UNIVERSITY OF TRENTO - Italy

LoD – The practice

(T2MP)

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- **Language of etype percepts**
- Language of composite etype percepts
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Alphabet

Definition (Alphabet A)*

$$A_T = < \{T\}, \{P\} >$$

where:

- $\{T\} = \{E_i\} \cup \{D_i\}$ is a set of unary predicates standing for **etypes** and **dtypes**;
- $\{P\} = \{O_i\} \cup \{A_i\}$ is a set of binary **properties**, where O_i is an **object property**, also called a **role**, and A_i is an **attribute**.

Observation (Alphabet of percepts). Similarly to LoE, A_T is an aphabet which denotes percepts in the domain (but denoting a different set of percepts).

*The elements of the alphabet are written in *italic* to distinsguish them from percepts

Formation rules – BNF

< $p_{\top}$ > ::= <etype> | <dtype> | ⊤ | ⊥

< etype > ::= ∃<objProp> .<etype> |
∃<dataProp>.<dtype> |
∀<objProp> .<etype> |
∀<dataProp> .<dtype>

<etype> ::= E_1 | ...| E_n

<dtype> ::= D_1 | ...| D_n

<objProp> ::= O_1 | ...| O_n

<dataProp> ::= A_1 | ...| A_n

Observation (BNF). This BNF does allow the iterative application of the formation rules on etypes (dtypes cannot be changed). It allows for the generation of etype percepts of any depth.

Observation (BNF). Entities are not mentioned (not part of the language). They are referred implicitly via the existential quantifier and also, somehow via the universal quantifier.

Interpretation of etype percepts

$I_T(\top)$ = U, with U the universe of interpretation

$I_T(\bot)$ = Ø, with Ø the empty set

$I_T(E_i) = E_i$

$I_T(D_i) = D_i$

$I_T(\exists P.T) = \{d \in U \mid$ there is an $e \in U$ with $(d, e) \in I_T(P)$ and $e \in I_T(T)\}$

$I_T(\forall P.T) = \{d \in U \mid$ for all $e \in U$ if $(d, e) \in I(P)$ then $e \in I_T(T)\}$

where I_T is the interpretation function of L_T

Observation (Interpretation function). For an intensional view of the interpretation functions for etypes, dtypes, object properties and attributes, follow what done with LoE.

Observation (Interpretation of nested etypes). It is sufficient to interpret the application of the second external quantifier to the etype built via the application of the first quantifier.

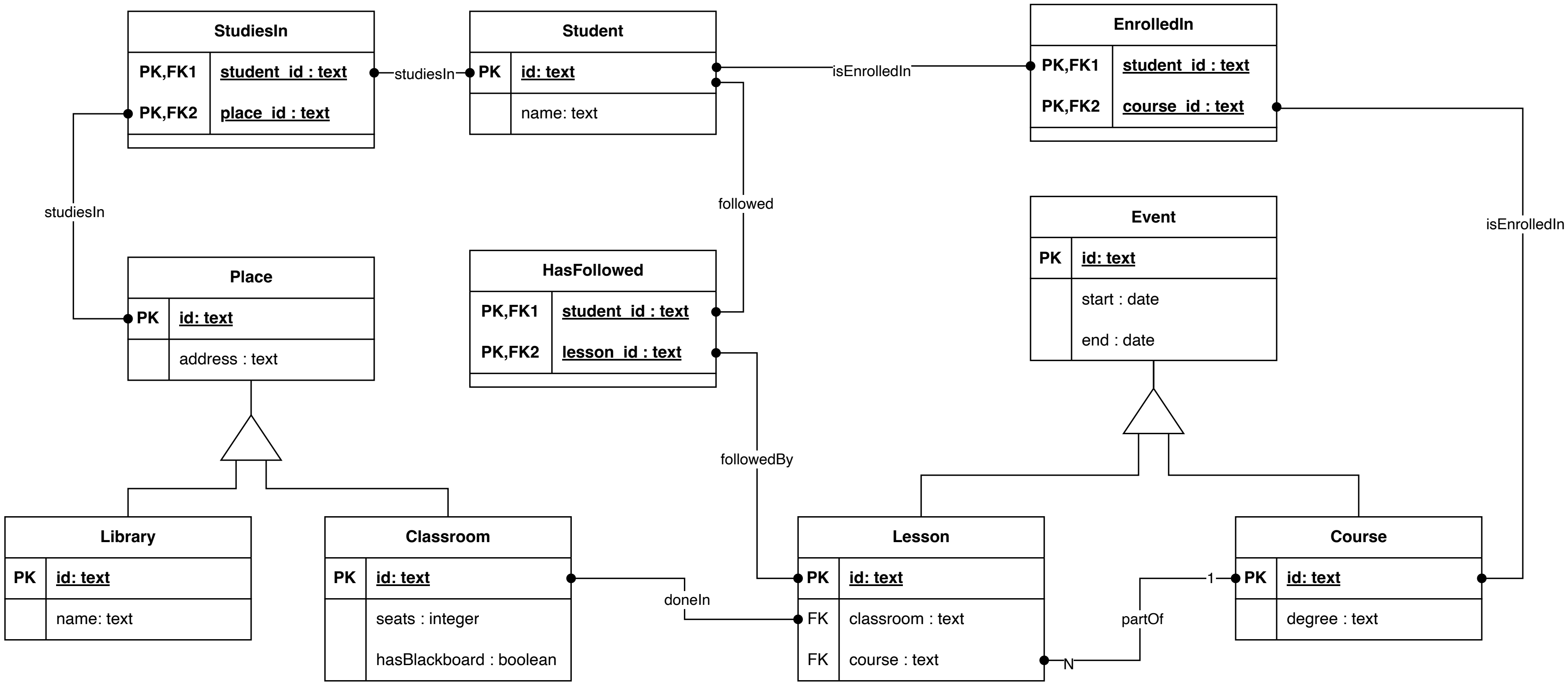
exercise 1 - Informal to formal (Language of etype percepts)

Formalize the following definitions in natural language using the Language of etype percepts.

- The set of entities that study in the Library. $\exists studiesIn.Library$
- The set of entities that reads Books. $\exists reads.Book$
- The set of entities that reads only Comic Books. $\forall reads.ComicBook$
- The set of entities that are friends with only entities that study in the Library. $\forall friendsWith.(\exists studiesIn.Library)$

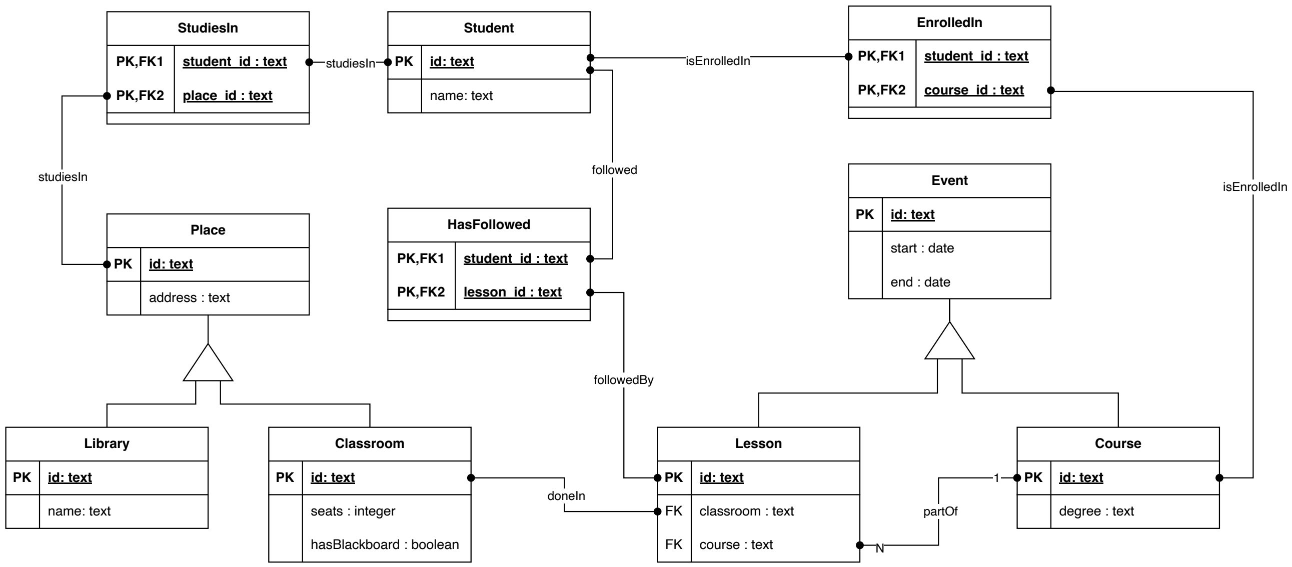
exercise 2 : Semiformal to Formal (Language of etype percepts)

Formalize using the Language of etype percepts the fact represented in the following EER diagram.



exercise 2 : Semiformal to Formal (Language of etype percepts)

Formalize using the Language of etype percepts the fact represented in the following EER diagram.



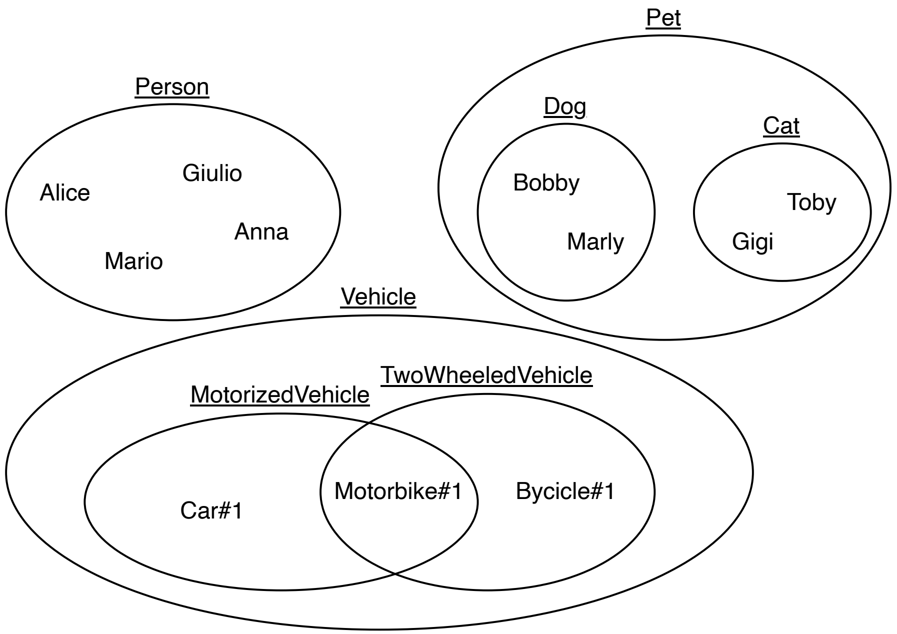
$Student$
$Place$
$Library$
$Classroom$
…

$\exists hasName.Text$
$\forall hasName.Text$
$\exists hasStart.Date$
$\forall hasStart.Date$
…

$\exists studiesIn.Place$
$\forall studesIn.Place$
$\exists studiesIn.Library$
$\forall studiesIn.Library$
$\exists studiesIn.Classroom$
$\forall studiesIn.Classroom$
…

exercise 4: Intended model (Language of etype percepts)

Given the following intended model, determine the set of entities represented by the assertions in language of etype percepts.



$< Alice, Toby > \in ownerOf$
$< Giulio, Gigi > \in ownerOf$
$< Anna, Marly > \in ownerOf$
$< Mario, Motorbike\#1 > \in ownerOf$
$< Anna, Bycicle\#1 > \in ownerOf$

$MotorizedVehicle$	$\{Car\#1, Motorbike\#1\}$
Pet	$\{Bobby, Marly, Toby, Gigi\}$
$\exists ownerOf.Pet$	$\{Alice, Anna, Giulio\}$
$\forall ownerOf.Cat$	$\left\{\begin{matrix} Alice, Giulio, Car\#1, \\ Motorbike\#1, Bycicle\#1, \\ Toby, Bobby, Gigi, Marly \end{matrix}\right\}$

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Formation rules – BNF

$$< p_C > \ ::= \ < p_C > \sqcap < a_C > \ |$$
$$< p_C > \sqcup < p_C > \ |$$
$$\neg < p_C >$$
$$< p_C > \ ::= \ < p_T >$$

Notation (BNF). $< p_C >$ is a nonterminal symbol and it stands for a p_C percept. $< p_T >$ is an L_C terminal symbol and it stands for an L_T percept. See the BNF of L_T to see how to expand it to a LoD terminal symbol.

Observation (BNF). This BNF does allow the iterative application of the formation rules. It allows to generate percepts of any depth.

Interpretation of composite etype percepts

$$I_C(p_1 \sqcap p_2) = I_C(p_1) \cap I_C(p_2)$$
$$I_C(p_1 \sqcup p_2) = I_C(p_1) \cup I_C(p_2)$$
$$I_C(\neg p_1) = U \setminus I_C(p_1)$$
$$I_C(p_T) = I_T(p_T)$$
$$I_T(p_T) = \mathrm{p}_T$$

where:

- I_C is the interpretation function of L_C
- I_T is the intepretation function for L_T, the language of etype percepts.
- p_1, p_2 are composite etype percepts
- p_T (in *italic*) is (the name of an) etype percept denoting the domain percept p_T (not in italic)

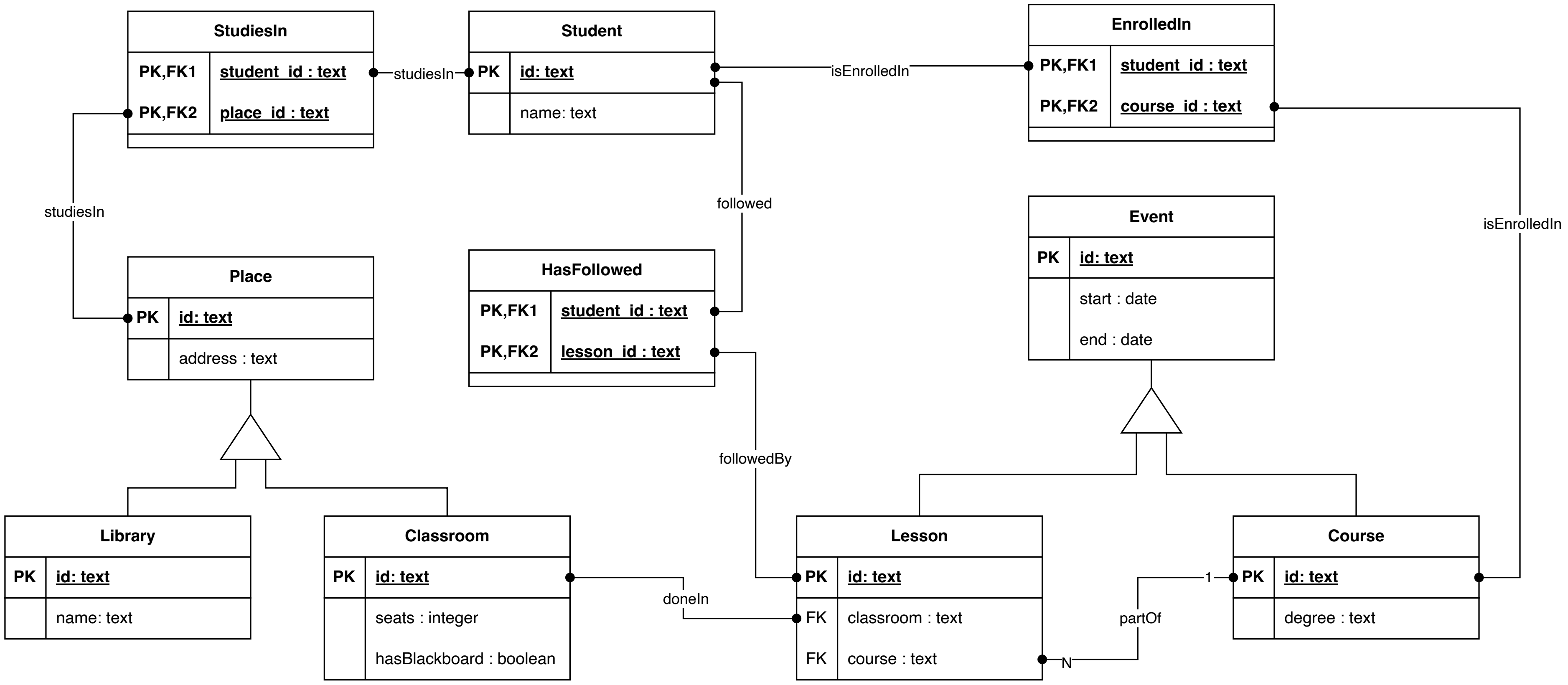
exercise 5 - Informal to formal (Language of composite etype percepts)

Formalize the following definitions in natural language using the Language of composite etype percepts.

- The set of Employees that work at the Library. $Employee \sqcap \exists worksAt.Library$
- The set of Black tea and Green tea. $BlackTea \sqcup GreenTea$
- The set of Persons that do not drink Green tea. $Person \sqcap \neg\exists drinks.GreenTea$
- The set of entities that drink anything but Black tea. $\forall drink.\neg BlackTea$

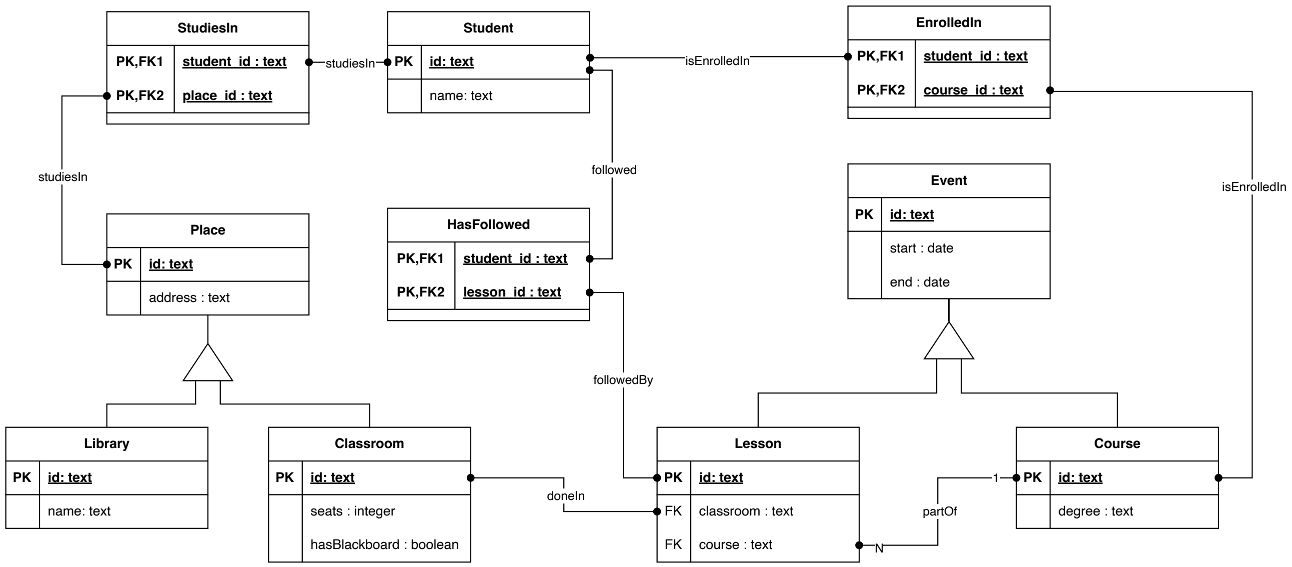
exercise 6 - semiformal to formal (Language of composite etype percepts)

Formalize using the Language of composite etype percepts the fact represented in the following EER diagram.



exercise 6 : Semiformal to Formal (Language of composite etype percepts)

Formalize using the Language of etype percepts the fact represented in the following EER diagram.



$Student \sqcap \exists studiesIn.Library$

$Student \sqcap \forall studiesIn.Library$

$Library \sqcup Classroom$

$Lesson \sqcap \exists partOf.Course$

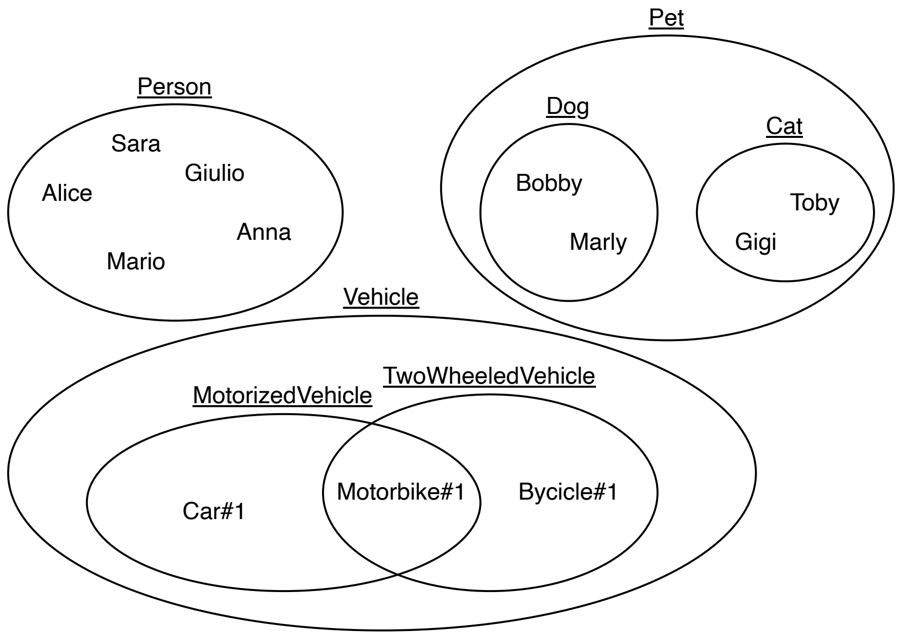
$Lesson \sqcup \exists hasName.Text$

$Place \sqcap \exists hasName.Text$

...

exercise 7: Intended model (Language of composite etype percepts)

Given the following intended model, determine the set of entities represented by the assertions in language of composite etype percepts.



$< Alice, Toby >\in ownerOf$
$< Giulio, Gigi >\in ownerOf$
$< Anna, Marly >\in ownerOf$
$< Mario, Motorbike\#1 >\in ownerOf$
$< Anna, Bycicle\#1 >\in ownerOf$

$Person \sqcap \exists ownerOf.\neg Pet$	$\{Mario, Anna\}$
$\neg Vehicle \sqcap \neg Dog \sqcap \forall ownerOf.\bot$	$\{Toby, Gigi, Sara\}$
$\exists ownerOf.(Pet \sqcap \neg Cat)$	$\{Anna\}$
$Person \sqcap \neg\forall ownerOf.Cat$	$\{Anna, Mario\}$

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(LoD) Descriptions – BNF

$$< a_{\text{LoD}} > ::= < p_{\text{C}} > \sqsubseteq < p_{\text{C}} > \mid < p_{\text{C}} > \equiv < p_{\text{C}} >$$

where:

- $< p_{\text{C}} >$ is a composite etype percept.
- a_{LoD} is a LoD description, an assertion involving two composite etype percepts.

Terminology (LoD Description). A **LoD description** describes how the extensions of two composite etype percepts correlate. It is a constraint which reflects back into the component etypes. We call the first a **subsumption** (description) and the second an **equivalence** (description).

Terminology (Subsumption). $\sqsubseteq$ is a **subsumption relation**. $p_1 \sqsubseteq p_2$ is to be read as p_1 **is subsumed by** p_2, or, vice versa that p_2 **subsumes** p_1.

Terminology (Equivalence). $\equiv$ is an **equivalence relation.** We have

$$p_1 \equiv p_2 \text{ if and only if } p_1 \sqsubseteq p_2 \text{ and } p_2 \sqsubseteq p_1$$

Exercise 8 - Informal to formal (Language of descriptions)

"Mechanical wrist watches are an accessory not powered by electricity".

$\text{MechanicalWatch} \sqcap \exists \text{wearedOn.Wrist} \sqsubseteq \text{Accessory} \sqcap \neg \exists \text{poweredBy.Electricity}$

"Wives and husbands are exactly all the married persons".

$\text{Wife} \sqcup \text{Husband} \equiv \text{Person} \sqcap \text{Married}$

"Birthdays and holidays are days in which you can have fun or rest"

$\text{Birthday} \sqcup \text{Holyday} \sqsubseteq \text{Day} \sqcap (\exists \text{doActivity.havingFun} \sqcup \exists \text{doActivity.Resting})$

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(LoD) Definitions – BNF

$$< a_{\mathrm{LoD}} > ::= < E > \sqsubseteq < p_{\mathrm{C}} > \mid < E > \equiv < p_{\mathrm{C}} >$$

$$< E > ::= E_1 \mid \ldots \mid E_n$$

where:

- $< E >$ is an atomic etype percept (an etype in $\mathrm{L_T}$).
- $E_1 \mid \ldots \mid E_n$ are (names of) etype percpets
- p_{C} is a composite etype percept.
- a_{LoD} is a **LoD definition**.

Terminology (LoD definition). A LoD definition is a LoD description that describes the extension of an atomic etype. It constrains the extension of $< E >$.LoD definitions allow to introduce new etypes by defining their extension.

Terminology (Etype subsumption, etype equivalence). The first definition is an **etype subsumption**. The second is an **etype equivalence**. Equivalences allow to precisely define the extension of $< E >$.

Exercise 9 - Informal to formal (Language of definitions)

"Wristwatches are exactly the watches that are worn on the wrist"

Wristwatch $\equiv$ Watch $\sqcap$ $\exists$wearedOn.Wrist

"Violinists are all the musicians that play the violin"

Violinist $\equiv$ Musician $\sqcap$ $\exists$play.Violin

"Monkeys are primates with opposable thumbs"

Monkey $\sqsubseteq$ Primate $\sqcap$ $\exists$has.OpposableThumb

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Exercise 10 - Unfolding

Given the following Tbox, unfold it into only primitive etypes.

Vehicle ≡ Thing ⊓ ∃travelsOn.T ⊓ ∃usedFor.Transportation

GasFueledVehicle ≡ Vehicle ⊓ ∃poweredBy.Gas

ElectricVehicle ≡ Vehicle ⊓ ∃poweredBy.Electricity

RoadVehicle ≡ Vehicle ⊓ ∀travelsOn.Road

Bus ≡ RoadVehicle ⊓ (ElectricVehicle ⊔ GasFueledVehicle) ⊓ PubliclyAvailable

Exercise 10 - Unfolding

Given the following Tbox, unfold it into only primitive etypes.

Vehicle ≡ Thing ⊓ ∃travelsOn.T ⊓ ∃usedFor.Transportation

GasFueledVehicle ≡ Thing ⊓ ∃travelsOn.T ⊓ ∃usedFor.Transportation ⊓ ∃poweredBy.Gas

ElectricVehicle ≡ Thing ⊓ ∃travelsOn.T ⊓ ∃usedFor.Transportation ⊓ ∃poweredBy.Electricity

RoadVehicle ≡ Thing ⊓ ∃travelsOn.T ⊓ ∃usedFor.Transportation ⊓ ∀travelsOn.Road

Bus ≡ Thing ⊓ ∃usedFor.Transportation

⊓ ∃travelsOn.T ⊓ ∀travelsOn.Road

⊓ (∃poweredBy.Electricity ⊔ ∃poweredBy.Gas)

⊓ PubliclyAvailable

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Cyclic/Acyclic Tboxes and Terminologies

Definition (Uses). Let T be definitional TBox. Let $E \sqsubseteq p$ or $E \equiv p$ be a definition in T. Then we say that E **directly uses** E', where E' is an atomic etype, if E' occurs in *p.* We say that E **uses** E' if E' occurs in the right hand side of a definition of an etype mentioned in *p*, and so on recursively.

Observation (Uses). **"**Uses" is defined as the transitive closure of directly uses.

Observation (Acyclic definitional TBox). A definitional TBox is **acyclic** if

- There is no type that uses itself , and
- There are no two definitions of the same etype

Observation 1 (acyclic TBox). The second requirement avoids any type using itself.

Observation 2 (acyclic TBox). An acyclic Tbox avoids the following situation:

$$E_1 \sqsubseteq \dots E_2 \dots, \quad E_2 \sqsubseteq \dots E_3 \dots, \quad \dots \quad, \quad E_n \sqsubseteq \dots E_1 \dots$$

Definition (Terminology). A **Terminology** is an acyclic definitional TBox.

Observation (Terminology). Terminologies are key in the construction of human lexicons and knowledge.

Exercise 11 - Cyclic/Acyclic TBox

Check if the following TBoxes are Cyclic or Acyclic.

WristAccessory ≡ Accessory ⊓ ∃wearedOn.Wrist
NeckAccessory ≡ Accessory ⊓ ∃wearedOn.Neck
WristWatch ≡ Watch ⊓ WristAccessory
Necklace ≡ NeckAccessory ⊓ ∀hasFunction.Decorative

Acyclic

WristAccessory ⊑ Accessory
NeckAccessory ⊑ Accessory
WristAccessory ⊑ ¬NeckAccessory
WristWatch ≡ Watch ⊓ WristAccessory
Necklace ≡ NeckAccessory ⊓ ∀hasFunction.Decorative

Acyclic

Exercise 11 - Cyclic/Acyclic TBox

Check if the following TBoxes are Cyclic or Acyclic.

WristAccessory ≡ ¬NeckAccessory
NeckAccessory ≡ Accessory ⊓ ∃wearedOn.Neck
WristWatch ≡ Watch ⊓ WristAccessory
Necklace ≡ NeckAccessory ⊓ ∀hasFunction.Decorative
Accessory ≡ WristWatch ⊔ Necklace

Cyclic

Because "Accessory" is defined in terms of "WristWatch" and "Necklace" which are in turn defined in terms of "NeckAccessory" which is defined in terms of "Accessory".

WristAccessory ≡ Accessory ⊓ ¬NeckAccessory
NeckAccessory ≡ Accessory ⊓ ¬WristAccessory
WristWatch ≡ Watch ⊓ WristAccessory
Necklace ≡ NeckAccessory ⊓ ∀hasFunction.Decorative

Cyclic

Because "WristAccessory" and "NeckAccessory" are both defined in terms of the other.

Exercise 12 - Terminology

Check if the following TBoxes are a Terminology.

WristAccessory ≡ Accessory ⊓ ∃wearedOn.Wrist
NeckAccessory ≡ Accessory ⊓ ∃wearedOn.Neck
WristWatch ≡ Watch ⊓ WristAccessory
Necklace ≡ NeckAccessory ⊓ ∀hasFunction.Decorative

Terminology

WristAccessory ≡ Accessory ⊓ ∃wearedOn.Wrist
NeckAccessory ≡ Accessory ⊓ ∃wearedOn.Neck
WristAccessory ⊑ ¬∃wearedOn.Neck
WristWatch ≡ Watch ⊓ WristAccessory
Necklace ≡ NeckAccessory ⊓ ∀hasFunction.Decorative

Not a Terminology

Because it includes a description of "WristAccessory"

WristAccessory ≡ Accessory ⊓ ∀wearedOn.Wrist
NeckAccessory ≡ Accessory ⊓ ∀wearedOn.Neck
WristWatch ≡ Watch ⊓ ∃wearedOn.Wrist ⊓ ¬Accessory
Necklace ≡ NeckAccessory ⊓ ∀hasFunction.Decorative
Accessory ≡ ∃wearedOn.T ⊓ ¬WristWatch

Not a Terminology

Because it's cyclic.

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Ask - Reasoning problems

Entailment

M $|= p_1 \sqsubseteq p_2$ iff $I(p_1) \subseteq I(p_2)$

M $|= p_1 \equiv p_2$ iff $I(p_1) = I(p_2)$

iff $I(p_1) \subseteq I(p_2)$ and $I(p_2) \subseteq I(p_1)$

with p_1, $p_1 \in L_{LoD}$.

LoD reasoning problems. The four LoD core reasoning problems are:

- T $|=$ C, **Satisfiability with respect to a TBox T**
- T $|=$ C $\sqsubseteq$ D, **Subsumption with respect to a TBox T**
- T $|=$ C $\equiv$ D, **Equivalence with respect to a TBox T**
- T $|=$ C $\perp$ D, **Disjointness with respect to a TBox T**

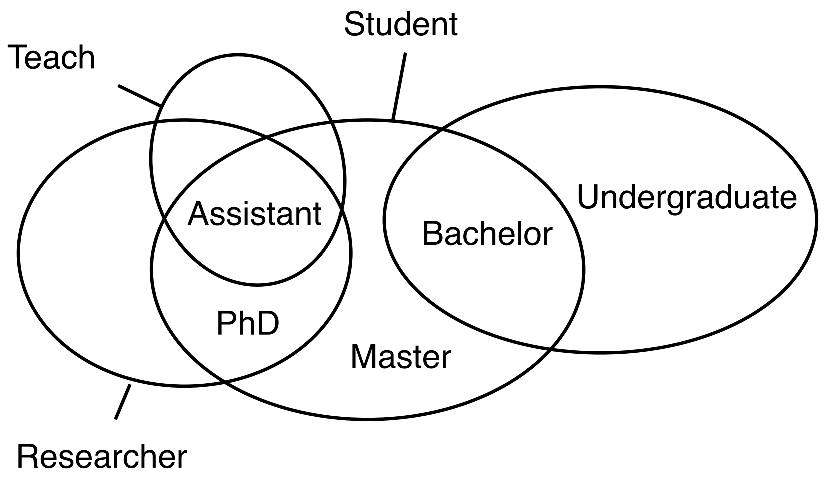
where T can also be empty.

Exercise 13 - Reasoning

Given the TBox below, determine if the assertions on the right are satisfiable using Venn diagrams.

M:

Undergraduate ⊑ ¬Teach
Bachelor ≡ Student ⊓ Undergraduate
Master ≡ Student ⊓ ¬Undergraduate
PhD ≡ Student ⊓ Researcher
Assistant ≡ PhD ⊓ Teach



M ⊨ Bachelor ⊓ PhD	No
M ⊨ PhD ⊑ Student	Yes
M ⊨ Student ≡ Bachelor ⊔ Master	No
M ⊨ Undergraduate ⊓ Assistant ⊑ ⊥	Yes

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Exercise 14 - Reasoning

Given the TBox below, determine if the assertions on the right are satisfiable using Unfolding.

M:

- Violinist ≡ Musician ⊓ ∀plays.Violin
- Musician ≡ Person ⊓ ∃plays.Instrument
- Violin ≡ StringedInstrument ⊓ ∃playedWith.Bow ⊓ ¬Viola
- Viola ≡ StringedInstrument ⊓ ∃playedWith.Bow ⊓ ¬Violin
- StringedInstrument ≡ Instruments ⊓ ∃has.Strings

M ⊨ Violin ⊑ Instrument	⊤
M ⊨ Violinist ⊑ Musician ⊓ ∀plays.Viola	⊥
M ⊨ Violin ≡ ¬Viola	⊥
M ⊨ Violin ⊑ ¬Viola	⊤
M ⊨ Viola ⊓ Violin ⊑ Musician	⊤

Exercise 14 - Reasoning

Given the TBox below, determine if the assertions on the right are satisfiable using Unfolding.

M:

- Violinist ≡ Musician ⊓ ∀plays.Violin
- Musician ≡ Person ⊓ ∃plays.Instrument
- Violin ≡ StringedInstrument ⊓ ∃playedWith.Bow
- Viola ≡ StringedInstrument ⊓ ∃playedWith.Bow
- StringedInstrument ≡ Instruments ⊓ ∃has.Strings

M ⊨ Violin ⊑ Instrument	⊤
M ⊨ Violinist ⊑ Musician ⊓ ∀plays.Viola	⊤
M ⊨ Violin ≡ ¬Viola	⊥
M ⊨ Violin ⊑ ¬Viola	⊥
M ⊨ Viola ⊓ Violin ⊑ Musician	⊥

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Ontology – a formalized lexicon

Definition (Genus-differentia definition, LoD definition). A genus-differentia definition is as follows

$$\text{Label} \equiv \text{Genus} \sqcap \text{Differentia}$$

where:

- There is a root primitive etype, also called the Root genus
- A genus is an etype (label in the definition above) defined by a genus-differentia definition, starting from the root genus.
- A differentia etype is an primitive etype never occurred before (above) in the hierarchy;
- For all siblings i, j of the same genus,

$$\text{Differentia}_i \perp \text{Differentia}_j$$

A Genus-differentia definition is a **LoD definition.**

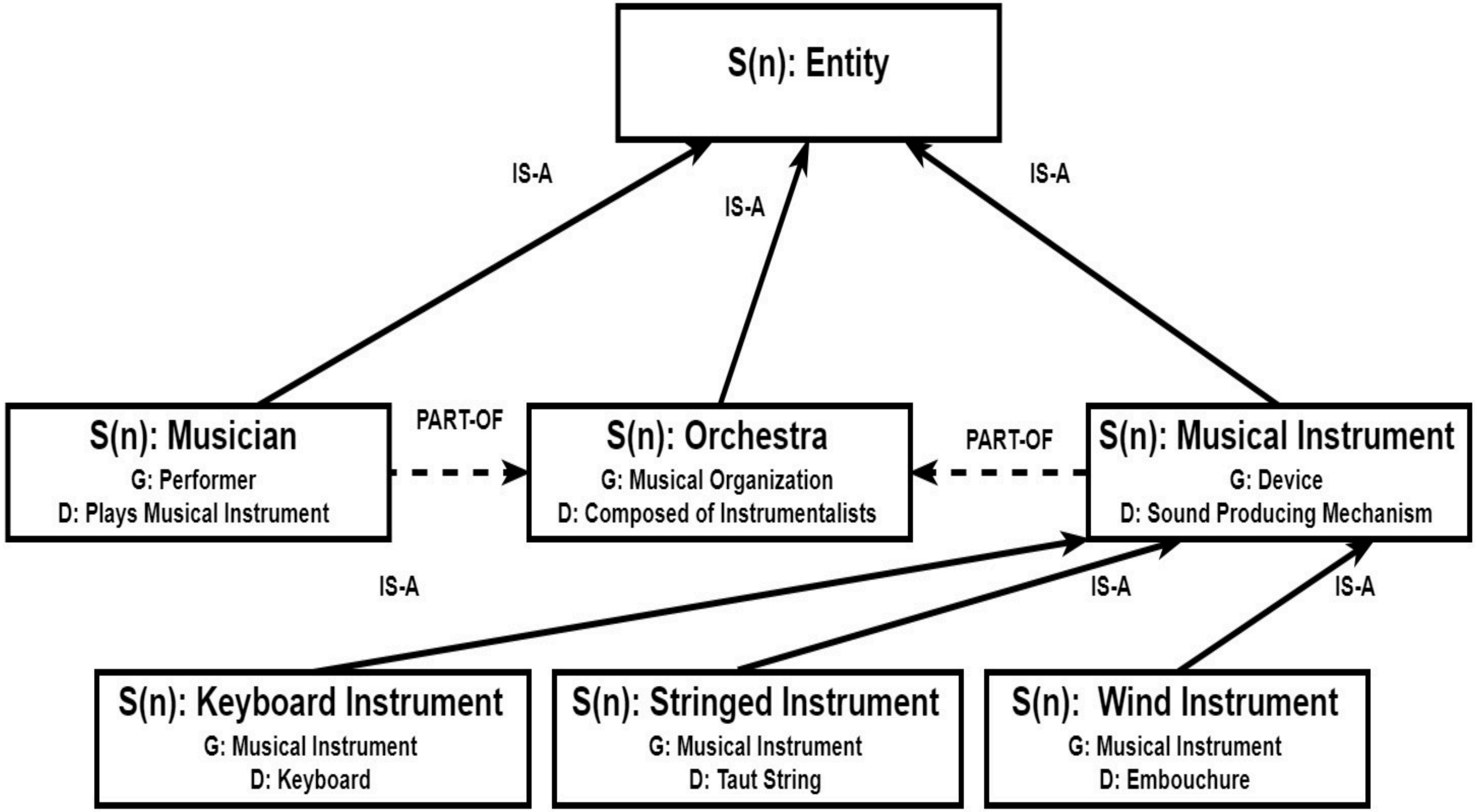
Definition (Ontology, LoD concept). An ontology is a terminology formalizing tree of nodes, each link associated with a genus-differentia definition, where:

- There is only on root genus;
- each node label but the root (genus) is defined with a genus-differentia definition;
- each node label but the root (genus) is defined only once (as from the definition of Tbox).

All labels in an ontology are **(LoD) concepts**.

Exercise 15 - Lexicon Formalization

Formalize the following lexicon into an Ontology.



Exercise 15 - Lexicon Formalization

Musician ≡ Performer ⊓ PlayMusicalInstrument

Orchestra ≡ MusicalOrganization ⊓ ComposedOfInstrumentalists

MusicalInstrument ≡ Device ⊓ SoundProducingMechanism

KeyboardInstrument ≡ MusicalInstrument ⊓ Keyboard

StringedInstrument ≡ MusicalInstrument ⊓ TautString

WindInstrument ≡ MusicalInstrument ⊓ Embouchure

Keyboard ⊥ TautString

Embouchure ⊥ Keyboard

TautString ⊥ Embouchure

Knowledge teleontology – a formalized EER model

Definition (Teleontology etype description). A teleontology etype description is as follows

$$\text{LabelEtype} \equiv \text{GenusEtype} \sqcap \text{GenusProperty}$$

where:

- There is a root etype, which is a concept
- A GenusEtype is an etype (LabelEtype in the definition above) defined by a LoD description, starting from the root concept.
- A GenusProperty is a conjunction of object and data properties.

We call any definition above a (**LoD**) **Description**. Label is a (**LoD**) **etype**.

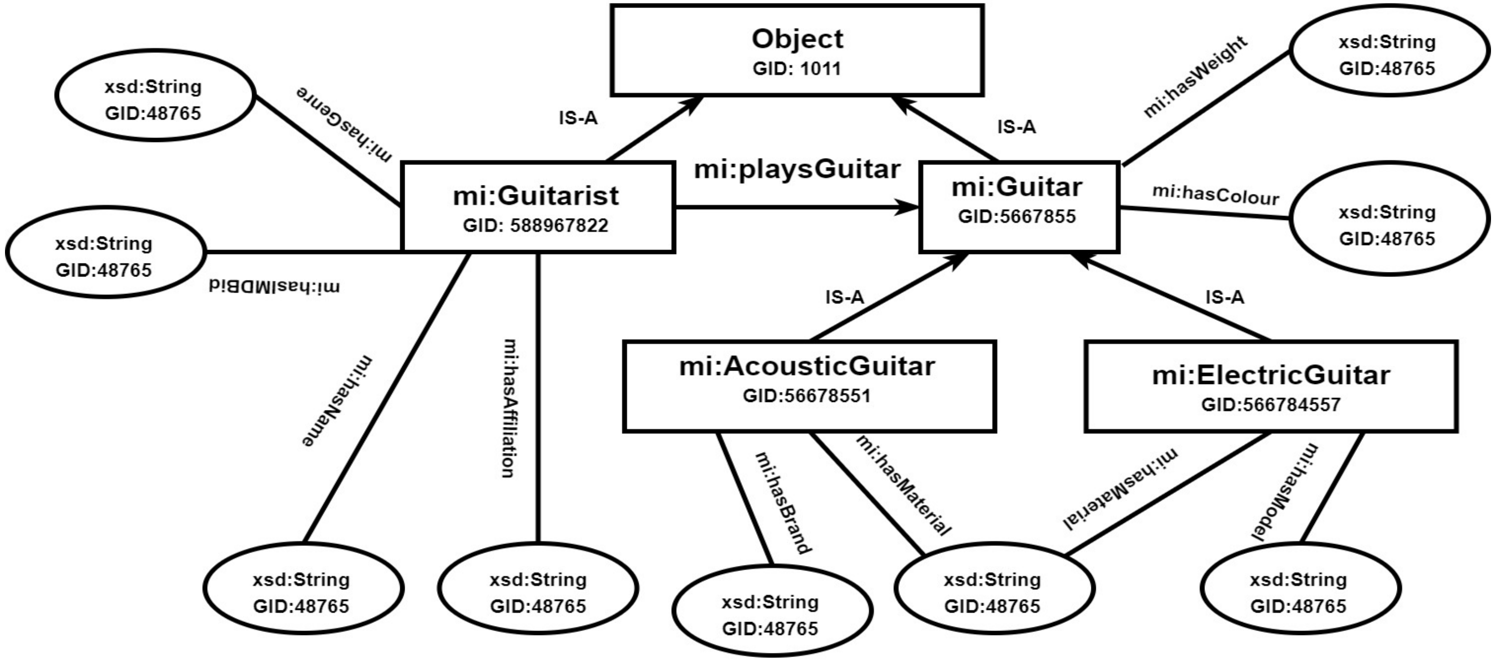
Definition (Knowledge Teleontology). A knowledge teleontology is a language teleontology, possibly consisting of a single genus-differentia definition, extended with a set of etype descriptions.

Observation (language vs. knowledge teleontologies). Language telentologies **define** the meaning of the concepts modeling the elements of the world. Knowledge teleontologies **describe** the properties of the language teleontology concepts by adding new etypes and by providing relevant properties.

Definition (Language teleontology). A language teleontology is any terminology which is a subtree of an ontology.

Exercise 16 - Lexicon Formalization

Formalize a Teleontology from the following EER, starting from the Language Teleontology below.



ElectrictGuitar ≡ Guitar ⊓ ElectricComponents

Guitarist ≡ Musician ⊓ PlayGuitar

Exercise 16 - Lexicon Formalization

ElectrictGuitar ≡ Guitar ⊓ ElectricComponents

Guitarist ≡ Musician ⊓ PlayGuitar

FamousGuitarist ≡ Guitarist ⊓ ∃hasAffiliation.String ⊓ ∃hasIMDBid.String

ColoredGuitar ≡ Guitar ⊓ ∃hasColor.String

SpecificGuitar ≡ Guitar ⊓ ∃hasModel.String ⊓ ∃hasColor.String

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LoD – The practice
(T2MP)