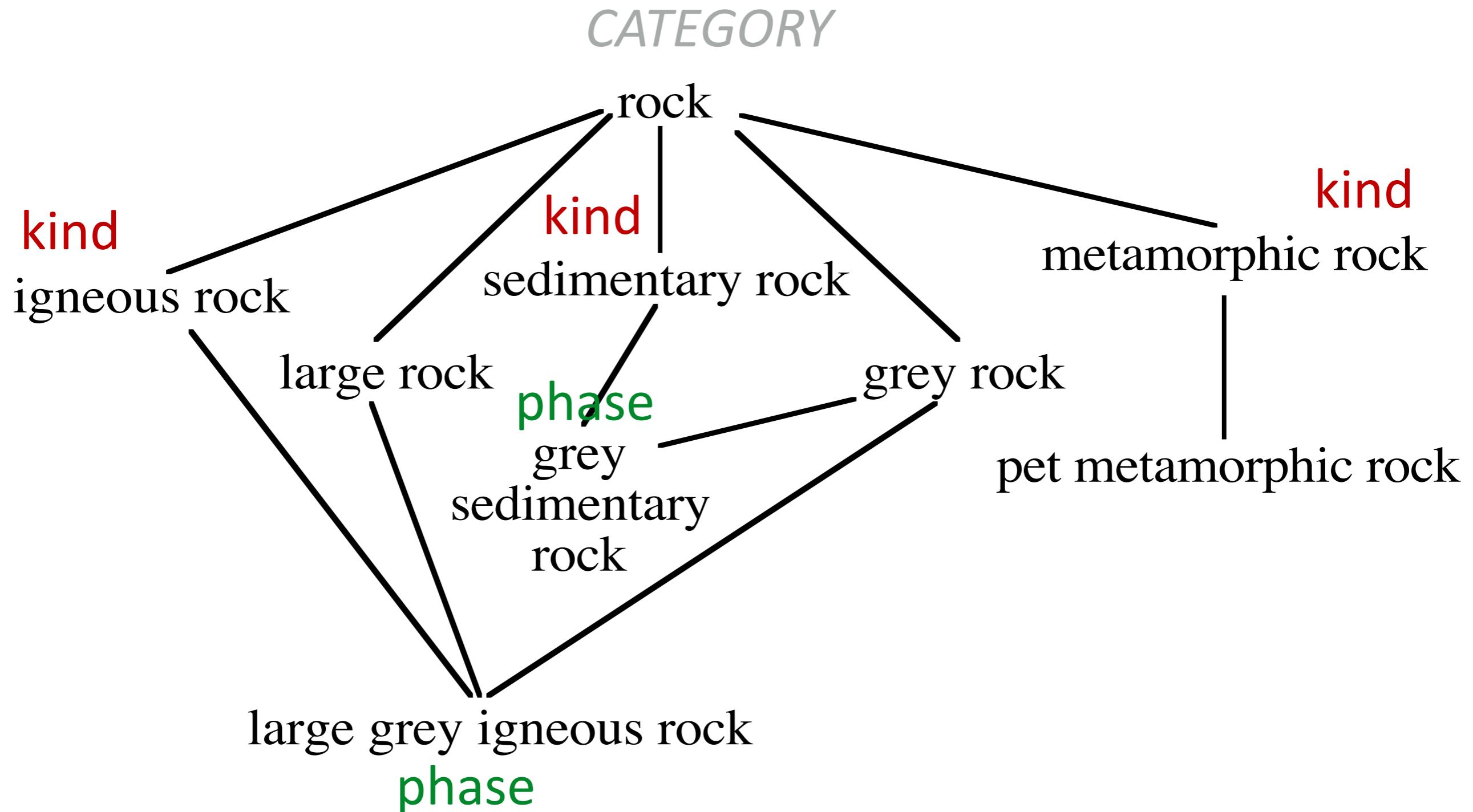
How many kinds of rock?



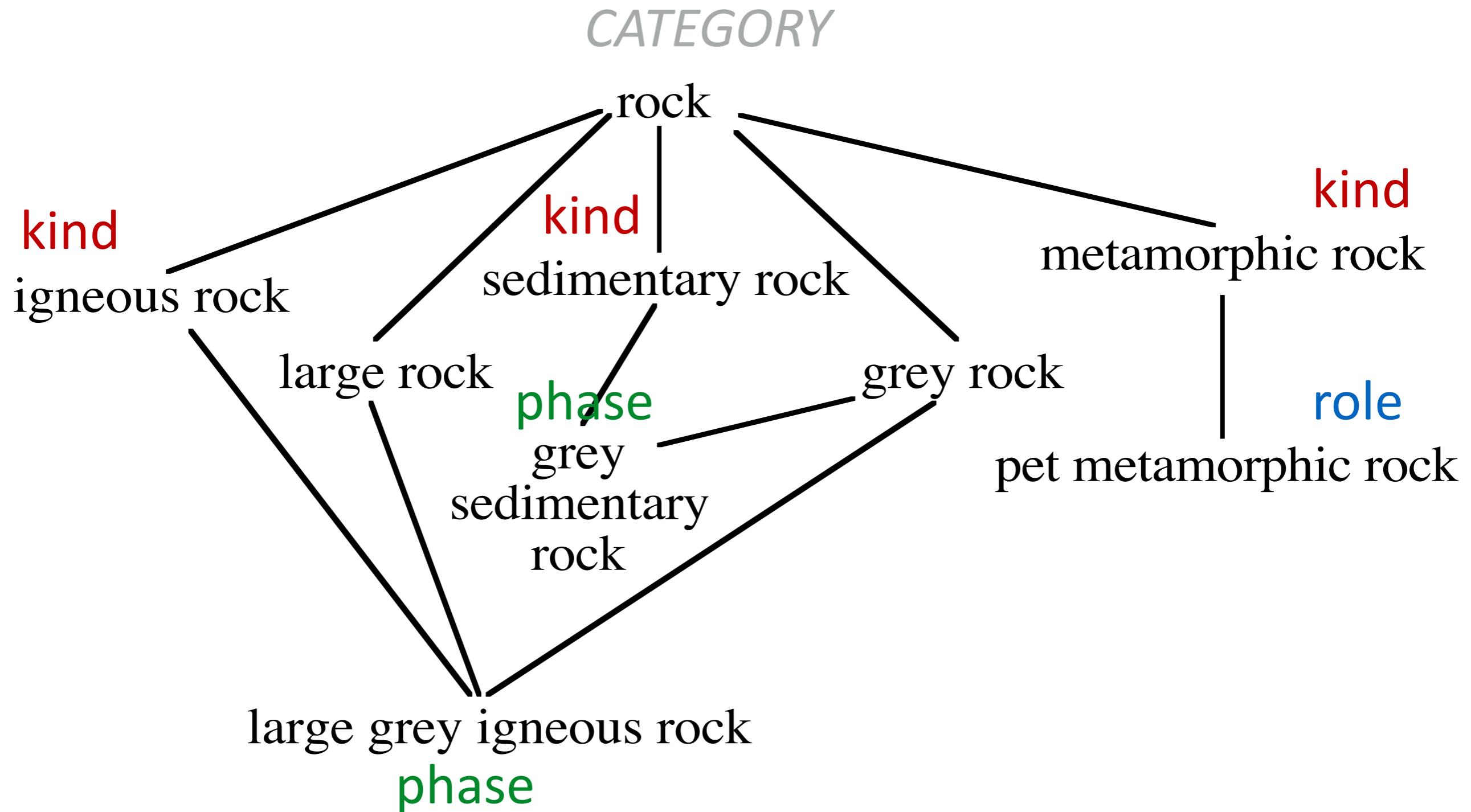
How many kinds of rock?



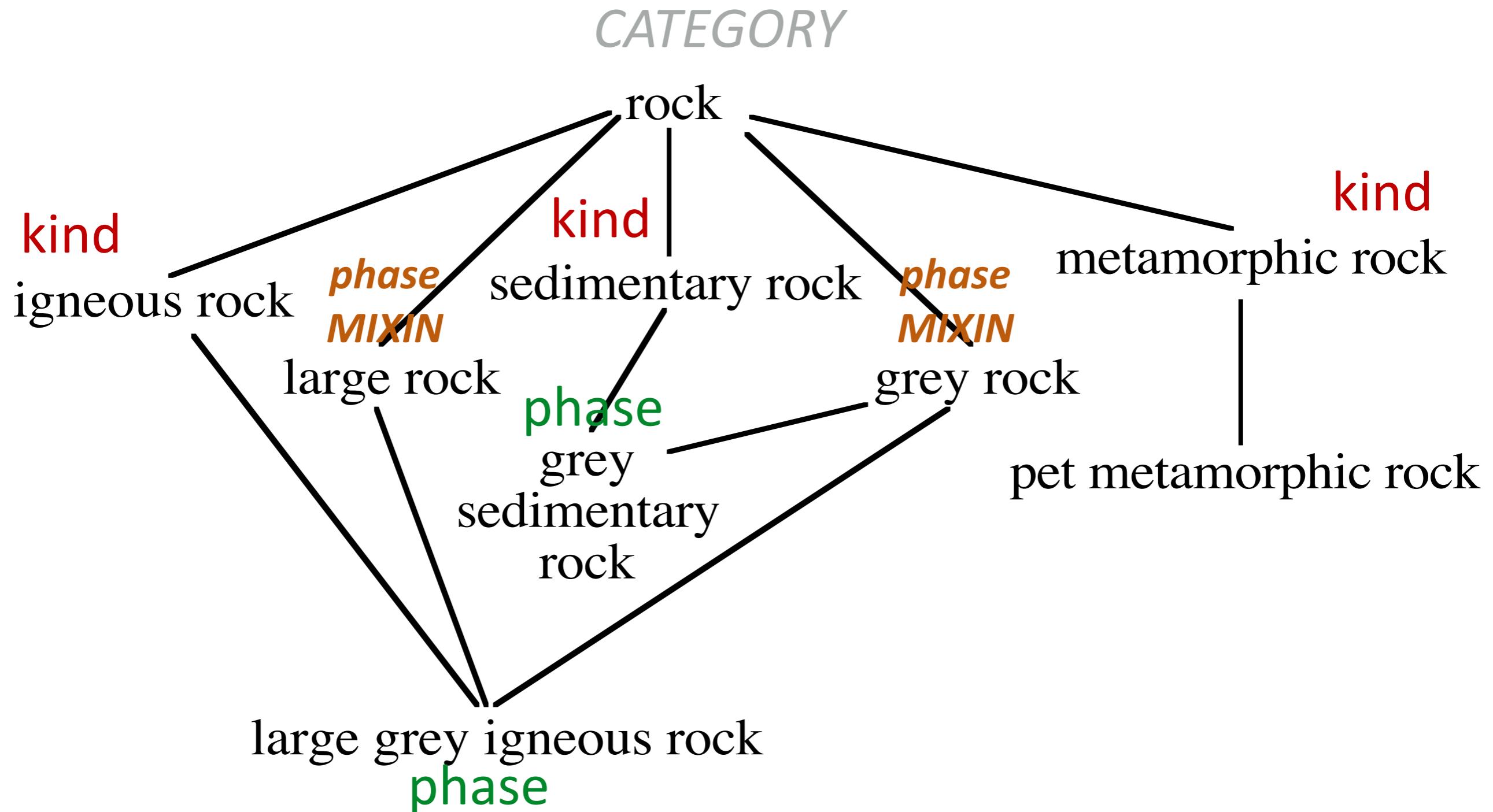
How many kinds of rock?



How many kinds of rock?

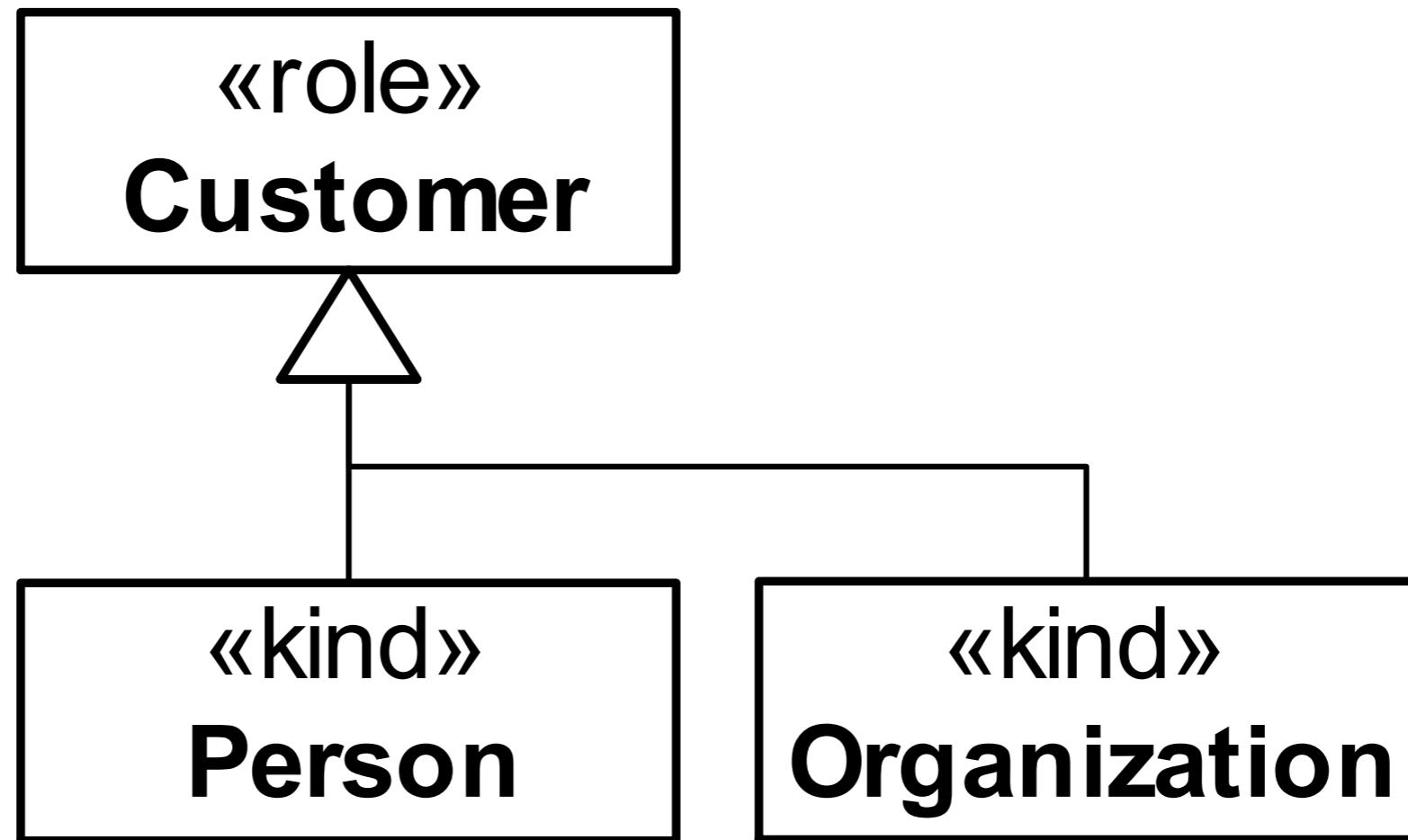


How many kinds of rock?

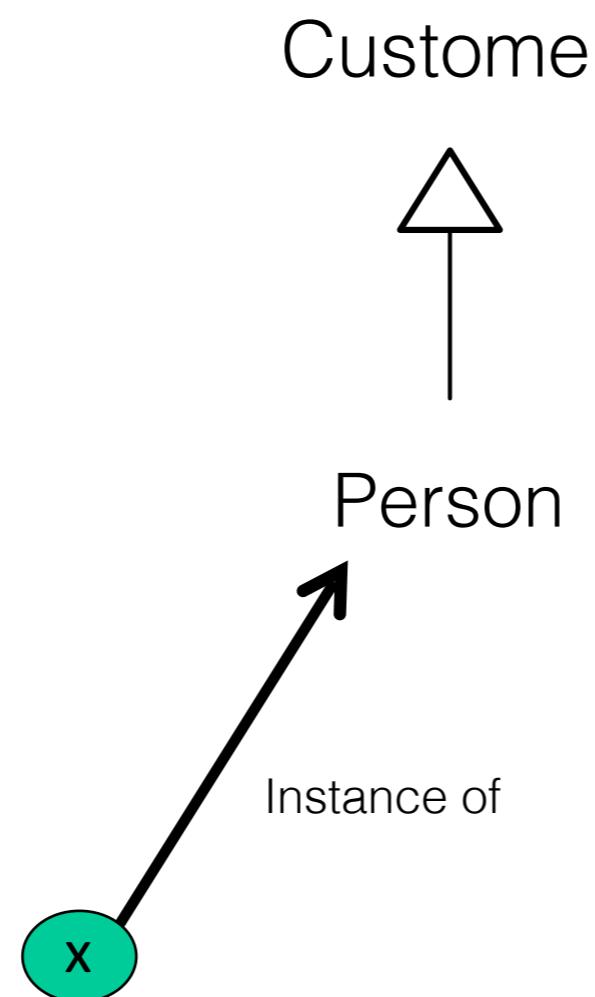


A Classic Problem

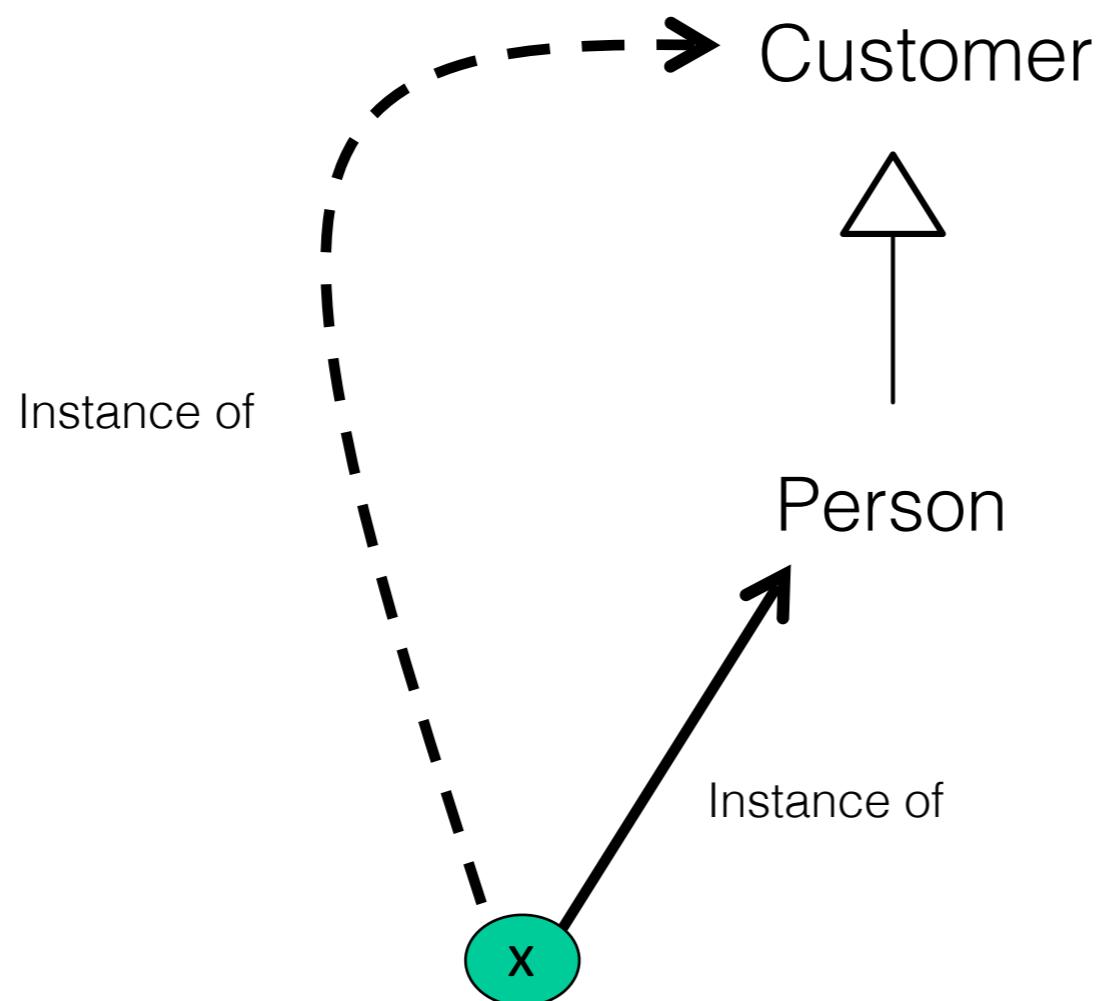
Suppose that I want to represent that the ROLE Customer can be played by entities of different KINDS, namely, People and Organizations. How to relate the ROLE and its *allowed types* using subtyping relations?



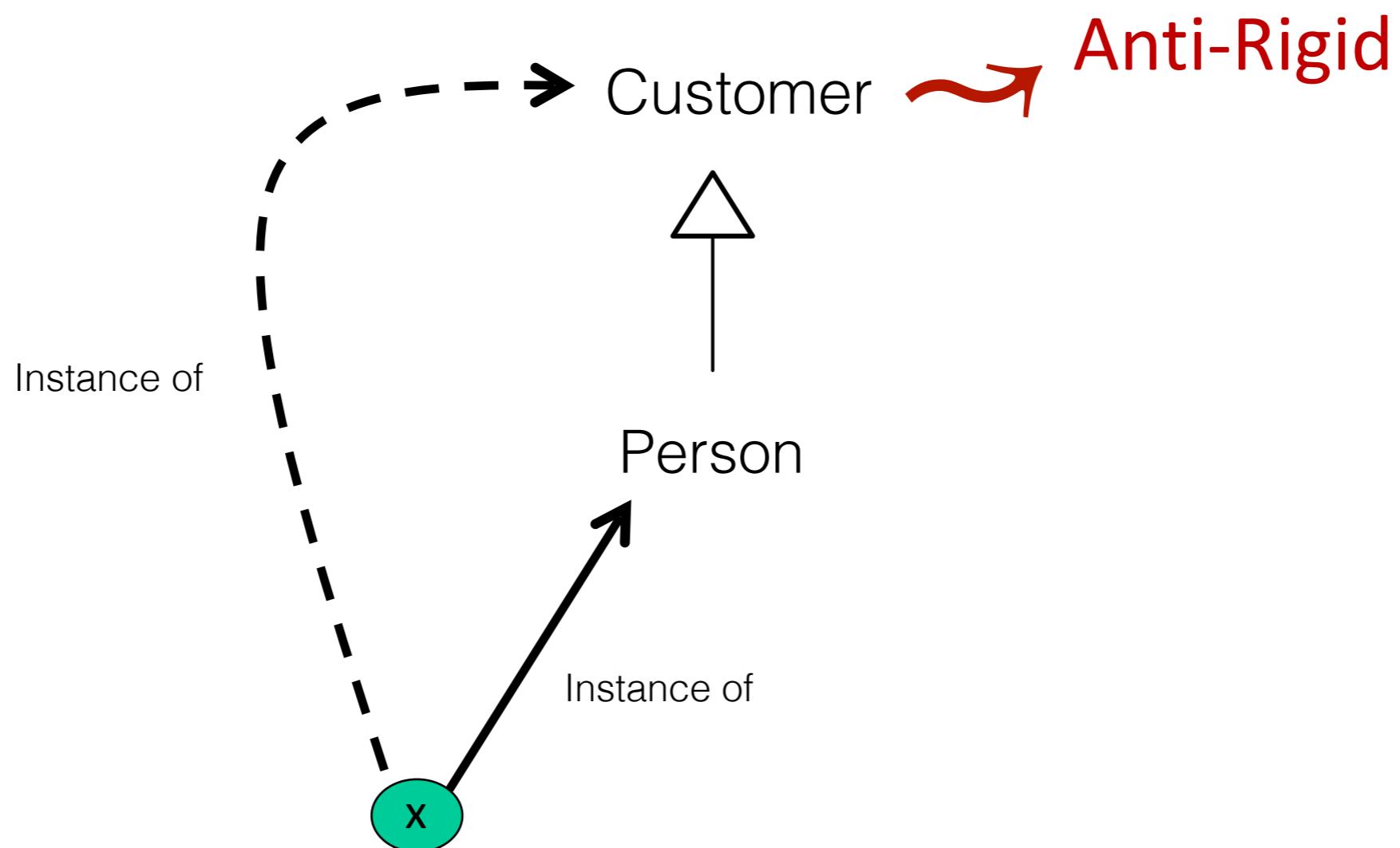
WORLD W



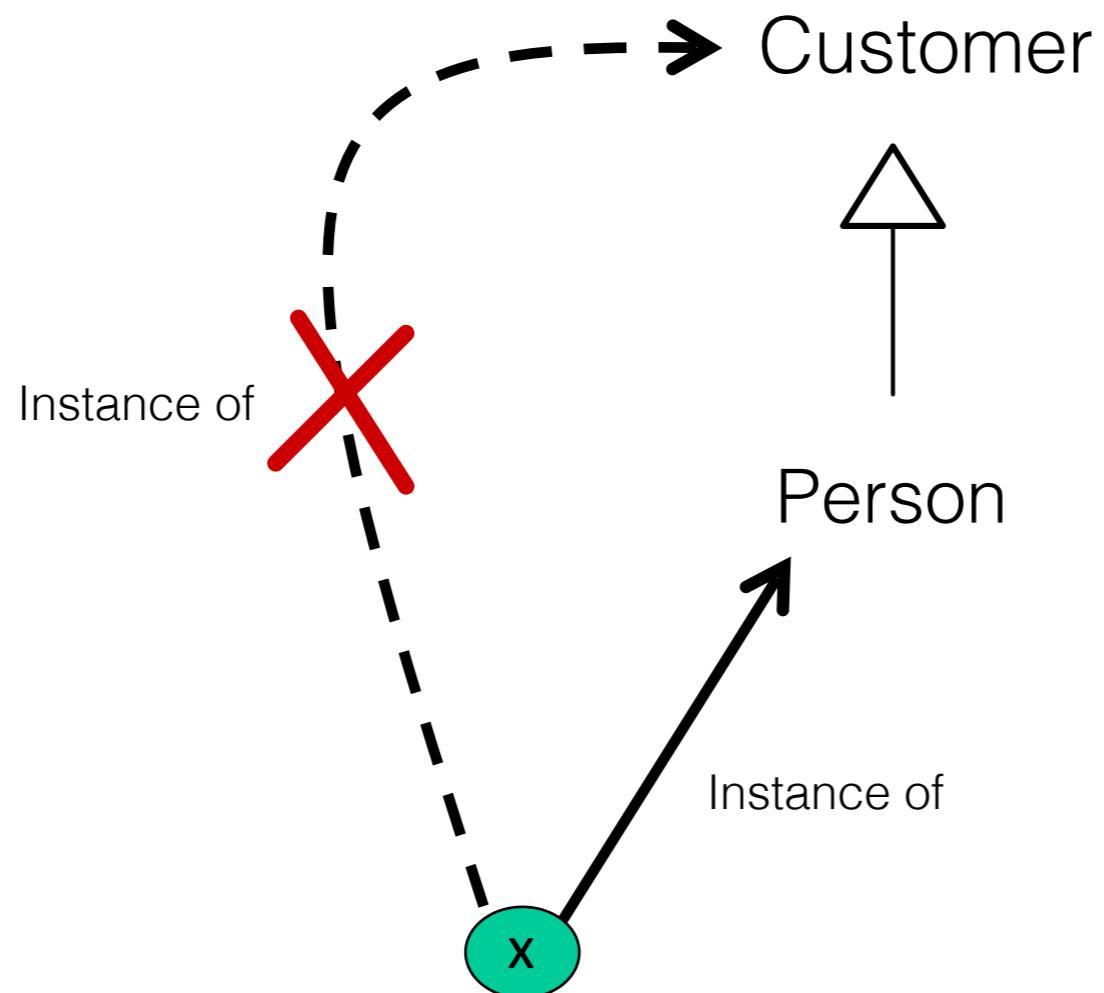
WORLD W



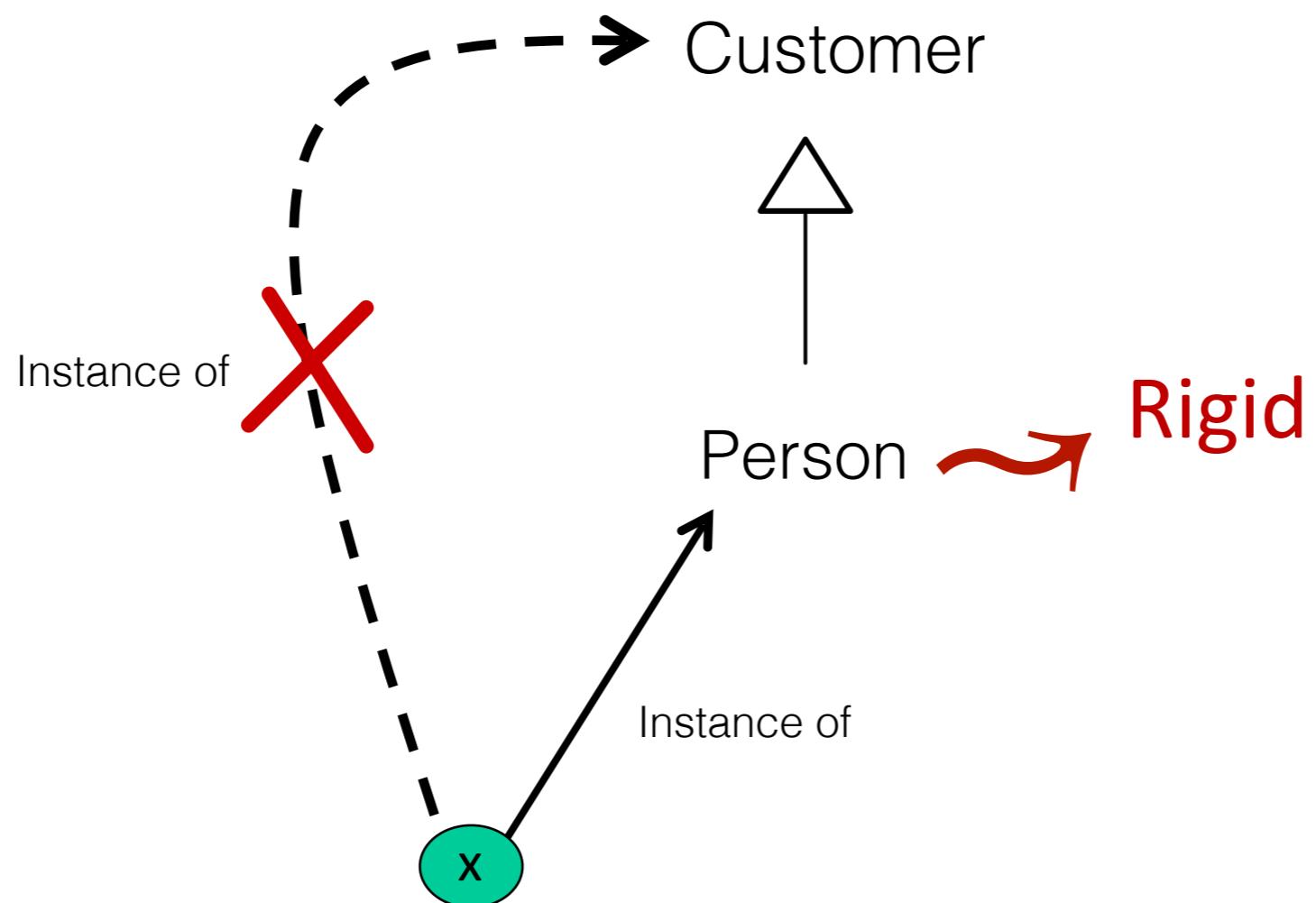
WORLD W



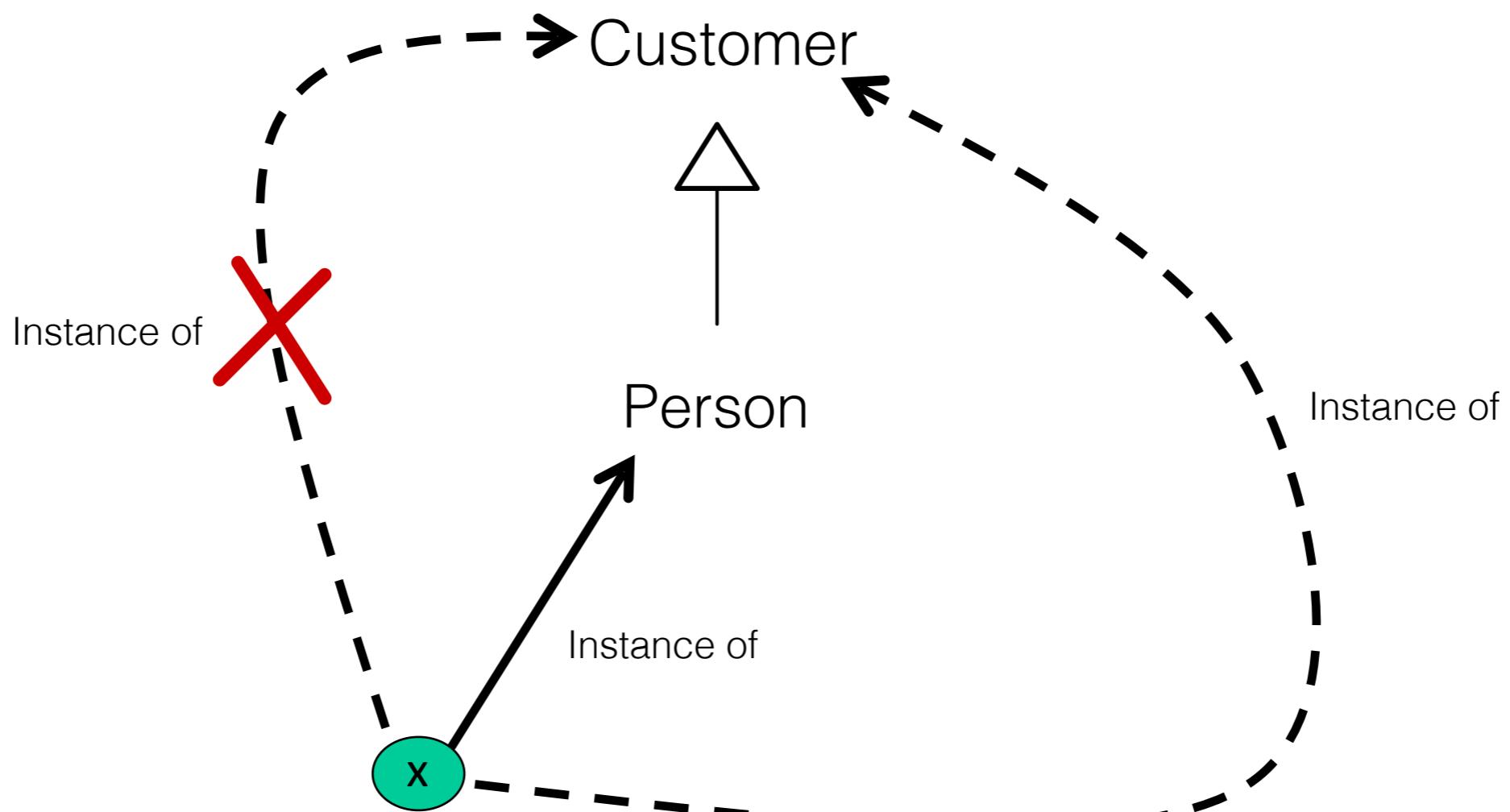
WORLD W'



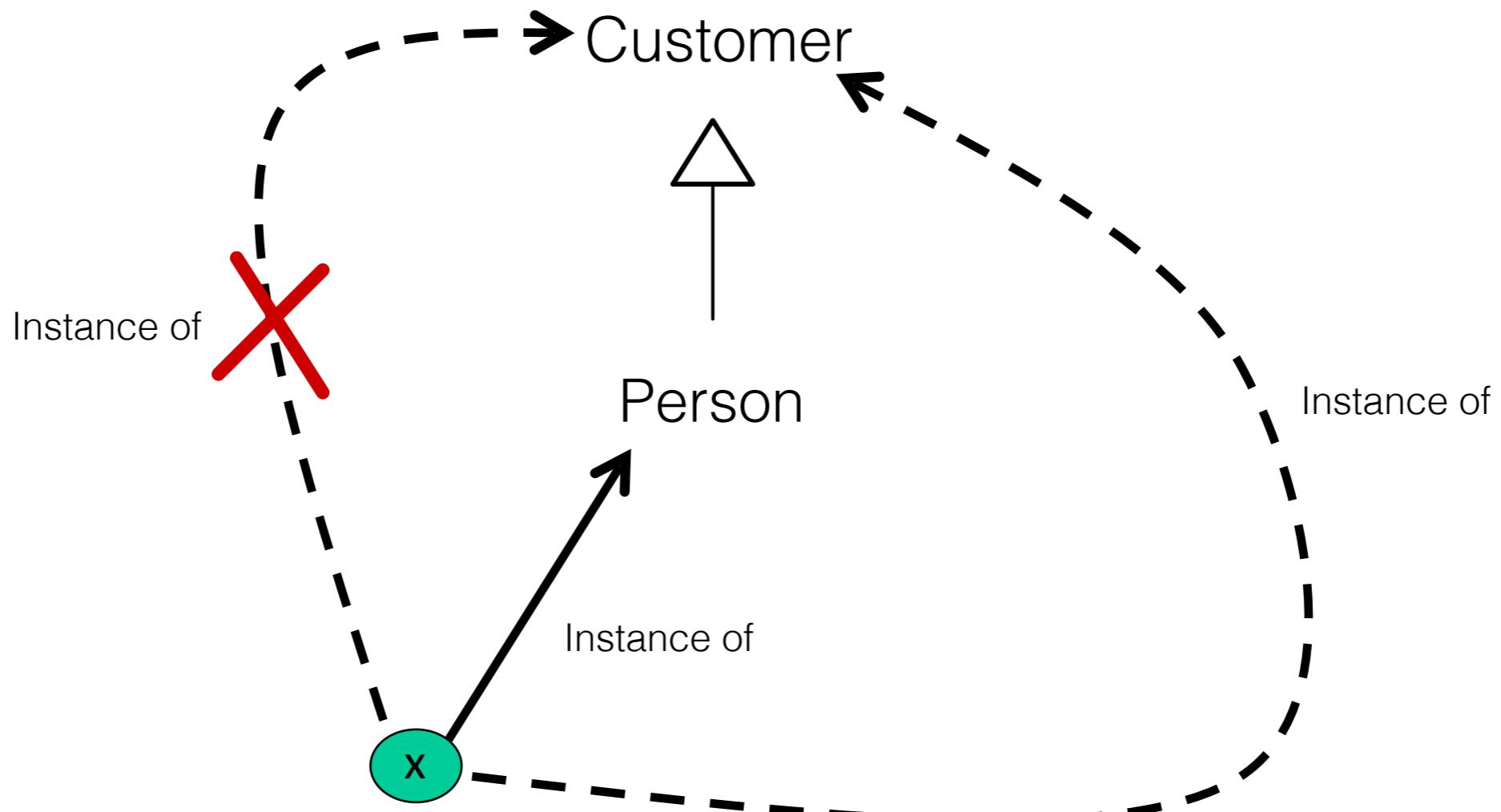
WORLD W'



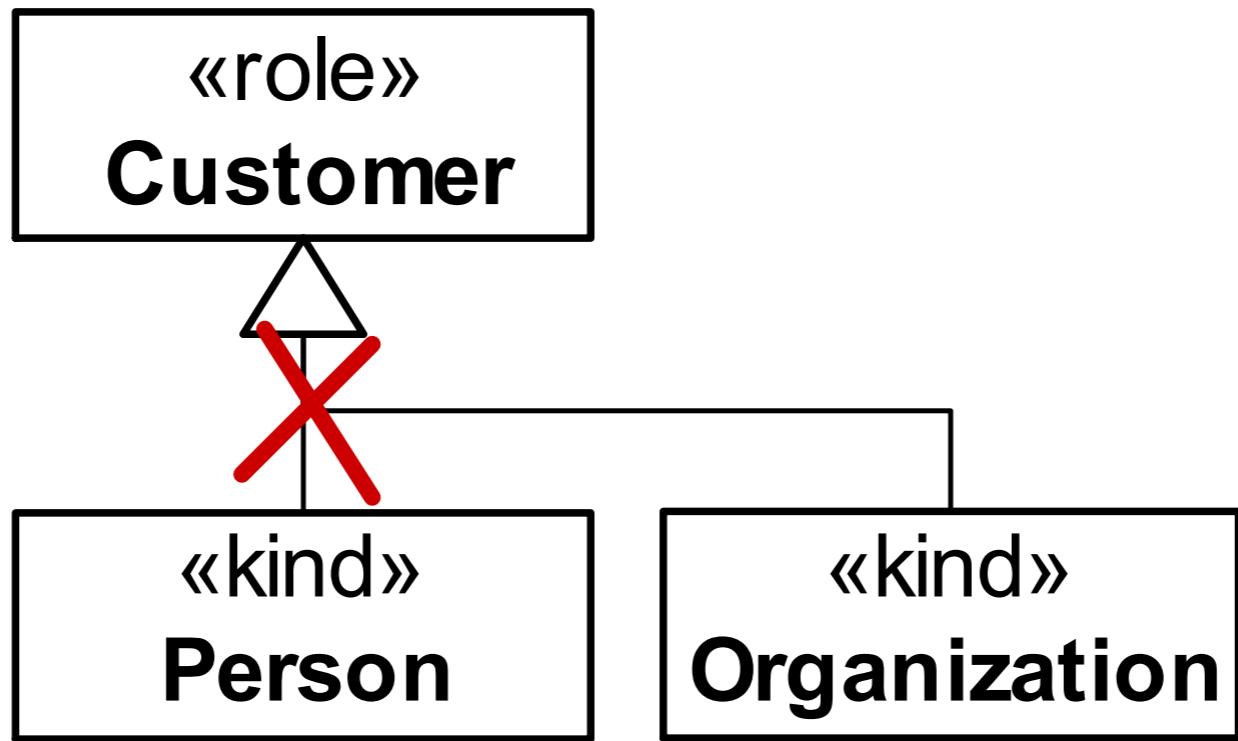
WORLD W'



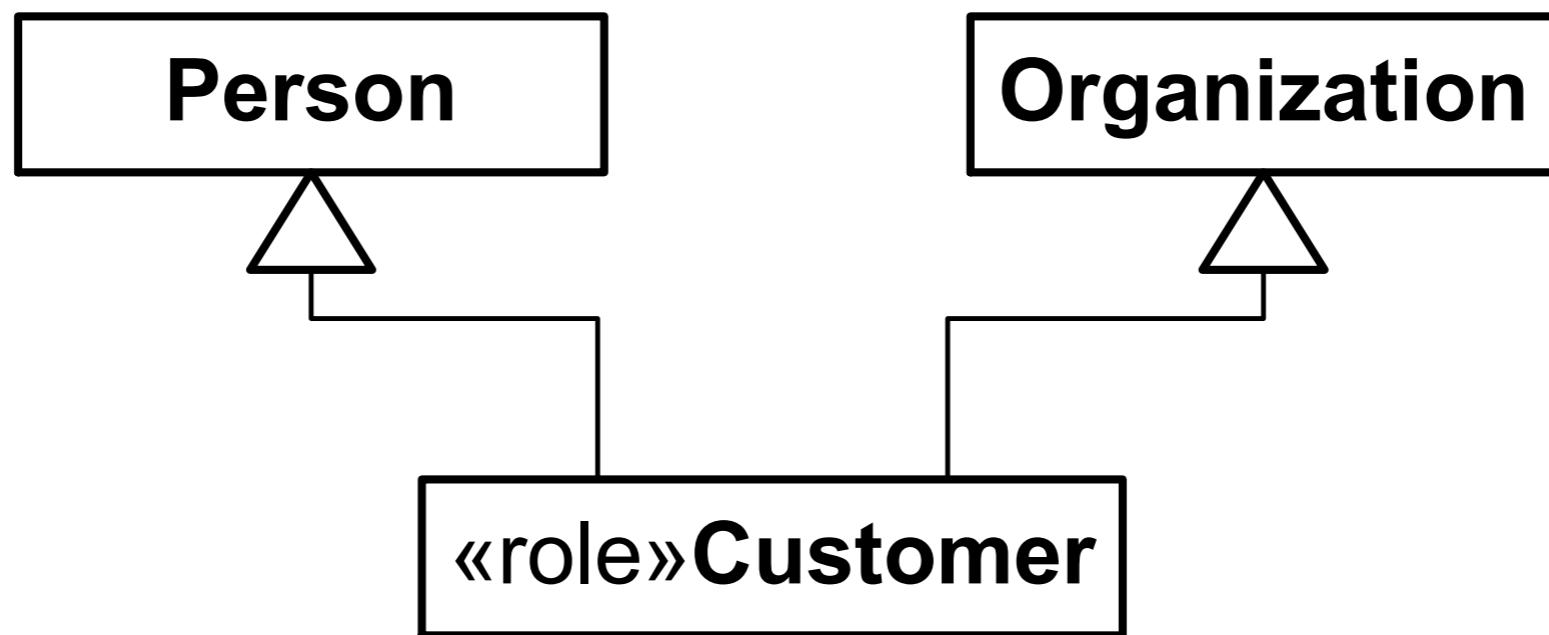
WORLD W'



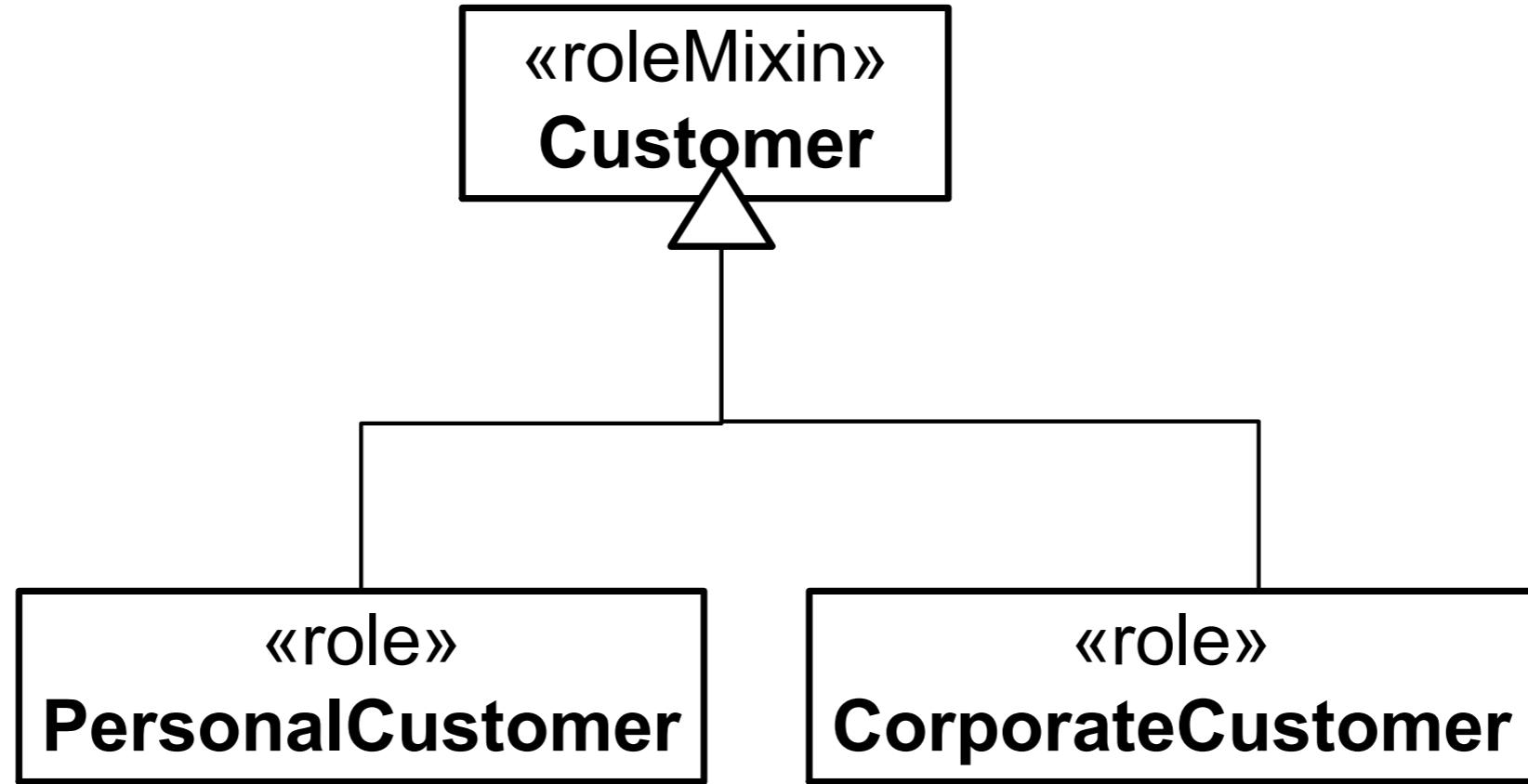
We run into a logical contradiction!

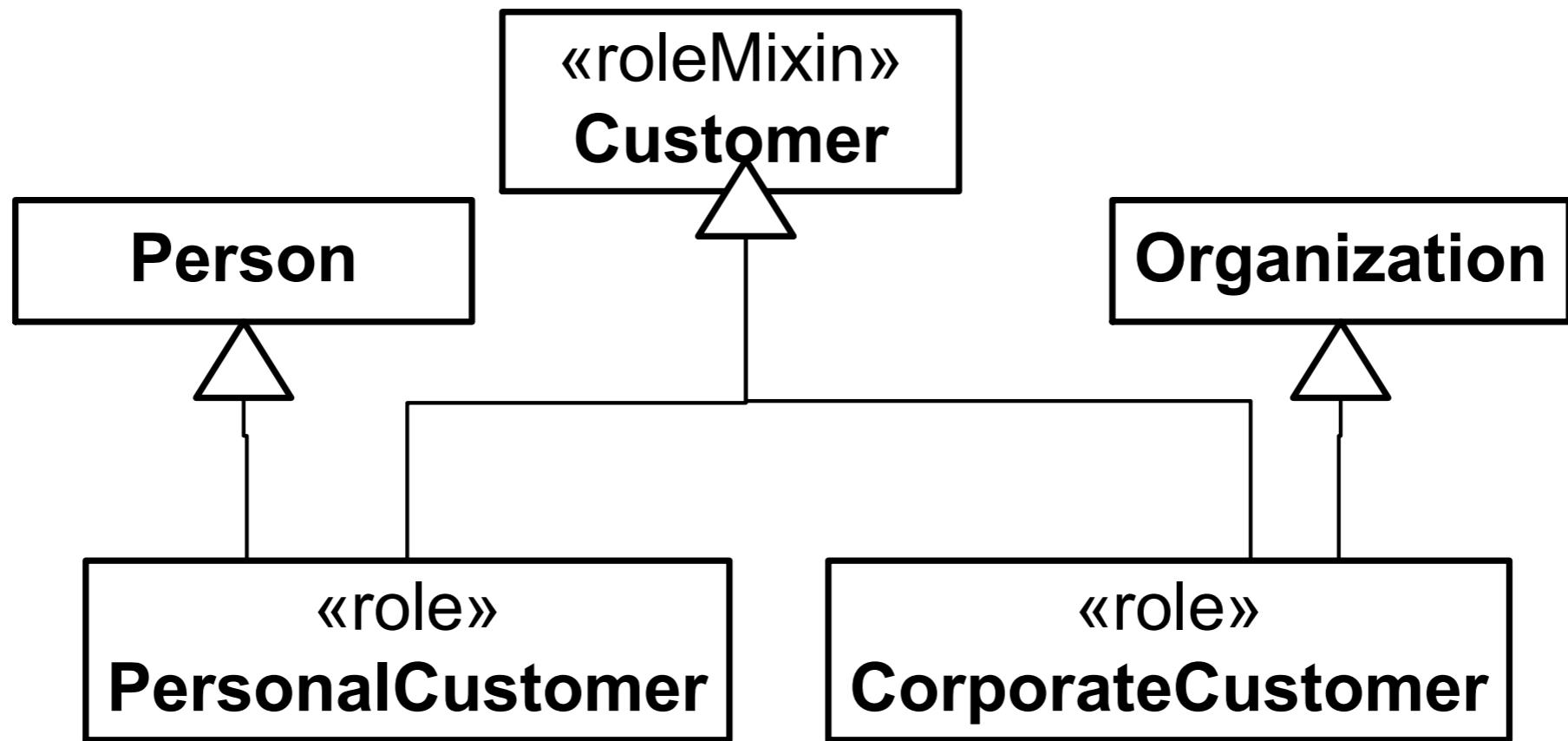


A Possible Alternative?



«roleMixin»
Customer



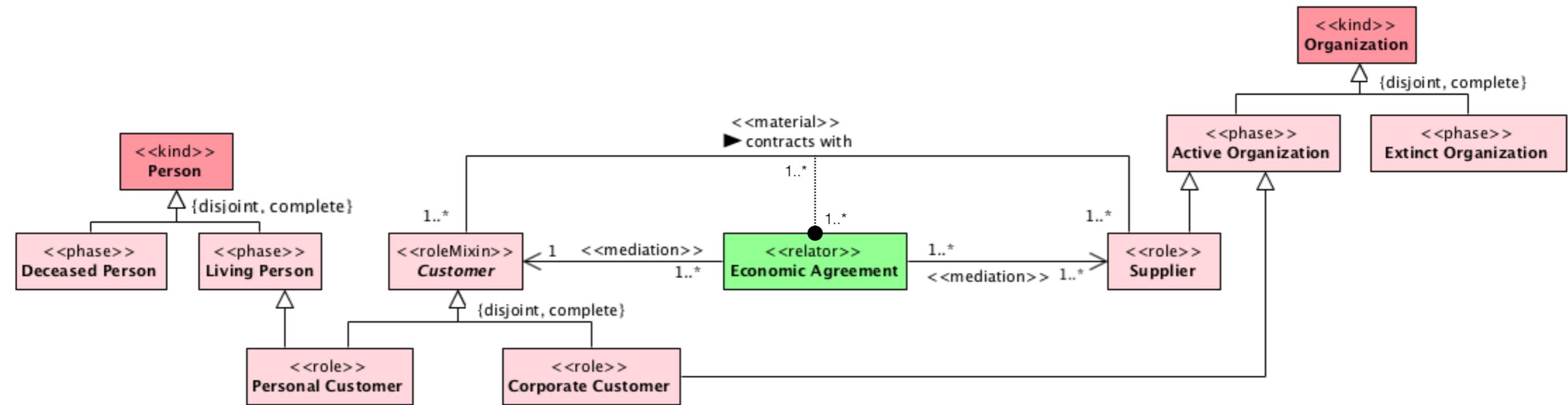


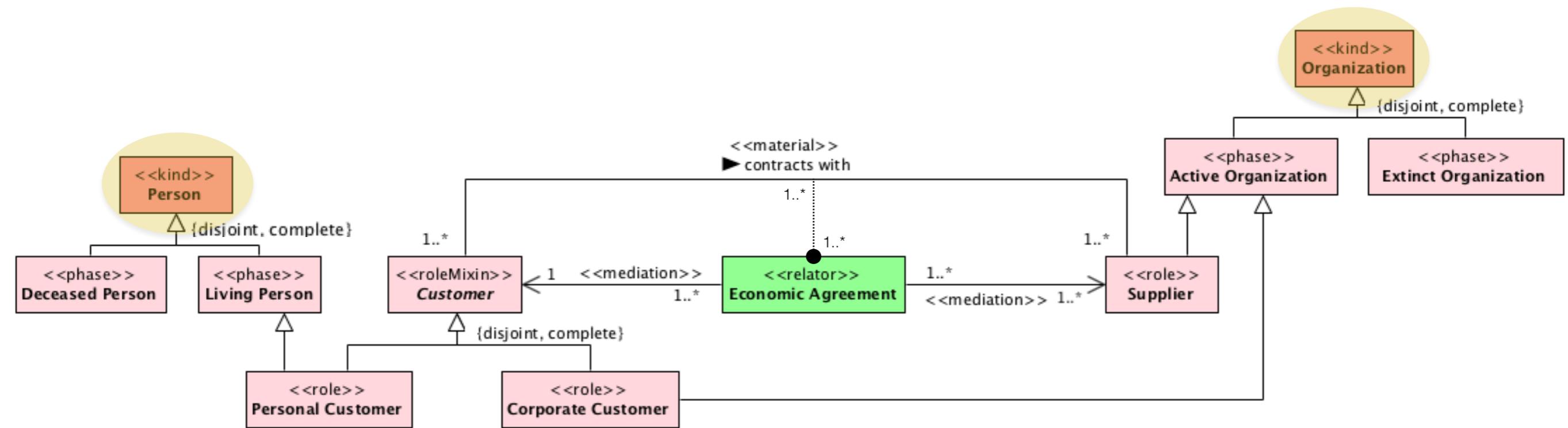


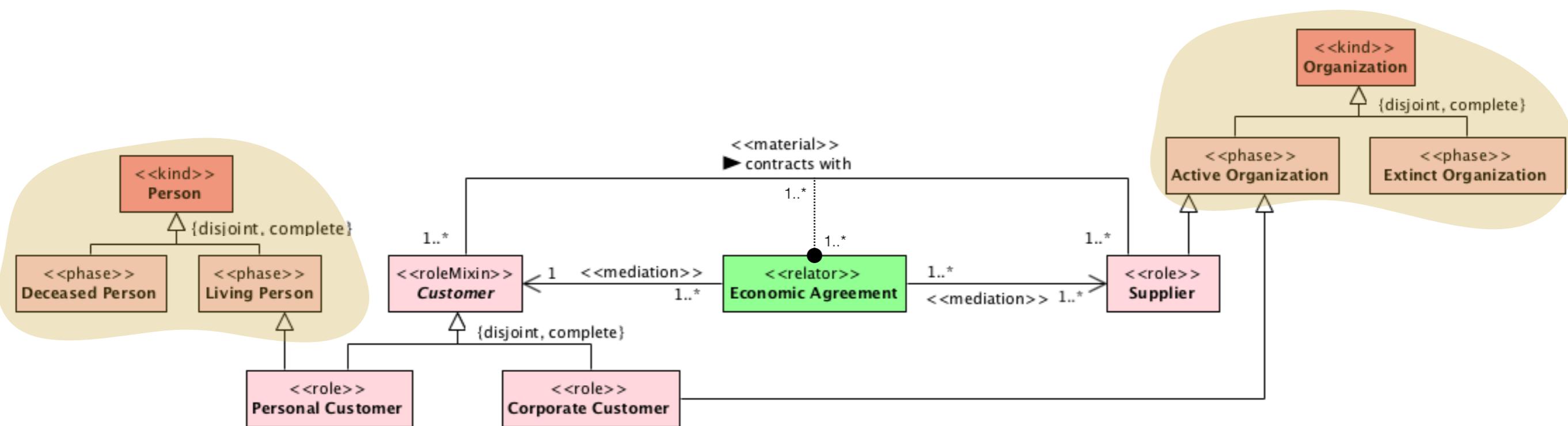
Unified Foundational
Ontology

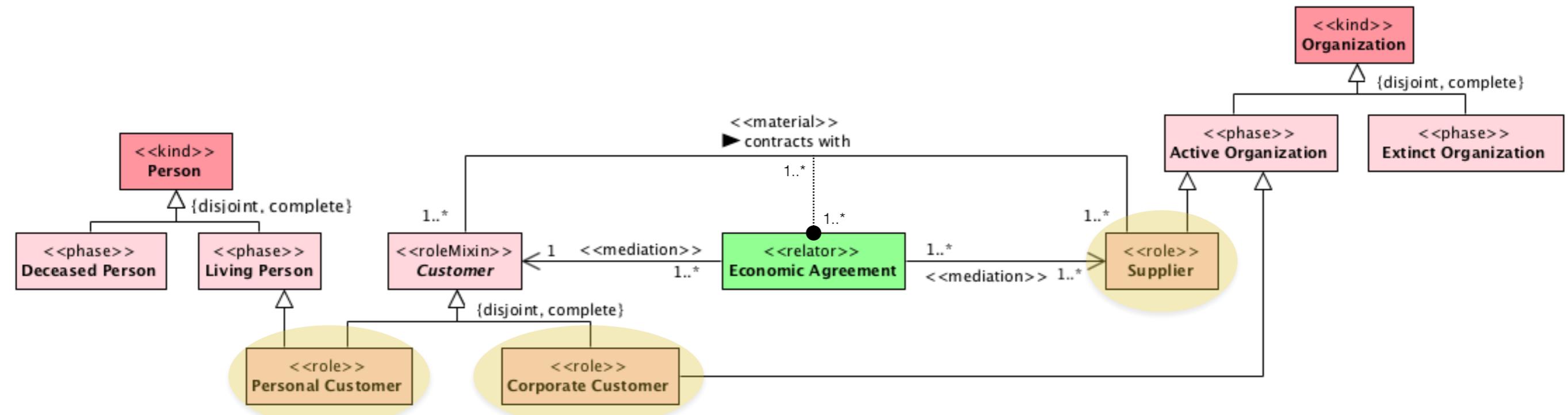


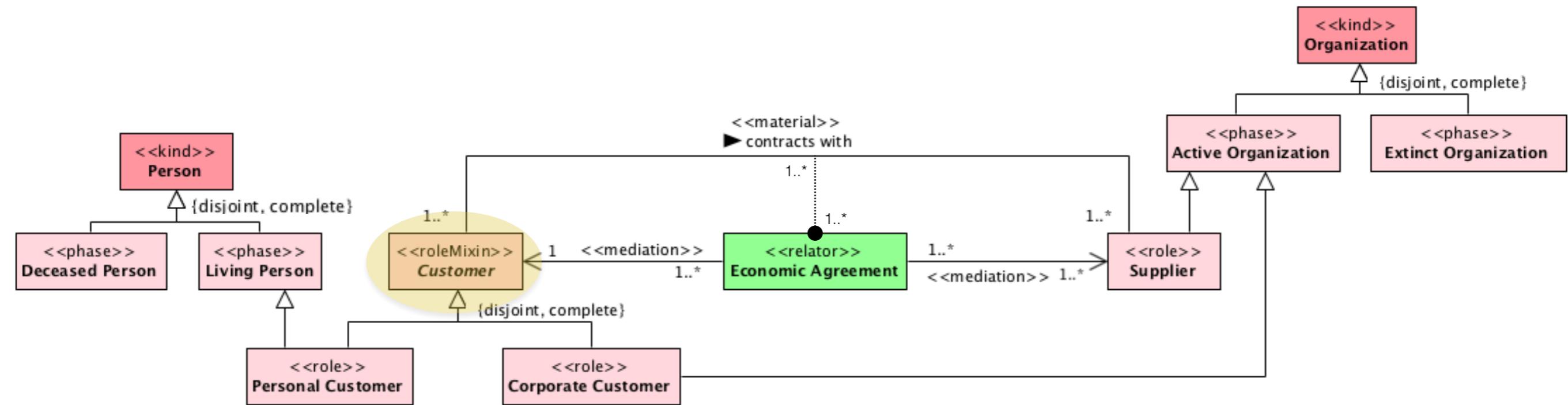
1. **Primitives** reflecting ontological **distinctions**
2. **Grammar** reflecting ontological **axiomatization**
3. **Patterns** reflecting ontological **micro-theories**





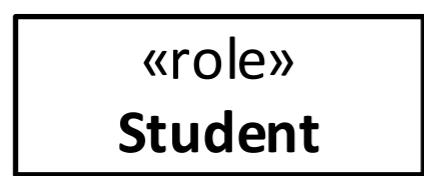




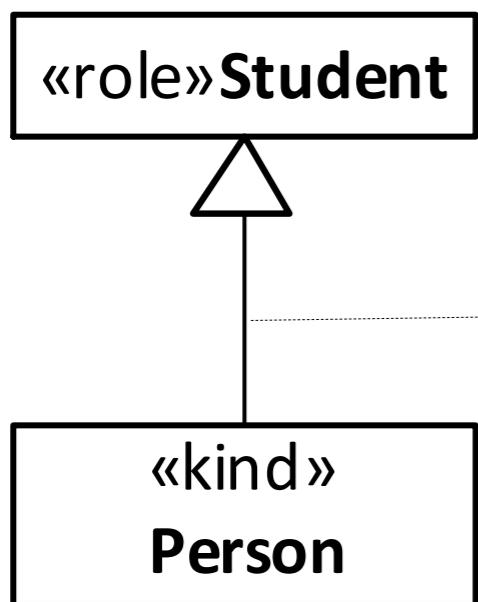


Role

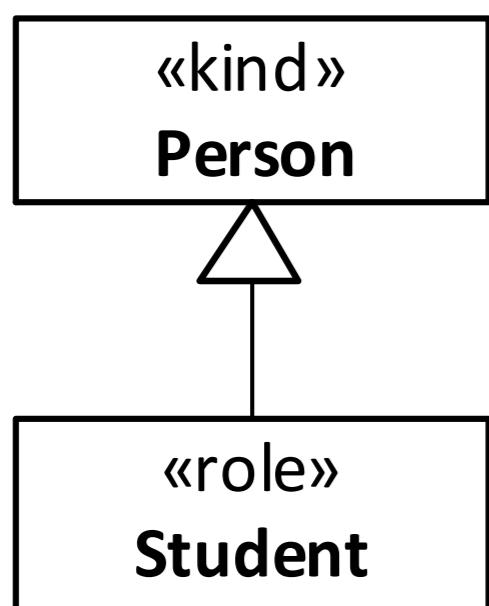
- All instances of a given ROLE are of the same KIND (e.g., all Students are Person)
- All instances of a ROLE instantiate that type only contingently (e.g., no Student is necessarily a Student)
- Instances of a KIND instantiate that ROLE when participating in a certain RELATIONAL CONTEXT (e.g., instances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



NO!



NO!



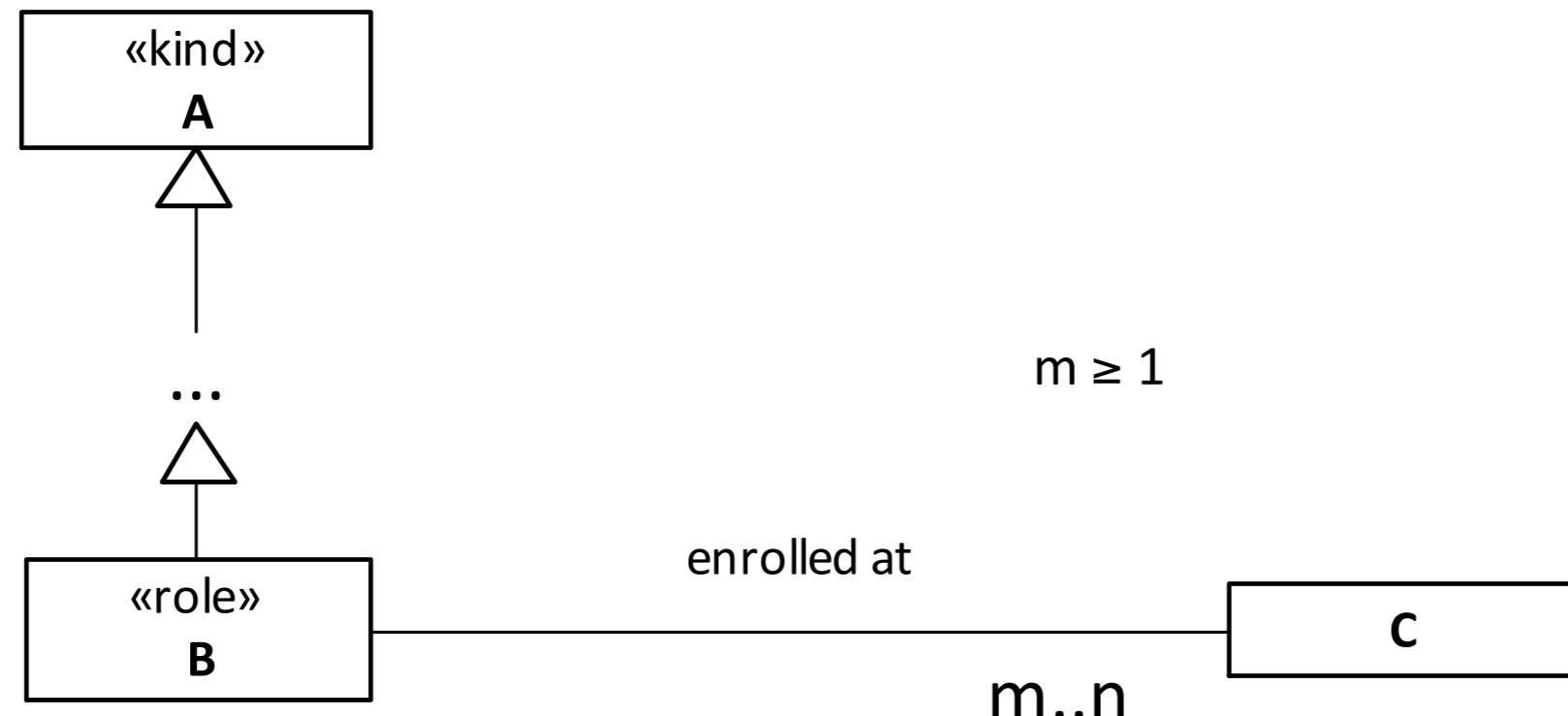
enrolled at

0..n

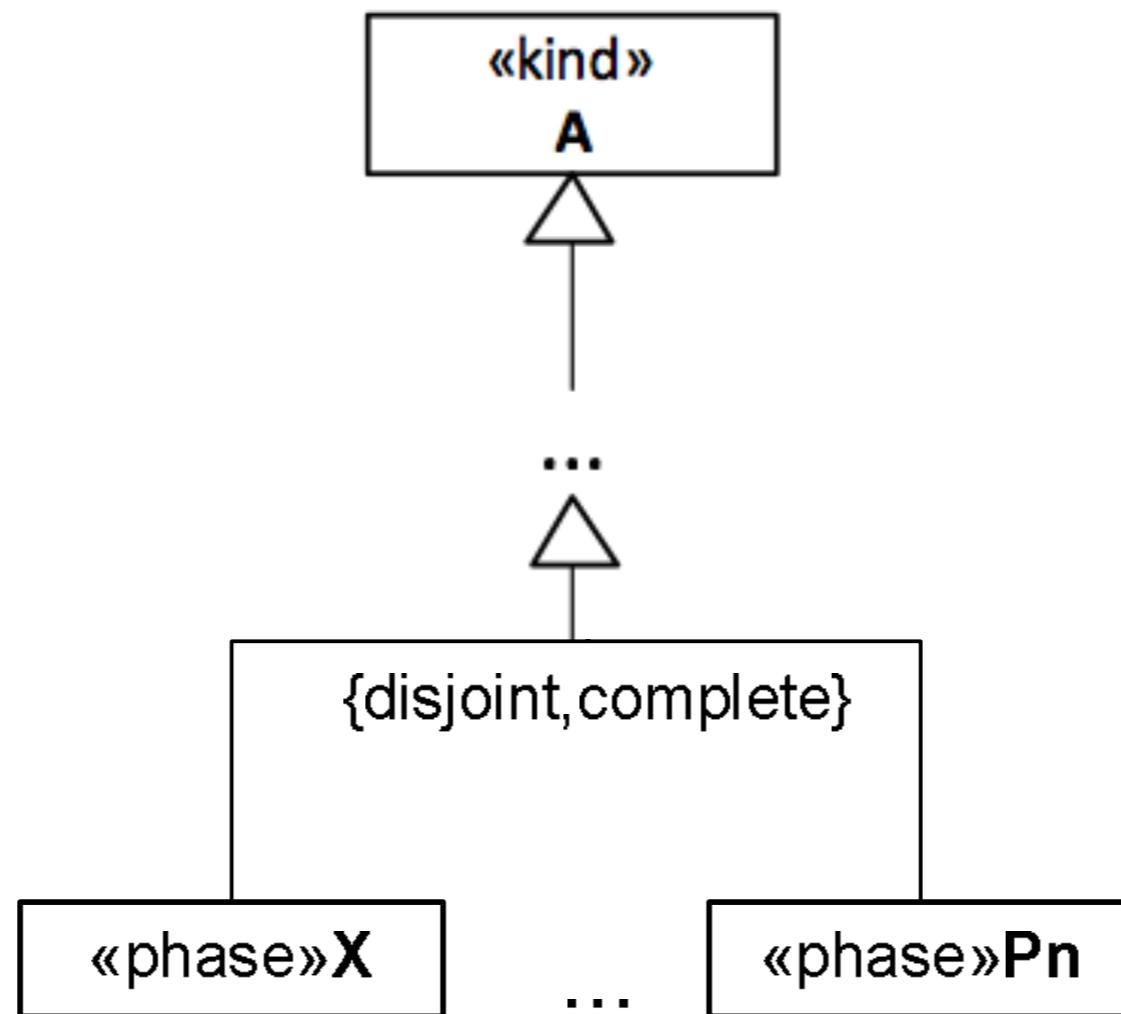


NO!

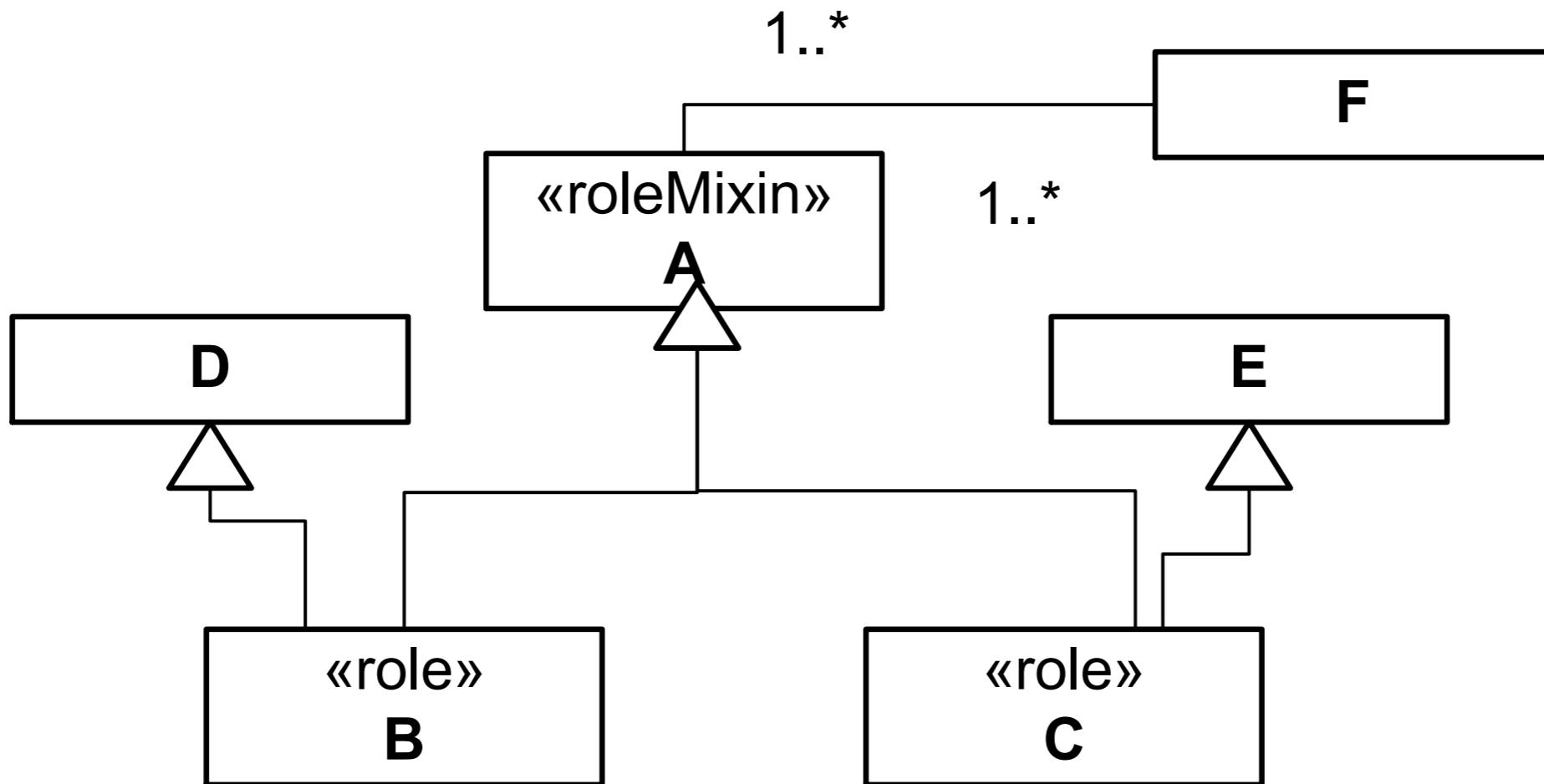
The Emerging Role Pattern

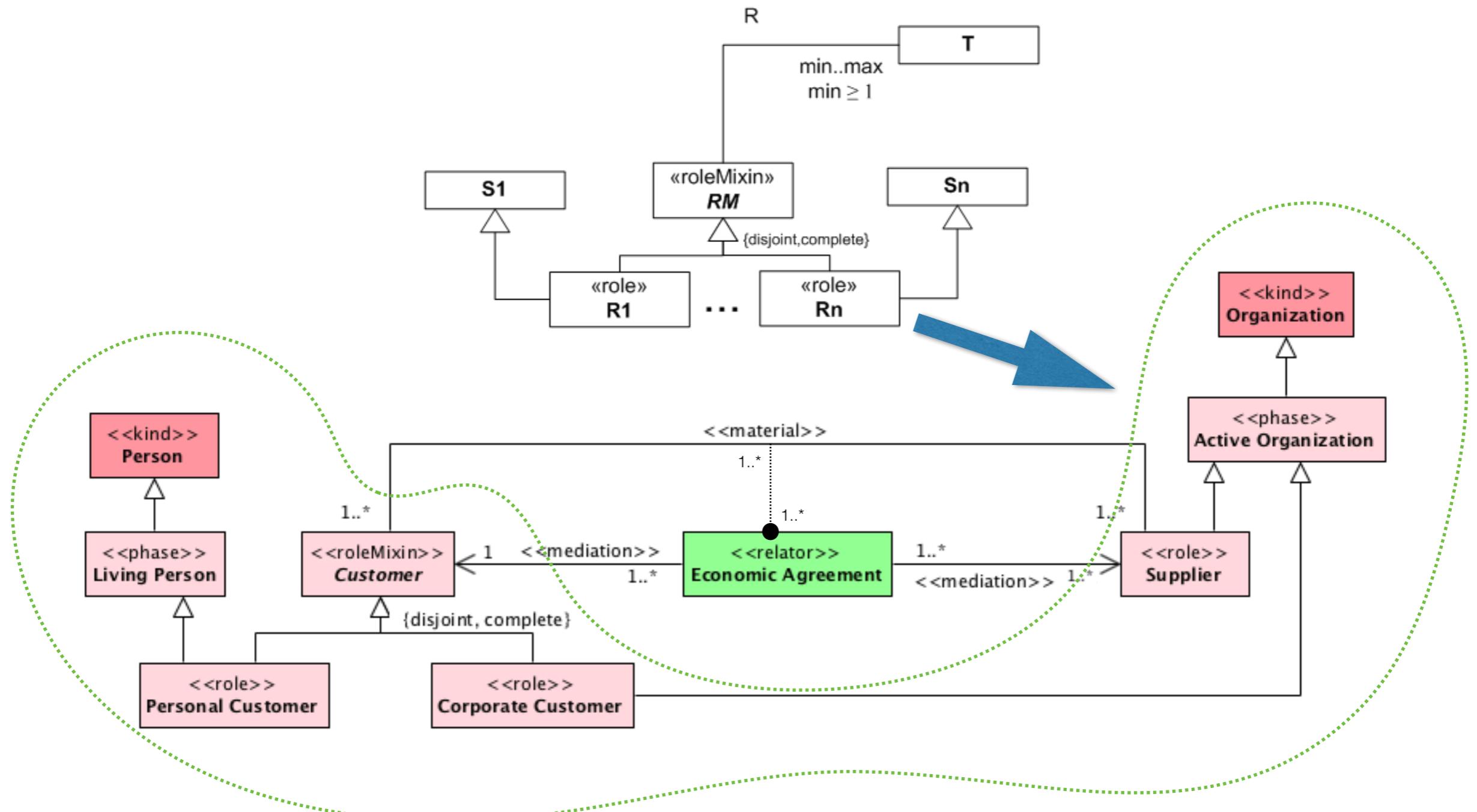


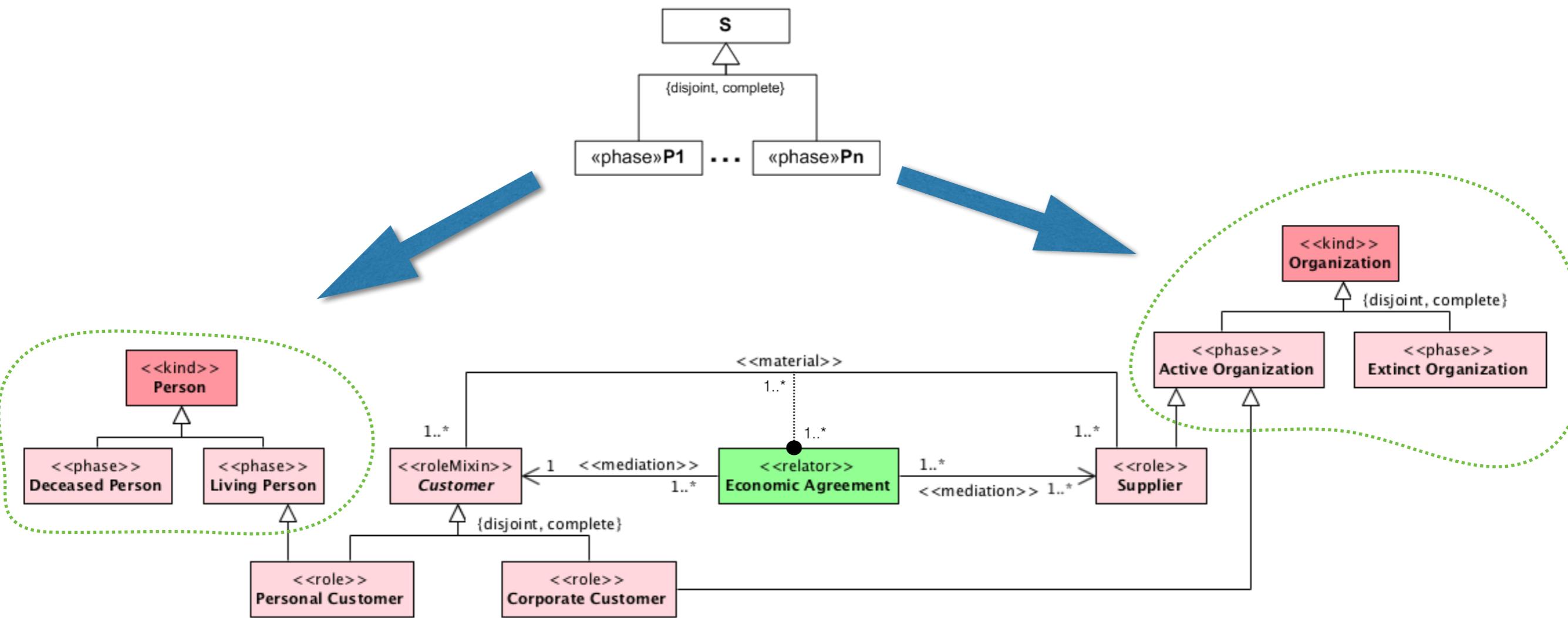
The Emerging Phase Pattern

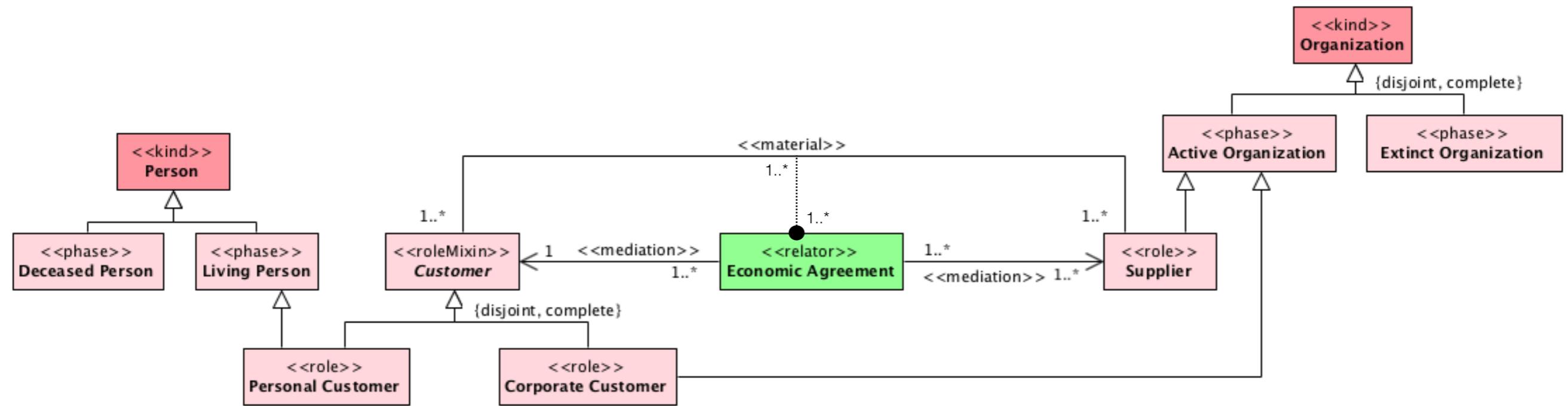


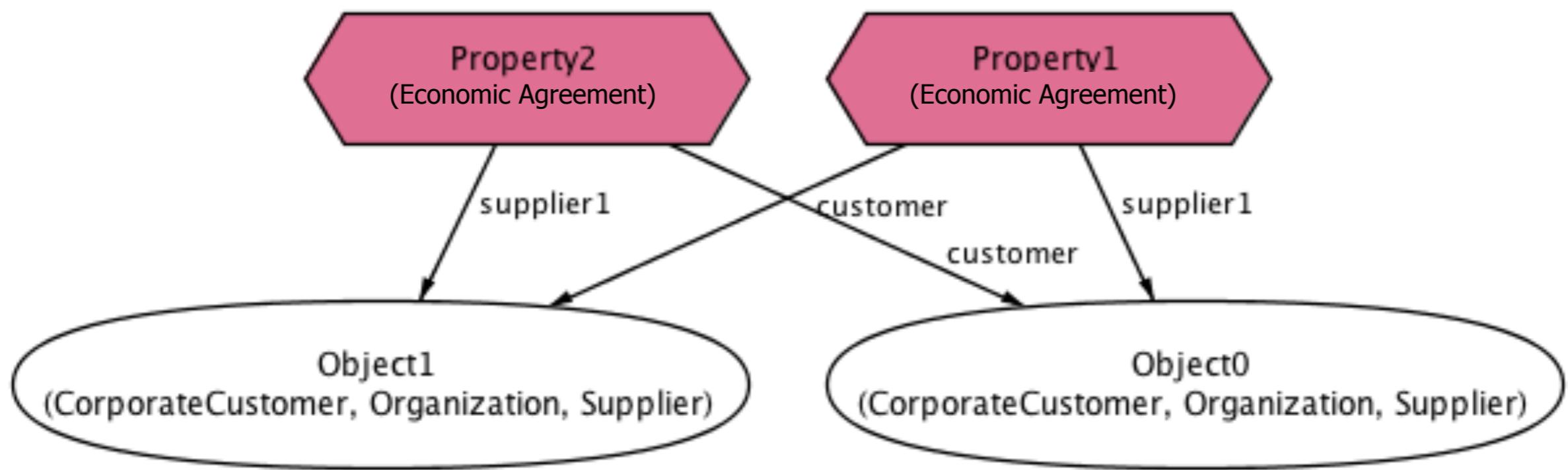
The emerging **RoleMixin** Pattern

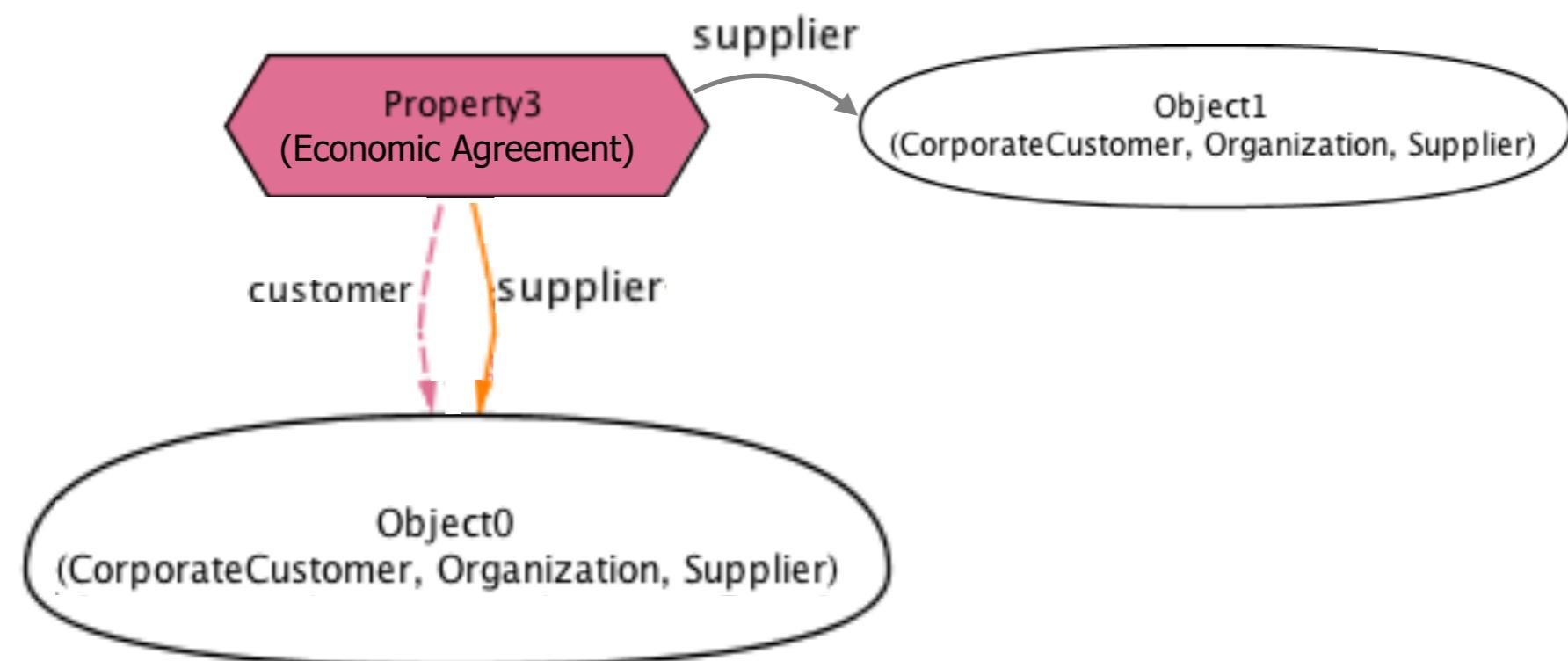


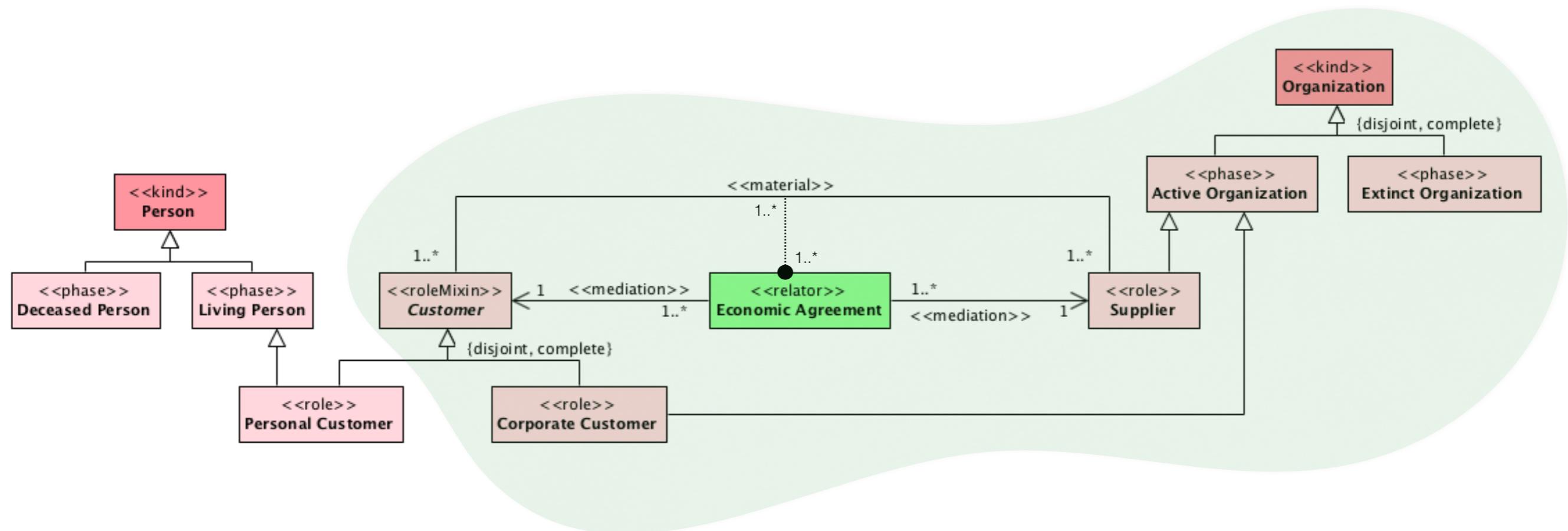




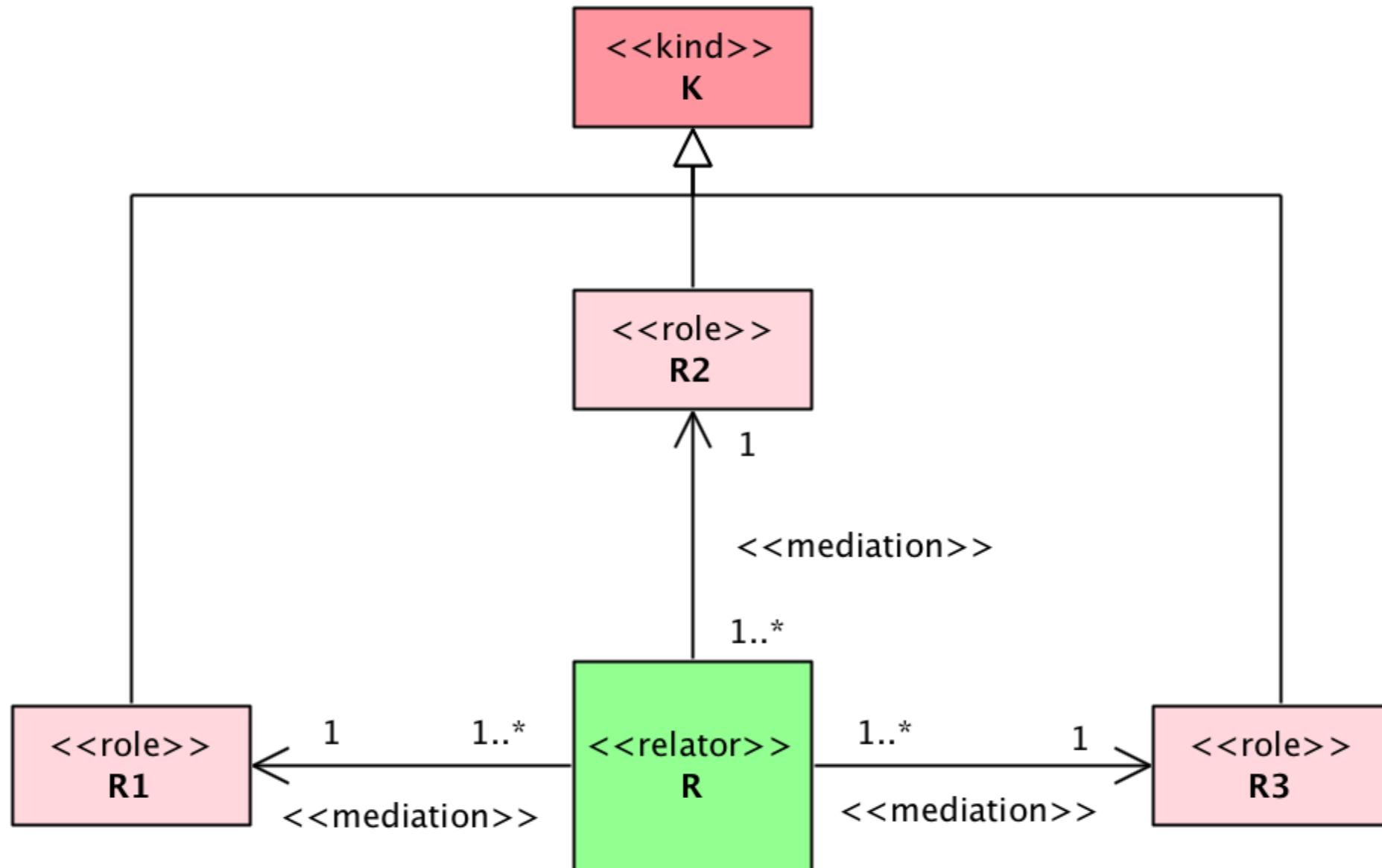


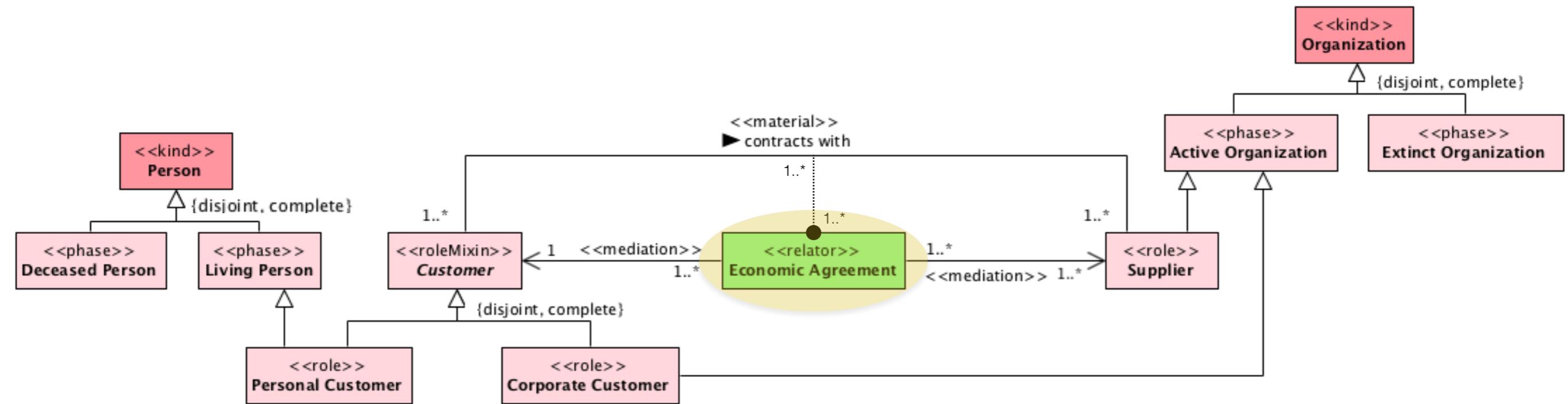


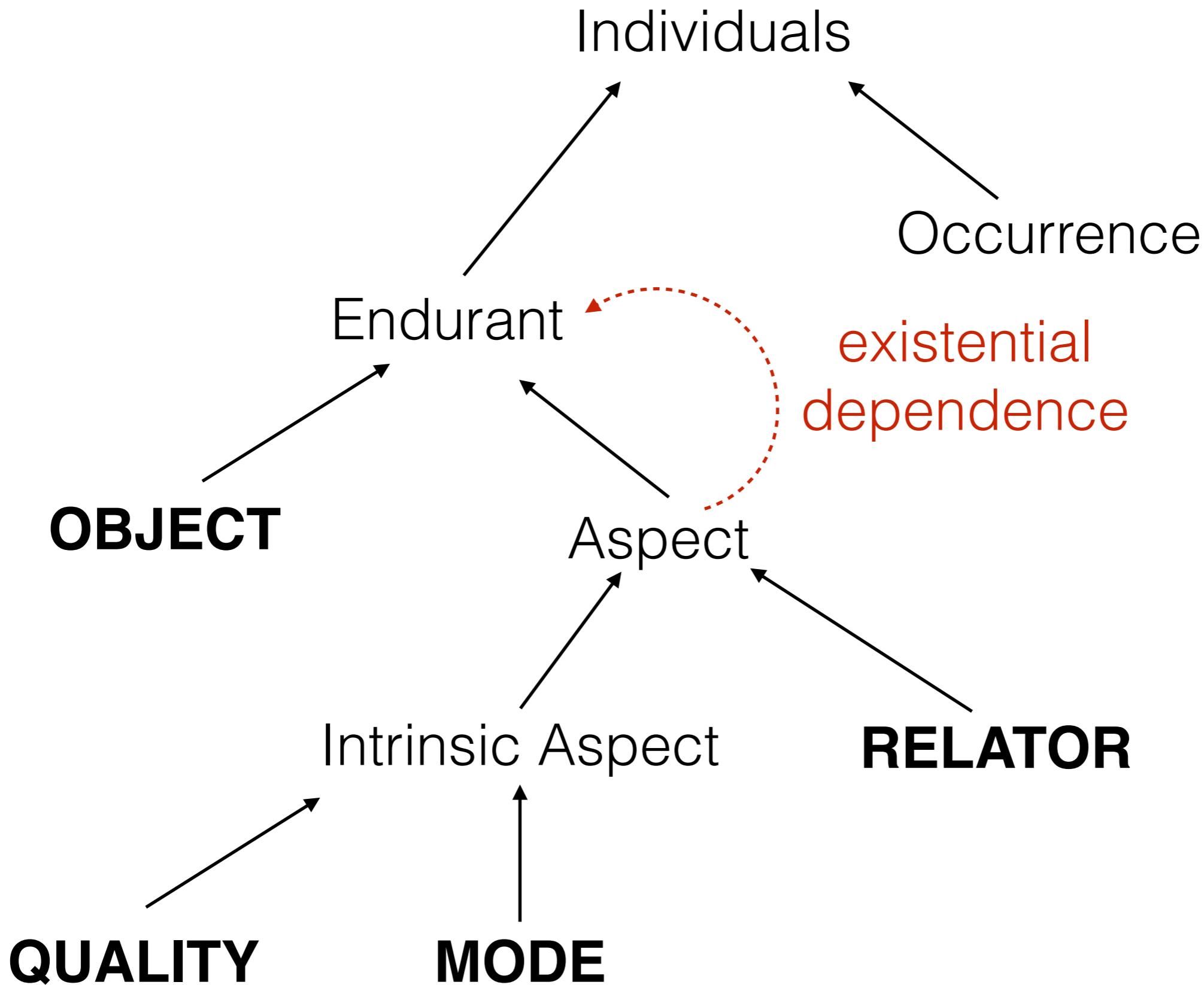




The Emerging Anti-Pattern









- A language whose semantics is defined in terms of a fully **axiomatized ontological theory** and whose syntax is defined in terms of a **Pattern Grammar**
- A set of **methodological** principles and computational **tools** for (pattern-based) model construction, verification, validation (including anti-pattern detection and rectification), verbalization, axiom learning

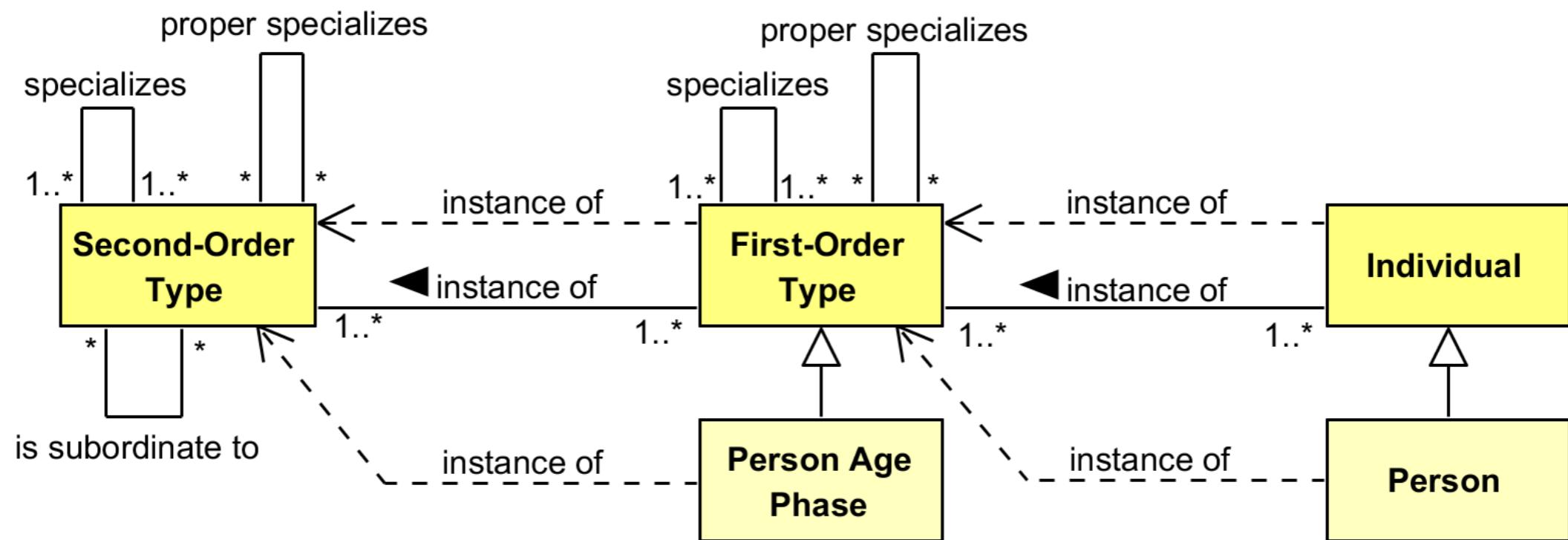
2

Logical Aspects of **Higher-Order Types**

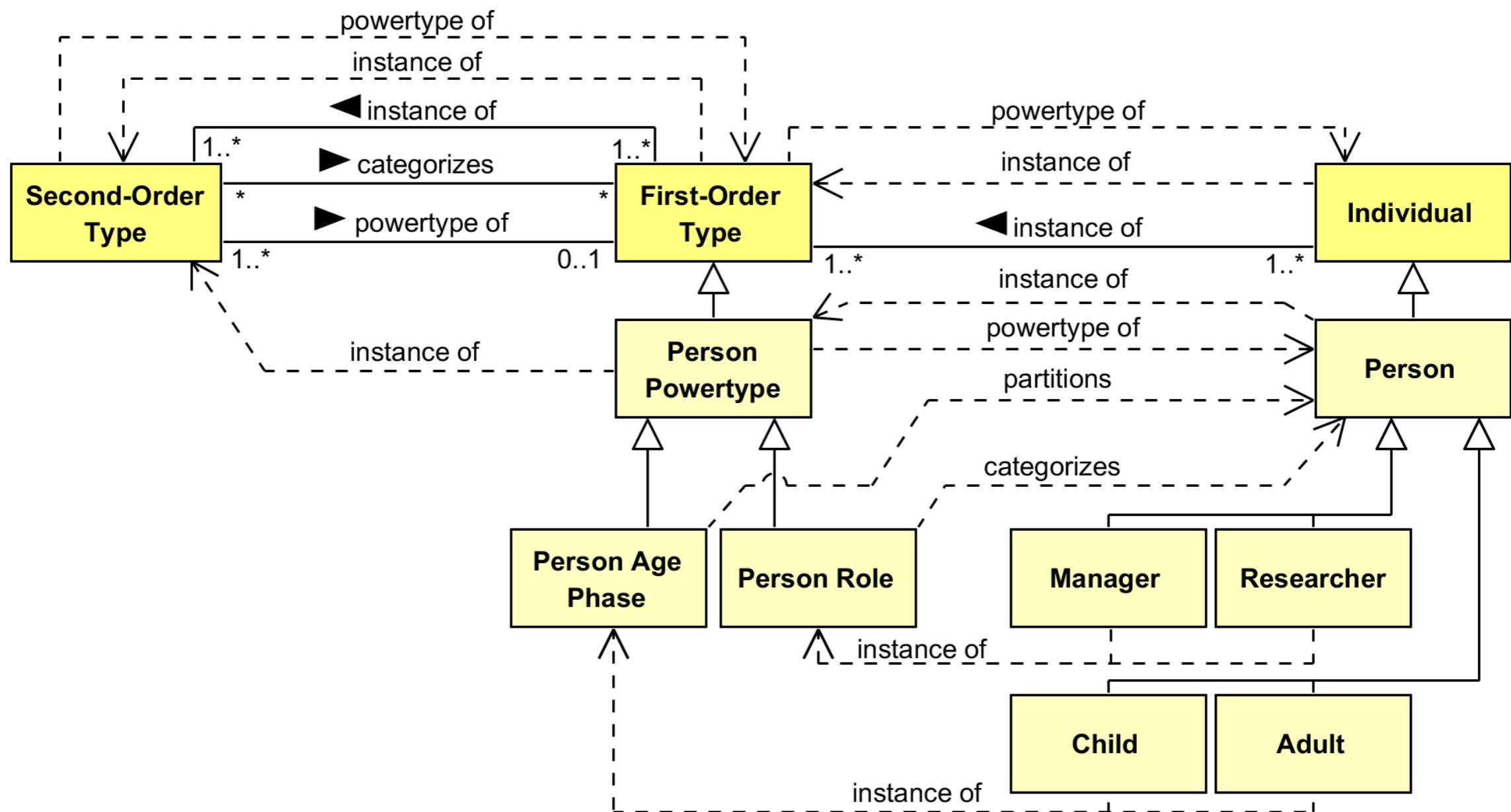
Multi-Level Theory (MLT)



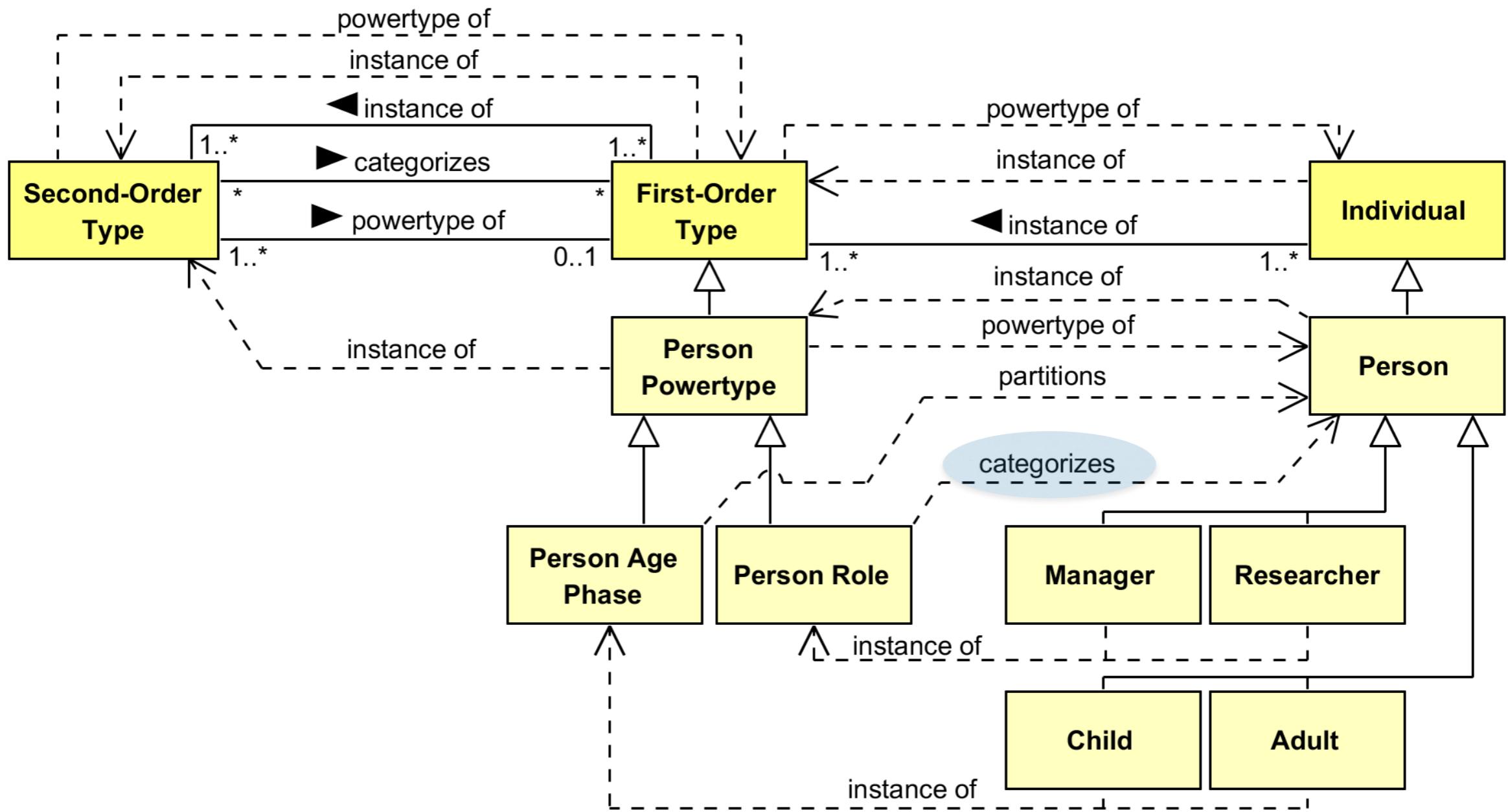
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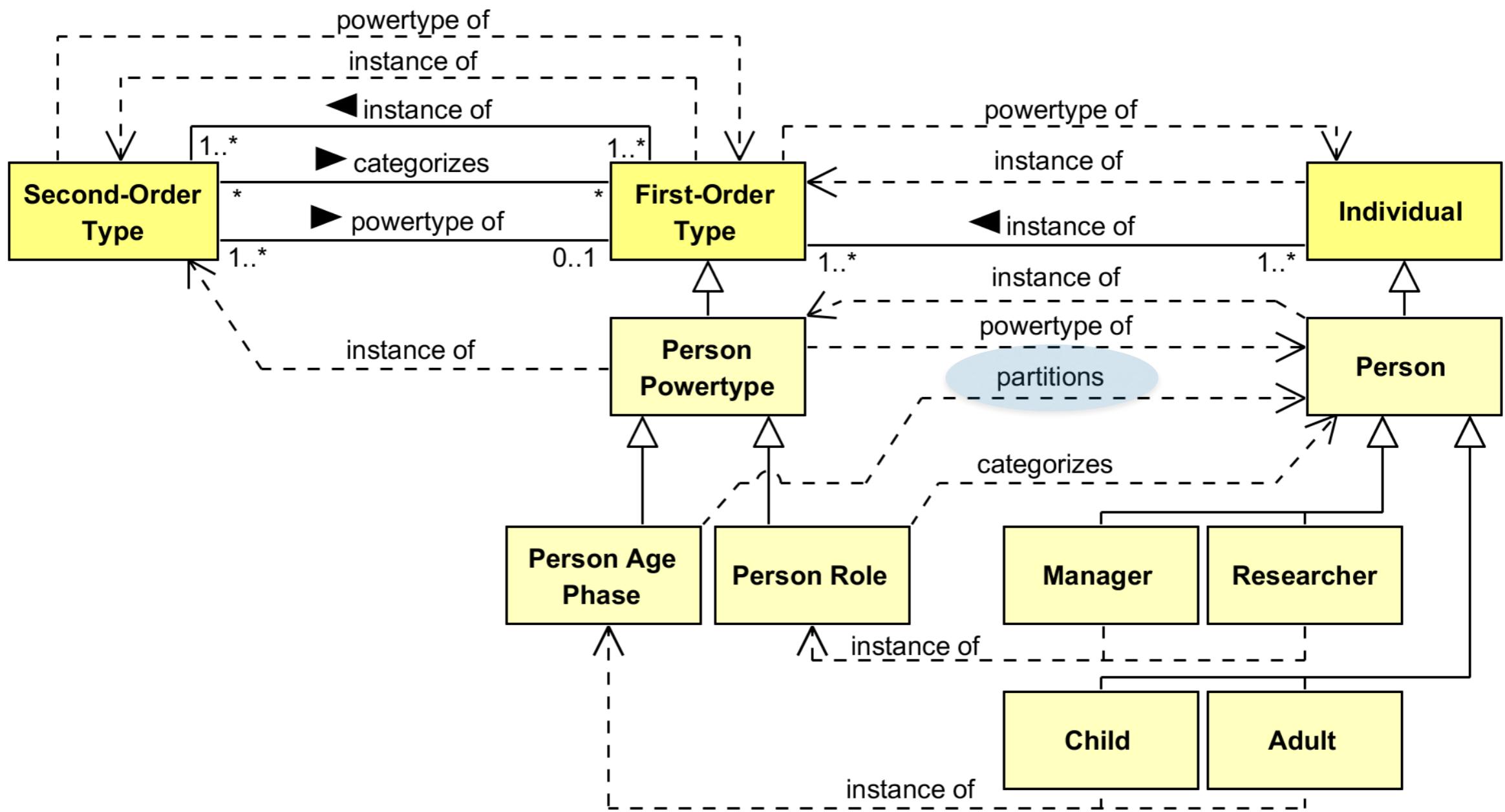
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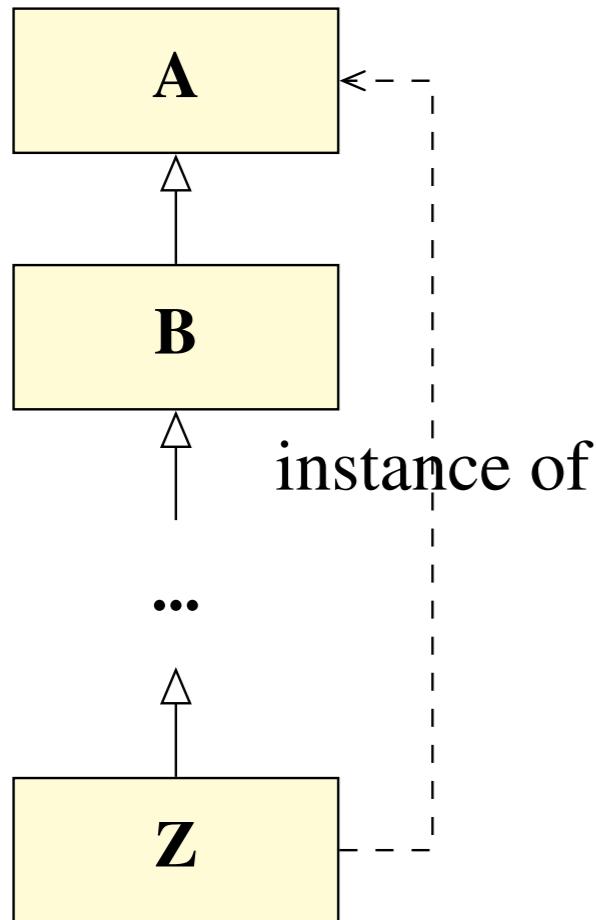
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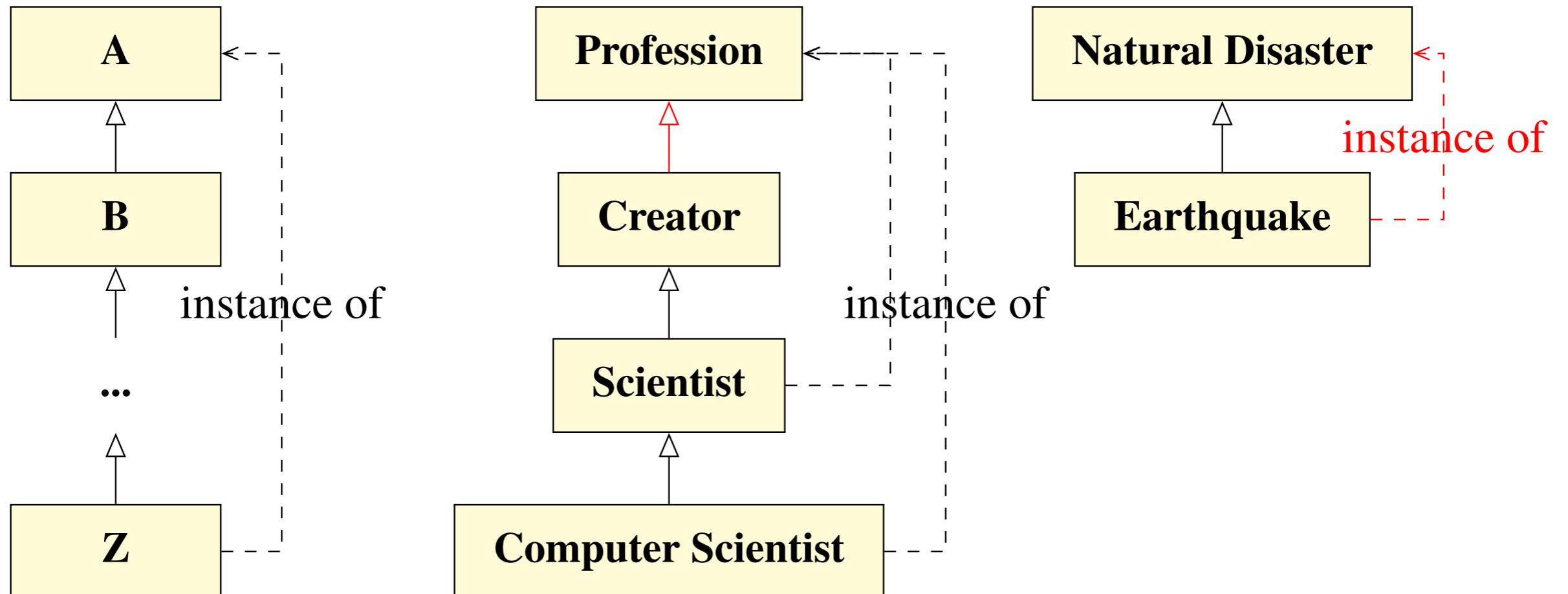
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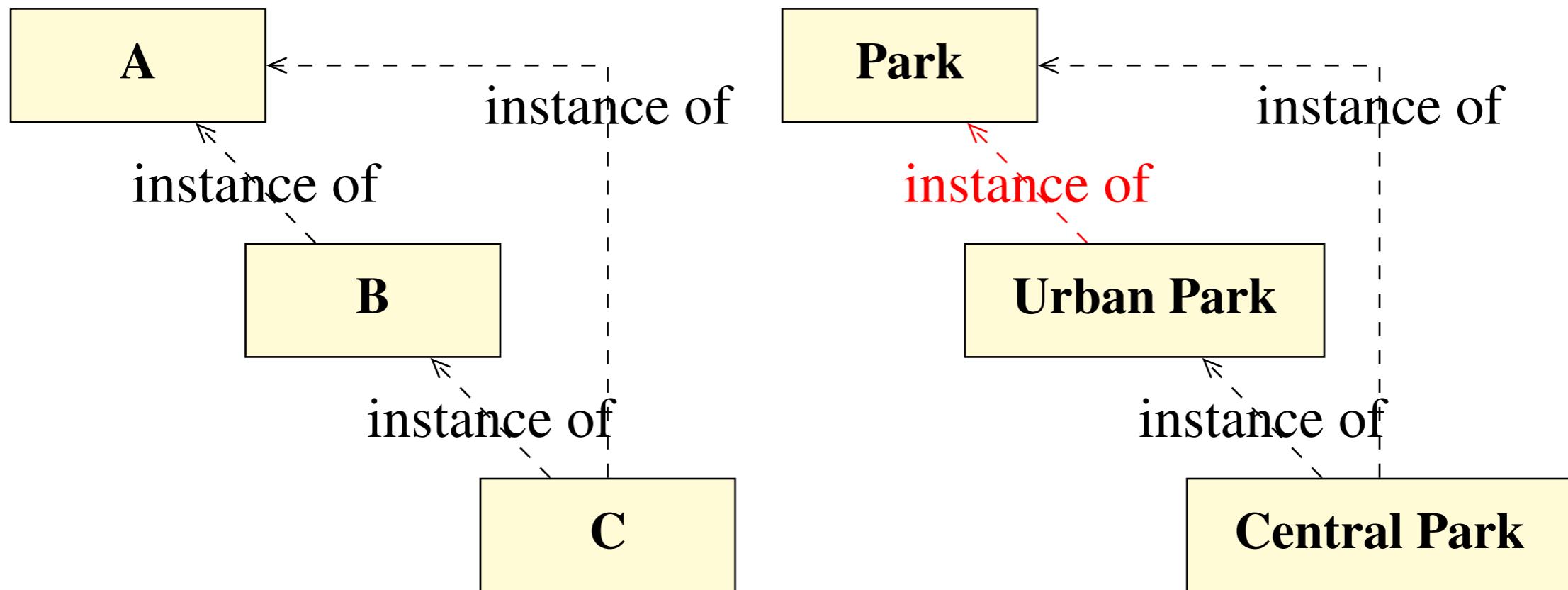
Anti-Patterns



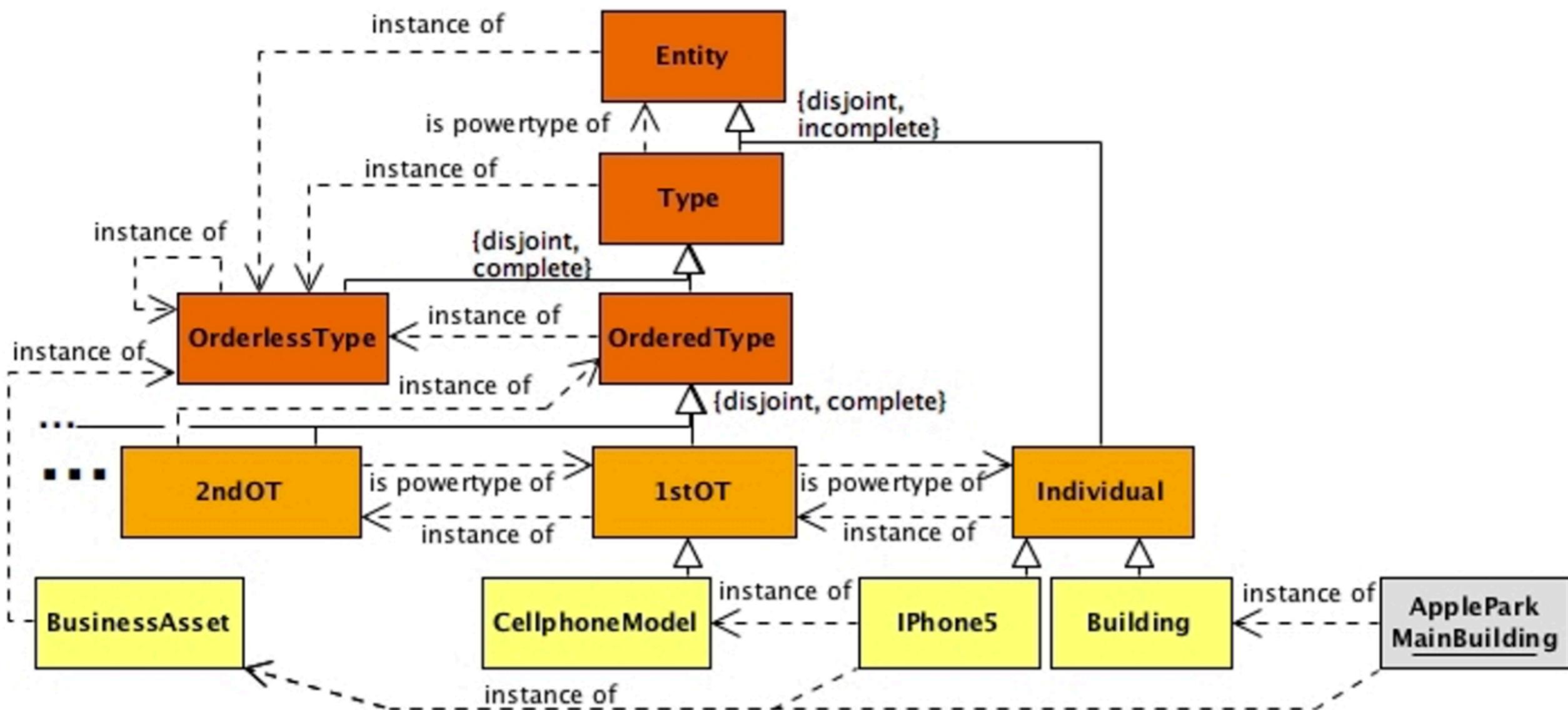
Anti-Patterns



Anti-Patterns



MLT*



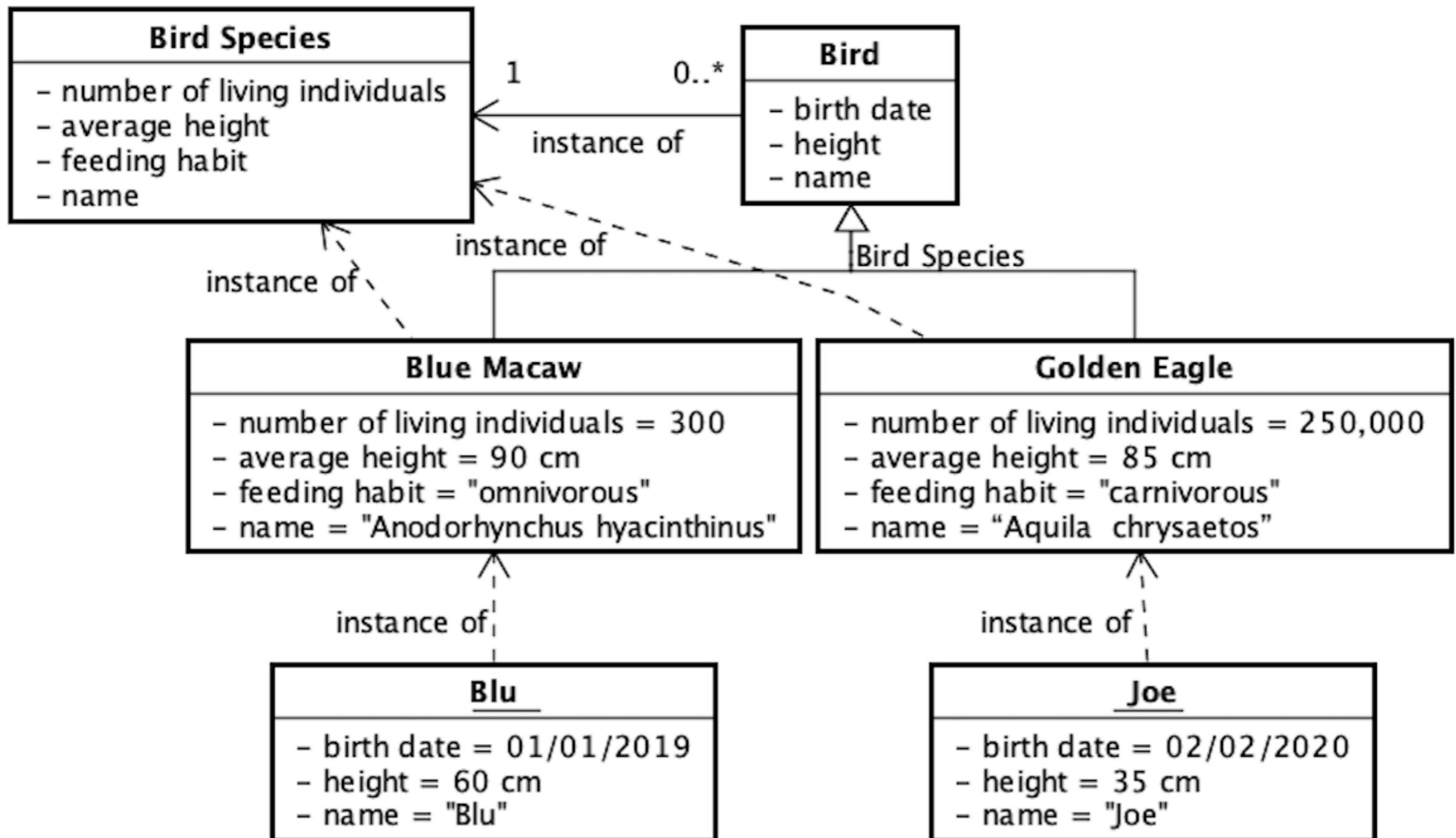
Fundamental Problems

1. **Ontological Extravagance:** Allow for types that are not ontologically genuine
2. **Ontological Incompleteness** :no differentiation between types of types, which leads to a **semantic overload** of the corresponding construct in language

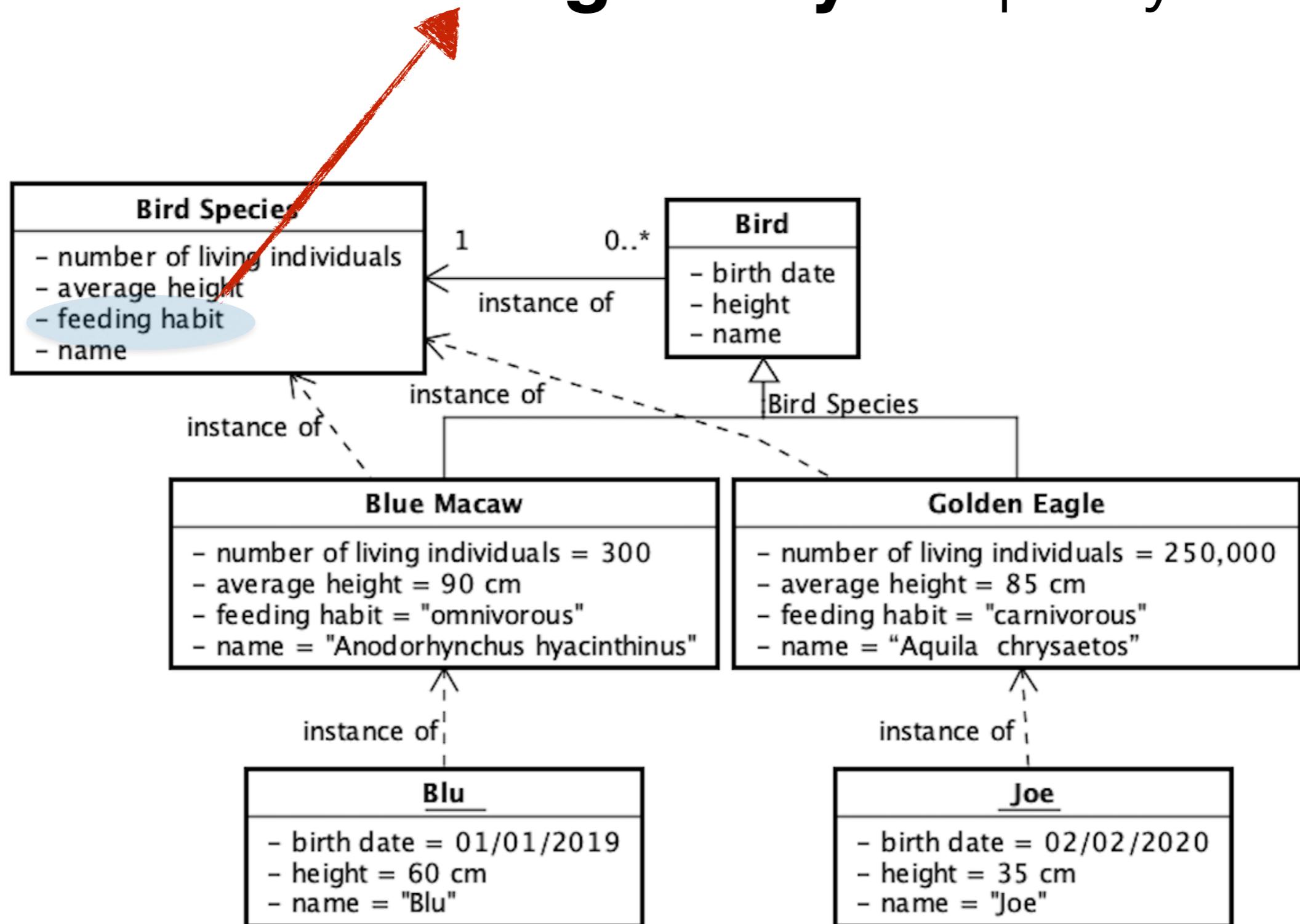
3

Ontological Aspects of Higher-Order Types

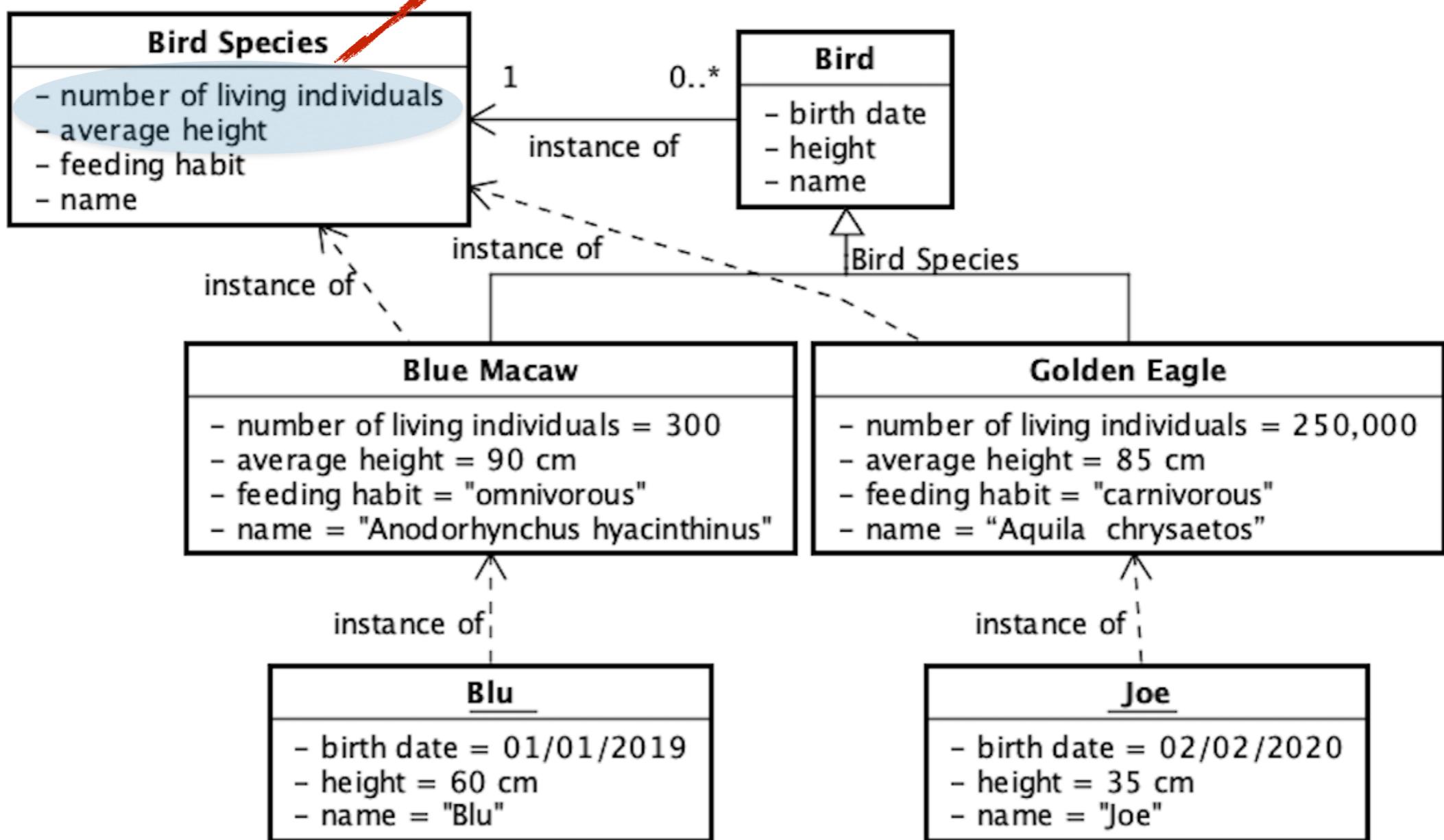
a9 $\forall t_1, t_2 (\text{type}(t_1) \wedge \text{type}(t_2) \rightarrow (t_1 = t_2 \leftrightarrow \forall x (\text{iof}(x, t_1) \leftrightarrow \text{iof}(x, t_2))))$



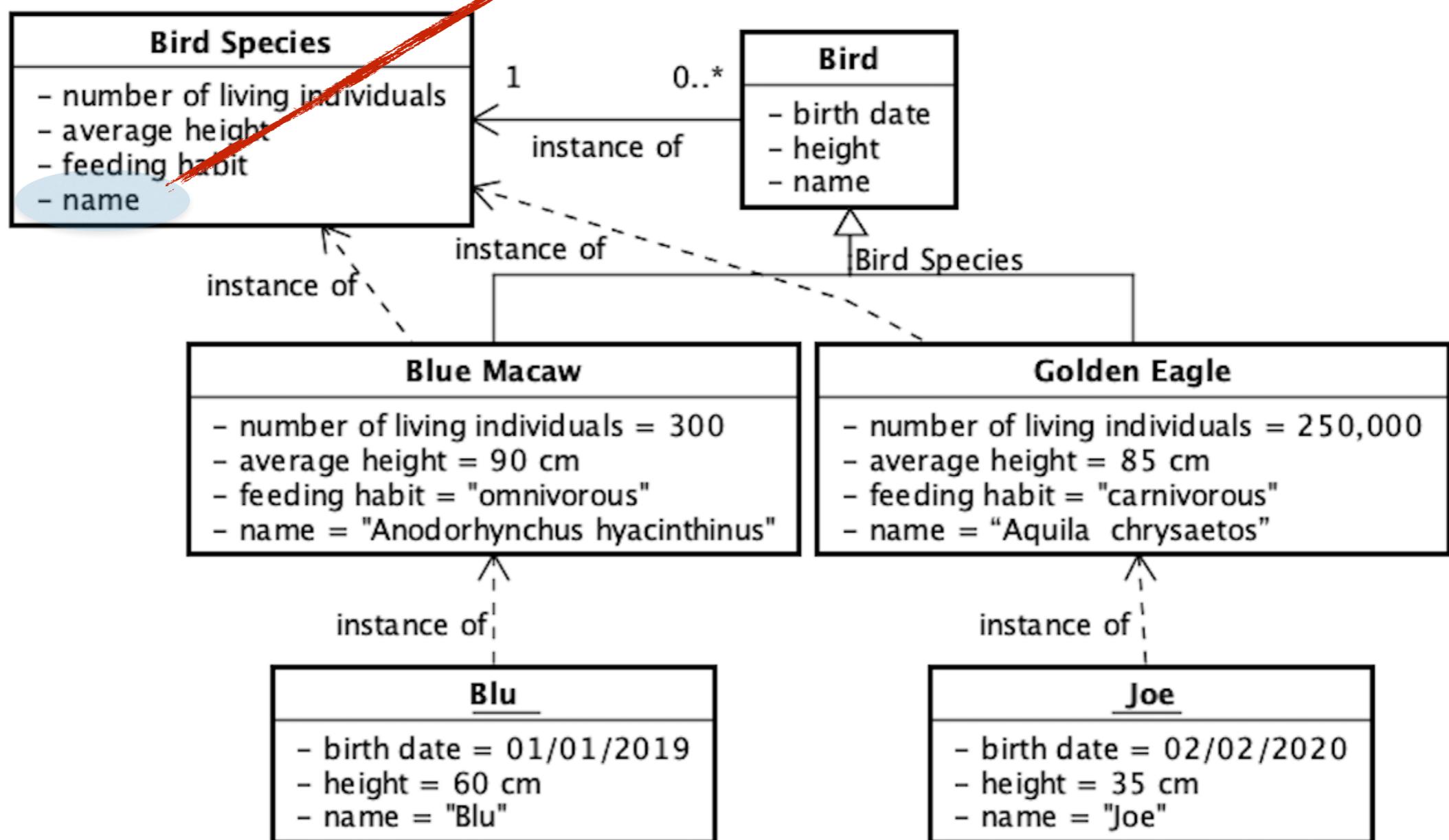
Regularity Property



Resultant Property



Direct Property



Fundamental Questions

- What is the relation between the entity T' subtyping a base type T and the corresponding instance T'_i of the higher-order type HT that T instantiates?
- What does it mean to provide a principle of identity (for types)?
- What exactly is a type, ontologically speaking?

What's in a type?

What's in a type?

1. An **abstract** entity

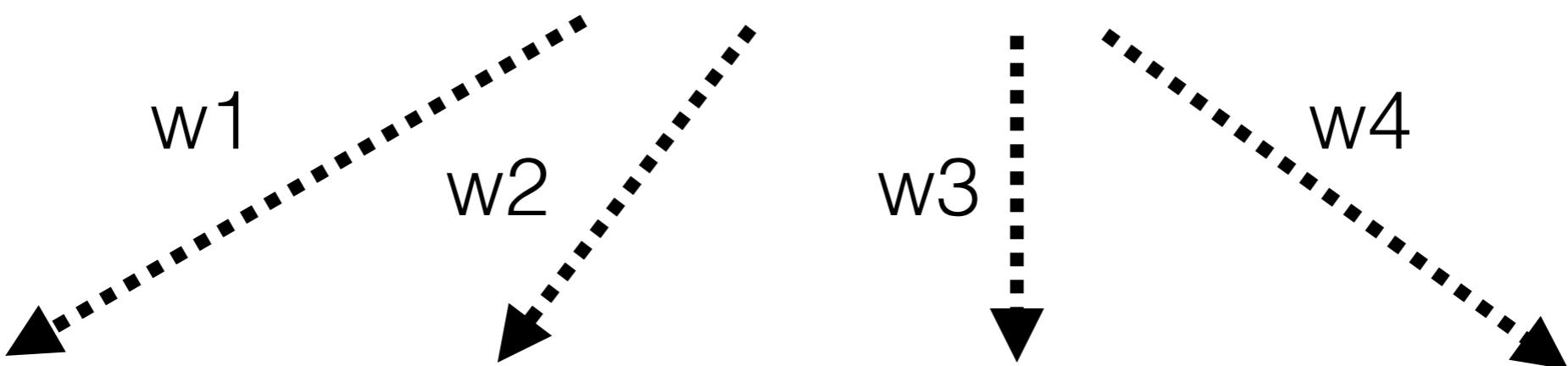
What's in a type?

1. An **abstract** entity
2. A **mereological sum** of instances

What's in a type?

1. An **abstract** entity
2. A **mereological sum** of instances
3. A **variable embodiment**

Mick Jagger



Person

instantiation



Mick Jagger

w1

w2

w3

w4



Person

instantiation



Mick Jagger

w1

w2

w3

w4

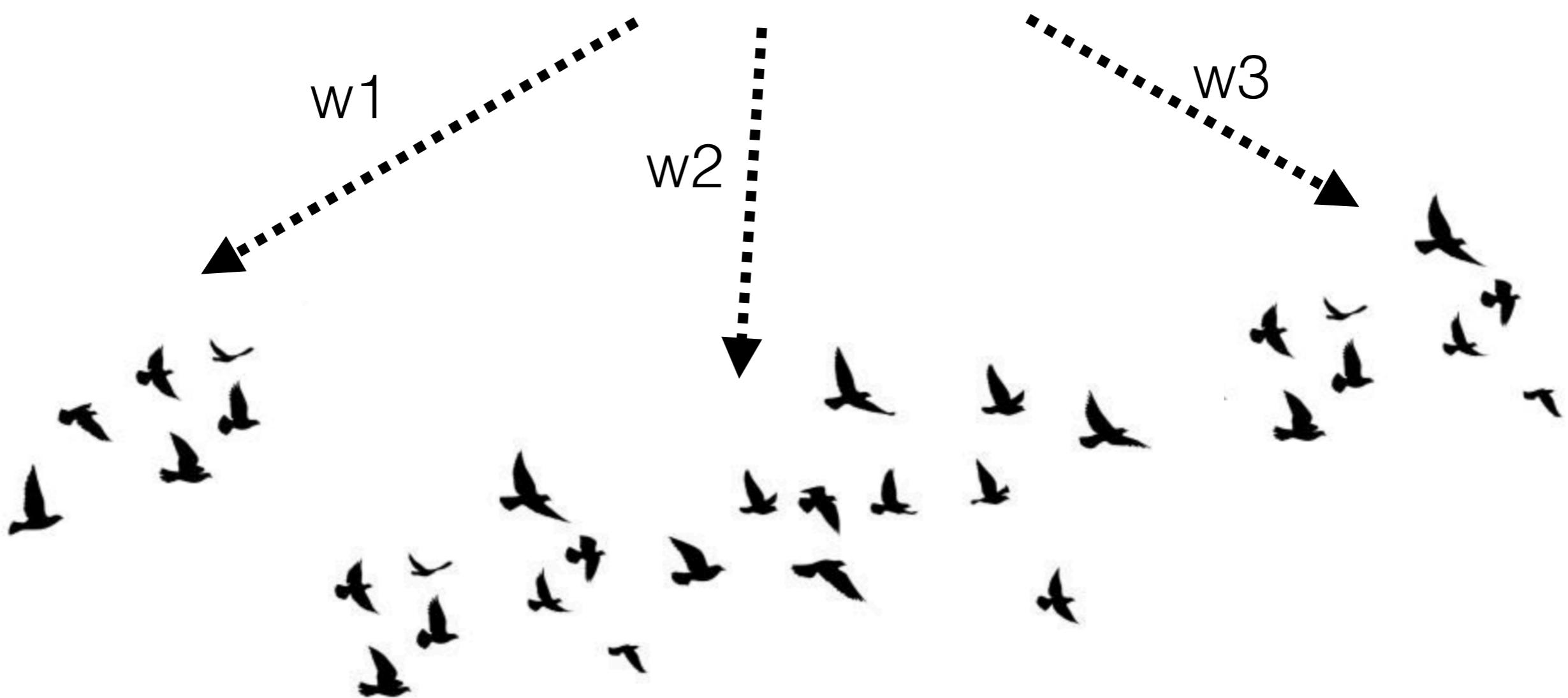


Bird Species

instantiation

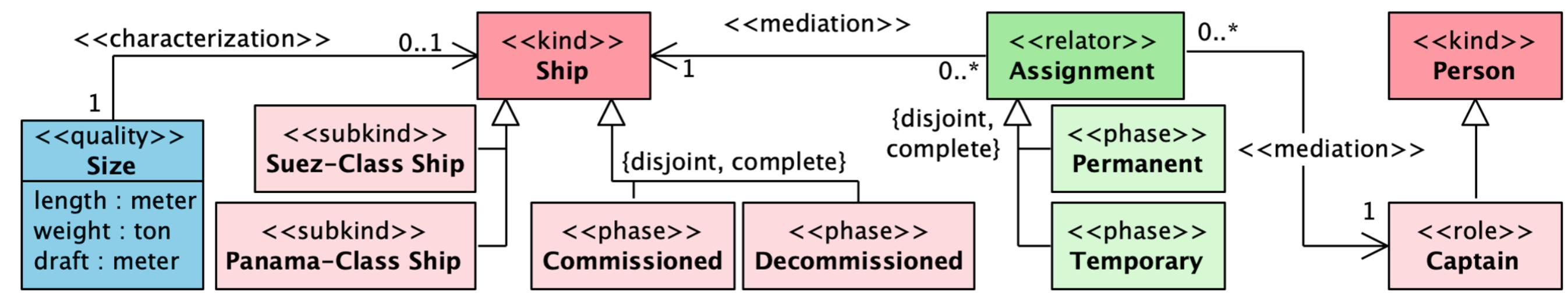
Golden Eagle

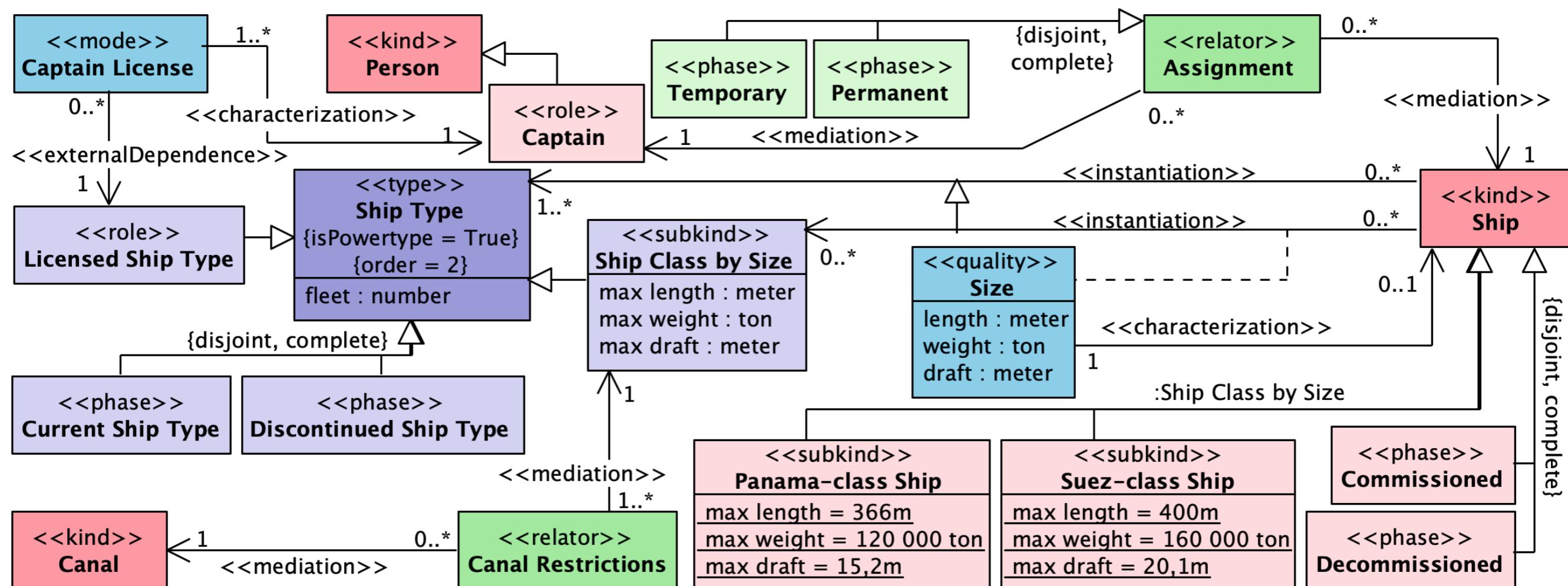
intension
of a specific
subtype of Bird



What's in a type?

1. An **abstract** entity
2. A **mereological sum** of instances
3. A **variable embodiment**, i.e., full fledged **endurant E** such that:
 - in each world, E it is **constituted by** a sum S
 - the principle of **identity** of E is the **intension** of the associated type, which is also the **principle of individuation** for the constituents of E





Take Away Messages

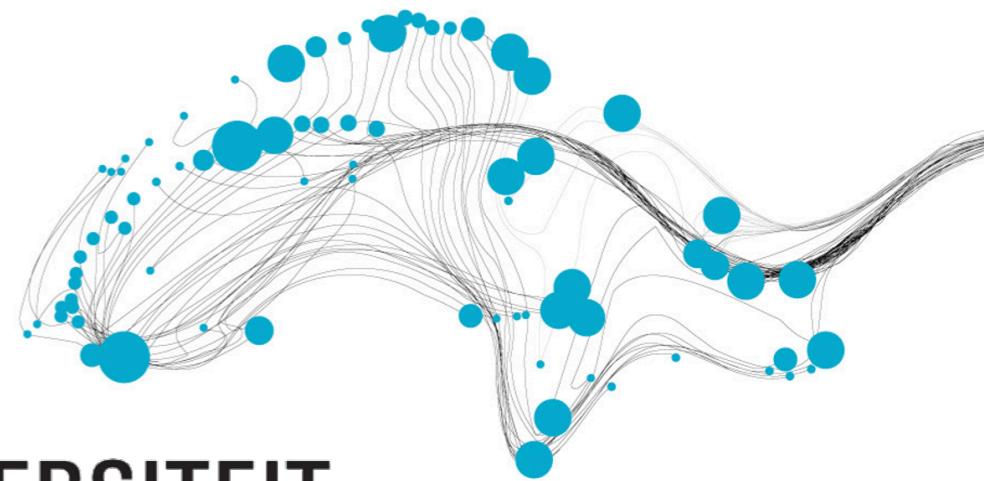
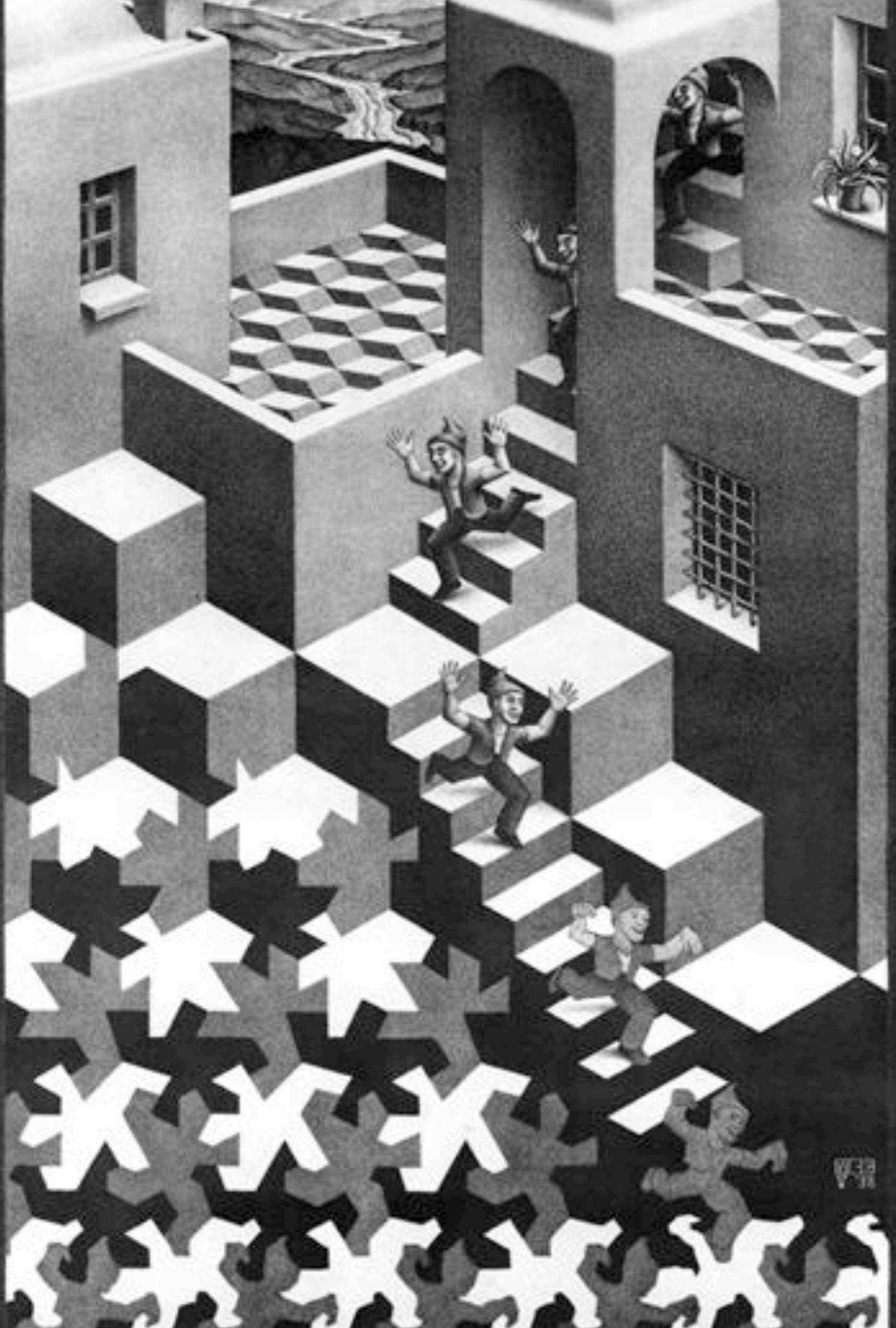
- Types are absolutely fundamental in modeling but we need a **proper theory of (higher-order) types** that is both **formal** and **ontologically sound**
- Once we have that we can produce **engineering tools for multi-level modeling** including modeling languages, patterns, anti-patterns, methodological principles, computational tools, etc.

To know more

- *Types and taxonomic structures in conceptual modeling: A novel ontological theory and engineering support*, G Guizzardi et al., Data & Knowledge Engineering 134, 2021.
- *Multi-level conceptual modeling: Theory, language and application*, CM Fonseca, JPA Almeida, G Guizzardi, VA Carvalho, Data & Knowledge Engineering 134, 2021.
- Incorporating Types of Types in Ontology-Driven Conceptual Modeling, CM Fonseca, G Guizzardi, JPA Almeida, TP Sales, D Porello, International Conference on Conceptual Modeling, 18-34, 2021.

To know more

- A Note on Properties in Multi-Level Modeling, JPA Almeida, VA Carvalho, CM Fonseca, G Guizzardi, 2021 ACM/IEEE International Conference on Model Driven Engineering Languages Companion Volume (MODELS-C), 2021.
- *Using a well-founded multi-level theory to support the analysis and representation of the powertype pattern in conceptual modeling*, VA Carvalho, JPA Almeida, G Guizzardi, CAiSE'16.
- Towards an ontological analysis of powertypes, G Guizzardi, JP Almeida, N Guarino, VA Carvalho, JOWO@IJCAI, 2015.



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