NJUAI 南京大学 人工智能学院
SCHOOL OF ARTIFICIAL INTELLIGENCE, NANJING UNIVERSITY

人工智能：知识表示与处理

赵一铮

南京大学人工智能学院

0

课程基本信息

南京大学
NANJING UNIVERSITY

Organizational

This course is taught by:

- 赵一铮 (zhaoyz@nju.edu.cn)

  with TAs:

- 邓一鸣 (mg21370004@smail.nju.edu.cn)
- 王森 (mg21370034@smail.nju.edu.cn)
- 肖棣月 (mushmnot@gmail.com)

Prerequisites: some familiarity with:

- mathematical logics (esp. first-order logic)
- programming with basic Java

Teaching mode:

- lectures (online at Tencent Meeting for Weeks 1 and 2,
  onsite at Yi-B 101 for the rest semester, provisional)

Organizational

Assessment:

- Assignments (50%)
- Final exam (50%)

Assignments released via PS:

- Five assignments in total, with each contributing 10%
- Immediately after lecture 3n (n = 1, 2, 3, 4, 5)

Solution submitted via PS:

- Due 2 weeks after each assignment release (e.g., 1st assignment to be released on 2nd March and solutions due on 16th March)
- Late submission (capped at 60%, unless having mitigating circumstances)

Marks & feedback given via PS

Assignments

Small questions:

- To ensure that you grasp the basics taught in lectures

Short essays of 200 – 500 words:

- To make you think
- To practice academic writing

Modeling tasks:

- To get your hands dirty
- To appreciate numerous ways in which things can be done

Programming tasks:

- To hone your Java programming skills
- Instructed stepwise by TAs and myself

Final Exam

Two hours – offline

EXAM PAPER MUST NOT BE REMOVED FROM THE EXAM ROOM

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KNOWLEDGE REPRESENTATION AND PROCESSING

Date: Sunday, 27th June 2021

Time: 10:30 - 12:30

This is an offline examination.
The examination contains NINE base questions and ONE bonus question.
Be sure to answer at least ALL base questions.

This is a CLOSED book examination

The use of electronic devices is NOT permitted

Question 10. Bisimulation (BONUS question)
Interpretations of ALC can be represented as graphs, with edges labelled by roles and nodes labelled by sets of concept names. More precisely, in such a graph

- each node corresponds to an element in the domain of the interpretation and it is labelled with all the concept names to which this element belongs in the interpretation;
- an edge with label r between two nodes says that the correspondsing two elements of the interpretation are related by the role r.

Definition 1 (Bisimulation) *Let $\mathcal{I}_1$ and $\mathcal{I}_2$ be interpretations. The relation $\bigotimes \subseteq \Delta^{\mathcal{I}_1} \times \Delta^{\mathcal{I}_2}$ is a* bisimulation *between $\mathcal{I}_1$ and $\mathcal{I}_2$ if:*

(i) $d_1 \bigotimes d_2$ implies $d_1 \in A^{\mathcal{I}_1}$ iff $d_2 \in A^{\mathcal{I}_2}$, for any $d_1 \in \Delta^{\mathcal{I}_1}$, $d_2 \in \Delta^{\mathcal{I}_2}$, and A any concept name;

(ii) $d_1 \bigotimes d_2$ and $(d_1, d_1') \in r^{\mathcal{I}_1}$ implies the existence of $d_2' \in \Delta^{\mathcal{I}_2}$ such that $d_1' \bigotimes d_2'$ and $(d_2, d_2') \in r^{\mathcal{I}_2}$, for any $d_1, d_1' \in \Delta^{\mathcal{I}_1}$, $d_2 \in \Delta^{\mathcal{I}_2}$, and r any role name;

(iii) $d_1 \bigotimes d_2$ and $(d_2, d_2') \in r^{\mathcal{I}_2}$ implies the existence of $d_1' \in \Delta^{\mathcal{I}_1}$ such that $d_1' \bigotimes d_2'$ and $(d_1, d_1') \in r^{\mathcal{I}_1}$, for any $d_1 \in \Delta^{\mathcal{I}_1}$, $d_2, d_2' \in \Delta^{\mathcal{I}_2}$, and r any role name;

Given $d_1 \in \Delta^{\mathcal{I}_1}$ and $d_2 \in \Delta^{\mathcal{I}_2}$, we define $(\mathcal{I}_1, d_1) \sim (\mathcal{I}_2, d_2)$ if there is a bisimulation $\bigotimes$ between $\mathcal{I}_1$ and $\mathcal{I}_2$ such that $d_1 \bigotimes d_2$, and say that $d_1 \in \mathcal{I}_1$ is bisimilar *to $d_2 \in \mathcal{I}_2$.*

Intuitively, d_1 and d_2 are bisimilar if (i) they belong to the same concept name and (ii) for each role name r, they have bisimilar r-successors.[1] Following the above definition, answer the questions below:

(1) Determine whether $a_1 \in \mathcal{I}_1$ is bisimilar to $b_1 \in \mathcal{I}_2$ as depicted in Figure 1. Justify your answers. (2 mark)
(2) Determine whether $a_1 \in \mathcal{I}_1$ is bisimilar to $b_1 \in \mathcal{I}_2$ as depicted in Figure 2. Justify your answers. (2 mark)
(3) Determine whether $a_2 \in \mathcal{I}_1$ is bisimilar to $b_2 \in \mathcal{I}_2$ as depicted in Figure 3. Justify your answers. (2 mark)
$\star$: a_i, b_j $(1 \leq i \leq 4, 1 \leq j \leq 5)$ are elements, M (Male) and F (Female) are concept names, and c (hasChild) is a role name.

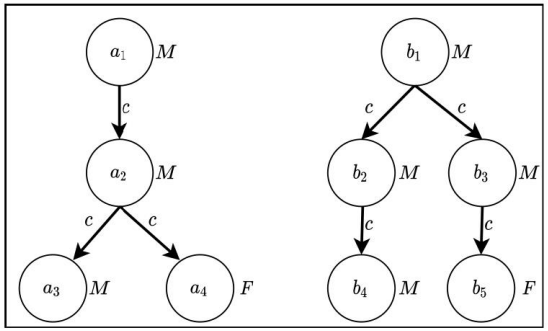

Figure 1: The interpretations $\mathcal{I}_1$ and $\mathcal{I}_2$ represented as graphs

[1] An element q is called an r-successor of an element p if the two elements are related via the relation r such that $r(p, q)$

*

关于“定义”

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Definitions

Extensional definitions:

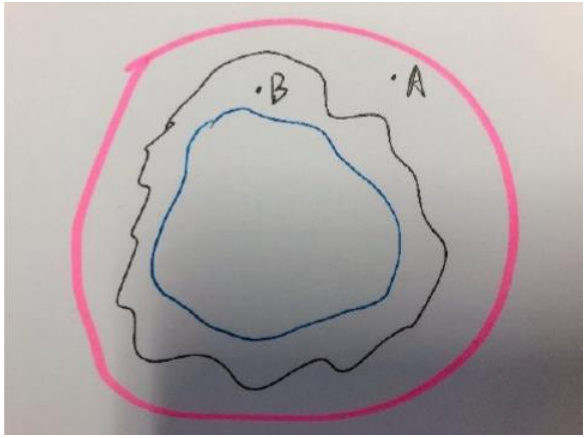
- Define a term by listing everything that falls under that definition
- E.g., Permanent Five: {China, France, Russia, UK, USA

Intensional definitions:

- Define by specifying necessary and sufficient conditions for when the term should be used
- E.g., Mother: a female who has children

Mother: a female who has children

Mother: a female who has 2 children



1

基于“计算”的人工智能

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What is artificial intelligence (AI)?

Intensional and imperfect definition of AI:

- the study of how to produce machines that have some of the qualities that human mind has, such as the ability to understand language, recognize pictures, solve problems, and learn
- Use artifacts (often machines) to simulate intelligent behavior

Definitions of intelligent behavior:

- Intensional: a group of general mental abilities
- Extensional: the ability to see, to hear, to smell, to feel, to think, to reason, to calculate, to communicate, to read, to understand, to imagine…to love
- Cannot find a perfect definition…

Definitions of intelligent behavior

Action (physical):

- the abilities to move, act…

Perception (physical & mental):

- the abilities to see, hear, smell, feel, or become aware of something through the senses (inputs)

Cognition (mental):

- the abilities to think, reason, calculate, communicate, or other mental processes of acquiring knowledge and understanding through thought, experience, and the senses (outputs)

Why AI is so important?

Generally speaking:

- to enhance the speed, precision and effectiveness of human efforts (to liberate productive forces and raise productivity)

Why AI is so powerful?

Generally speaking:

- Machines are computationally more powerful than humans, i.e., machines are more powerful for computation than humans
- Electrical energy superiority over bio energy
  - Faster processing of information (more efficient computation)
  - Better memory
  - Round-the-clock

Intensional definition of computation:

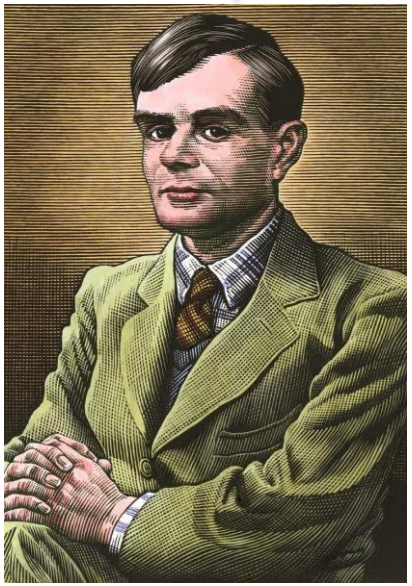
- Executes a set of instructions (called program) step by step
- Both arithmetical and non-arithmetical steps
- Relies heavily on mathematics

Subfields of AI

Yes, I posed questions but I proposed insights too!

To pass the Turing Test, a machine must possess (at least) the following capabilities:

1. to manipulate objects and move about (robotics)
2. to perceive objects (computer vision)
3. to allow it to communicate successfully in human language (natural language processing)
4. to store what it knows (knowledge representation)
5. to use the stored knowledge to answer questions and draw new conclusions (automated reasoning)
6. to adapt to new circumstances and to detect and extrapolate patterns (machine learning)



Pattern Recognition via Computation

An intelligent behavior:

- Input: an image

- Output: golden retriever (小金毛)
- Recognized in different ways:

  - via eyes and other bio-process for humans

  - via computation for machines

Language Understanding via Computation

An intelligent behavior:

- Input: a paragraph

> The metal porch swing virtually sizzled on the old wooden front porch today. But we sat there anyway. Gramma wouldn't hear of anything else. I suggested a walk through the forest, hoping to entertain a breeze or two and to take advantage of the shade. Gramma shook her head. You were supposed to sit on the porch after supper, and that's what we were going to do.

  - Question: This author implies that Gramma could not hear very well

- Output: no, but done in different ways:

  - via understanding and reasoning for humans

  - via computation for machines

All Done via Computation

Perception (physical & mental):

- the abilities to see, hear, smell, feel, or become aware of something through the senses (inputs – learning process)
- proper situations for machine learning

Cognition (mental):

- the abilities to think, reason, calculate, communicate, or other mental processes of acquiring knowledge and understanding through thought, experience, and the senses (outputs)

➢ Can machine learning do everything without help?

- hopefully yes, then we do not need to study this course, but unfortunately no☺

Limitations of Data-Driven AI

Consider a puzzle:

A Puzzle

You are on a strange island where people are divided into

- Knights – always saying the truth
- Knaves – always saying lies

You meet two natives of the island Alice and Bob, and ask them

"Are you knights or knaves?"

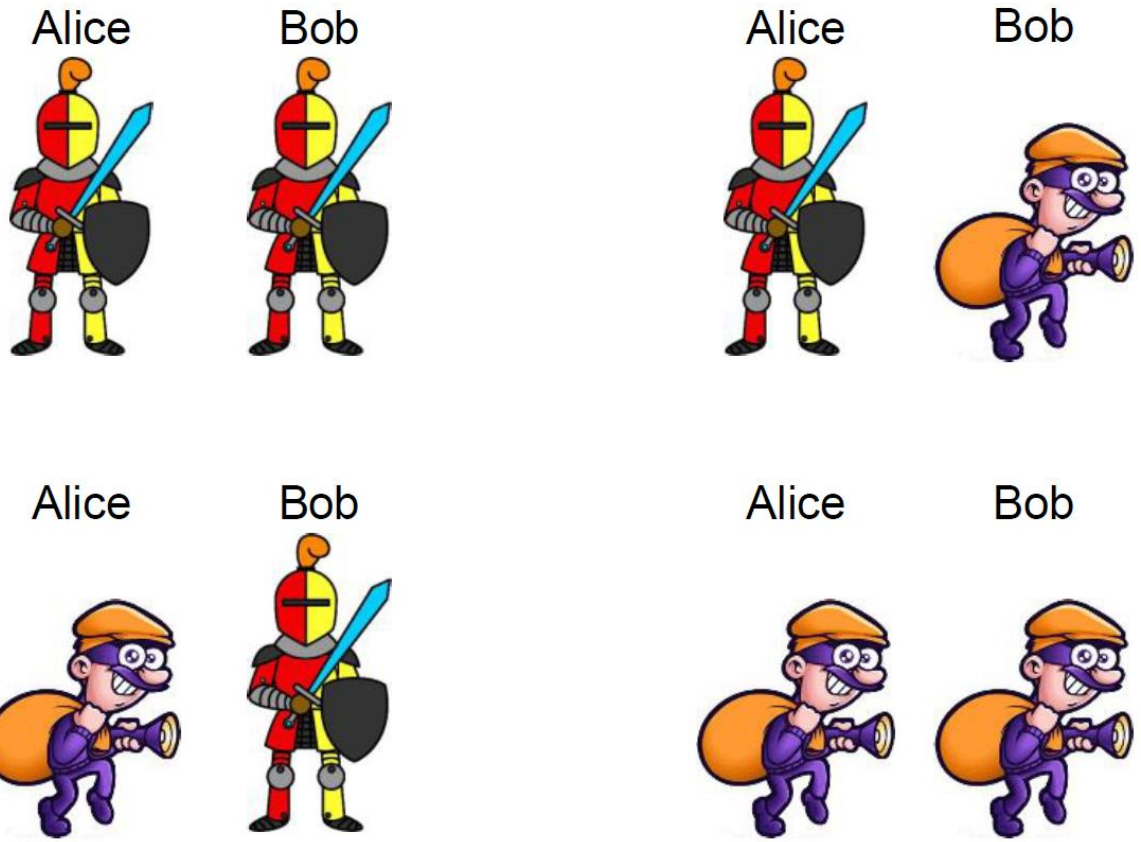
Alice answers *"At least one of us is a knave"*

What are Alice and Bob?

Limitations of Data-Driven AI

Consider a puzzle:

Alice: *"At least one of us is a knave"*



Limitations of Data-Driven AI

"I was lured into the world of machine learning while trying to discover the world of AI. I admit, it is exhilarating to make a computer do complex things to my liking without saying how it should do this. I ran riot in this world and have long forgotten my original goal whilst studying how to prepare data, engineer features and build deep networks"

Main limitations:

- the issue of the availability, quantity and quality of associated data often remained wanting
- the increased acceptance of artificial intelligence in the industry gave rise to fear, skepticism and resentment
- People replaced by a black box, though the outputs seem to be identical (an opaque box is required, particularly in some areas)

2

知识表示

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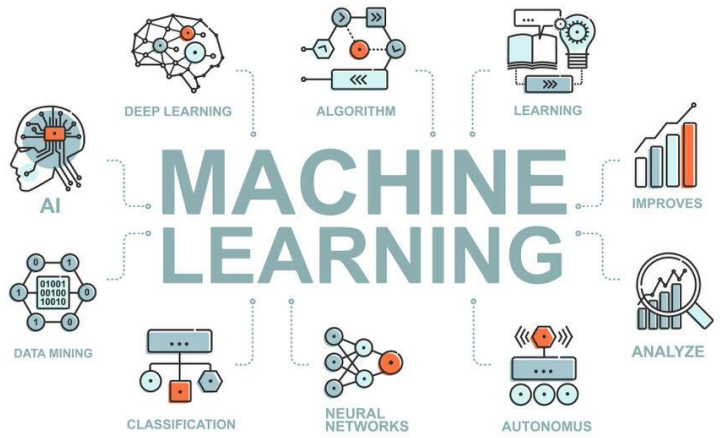
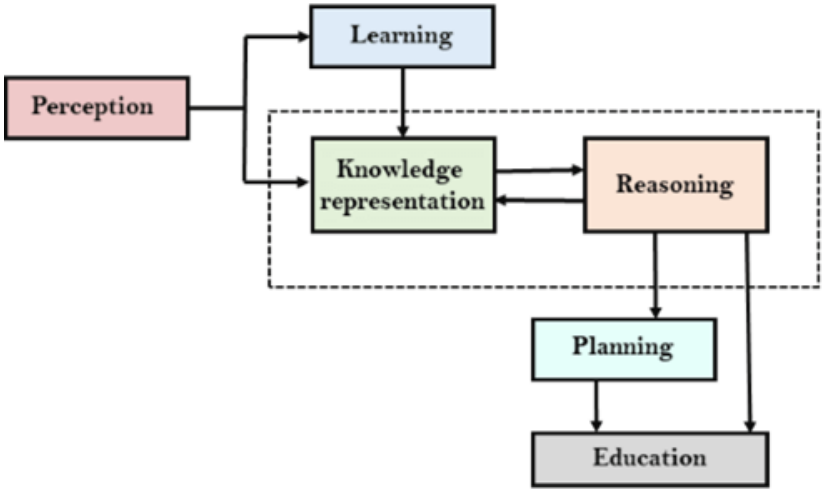
Two Crucial Facets of Intelligence



The ability to **learn from experience** and perform better when confronted with similar situations or adapt to new situations

The ability to maintain an internal (abstract) state of knowledge and **reason over that knowledge** to draw new conclusions

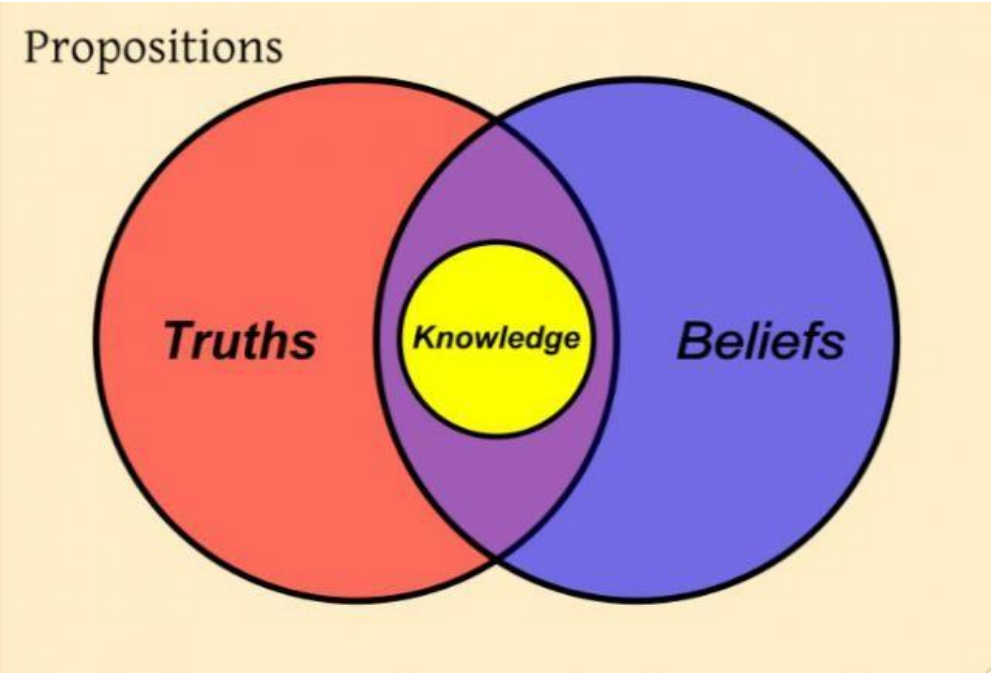


What is Knowledge?

"Knowledge": dates back to Ancient Greek

- not totally demystified
- relation between knower and proposition

e.g. John knows that P = Johns knows that it is true that P



"knows" vs "believes"

- more prop. attitudes: "hopes", "regrets", "doubts"…

- **Idea:** John takes the world in one way, not another

What is Knowledge Representation?

"Representation": as philosophically vexing as that of "Knowledge"

- not totally demystified
- relation between two domains

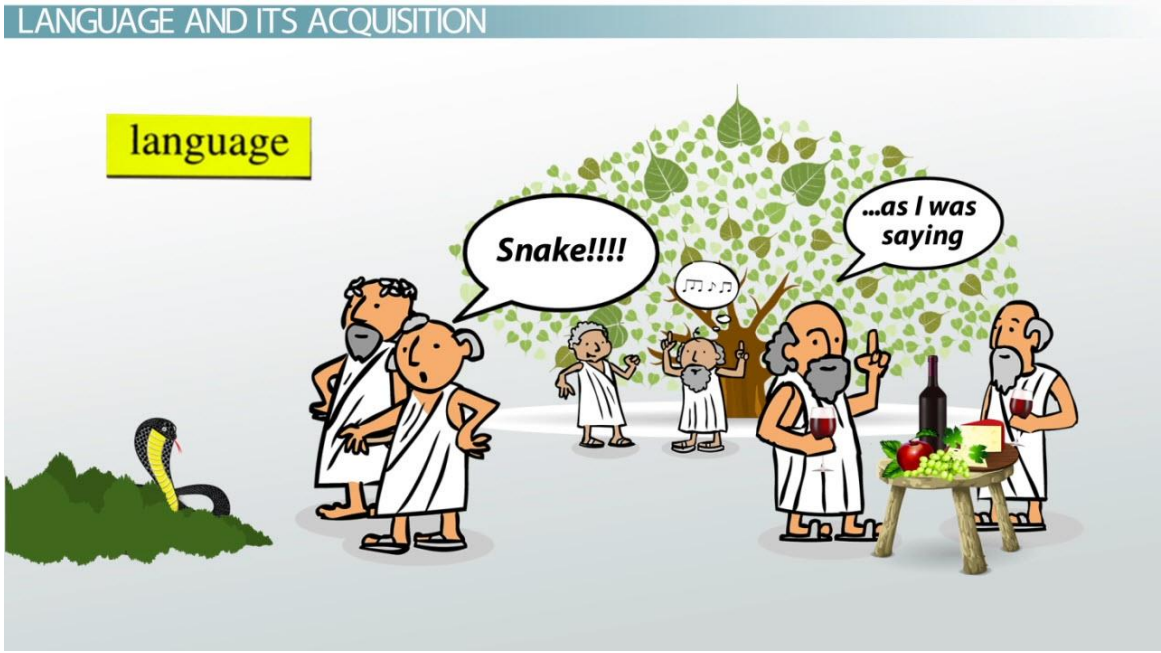
  - one domain **(representor)** stands for/takes place of another domain **(representee)**

- **representor**: more concrete, immediate, accessible in some way

How to Represent Knowledge?

“Natural Language” for human beings

Therefore must be **“human processible”**



Nigiri is a type of Sushi which has ingredient Rice and Fish

How to Represent Knowledge?

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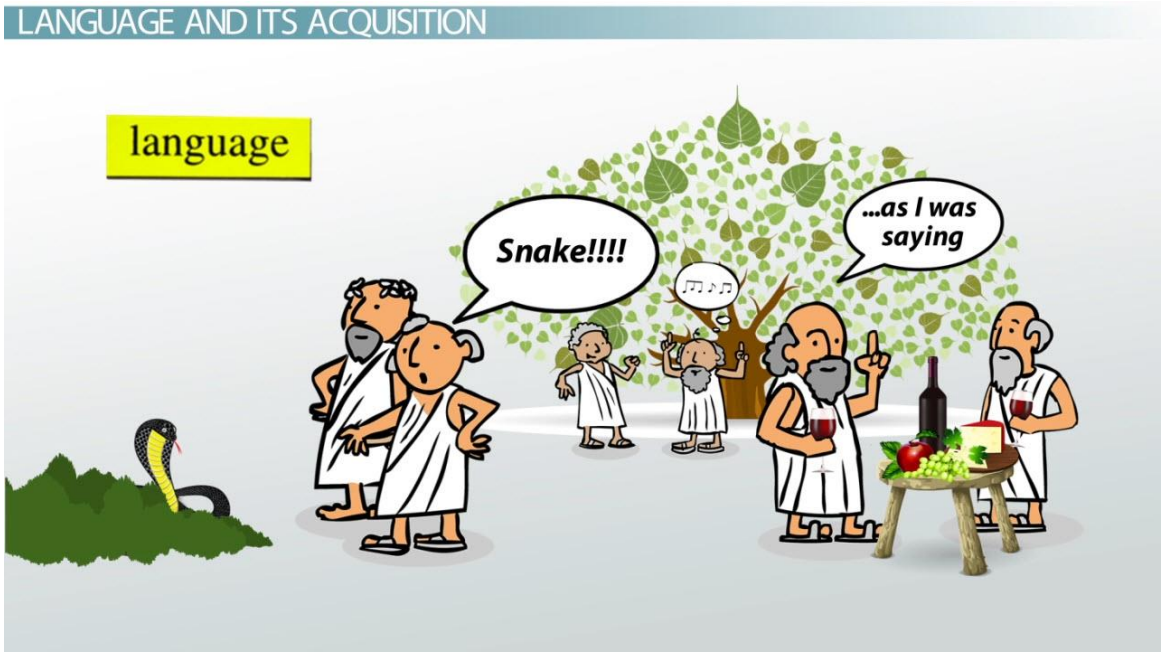
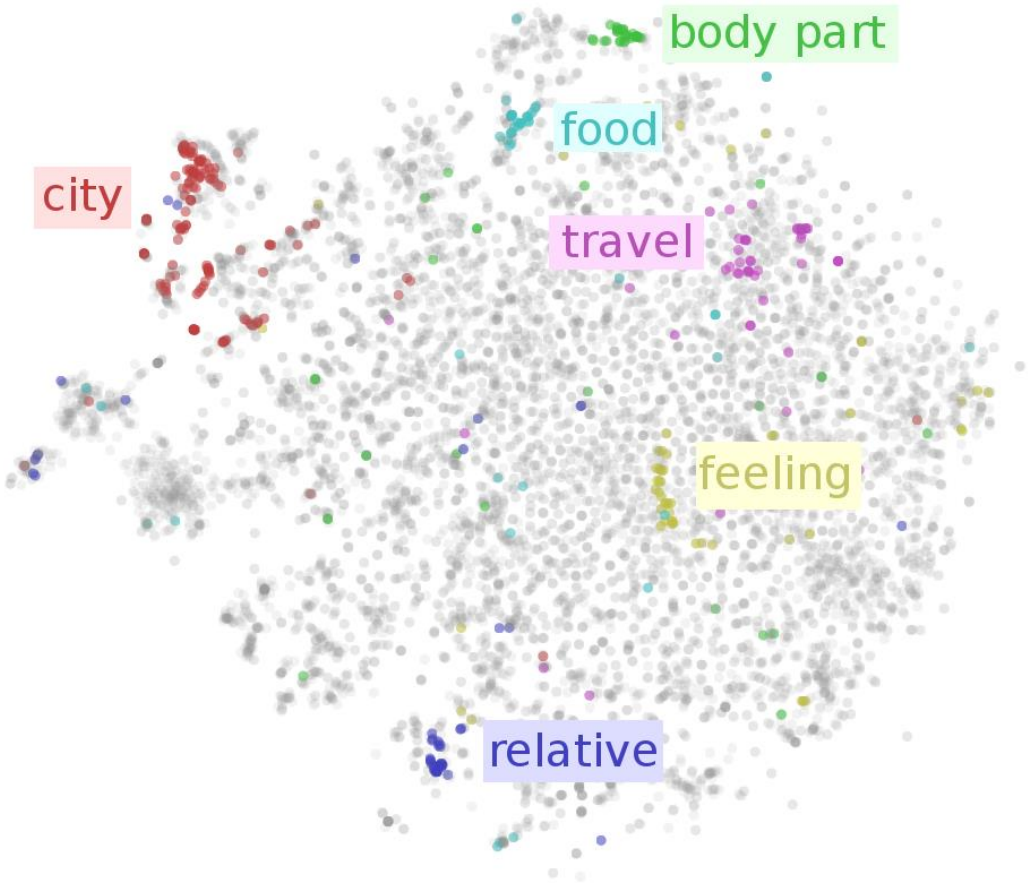


Nigiri is a type of Sushi which has ingredient Rice and Fish

How to Represent Knowledge?

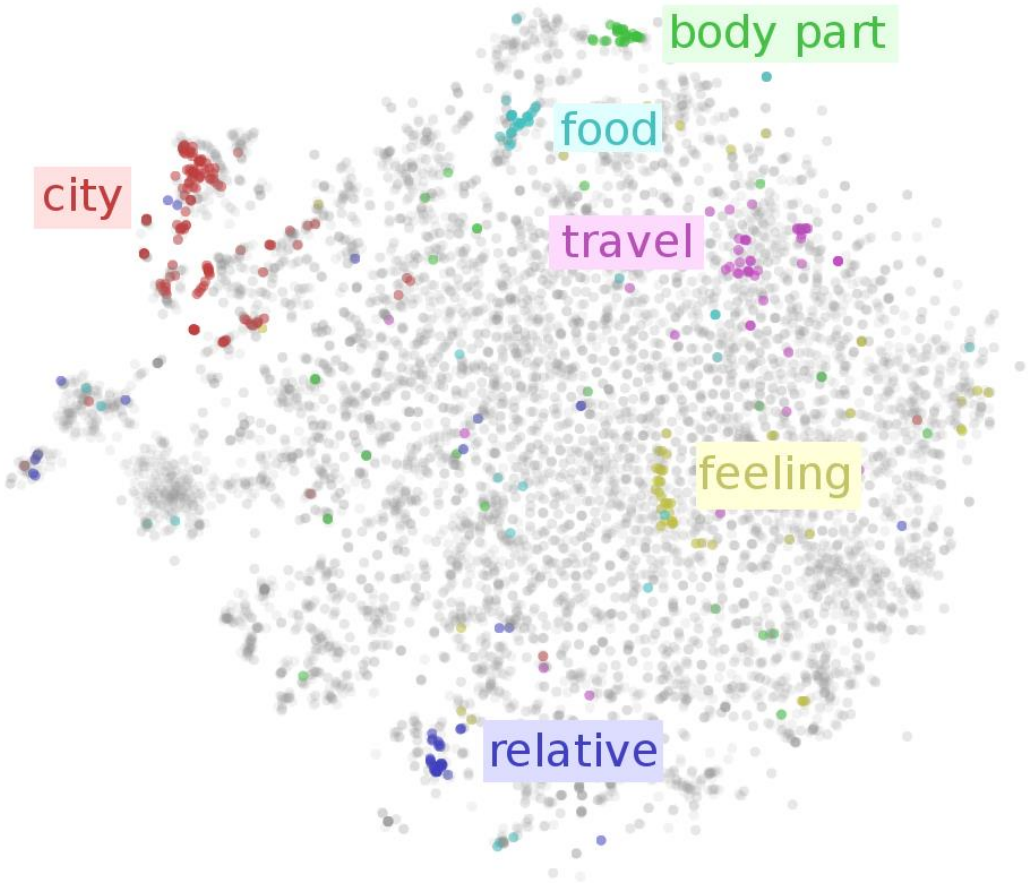
“computer processible”
representation



Computational Model

How to Represent Knowledge?

“computer processible”
representation

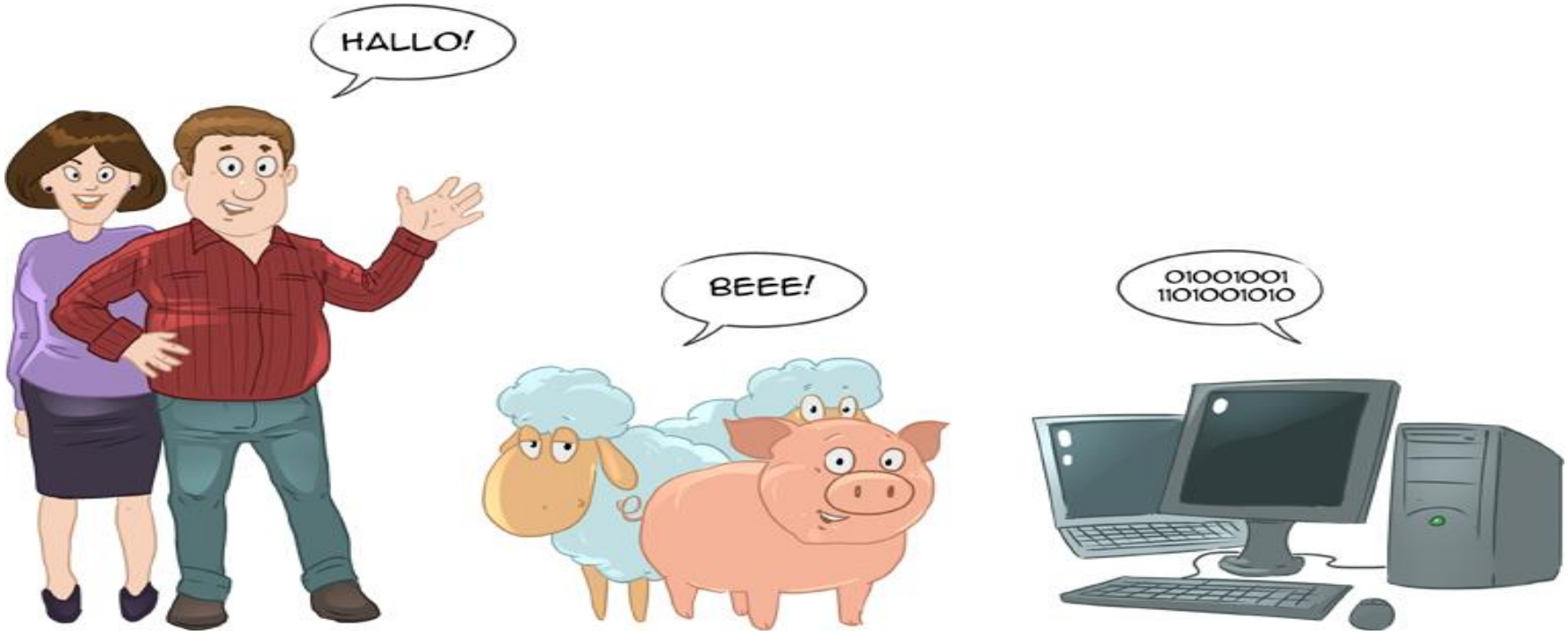


Computational Model

“word embedding”

How to Represent Knowledge?

Can we find a KR language that unifies the understanding of knowledge for both human beings and computer beings?



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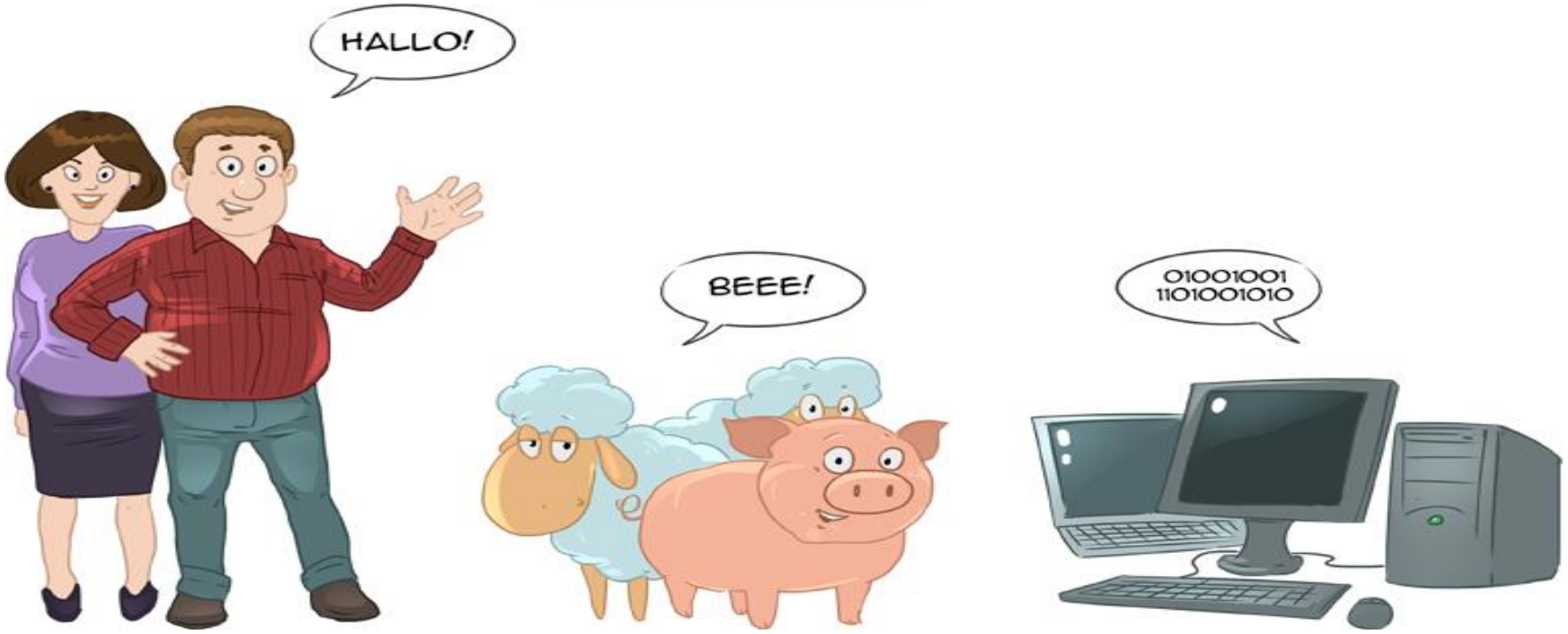

3

本体与描述逻辑

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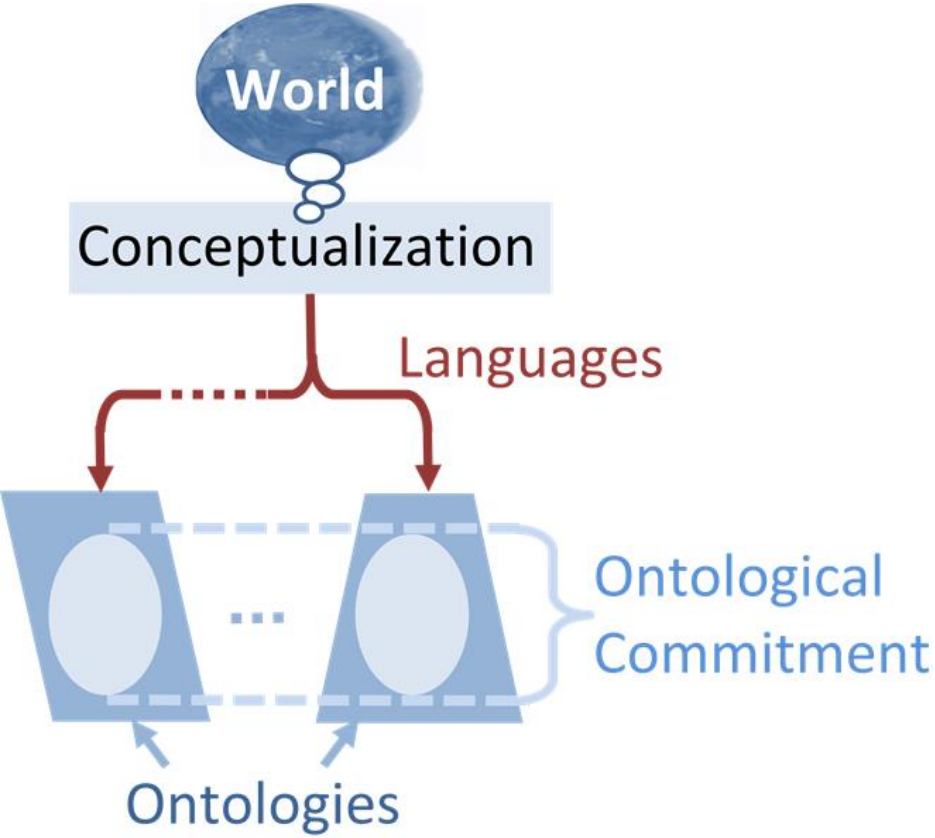
What is an Ontology?



A **conceptualization** is an **abstract simplified view** of some selected part (domain) of the world

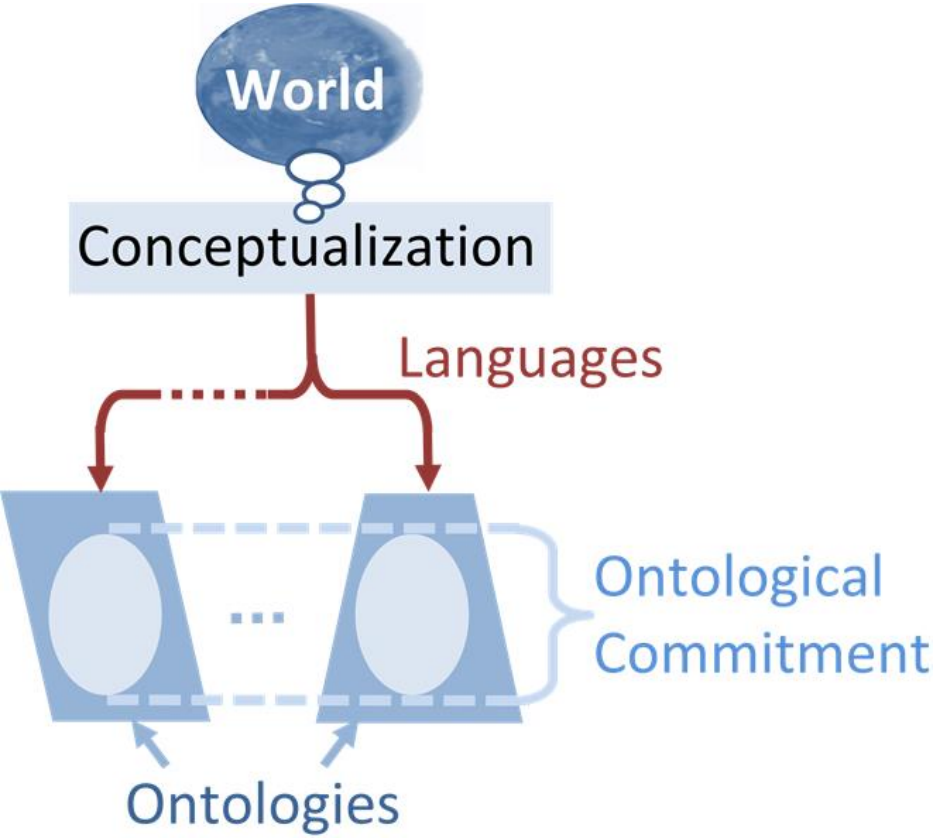
The **world**:

physical objects

The **conceptualization**:

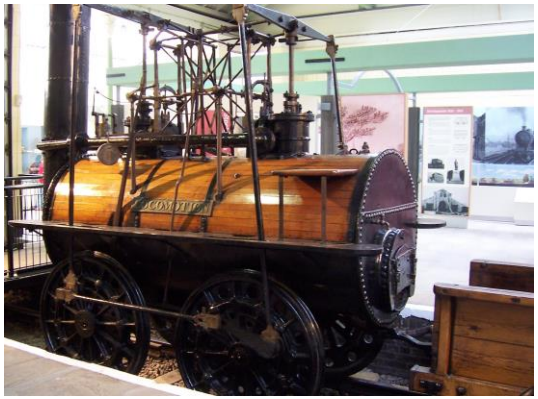
models of physical objects

What is an Ontology?

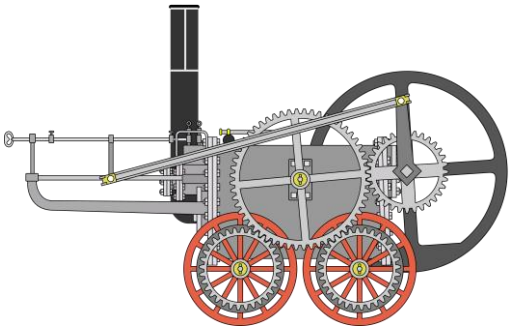


A conceptualization is an abstract simplified view of some selected part (domain) of the world

A physical train in real world



A model of the physical train in the conceptualization



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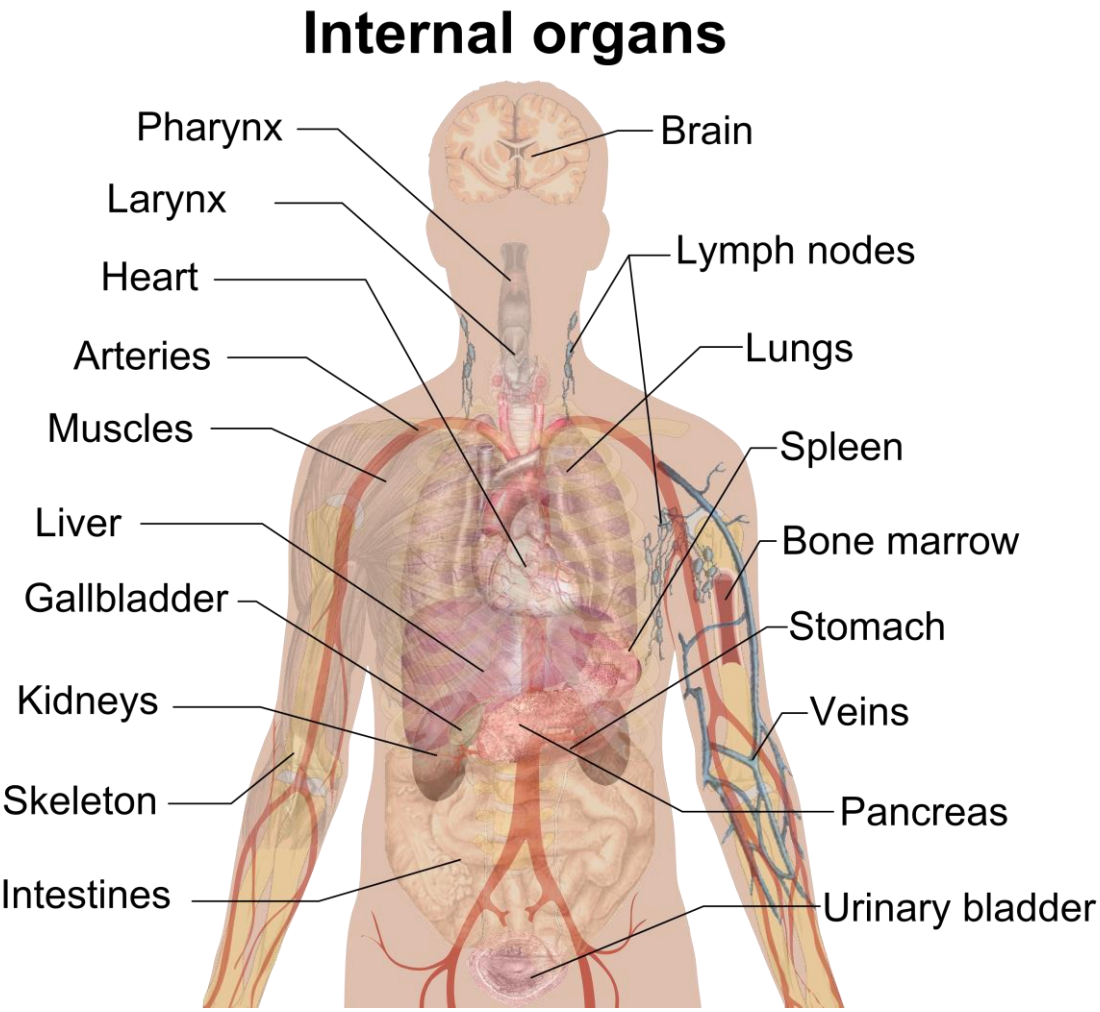
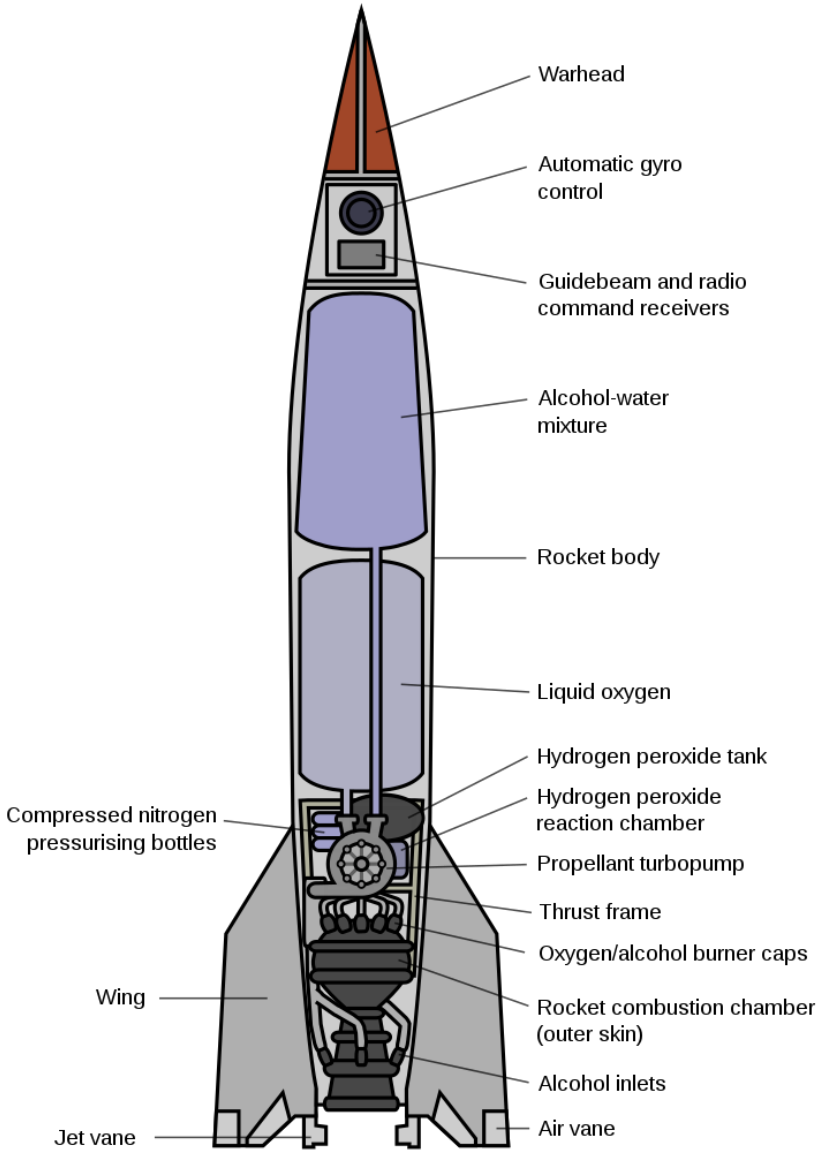


Fix **vocabulary** relevant to domain, e.g.,

- **Anatomy**

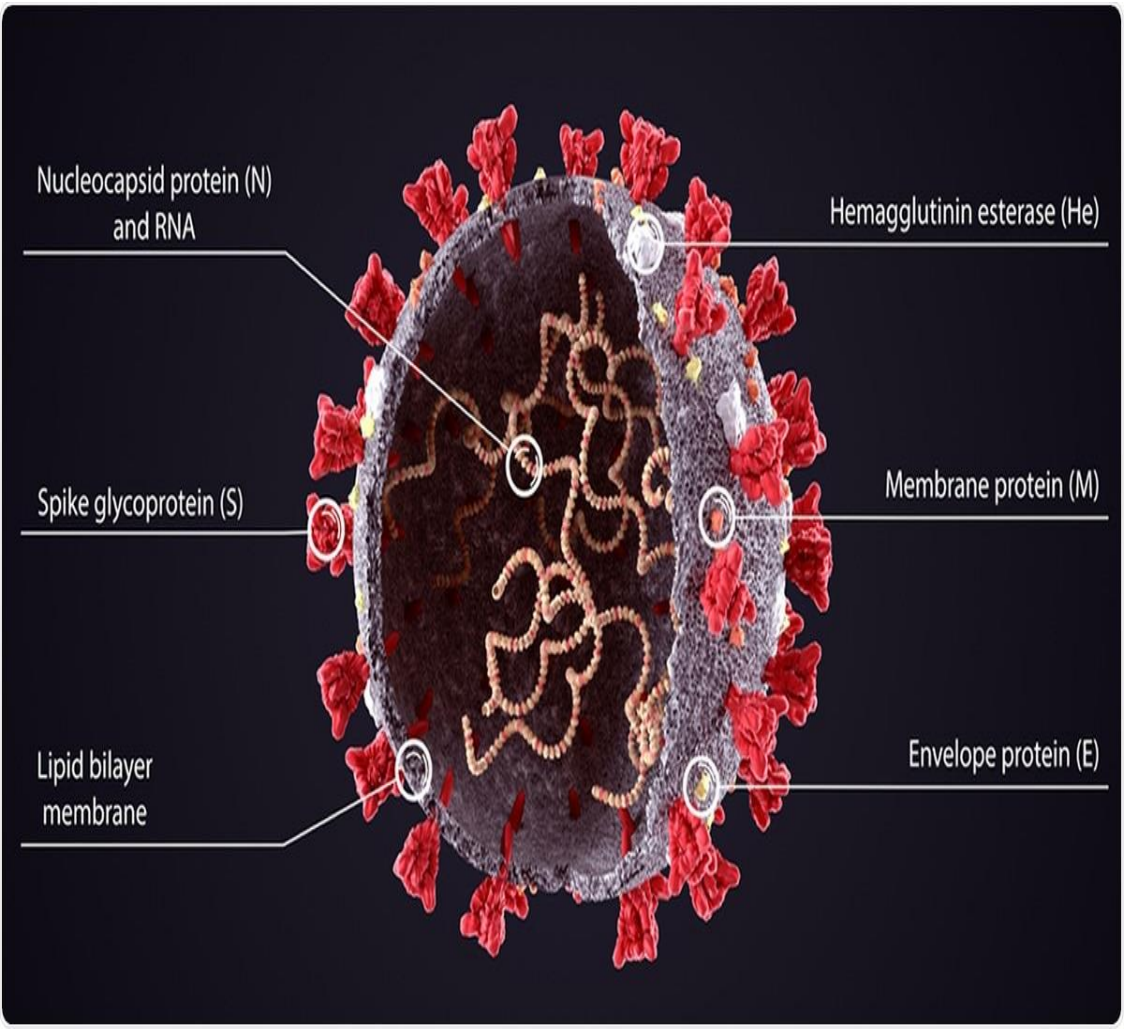
What is an Ontology?



Fix **vocabulary** relevant to domain, e.g.,

- **Anatomy**
- **Rocket**

What is an Ontology?



Fix vocabulary relevant to domain, e.g.,

- **Anatomy**
- **Rocket**
- **COVID-19**

What is an Ontology?

Fix **vocabulary** relevant to domain

Fix **meaning (semantics)** of terms in vocabulary

Nigiri is a type of Sushi which has ingredient Rice and Fish

Ontology: A Computational Model?

Fix vocabulary relevant to domain

Fix meaning (semantics) of terms in vocabulary

Nigiri is a type of Sushi which has ingredient Rice and Fish

Specified in formal logic

$$\forall x.[\text{Nigiri}(x) \rightarrow \text{Sushi}(x) \wedge \exists y.[\text{hasIngredient}(x,y) \wedge \text{Rice}(y)] \wedge \exists z.[\text{hasIngredient}(x,z) \wedge \text{Fish}(z)]]$$

Ontology: A Computational Model?

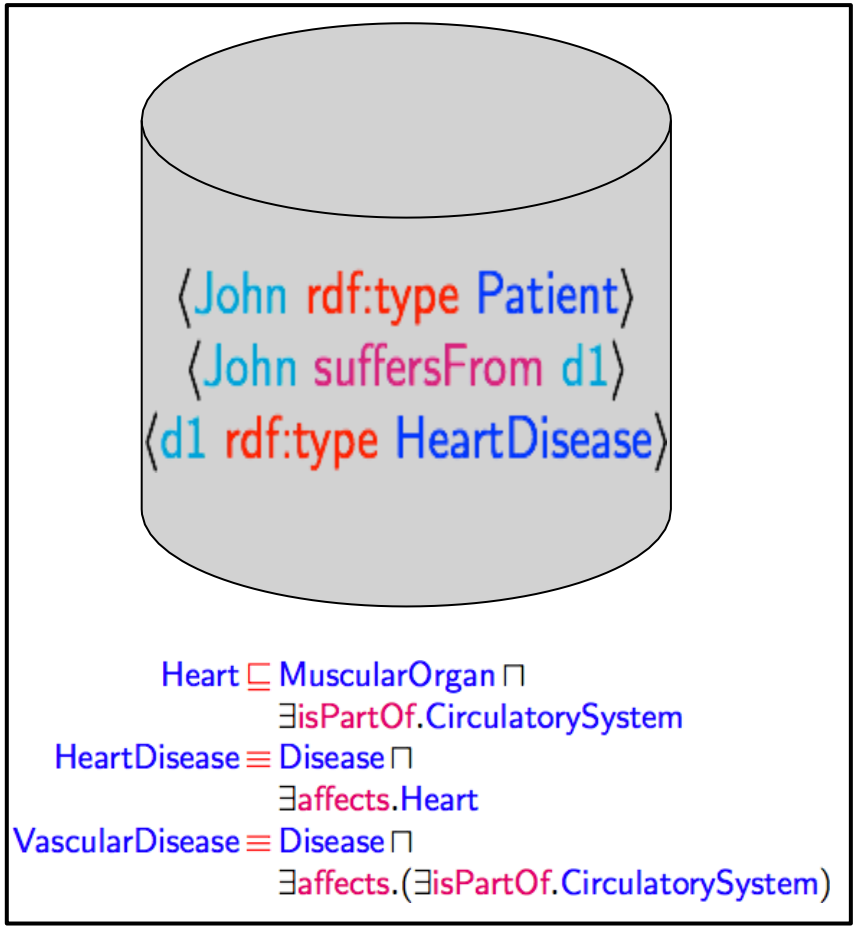
Fix **vocabulary** relevant to domain

Fix **meaning (semantics)** of terms in vocabulary

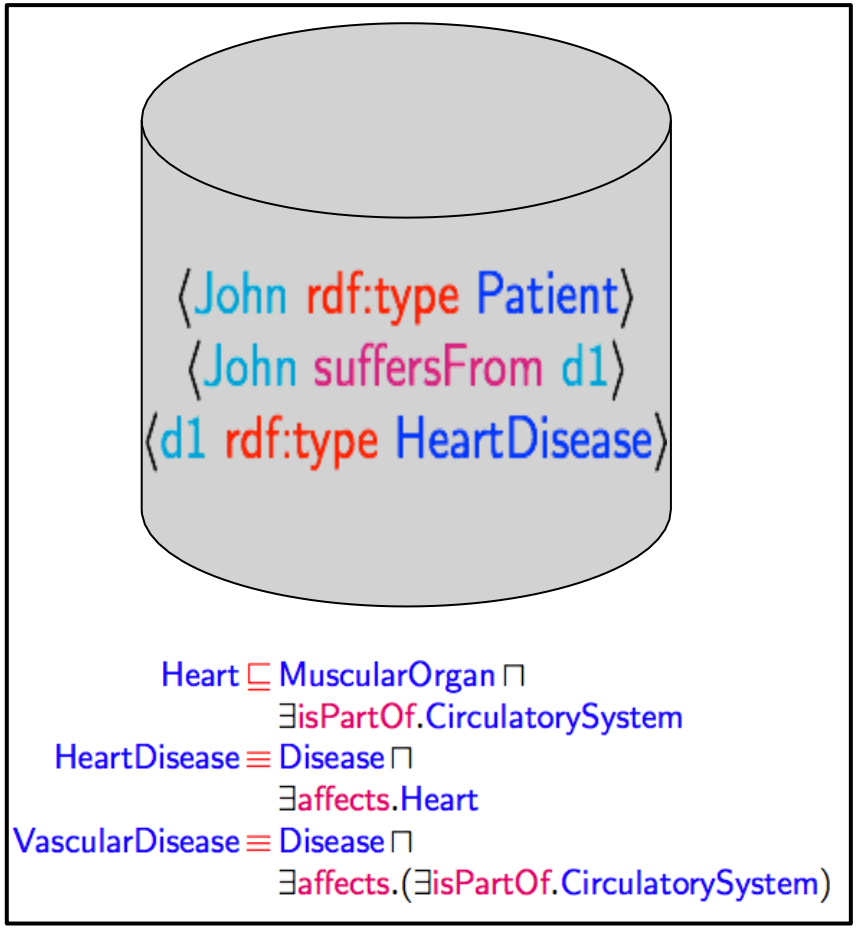
Nigiri is a type of Sushi which has ingredient Rice and Fish

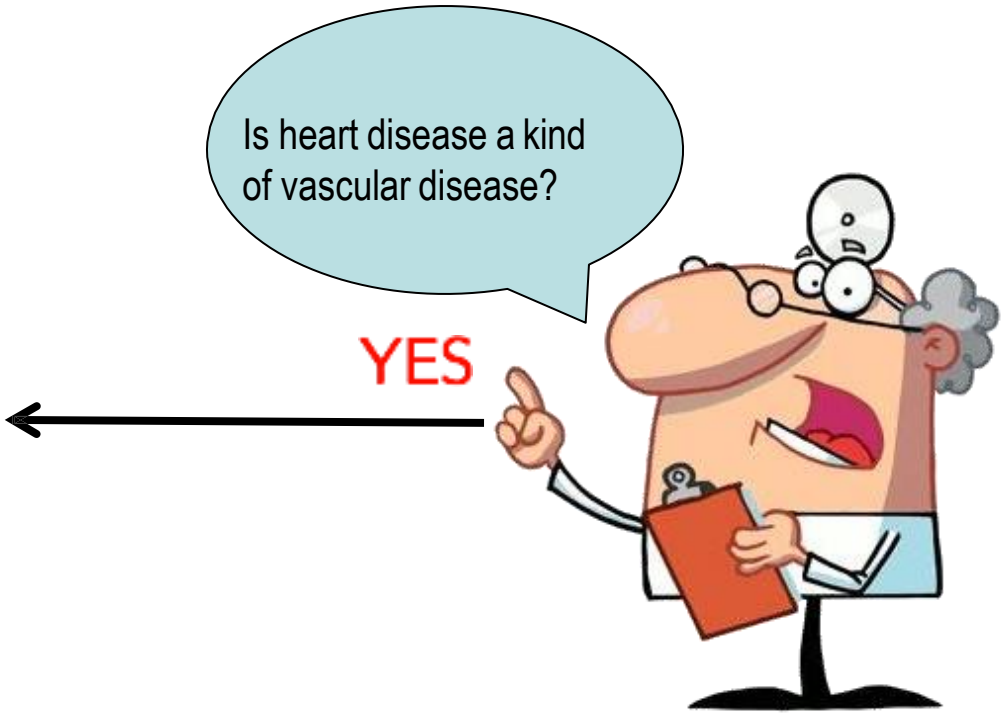
Natural language is NOT a computational model!

Standard Reasoning

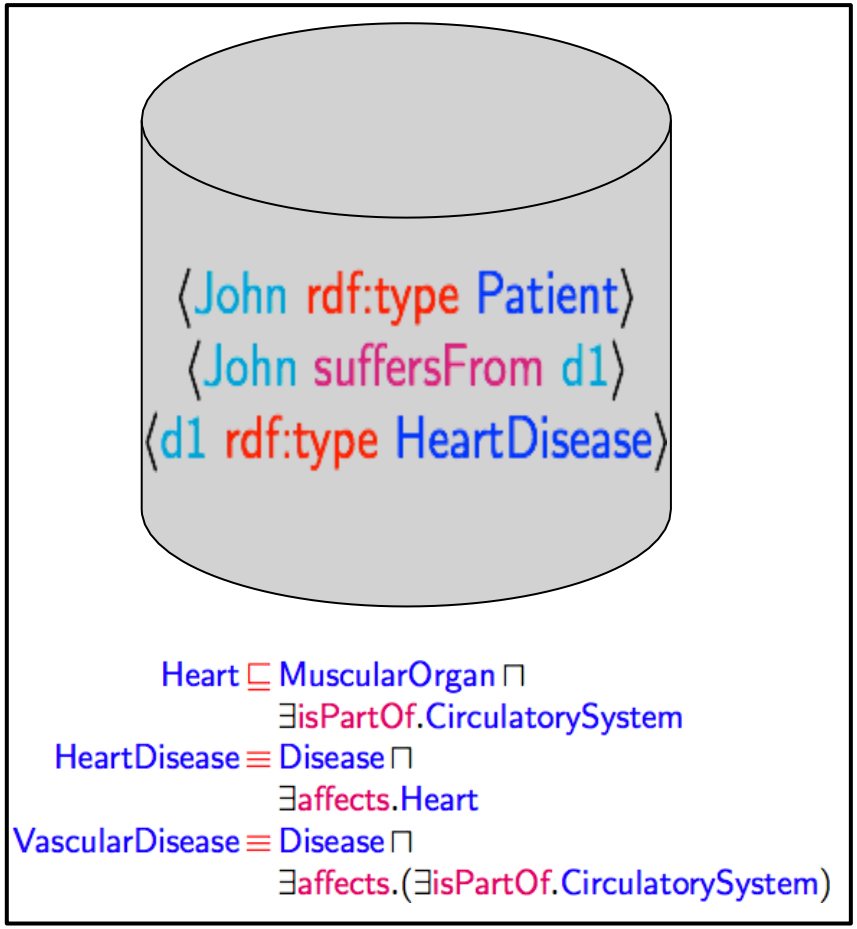


Standard Reasoning

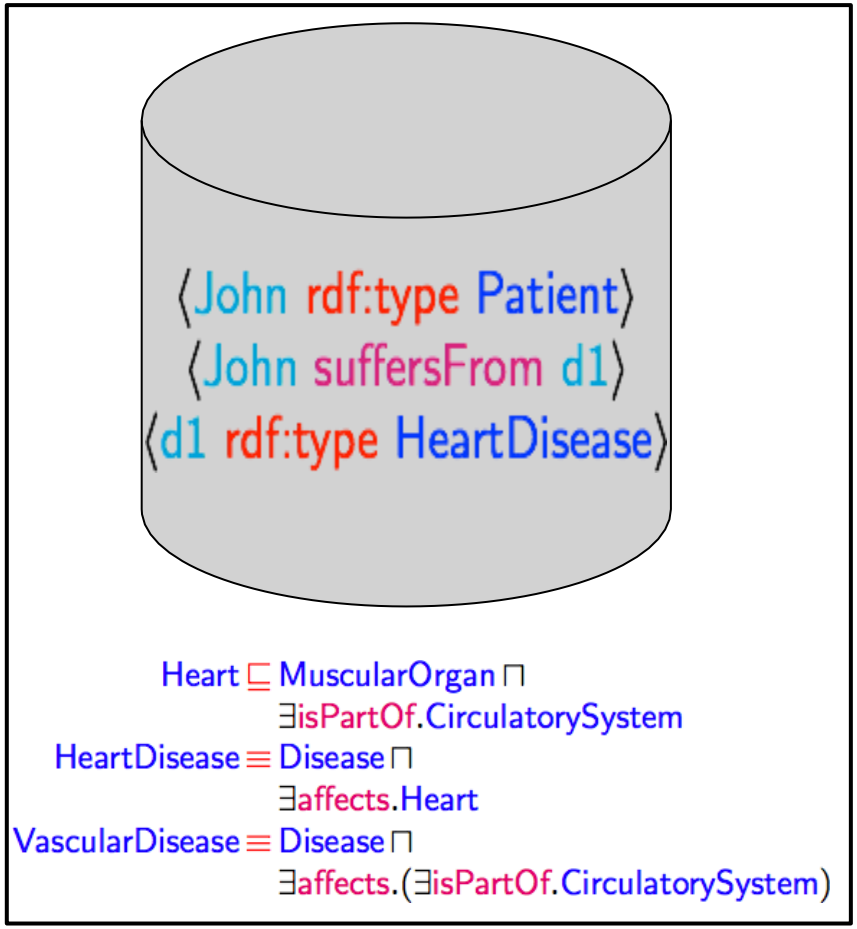


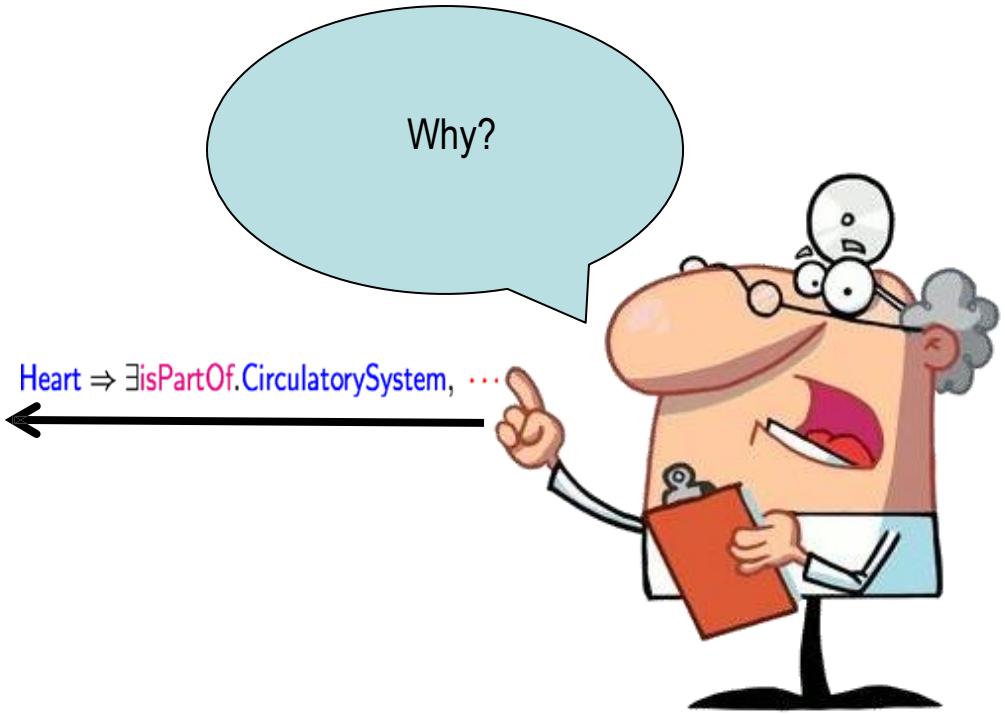


Non-Standard Reasoning



Non-Standard Reasoning





Description Logics (DLs)

- **Fragments of first order logic designed for KR**
- **Desirable computational properties**
  - **Decidable (essential)**
  - **Low complexity (desirable)**
- **Succinct and variable free syntax**

Description Logics (DLs)

- **Fragments of first order logic (FOL) designed for KR**
- **Desirable computational properties**
  - **Decidable (essential)**
  - **Low complexity (desirable)**
- Succinct and **variable free syntax**

FOL:

$$\forall x.[\mathbf{Nigiri}(x) \rightarrow \mathbf{Sushi}(x) \wedge \exists y.[\mathbf{hasIngredient}(x,y) \wedge \mathbf{Rice}(y)] \wedge \exists z.[\mathbf{hasIngredient}(x,z) \wedge \mathbf{Fish}(z)]]$$

DL:

$$\mathbf{Nigiri} \sqsubseteq \mathbf{Sushi} \sqcap \exists \mathbf{hasIngredient}.\mathbf{Rice} \sqcap \exists \mathbf{hasIngredient}.\mathbf{Fish}$$

Description Logics (DLs)

DL Knowledge Base (KB) consists of two parts:

- **Ontology (aka TBox) axioms define terminology (schema)**

$$\text{Nigiri} \sqsubseteq \text{Sushi} \sqcap \exists \text{hasIngredient.Rice} \sqcap \exists \text{hasIngredient.Fish} \sqcap$$

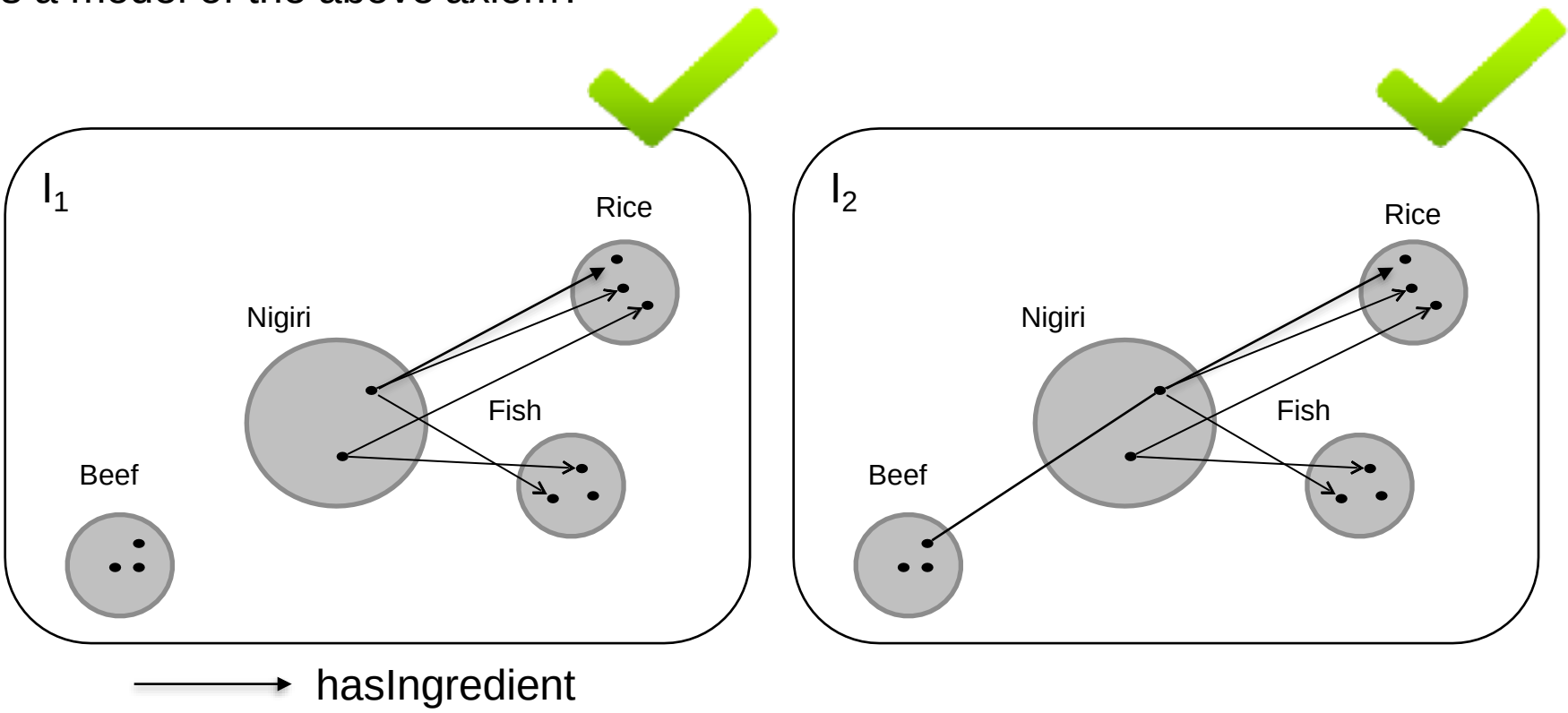
- **Ground facts (aka ABox) use the terminology (data)**

$$\text{messi} : \text{Person} \sqcap \exists \text{hasOccupation.Footballer}$$

Model-Theoretic Semantics

$$\text{Nigiri} \sqsubseteq \text{Sushi} \sqcap \exists \text{hasIngredient}.\text{Rice} \sqcap \exists \text{hasIngredient}.\text{Fish}$$

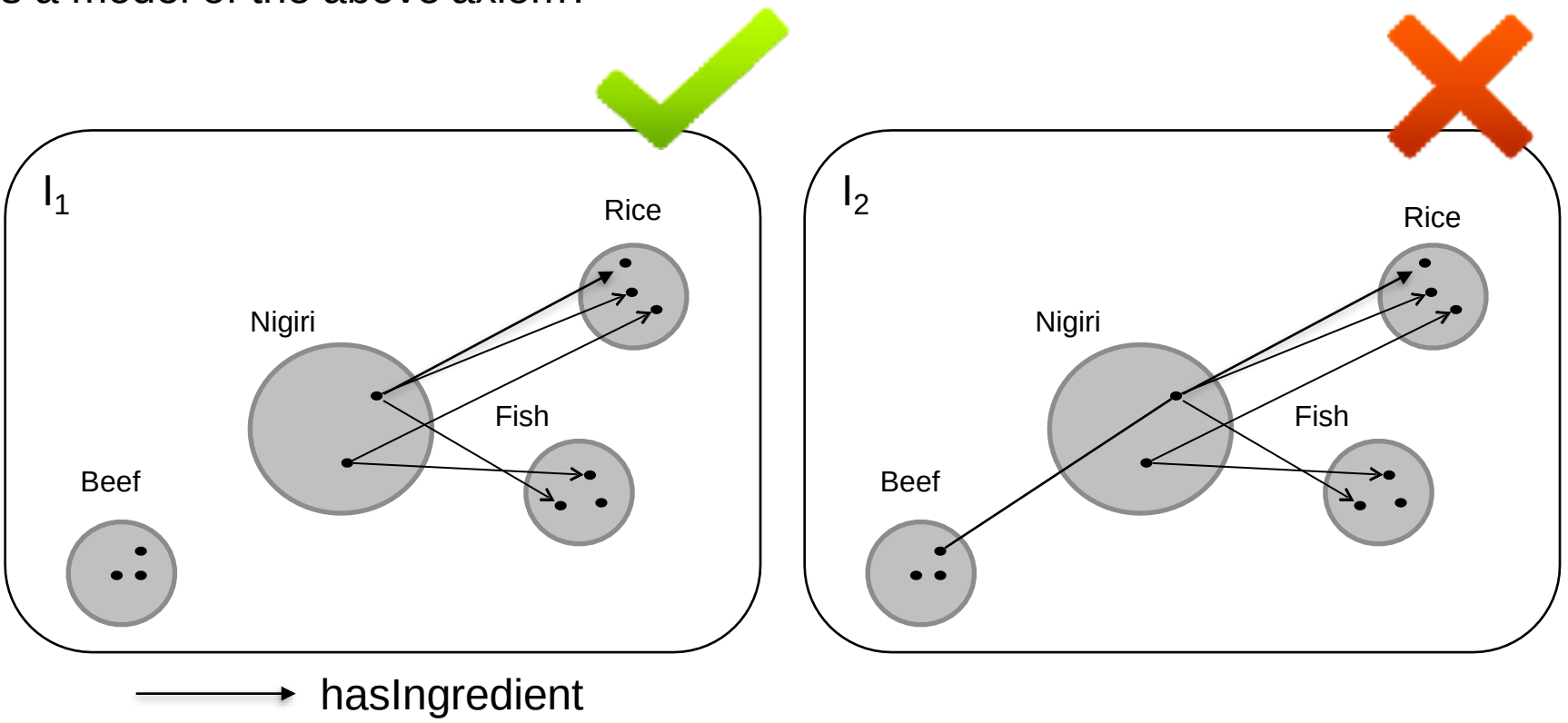
Which of these interpretations is a model of the above axiom?



Model-Theoretic Semantics

$$\text{Nigiri} \sqsubseteq \text{Sushi} \sqcap$$
$$\exists \text{hasIngredient.Rice} \sqcap$$
$$\exists \text{hasIngredient.Fish} \sqcap$$
$$\forall \text{hasIngredient.}(\text{Rice} \sqcup \text{Fish})$$

Which of these interpretations
is a model of the above axiom?



3

基于逻辑语义的本体推理

南京大学
NANJING UNIVERSITY

Research Problems

To find proper logical languages for KR

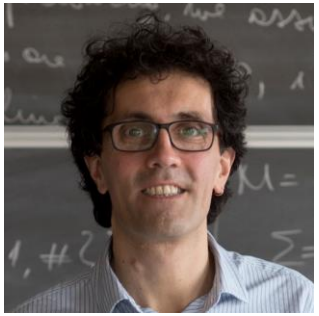
- **Expressiveness**
  more expressive power comes with computational cost

- **Computational properties**
  - **decidability**
    e.g. first-order logic is undecidable
  - **complexity**
    polynomial or exponential or even worse?

Franz Baader
TU Dresden

Carsten Lutz
Univ. of Bremen

Frank Wolter
Univ. of Liverpool

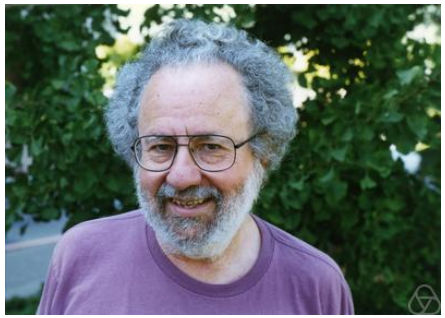


Diego Calvanese
Free Univ. of Bozen-Bolzano

Research Problems

To develop reasoning methods for KR languages

- **Standard reasoning (entailment checking)**
  e.g. Boolean queries, check if KB ⊨ α
- **Non-standard reasoning**
  derive new knowledge from the existing, KB ⊨ KB'
  e.g. Jack has a child who is a lawyer
  Jack has a child who is not a lawyer
  What can you derive from these?
  usually harder than standard reasoning



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Standard Reasoning Tools

Major benefit of using DLs has been huge increase in range and sophistication of tools and infrastructure:

- Editors/development environments
- Reasoners

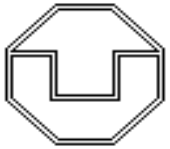

Hermit

FaCT++

Racer

Pellet


KAON2


CEL