World models

(Informal to formal - 1)
(HP2T)

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- **Representations**
- World models – intuition
- (AR2LR) Percept and word
- (AR) Fact, model, domain
- (LR) Assertion, assertional theory, assertional language
- (LR2AR) Interpretation function
- Truth and Falsity

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

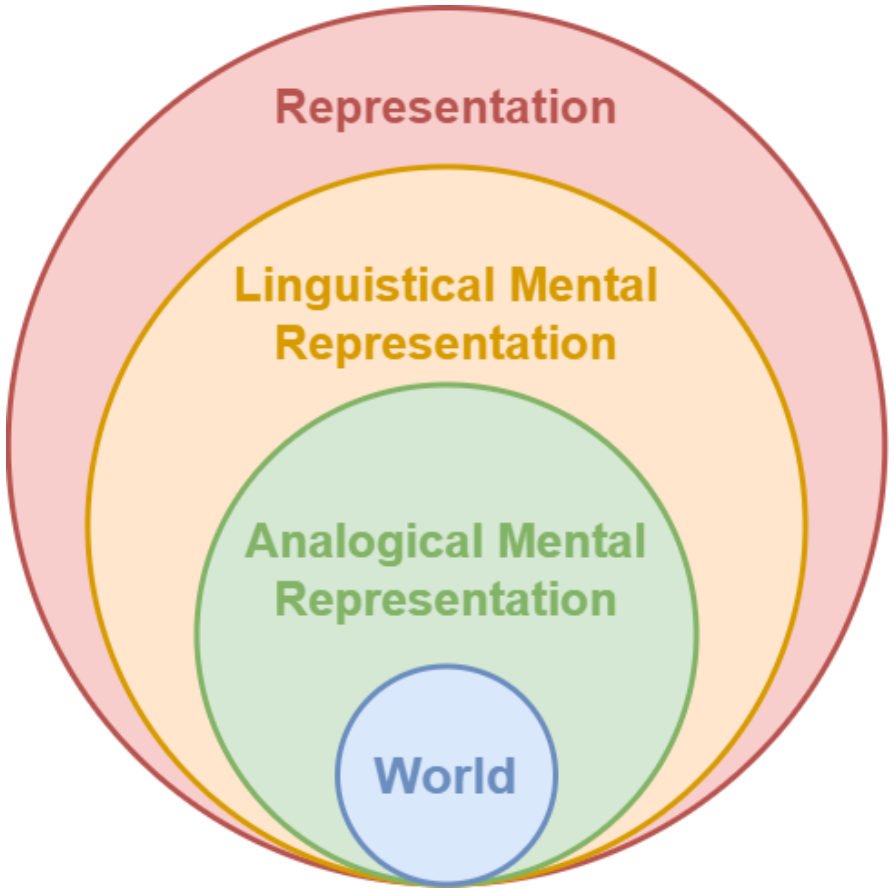
Representations are **accessible**, via one of the five senses, to other humans.

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?)

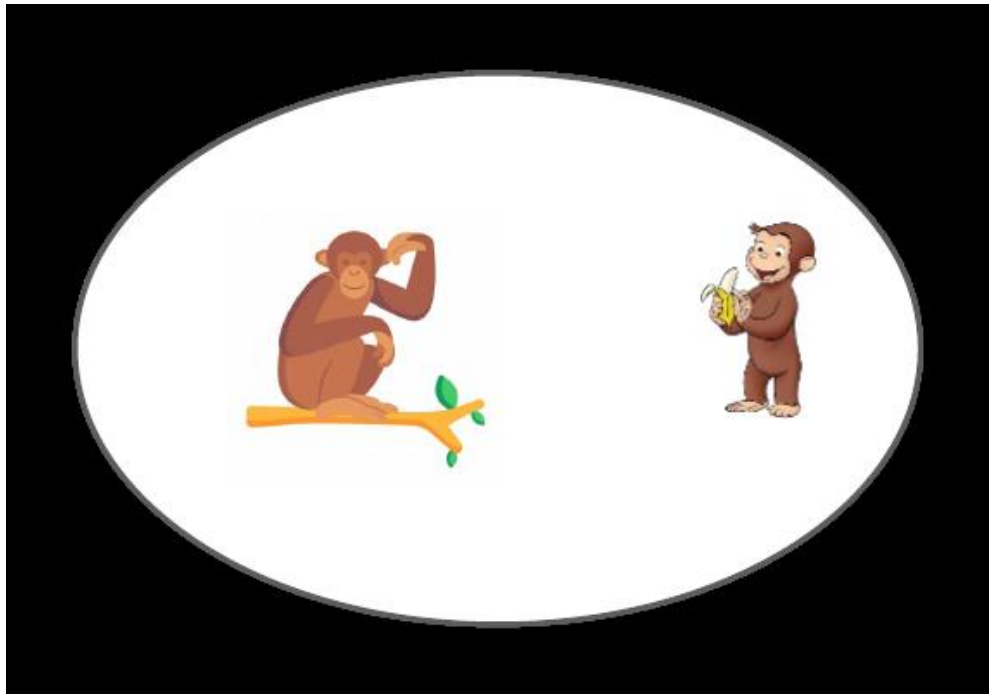
Intuition 2.12 (Linguistic Representations) Linguistic representations **describe** analogic mental representations.

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

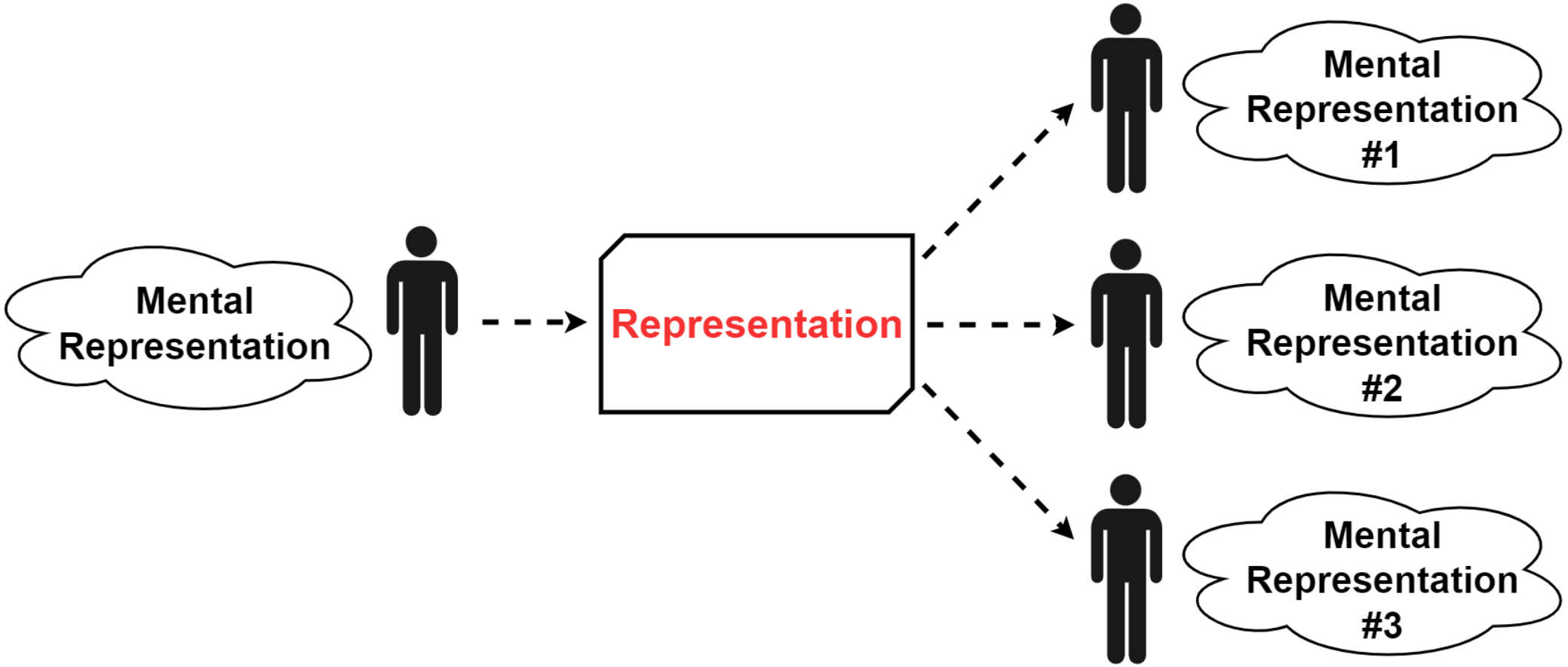
Intuition 2.11 (Analogical vs Linguistic Representations) How we build analogical representations is innate. We learn how to build linguistic representations. This is why all the CS teaching – till now – has focused on how to build linguistic representations.

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



Mental representations of representations



Mental representations of representations (continued)

Observation (Difficulty). The previous slide may suggest that there is no solution to the problem of subjectivity of mental representations. However this is not the case!

Observation (Requirement on representations). Representations are built with the goal of minimizing the probability of different interpretations and, therefore, of mental representations.

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

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World models - intuition

Intuition (World models): World models should encode

1. The information encoded in analogical representations (AR)
2. The information encoded in linguistic representations (LR)
3. The mapping from linguistic to analogical representations (AR2LR2AR)

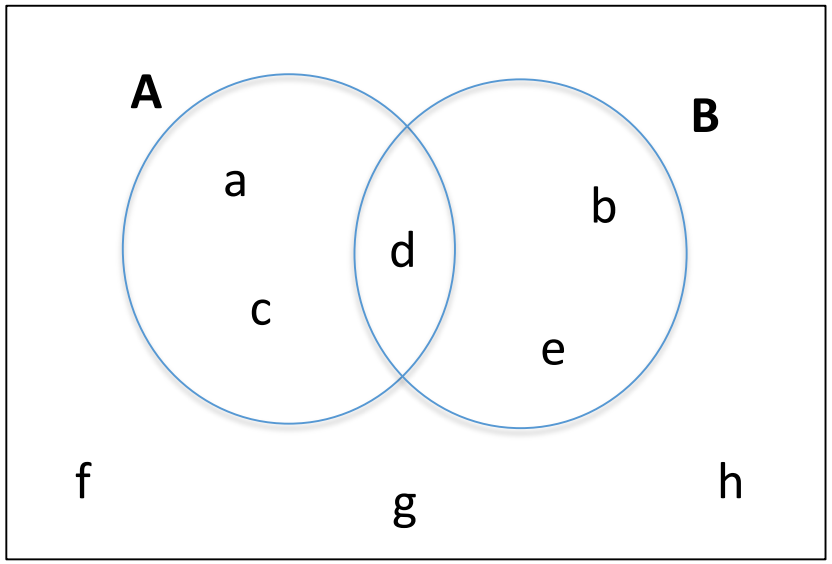
All the three components above should be encoded in a intuitive, univocal manner.

World Models – intuition (continued)

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

- Percepts and words conceptualizing them (AR2LR)
- Percepts organized into facts (as from AR)
- Sentences describing them (as from LR)
- Sentences mapped to facts via concepts (LR2AR)

An analogical representation -What do you see?



- Entities,
- Properties of entities,
- Relations among entities,
- Sets of entities (etypes) with the same properties,
- Properties of etypes,
- Relations among etypes

Analogical representations modeled in set theory!

Why set theory?

- It is self-evident – it formalizes dissimilarity (**entities**) and similarity (**etypes**) via **properties**, i.e., what is different from what and what is similar to what, and how entities and etypes interact (**relations**)
- It is universal – it can be used to represent ANY real world situation. Modulo details, any analogical representation can be reduced to a combintation of elements, sets, relations
- It is a language
- It is a language with a not ambiguous mapping between analogical and linguistic representations

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Percepts

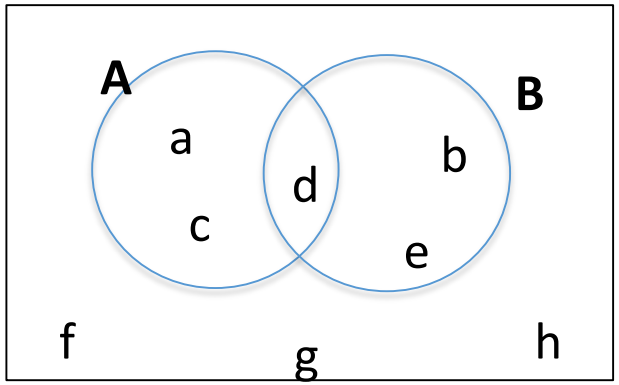
Intuition (percept) A **percept** is something which is perceived together (some of its) **properties**, as distinct from others.

Examples: The percepts denoted by the sentences below

1. *An entity you know,* e.g., Sofia, Paolo, Rocky (an entity)
2. *A blond person* (a property of an entity)
3. *Sofia near Paolo* (a relation between entities)
4. *A set of walking entities* , e.g., a set of men (an etype)
5. *People who are blond* (a property of an etypes)
6. *People talking to people* (a relation between etypes)

Percepts in set theory

- Entities as elements (e.g., Sofia, Rocky)
- Properties of entities as (binary) relations between elements (e.g., Sofia is blond)
- Relations between entities as (n-ary) relations among entities (e.g., Rocky is between Sofia and Mark)
- Etypes as sets of elements (e.g., person)
- Properties of etypes as (binary) relations between sets (e.g., Swedish people are blond)
- Relations among entity types as (n-ary) relations among sets (e.g., breaks happen between lectures)



Percepts and words (Alphabet)

Observation 3.5 (word, alphabet) A percept, to be a percept, must be linguistically described as such. **Words name** percepts. An **alphabet** is a set of words

Example (words). We have the following

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

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Facts

Intuition (Fact) A **fact f** is something, involving percepts, happening at certain spacetime coordinates.

Example (fact). Facts involving 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 near the square
- *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

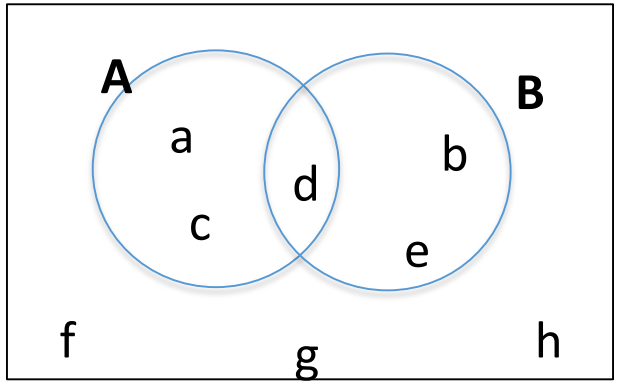
Observation (Domain) A Domain defines all and only what can be potentially perceived. It can be thought of as the set of all the possible things and also as the set of all the possible models.

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.

World models in set theory

- A domain is the set of all elements under consideration and, therefore, of all the possible models constructed from its elements
- A model is a specific set of elements, properties, sets, relations
- A fact is a property or a relation (element-element element-set, set-set)
- A precept is any component of the domain (as from above)



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Assertions

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

Intuition (Facts and assertions). An **Assertion** a is an **atomic sentence**, that is, a sentence which cannot be decomposed into simpler sentences, which unambiguously describes a single fact.

Assertions - continued

Observation 3.6 (Assertions and alphabet) Assertions are built from the **words of an alphabet**. This choice is arbitrary, it depends on which types of facts one wants to describe. This is why we have many different world models (e.g. ER models, EER models, DBs, ..., see exercizes)

Example (assertion). An obvious 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 (Assertional theories). Assertions are linguistic descriptions of facts. **Assertional theories** are linguistic descriptions of models

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

$$T_A = \{a\}$$

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 (alphabet + formation rules generating sentences) defined 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.

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., all the facts of the domain of interpretation).

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.

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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 the assertion a is a linguistic description of f.

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

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*
- ….

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Terminology – True / False

Terminology (True and False assertion).

- Given a domain D,
- given an assertional language L_A that we use to describe D,
- given and an interpretation function $I_A : L_A \rightarrow D$,
- given an intended model $M \subseteq D$ which depicts what are interested in

we say that an assertion

$a \in L_A$ is **True** if the fact $f = I_A(a) \in M$, **False** otherwise.

Observation (Truth / Falsity). The notions of Truth and Falsity are meaningful only if made with a reference model, called the **intended model.**

Terminology – Syntax and Semantics

Terminology (Syntax and semantics). When talking about world models, people informally talk 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.**

Observation (Syntax and semantics). Without a precise understanding of the intended semantics of a given syntax it is impossible to univocally assert whether a certain assertion (sentence) is true or false.

Key notions

- Representation vs. mental representation
- World model
- Analogical representation and set theory
- Percept, word, alphabet
- Fact, model, domain
- Assertion, assertional theory, assertional language
- Interpretation function
- Truth and Falsity
- Syntax and semantics

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