

# Human-Robot Interaction

an introduction

Aurélie CLODIC

# Why do we develop robots?

# why?

- To replace humans



# why?

- To replace humans



- To assist and serve  
humans

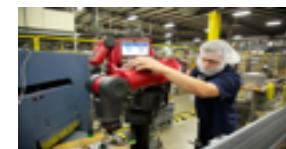
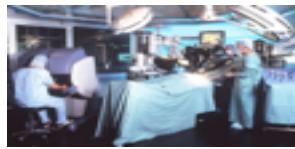


# why?

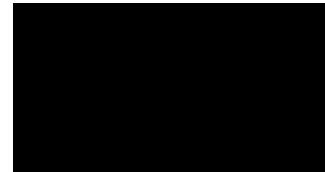
- To replace humans



- To assist and serve humans



- To rehabilitate/augment humans



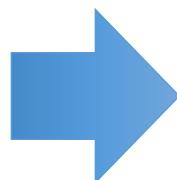
# domains

Manufacturing, hostile environments, transportation, logistics,  
agriculture, construction, health, entertainment, defense,...

# domains

Manufacturing, hostile environments, transportation, logistics, agriculture, construction, health, entertainment, defense,...

e.g. : From Automated to Cooperative Manufacturing...



Programmed and repetitive activity:  
welding, painting, assembling ...

# domains

Manufacturing, hostile environments, transportation, logistics, agriculture, construction, health, entertainment, defense,...

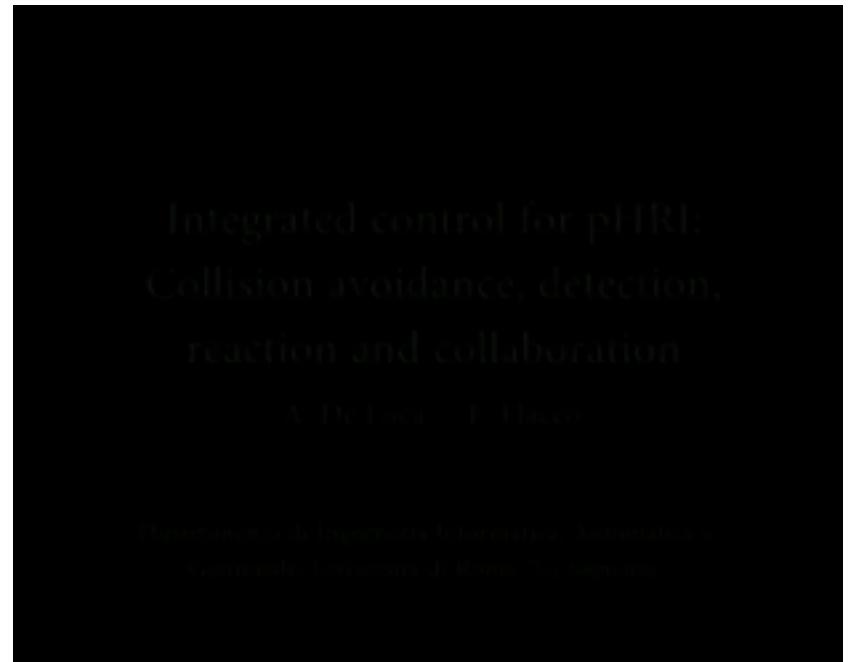
e.g. : From Automated to Cooperative Manufacturing... to Human-Robot co-habitation in the Factory...



# domains

Manufacturing, hostile environments, transportation, logistics, agriculture, construction, health, entertainment, defense,...

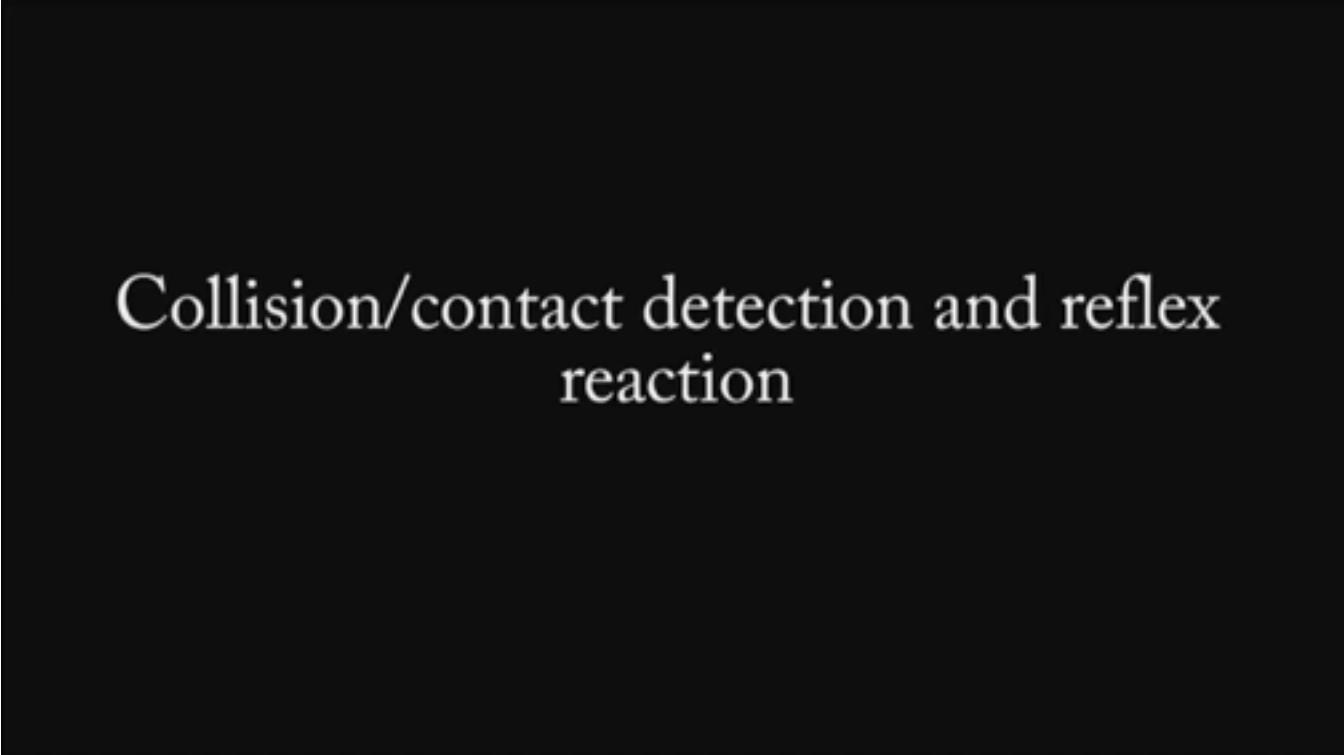
e.g. : From Automated to Cooperative Manufacturing... to Human-Robot co-habitation in the Factory...



# domains

Manufacturing, hostile environments, transportation, logistics, agriculture, construction, health, entertainment, defense,...

e.g. : From Automated to Cooperative Manufacturing... to Human-Robot co-habitation in the Factory...

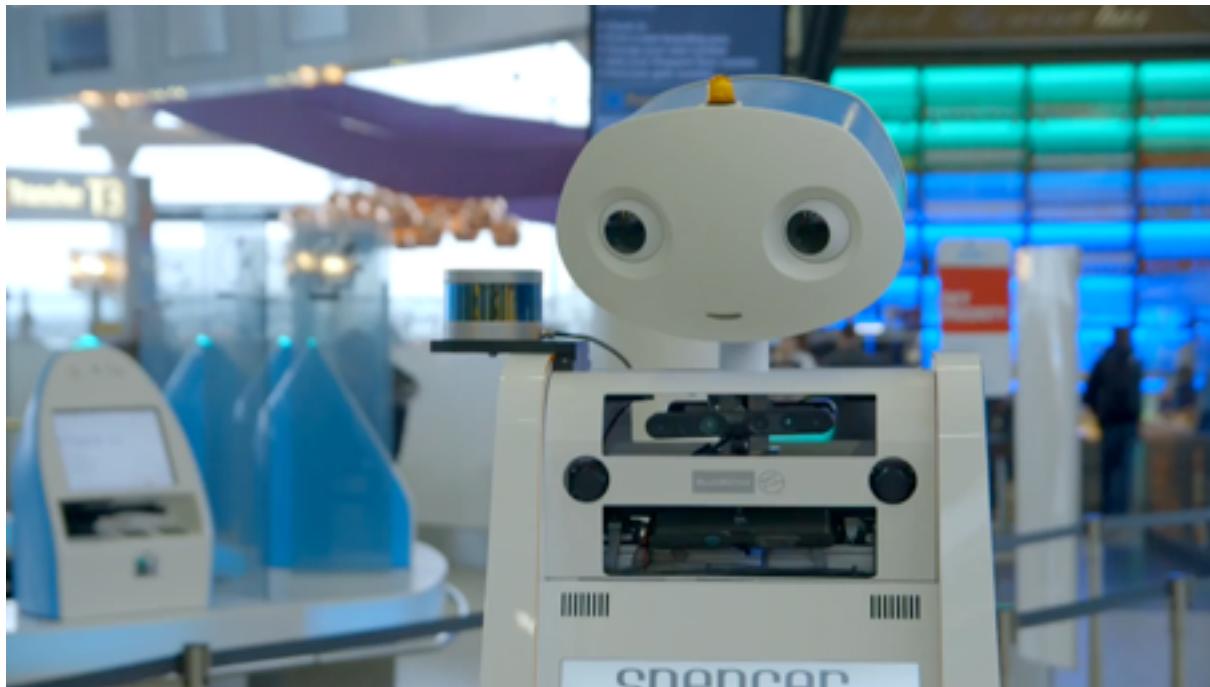


Collision/contact detection and reflex reaction

# domains

Manufacturing, hostile environments, transportation, logistics, agriculture, construction, health, entertainment, defense,...

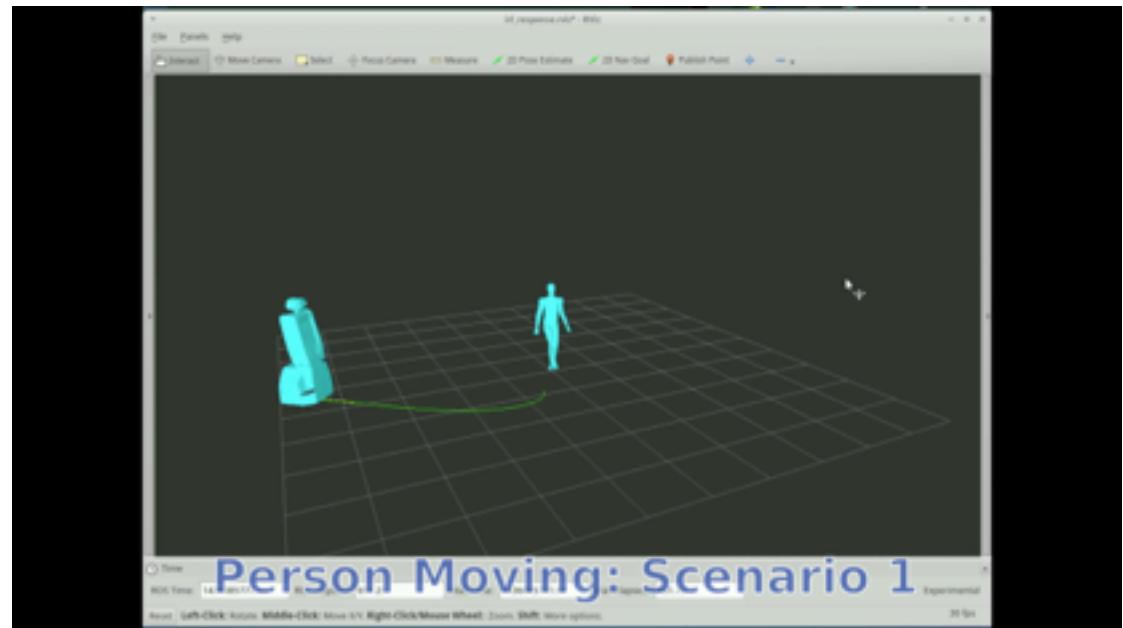
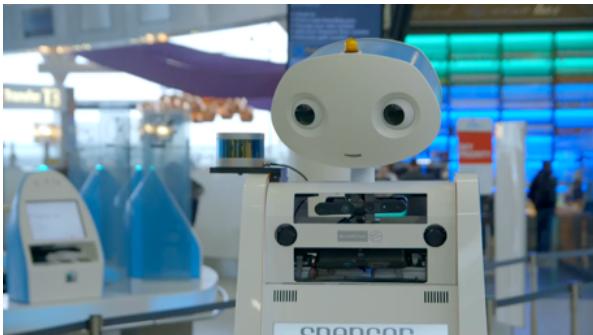
e.g. : Robot in Public Space (Spencer Project - Schipol Airport - 2015)



# domains

Manufacturing, hostile environments, transportation, logistics, agriculture, construction, health, entertainment, defense,...

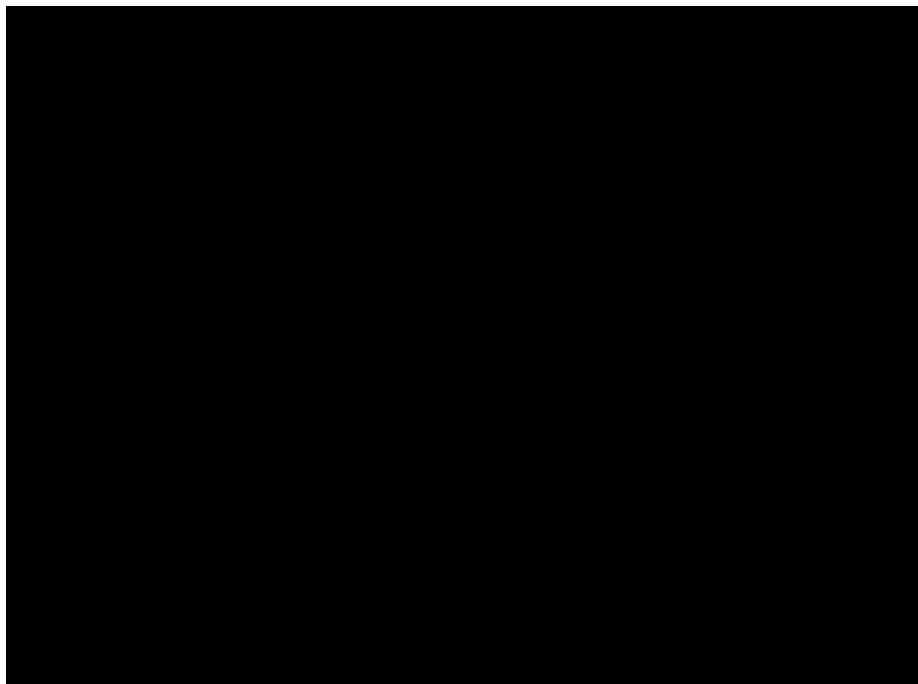
e.g. : Robot in Public Space (Spencer Project - Schipol Airport - 2015)



# domains

Manufacturing, hostile environments, transportation, logistics, agriculture, construction, health, entertainment, defense,...

e.g. : Healthcare rehabilitation



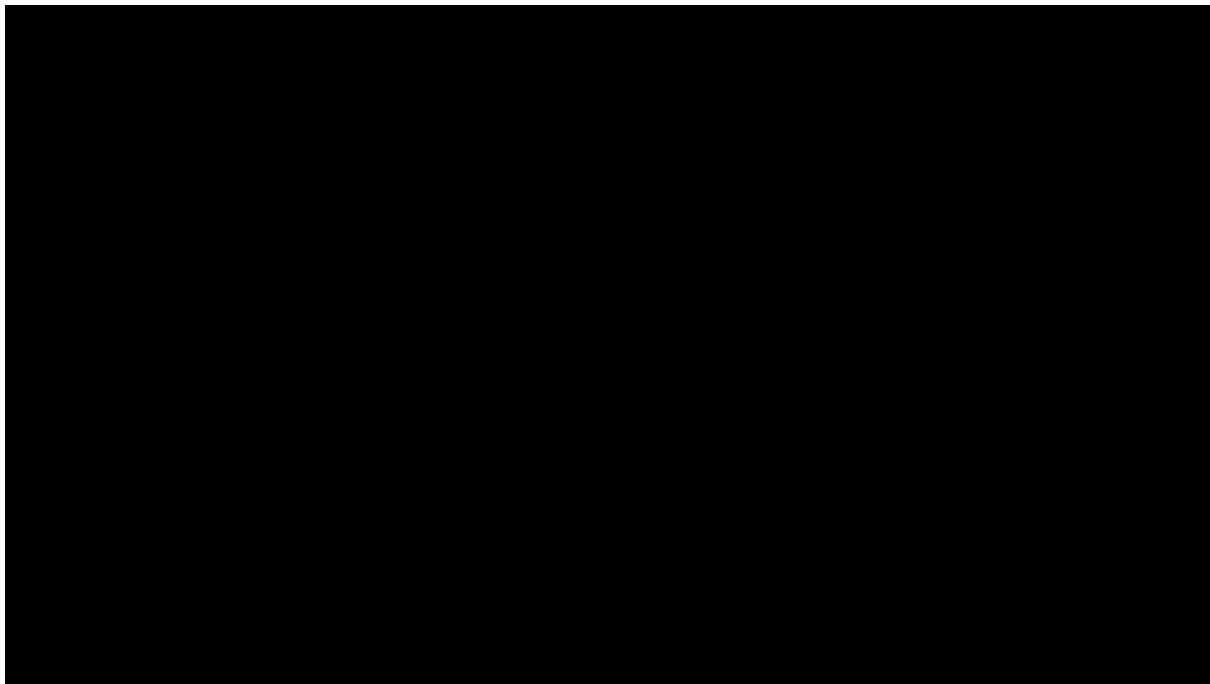
Haptic sensing and feedback

Shared motion control

# domains

Manufacturing, hostile environments, transportation, logistics, agriculture, construction, health, entertainment, defense,...

e.g. : Ocean Exploration



# remarks

Science et Vie

June 1960





# remarks

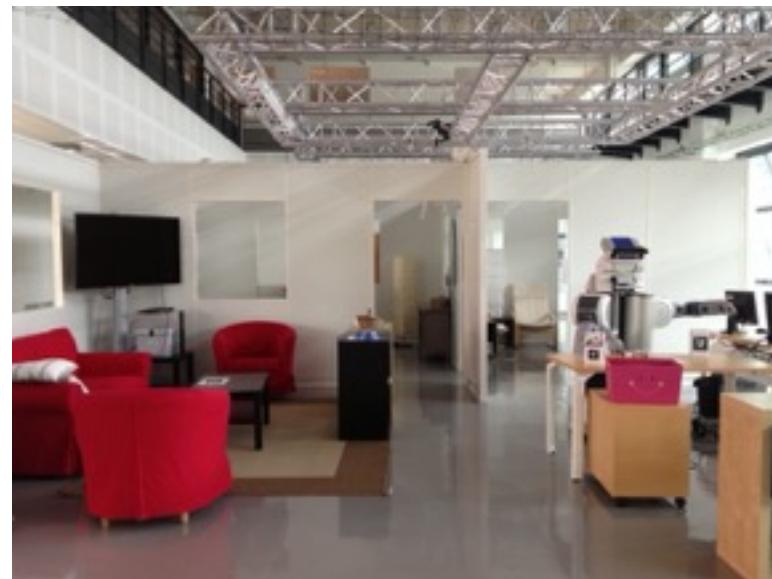
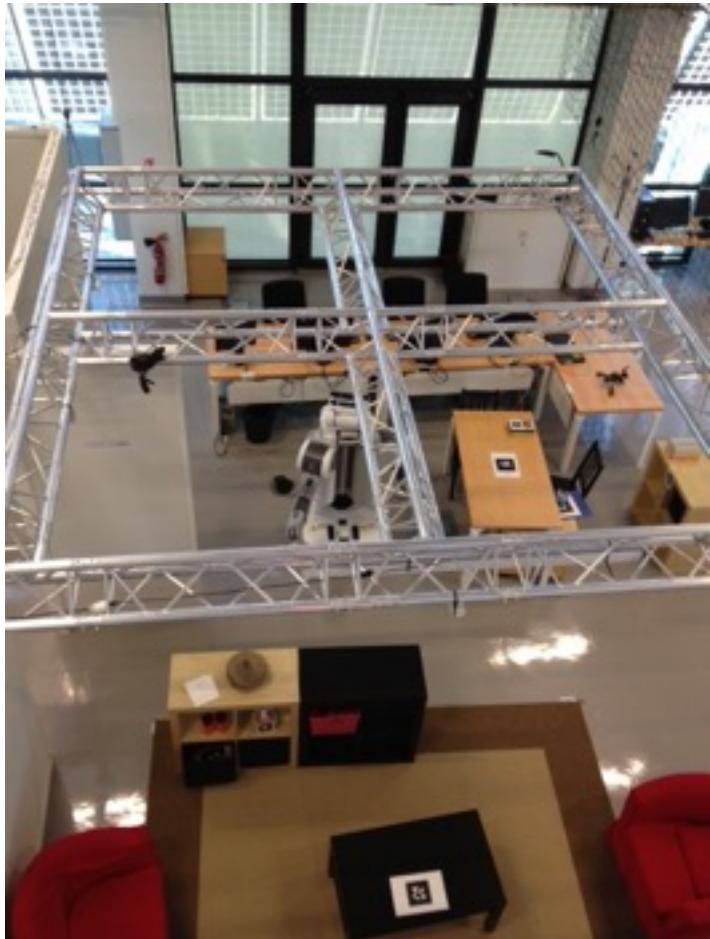
- Development of HRI is mostly driven by some industry needs for manufacturing or service robots.
- Research addresses several topics related to enabling “natural interactions”.
- Actual state of the art is well below PR videos.
- Some research and use cases raise philosophical questions and ethical concerns that are generally ignored (anthropomorphism in shape and behavior and emotions).
- Just because you can doesn't mean you should.

# What is it to implement joint action ?

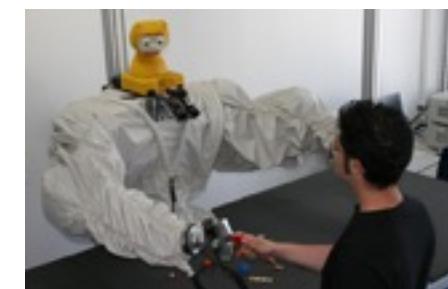
and a guided tour through some  
LAAS contributions

**Aurélie CLODIC, Rachid ALAMI**

# LAAS-CNRS



**Joint Action** "a social interaction whereby two or more individuals coordinate their actions in space and time to bring about a change in the environment." \*



\* Knoblich, G., Butterfill, S., & Sebanz, N. (2011). Psychological research on joint action: theory and data. In B. Ross (Ed.), *The Psychology of Learning and Motivation*, 51, 1–52. (Ed.)

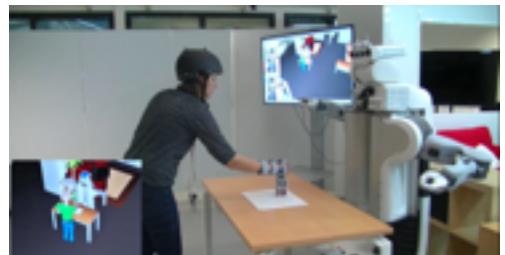
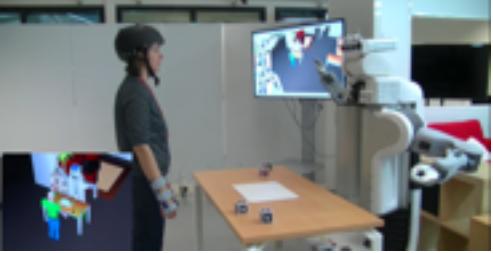
# a precursor...





# coordination processes in joint action

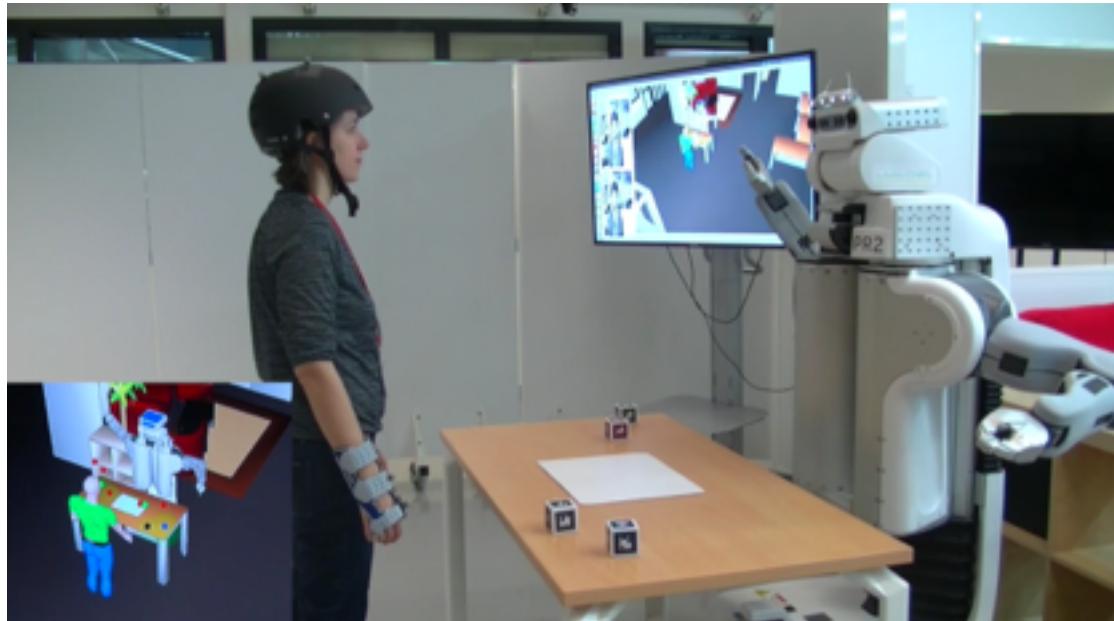
- Self-Other Distinction
- Joint Attention
- Understanding of Intentional Action
- Shared Task Representations



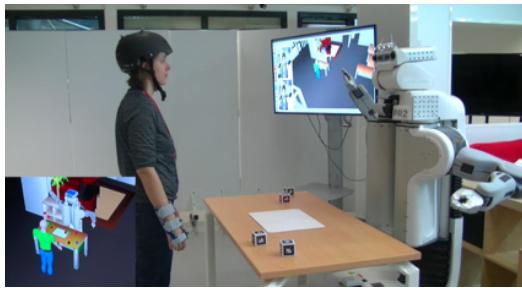
# Self-Other distinction

"for shared representations (...) to foster coordination rather than create confusion, it is important the agents be able to keep apart representations of their own and other's actions and intentions" (Pacherie 2012)

# Self-Other Distinction



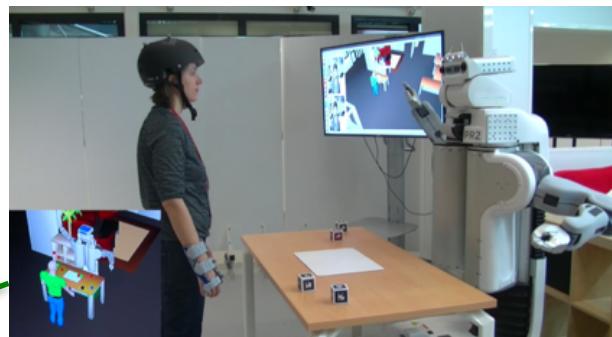
# Self-Other Distinction



the robot needs to be able to handle a representation of itself and a representation of the human it interacts with

# Self-Other Distinction

how does the human handle such self-other distinction in a human-robot case ?



the robot needs to be able to handle a representation of itself and a representation of the human it interacts with

# Joint attention

Attention the cognitive process of selectively concentrating on one aspect of the environment while ignoring other things.

Joint Attention involves more than just two people attending to the same object or event. At least two additional conditions must obtain. First, there must be some causal connection between the two subject's acts of attending (causal coordination). Second, each subject must be aware in some sense, of the object as an object that is present to both; in other words the fact that both are attending to the same object or event should be open or mutually manifest (mutual manifestness). (Pacherie, 2012).

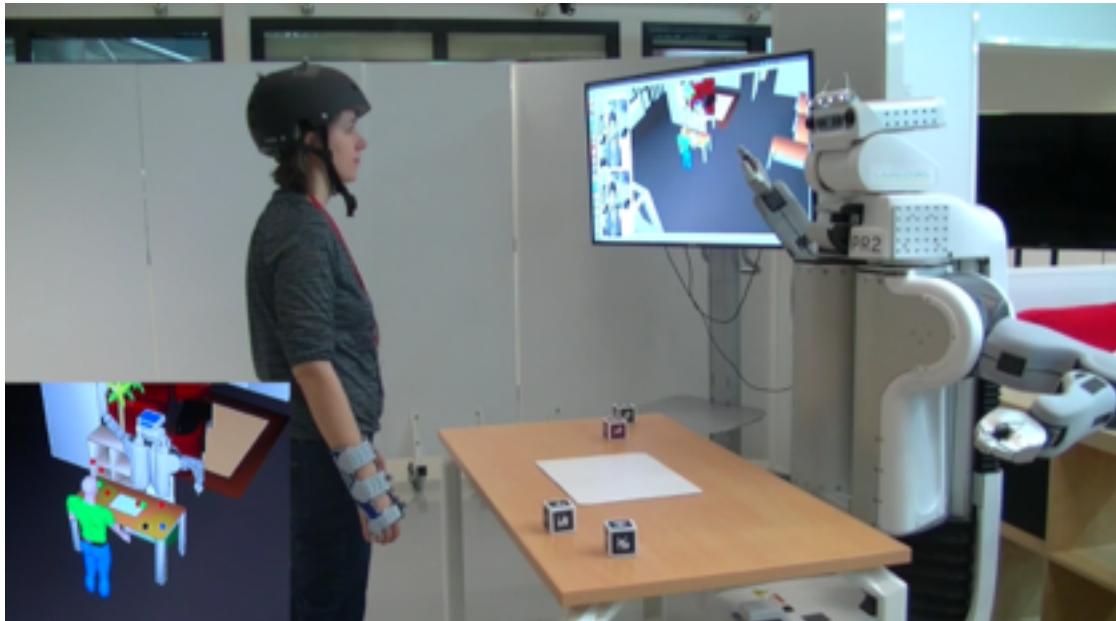
Joint Attention provides a basic mechanism for sharing representations of objects and events and thus for creating a "perceptual common ground" in joint action. (Tomasello, 1995, 1999; Tomasello & Carpenter, 2007; Tollefson, 2005; Sebanz et all, 2006).

# Joint attention



the objects to be acted upon, their location as well as the location of possible obstacles, be identified by the co-agents and thus that they track the same objects and features of the situation and be mutually aware that they do so. (Pacherie, 2012).

# Joint attention



???

# Situation assessment



## TOASTER: An Open-Source Situation Assessment Framework for HRI

Situation assessment for human-robot interactive object manipulation, EA Sisbot, R Ros, R Alami  
RO-MAN, 2011

Lemaignan, S., Ros, R., Sisbot, E. A., Alami, R., & Beetz, M. (2012). Grounding the interaction: Anchoring situated discourse in everyday human-robot interaction. International Journal of Social Robotics, 4(2), 181-199.

A framework for endowing an interactive robot with reasoning capabilities about perspective-taking and belief management, G Milliez, M Warnier, A Clodic, R Alami, RO-MAN 2014

# Situation assessment

perception

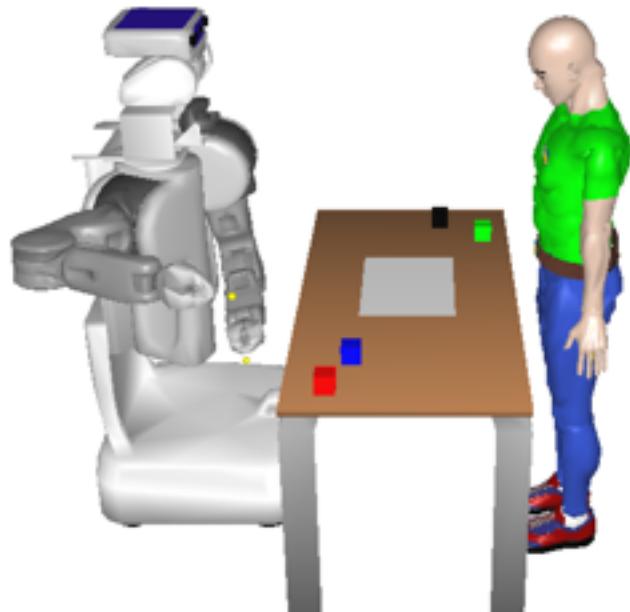


# Situation assessment

perception



robot position  
robot arm position  
robot head position



human position  
human hand position  
human head orientation

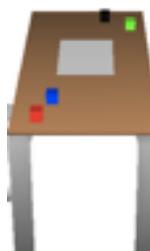


table position



game board position  
green cube position  
red cube position  
blue cube position  
black cube position



# Situation assessment

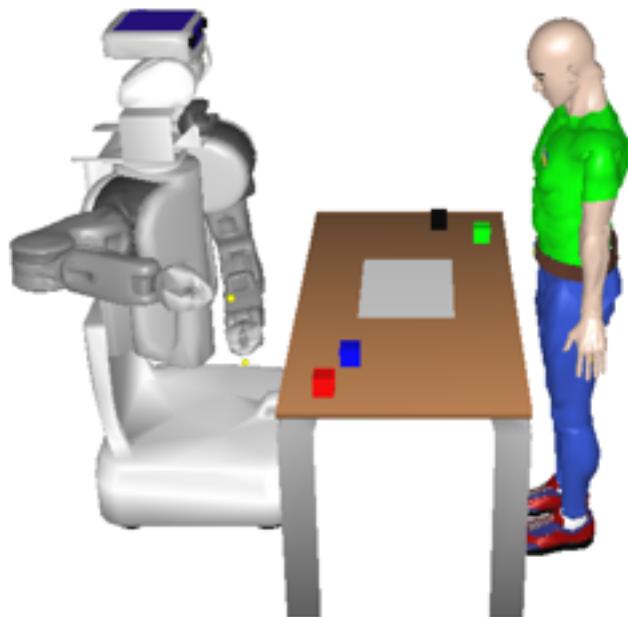
perception



green cube position ???

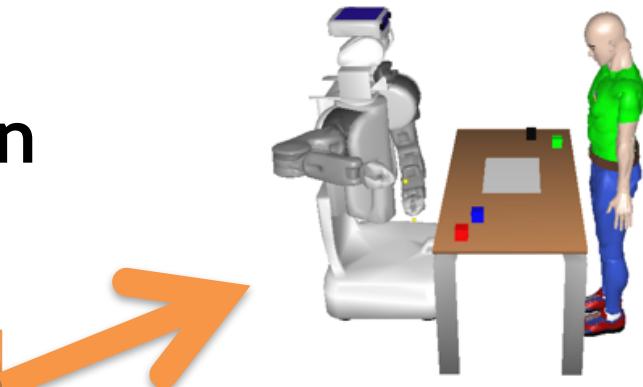
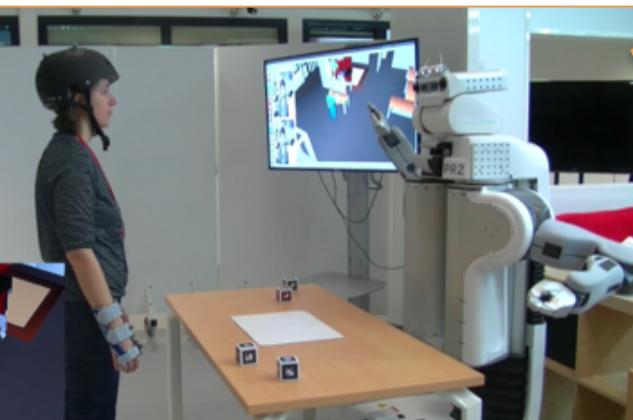
■  
frame base\_link  
x -0.5  
y 0.75  
z 0.9  
theta 0.0

■ is on the table

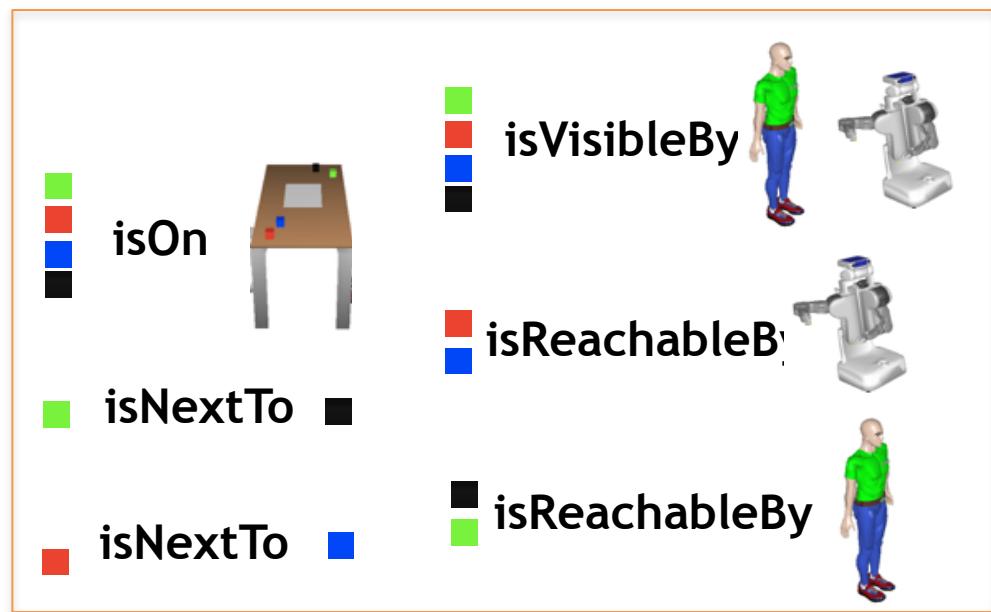


# Situation assessment

perception

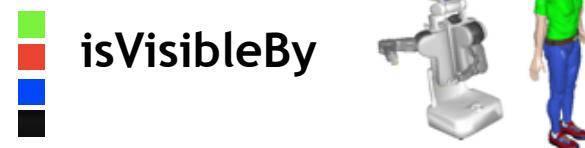
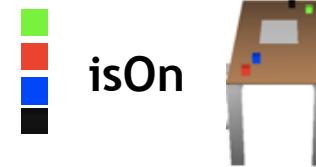
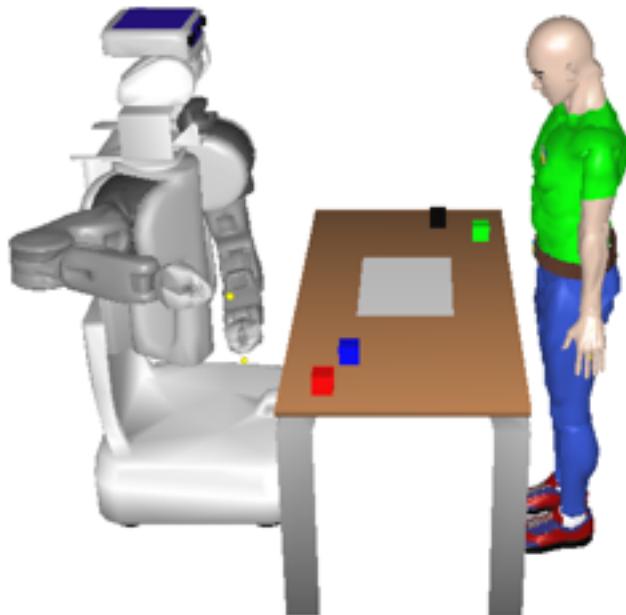


spatial  
reasoning



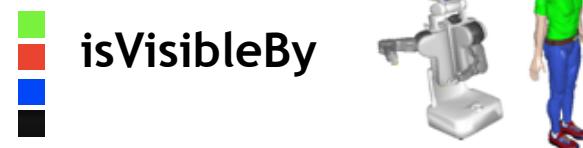
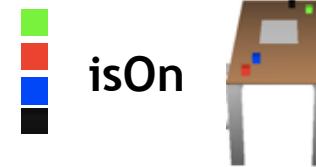
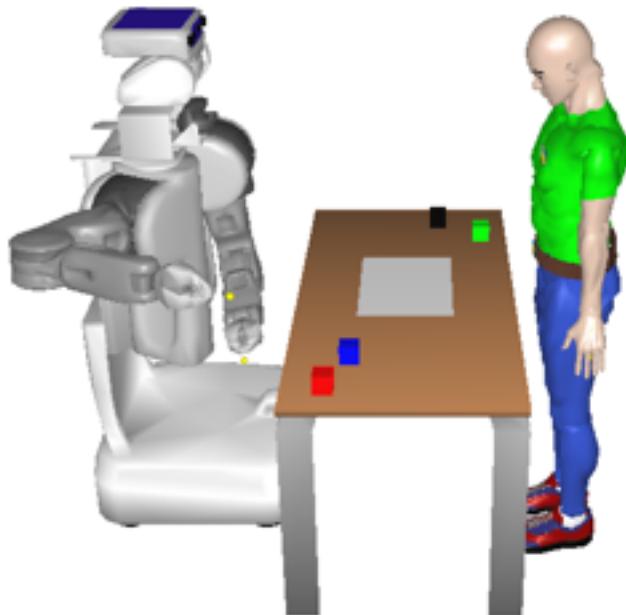
# Situation assessment

## spatial-reasoning



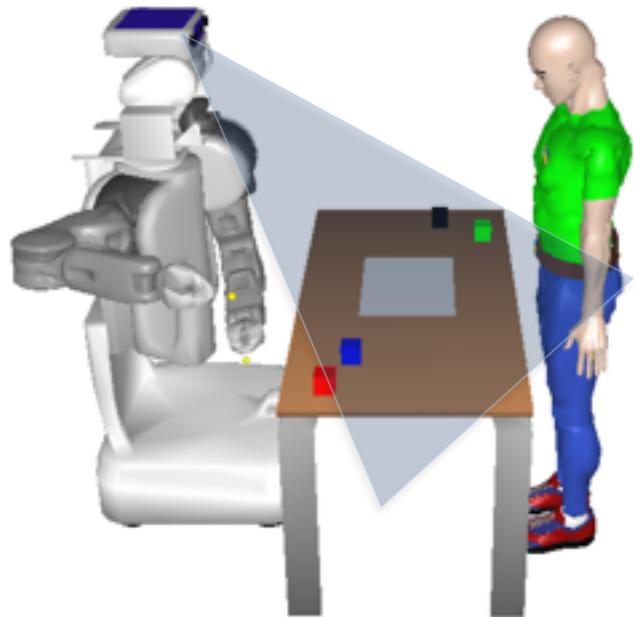
# Situation assessment

## spatial-reasoning



# Situation assessment

## mental state management



■ isOn ■

■ isNextTo ■

■ isReachableBy ■



■ isReachableBy ■

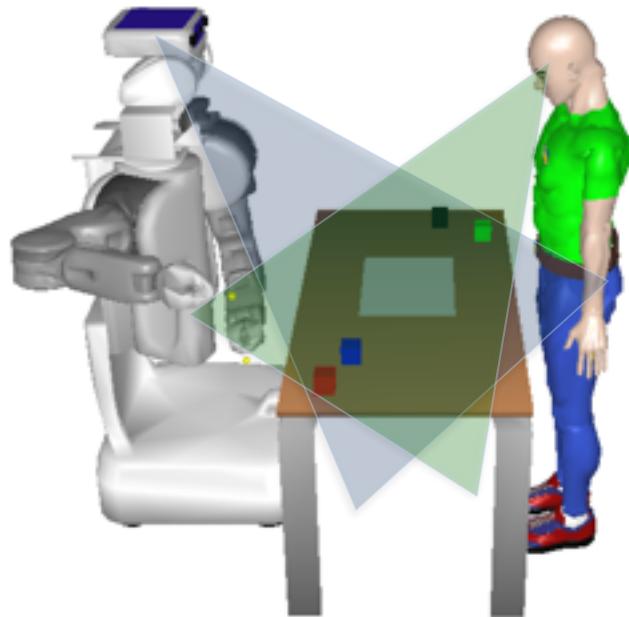
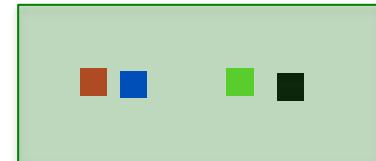
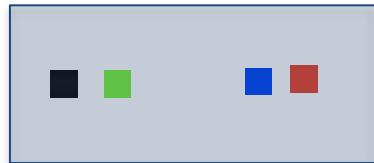


■ isVisibleBy  
■ ■ ■



# Situation assessment

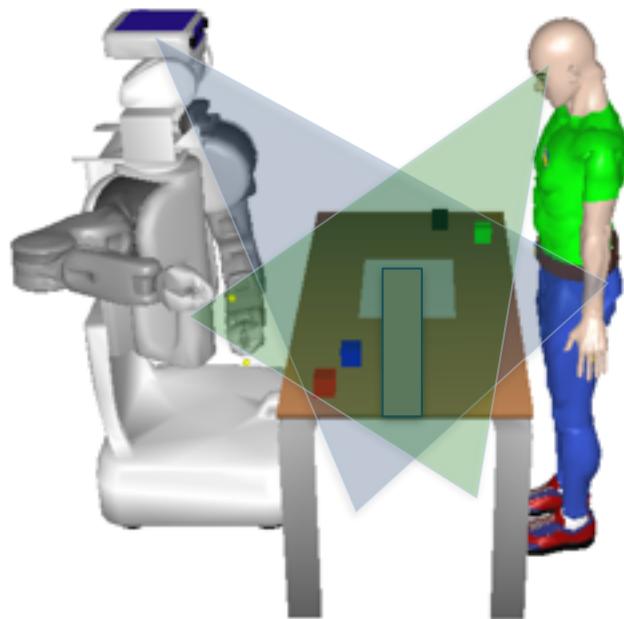
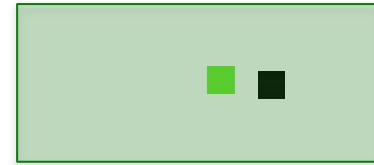
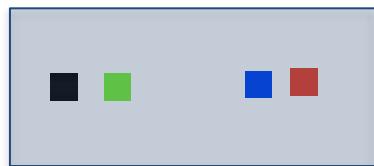
## mental state management



order of the cubes on the table ???

# Situation assessment

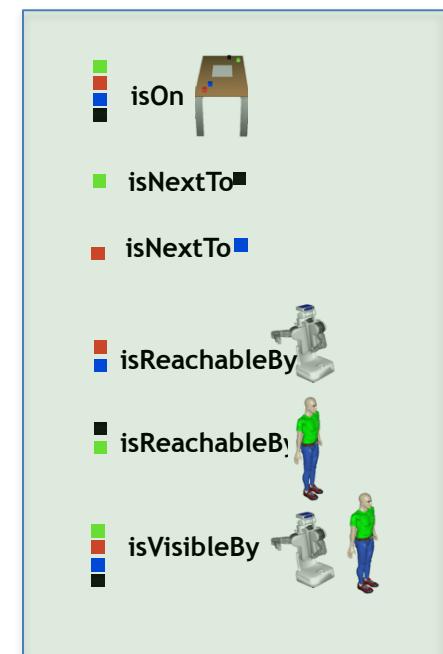
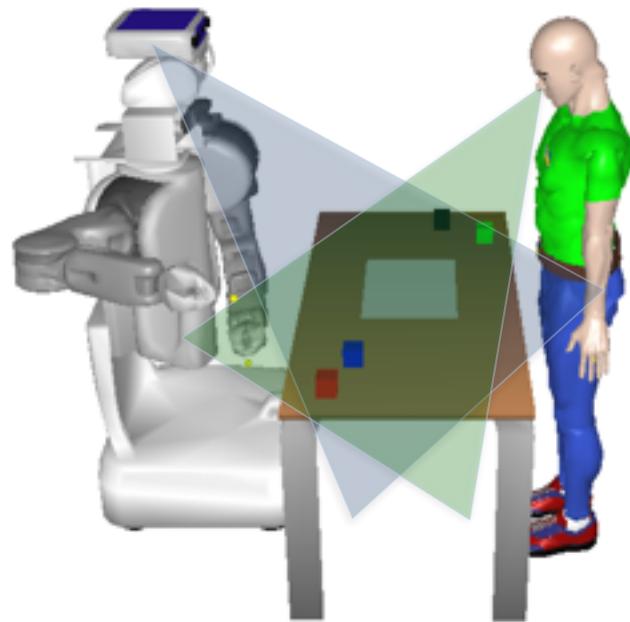
## mental state management



order of the cubes on the table  
what if something is hidden ?

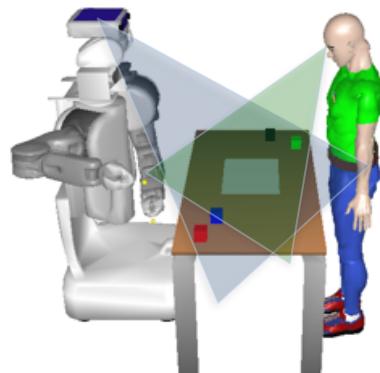
# Situation assessment

## mental state management



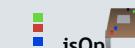
# Situation assessment

perception



spatial  
reasoning

mental state  
management



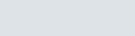
isOn



isNextTo



isNextTo



isReachableBy



isReachable



isVisibleBy



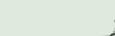
isOn



isNextTo



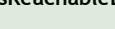
isNextTo



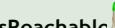
isReachableBy

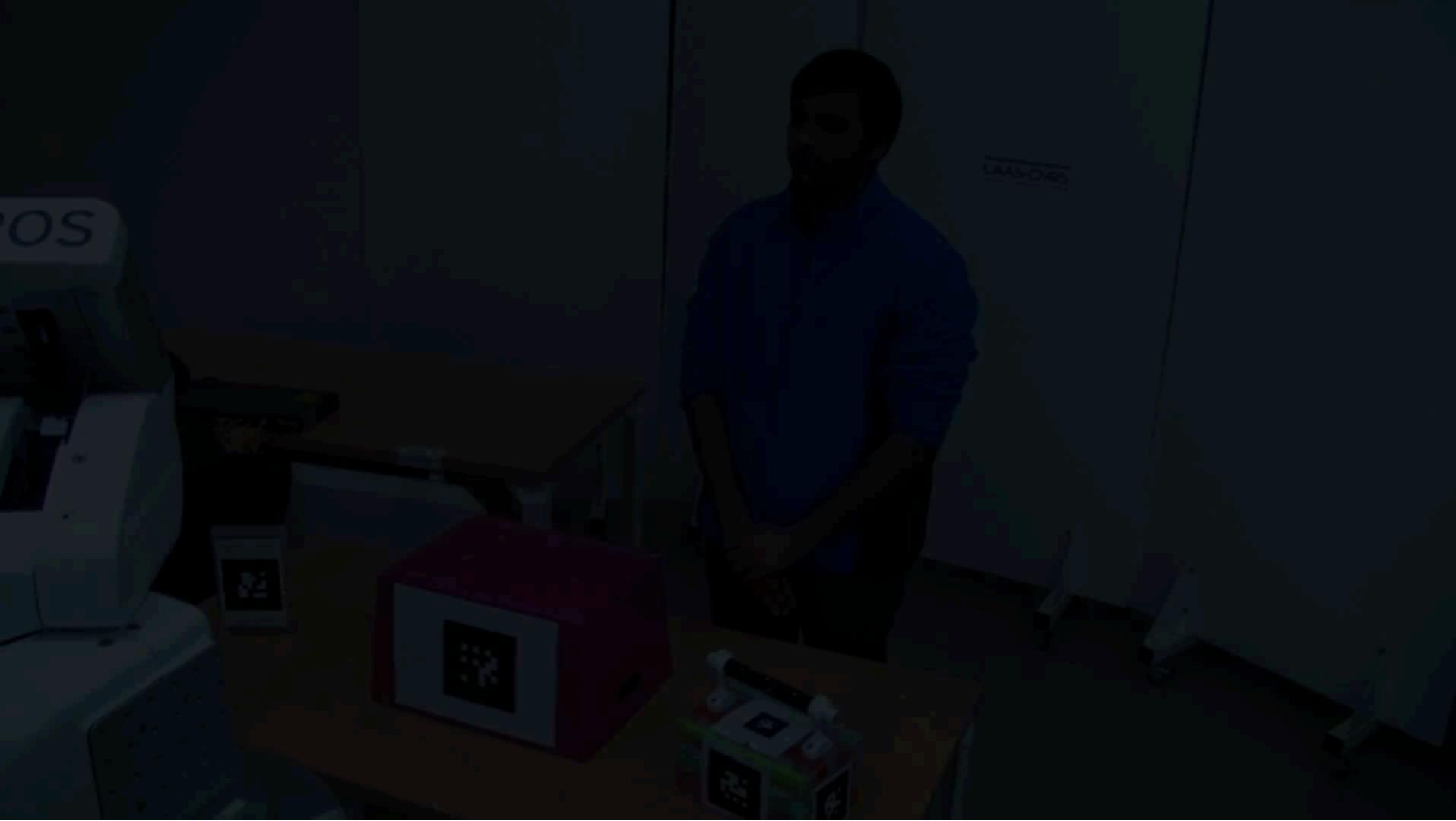


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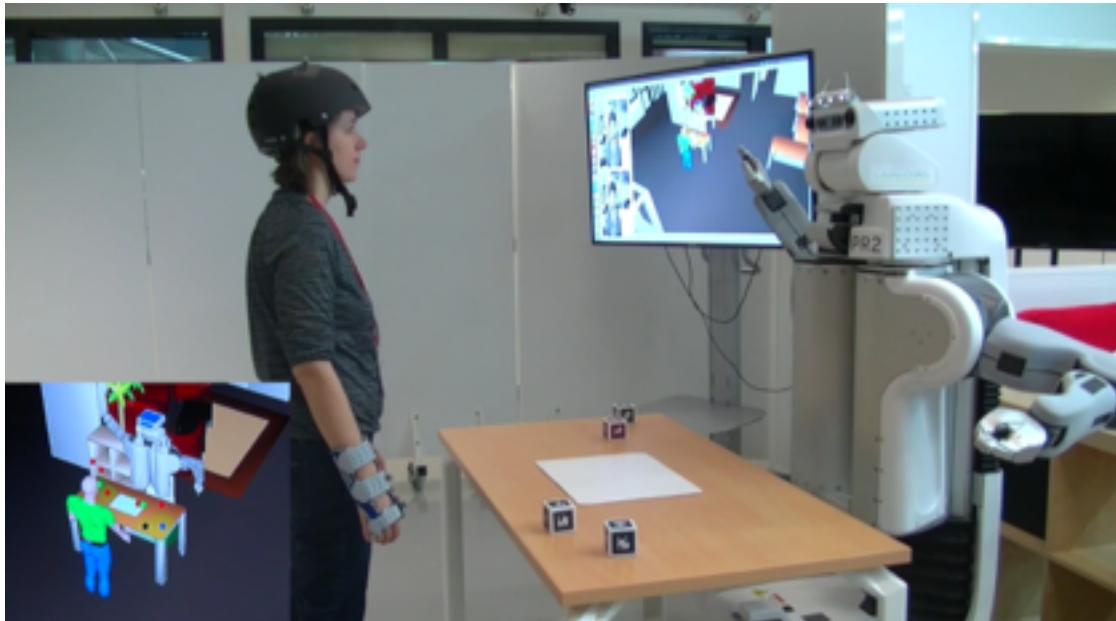


isVisibleBy





# Joint attention

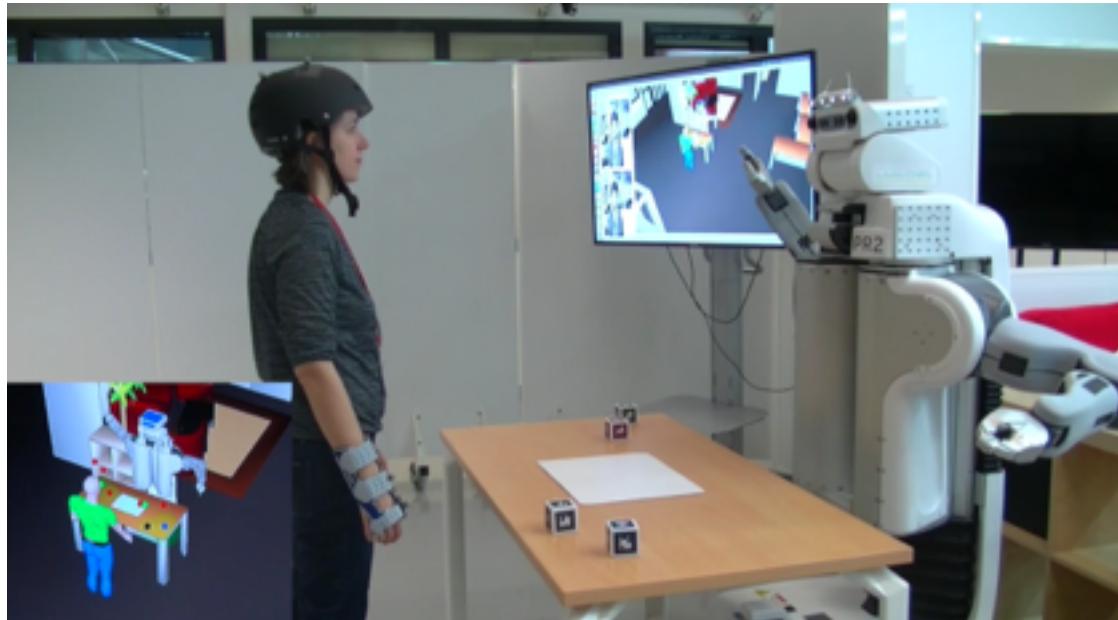


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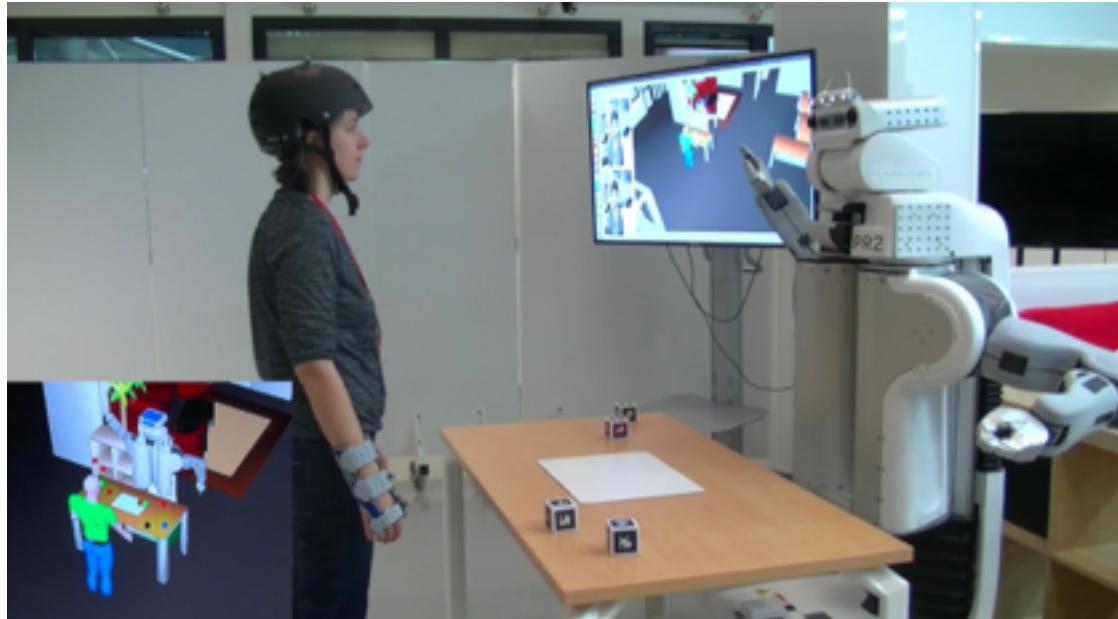
Are robot perception abilities readable ?

# Joint attention



Mutual manifestness ?

# Joint attention



## Mutual manifestness ?

" (...) each subject must be aware in some sense, of the object as an object that is present to both; in other words the fact that both are attending to the same object or event should be open or mutually manifest..."

# Joint attention

how can a robot exhibit joint attention ?

what cues the robot should exhibit to let the human infer that joint attention is met ?



how can a robot know that the human it interacts with attended with him to the joint task ?

what are the cues that should be collected to infer joint attention ?

## Mutual manifestness ?

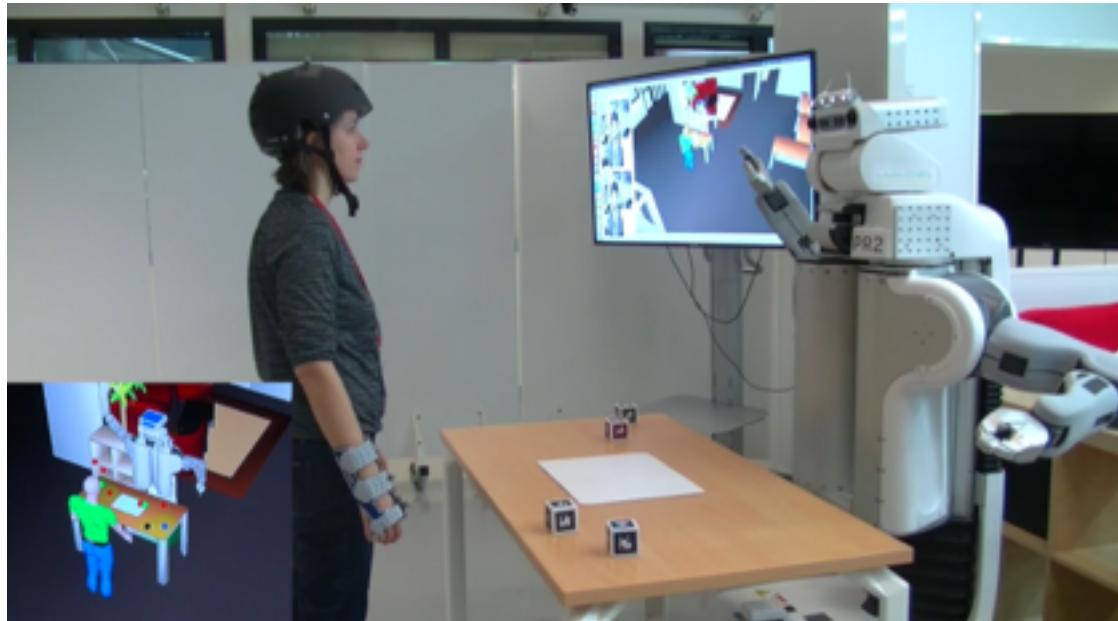
" (...) each subject must be aware in some sense, of the object as an object that is present to both; in other words the fact that both are attending to the same object or event should be open or mutually manifest..."

# Intentional Action Understanding

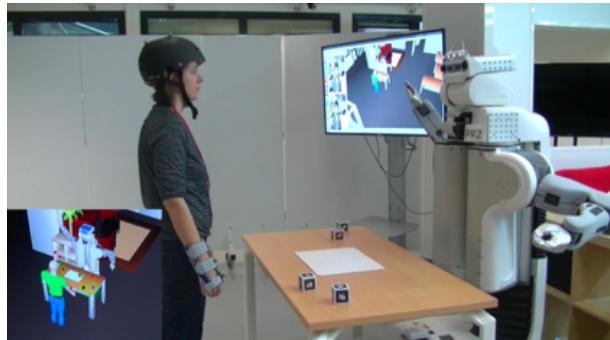
"... each agent should be able to read its partner's actions. (...) To understand an intentional action, an agent should, when observing a partner's action or course of actions, be able to infer their partner's intention" Tomassello 2005

\* partner's intention = goal + plan

# Intentional Action Understanding

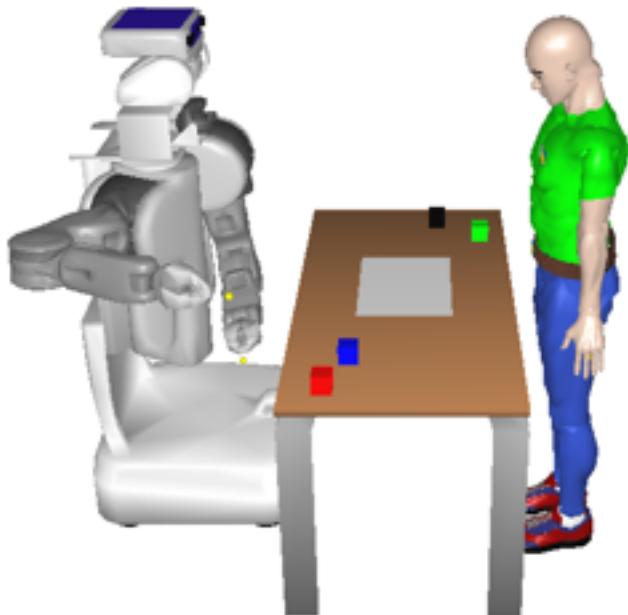


# Intentional Action Understanding



the robot needs to be able to understand what the human is currently doing and to be able to predict the outcomes of human's actions= it must be equipped with action recognition abilities

# Intention detection/prediction

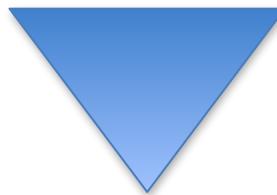


extended set of computed facts

agent/agent\_joint is\_moving

agent/agent\_joint is\_moving\_toward agent/agent\_joint

agent/agent\_joint distance\_to object far/medium/close



combined to detect actions

e.g.

agent\_hand is\_moving\_toward █

+

agent\_hand distance\_to █ close

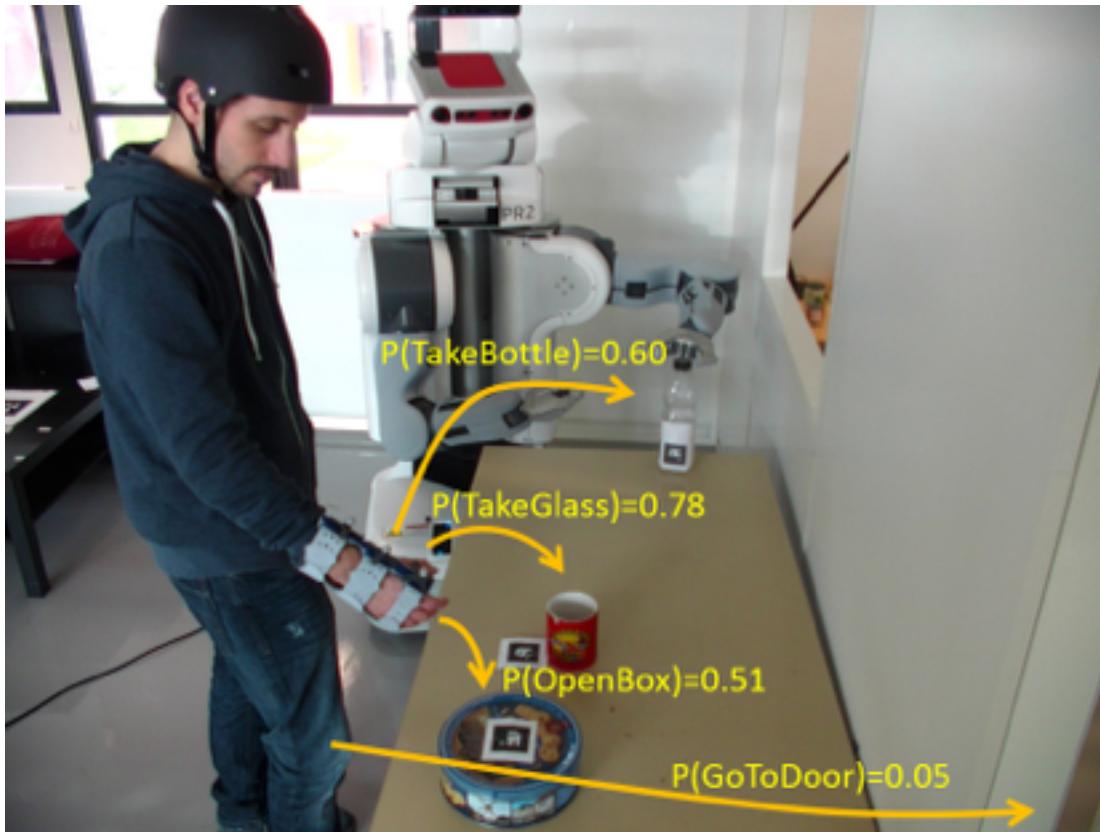
+

█ isOn table

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probability that agent will pick █ soon is high

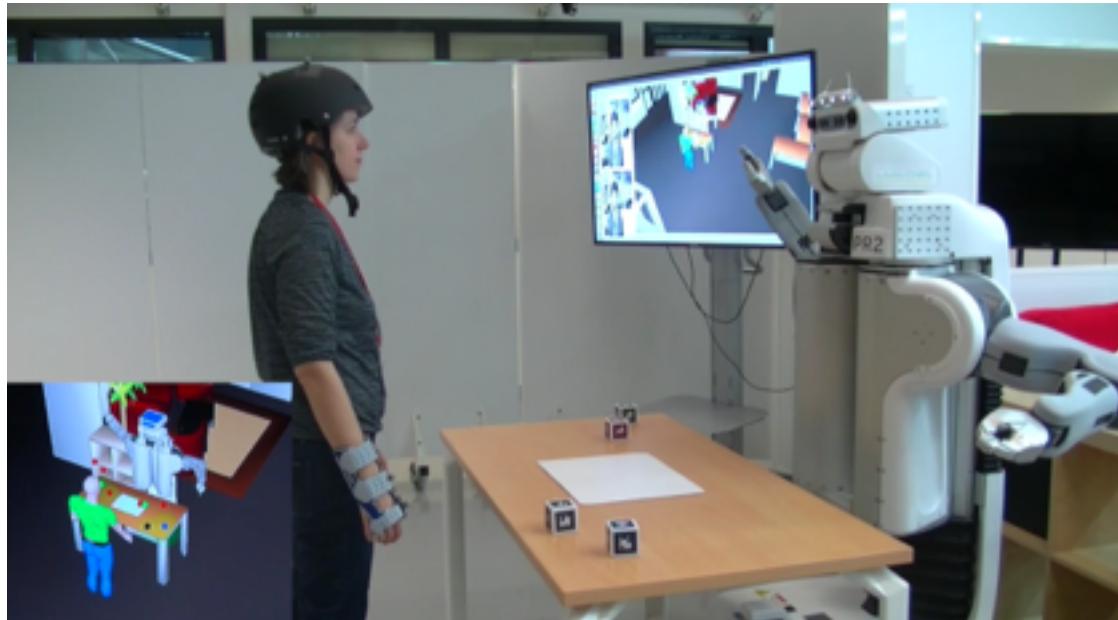
# Intention detection/prediction



MDP linking intentions to human actions

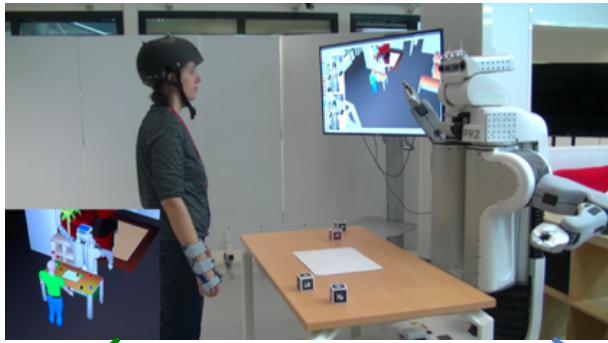
Humans mental state are used as current state for the MDP

# Intentional Action Understanding



???

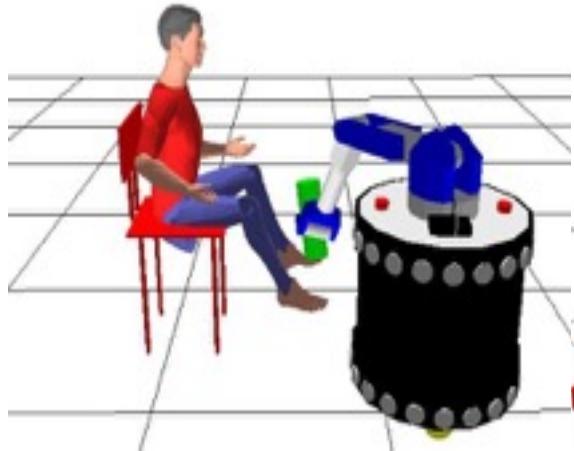
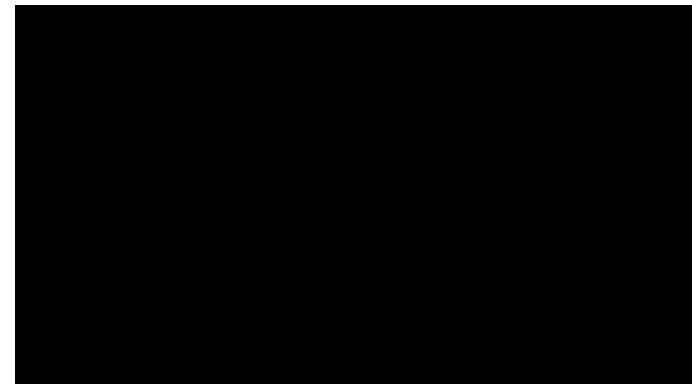
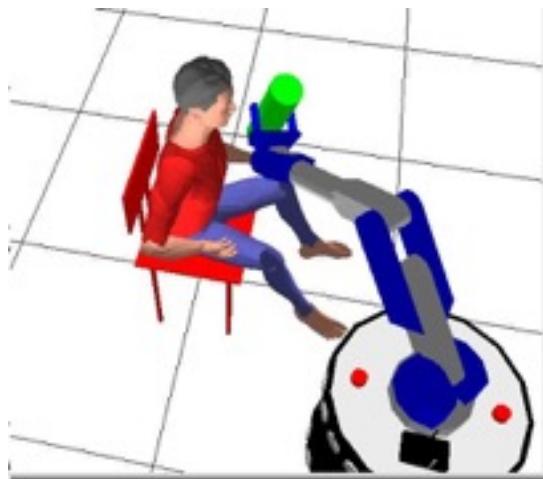
# Intentional Action Understanding



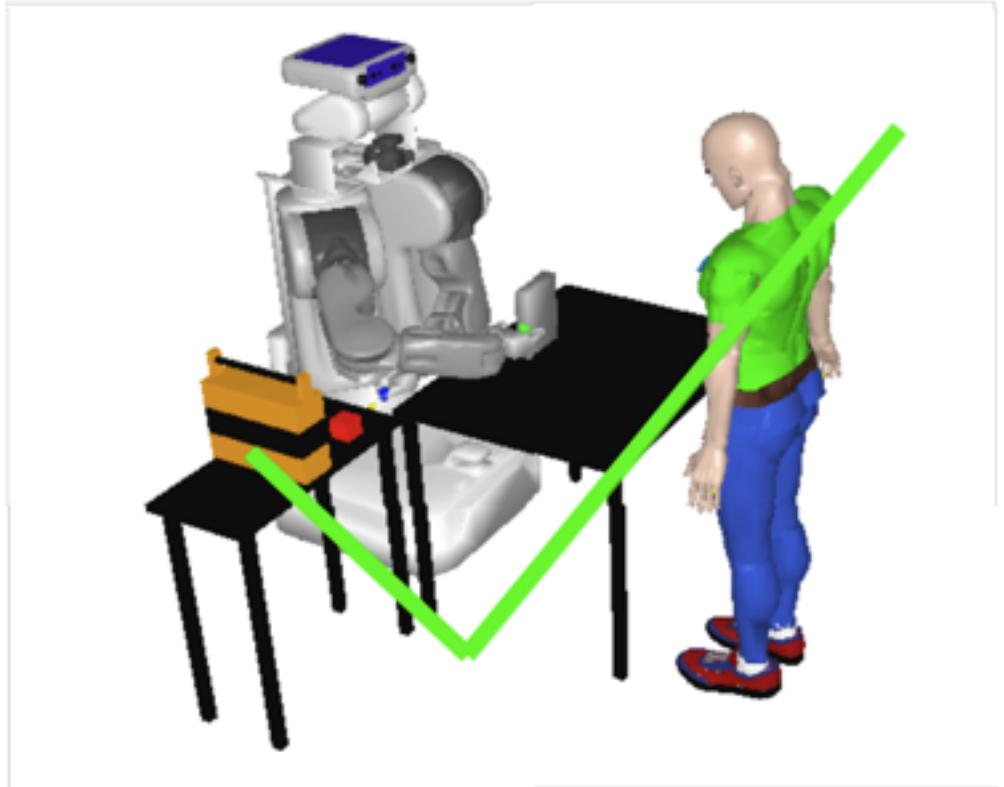
the human needs to be able to understand what the robot is currently doing and be able to predict the outcomes of robot actions  
= viewing a movement, it must be able to infer what is the underlying action of the robot

the robot needs to be able to understand what the human is currently doing and to be able to predict the outcomes of human's actions  
= it must be equipped with action recognition abilities

# ~~Human-Aware Motion Planning~~



# Human-Aware Motion Planning

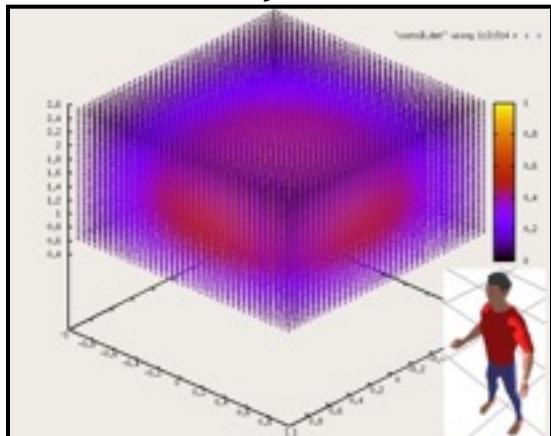


Sisbot, E. A., & Alami, R. (2012). A human-aware manipulation planner. *Robotics, IEEE Transactions on*, 28(5), 1045-1057.

# Human-Aware Motion Planning

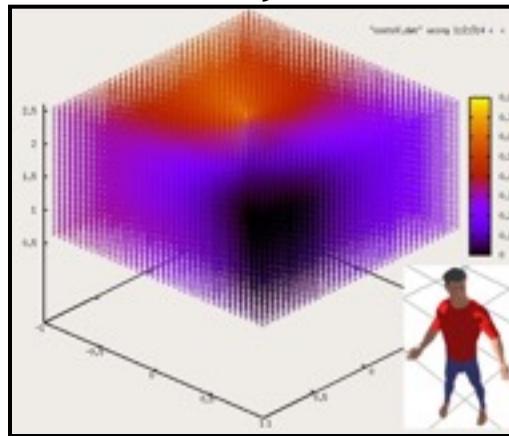
3 different HRI properties are defined and represented as 3D cost grids around the human

Safety



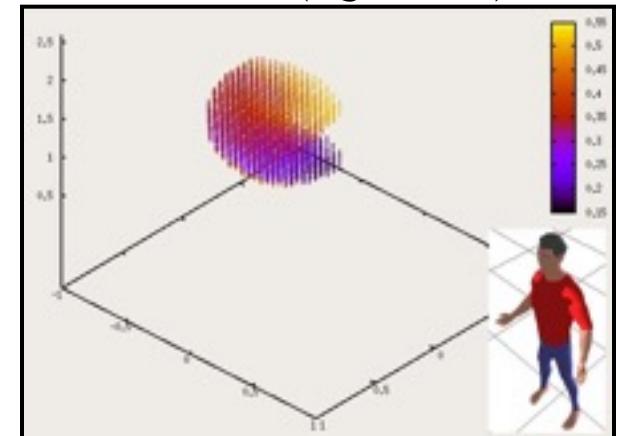
Proportional to the distance to human

Visibility

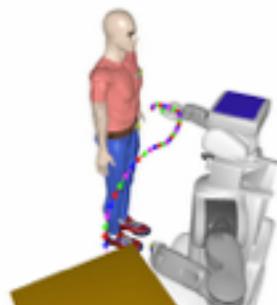


Reflects the effort to see a point

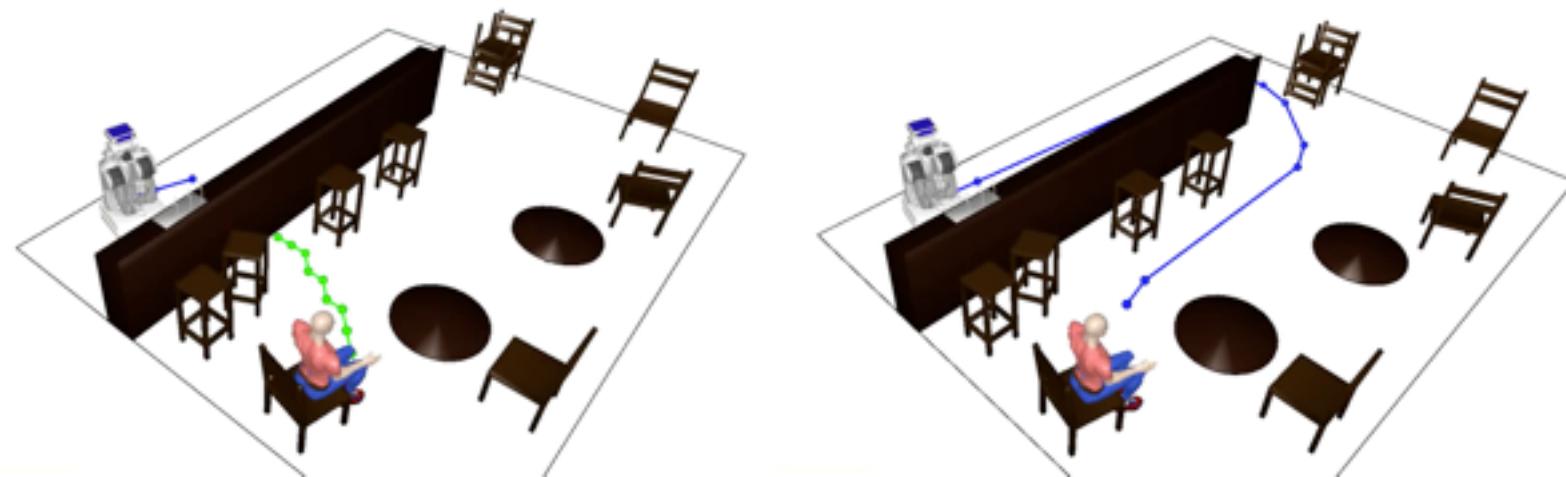
Arm Comfort(right/left)



Combination of d.o.f difference and potential energy



# Human-Aware Motion Planning



# Human-Aware Motion Planning

HRI 2013

*Natural Interaction for Object Hand-over*

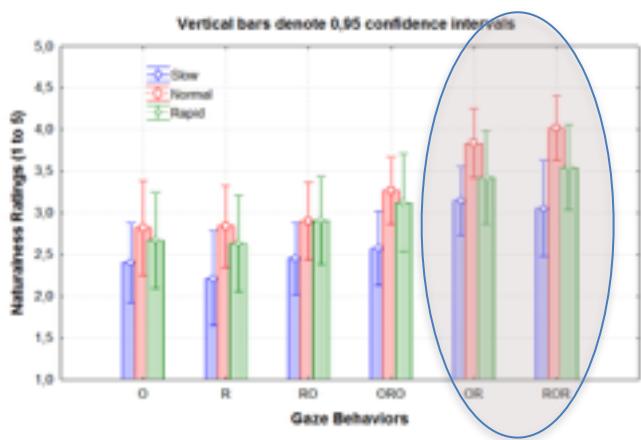
Mamoun Gharbi, Séverin Lemaignan,  
Jim Mainprice, Rachid Alami

2012



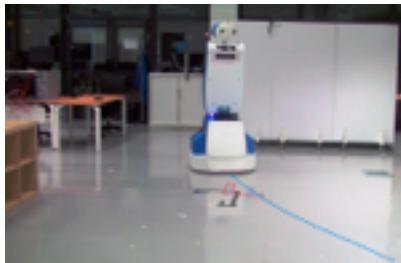
Understandable? Readable?  
**Human-Aware Motion Planning**





Gharbi, M., Paubel, P.-V., Clodic, A., Carreras, O., Alami, R., & Cellier, J.-M. (2015). Toward a better understanding of the communication cues involved in a robot-human object transfer. In *International Symposium on Robot and Human Interactive Communication (RO-MAN)*.

- Making robot intent legible
  - multi-criteria decision-making based approach for head pan-tilt motion control.
  - A head-behavior module have been developed that exhibits **look-at-path** and **glance-at-human** behaviors for **legibility of robot intent**





## coordination smoothers

"any kind of modulation of one's movements that reliably has the effect of simplifying coordination" (Vesper et al 2010)

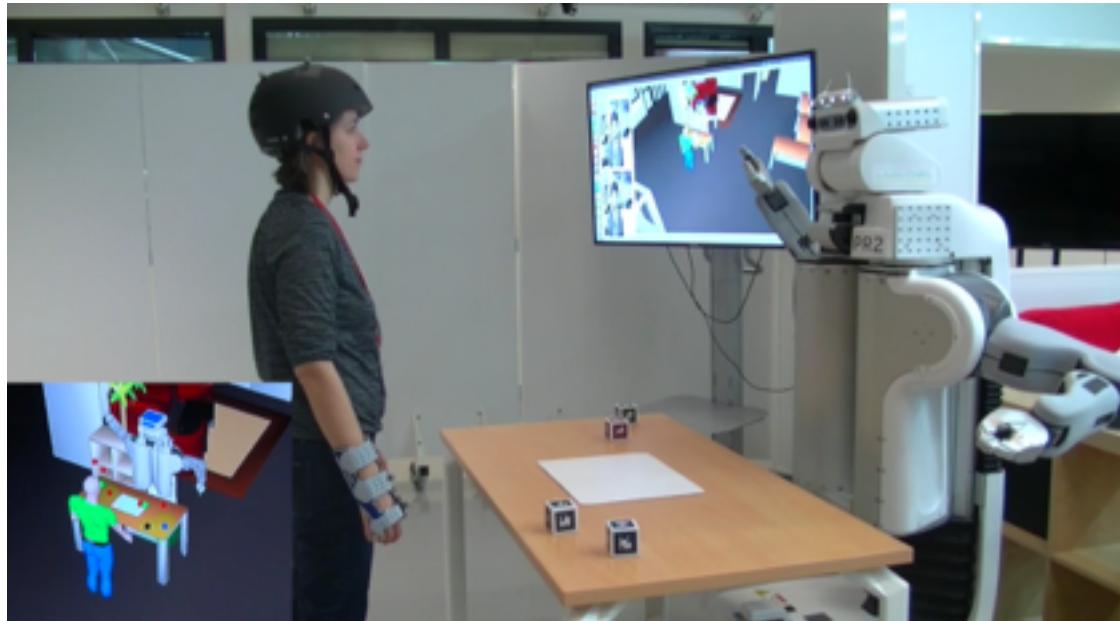
Vesper, C., Butterfill, S., Knoblich, G. & Sebanz, N. (2010). A minimal architecture for joint action. *Neural Networks*, 23, 998-1003.

# Shared Task Representations

Shared task representations play an important role in goal-directed coordination

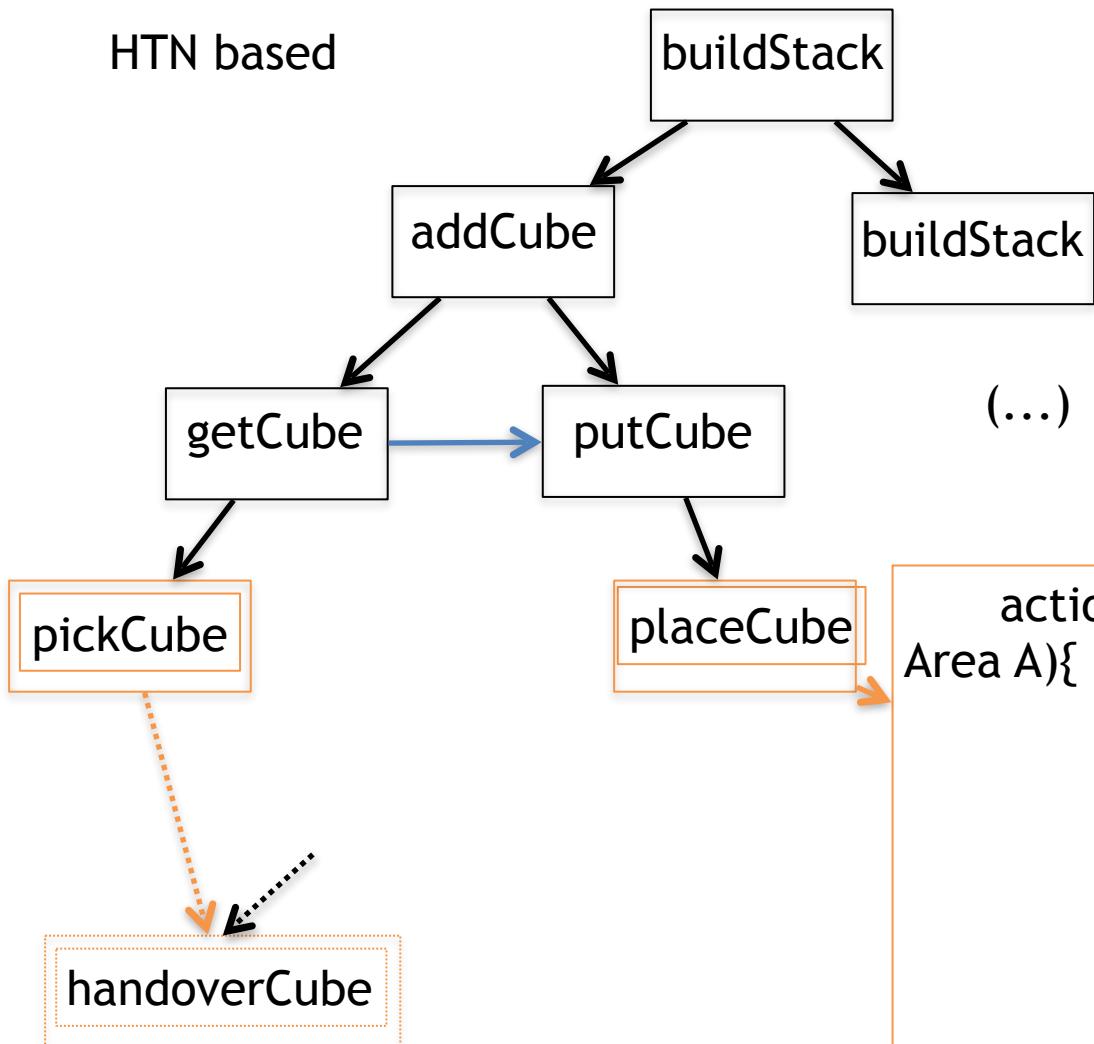
Knoblich, G., Butterfill, S., & Sebanz, N. (2011). Psychological research on joint action: theory and data. In B. Ross (Ed.), *The Psychology of Learning and Motivation*, 54 (pp. 59-101),

# Shared Task Representations



# Human-Aware Task Planner

HTN based



domain definition  
represents "expert"  
knowledge about the task  
it is human-readable

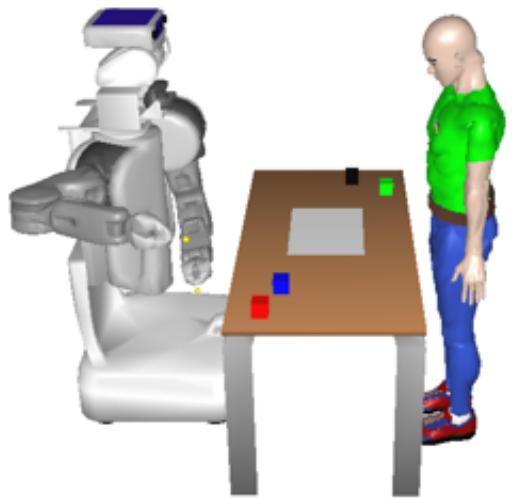
```
action placeCube(Agent R, Cube C,  
Area A){  
    preconditions{  
        R.hasInHand == C;  
    };  
    effects{  
        R.hasInHand = NULL;  
        A.stack <= C;  
    };  
    cost{};  
    duration{};  
}
```

Montreuil, Vi.; Clodic, A.; Ransan, M.; Alami, R.. Planning human centered robot activities. IEEE International Conference on Systems, Man and Cybernetics, 2007.

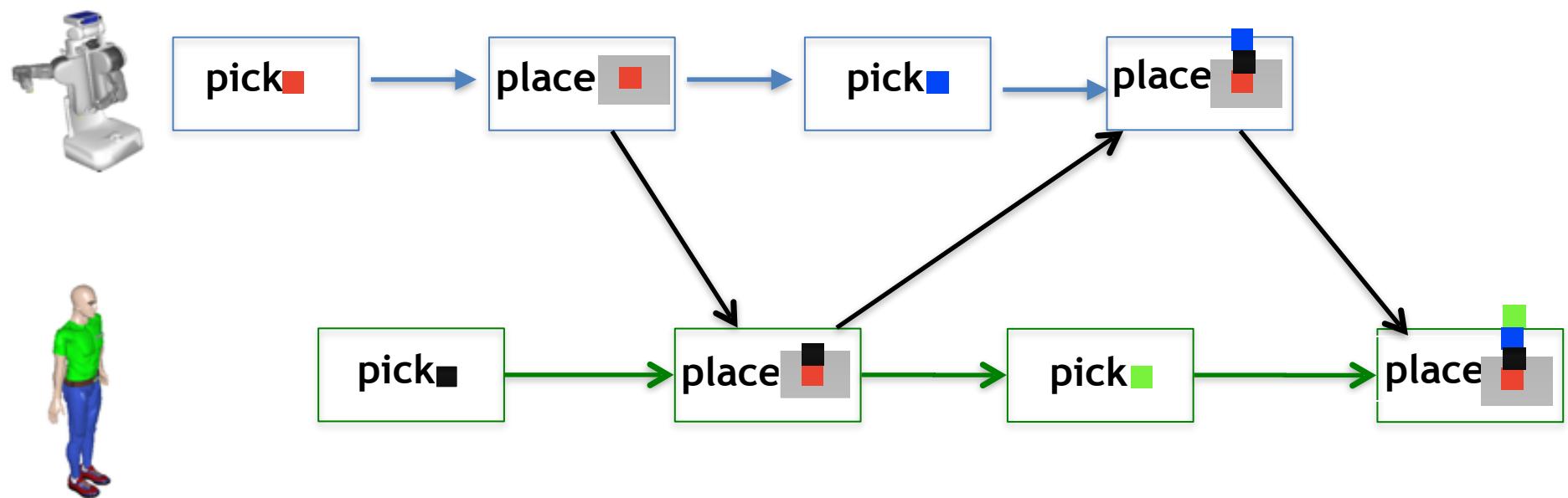
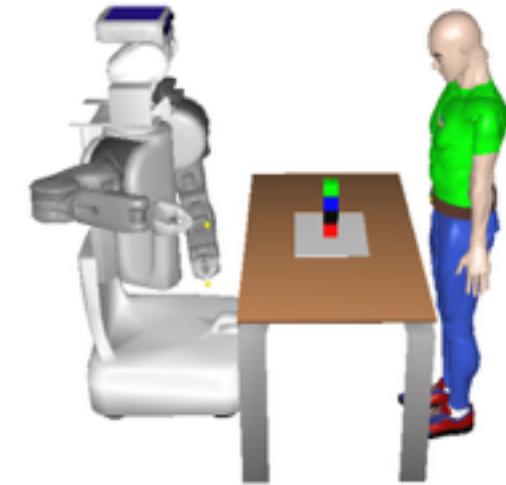
Allili, S., Alami, R., Montreuil V., A task planner for an autonomous social robot, Distributed Autonomous Robotic Systems 8

Lallement, R., De Silva, L. & Alami, R. (2014). Hatp: An htn planner for

# Human-Aware Task Planner



the planner plans for  
the robot **AND** the  
human it interacts with

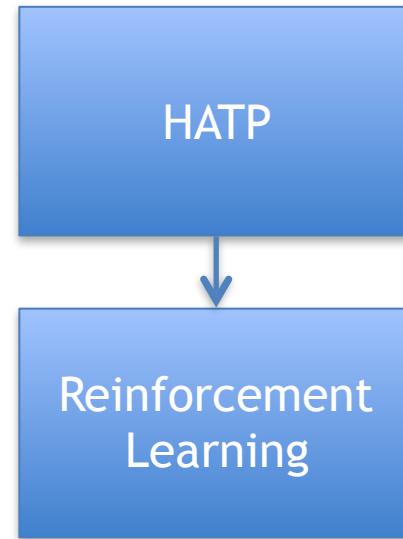


but the domain is static..., once written, it could not be enhanced online

what about learning ?

pb with reinforcement learning, it  
may test every actions to learn  
=> could lead to inconsistent  
behavior that would not be  
acceptable in HRI context

idea: use HATP to bootstrap a  
reinforcement learning  
algorithm



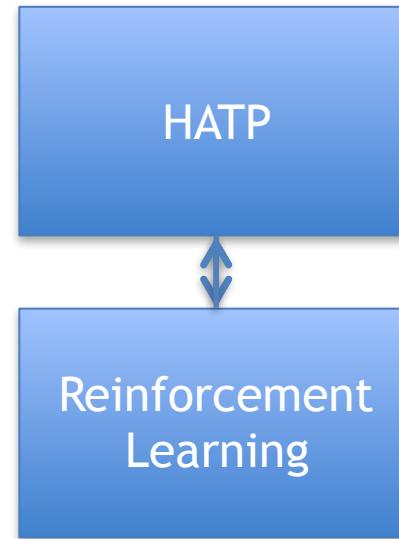
"Learning to Interact with Humans Using Goal-Directed and Habitual Behaviors",  
E. Renaudo, S. Devin, B. Girard, R. Chatila, R. Alami, M. Khamassi and A. Clodic  
RO-MAN'15 workshop on learning for Human-Robot Collaboration

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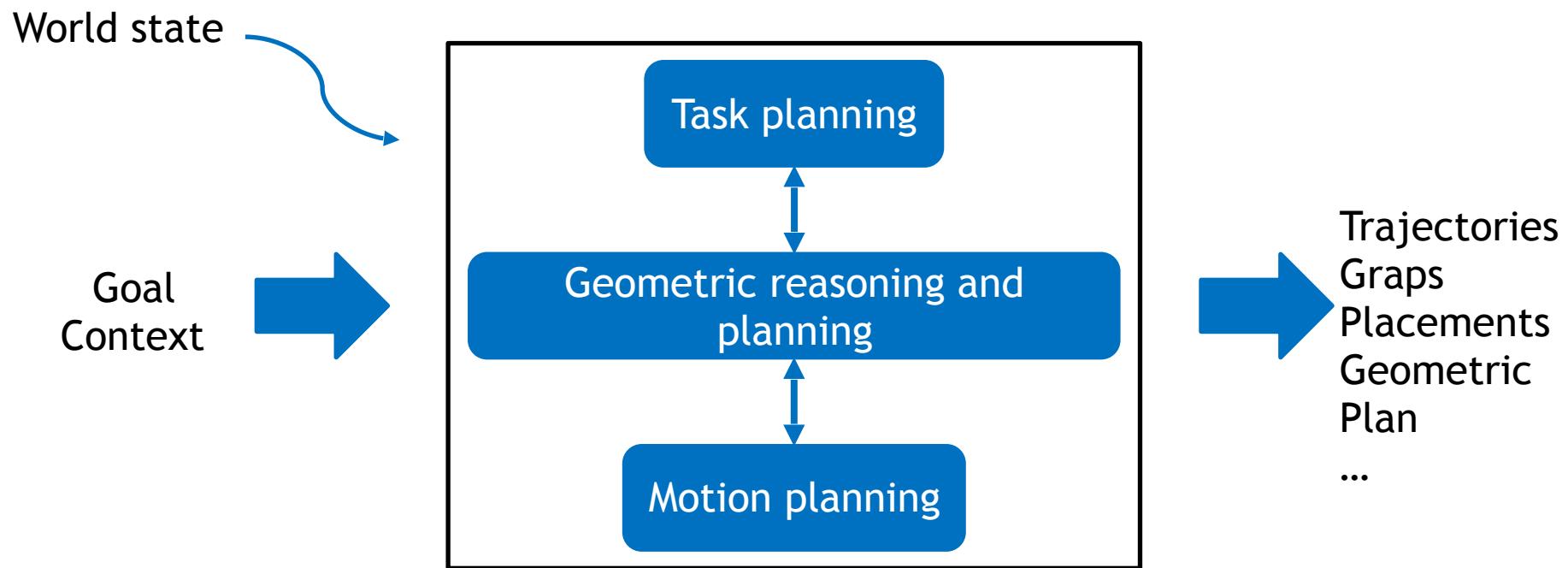
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"Learning to Interact with Humans Using Goal-Directed and Habitual Behaviors",  
E. Renaudo, S. Devin, B. Girard, R. Chatila, R. Alami, M. Khamassi and A. Clodic  
RO-MAN'15 workshop on learning for Human-Robot Collaboration

but a symbolic planner could lead to plan that is geometrically unfeasible...

idea: link task planning to motion planning



De Silva, L., Gharbi, M., Pandey, A. K., & Alami, R. (2014). A New Approach to Combined Symbolic-Geometric Backtracking in the Context of Human-Robot Interaction. *International Conference on Robotics and Automation*.

Gharbi, M., Lallement, R., & Alami, R. (2015). Combining Symbolic and Geometric Planning to synthesize 85 human-aware plans: toward more efficient combined search. In *International Conference on Intelligent Robots and Systems (IROS)*.

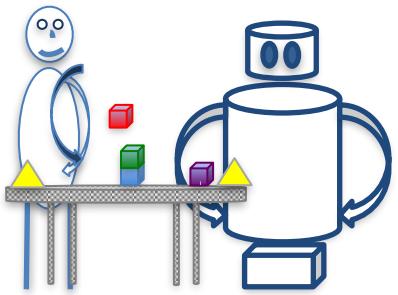


# Shared Task Representations

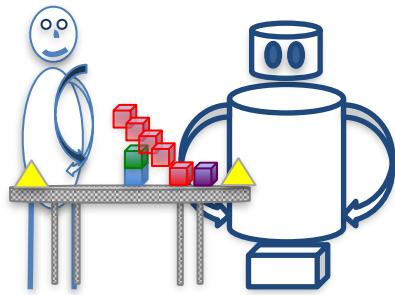
"Shared task representations do not only specify in advance what the respective tasks of each of the co-agents are, they also provide control structures that allow agents to monitor and predict what their partners are doing, thus enabling interpersonal coordination in real time."

=> In intentional coordination, agents plan their own motor actions in relation to the joint goal and also to some extent to their partners' actions.

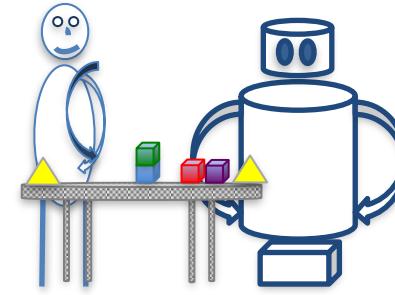
Knoblich, G., Butterfill, S., & Sebanz, N. (2011). Psychological research on joint action: theory and data. In B. Ross (Ed.), *The Psychology of Learning and Motivation*, 54 (pp. 59-101),



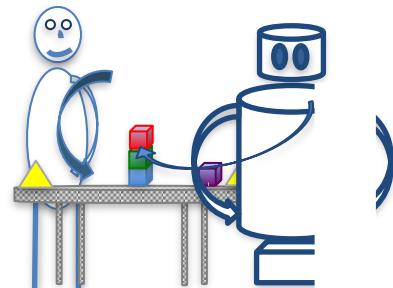
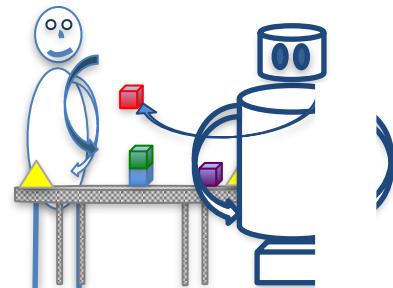
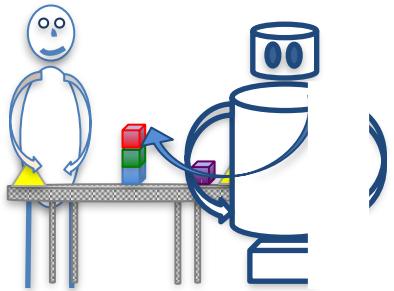
**Triadic adjustment**  
i.e. adjustment toward  
the joint goal



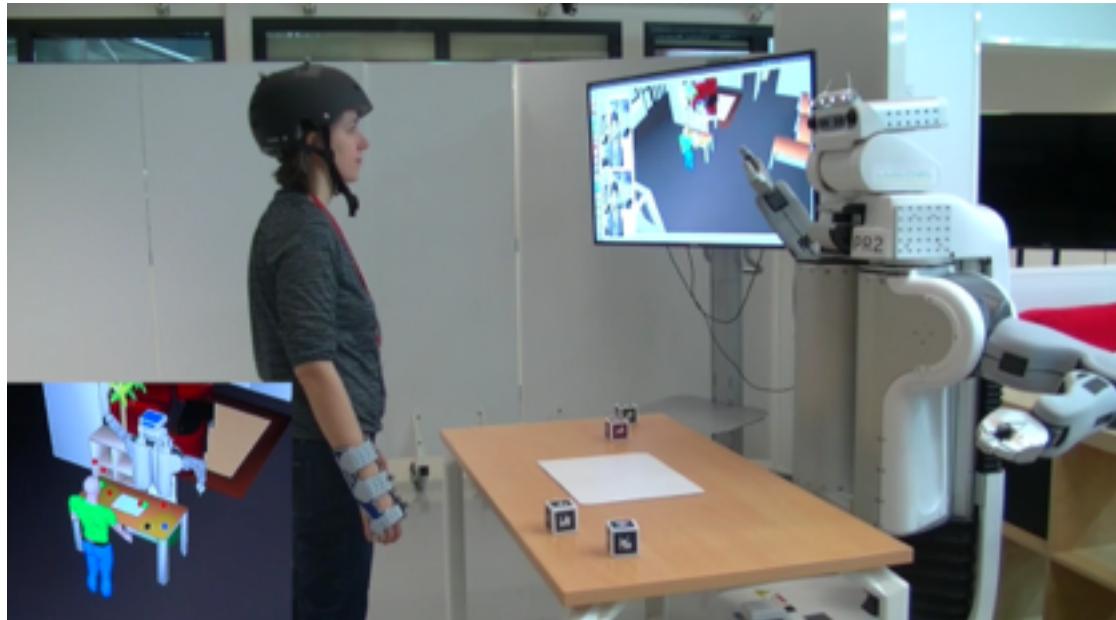
**Dyadic adjustment**  
i.e. adjustment toward  
the current action



**Collaborative adjustment**  
(from Tomasello [30])



# Shared Task Representation



can be considered as putting in perspective all the processes already described: e.g. knowing that we track each other the same block in the interaction scene through joint attention and that the robot is currently moving this block in the direction of the stack by the help of intentional action understanding , make sense in the context of the two of us building a stack together

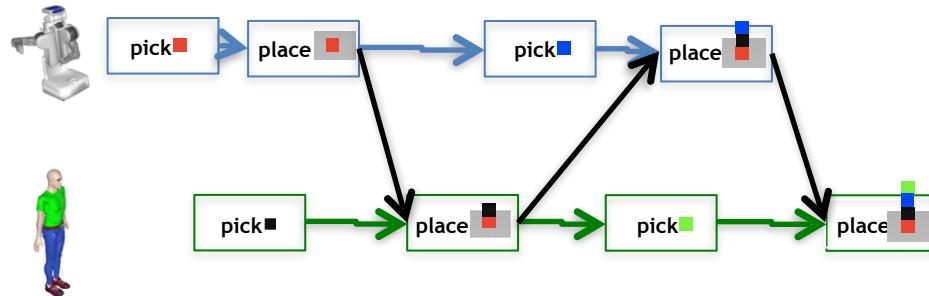
# Shared Plan Management

Taking others mental state during execution



S. Devin and R. Alami, “An implemented theory of mind to improve human-robot shared plans execution.,” in ACM/IEEE International Conference on Human-Robot Interaction, HRI’16, New Zealand, March 7-10, 2016.

# Shared Plan Management



action status



place

DONE

place

PROGRESS

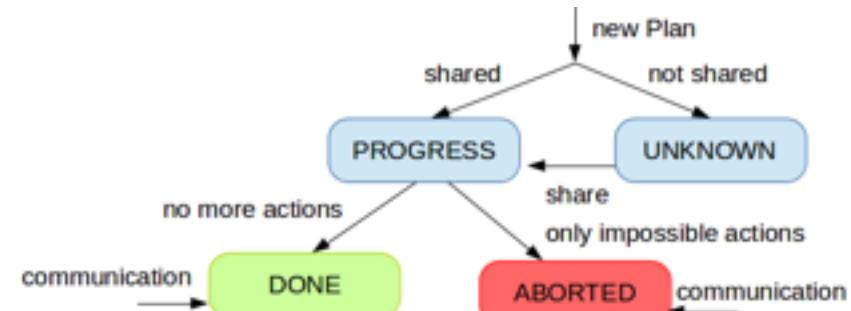
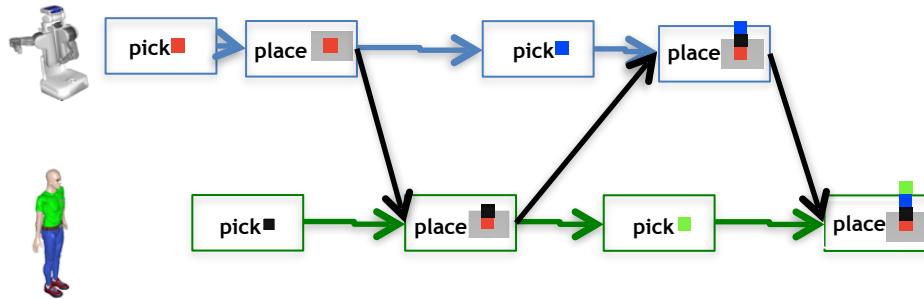
place

READY

place

PLANNED

# Shared Plan Management

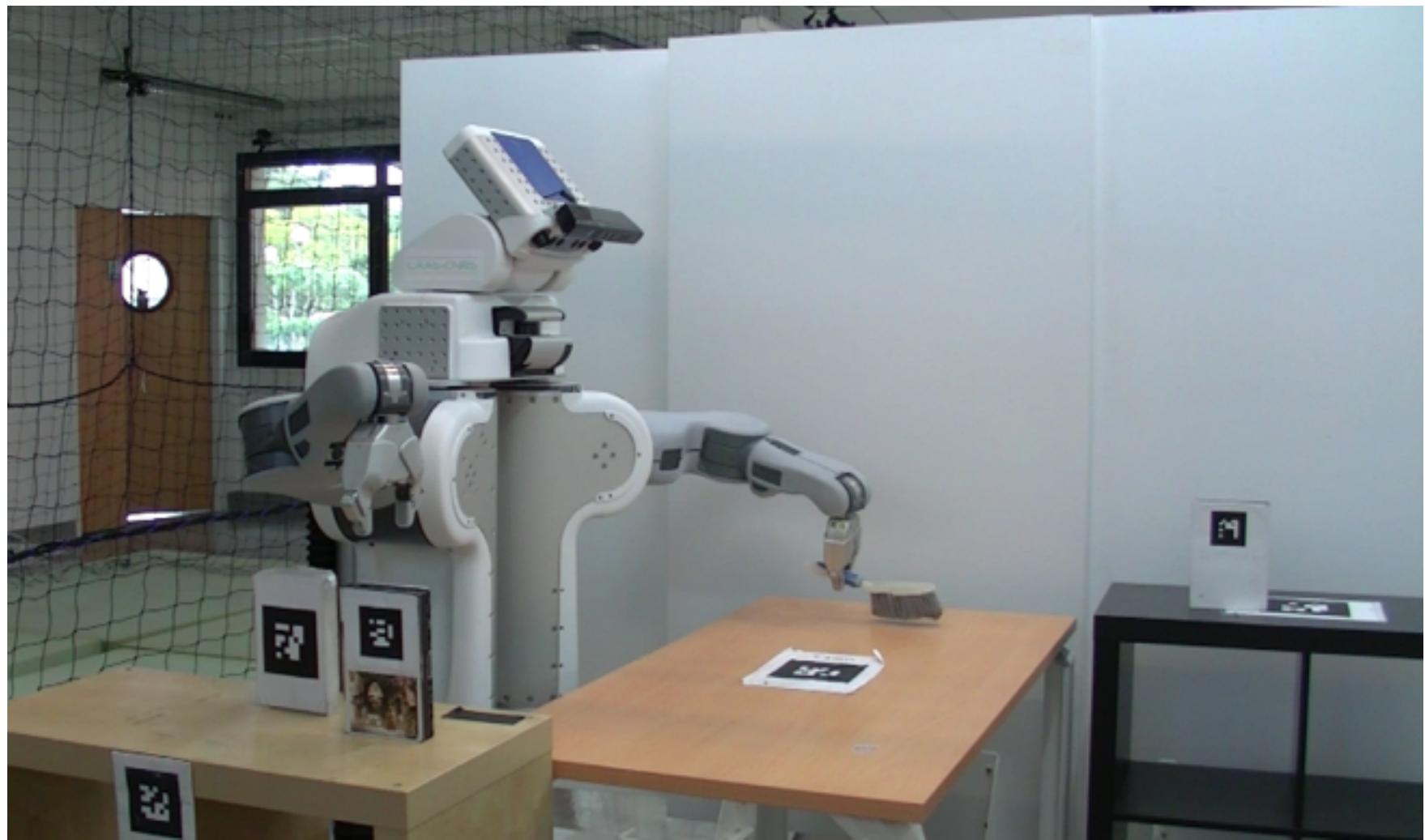


plan status

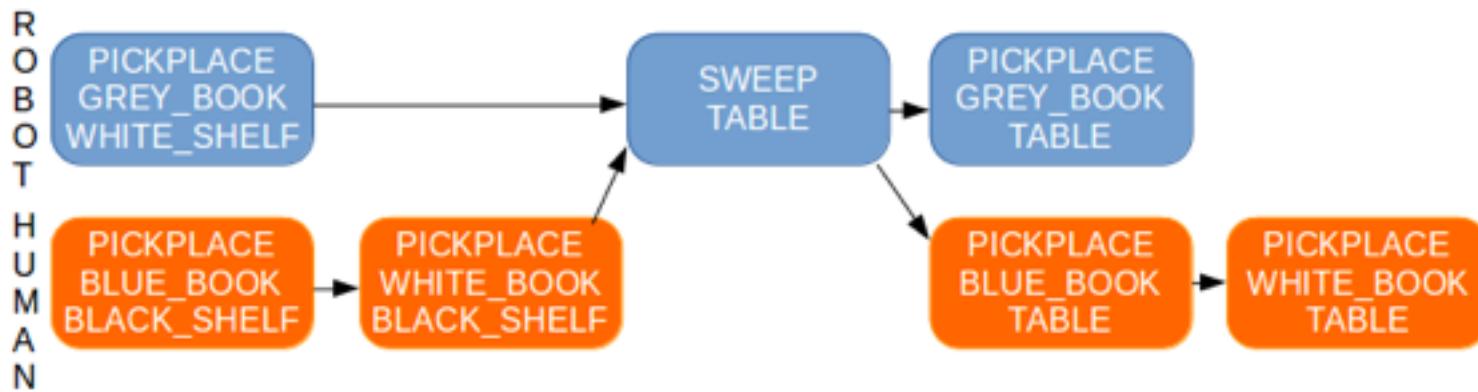


ABORTED

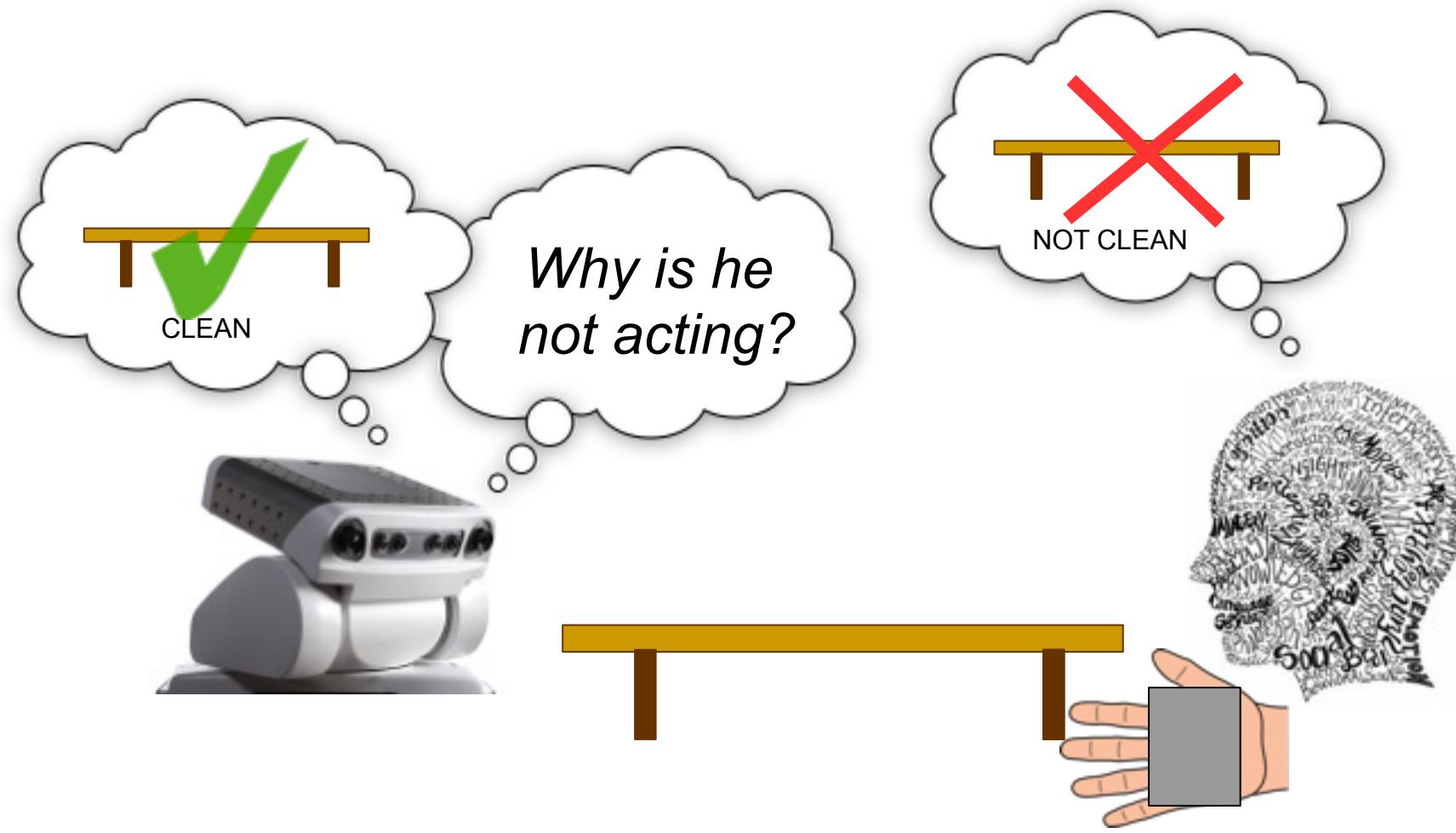
PROGRESS



- ✓ Already established shared plan



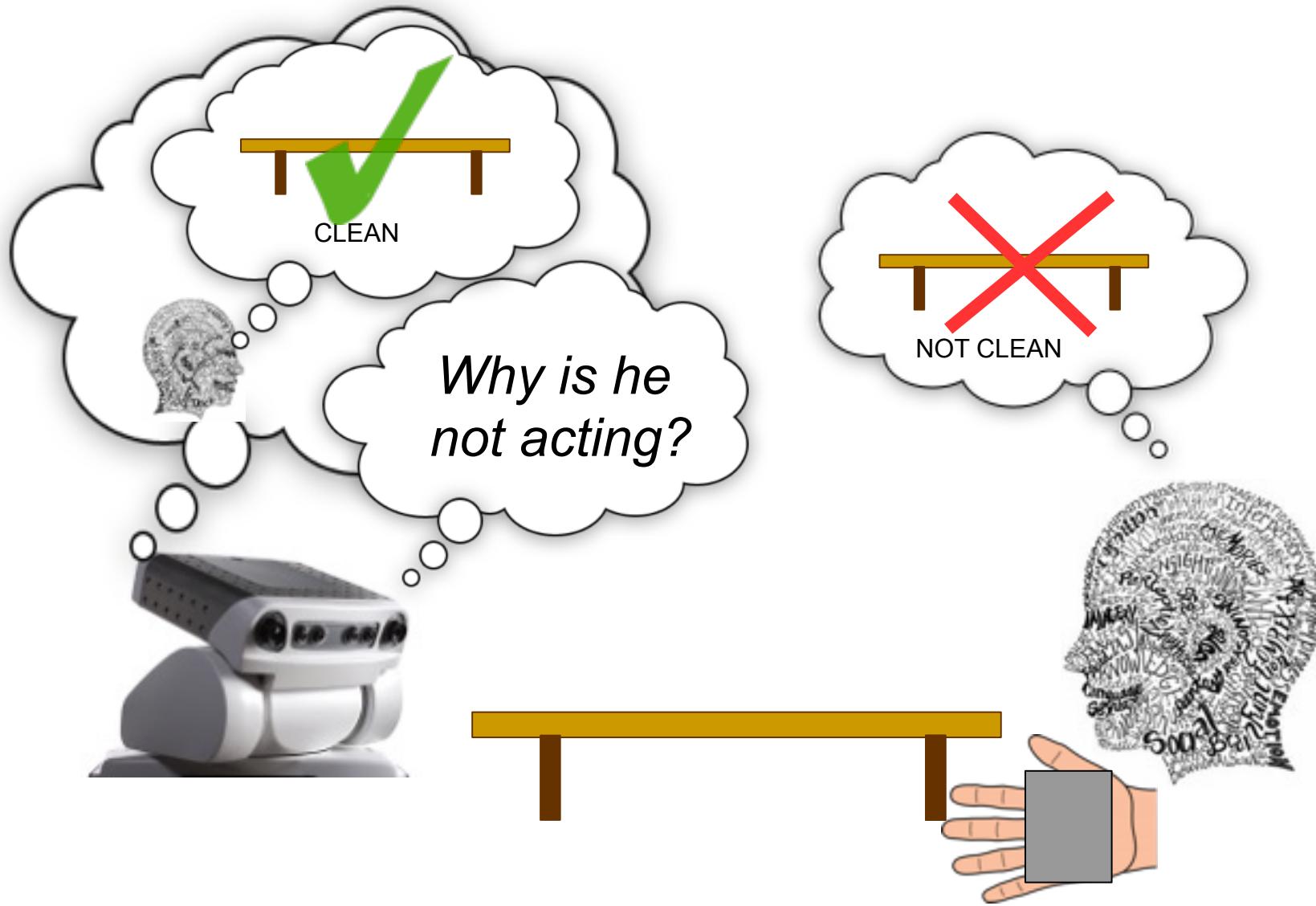
# Before humans' actions



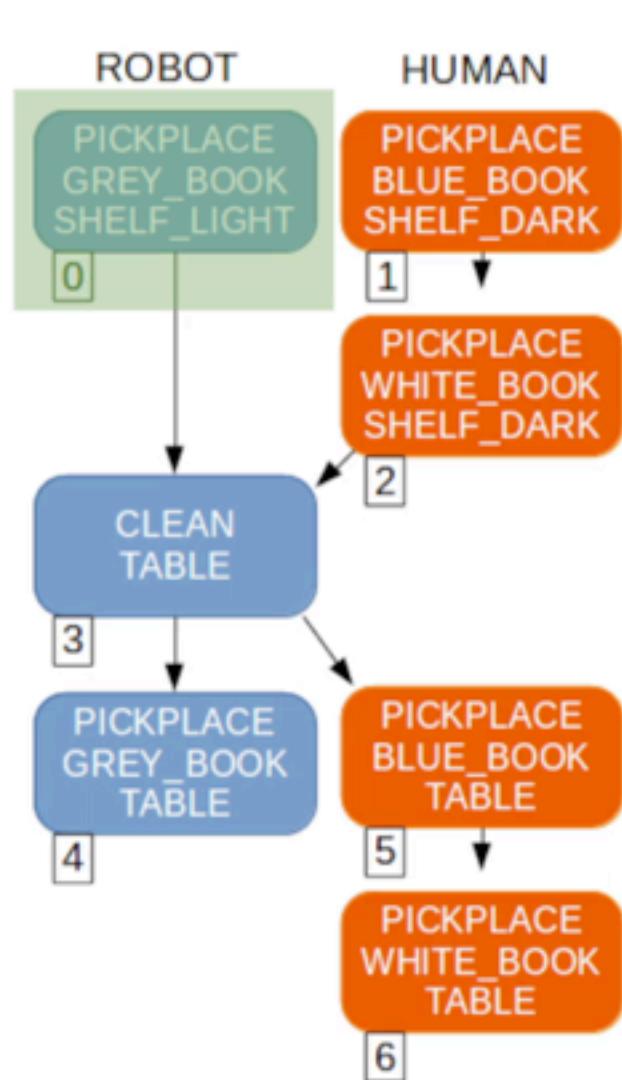
# Preventing mistakes



# Inaction and uncertainty

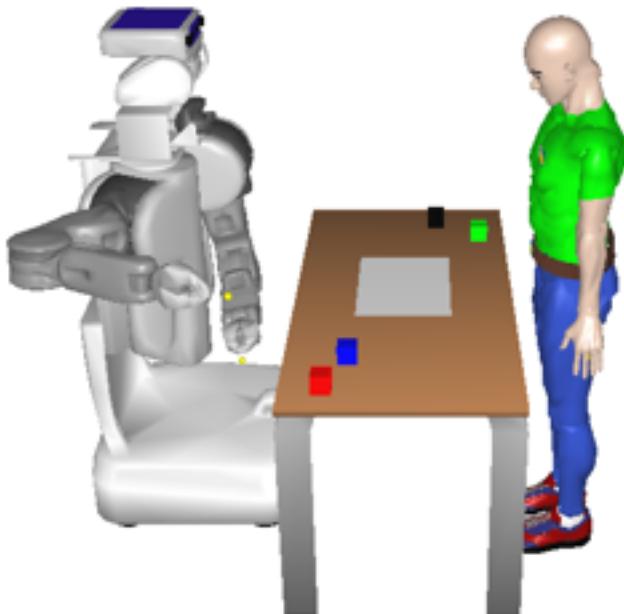


# Shared Plan Management



The robot starts to pick and place the grey book

# Alignment issue (and more)



Tuomela (2007) : group ethos

Tomasello et al. (2005) : cultural creation/lear

Clark : common ground

= the set of values, standards,  
beliefs, practices, social  
coordination conventions, pre-  
established scripts and routines

