Symbolic Reasoning for HRI

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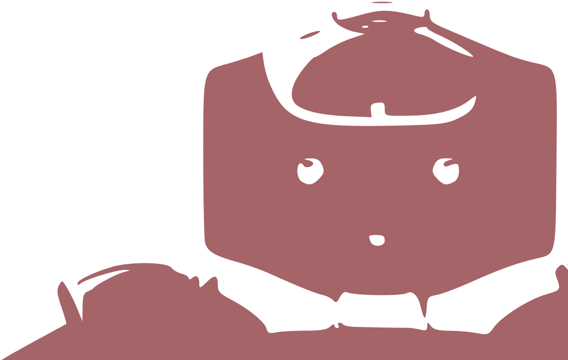

IN THIS LECTURE

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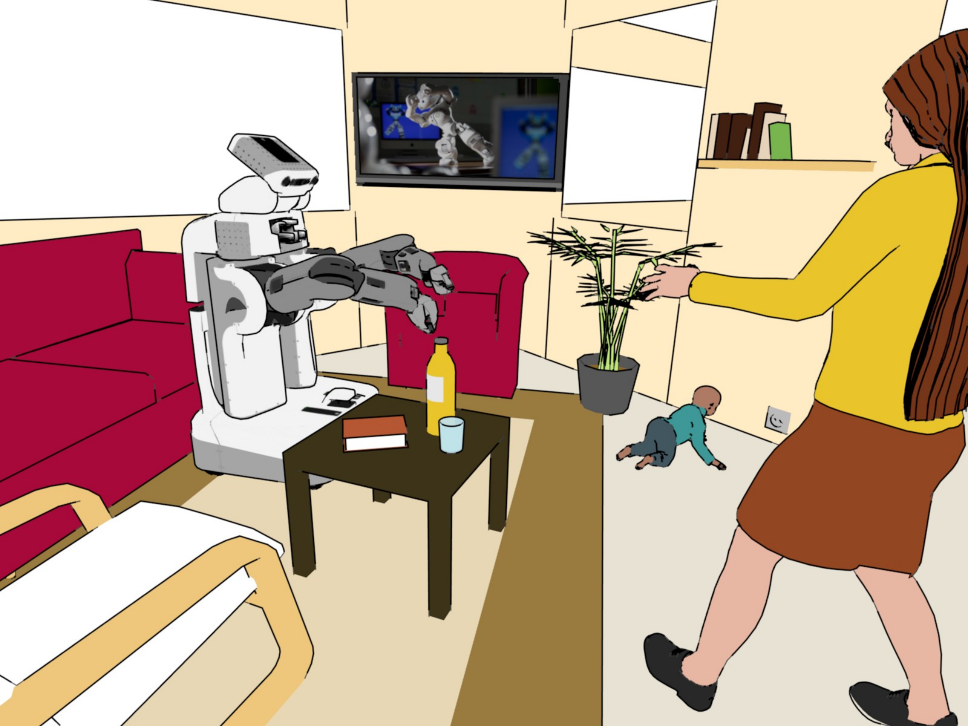
- Today: **meaning** (both semantics and pragmatics)

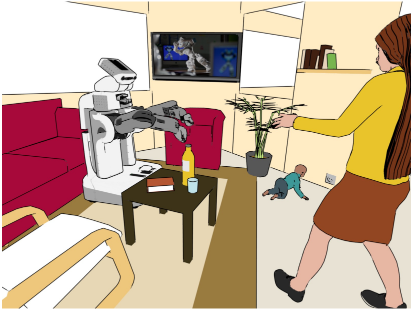
  How to attach ***meaning*** to perceptions & natural language?
  What are ontologies?
  How is 'meaning' represented and used within the robot?
  How does it relate to ***mental models***?



Situated dialogue effectively evidences the challenges

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

“Can you give me that book?”



THE SYMBOL GROUNDING PROBLEM

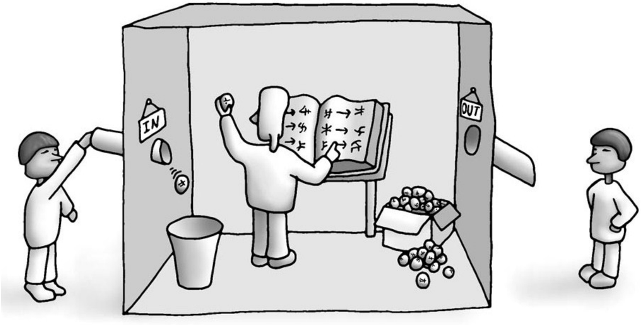
How to attach meaning to a symbol?

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

THE SYMBOL GROUNDING PROBLEM

How to attach meaning to a symbol?

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?

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

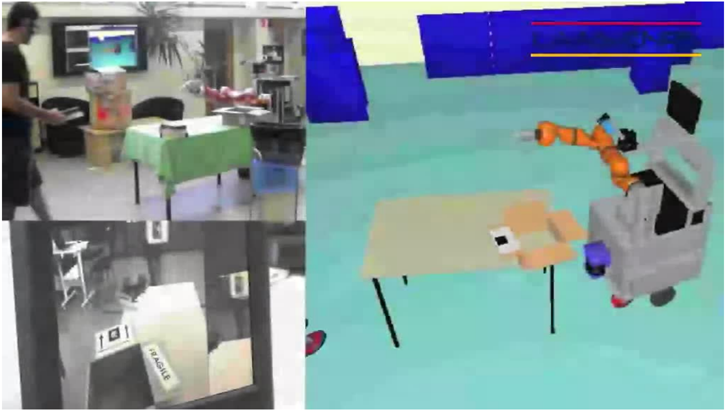
THE SYMBOL GROUNDING PROBLEM

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

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

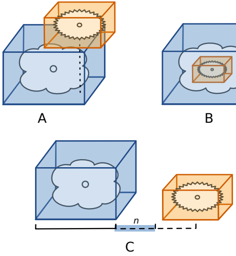
SITUATED, GROUNDED, SYMBOLIC SOCIAL COGNITION

SITUATION ASSESSMENT

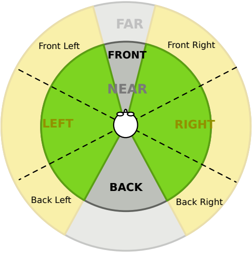


[Lemaignan et al., *Artificial Cognition for Social Human-Robot Interaction: An Implementation*, Artifical Intelligence, 2017]

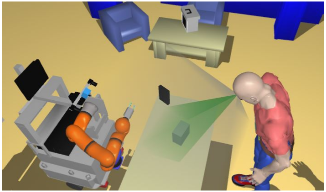
VISUAL PERSPECTIVE TAKING

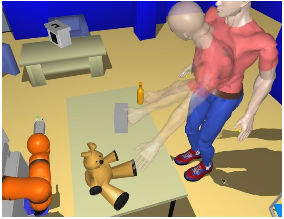


allocentric



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`

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

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

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human_1 sees teddybear
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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

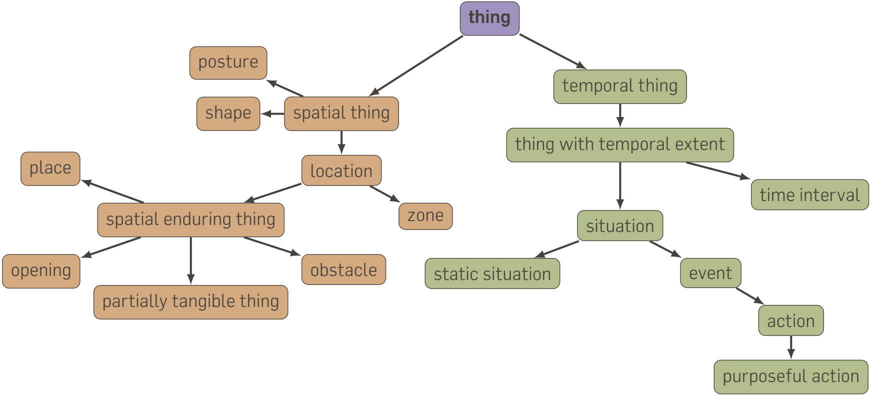
The robot's newly acquired beliefs typically have to be **anchored** in pre-existing knowledge.

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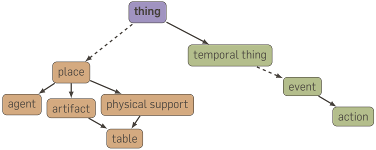
Ontologies are represented using a **knowledge description** language. The **Web Ontology Langage (OWL)** is a very common choice that uses a XML encoding.

ONLINE INSTANCIATION



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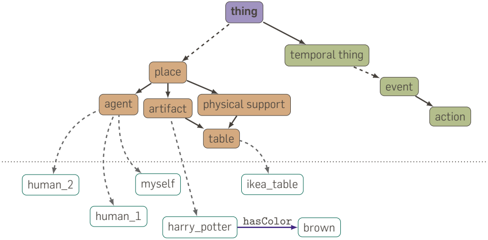

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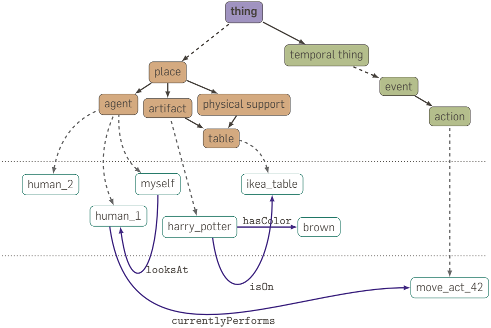
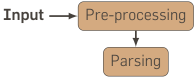


Back to our initial example:

Give me that book!

DIALOGUE GROUNDING



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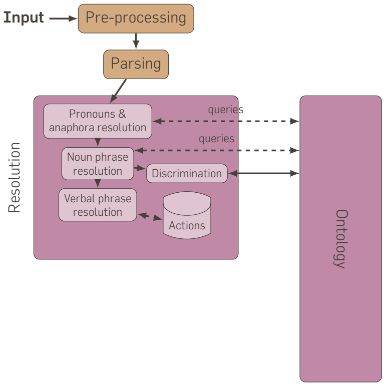

[Lemaignan et al. *Grounding the Interaction: Anchoring Situated Discourse in Everyday HRI* – Intl. J. of Social Robotics 2011]

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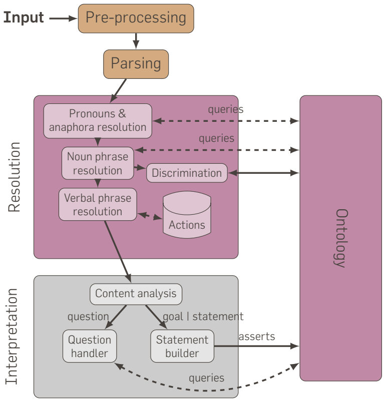

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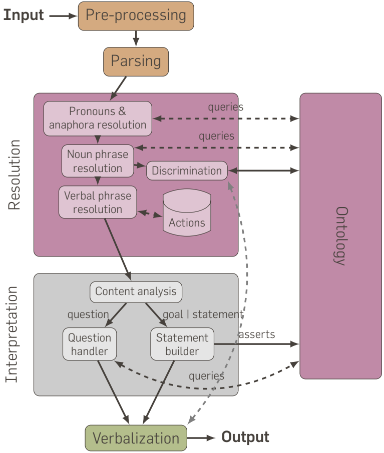
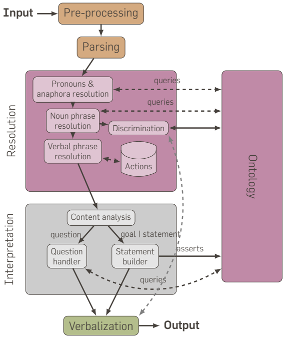


DIALOGUE GROUNDING

“Give me the book on the table”



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DIALOGUE GROUNDING

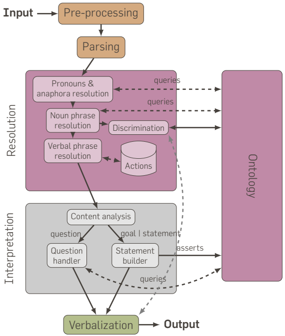
"Give me the book on the table"

$\downarrow$

`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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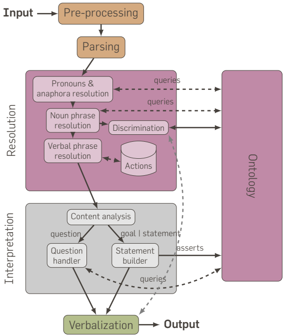
$\downarrow$

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**



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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`)

EXAMPLE OF FIRST-ORDER LOGIC REASONING

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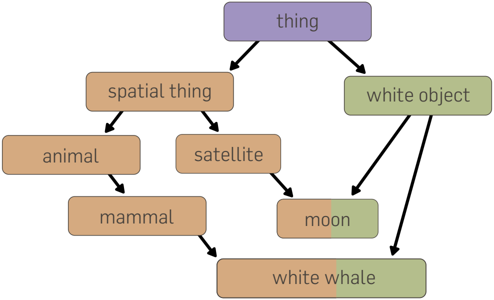
↓

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

Symbolic approaches effective at dealing with this kind of constraints

REASONING EXAMPLE: BEST DESCRIPTOR FOR A CONCEPT



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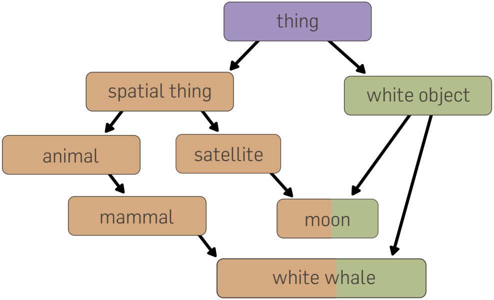
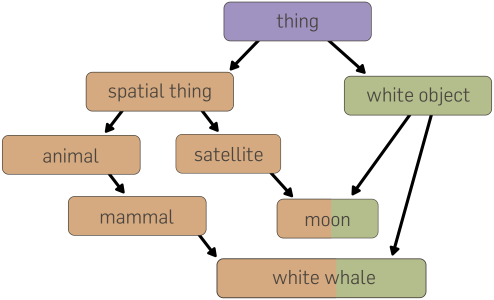


Algorithm 2.1: CommonAncestors(*concept*1, *concept*2)

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

REASONING EXAMPLE: BEST DESCRIPTOR FOR A CONCEPT



Algorithm 2.2: FirstDifferentAncestors($\boldsymbol{concept}1, \boldsymbol{concept}2$)

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

INTERACTION EXAMPLE: I SPY WITH MY LITTLE EYE

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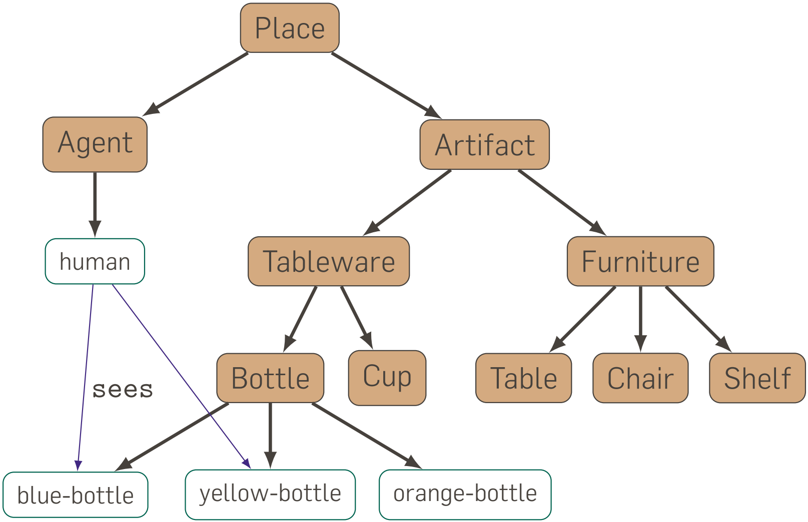
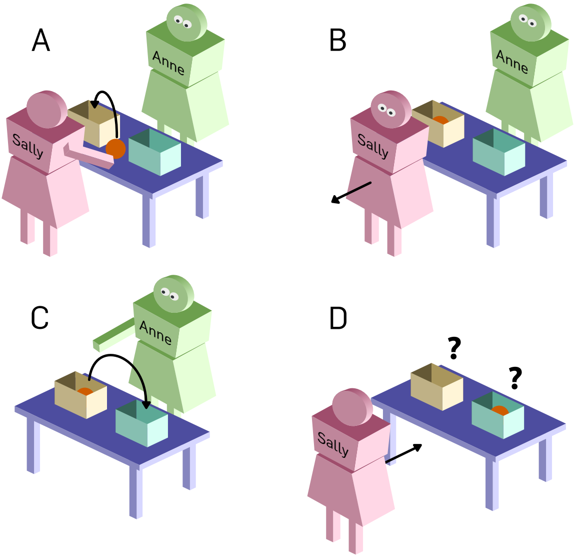


INTERACTION EXAMPLE: I SPY WITH MY LITTLE EYE

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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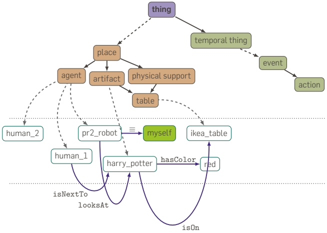
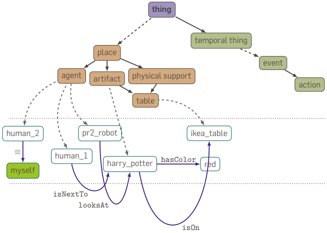
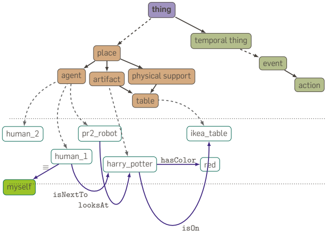
False-belief situation

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:

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Slides:

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