You can download the sources of this presentation here:
github.com/severin-lemaignan/lecture-hri-symbolic-reasoning

Symbolic Reasoning for HRI

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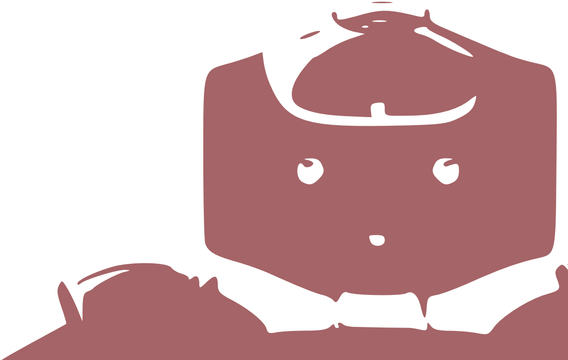

IN THIS LECTURE

- Lecture on speech: NLP down to syntax parsing

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Semantics vs Pragmatics

Semantics is the (conventional) meaning attached to words and sentences; *Pragmatics* study the actual meaning coming out of the context: who speaks? how they speak? what common knowledge between the speaker and the listener? what is the situation? etc.

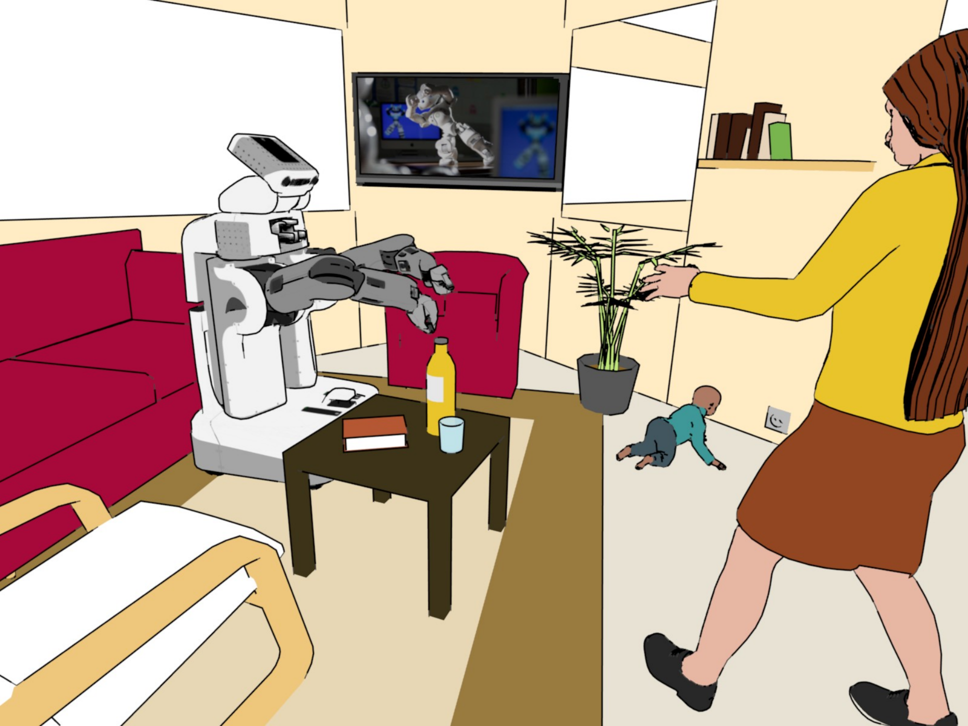
IN THIS LECTURE

- Lecture on speech: NLP down to syntax parsing
- Today: **meaning** (both semantics and pragmatics)

  How to attach ***meaning*** to perceptions & natural language?
  What are ontologies?
  How is 'meaning' represented and used within the robot?
  How does it relate to ***mental models***?

Semantics vs Pragmatics

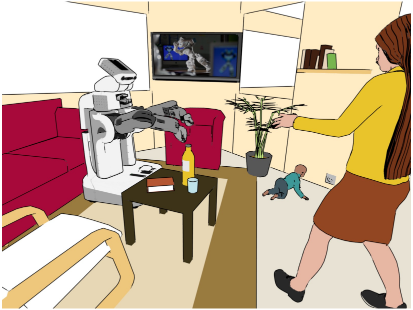
Semantics is the (conventional) meaning attached to words and sentences; *Pragmatics* study the actual meaning coming out of the context: who speaks? how they speak? what common knowledge between the speaker and the listener? what is the situation? etc.



Situated dialogue effectively evidences the challenges

How can the robot make sense of and act upon a sequence of letters like:

“Can you give me that book?”



THE SYMBOL GROUNDING PROBLEM

How to attach meaning to a symbol?

[Harnad, *The Symbolic Grounding Problem*, 1990]

THE SYMBOL GROUNDING PROBLEM

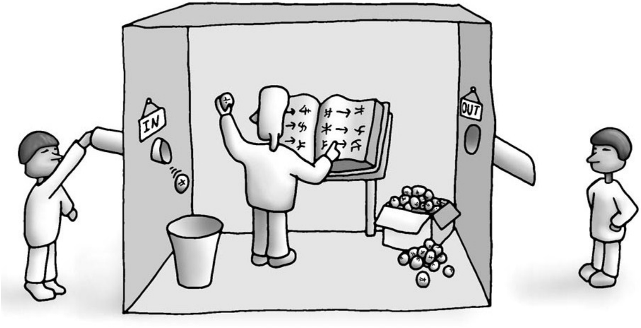
Google Translate translates French "*Il pleut comme vache qui pissent*" into English "*It's raining cats and dogs*".

...no peeing cow?? Does Google Translate *understand* French and/or English?

[Harnad, *The Symbolic Grounding Problem*, 1990]

THE SYMBOL GROUNDING PROBLEM

The mind as a computer:
functionalism & Searle's **Chinese Room Argument**



Read more on Wikipedia

[Harnad, ***The Symbolic Grounding Problem***, 1990]

THE SYMBOL GROUNDING PROBLEM

How to attach meaning to a symbol?

Is it possible at all? Is it actually necessary?

[Harnad, ***The Symbolic Grounding Problem***, 1990]

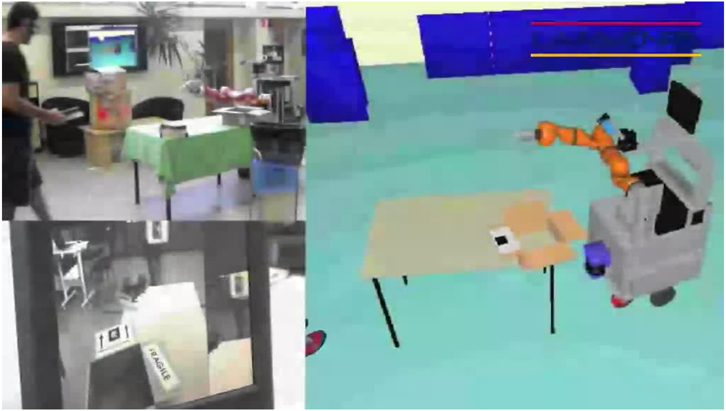
THE SYMBOL GROUNDING PROBLEM

Embodiement is part of the answer. In robotics, we talk of **Situated AI**.

[Harnad, *The Symbolic Grounding Problem*, 1990]

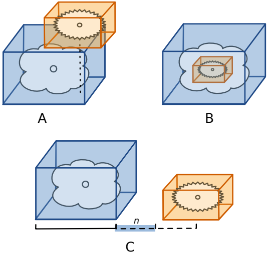
SITUATED, GROUNDED, SYMBOLIC SOCIAL COGNITION

SITUATION ASSESSMENT

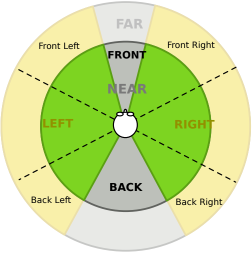


[Lemaignan et al., *Artificial Cognition for Social Human-Robot Interaction: An Implementation*, Artifical Intelligence, 2017]

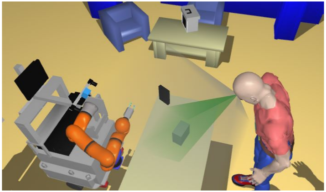
VISUAL PERSPECTIVE TAKING

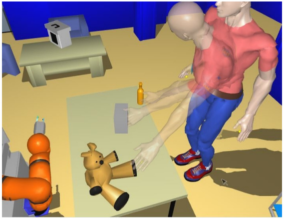


allocentric



egocentric





Subject	Predicate	Object
Location	isAt	Location
	→ isOn	
	→ isIn	
	→ isNextTo	
Location	isAbove	Location
Location	isBelow	Location
Location	hasRelativePosition	Location
	→ behind	
	→ inFrontOf	
	→ leftOf	
	→ rightOf	
Object	farFrom	Agent
Object	near	Agent
Agent	looksAt	SpatialThing
Agent	sees	SpatialThing
SpatialThing	isInFieldOfView	xsd:boolean
Agent	pointsAt	SpatialThing
Agent	focusesOn	SpatialThing
Agent	seesWithHeadMovement	SpatialThing
Agent	canReach	Object

[Lemaignan et al., *Artificial Cognition for Social Human-Robot Interaction: An Implementation*, Artifical Intelligence, 2016]

STATEMENT, BELIEFS

```
human_1 sees teddybear
```

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A **statement** is a true proposition (in a given model)

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`teddybear isOn table_1`

STATEMENT, BELIEFS

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A **statement** is a true proposition (in a given model) $\equiv$ **belief**

`teddybear type Toy`

`teddybear isOn table_1`

`human_1 hates robot_1` (in the human's model only!)

STATEMENT, BELIEFS (2)

```
human_1 sees teddybear
```

Triplet $\langle S, P, O \rangle$: subject, predicate, object

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`human_1 sees teddybear`

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P is a predicate of **arity** 2: $P(S, O)$

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Triplet $\langle S, P, O \rangle$: subject, predicate, object

P is a predicate of **arity** 2: $P(S, O)$

Some logic language (like Prolog) allows arbitrary arities:
`give(robot_1, human_1, teddybear)`

STATEMENT, BELIEFS (2)

`human_1 sees teddybear`

Triplet $\langle S, P, O \rangle$: subject, predicate, object

P is a predicate of **arity** 2: $P(S, O)$

Many do not (like the OWL language). In this case, **reification**:

```
give_act_1 type Give
give_act_1 performedBy robot_1
give_act_1 receivedBy human_1
give_act_1 actsOnObject teddybear
```

TOWARDS ONTOLOGIES

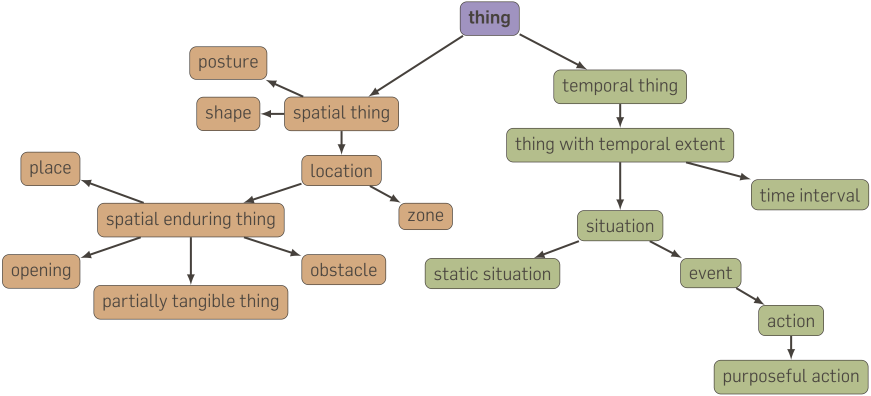
The robot's newly acquired beliefs typically have to be **anchored** in pre-existing knowledge.

→ We usually endow the robot with **background knowledge** (also known as **common-sense knowledge**) with statements like:

```
Object rdfs:subclassOf PhysicalThing
```

```
Location rdfs:subclassOf SpatialThing
```

TOWARDS ONTOLOGIES



Example of an **upper ontology**

ONTOLOGIES

An **ontology** encompasses a representation, formal naming, and definition of the categories, properties, and relations between the concepts, data, and entities that substantiate one, many, or all domains.

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Ontologies often have close relationships with **first-order logic (FOL)** – more about that later.

ONTOLOGIES

- **T-box** statements: the ***conceptualisation*** of the domain, for instance in terms of ***categories*** (classes): `Dog rdfs:subClassOf Animal`
- **A-box** statements: (T-box compliant) statements about *individuals* (instances) in the ontology: `SPOT rdf:type Dog`

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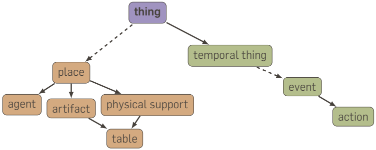
Ontologies are represented using a **knowledge description language**. The **Web Ontology Langage (OWL)** is a common choice that uses a XML encoding.

ONLINE INSTANCIATION



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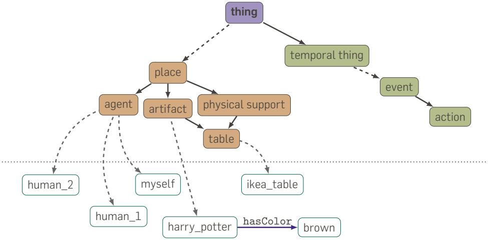

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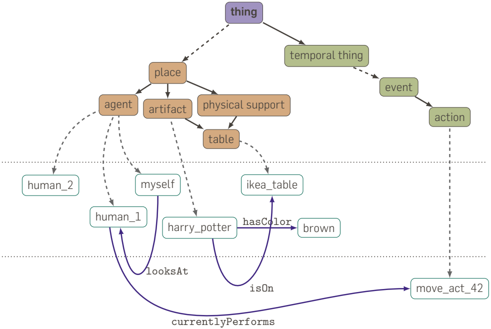
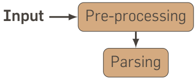


Back to our initial example:

Give me that book!

DIALOGUE GROUNDING



[Lemaignan et al. *Grounding the Interaction: Anchoring Situated Discourse in Everyday HRI* – Intl. J. of Social Robotics 2011]

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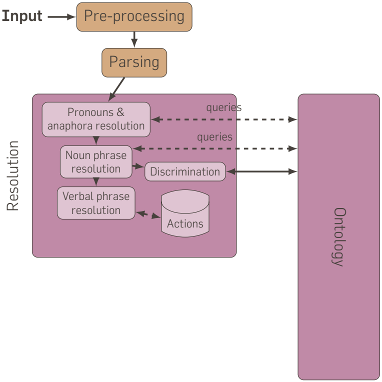

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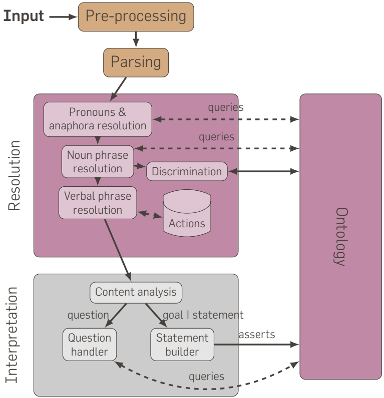

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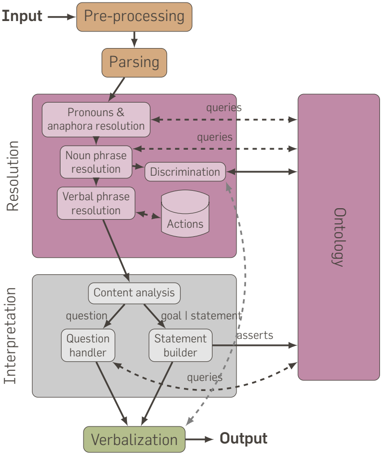

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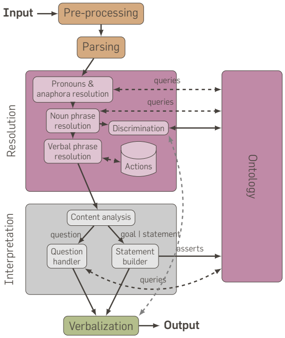
DIALOGUE GROUNDING

“Give me the book on the table”



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DIALOGUE GROUNDING

"Give me the book on the table"

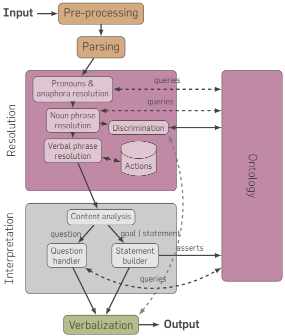
$\downarrow$

`me` $\rightarrow$ `human_1`

find(`?obj type Table`) $\rightarrow$ `ikea_table`

find(`?obj type Book, ?obj isOn ikea_table`) $\rightarrow$

`harry_potter`



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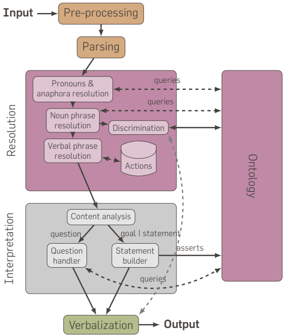
$\downarrow$

`human_1` `desires` **`give_act_1`**,
`give_act_1` `type` **`Give`**,
`give_act_1` `performedBy` **`myself`**,
`give_act_1` `actsOnObject` **`harry_potter`**,
`give_act_1` `receivedBy` **`human_1`**



[Lemaignan et al. *Grounding the Interaction: Anchoring Situated Discourse in Everyday HRI* Intl. J. of Social Robotics 2011]

MULTI-MODAL INTERACTION

What about

“Give me that book”?

(or even: **“Give me that!”**)

[Lemaignan et al., **Artificial Cognition for Social Human-Robot Interaction: An Implementation**, Artifical Intelligence, 2017]


LAAS-CNRS

EXAMPLE OF FIRST-ORDER LOGIC REASONING

"Where is the other tape?"

$\downarrow$

find(`?obj isAt ?loc, ?obj type VideoTape, ?obj differentFrom WALL_E`)

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Symbolic approaches effective at dealing with this kind of constraints

INTERACTION EXAMPLE: I SPY WITH MY LITTLE EYE

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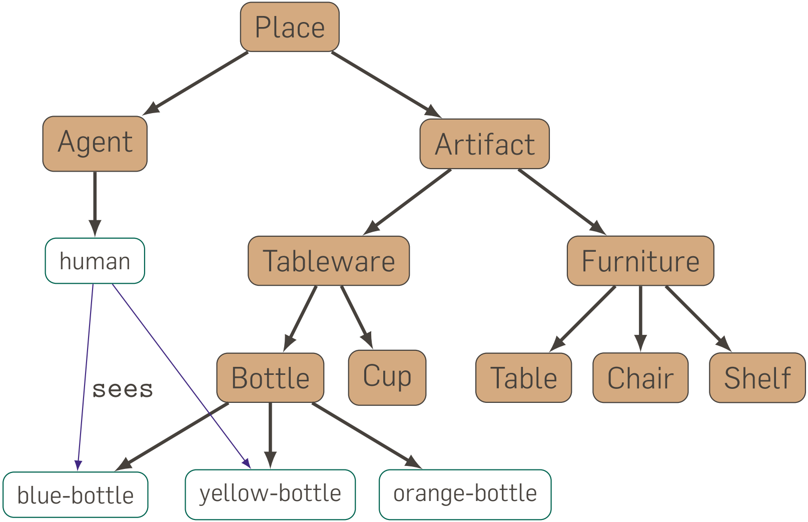
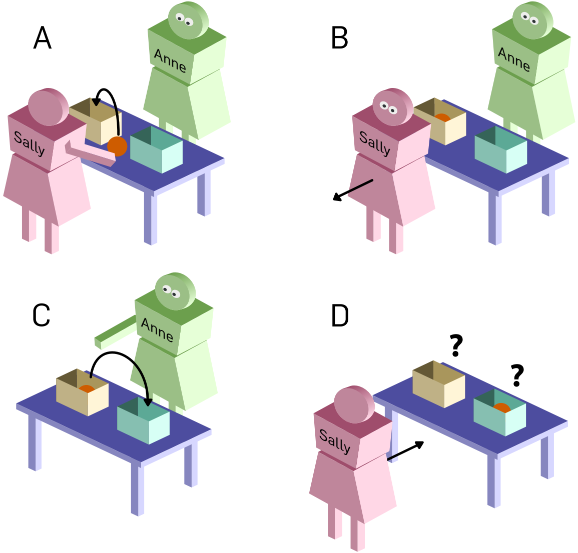


INTERACTION EXAMPLE: I SPY WITH MY LITTLE EYE

human	It is a tableware.
robot	*[retrieves possible objects: blue-bottle, yellow-bottle, orange-bottle, cup-with-handle]*
	[keeps human-visible objects: blue-bottle, yellow-bottle, cup-with-handle]
	[obtains discriminants: type, color.]
	Which type of object is: bottle or cup?
human	Bottle.
robot	*[obtains possible objects: blue-bottle, yellow-bottle.]*
	[obtains discriminants: color.]
	What color the object is: blue or yellow?
human	Blue.
robot	*[obtains possible objects: blue-bottle.]*
	The object is the blue-bottle!

ONE STEP FURTHER: THEORY OF MIND

1ST ORDER TOM: THE FALSE-BELIEF EXPERIMENT



[Wimmer and Perner, **Beliefs about beliefs: Representation and constraining function [...]**, Cognition, 1983]]

What if I ask for the video tape in the box, but the robot previously moved it somewhere else?

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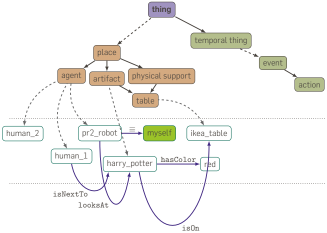
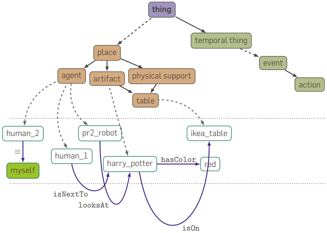
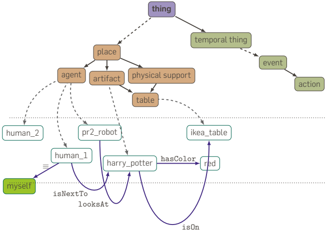
False-belief situation

PARALLEL MODELS: TOWARDS THEORY OF MIND







...

THE SYMBOLIC VS SUB-SYMBOLIC DEBATE

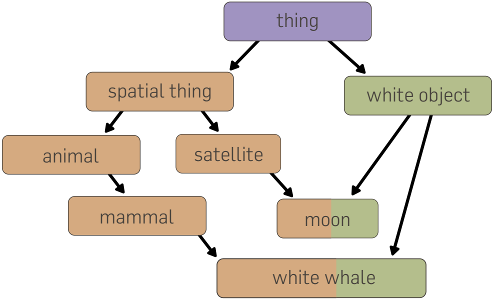
- Symbolic approaches assume a well-ordered, ‘regular’ world $\rightarrow$ not often the case + world full of exceptions! (`Bird subclassOf FlyingThing`?)
- Symbolic learning is possible, but not nearly as powerful as sub-symbolic machine learning
- How to bridge the epistemic gap between symbolic and sub-symbolic AI?

That's all for today, folks!

Questions:
severin.lemaignan@brl.ac.uk

Slides:
github.com/severin-lemaignan/lecture-hri-symbolic-reasoning

REASONING EXAMPLE: BEST DESCRIPTOR FOR A CONCEPT



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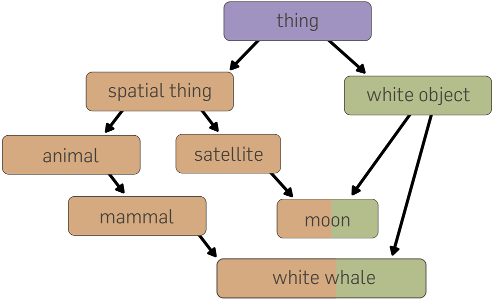
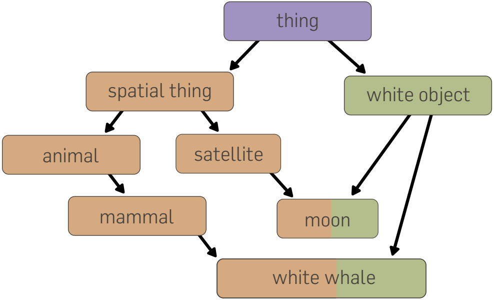


Algorithm 3.1: CommonAncestors(*concept*1, *concept*2)

$$\begin{cases} \mathcal{I} \leftarrow \text{Superclasses}(\boldsymbol{concept}1) \cap \text{Superclasses}(\boldsymbol{concept}2) \\ \textbf{return } (\boldsymbol{c} \in \mathcal{I} | \text{Subclasses}(\boldsymbol{c}) \cap \mathcal{I} = \emptyset) \end{cases}$$

REASONING EXAMPLE: BEST DESCRIPTOR FOR A CONCEPT



Algorithm 3.2: FirstDifferentAncestors(*concept*1, *concept*2)

$$\begin{cases} \mathcal{C} \leftarrow \text{CommonAncestors}(\textit{concept}1, \textit{concept}2) \\ \mathcal{S} \leftarrow \text{Superclasses}(\textit{concept}1) \cup \text{Superclasses}(\textit{concept}2) \\ \textbf{return } (\forall c \in \mathcal{C}, \text{DirectSubclasses}(c) \cap \mathcal{S}) \end{cases}$$