An **Ontological** View on **Types**

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Cybersecurity
& Services

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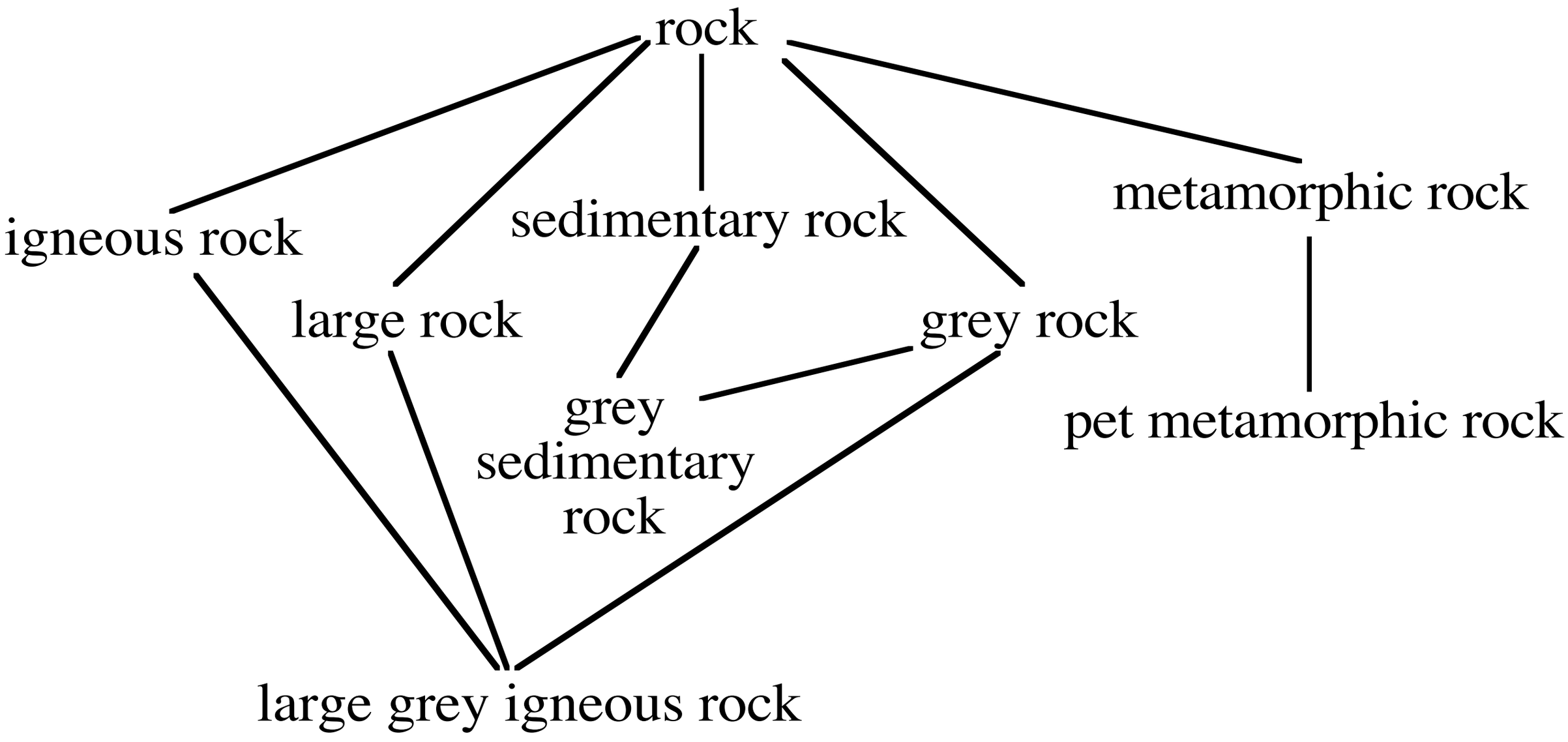
Acknowledgements

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

1

Ontological Aspects of **Types**

How many kinds of rock?



Brachman, Fikes and Levesque, 1985

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.

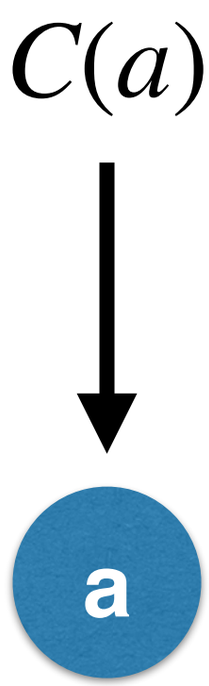
In order to behave knowledgeably in a real domain, a system will have to interact with experts using specialized terms like the above. Therefore, the application of knowledge representation to expert problems demands of a representation system the ability to ***develop***, ***augment***, and ***maintain*** 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

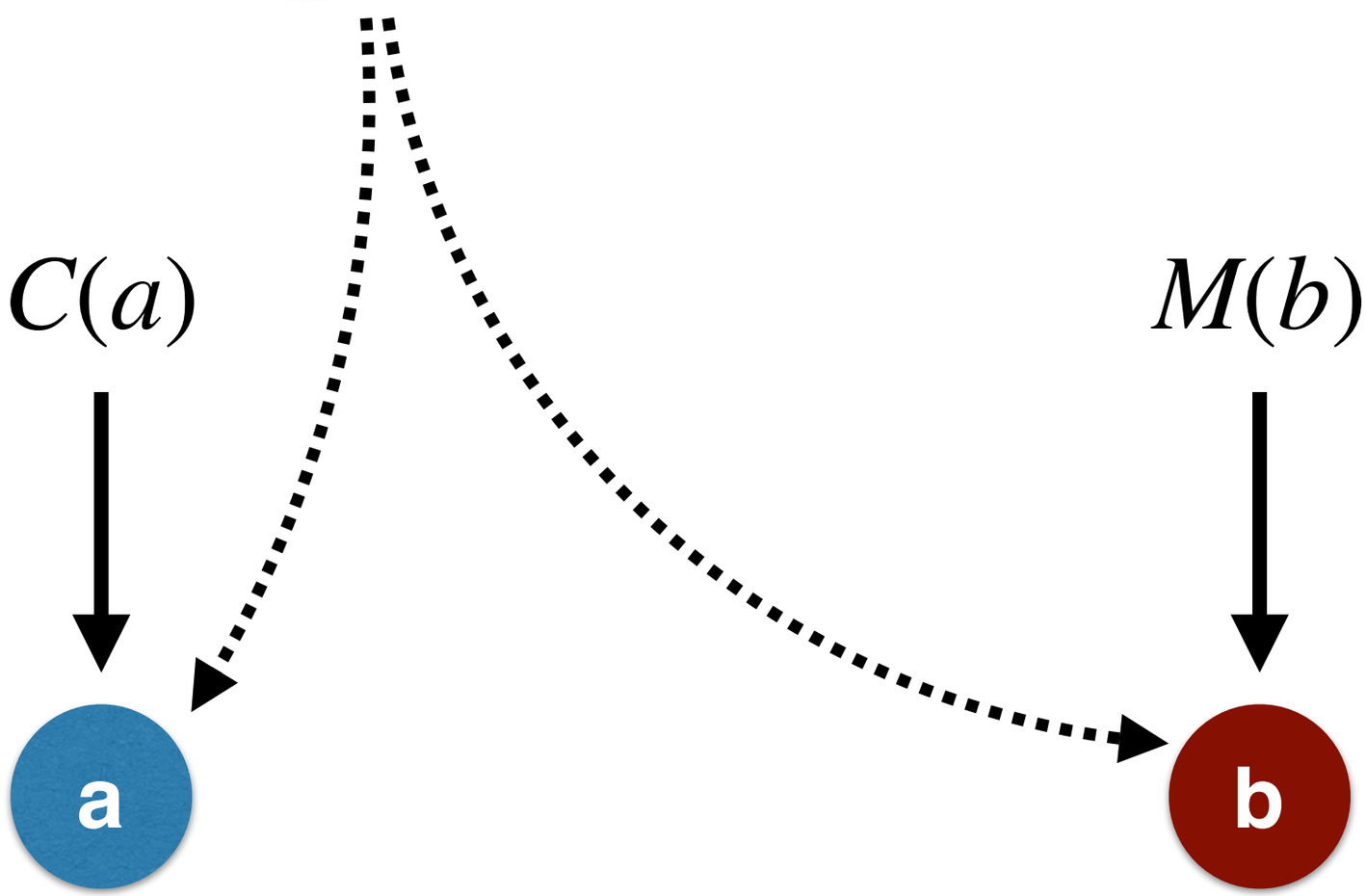
1. **Ontological Extravagance:** Allow for types that are not ontologically genuine
2. **Ontological Incompleteness** :no differentiation between types of types, which leads to a **semantic overload** of the corresponding construct in language


C(a)
a

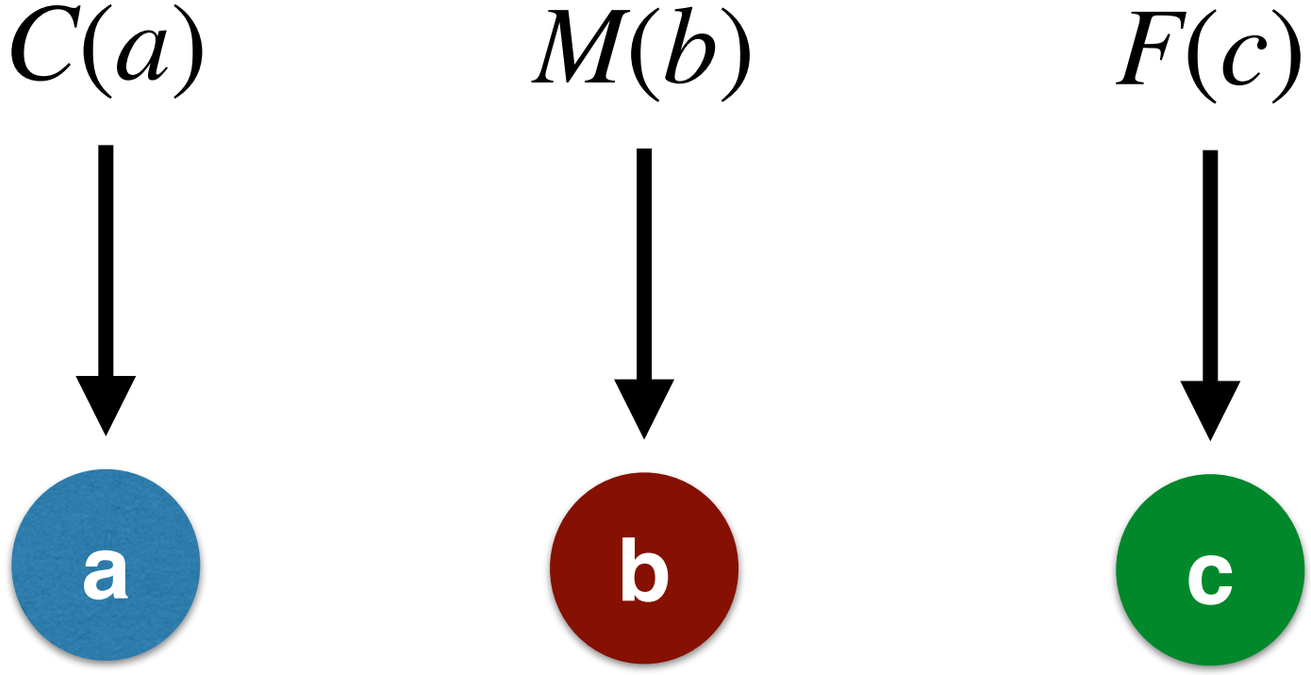

C(a)
M(b)
a
b

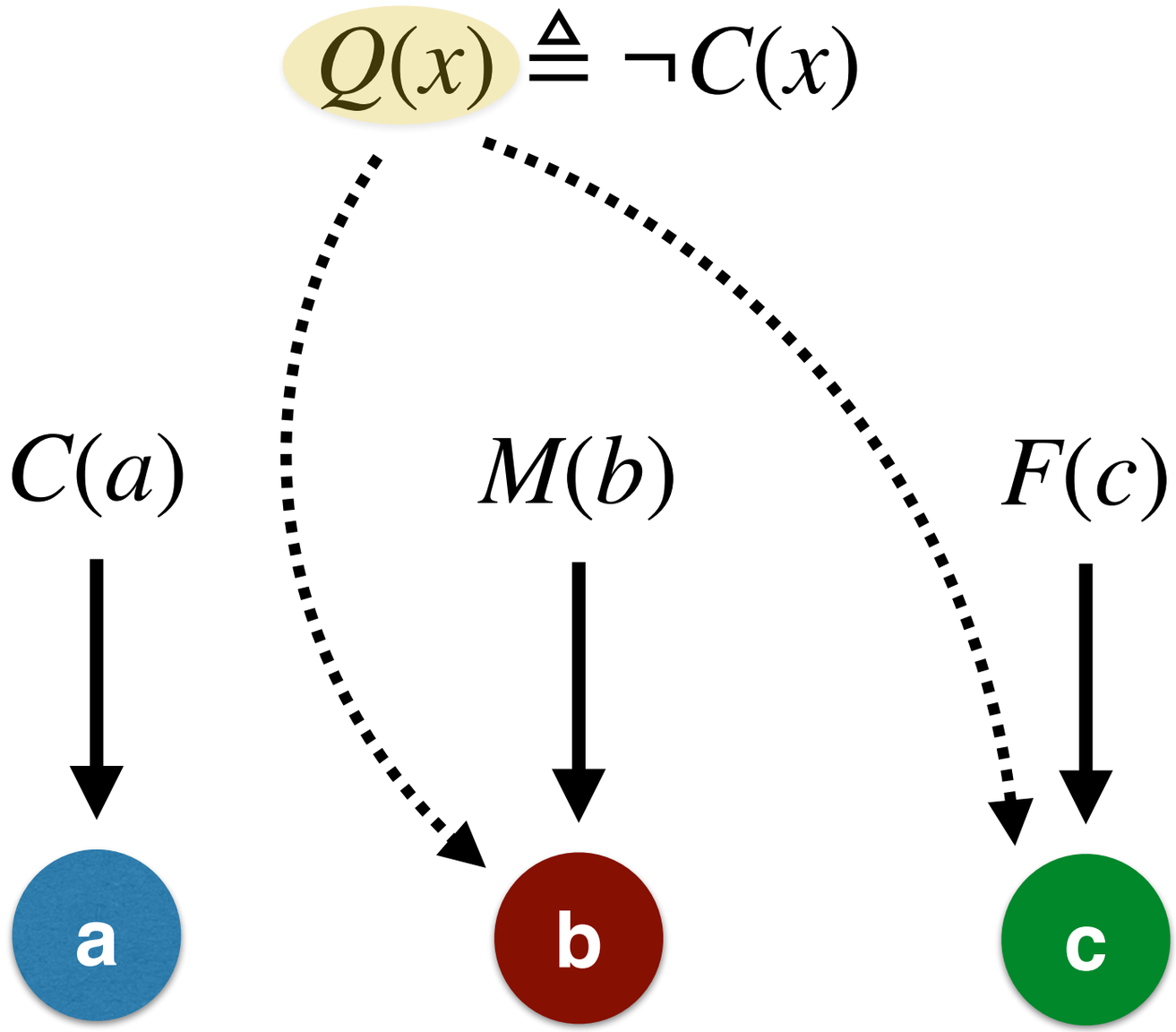
$$P(x) \triangleq C(x) \vee M(x)$$

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



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




$Q(x) \triangleq \neg C(x)$
$C(a)$
$M(b)$
$F(c)$
a
b
c

The **Logical** Level

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

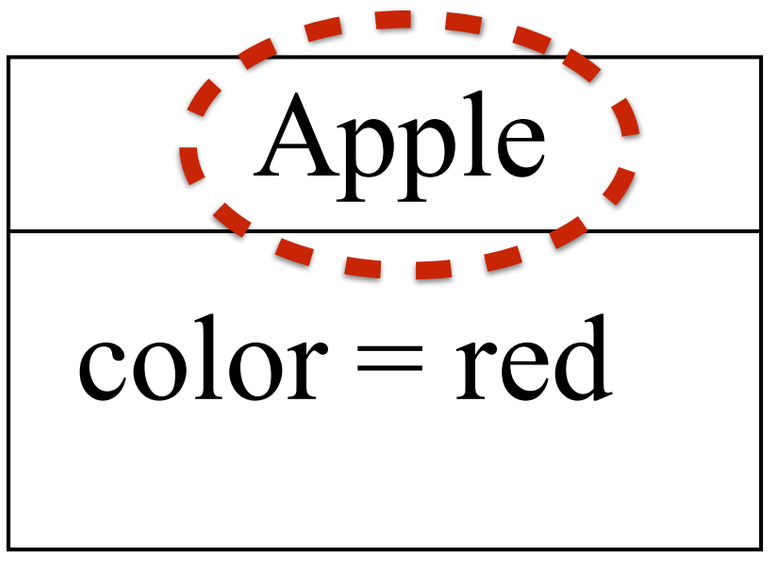
The **Espistemological** Level

Apple
color = red

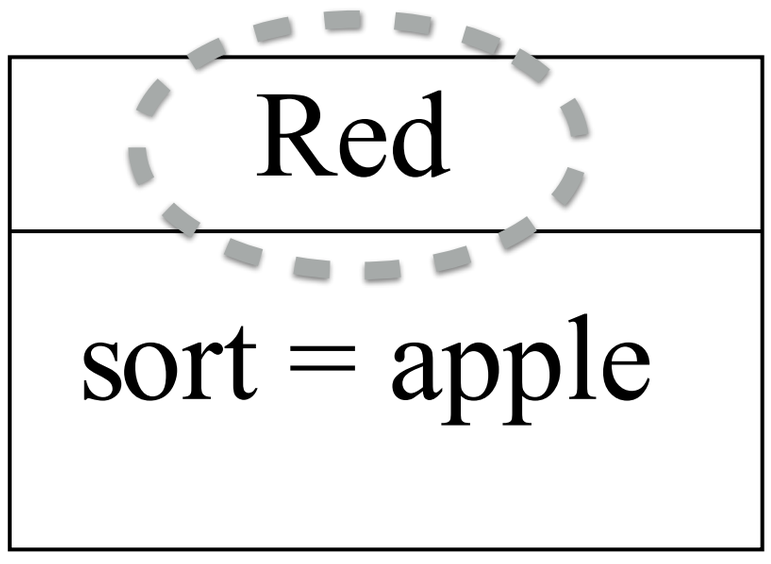
Red
sort = apple

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

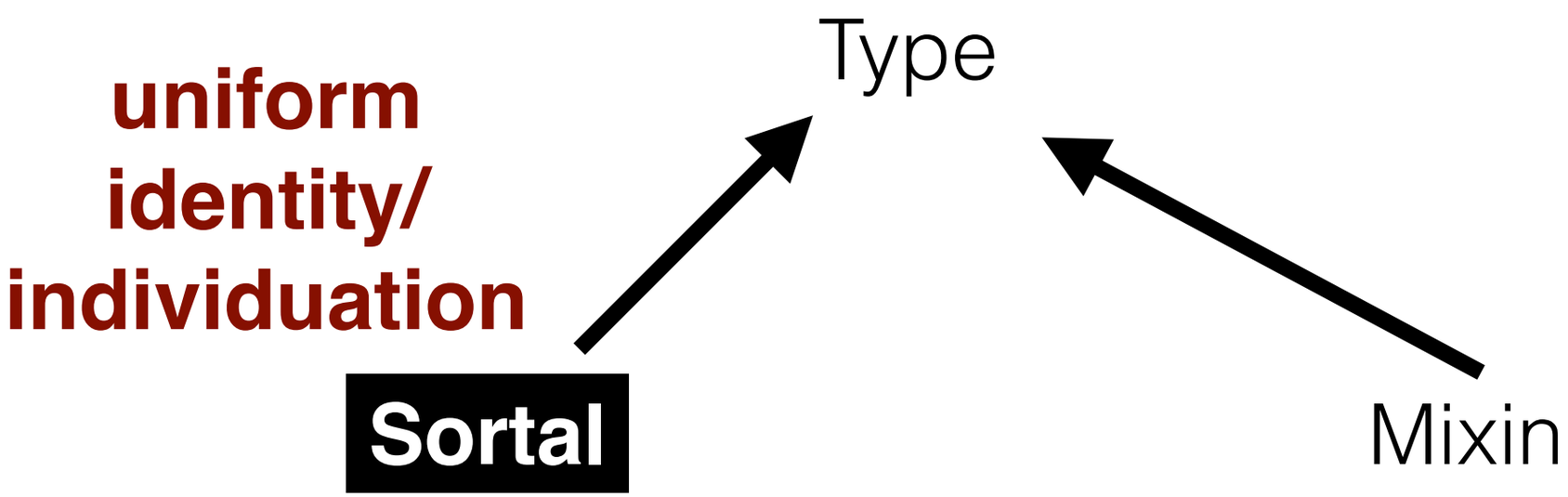
(i) exactly five X …

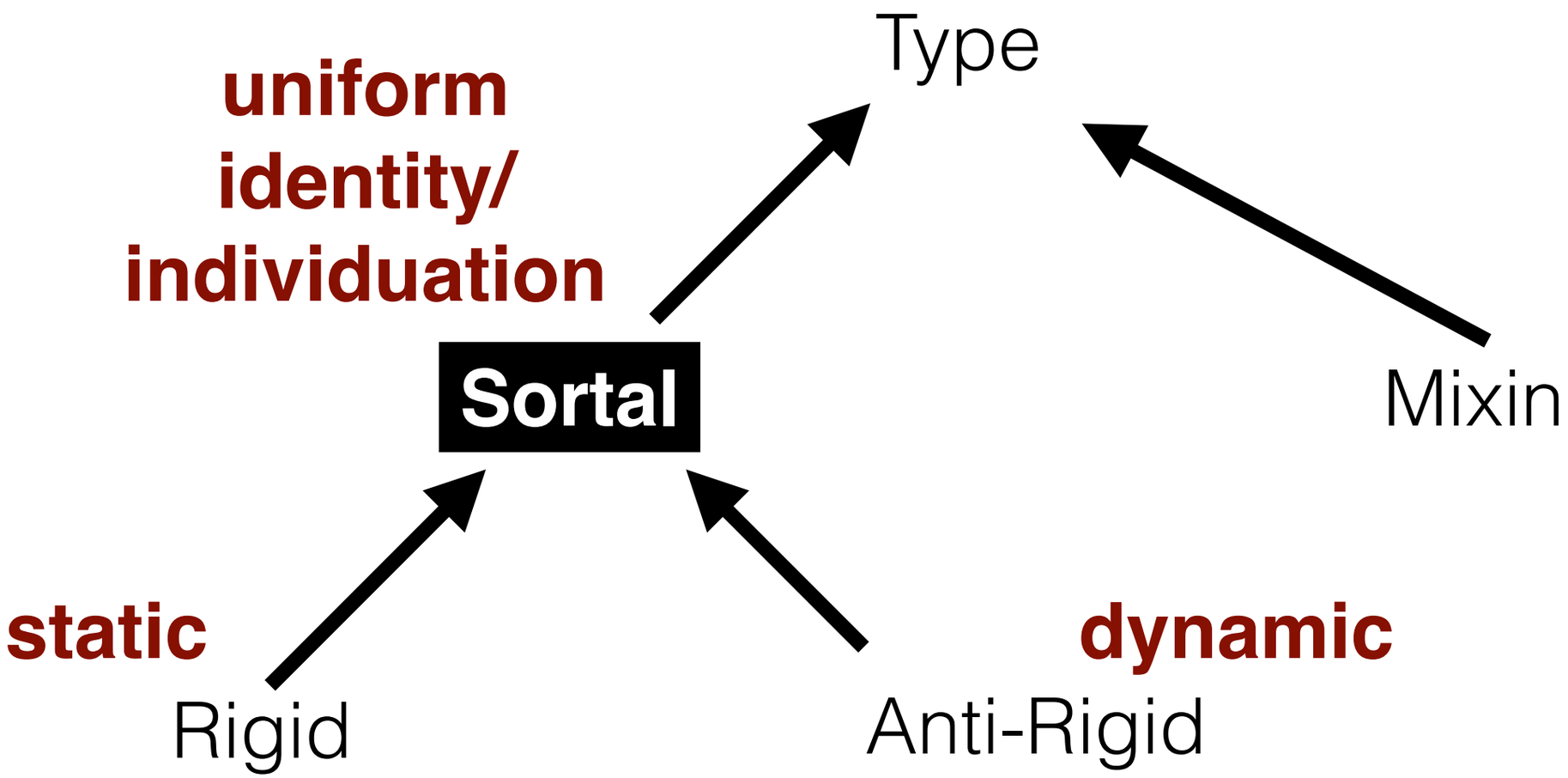
(ii) the Y which is Z…

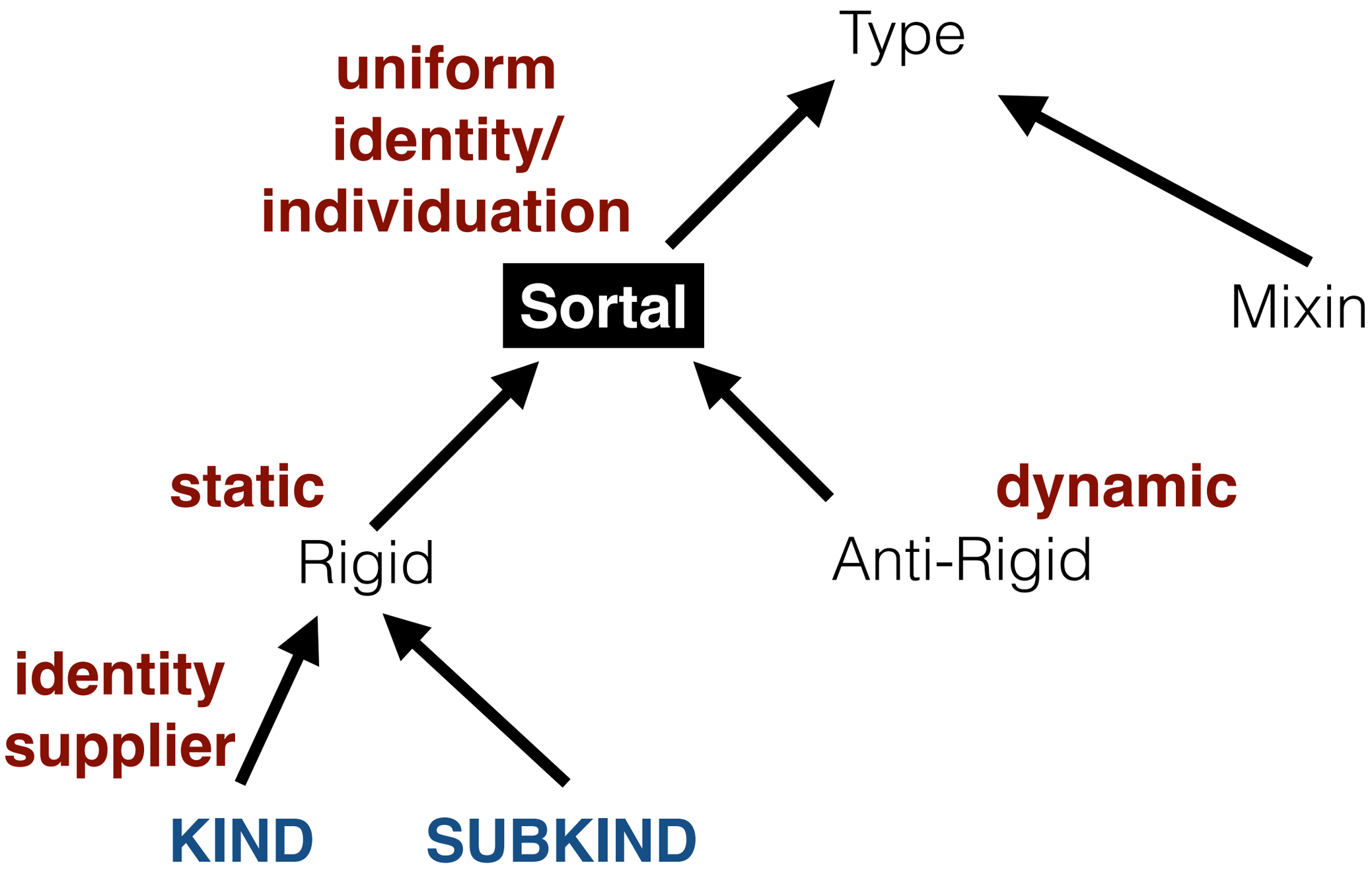
General Terms and Common Nouns

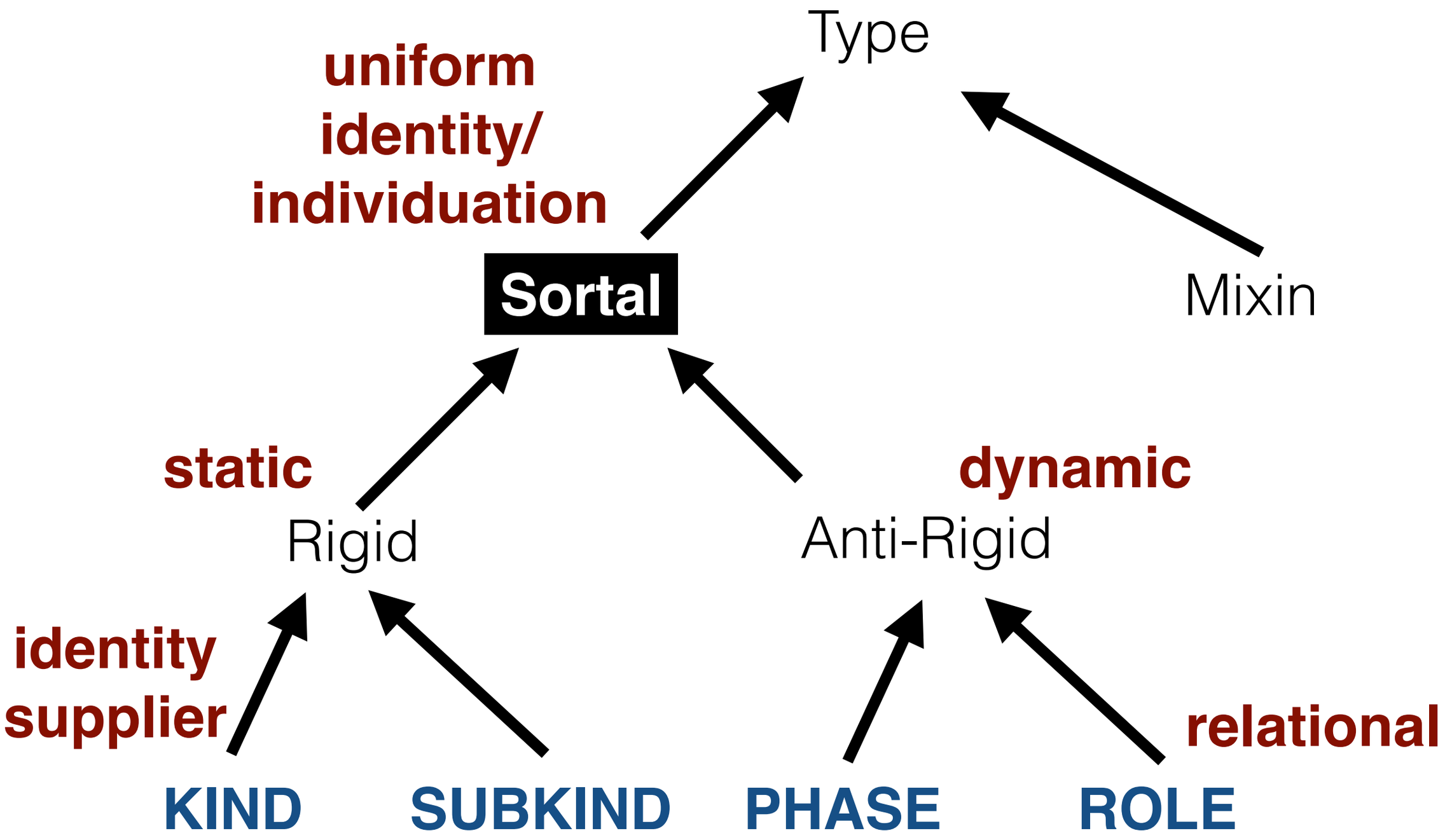
(i) exactly five *reds* were in the kitchen last night

(ii) the *red* which has ..., has been in turn ...

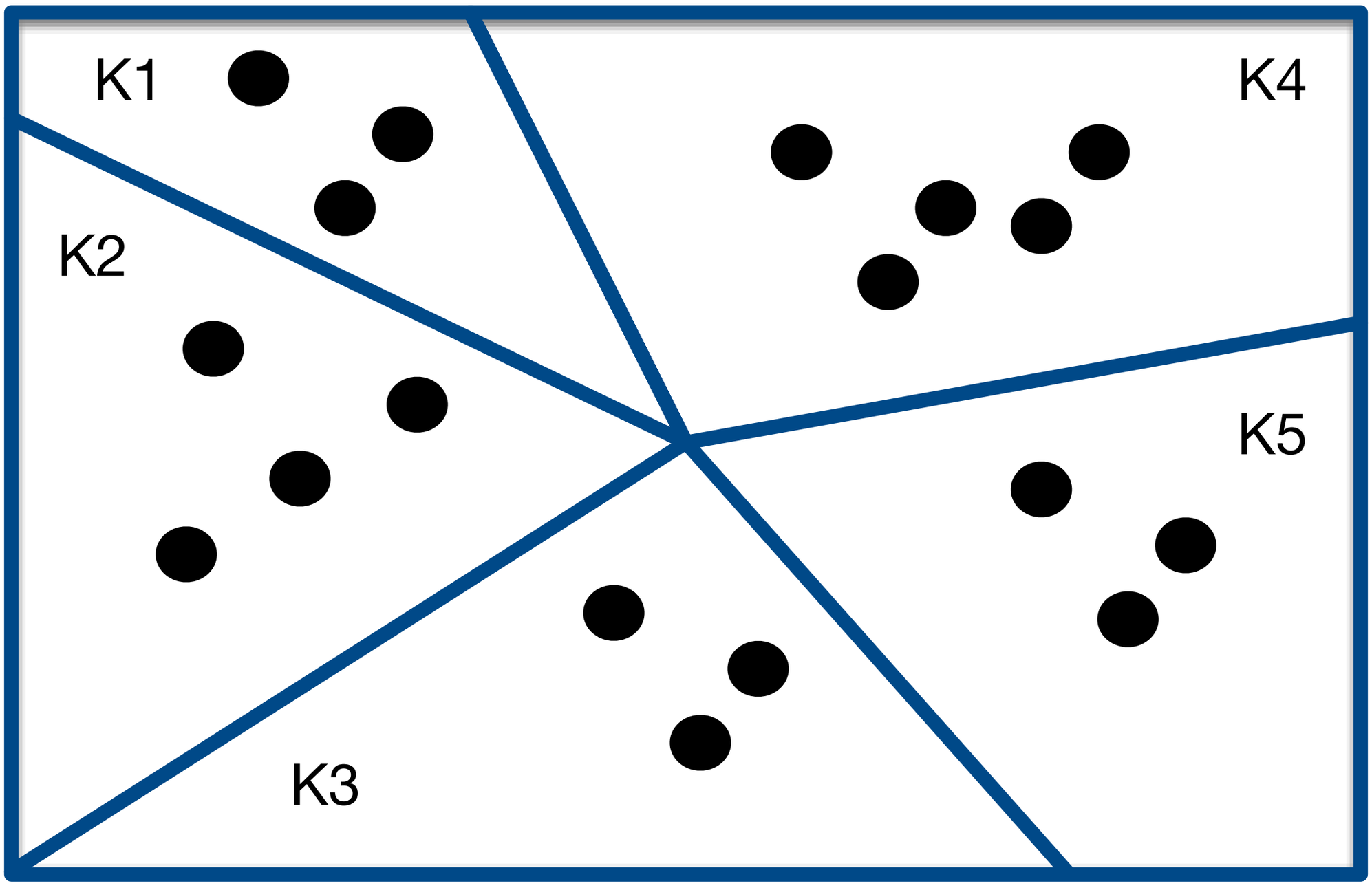

uniform
identity/
individuation
Sortal
Type
Mixin


Type
uniform
identity/
individuation
Sortal
Mixin
static
dynamic
Rigid
Anti-Rigid

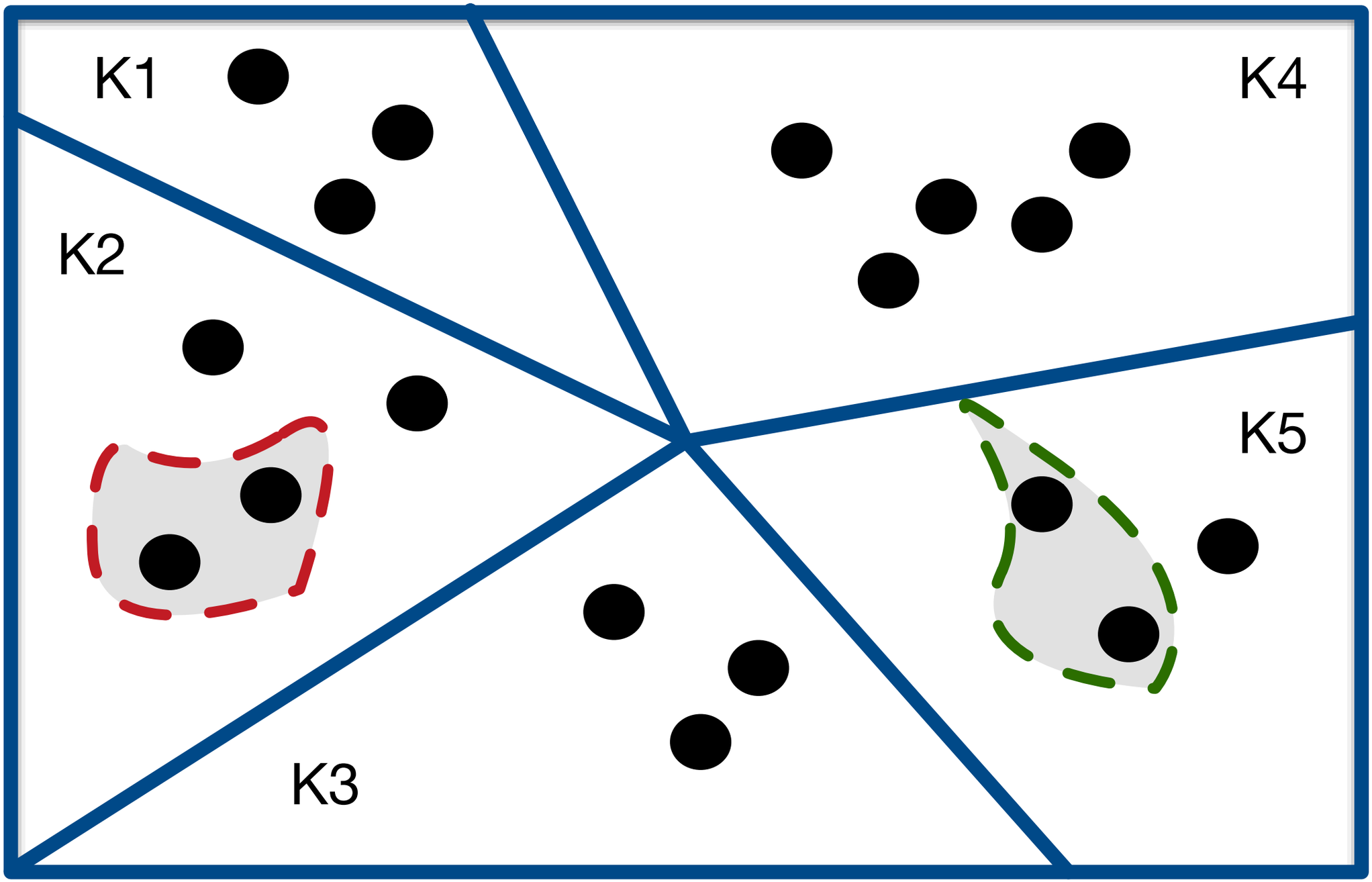

Type
uniform
identity/
individuation
Sortal
Mixin
static
dynamic
Rigid
Anti-Rigid
identity
supplier
KIND
SUBKIND


Type
uniform
identity/
individuation
Sortal
Mixin
static
dynamic
Rigid
Anti-Rigid
identity
supplier
relational
KIND
SUBKIND
PHASE
ROLE

Kinds



Anti-Rigid Sortals



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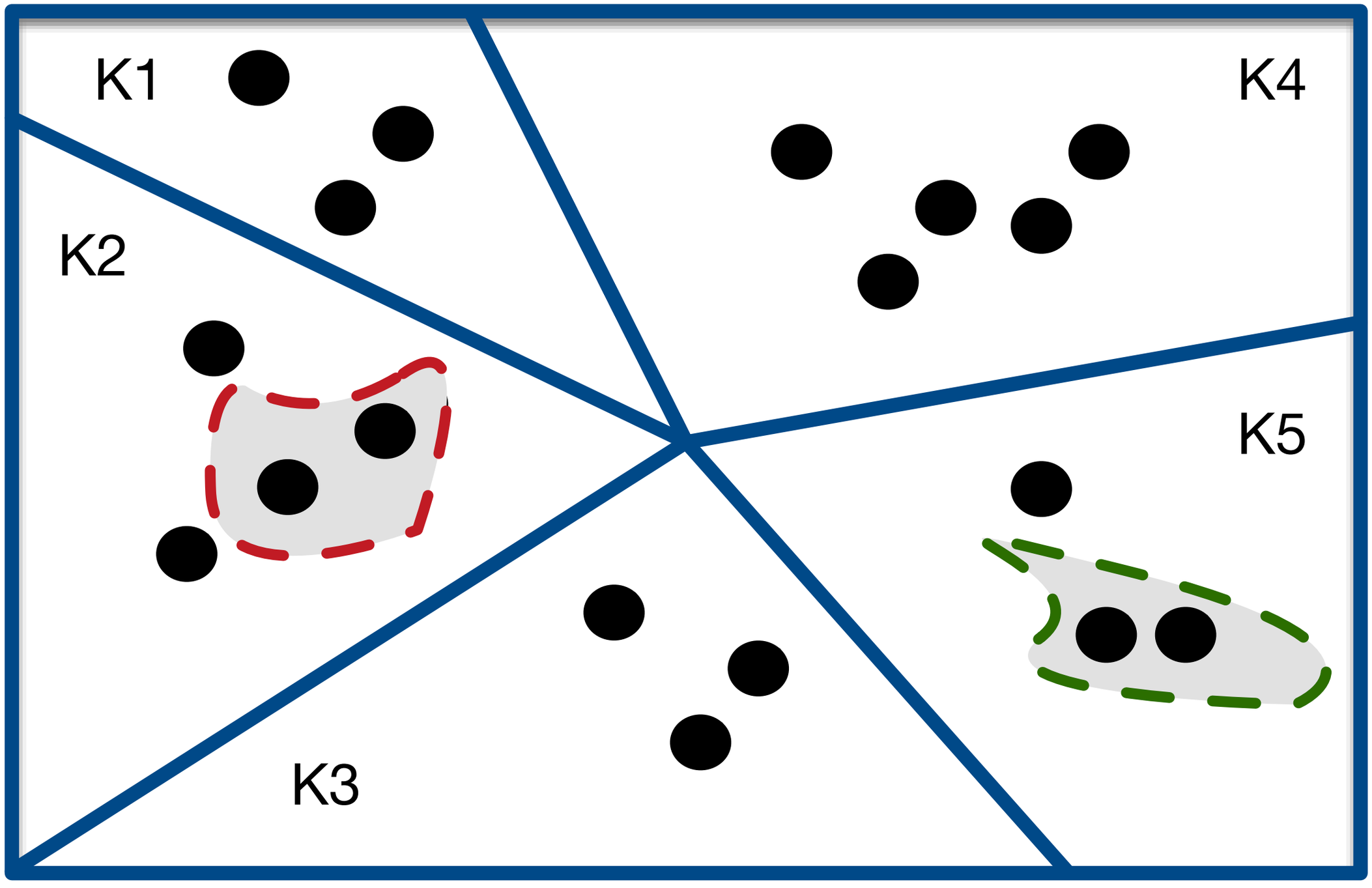


Band Member

Person

Adult Man

Living Person

Parent

British Citizen

Singer

Economist

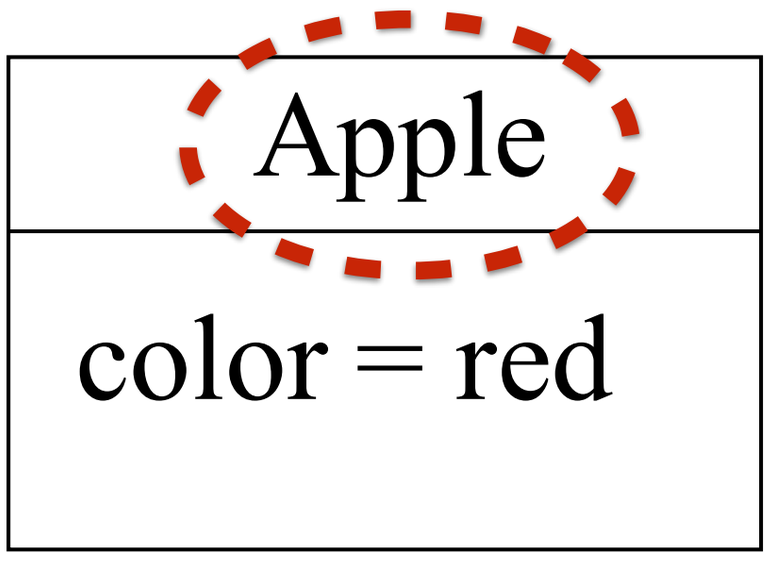
KIND = IDENTITY PROVIDER DEFINING ESSENTIAL PROPERTIES (e.g., **PERSON**)

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

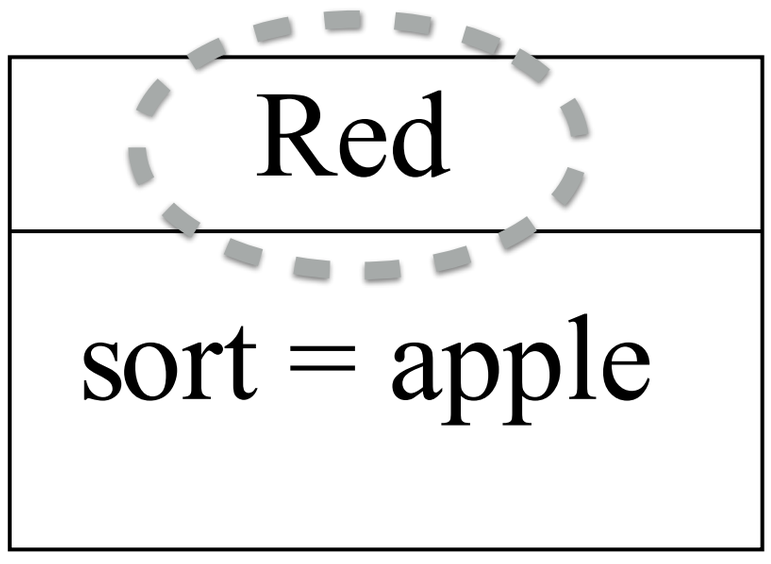
PHASE = DYNAMIC BUT NON-RELATIONAL (e.g., **LIVING PERSON, ADULT MAN**)

The **Ontological** Level

SORTAL



MIXIN



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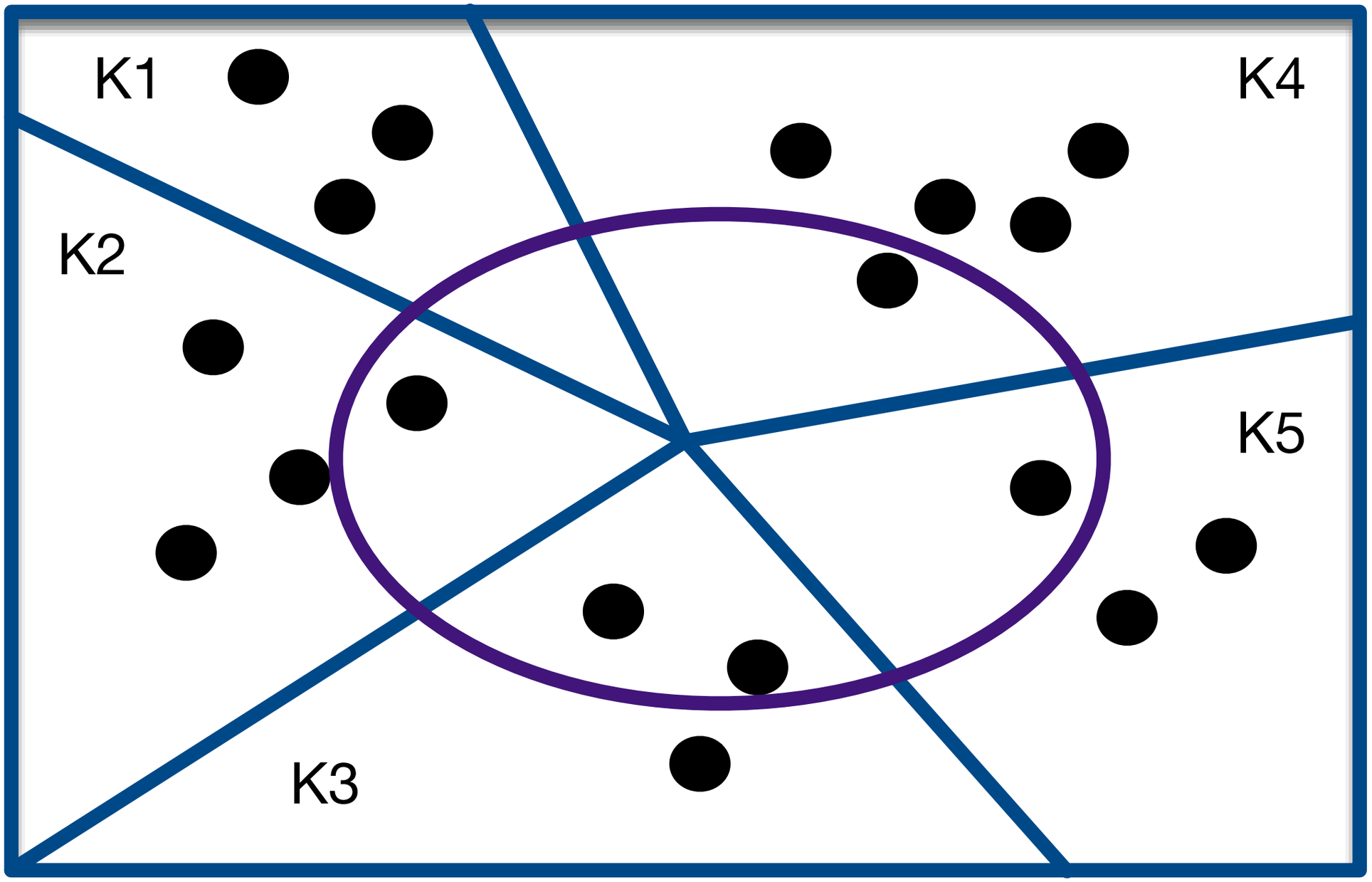
ROLE = DYNAMIC + RELATIONAL (e.g., **SINGER, ECONOMIST, BRITISH CITIZEN, KNIGHT OF THE BRITISH EMPIRE**)

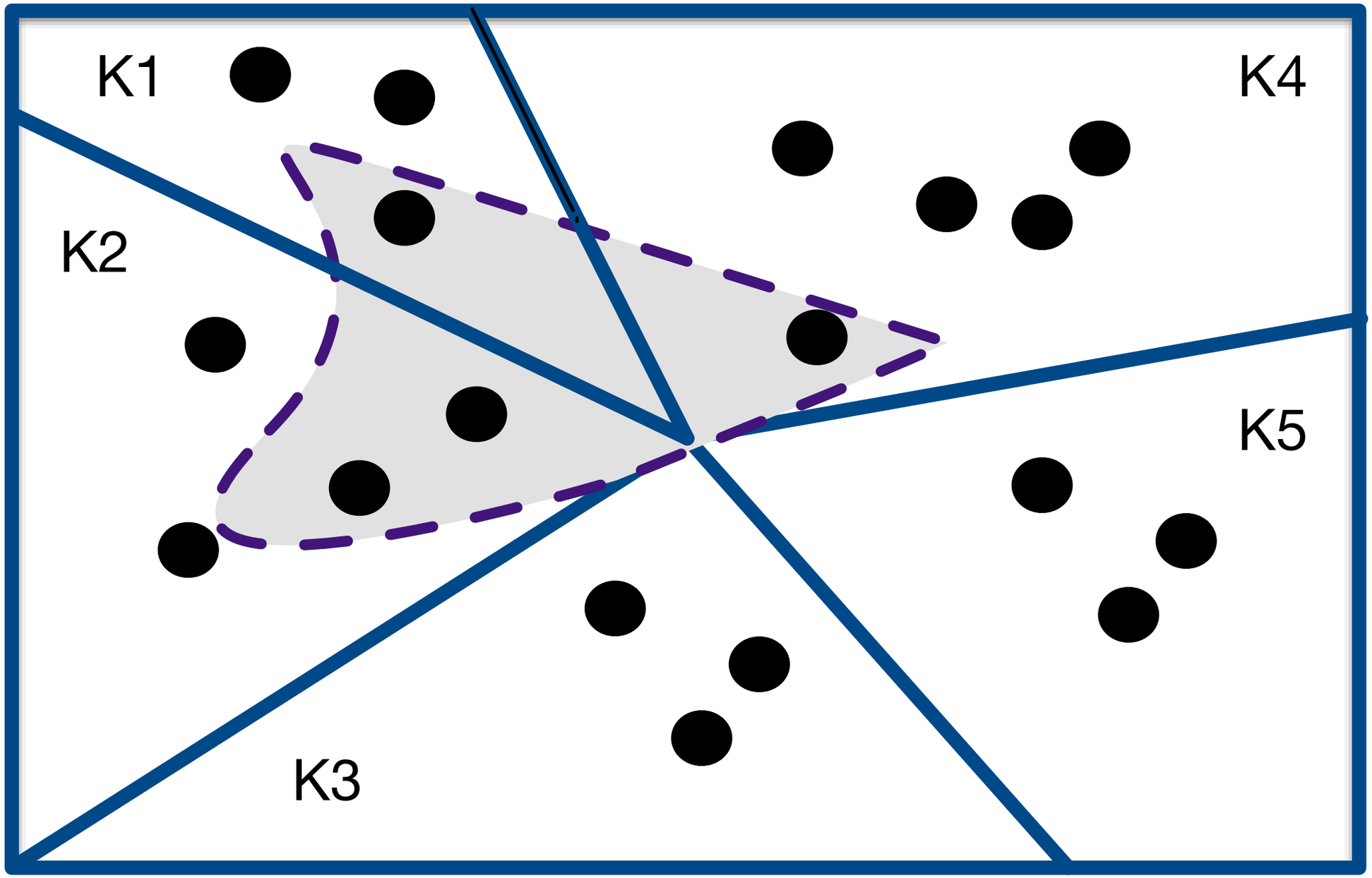
PHASE = DYNAMIC BUT NON-RELATIONAL (e.g., **LIVING PERSON, ADULT MAN**)

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

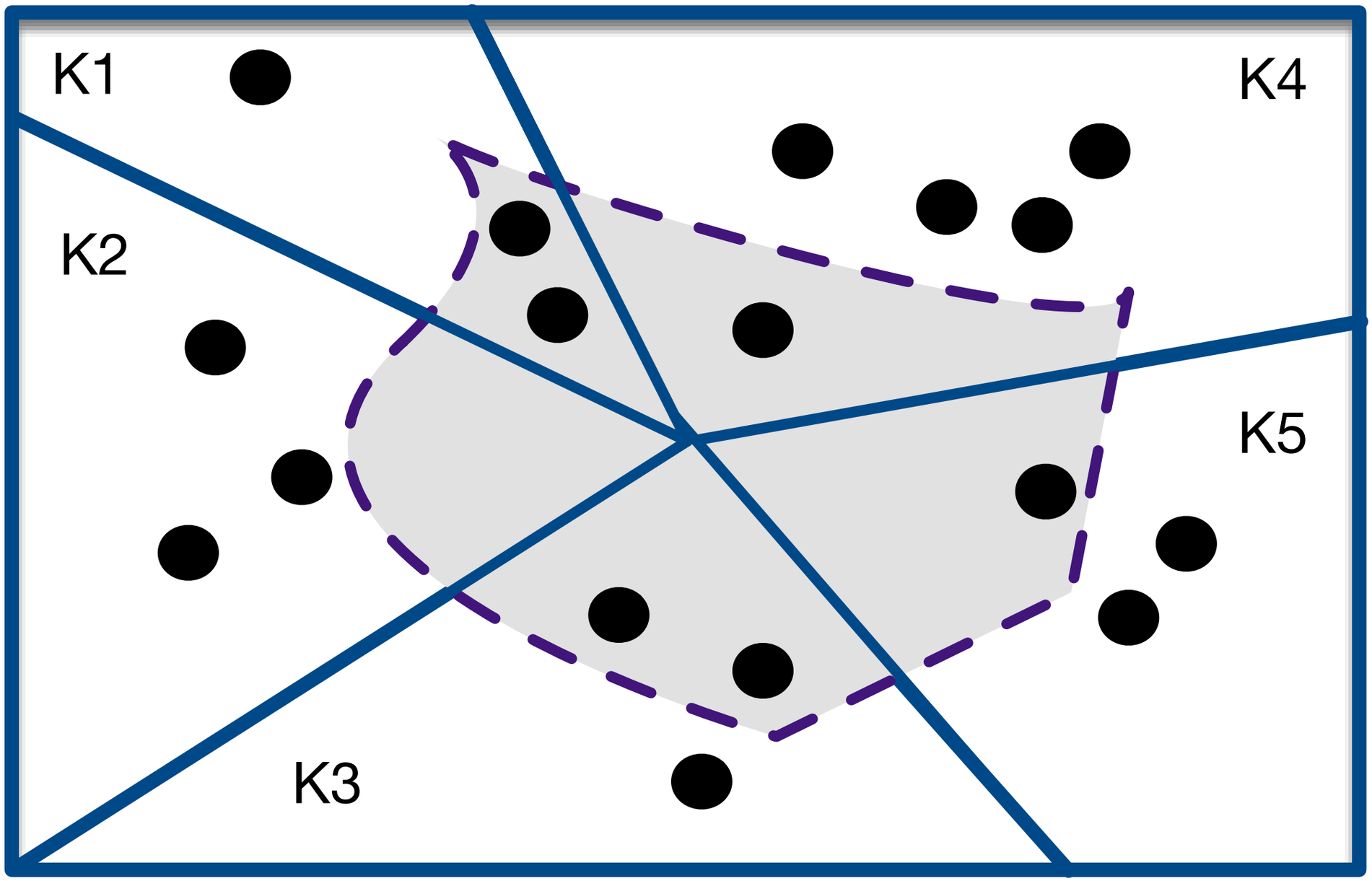
Mixin

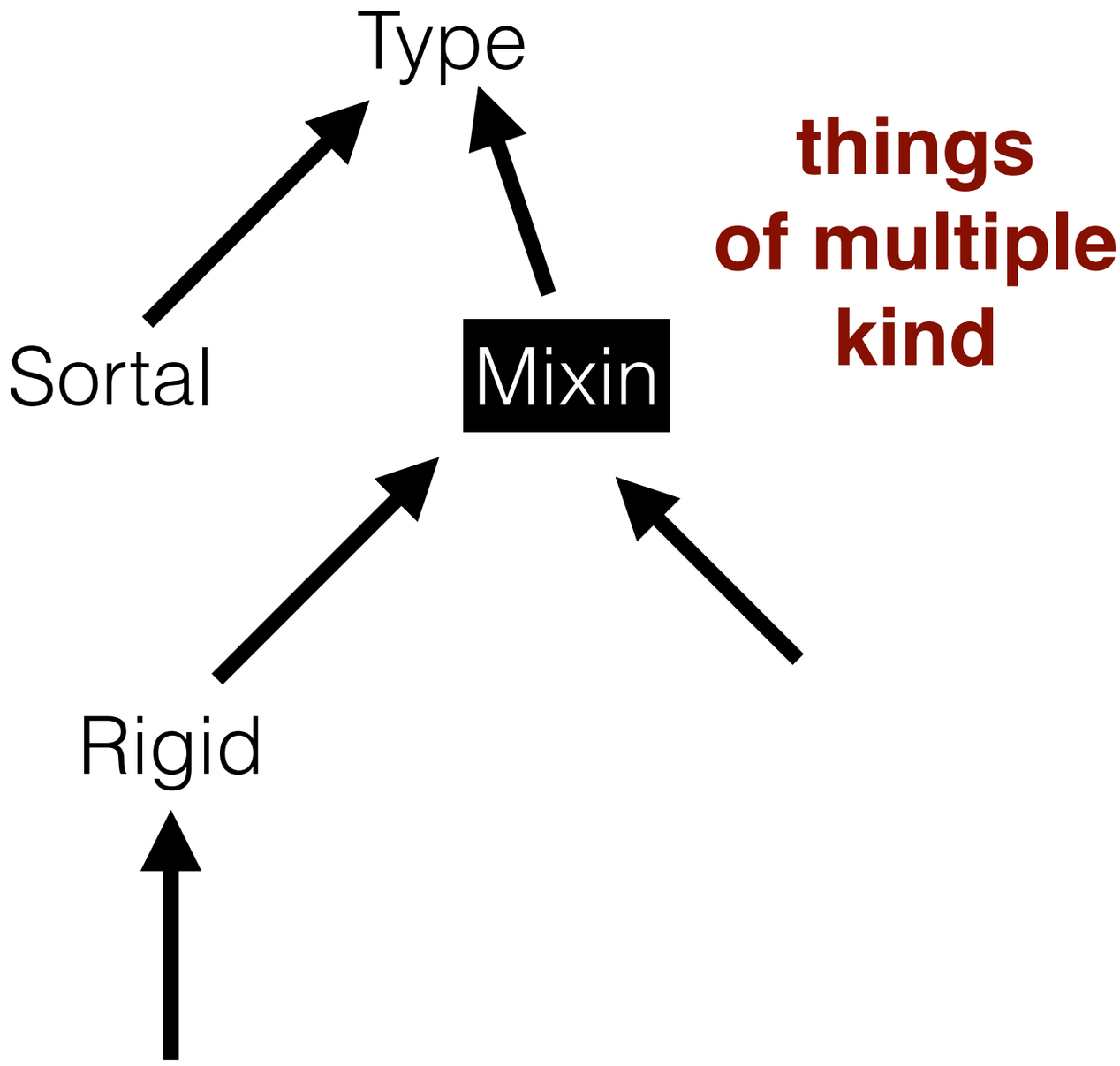


Anti-Rigid Mixin



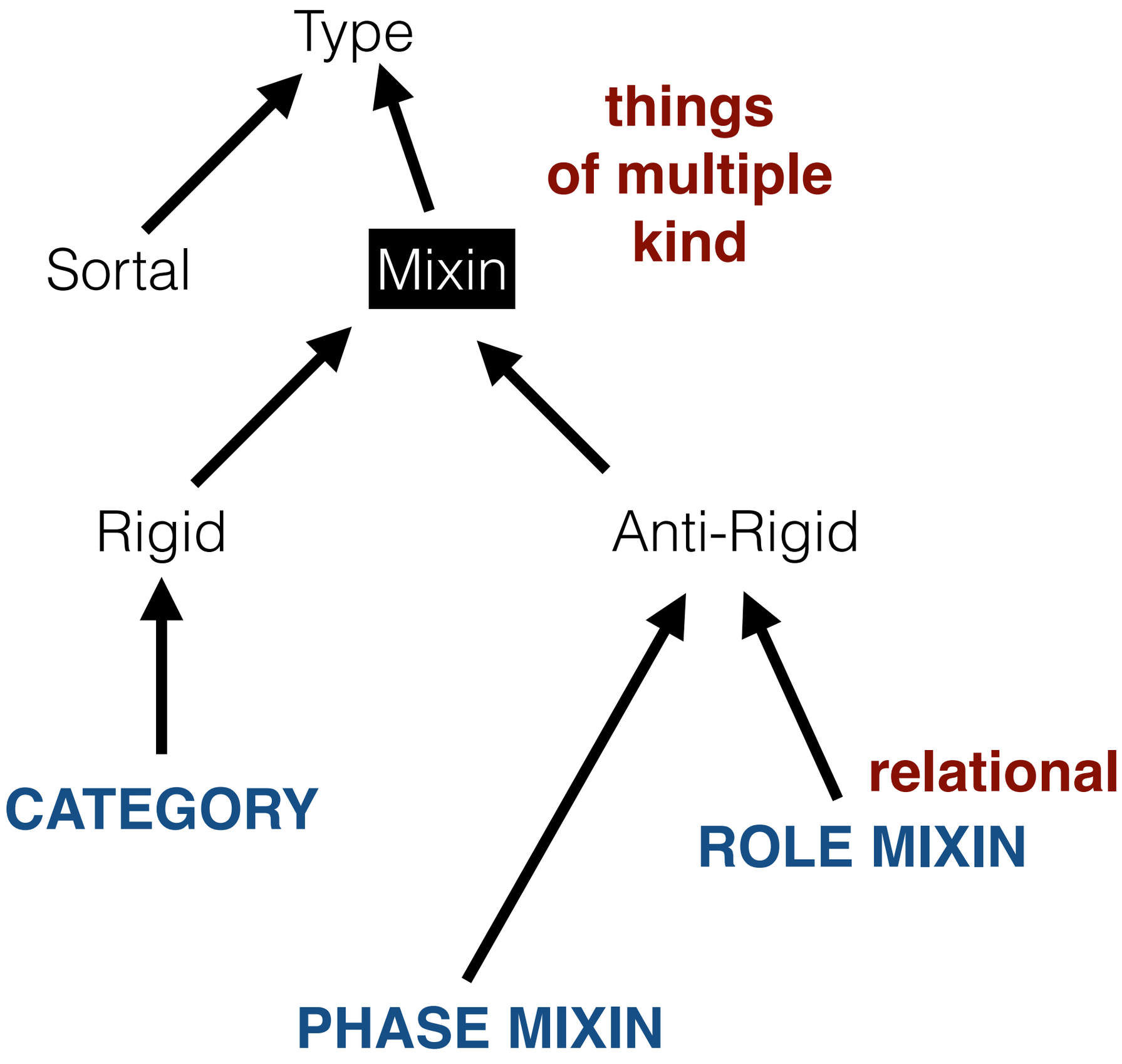
Anti-Rigid Mixin



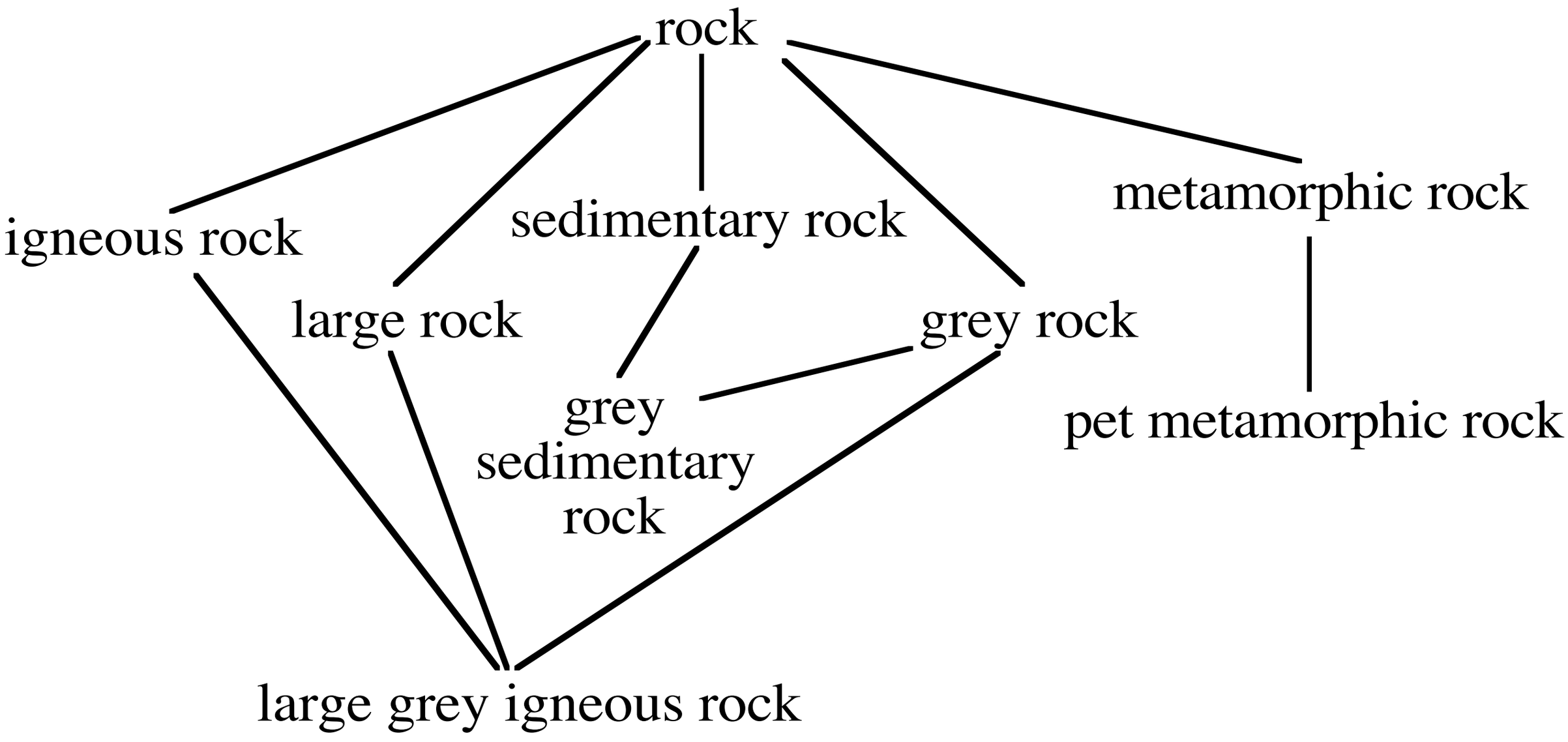


things of multiple kind

CATEGORY


Type
Sortal
Mixin
things
of multiple
kind
Rigid
Anti-Rigid
CATEGORY
relational
ROLE MIXIN
PHASE MIXIN

How many kinds of rock?



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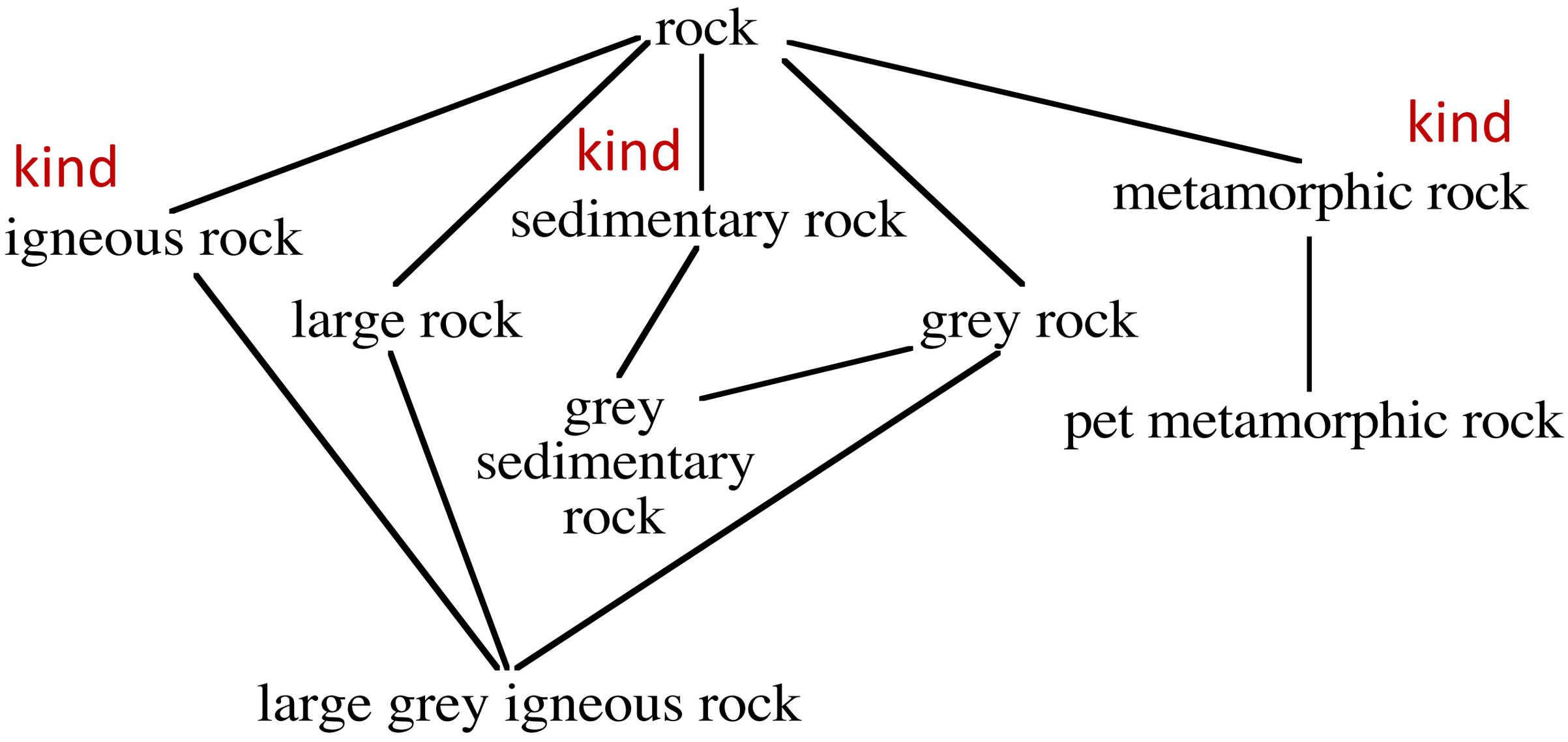

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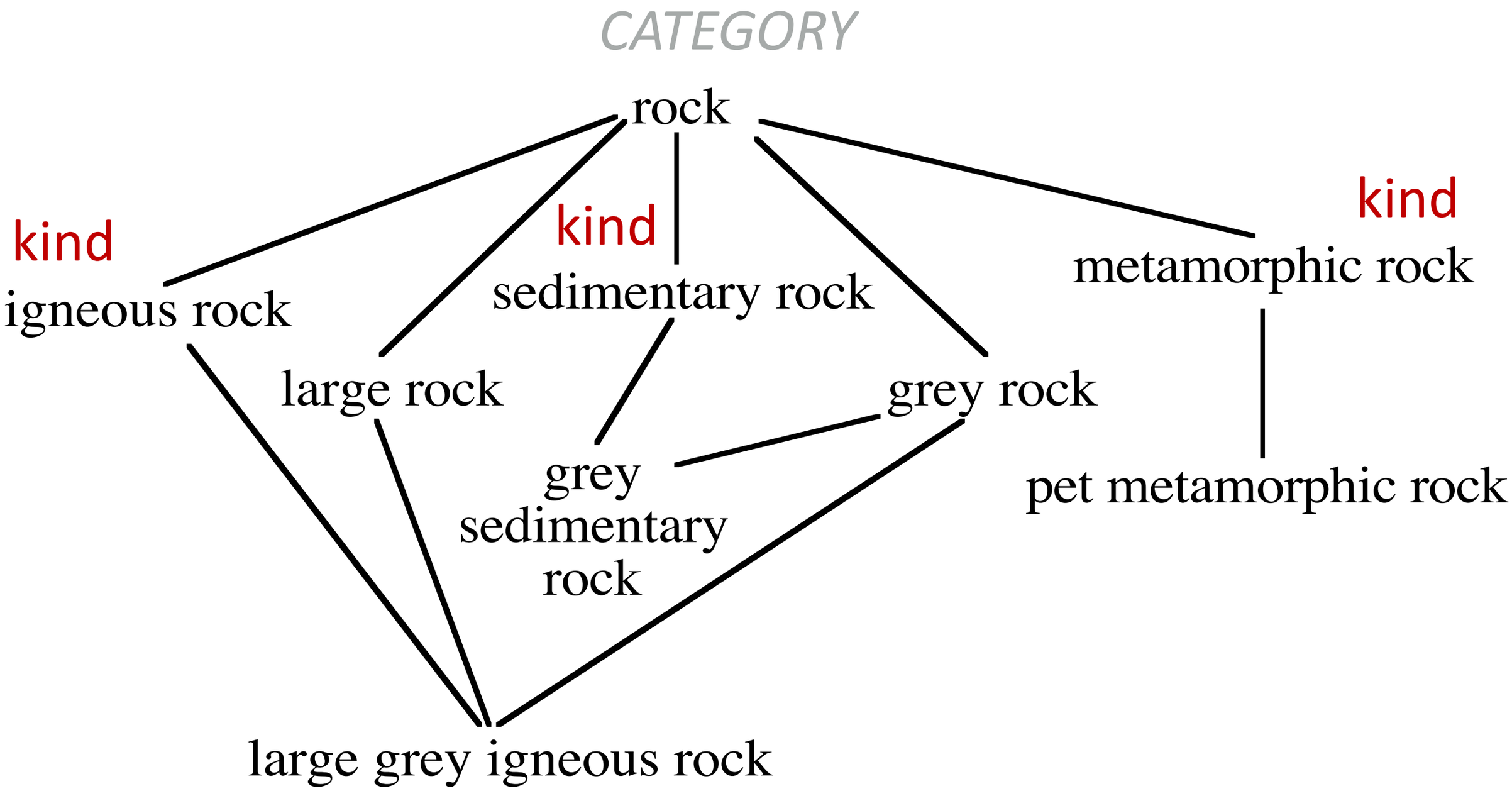

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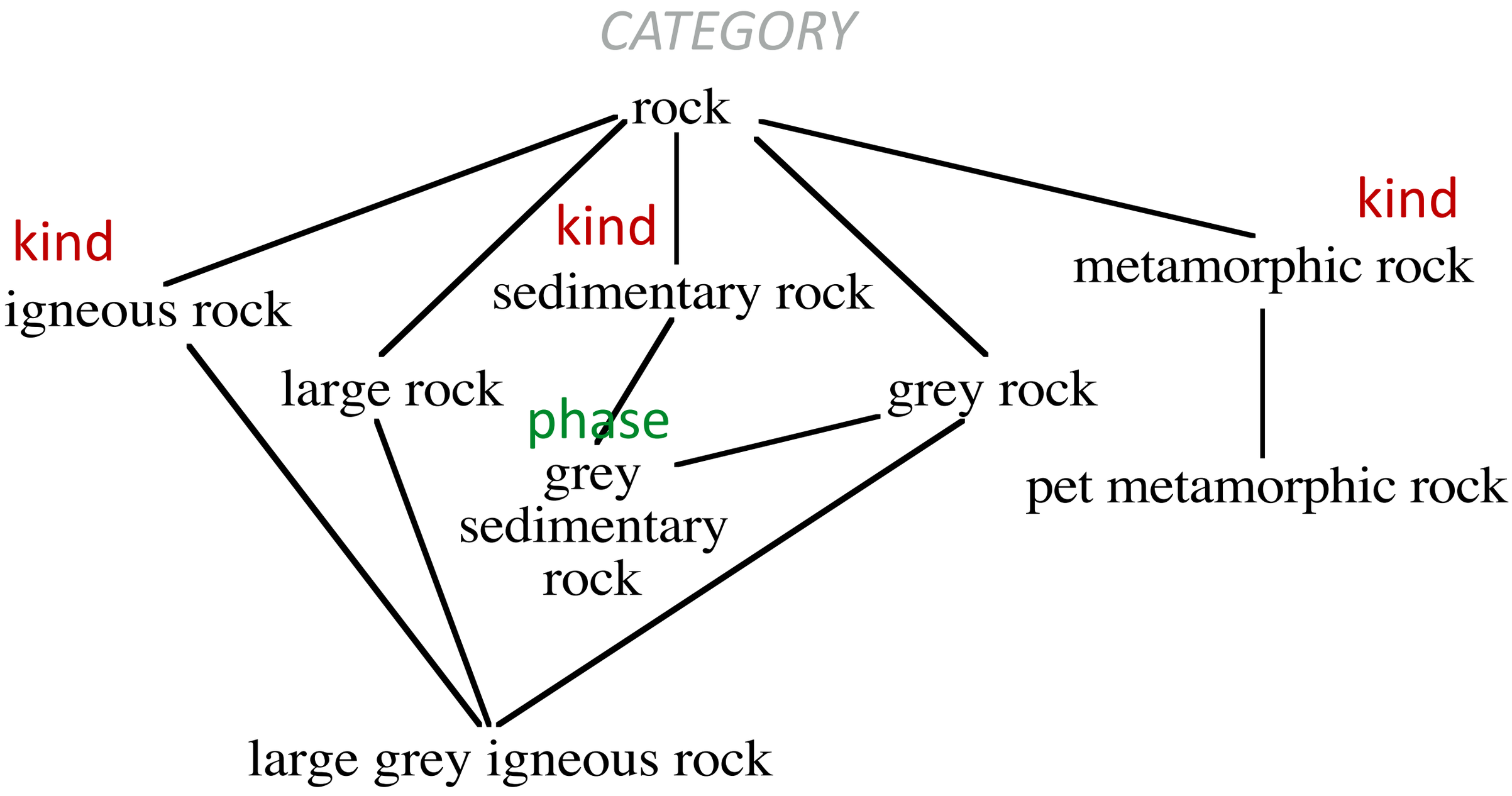

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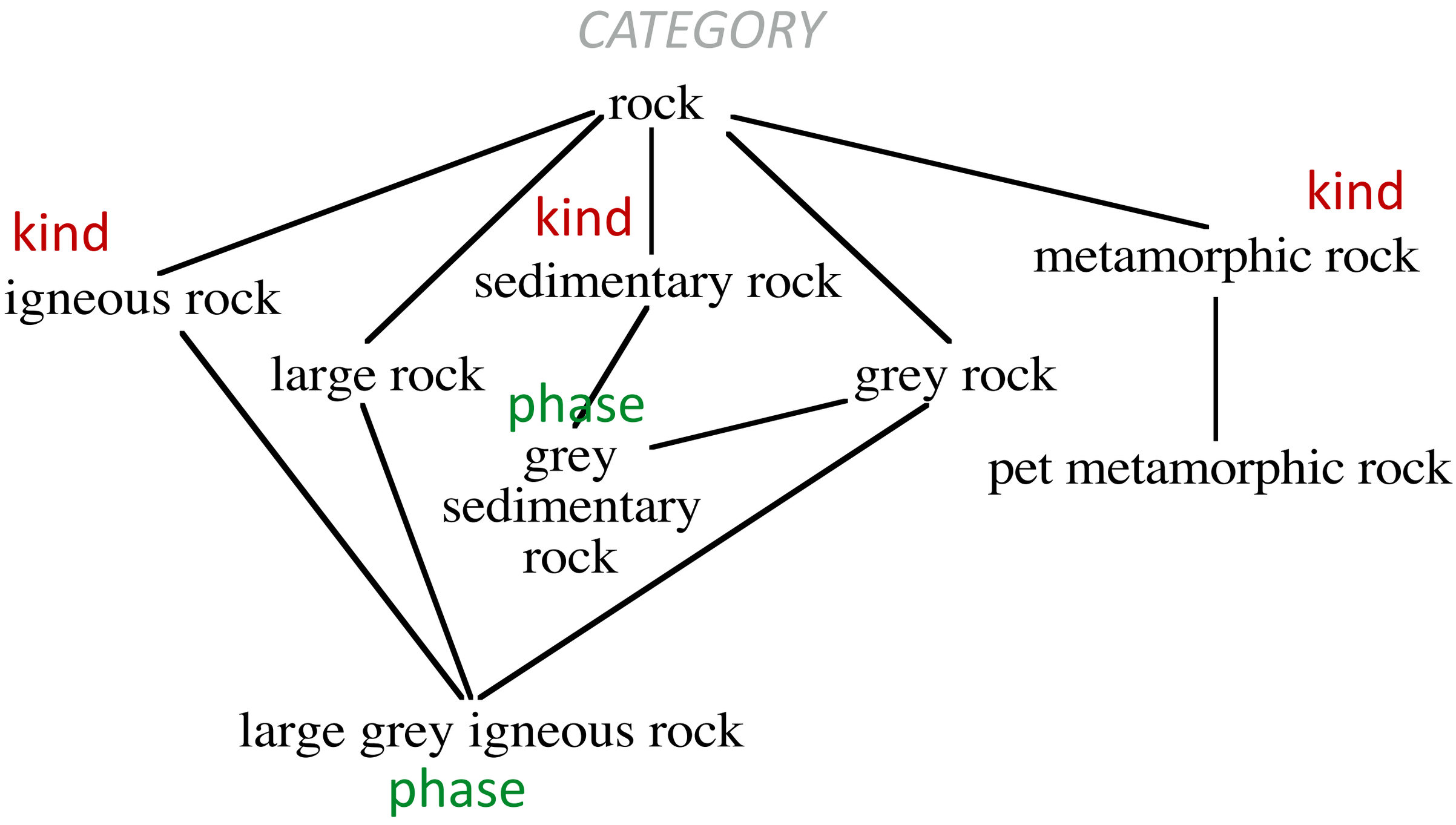

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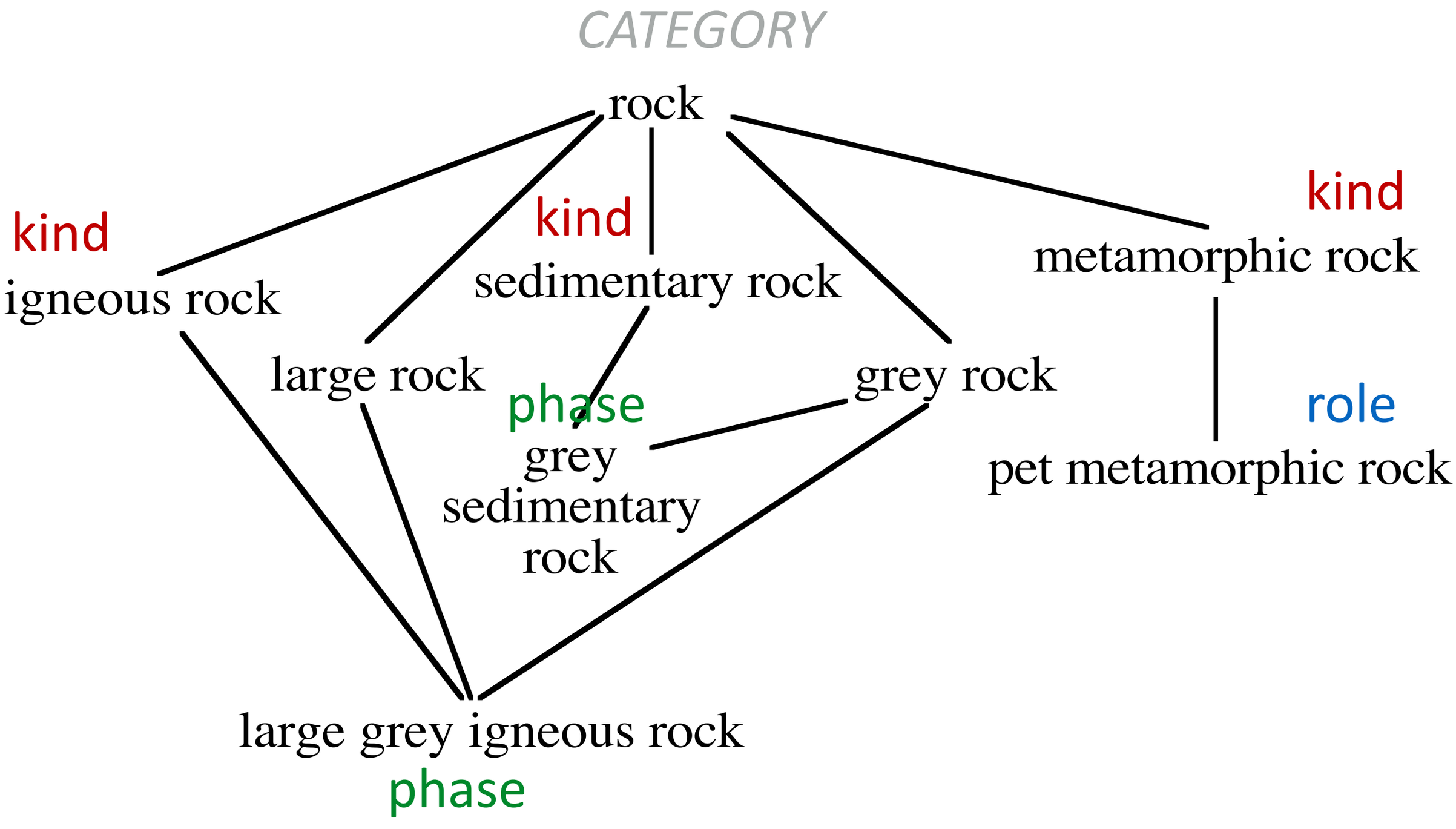
How many kinds of rock?



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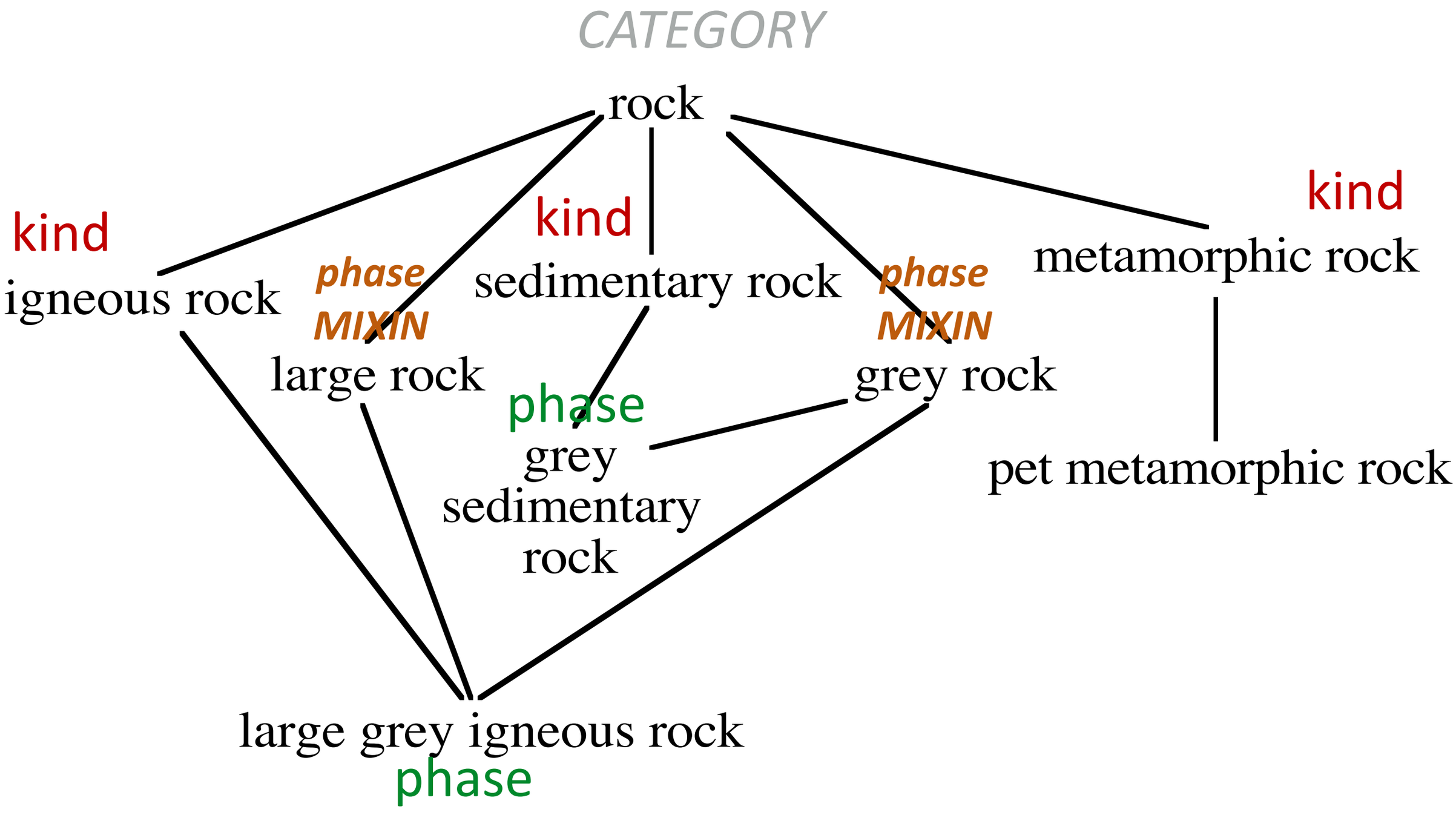
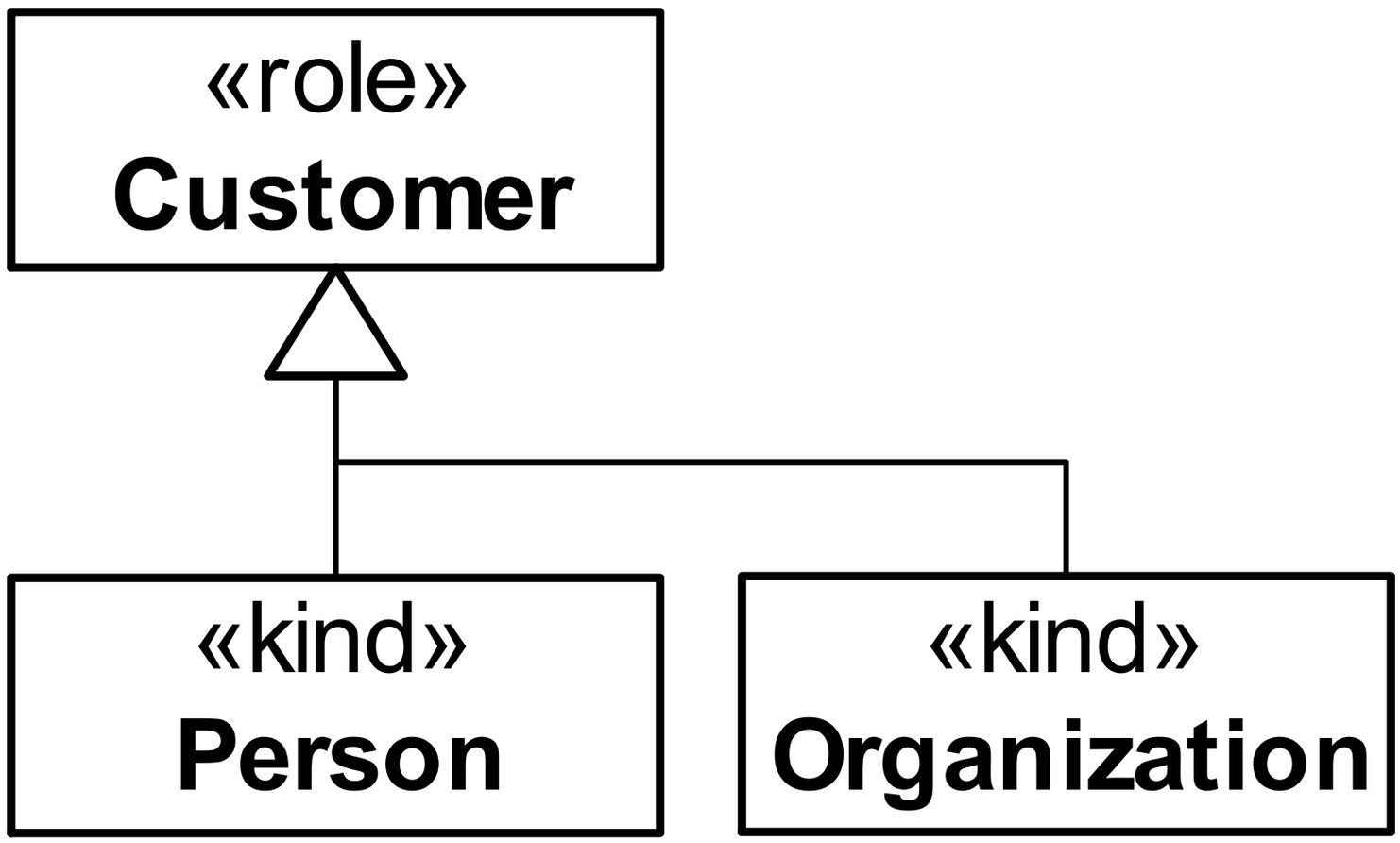


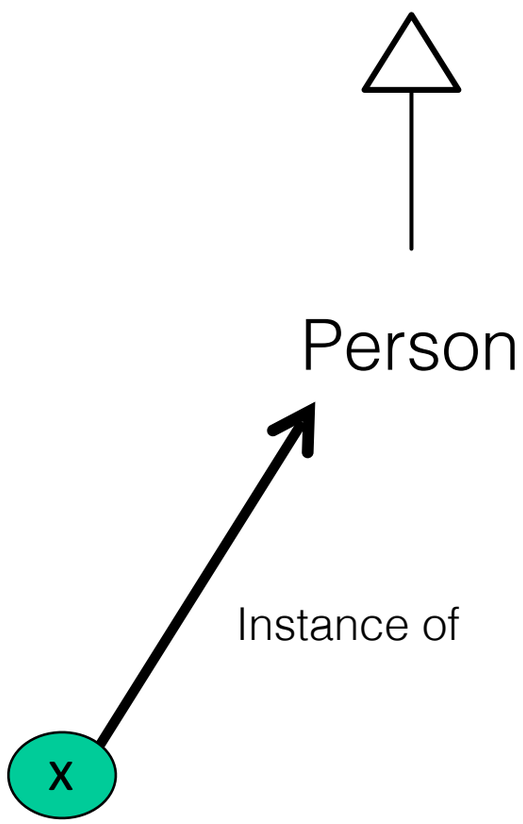
Brachman, Fikes and Levesque, 1985

A Classic **Problem**

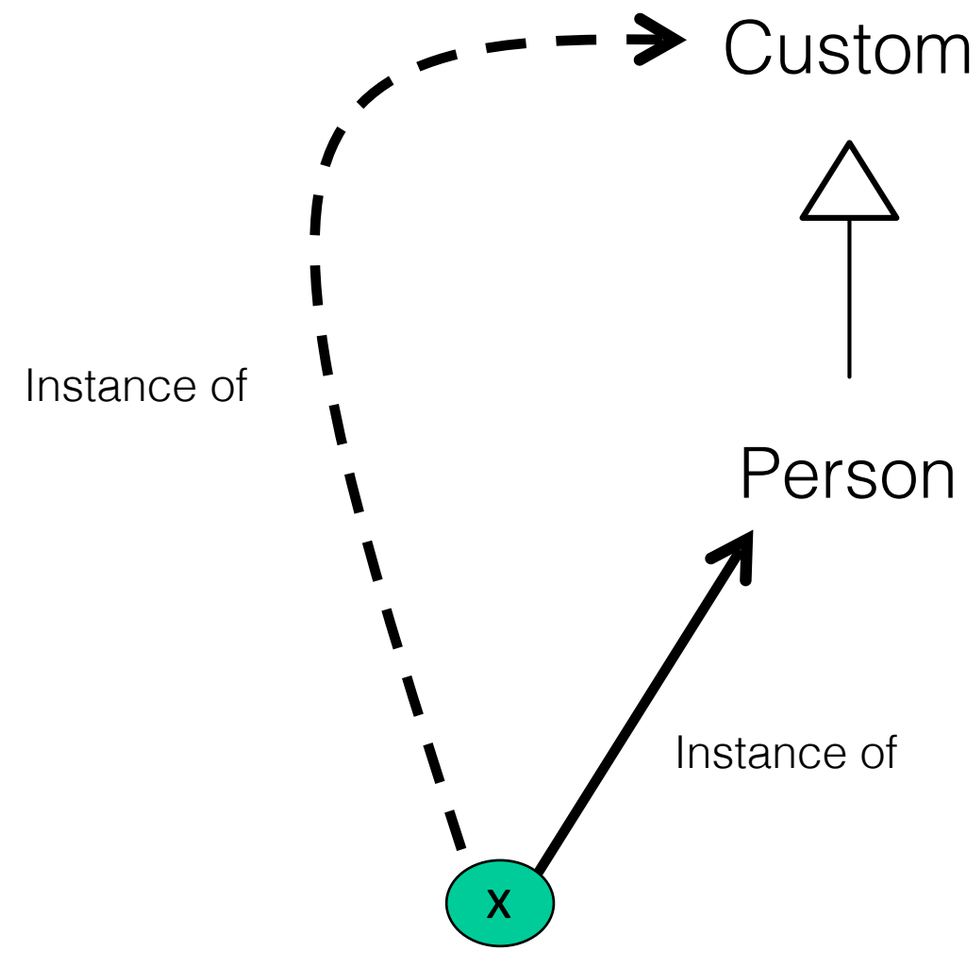
Suppose that I want to represent that the ROLE Customer can be played by entities of different KINDS, namely, People and Organizations. How to relate the ROLE and its *allowed types* using subtyping relations?


«role»
Customer
«kind»
Person
«kind»
Organization

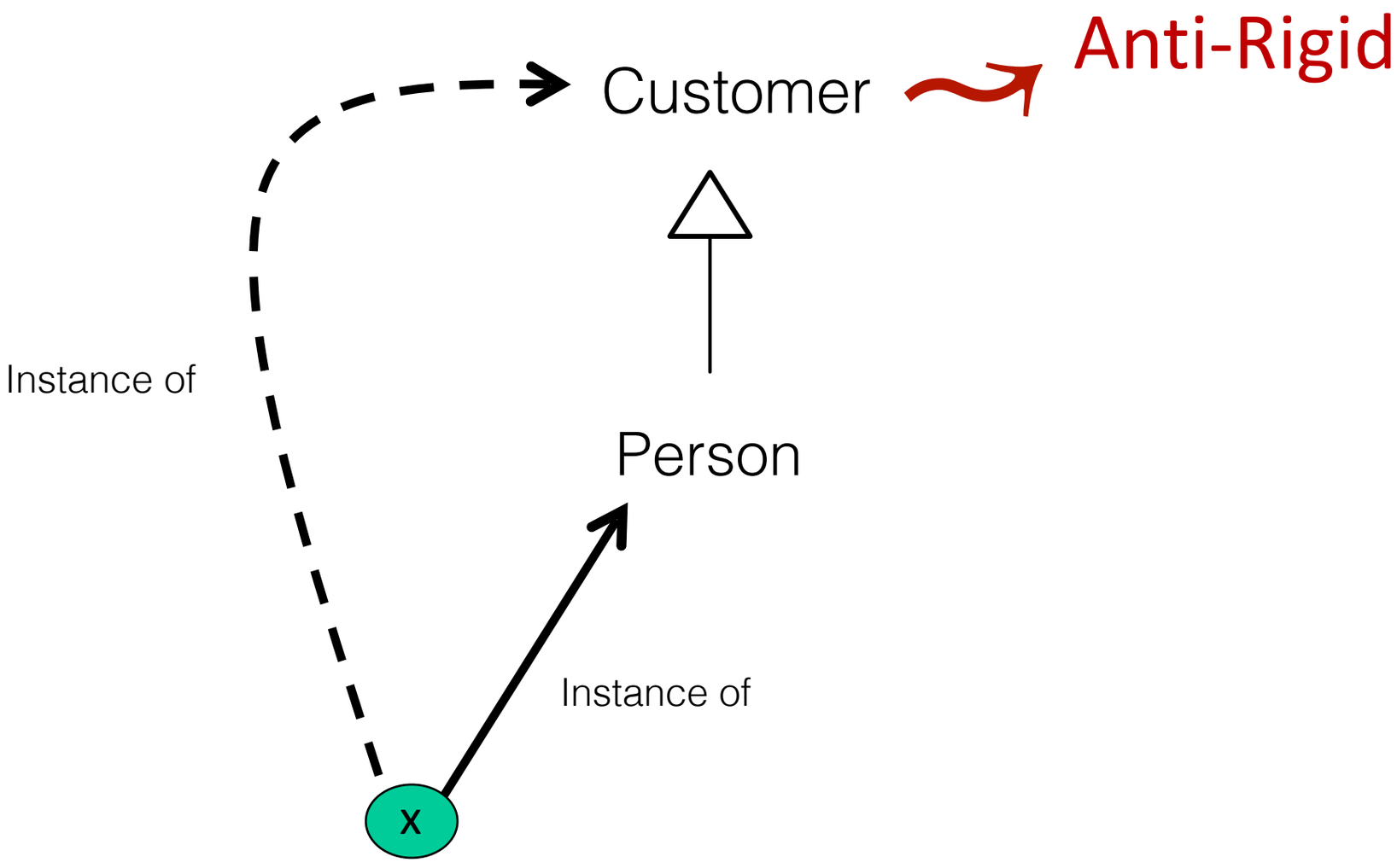
WORLD W



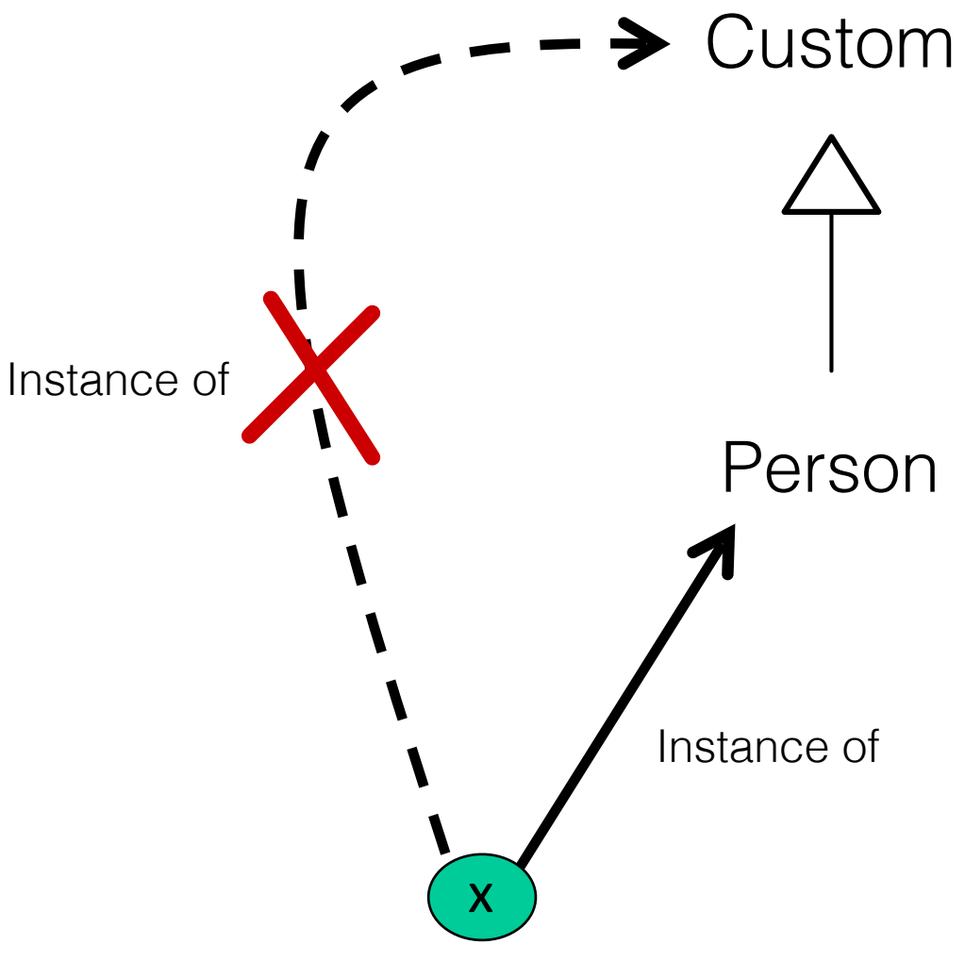
WORLD W



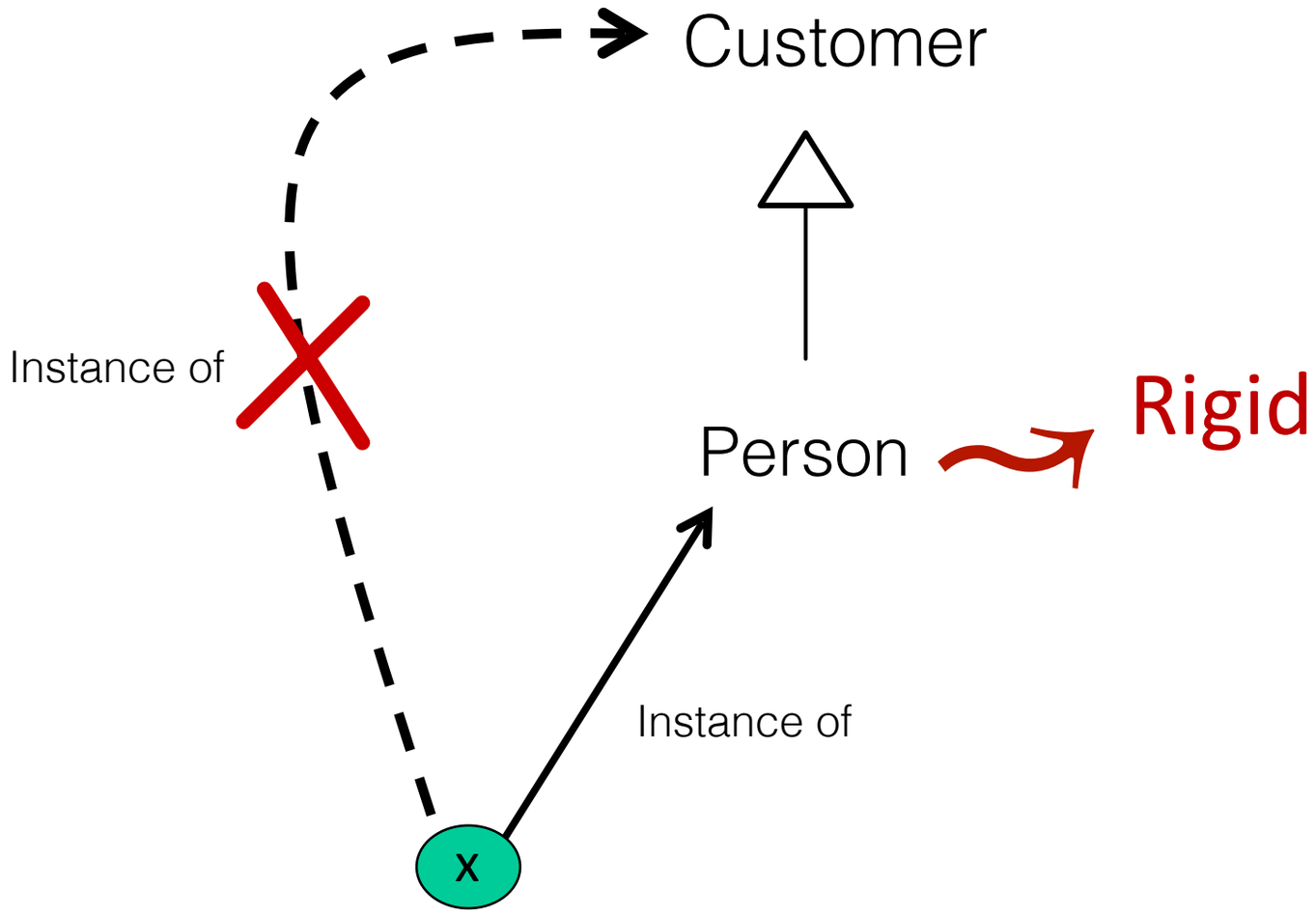
WORLD W



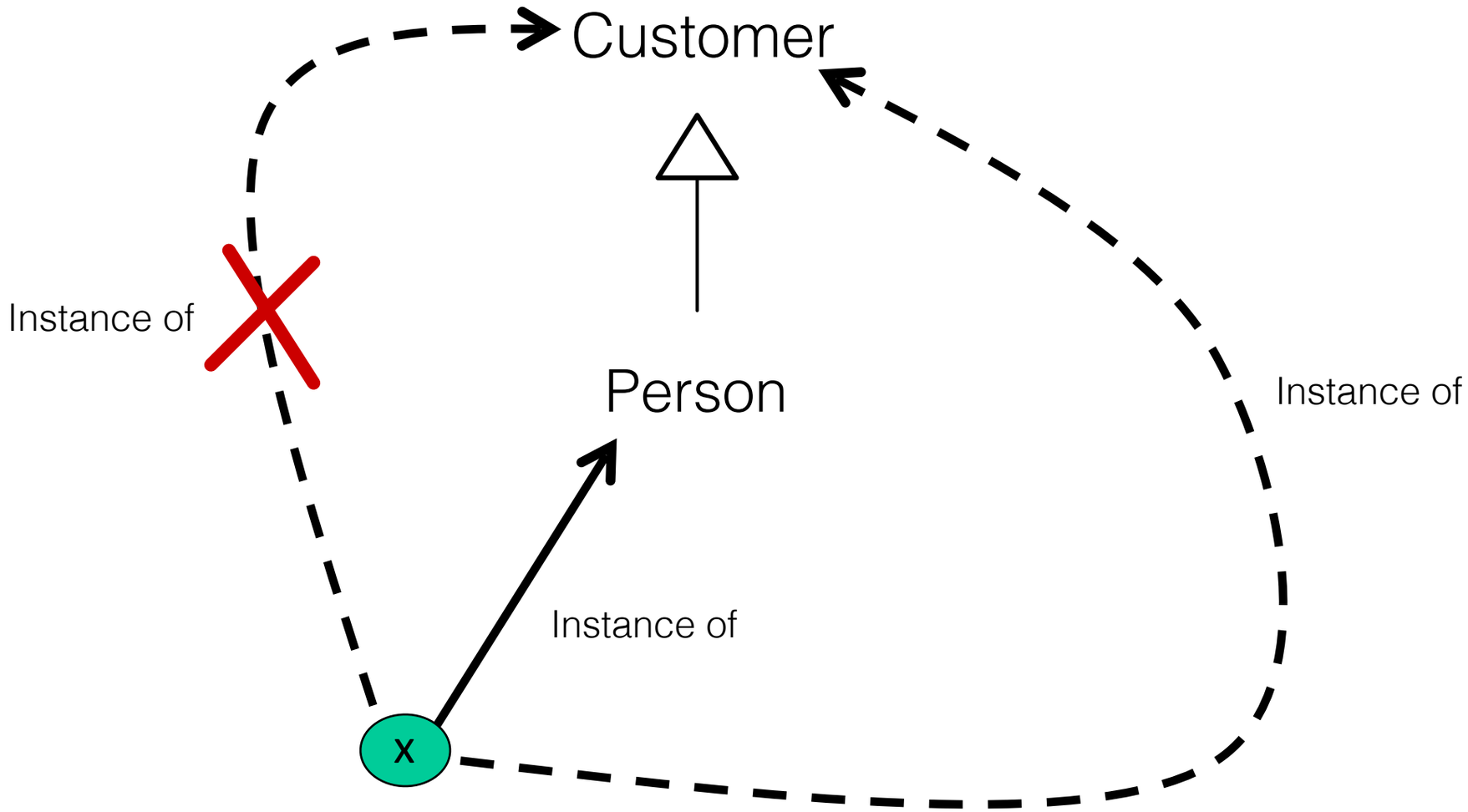
WORLD W’



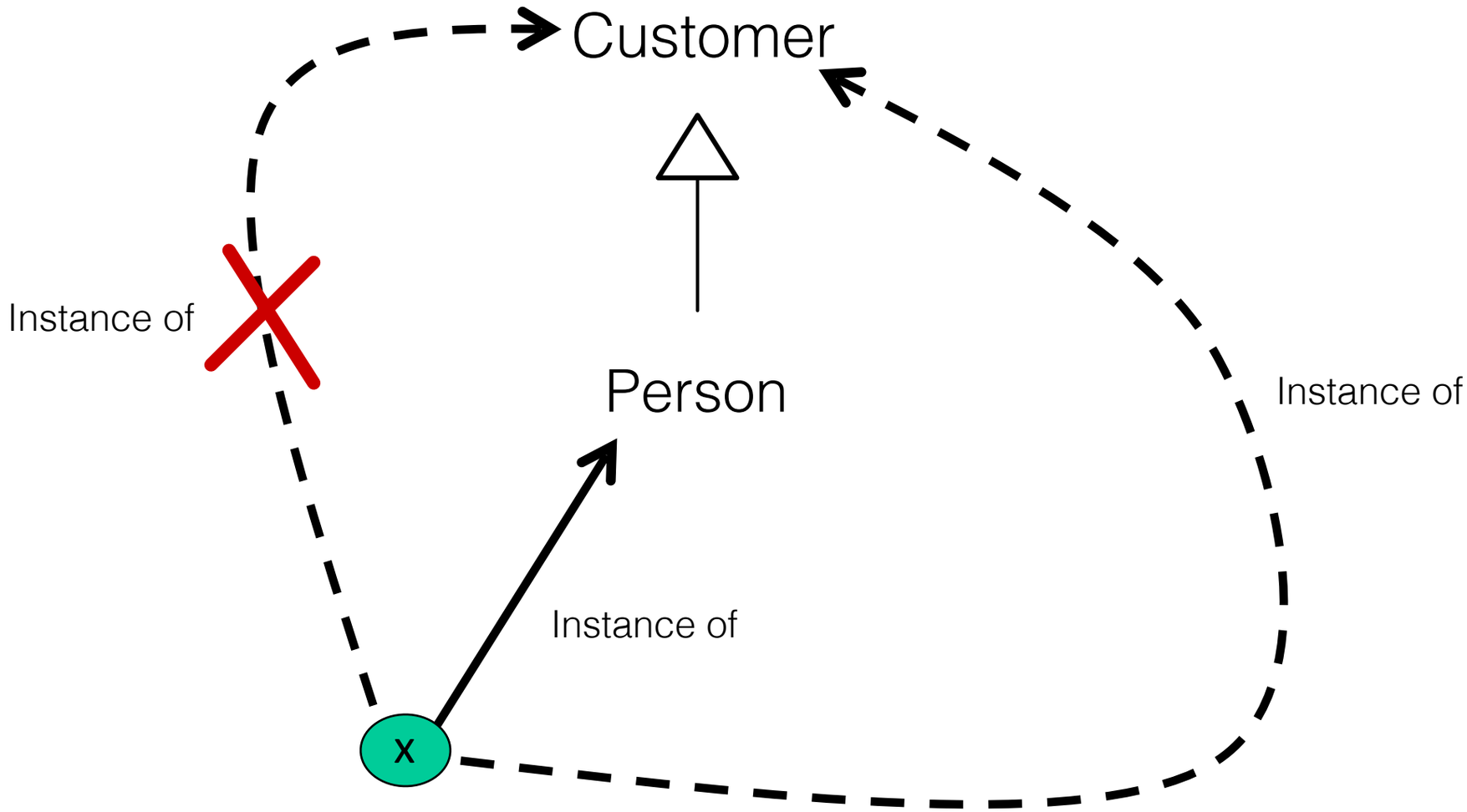
WORLD W’



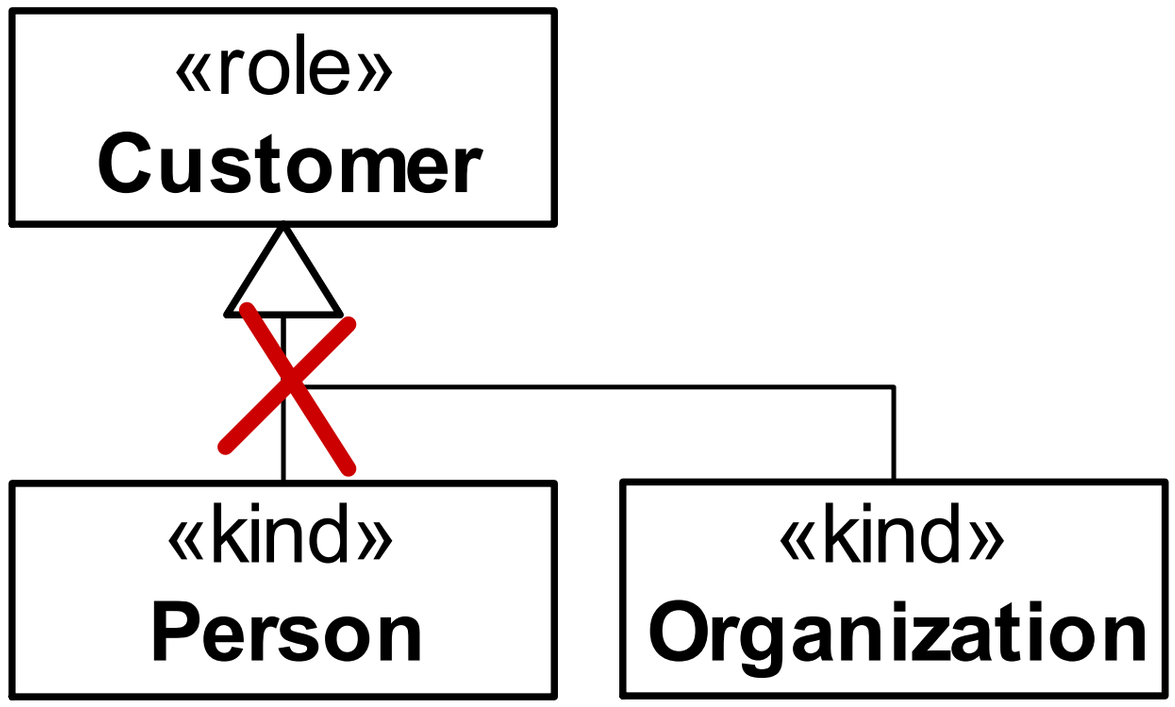
WORLD W’



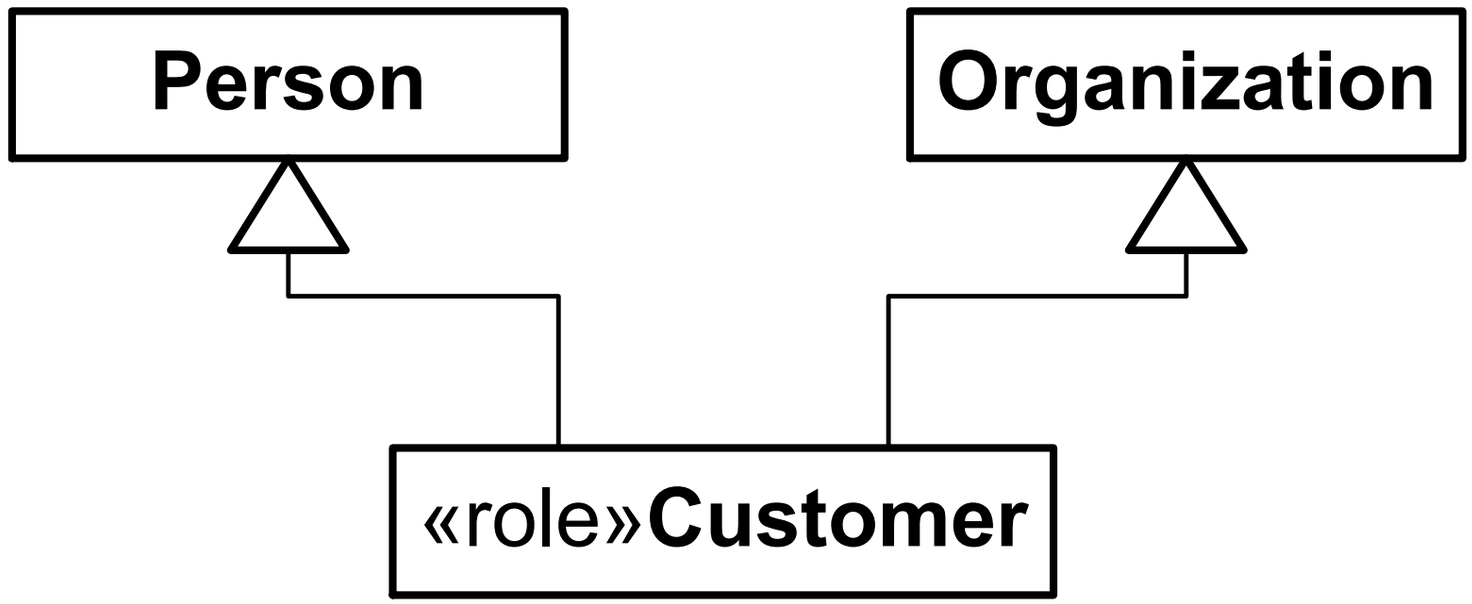
WORLD W’



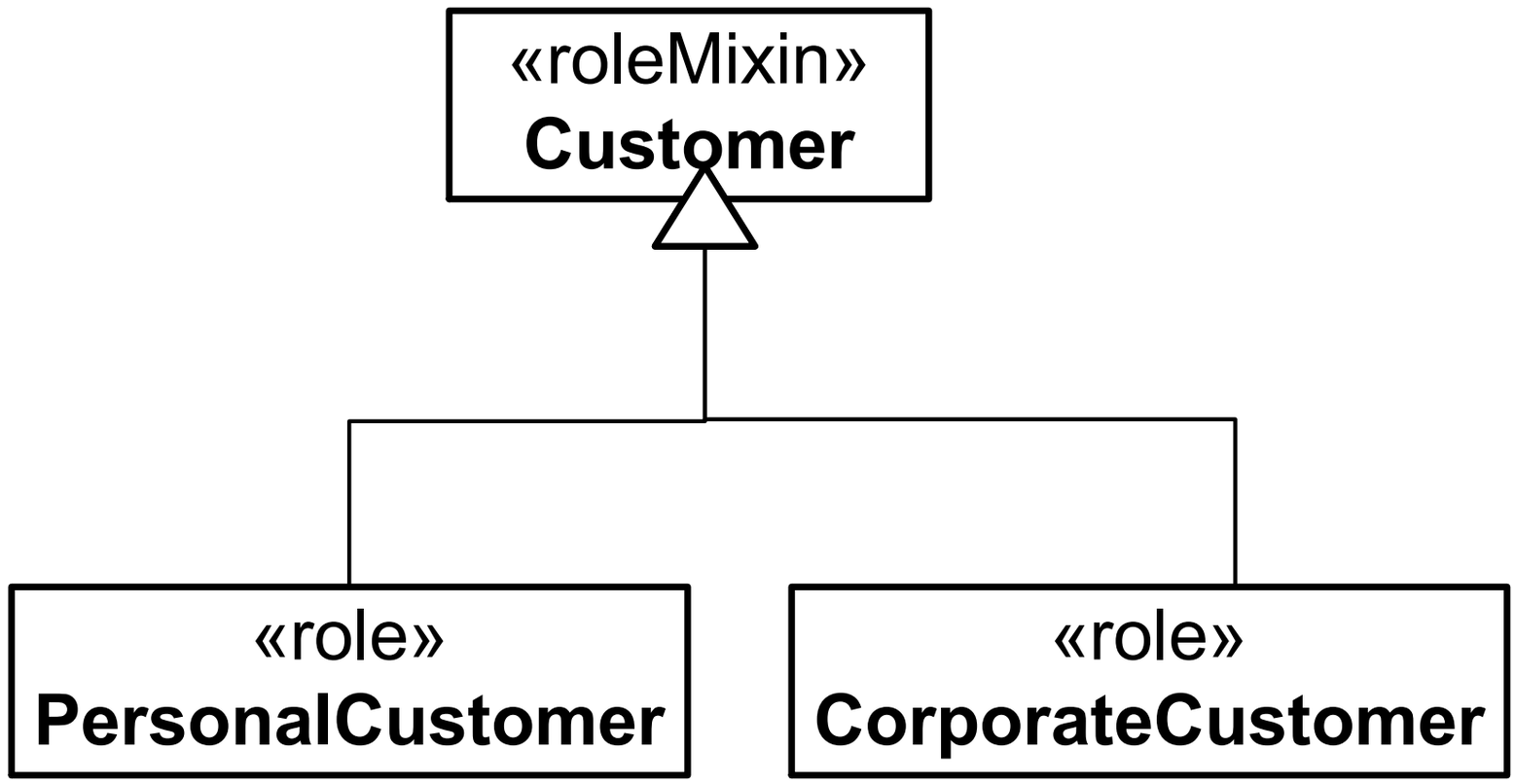
We run into a logical contradiction!

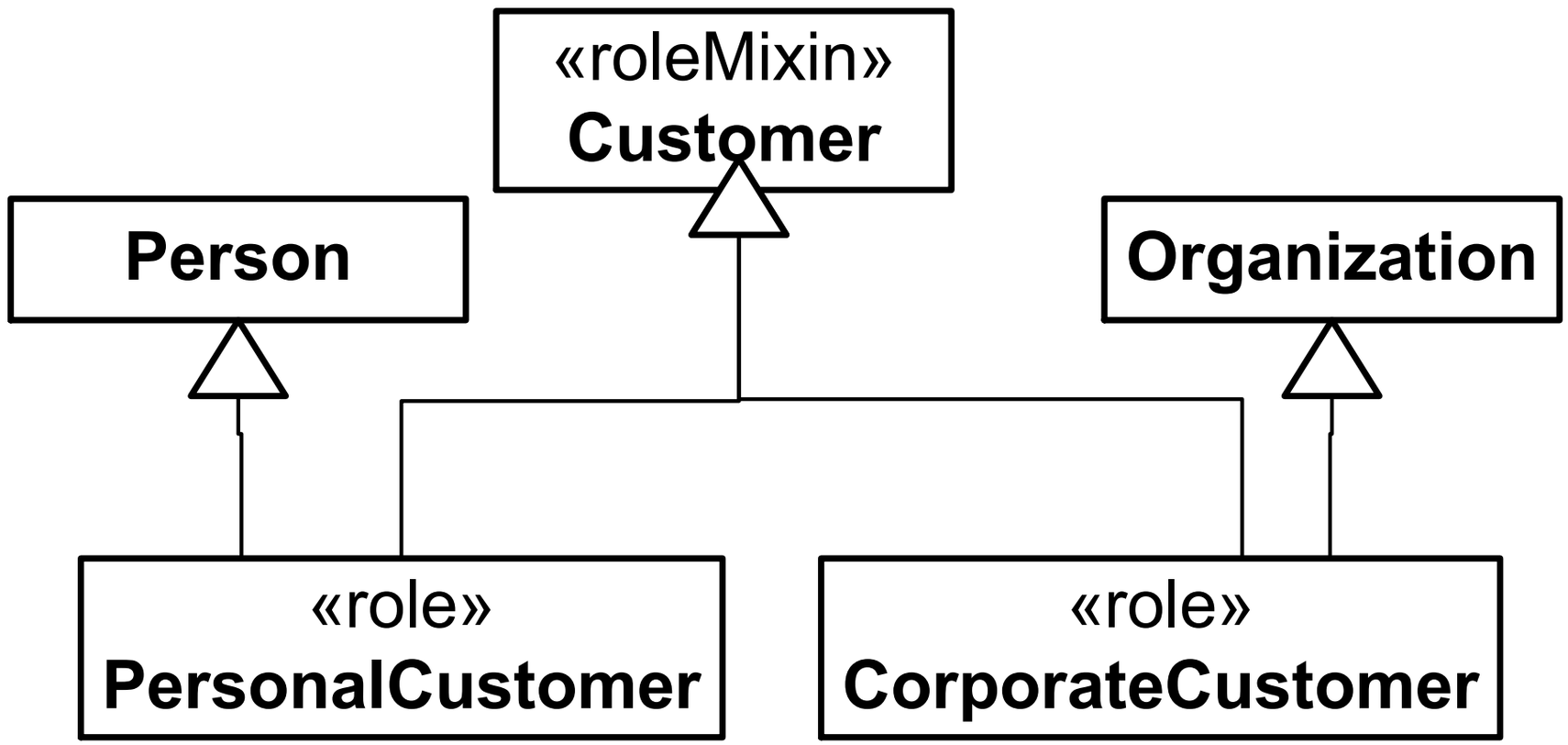

«role»
Customer
«kind»
Person
«kind»
Organization

A Possible **Alternative**?



«roleMixin»
Customer

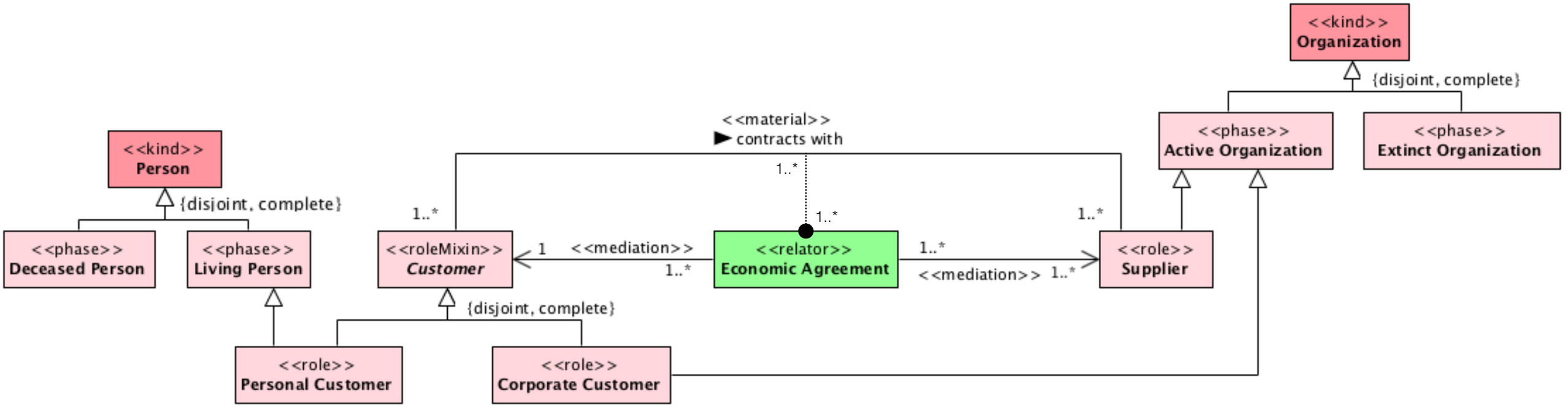

«roleMixin»
Customer
«role»
PersonalCustomer
«role»
CorporateCustomer

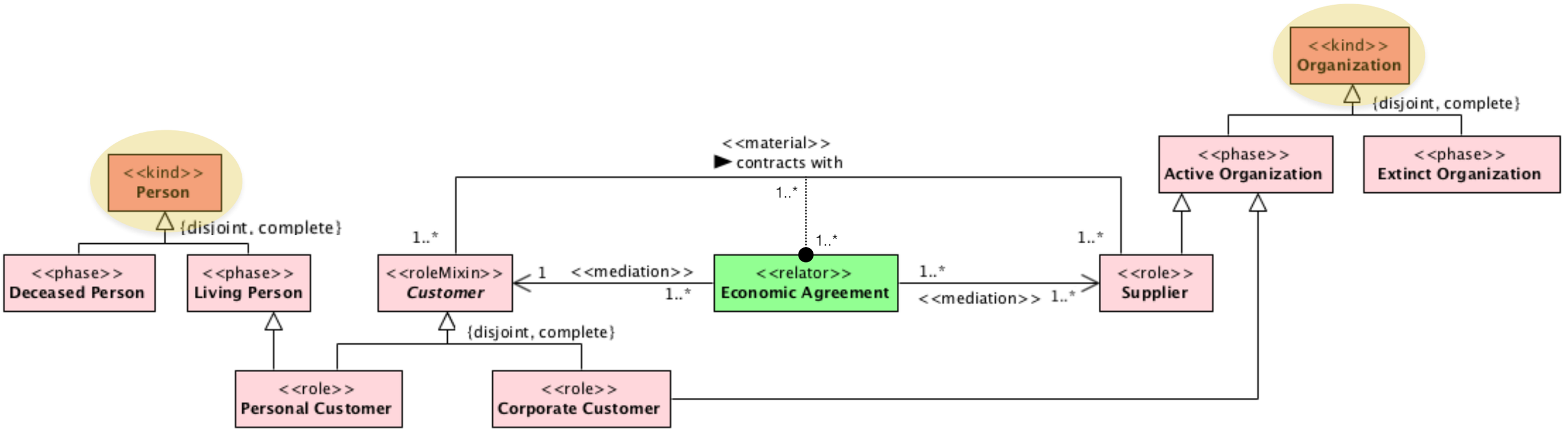

«roleMixin»
Customer
Person
Organization
«role»
PersonalCustomer
«role»
CorporateCustomer

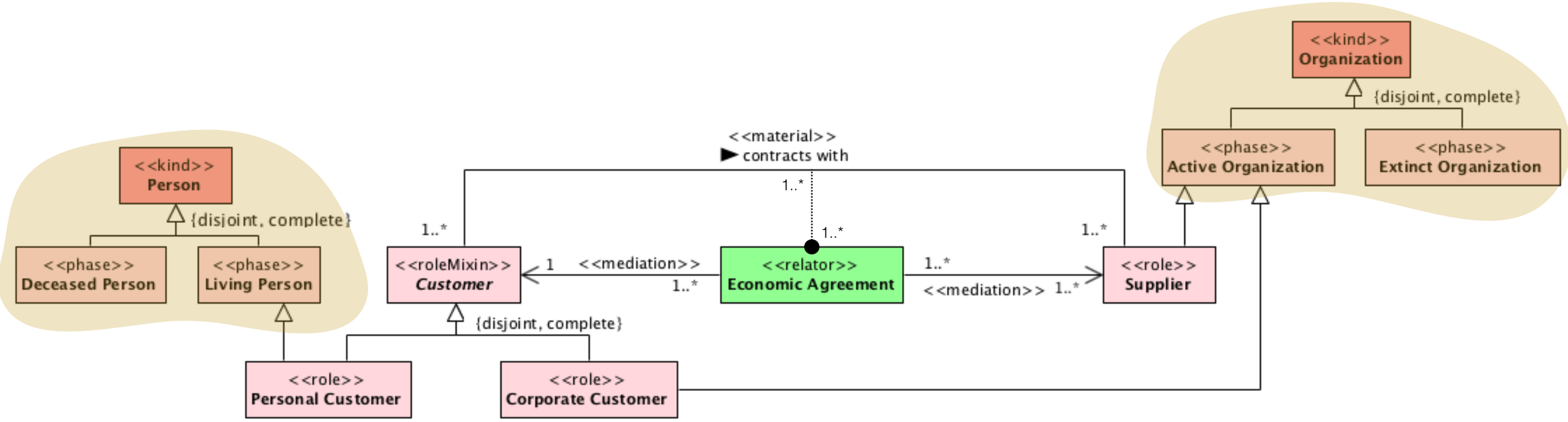
1. **Primitives** reflecting ontological **distinctions**

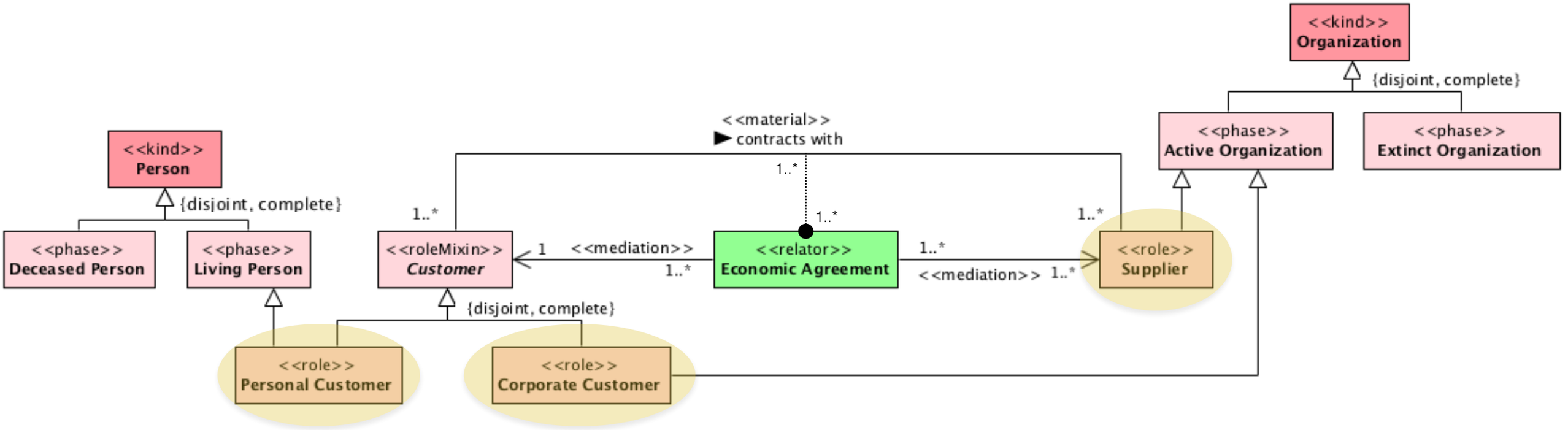
2. **Grammar** reflecting ontological **axiomatization**

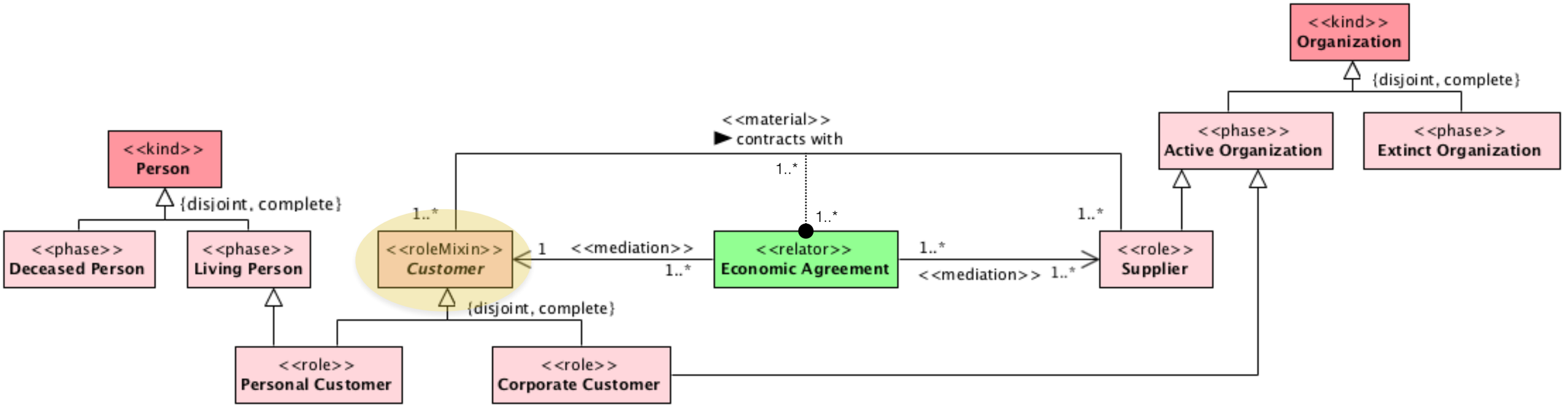
3. **Patterns** reflecting ontological **micro-theories**


<<kind>>
Organization
{disjoint, complete}
<<phase>>
Active Organization
<<phase>>
Extinct Organization
<<material>>
contracts with
1..*
1..*
1..*
1..*
<<kind>>
Person
{disjoint, complete}
<<phase>>
Deceased Person
<<phase>>
Living Person
<<roleMixin>>
Customer
1
<<mediation>>
1..*
<<relator>>
Economic Agreement
1..*
<<mediation>>
1..*
<<role>>
Supplier
{disjoint, complete}
<<role>>
Personal Customer
<<role>>
Corporate Customer


<<kind>>
Organization
{disjoint, complete}
<<phase>>
Active Organization
<<phase>>
Extinct Organization
<<kind>>
Person
{disjoint, complete}
<<material>>
contracts with
1..*
1..*
1..*
1..*
<<phase>>
Deceased Person
<<phase>>
Living Person
<<roleMixin>>
Customer
1
<<mediation>>
1..*
<<relator>>
Economic Agreement
1..*
<<mediation>>
1..*
<<role>>
Supplier
{disjoint, complete}
<<role>>
Personal Customer
<<role>>
Corporate Customer


<<kind>>
Person
{disjoint, complete}
<<phase>>
Deceased Person
<<phase>>
Living Person
<<material>>
contracts with
1..*
1..*
1..*
<<roleMixin>>
Customer
1
<<mediation>>
1..*
<<relator>>
Economic Agreement
1..*
<<mediation>>
1..*
<<role>>
Supplier
{disjoint, complete}
<<role>>
Personal Customer
<<role>>
Corporate Customer
<<kind>>
Organization
{disjoint, complete}
<<phase>>
Active Organization
<<phase>>
Extinct Organization


<<kind>>
Person
{disjoint, complete}
<<phase>>
Deceased Person
<<phase>>
Living Person
<<material>>
contracts with
1..*
1..*
1..*
<<roleMixin>>
Customer
1
<<mediation>>
1..*
<<relator>>
Economic Agreement
1..*
<<mediation>>
1..*
<<role>>
Supplier
{disjoint, complete}
<<role>>
Personal Customer
<<role>>
Corporate Customer
<<kind>>
Organization
{disjoint, complete}
<<phase>>
Active Organization
<<phase>>
Extinct Organization
1..*
1..*


<<kind>>
Organization
{disjoint, complete}
<<phase>>
Active Organization
<<phase>>
Extinct Organization
<<material>>
contracts with
<<kind>>
Person
{disjoint, complete}
<<phase>>
Deceased Person
<<phase>>
Living Person
<<roleMixin>>
Customer
1
<<mediation>>
1..*
<<relator>>
Economic Agreement
1..*
<<mediation>>
1..*
<<role>>
Supplier
{disjoint, complete}
<<role>>
Personal Customer
<<role>>
Corporate Customer

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**

«role»
Student

NO!

«role»**Student**

NO!

«kind»
Person

«kind»
Person

NO!

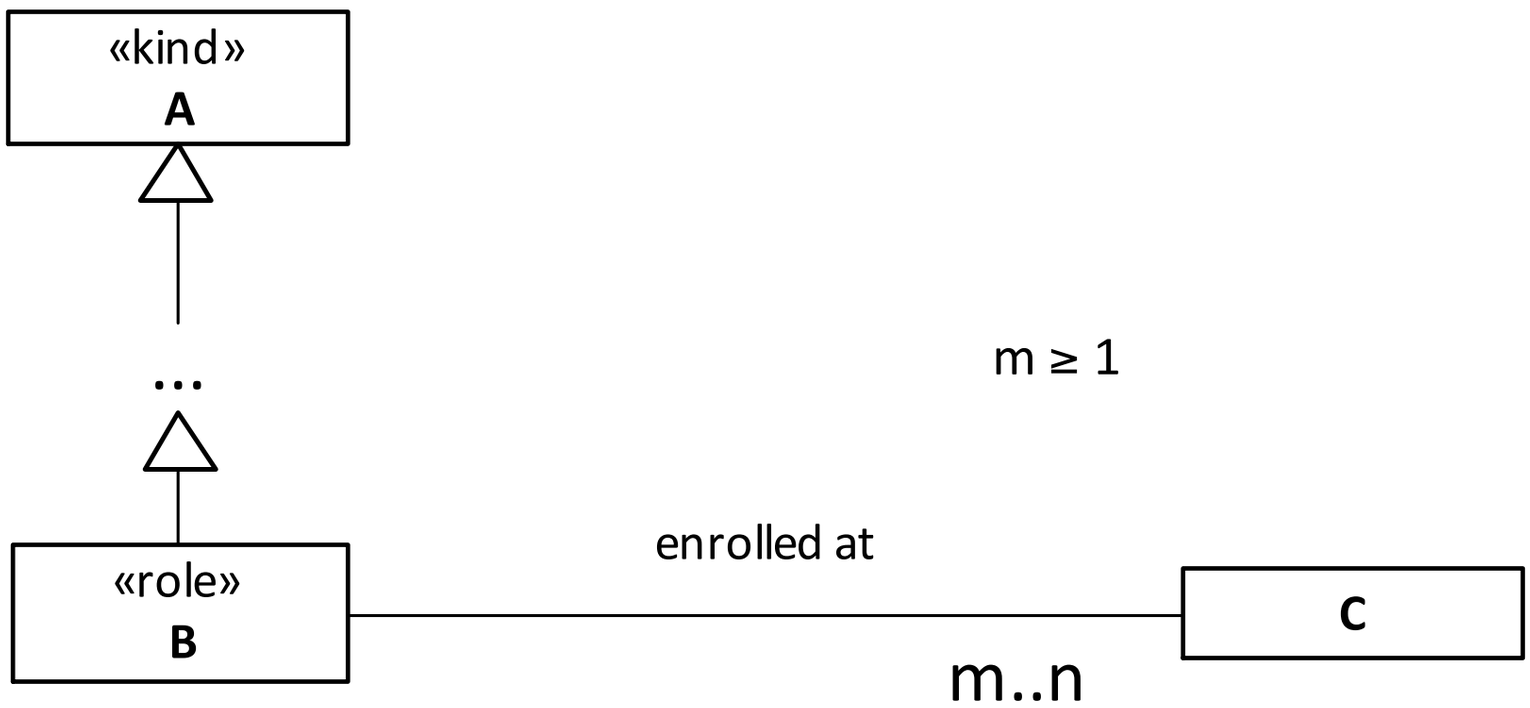
«role»
Student

enrolled at

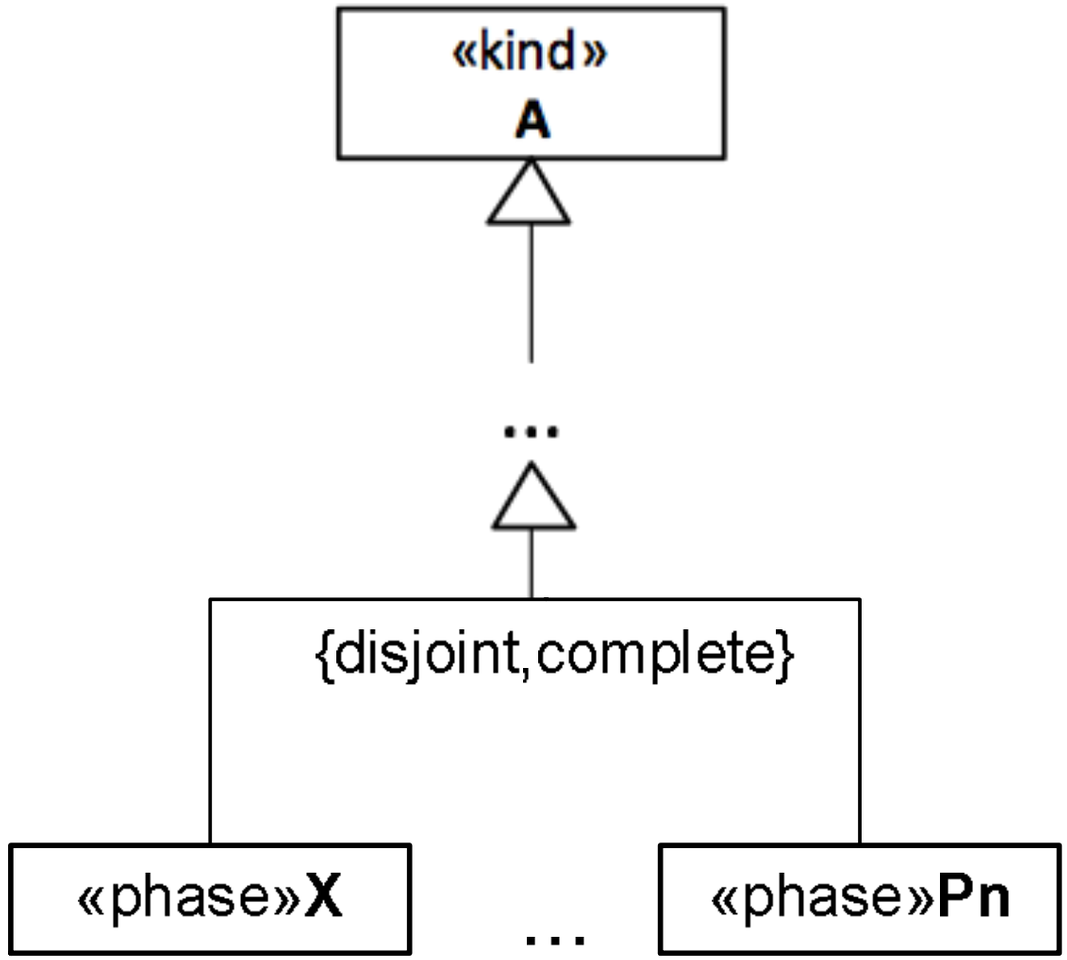
0..n

«kind»
Educational Institution

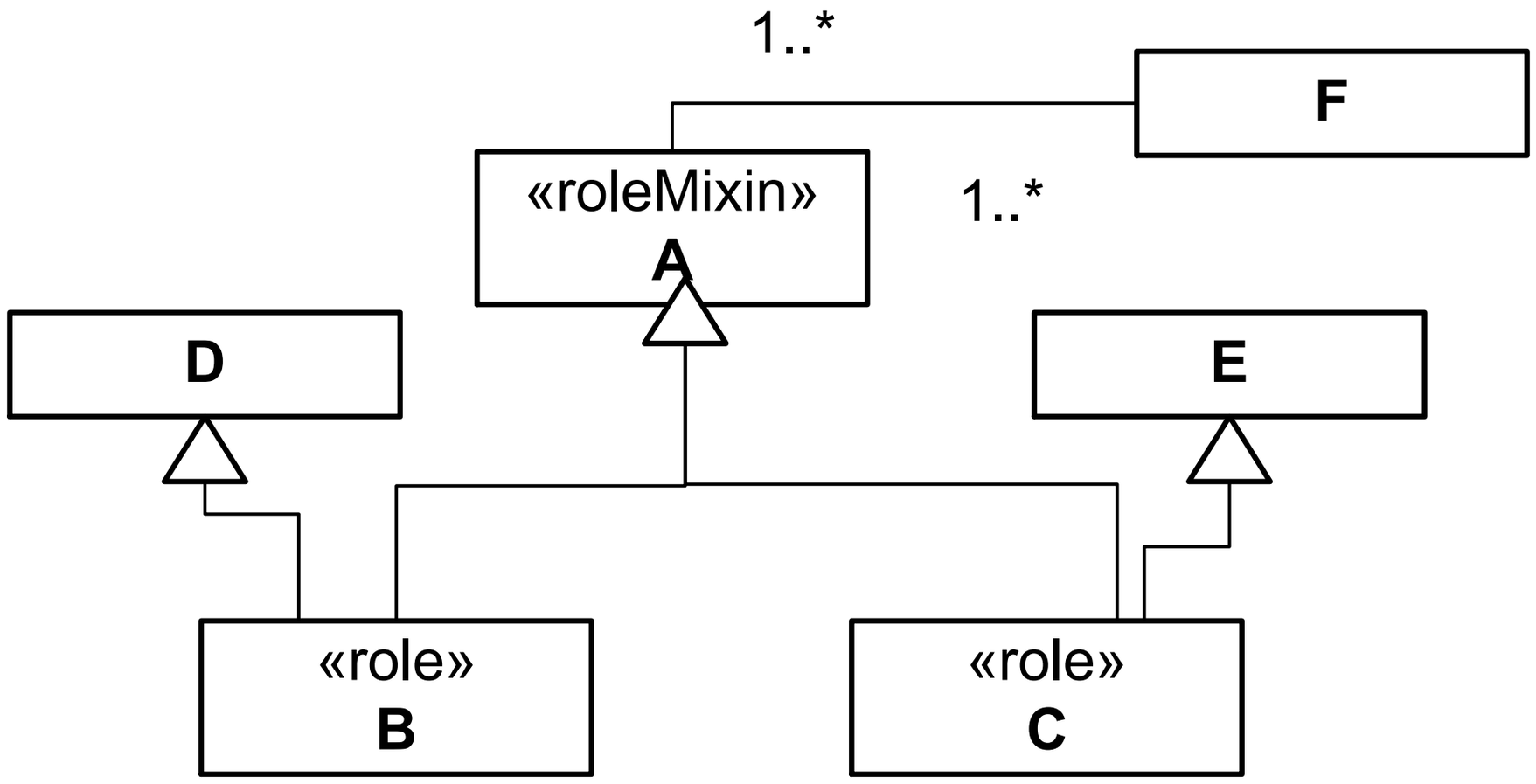
The Emerging **Role** Pattern

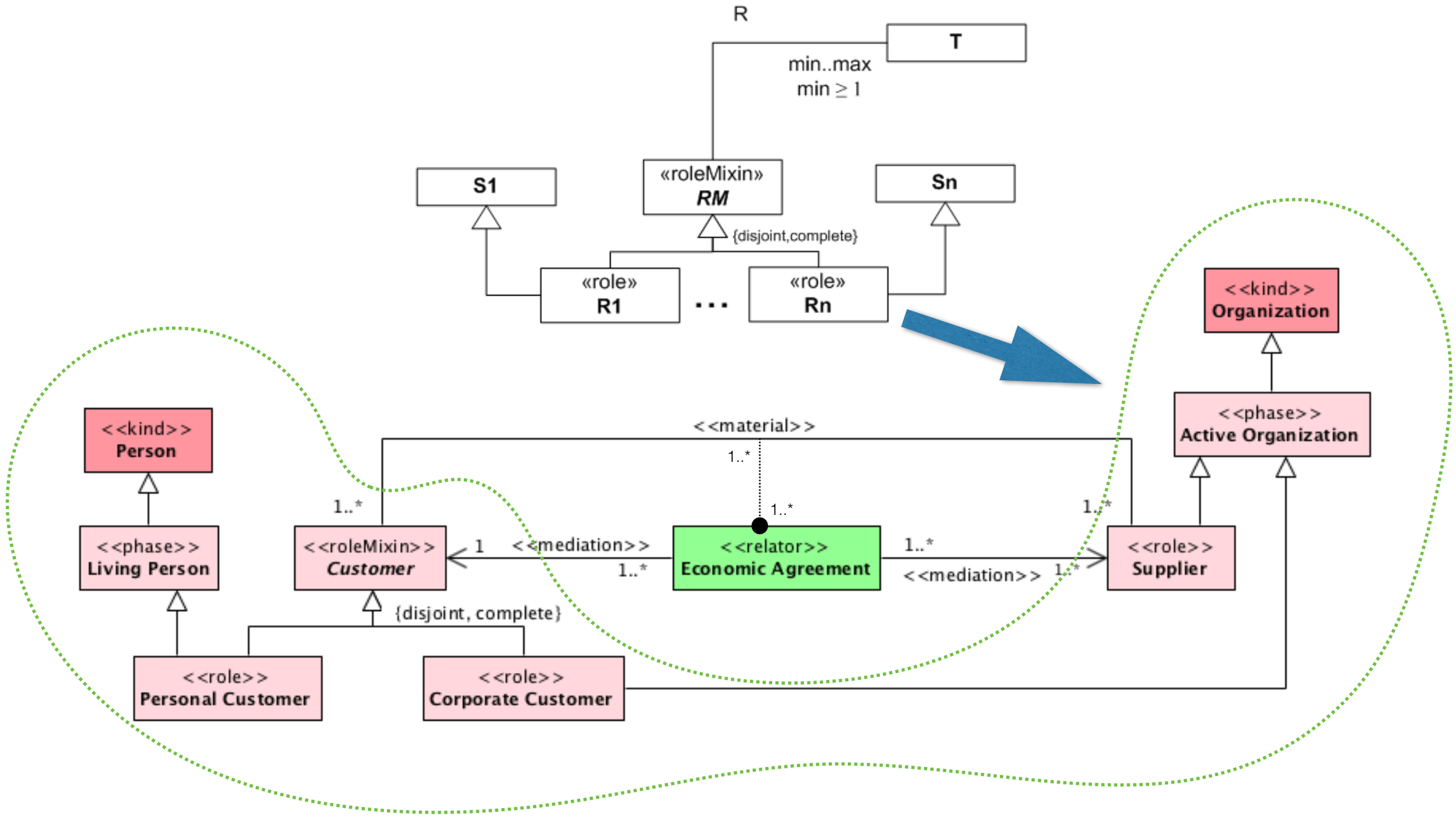


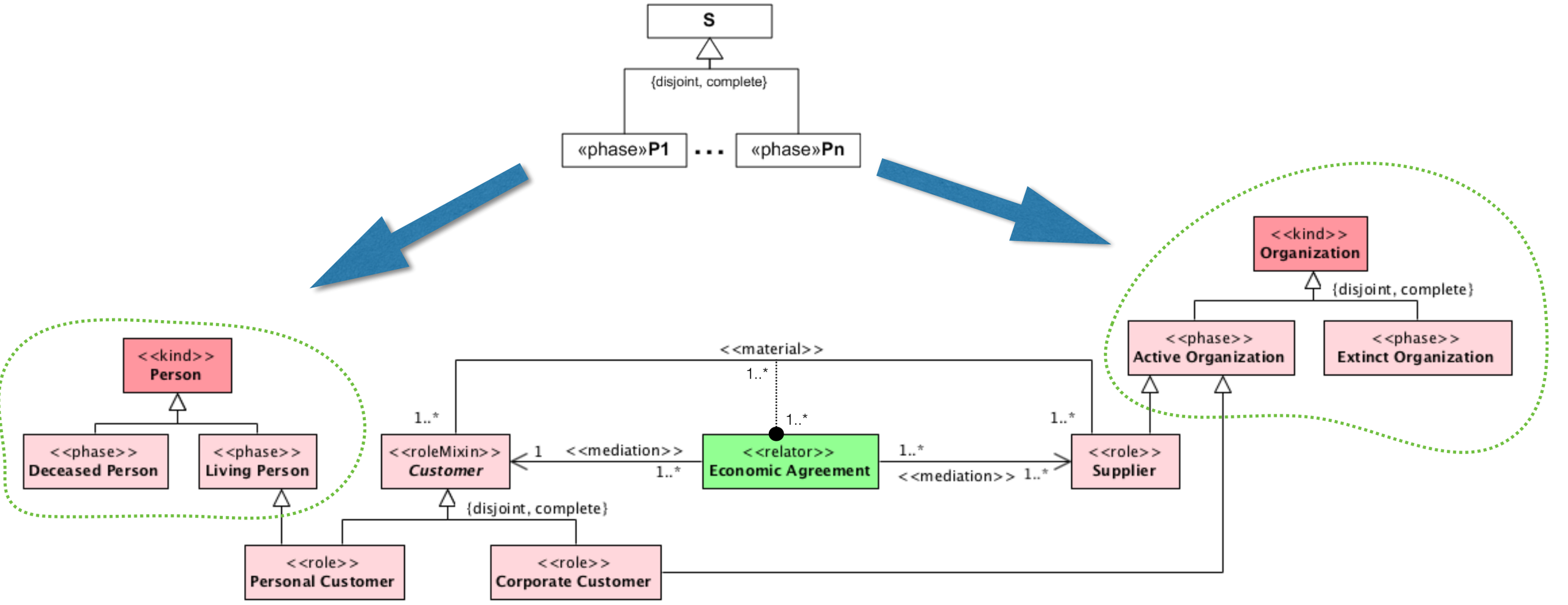
The Emerging **Phase** Pattern

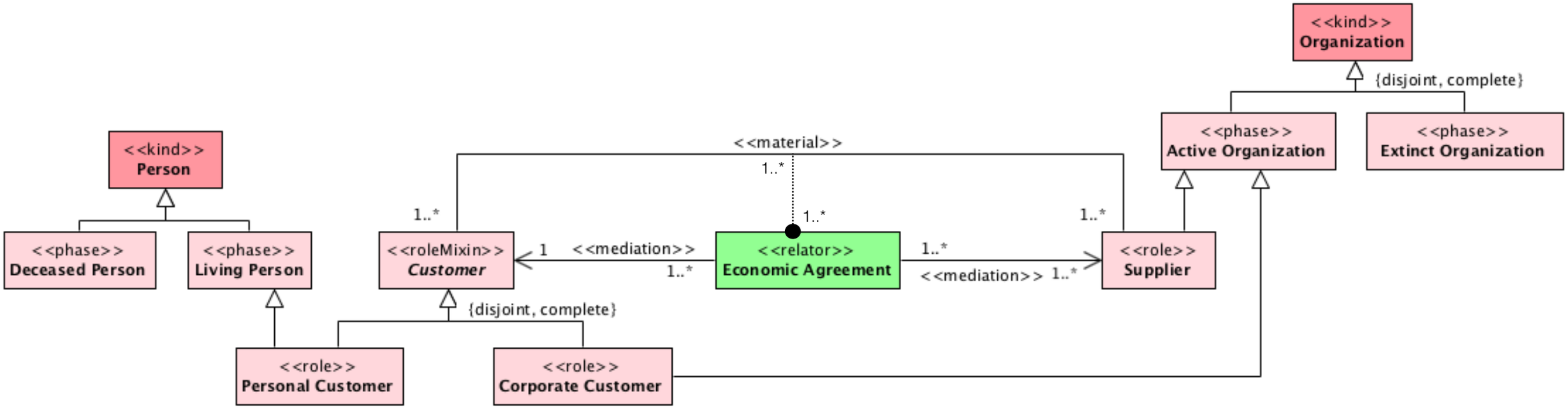


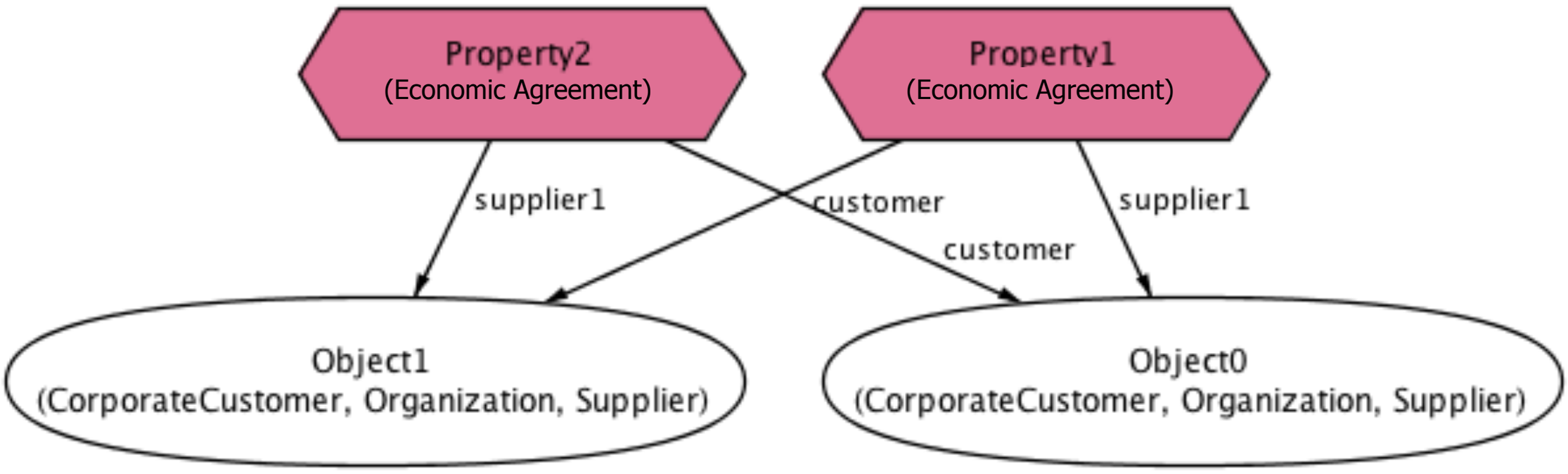
The emerging **RoleMixin** Pattern

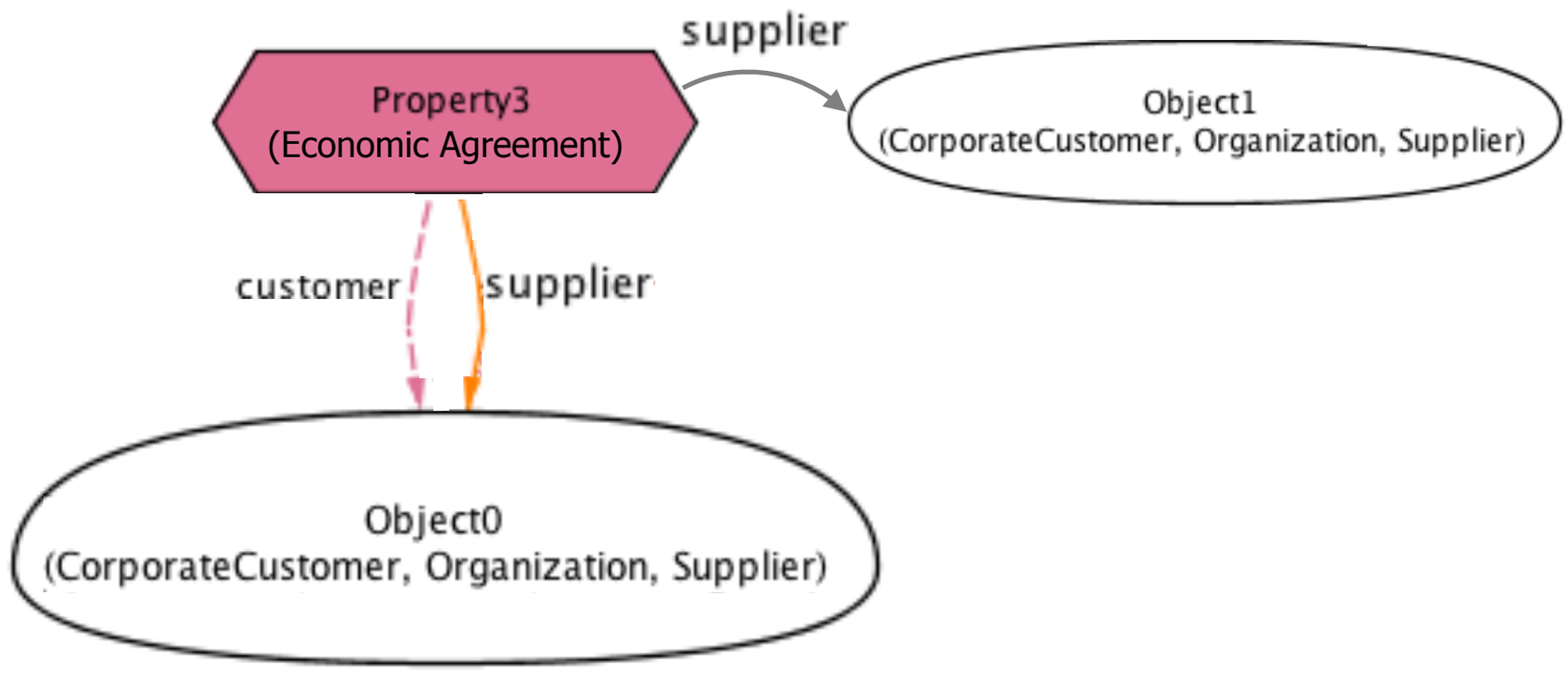


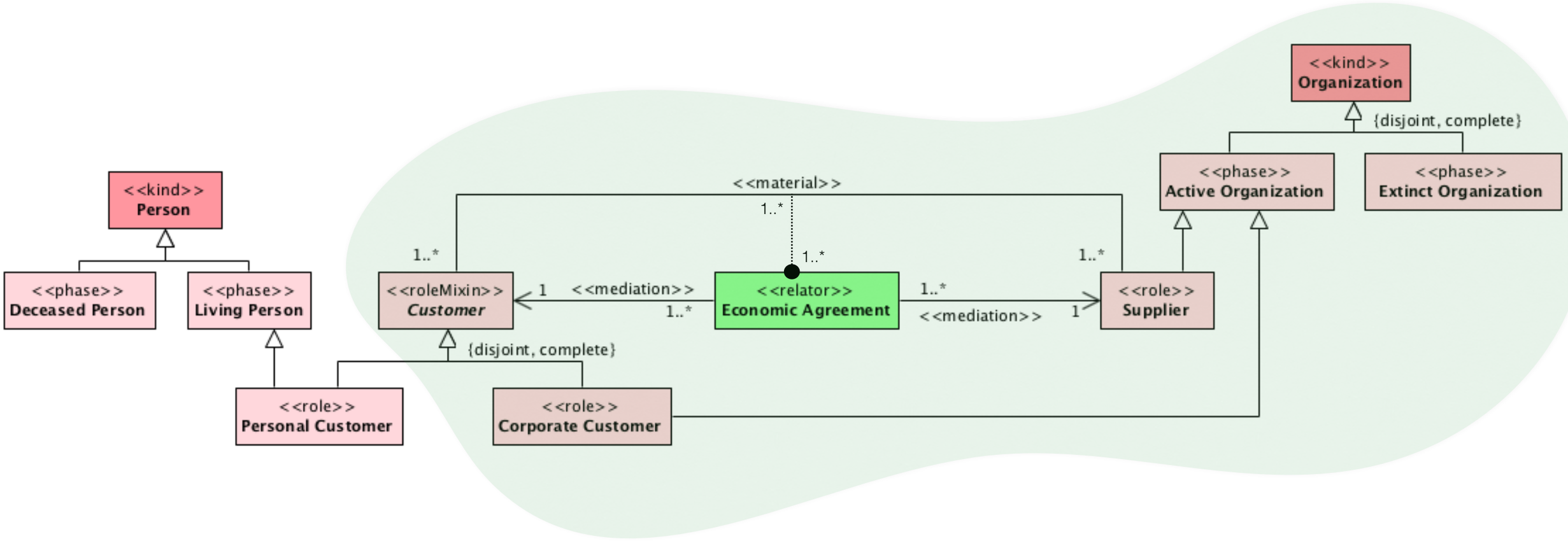

R
T
min..max
min ≥ 1
S1
«roleMixin»
RM
Sn
{disjoint,complete}
«role»
R1
«role»
Rn
<<kind>>
Organization
<<phase>>
Active Organization
<<material>>
1..*
1..*
1..*
1..*
<<kind>>
Person
<<phase>>
Living Person
<<roleMixin>>
Customer
1
<<mediation>>
1..*
<<relator>>
Economic Agreement
1..*
<<mediation>>
1..*
<<role>>
Supplier
{disjoint, complete}
<<role>>
Personal Customer
<<role>>
Corporate Customer


S
{disjoint, complete}
«phase»P1
«phase»Pn
<<kind>>
Person
<<phase>>
Deceased Person
<<phase>>
Living Person
<<material>>
1..*
1..*
1..*
1..*
<<roleMixin>>
Customer
1
<<mediation>>
1..*
<<relator>>
Economic Agreement
1..*
<<mediation>>
1..*
<<role>>
Supplier
<<kind>>
Organization
{disjoint, complete}
<<phase>>
Active Organization
<<phase>>
Extinct Organization
{disjoint, complete}
<<role>>
Personal Customer
<<role>>
Corporate Customer

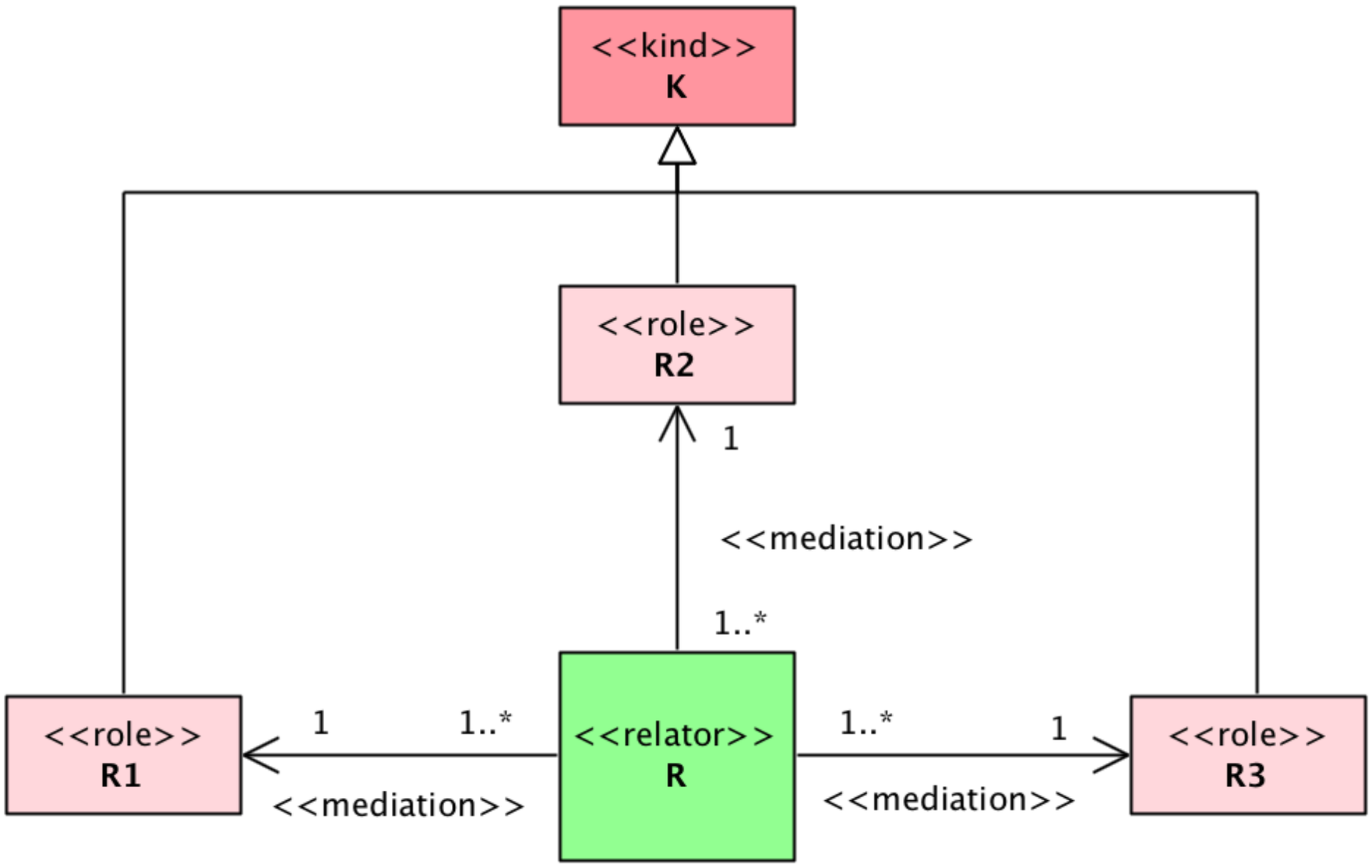

<<kind>>
Person
<<phase>>
Deceased Person
<<phase>>
Living Person
<<material>>
1..*
1..*
1..*
1..*
<<roleMixin>>
Customer
1
<<mediation>>
1..*
<<relator>>
Economic Agreement
1..*
<<mediation>>
1..*
<<role>>
Supplier
<<kind>>
Organization
{disjoint, complete}
<<phase>>
Active Organization
<<phase>>
Extinct Organization
{disjoint, complete}
<<role>>
Personal Customer
<<role>>
Corporate Customer

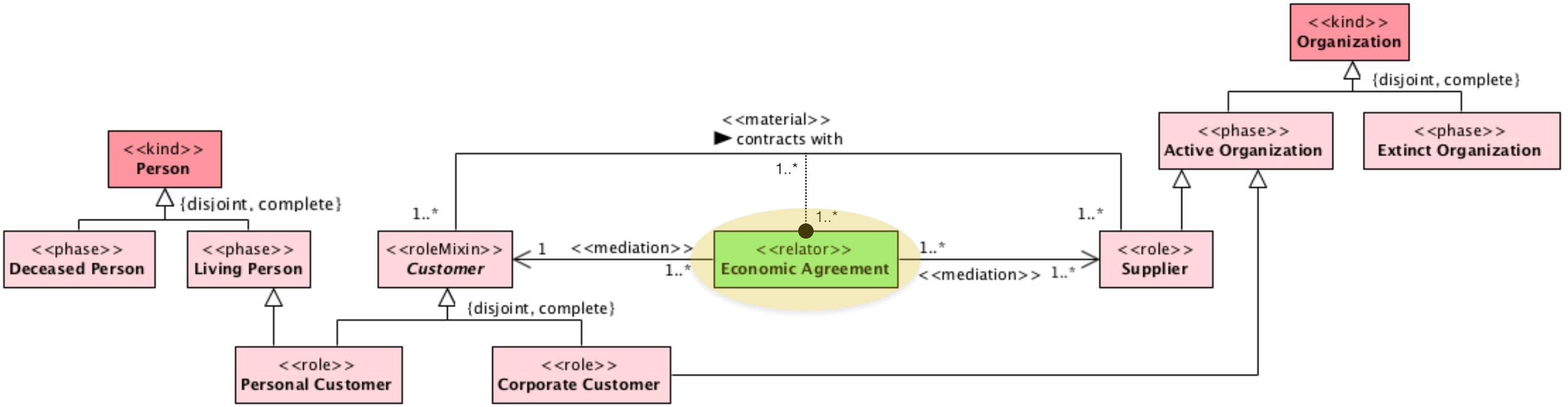

Property2
(Economic Agreement)
Property1
(Economic Agreement)
supplier1
customer
customer
supplier1
Object1
(CorporateCustomer, Organization, Supplier)
Object0
(CorporateCustomer, Organization, Supplier)

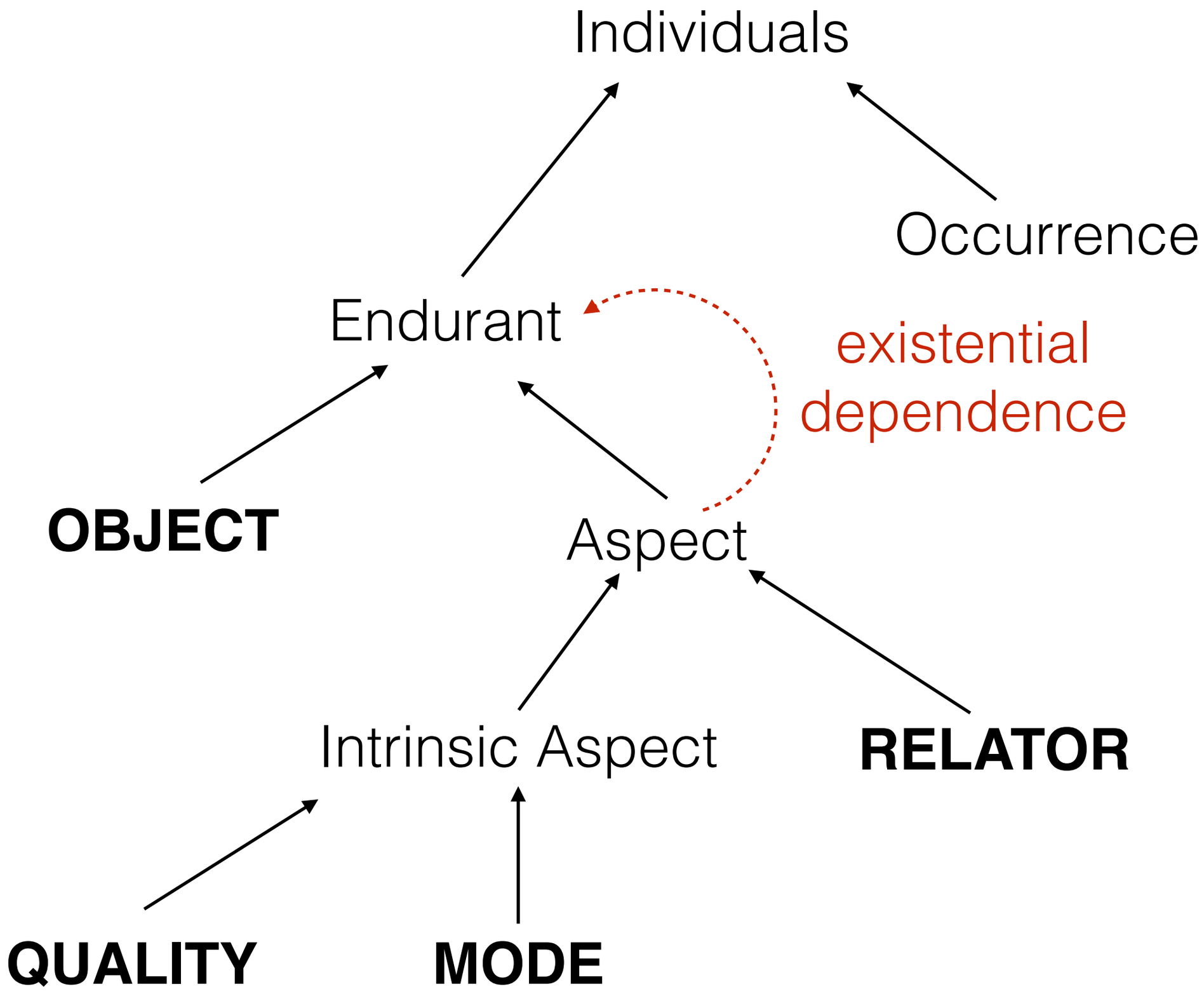

supplier
Property3
(Economic Agreement)
Object1
(CorporateCustomer, Organization, Supplier)
customer
supplier
Object0
(CorporateCustomer, Organization, Supplier)


<<kind>>
Person
<<phase>>
Deceased Person
<<phase>>
Living Person
<<material>>
1..*
1..*
1..*
1..*
<<roleMixin>>
Customer
1
<<mediation>>
1..*
<<relator>>
Economic Agreement
1..*
<<mediation>>
1
<<role>>
Supplier
<<kind>>
Organization
{disjoint, complete}
<<phase>>
Active Organization
<<phase>>
Extinct Organization
{disjoint, complete}
<<role>>
Personal Customer
<<role>>
Corporate Customer

The Emerging **Anti-Pattern**




<<kind>>
Person
{disjoint, complete}
<<phase>>
Deceased Person
<<phase>>
Living Person
<<material>>
contracts with
1..*
1..*
<<roleMixin>>
Customer
1
<<mediation>>
1..*
<<relator>>
Economic Agreement
1..*
<<mediation>>
1..*
<<role>>
Supplier
{disjoint, complete}
<<role>>
Personal Customer
<<role>>
Corporate Customer
<<kind>>
Organization
{disjoint, complete}
<<phase>>
Active Organization
<<phase>>
Extinct Organization


Individuals
Occurrence
Endurant
existential
dependence
OBJECT
Aspect
Intrinsic Aspect
RELATOR
QUALITY
MODE

ONTOUML

- 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

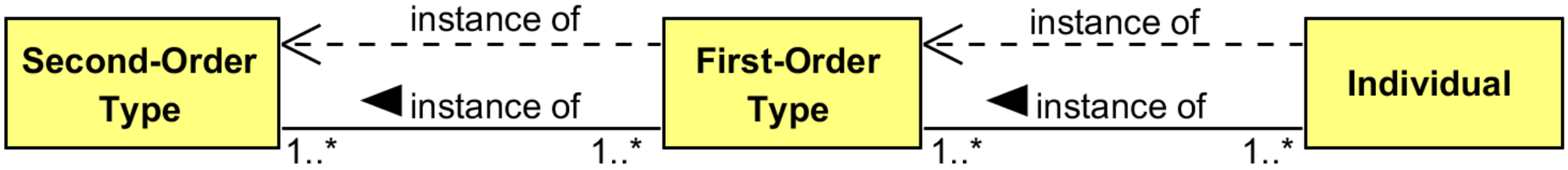
2

Logical

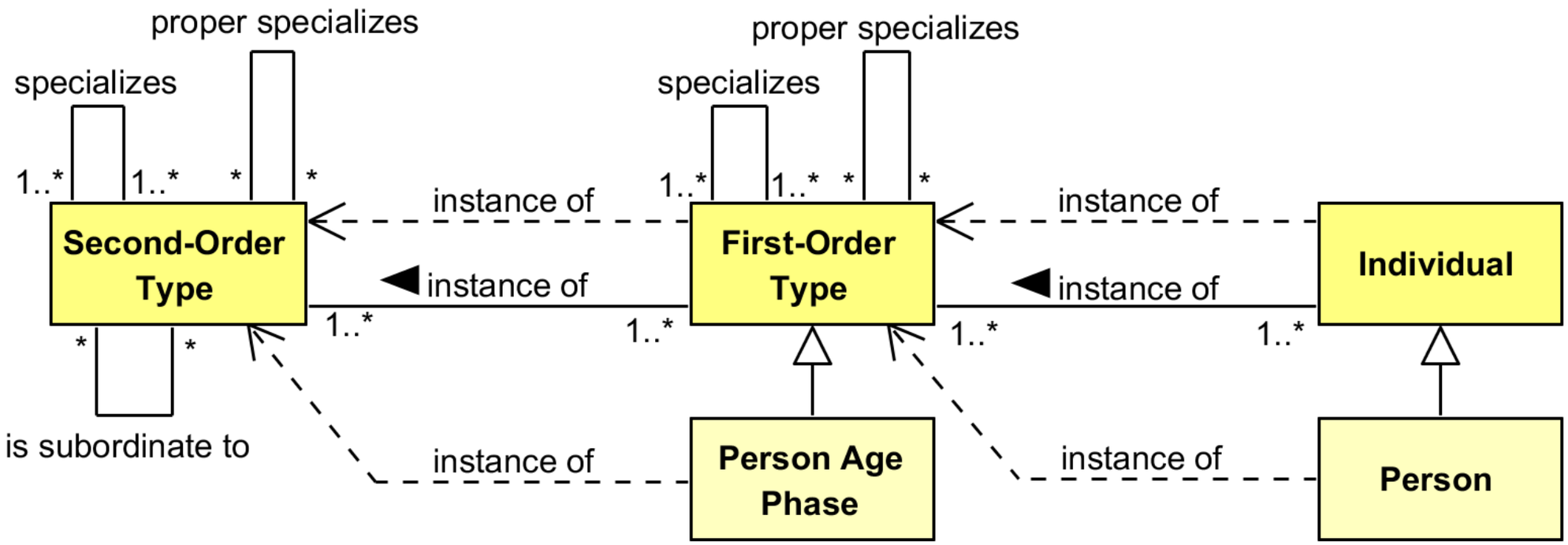
Aspects of

Higher-Order Types

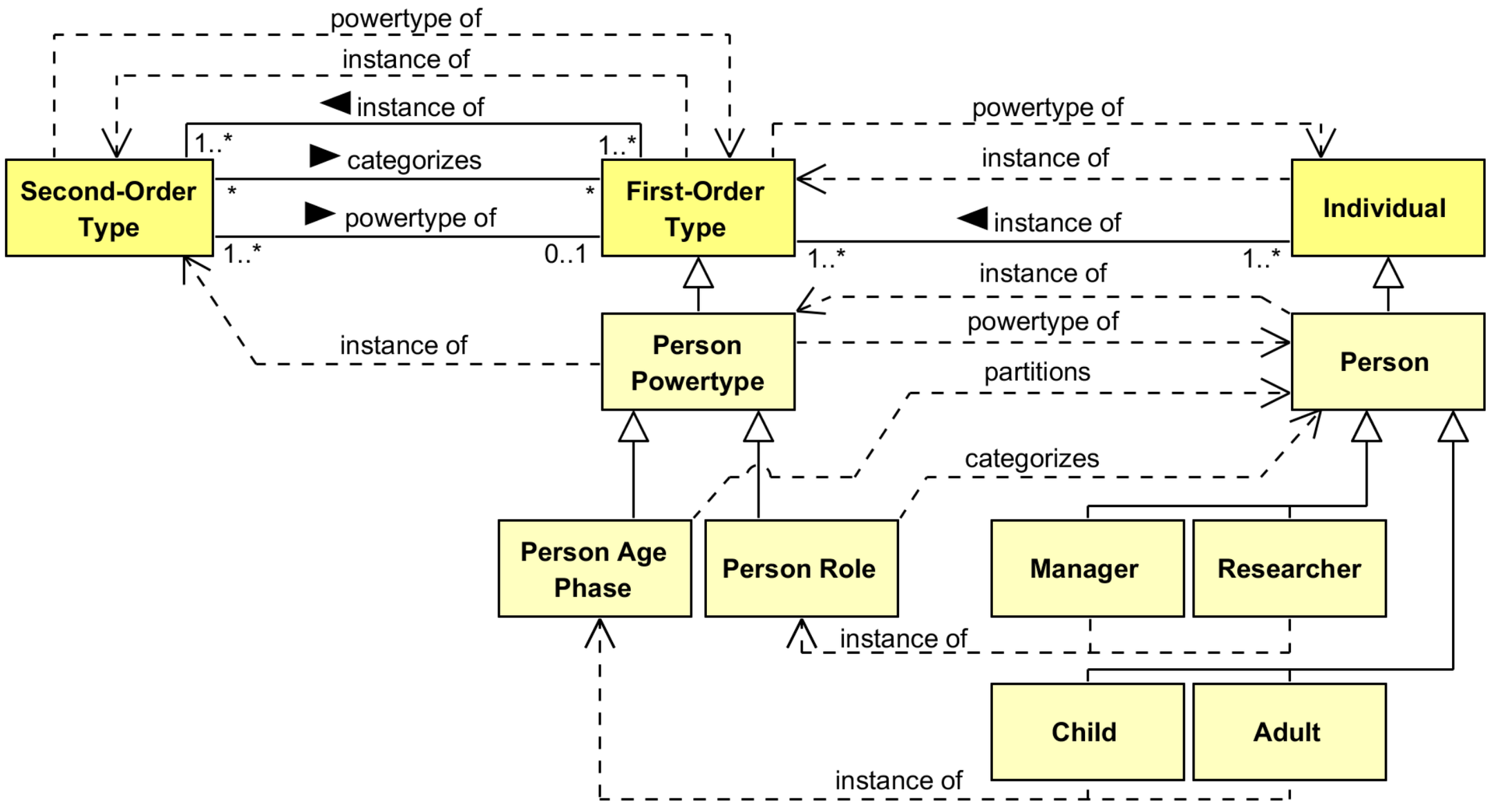
Multi-Level Theory (**MLT**)



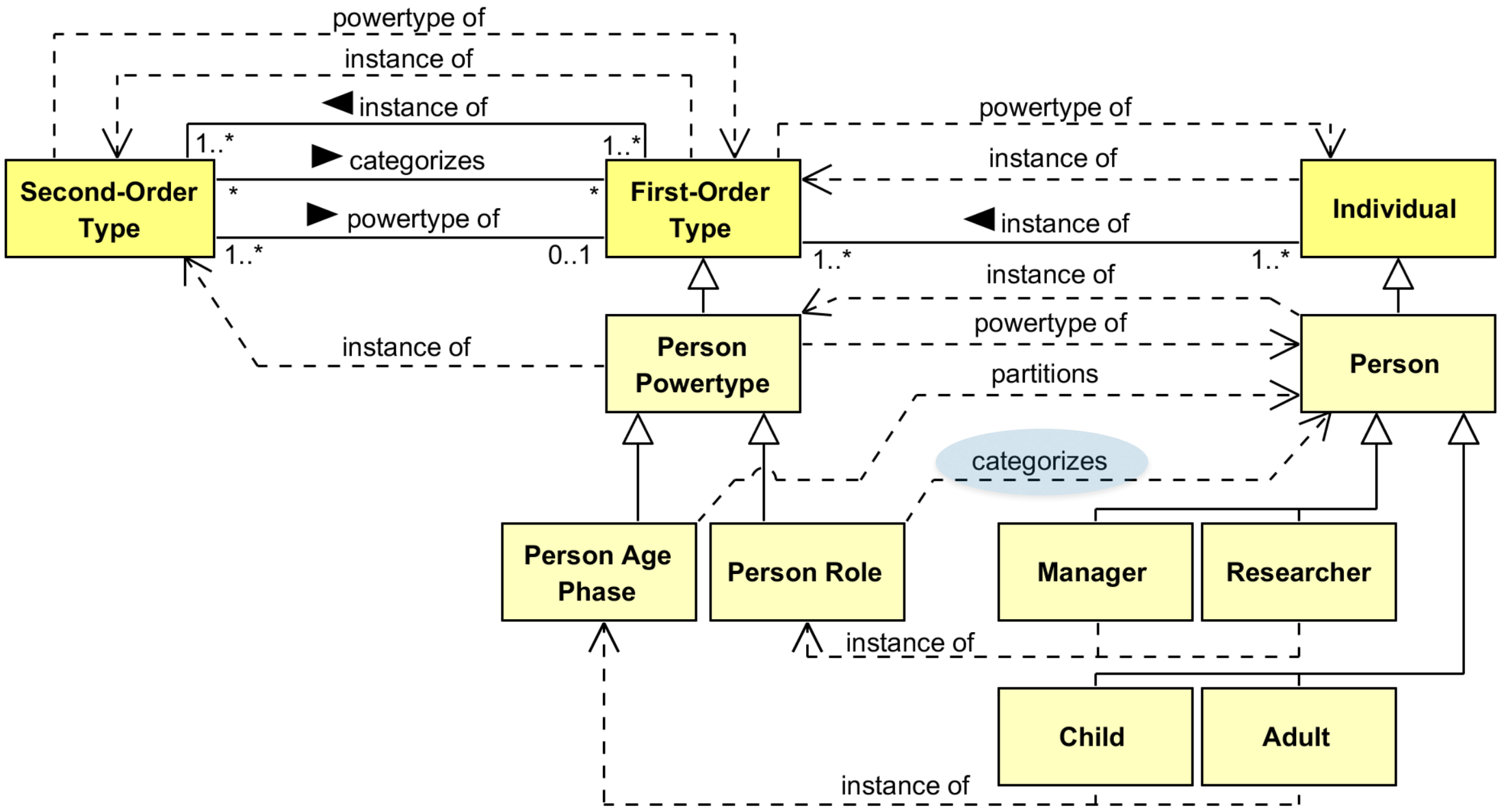
Multi-Level Theory (**MLT**)



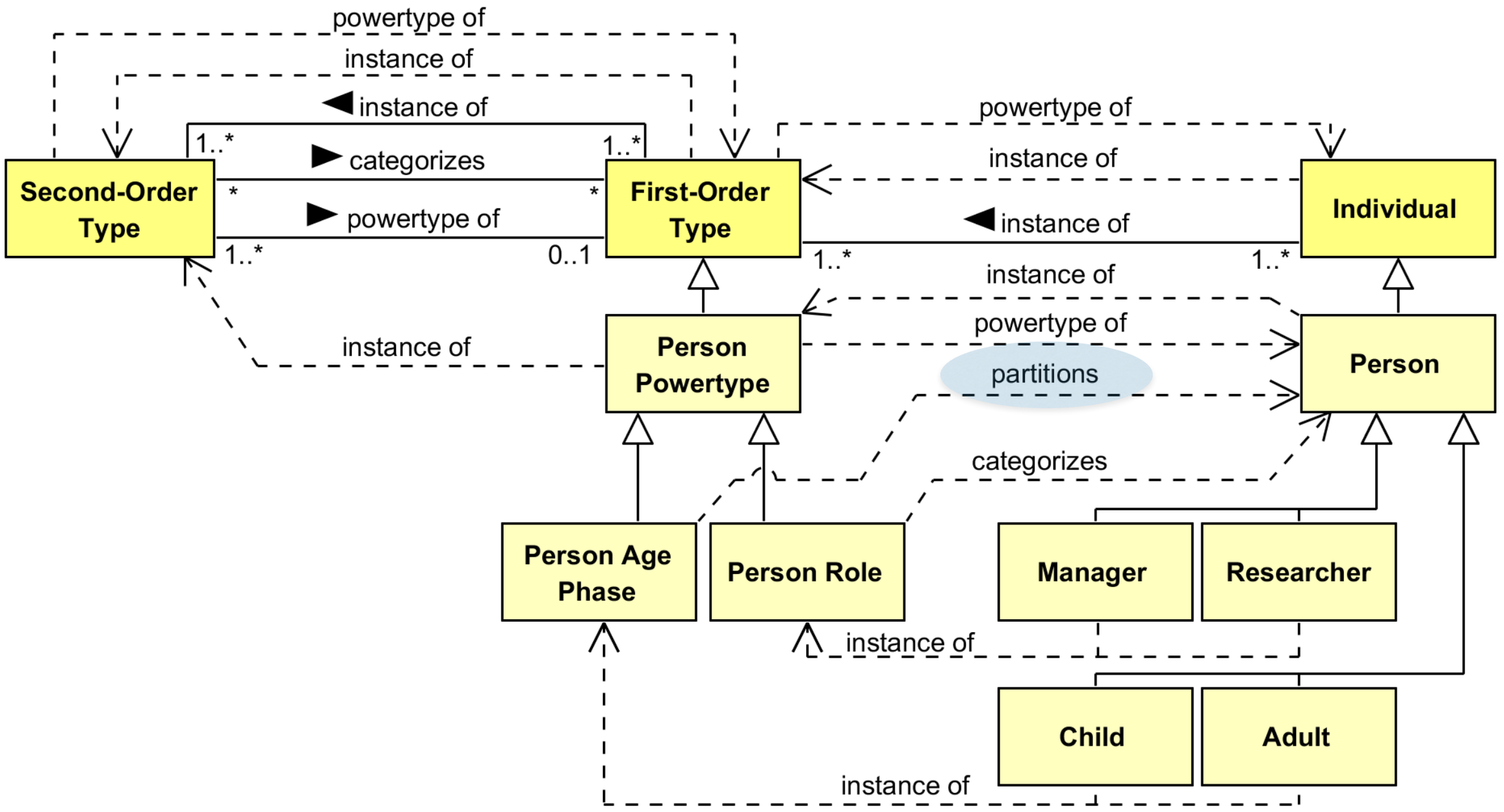
Multi-Level Theory (**MLT**)



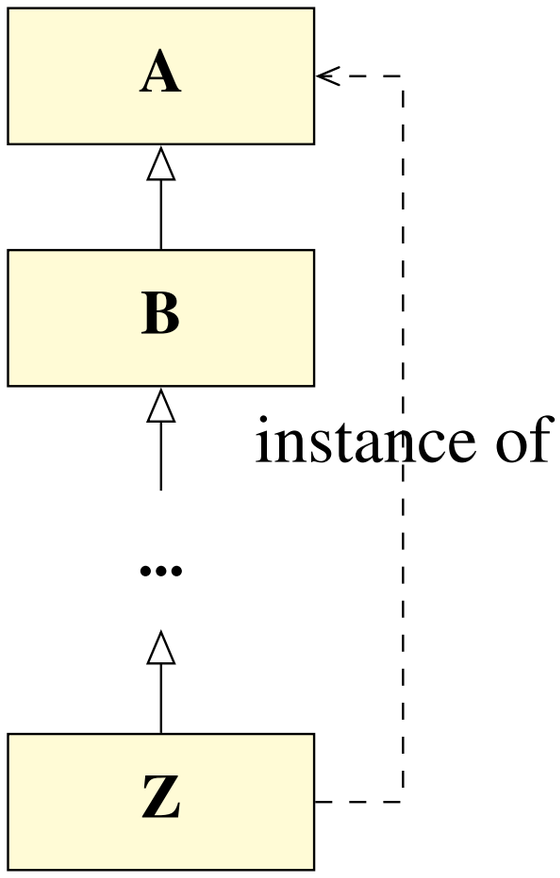
Multi-Level Theory (**MLT**)



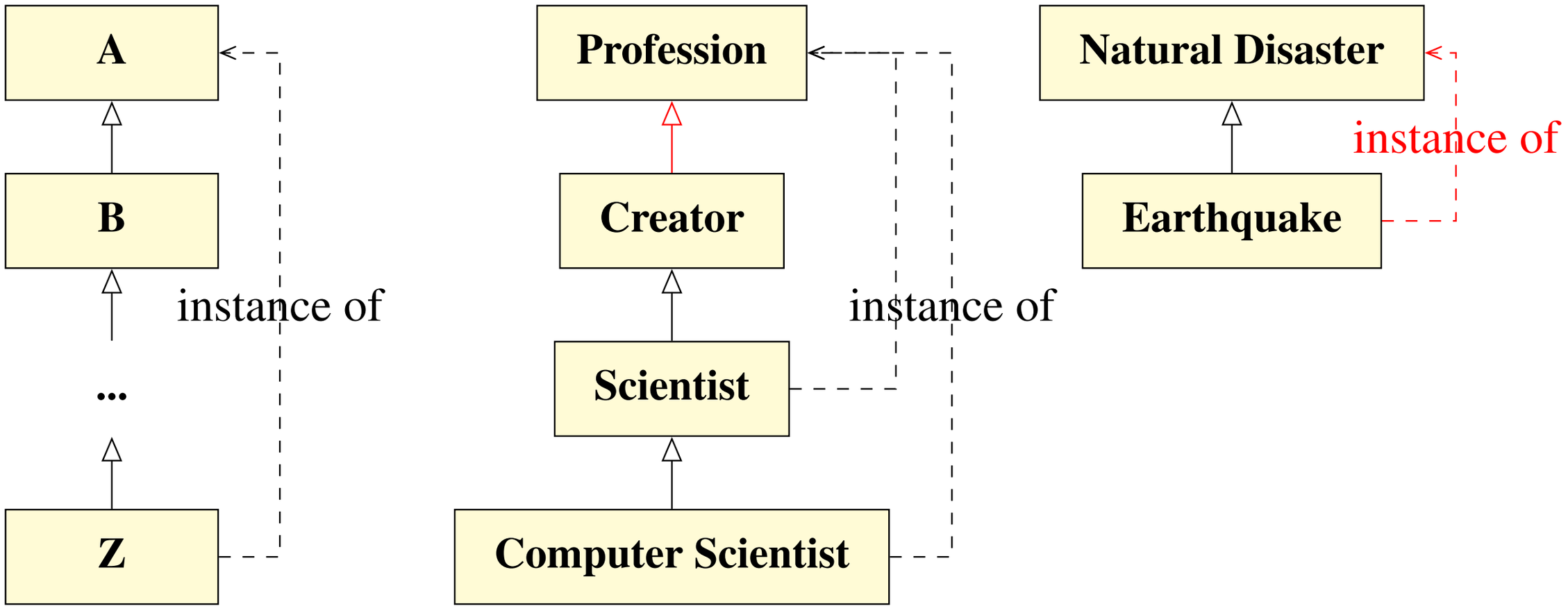
Multi-Level Theory (**MLT**)



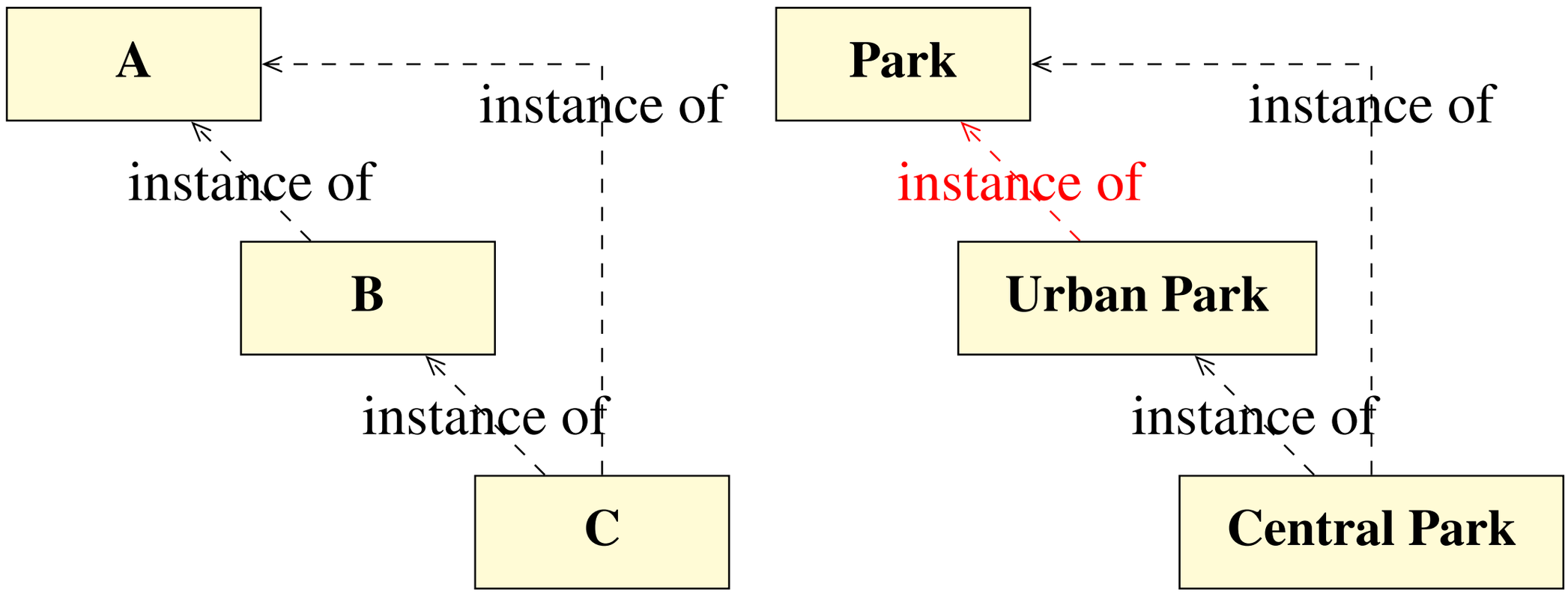
Anti-Patterns



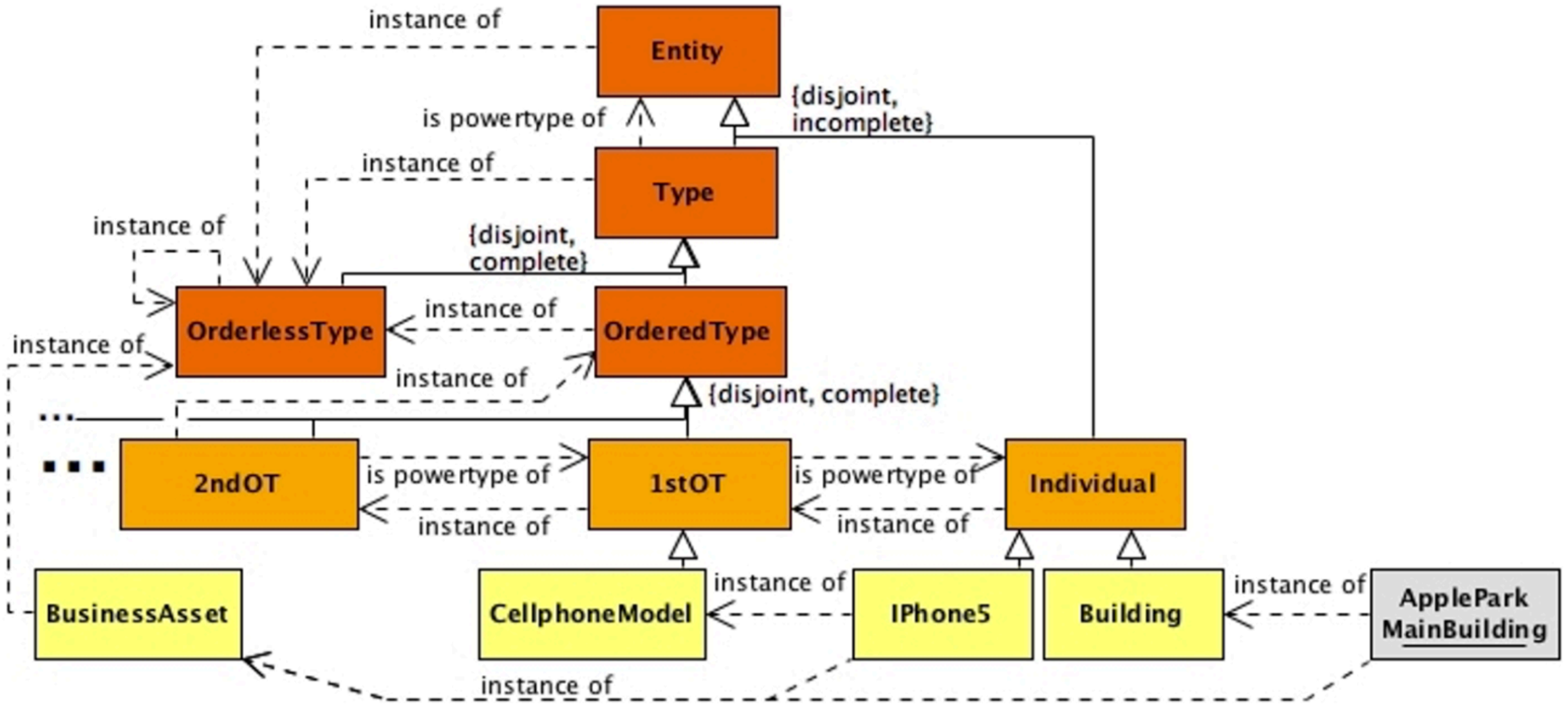
Anti-Patterns



Anti-Patterns



MLT*


instance of
Entity
{disjoint,
incomplete}
is powertype of
instance of
Type
instance of
{disjoint,
complete}
OrderlessType
instance of
OrderedType
instance of
instance of
{disjoint, complete}
2ndOT
is powertype of
1stOT
is powertype of
Individual
instance of
instance of
BusinessAsset
CellphoneModel
instance of
IPhone5
Building
instance of
ApplePark
MainBuilding
instance of

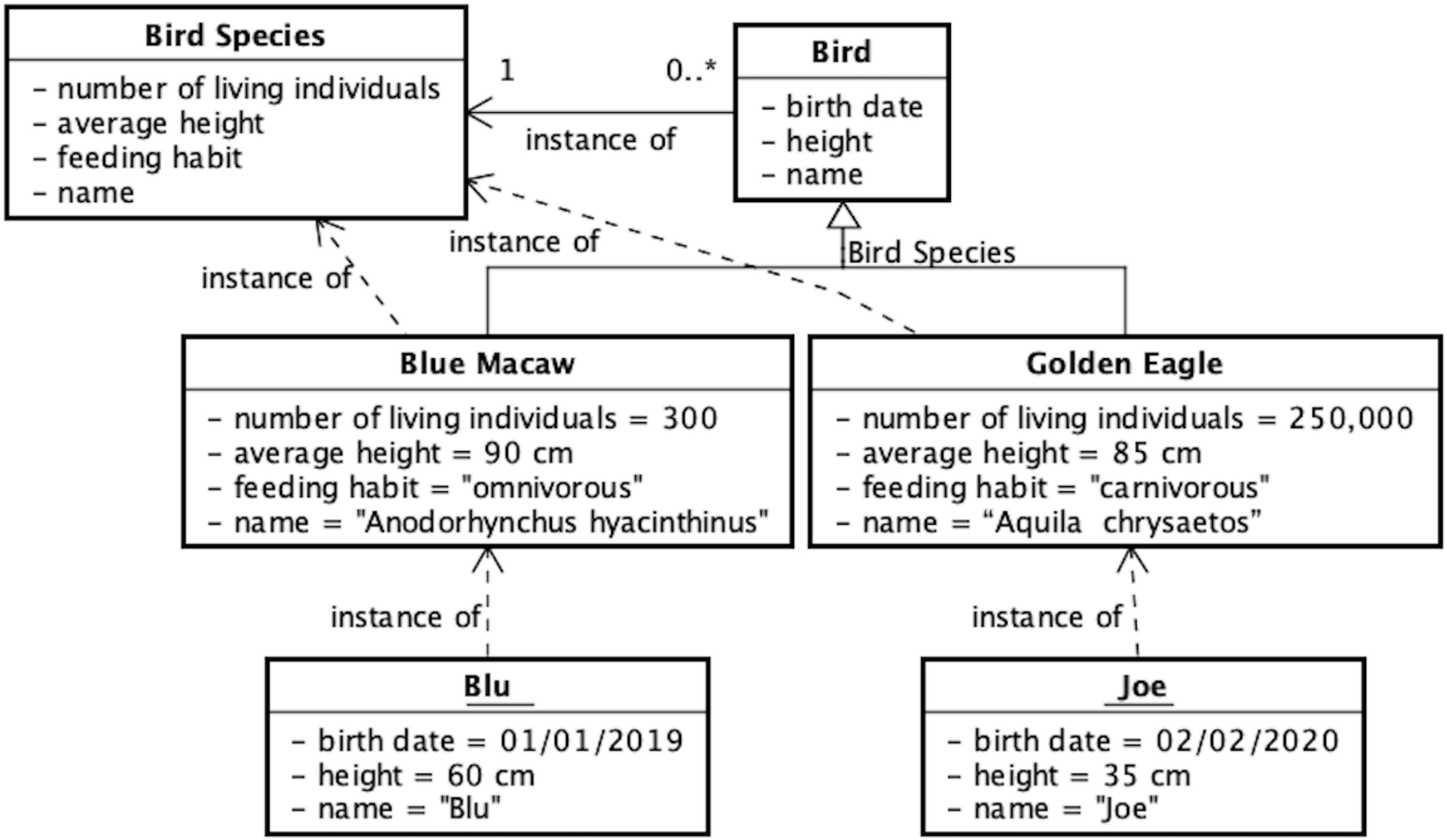
Fundamental Problems

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

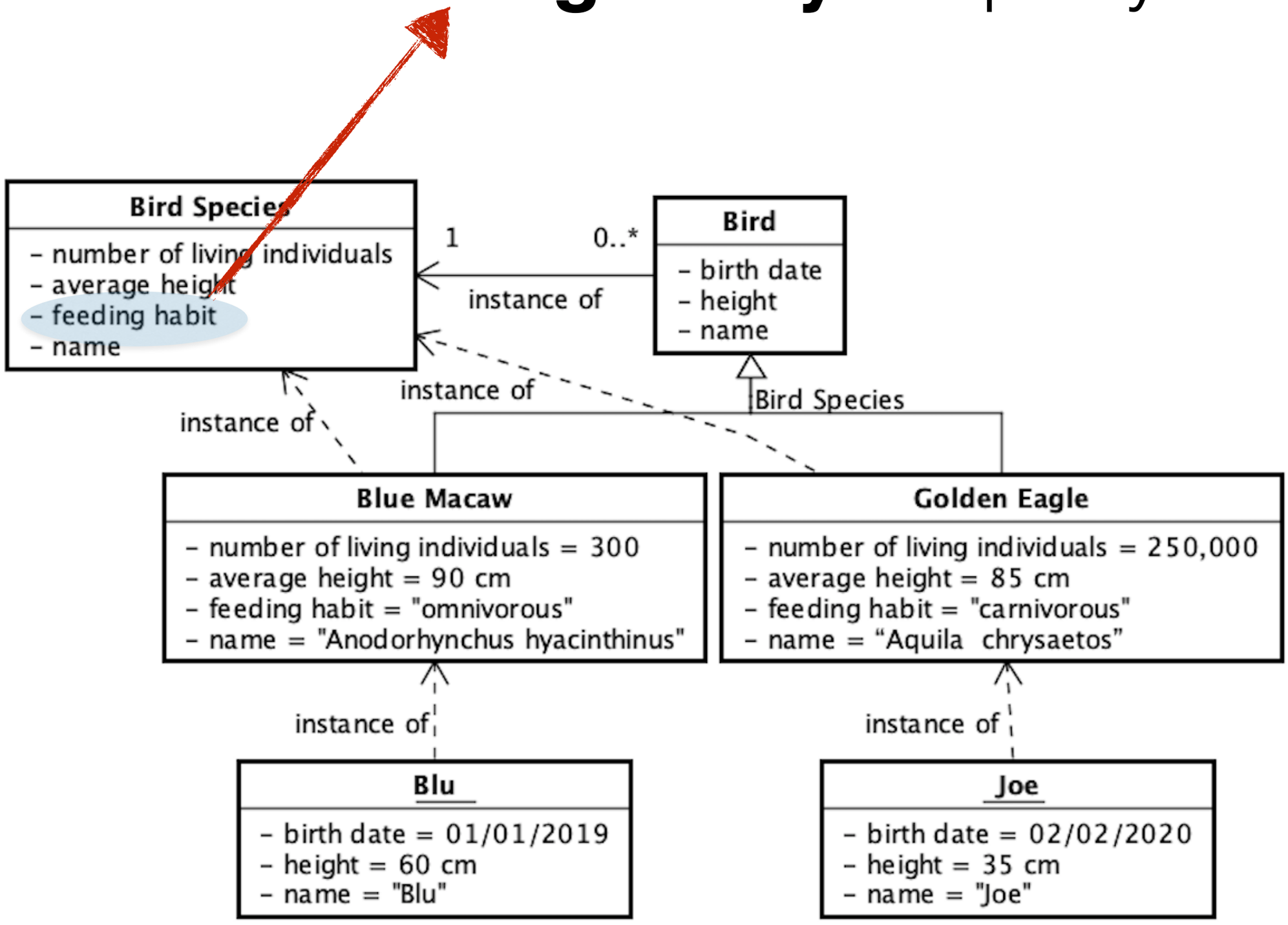
3

Ontological Aspects of **Higher-Order Types**

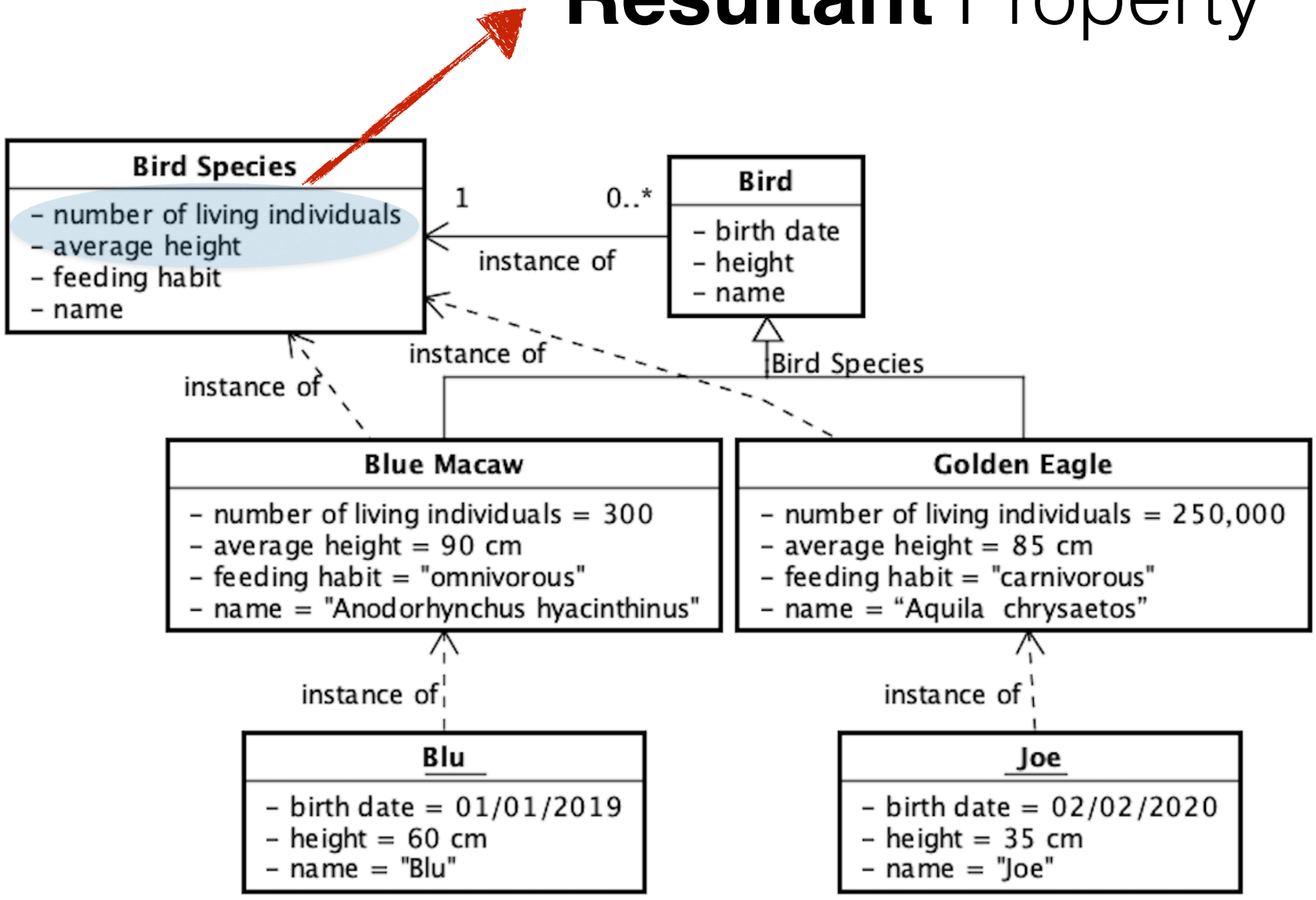
a9 $\forall t_1, t_2(\mathsf{type}(t_1) \wedge \mathsf{type}(t_2) \rightarrow (t_1 = t_2 \leftrightarrow \forall x(\mathsf{iof}(x, t_1) \leftrightarrow \mathsf{iof}(x, t_2))))$


Bird Species
- number of living individuals
- average height
- feeding habit
- name
1
0..*
instance of
Bird
- birth date
- height
- name
instance of
instance of
Bird Species
Blue Macaw
- number of living individuals = 300
- average height = 90 cm
- feeding habit = "omnivorous"
- name = "Anodorhynchus hyacinthinus"
Golden Eagle
- number of living individuals = 250,000
- average height = 85 cm
- feeding habit = "carnivorous"
- name = “Aquila chrysaetos”
instance of
instance of
Blu
- birth date = 01/01/2019
- height = 60 cm
- name = "Blu"
Joe
- birth date = 02/02/2020
- height = 35 cm
- name = "Joe"

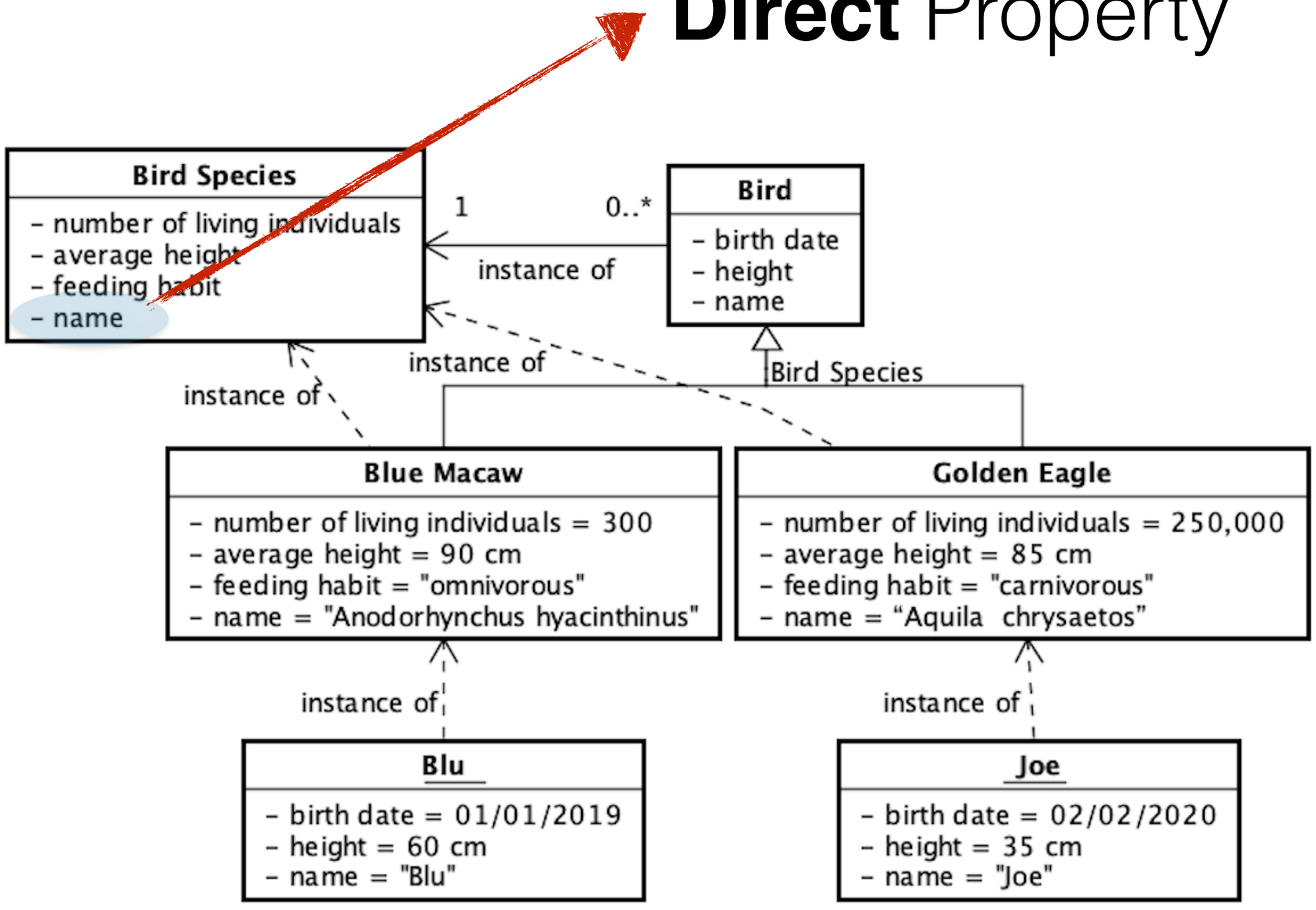
Regularity Property



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

w1

w2

w3

w4

Person ← instantiation

Mick Jagger

w1 w2 w3 w4

Person ← instantiation

Mick Jagger

w1 w2 w3 w4

Bird Species

instantiation

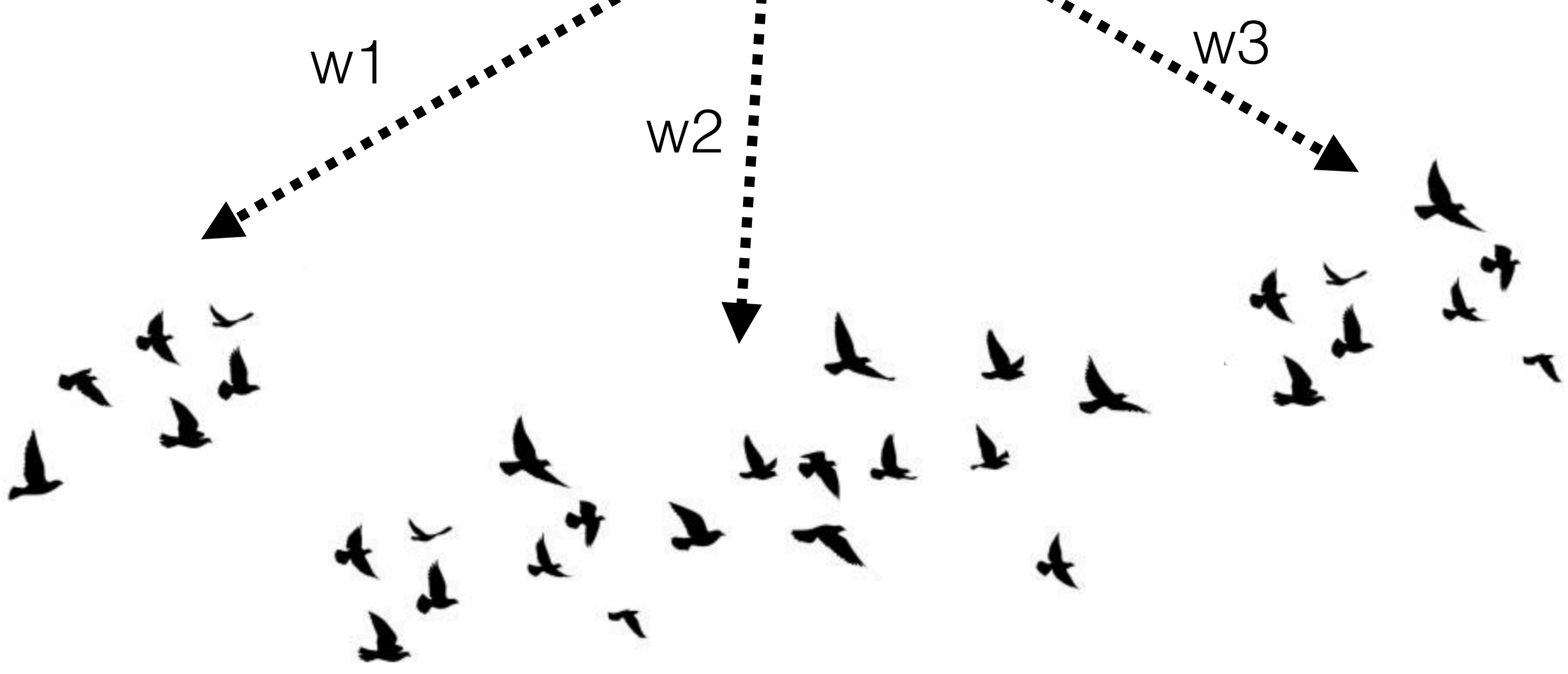
Golden Eagle

intension of a specific subtype of Bird

w1

w2

w3



What's in a **type**?

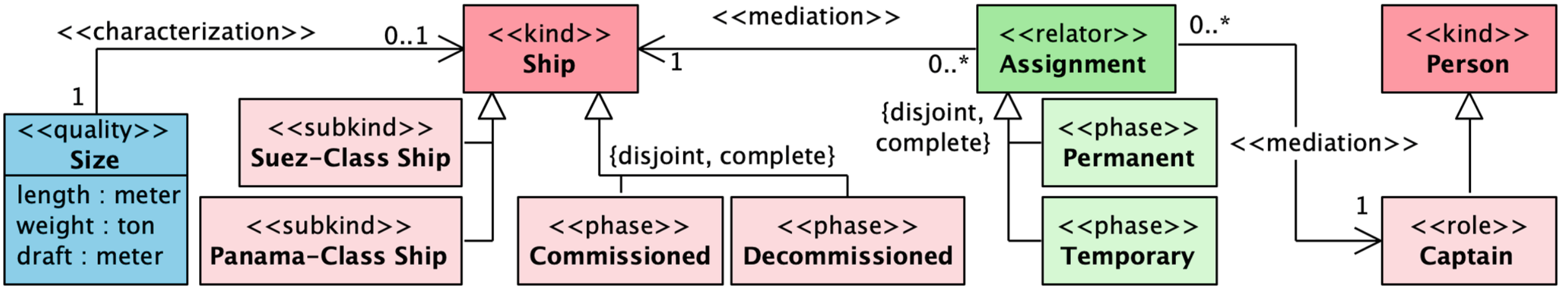
1. An **abstract** entity

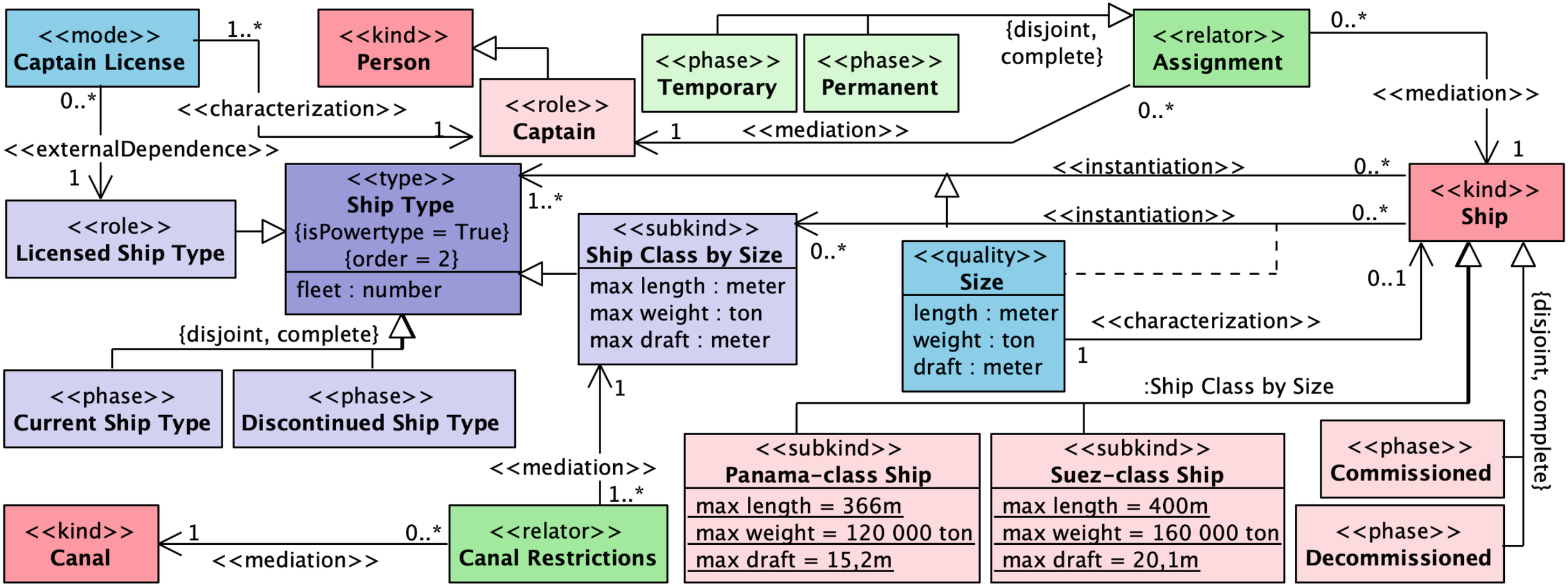
2. A **mereological sum** of instances

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


<<characterization>>
0..1
1
<<kind>>
Ship
<<mediation>>
1
0..*
<<relator>>
Assignment
0..*
<<kind>>
Person
1
<<quality>>
Size
length : meter
weight : ton
draft : meter
<<subkind>>
Suez-Class Ship
<<subkind>>
Panama-Class Ship
{disjoint, complete}
<<phase>>
Commissioned
<<phase>>
Decommissioned
{disjoint,
complete}
<<phase>>
Permanent
<<phase>>
Temporary
<<mediation>>
1
<<role>>
Captain


<<mode>>
Captain License
1..*
<<kind>>
Person
<<phase>>
Temporary
<<phase>>
Permanent
{disjoint,
complete}
<<relator>>
Assignment
0..*
<<mediation>>
0..*
<<characterization>>
1
<<role>>
Captain
1
<<mediation>>
0..*
<<externalDependence>>
1
<<instantiation>>
0..*
<<kind>>
Ship
<<type>>
Ship Type
{isPowertype = True}
{order = 2}
fleet : number
1..*
<<role>>
Licensed Ship Type
<<subkind>>
Ship Class by Size
max length : meter
max weight : ton
max draft : meter
0..*
<<instantiation>>
0..*
<<quality>>
Size
length : meter
weight : ton
draft : meter
0..1
<<characterization>>
1
:Ship Class by Size
{disjoint, complete}
<<phase>>
Current Ship Type
<<phase>>
Discontinued Ship Type
1
<<mediation>>
1..*
<<subkind>>
Panama-class Ship
max length = 366m
max weight = 120 000 ton
max draft = 15,2m
<<subkind>>
Suez-class Ship
max length = 400m
max weight = 160 000 ton
max draft = 20,1m
<<phase>>
Commissioned
<<phase>>
Decommissioned
{disjoint, complete}
<<kind>>
Canal
1
0..*
<<mediation>>
<<relator>>
Canal Restrictions

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.

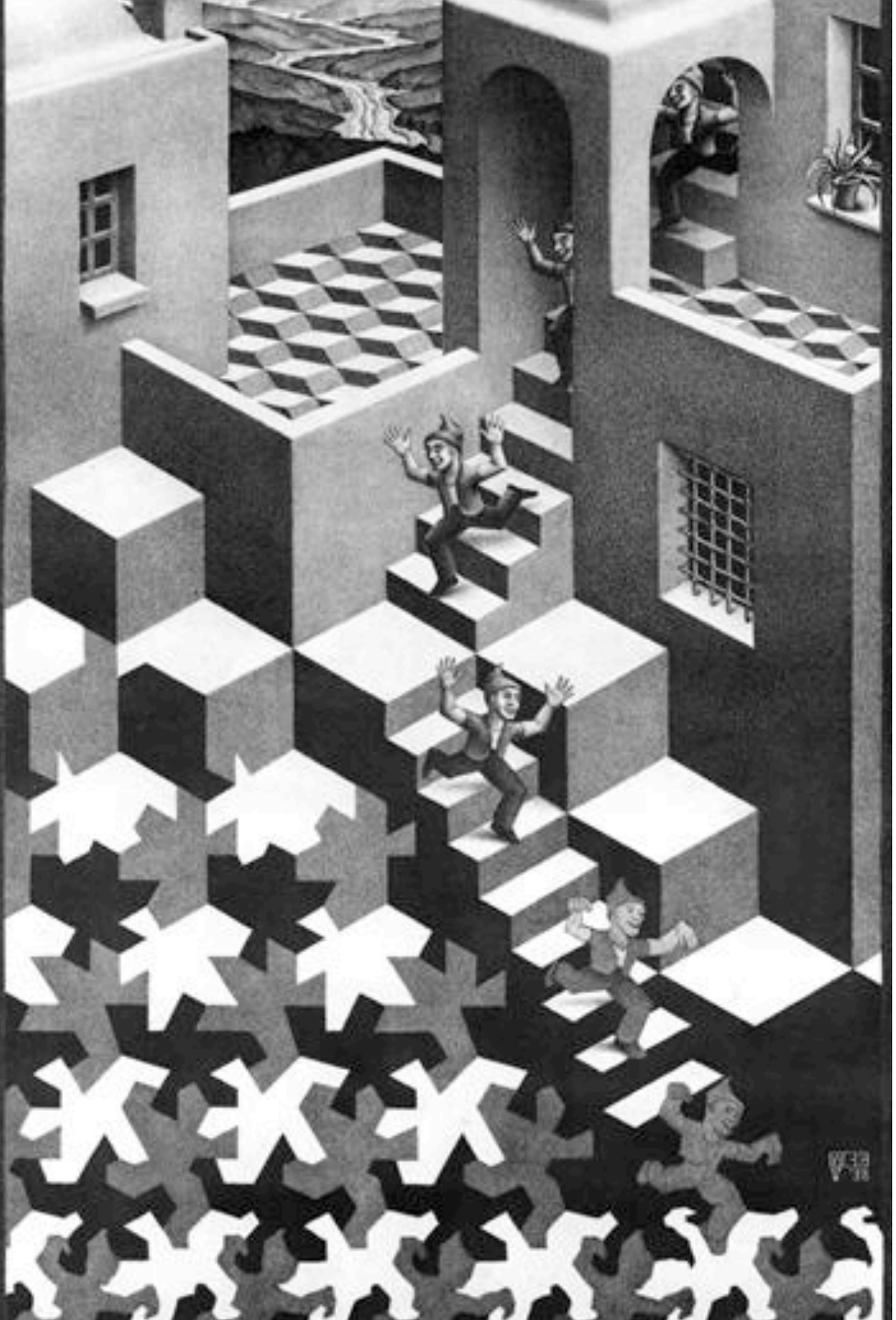
- Incorporating Types of Types in Ontology-Driven Conceptual Modeling, CM Fonseca, G Guizzardi, JPA Almeida, TP Sales, D Porello, International Conference on Conceptual Modeling, 18-34, 2021.

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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