World models

(Informal notion)
(HP2T)

Index

- **Representations**
- World models - intuition
- (AR) Percept, fact, model, domain
- (LR) Alphabet, formation rules, sentence, theory, language
- (LR2AR) Interpretation function

Representations

Intuition 2.10 (Representations) A **representation** is a part of the world, developed by a human, that represents that human's mental representation of the world

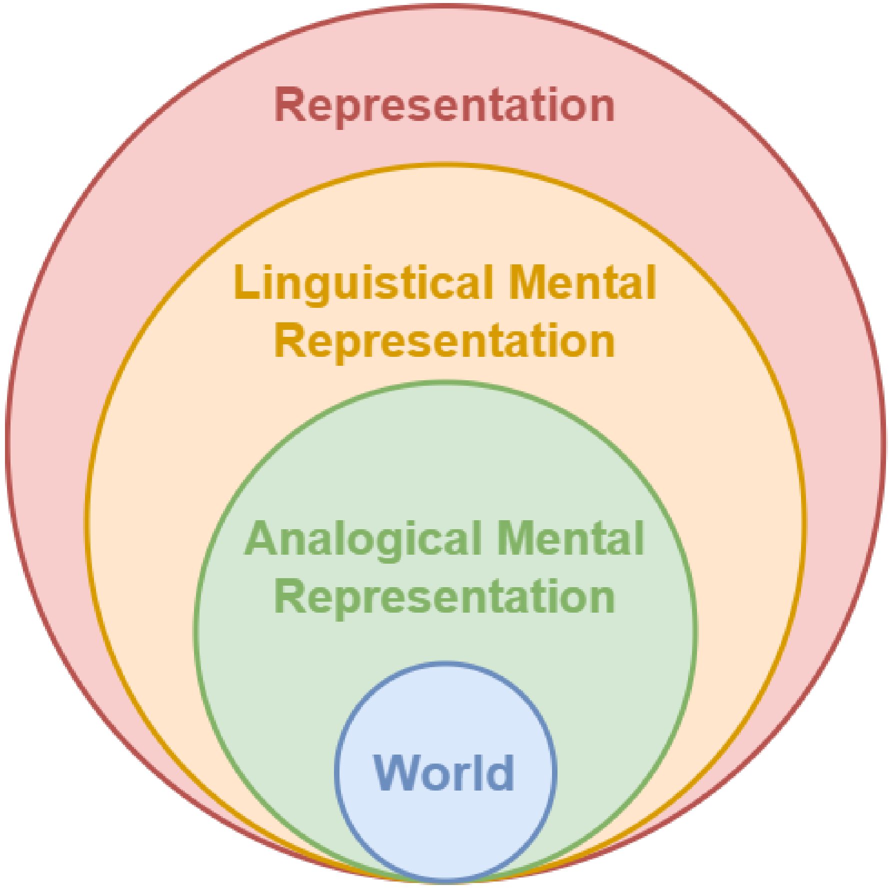
Representations are **accessible**, via one of the five senses, to other humans.

A representation can be perceived, in the same way as the reality it represents. The perception of a representation and of its represented reality can be compared for similarity checking.

Intuition 2.11 (Representations) Representations are the objectivation of mental representations. They allow humans

- to make public their mental representations,
- to communicate their mental representations,
- to build long standing public memories of their mental representations.

Representations (continued)



Two types of representation

- **Analogical representations**
- **Linguistic representations**

Representations

Intuition 2.11 (Analogical Representations) Analogical representations **depict** analogical mental representations.

Examples (Analogical representations). Photos, videos, paintings, recordings (representation of what we see and hear, what about taste, tact, smell?)

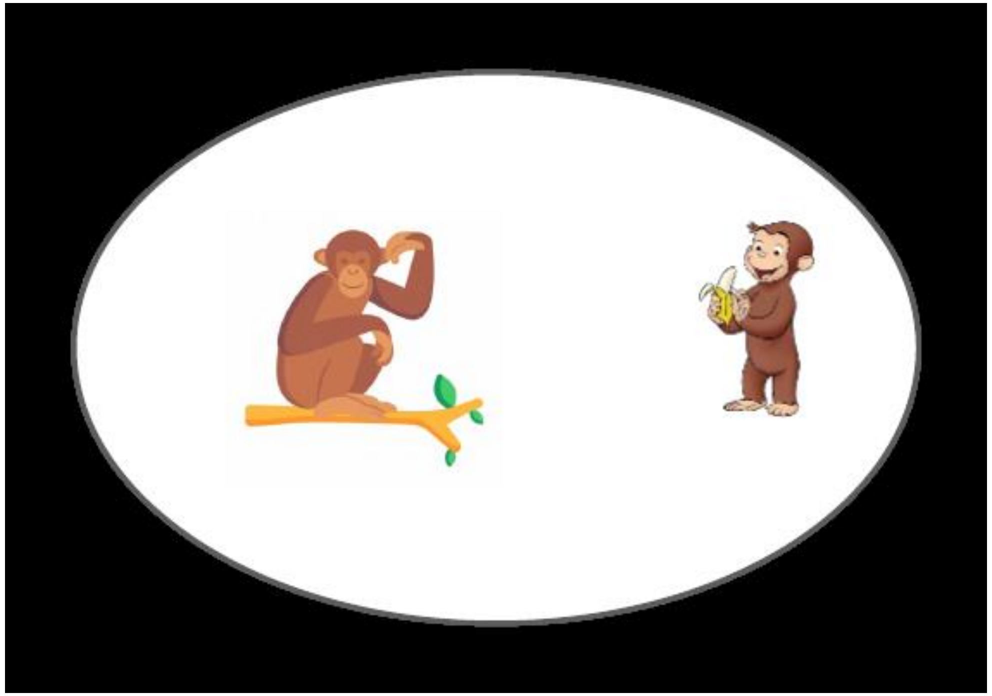
Intuition 2.12 (Linguistic Representations) Linguistic representations **describe** analogic mental representations.

Examples (Linguistic representations). What we represent using any natural language, the language of signs, Java, Python, ER / EER Graphs, tables

Intuition 2.11 (Analogical vs Linguistic Representations) How we build analogical representations is innate. We learn how to build linguistic representations. This is why all the CS teaching – till now – has focused on how to build linguistic representations.

Linguistic vs. analogical representations

- There is a tree
- There is a banana
- The monkey is eating a banana
- The monkey is sitting on a tree
- The monkey is scratching his head



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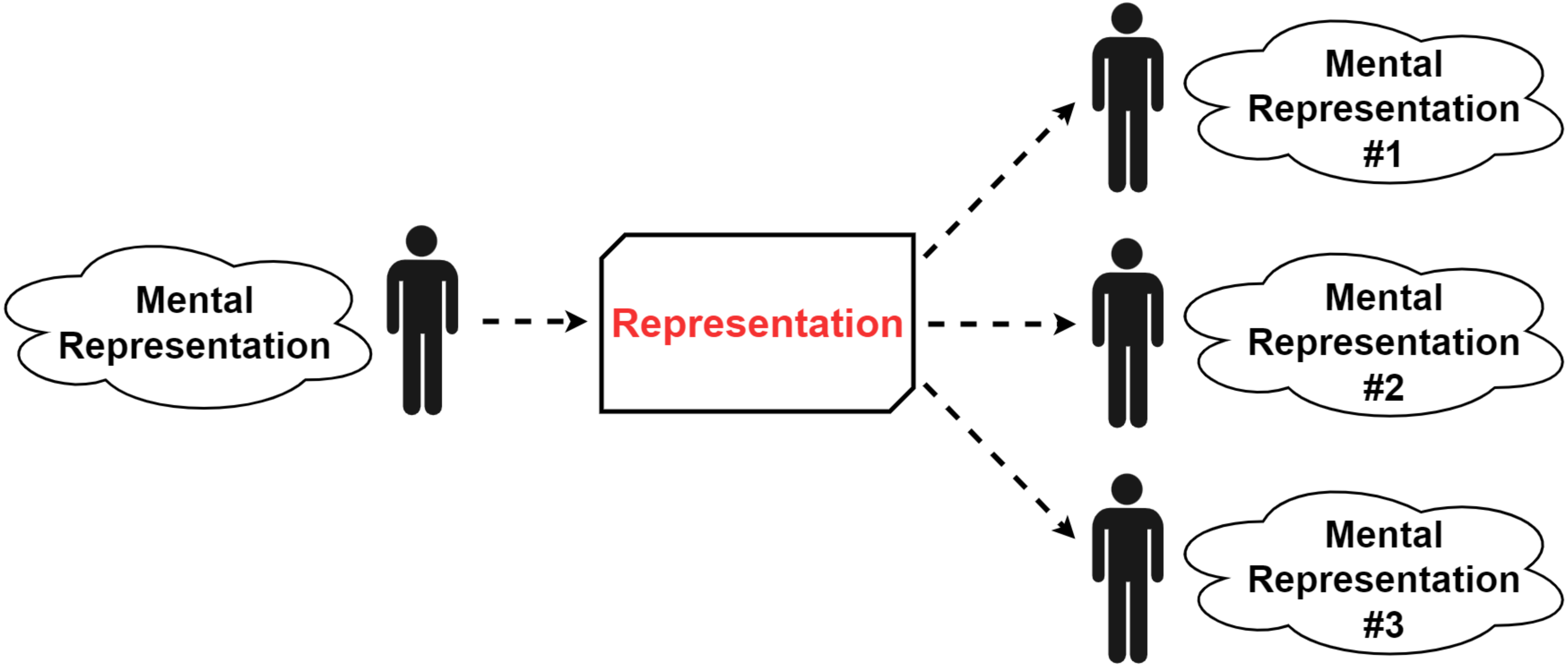
Mental representations of representations



Mental representations of representations (continued)

The previous slide may suggest that there is no solution to the problem of subjectivity of mental representations.

However this is not the case!

Representations are built with the goal of, minimizing the probability of different interpretations and, therefore, of mental representations.

Different interpretations still arise. Risk minimized (not eliminated) via SW and knowledge engineering methodologies.

World models - intuition

Intuition (World models): World models should encode

1. The information encoded in analogical (mental) representations (AR)
2. The information encoded in linguistic (mental) representations (LR)
3. The mapping from linguistic to analogical mental representations (LR2MR)

Key elements of World Model

Intuition (Elements of a World Model): World models need to represent four elements

1. Percepts organized into facts (as from AR)
2. Words (alphabet) organized, via formation rules, into sentences (as from LR)
3. Concepts as words mapped into percepts (LR2AR)

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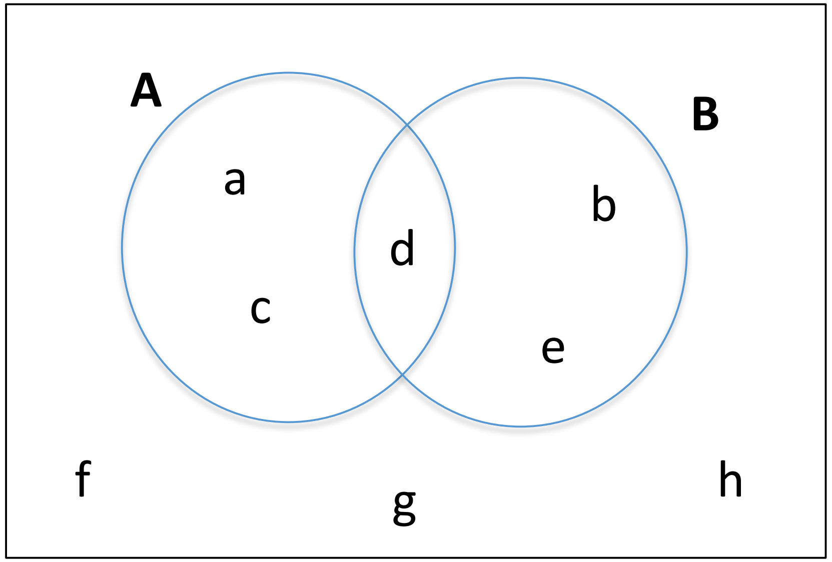
An analogical representation -What do you see?



- Entities
- Properties of entities
- Sets of entities with the same properties,
- Relations among entities,
- … which entities, properties, relations?

Analogical representations modeled in set theory!

Why set theory?

- It is self-evident
  - Entities as set elements
  - Entity types (i.e., similar entities) as sets
  - Relations among entities as relations
  - memberOf, subsetOf, ...
- It is universal, it can be used to represent ANY real world situation
- It is a language
- It is a language with a one-to-one mapping with its analogical «intended meaning»
- Analogical and linguistic representations coincide

Precepts

Intuition (precept) A **precept** is a thing which is perceived together (some of its) properties, as distinct from others.

Examples: The percepts denoted by the sentences below

1. *An entity you know,* e.g., Sofia, Paolo, Rocky (your dog)
2. *One or more entities you do not know*, e.g., one or more men (a set?),
3. *An entity you know but are not interested in describing*, e.g., a tree on the way to the university,
4. *An entity which is doing some act*, e.g., a moving train,
5. *An event evolving in time*, e.g. a lesson,
6. …

Facts

Intuition (Fact) A **fact** is something happening at certain spacetime coordinates.

Examples: The percepts and facts denoted by the sentences below

- *Spacetime invariant facts,* e.g., a bachelor is not a husband and vice versa, dogs are animals, Sofia is a woman
- *Time invariant facts,* e.g., there is a church in Trento
- *Space invariant facts,* e.g., moving across continents requires flying
- *Spacetime variant facts,* e.g., Sofia has blond hair, Sofia is a friend of Paolo, Sofia is walking, Paolo is talking to Sofia

Models

Definition 3.1 (Model) A **model** M is a set of facts M = {f}

M = {f}

Example: A possible model **M** is the set of facts described by the set of sentences below:

{*Sofia is a person, Paolo is a man,Rocky is a dog,*
Sofia is near Paolo,Sofia has blond hair, Sofia is a friend of Paolo,
*Rocky is an animal, Rocky is the dog of Sofia, ...***}**

Facts and models

Observation 3.2 (Facts and models) Facts are the atomic, not further decomposable, elements of a model. Note that, contrary to models, facts are a primitive notion and therefore cannot be formally defined

Observation 3.3 (The subjectivity of facts) Facts are what is observed and is also described, e.g., to third parties. Facts are subjective.

Observation 3.4 (Mutually (in)consistent facts in a model) The example model above could be extended by asserting the fact that Sofia is a woman. But NOT by adding the fact that Paolo is a woman, as we would have two mutually inconsistent facts, something that cannot happen in the world. A model cannot contain facts which are mutually inconsistent.

Models - limitations

Observation (limitations of models). Models have a main limitation. They consider only the facts of the model in focus. What about the many more facts which occur in all the other possible models, describing possibly very different, situations?

Domain of interpretation

Definition (Domain (of interpretation)). A Domain (of interpretation) is a set of facts {f}.

$$D = \{f\}$$

Definition (Model). Given a domain D, a model M is a subset of D.

$$M = \{f\} \subseteq D$$

Observation (Domain, model). A domain is the set of all facts that we are willing to consider. A model is just the subset of fact that we define as depicting what is the case in the current situation.

Models and domains

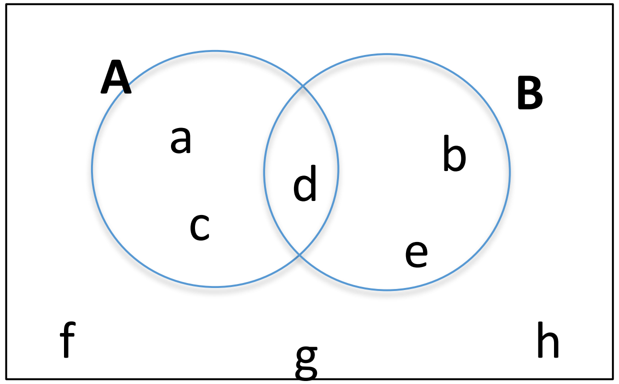
Observation (Domain) A Domain defines all and only what can be potentially perceived. It can be thought of as the set of all the possible things and also as the set of all the possible models.

Observation (Mutually inconsistent facts in a domain). A domain, differently from a model, can contain facts which are mutually inconsistent. Given a domain, there are many potential models, some of which are potentially mutually inconsistent.

Observation. Domains must allow for the possible instantiation of distinct mutually inconsistent models, as it is normally the case in the world.

Analogical representations in set theory

- A domain is the set of all elemens (and therefore of all the possible models constructed from its elements)
- A model is a specific set of elements, sets, relations
- A fact is a relation (element-set, set-set)
- A precept is an element



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Percepts and Alphabet (words)

Observation 3.5 (Percept) A percept, to be a percept, must be linguistically described as such.

The simplest way to think of an element of an alphabet is as a word which denotes some element of the domain of interpretation:

- a *name* naming an entity (e.g., *Stefania*),
- a *noun* naming a set (e.g., *person, female*),
- a *noun* naming a relation (e.g., *friend, owner*),
- a *verb* naming a relation (e.g., to *talk to, to walk with*),

Facts and assertions

Observation 3.5 (Facts and assertions) A fact, to be a fact, must be linguistically described as such.

It is not by chance that above we pointed to facts via a set of "simple" **sentences** which map 1-to-1 to facts. We call such sentences, **assertions**.

The simplest way to think of an assertion is as a declarative natural language sentence obtained by composing **words** via **formation rules**:

- a *subject* being a member of a certain class (as in, e.g., "*Stefania is a woman*"),
- a *subject* being in some more or less complex *relation* with an or *object* (as in, e.g., "*Stefania is walking with the dogs towards the city center*"),
- of a *subject* holding a certain more or less complex property (as in, e.g., "*Stefania is blond*").

Assertional theories

Observation 3.6 (Assertions and assertional theories) Assertions are indivisible, we say atomic, descriptions of fact. **Assertional theories** are descriptions of models

Intuition 3.2 (Assertion) An **assertion** a is an atomic **linguistic** representation of some fact f.

Definition 3.2 (Assertional theory) An **assertional theory** T_A is a set of assertions

$$\mathbf{T_A = \{}a\mathbf{\}}$$

Assertional theories - limitations

Assertional theories have two main limitations:

- We are considering only the facts of the model in focus. What about the facts which can occur in the other possible models, describing possibly very different, situations?
- The language consists only of the set of assertions which describe the facts of the model in focus. What about the assertions describing facts in the other models?

Language

Intuition 2.6 (Language). A **language** is any notation, generated by humans, agreed upon by humans, which allows to describe analogical representations.

Examples (Language). Any natural language, the language of signs, Java, Python, the graphic notation of ER / EER Graphs, or of tables.

Observation (Language). Defined in terms of a **grammar**, that is **alphabet** and **formation rules**. Alphabet and formation rules allow to costruct descriptions of the world, i.e., **sentences**.

Observation (A hierarchy of complexity of languages). L0, L1, L2, L3 – The Chomsky hierarchy.

Assertional languages and theories

Definition (Assertional language). An assertional language L_A is a set of assertions $\{a\}$

$$L_A = \{a\}$$

Definition (Assertional theory). Given an assertional language L_A, an assertional theory T_A is a subset of L_A.

$$T_A = \{a\} \subseteq L_A$$

Observation (Assertional language). An assertional language consists of the set of assertions which describe all the facts that can potentially occur (i.e., the domain of interpretation).

Assertional languages – completeness and correctness

Observation (Completeness and correctness of an assertional language L$_A$ with respect to a domain D). An assertional language is not necessarily complete, that is, it does not necessarily contain assertions for all the facts in a domain (which, among other things, are in principle infinite). The key feature is that is should contain all the assertions deemed relevant.

Vice versa an assertional language is requested to be correct, that is to contain only assertions which denote facts in the reference domain. This in order to avoid nonsensical assertions.

Assertional languages – Examples

1. Relational databases (DBs) describe facts about the world. The language used to describe the contents of a relational DB are tables;

2. Entity-relationship (ER) models describe general facts about the contents of databases. The are written using the ER diagram language, a specific labelled graph language

3. Languages which allow only for assertions in natural language of the form

   "<subject> <verb> <object>"

   describe facts about the world.

Examples of assertional languages

Relational databases (DBs) describe *data* about the world.

IsProfOf(Fausto,Marco)

Entity-relationship (ER) models describe *knowledge* about the world.

IsProfOf(Professor,Student)

Languages with assertions of the "<subject> <verb> <object>" can describe both data and knowledge about the world

IsProf(Fausto,Marco)
IsProfOf(Professor,Student)

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Interpretation function

Definition (Interpretation function) Let $\mathbf{L}_A$ **be a language of assertions** and **D a domain**. Then an **Interpretation Function** $\mathbf{I}_A$ is defined as

$$I_A : L_A \rightarrow D \ (I_A \subseteq L_A \times D)$$

We say that a fact f ∈ M is the interpretation of $a \in I_A$, and write

$$f = I_A(a) = a^I$$

to mean that a is a linguistic description of f.

We say that f is *the interpretation* of a, or, equivalently, that a *denotes* f.

Terminology (word, concept, percept). A word denoting a percept via an interpretation function is said to be a concept when referring to its intended meaning

Example (word, concept, percept). The word *car* denotes two concepts

Interpretation function (example)

- I_A(Sofia è una persona) = *Sofia ϵ person*
- I_A(Paolo è un uomo) = *Paolo ϵ man*
- I_A(Rocky is a dog) = *Rocky ϵ dog*
- I_A(Sofia is near Paolo) = *<Sofia, Paolo > ϵ near*
- I_A(Rocky è il cane di Sofia) = *{Rocky ϵ dog, <Sofia,Rocky > ϵ Owns}*
- I_A(Sofia è un'amica di Paolo) = *<Sofia, Paolo > ϵ friend*
- I_A(Sofia è bionda) = *Sofia ϵ blond*
- ….

Interpretation functions - observations

Observation (Interpretation function, non-ambiguity and synonymity) Interpretation functions, being functions, are not ambiguous thus not allowing for polysemous assertions and words, while allowing for synonymity.

Observation (Interpretation function, totality) Interpretation functions are total. This guarantees that any element of the language has an interpretation.

Observation (Interpretation function, non-surjectivity) Interpretation functions are not necessarily surjective. In other words, if $I_A : L_A \rightarrow D$, L_A may not be able to name all the facts in D. This property is useful with infinite domains or when one is not interested in mentioning all the known facts.

Interpretation function - polisemy

Observation 3.7 (Interpretation function, polysemy) I_A is assumed to be a function, that is, for any fact there is only one assertion describing it.

In fact, we must guarantee that, if two facts $f1$ and $f2$ are different then they cannot both be the result of the interpretation of the same assertion a, i.e., it cannot be that if $\mathrm{I}_A(a) = f1$ then also $\mathrm{I}_A(a) = f2$.

This phenomenon, called *polysemy,* is pervasive in natural languages. Think, e.g., of the words *car* and *Java*. (Average polysemy in the lexical resource *WordNet, the world de-facto* standard for lexical resources is around 2. To be introduced in one of the next lectures)

Interpretation function - synonymity

Observation 3.9 (Interpretation function, synonymity) Two assertions are synonyms when they have the same meaning, that is, the interpretation of two different assertions $a1$ and $a2$, may denote the same fact f , i.e., $I_A(a1) = I_A(a2) = f$.

Synonymous words are again pervasive in natural languages (e.g., *car* and *automobile*).

In logic synonymity is not a problem.

In relational DBs synonymity is not allowed, essentially for efficiency reasons (so-called *unique name assumption*). In DBs different strings always mean different things.

Syntax and semantics

Terminology (Syntax and semantics). When talking about world models, people talks of **syntax** meaning the language of the world model, and of **semantics** meaning the domain of interpretation, associated to the syntax, via the **interpretation function.**

Key notions

- Representation vs. mental representation
- Percept, fact, model, domain
- Alphabet, formation rules, sentence, theory, language
- Interpretation function
- Syntax and semantics

World models

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