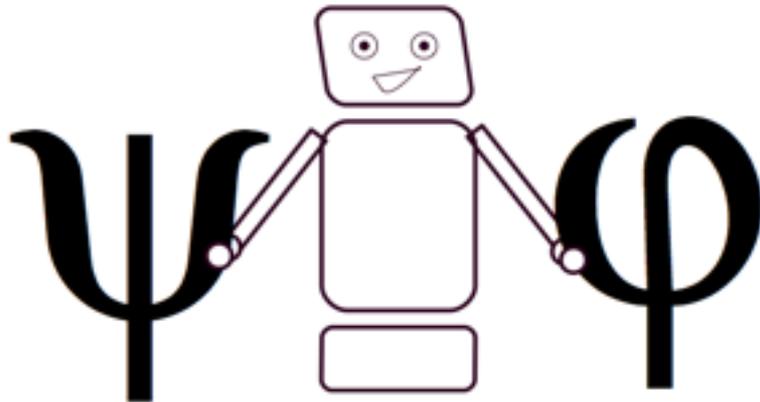


Deliverable 3.1 Challenges and requirements for a robotic architecture enabled for joint action

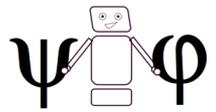


Action Jointe pour l'interaction Humain-Robot

JointAction4HRI

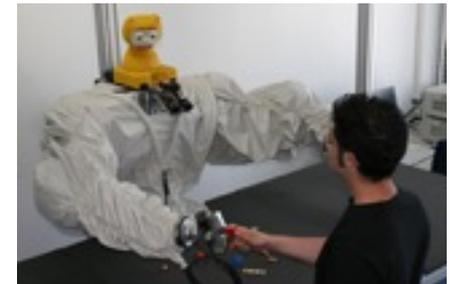
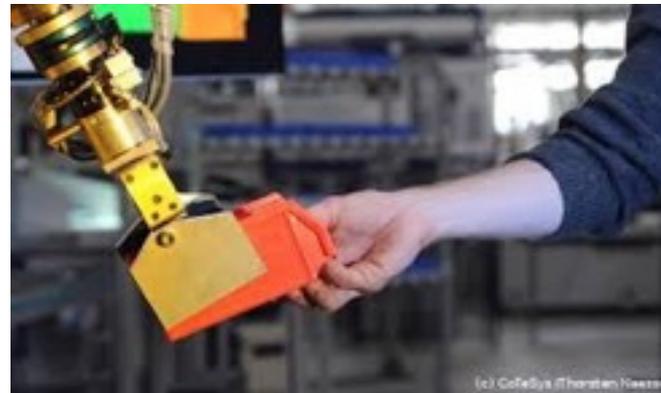


ANR-16-CE33-0017

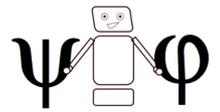


Deliverable 3.1 Challenges and requirements for a robotic architecture enabled for joint action

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." *

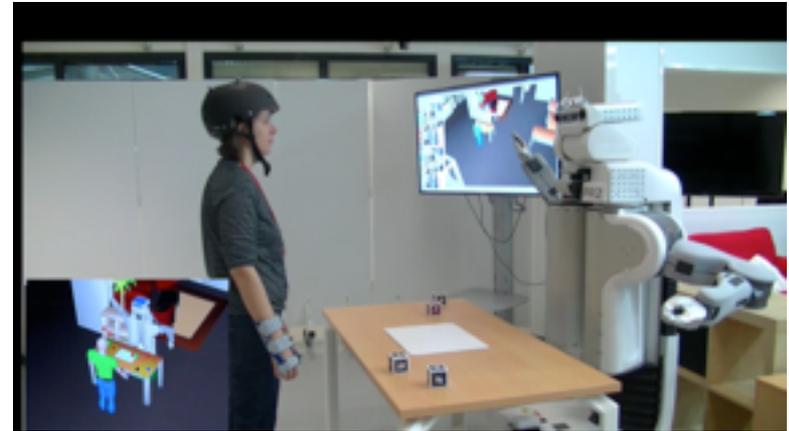


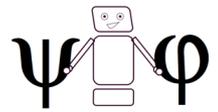
* Knoblich, G., Butterfill, S., & Sebanz, N. (2011). Psychological research on joint action: theory and data. In B. Ross (Ed.), *The Psychology of Learning and Motivation*, 54 (pp. 59-101),



coordination processes in joint action

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

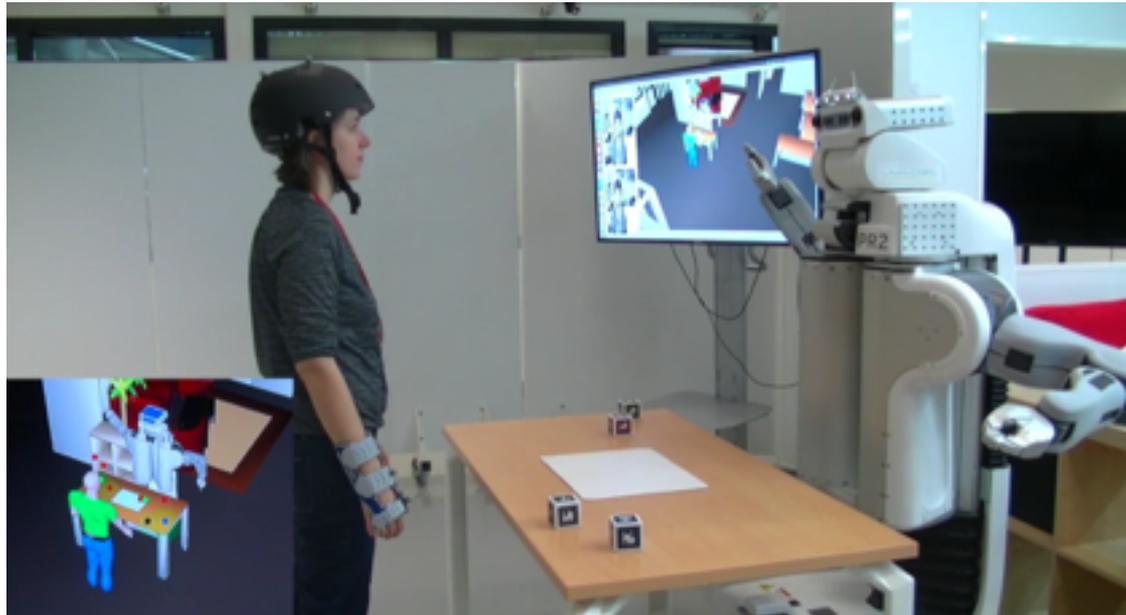
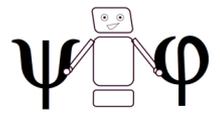




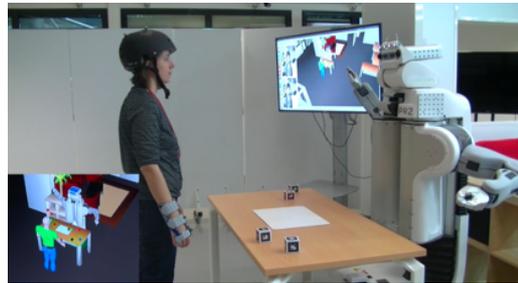
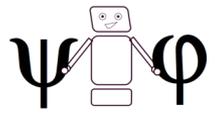
Self-Other distinction

"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)

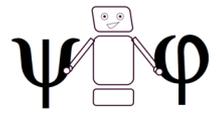
Self-Other Distinction



Self-Other Distinction

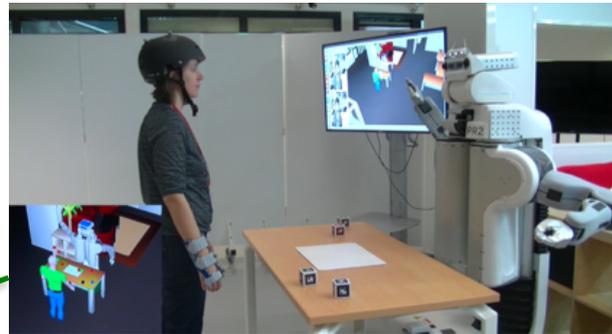


the robot needs to be able to handle a representation of itself and a representation of the human it interacts with



Self-Other Distinction

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



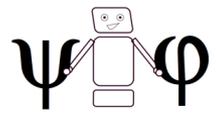
the robot needs to be able to handle a representation of itself and a representation of the human it interacts with

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).

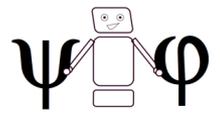
Joint Attention provides a basic mechanism for sharing representations of objects and events and thus for creating a "perceptual common ground" in joint action. (Tomasello, 1995, 1999; Tomasello & Carpenter, 2007; Tollefsen, 2005; Sebanz et al, 2006).



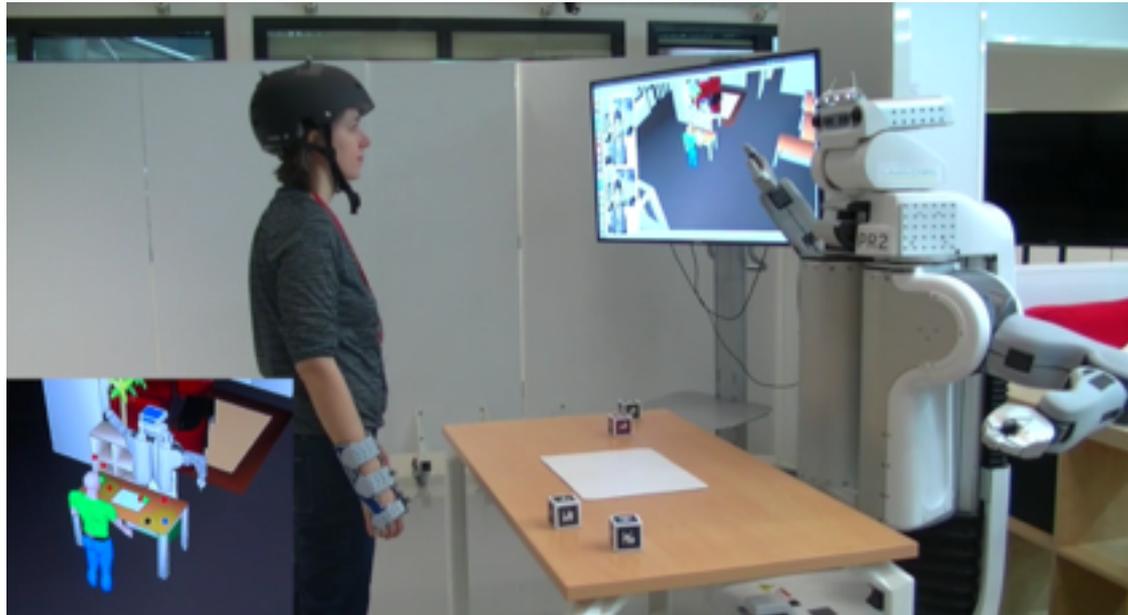
Joint attention



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 (RO-MAN 2016)

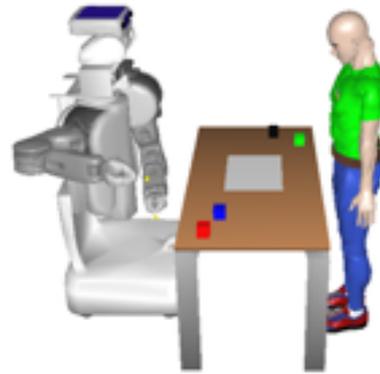
Situation assessment for human-robot interactive object manipulation, EA Sisbot, R Ros, R Alami
RO-MAN, 2011

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

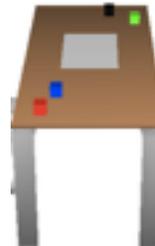


table position



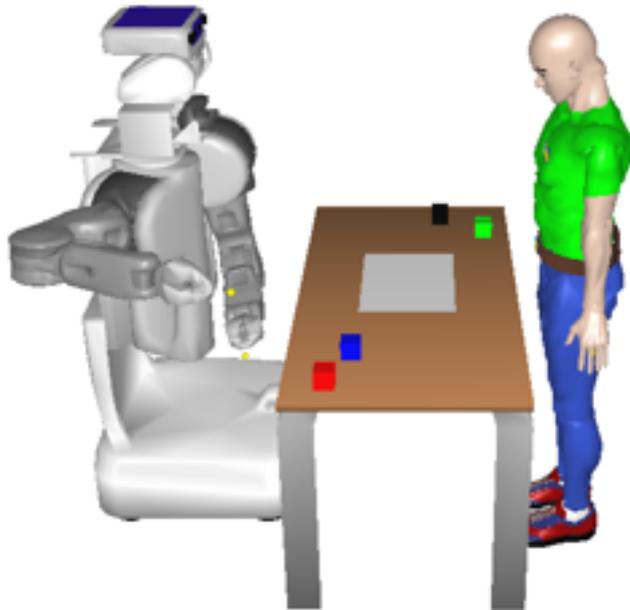
game board position

green cube position

red cube position

blue cube position

back cube position



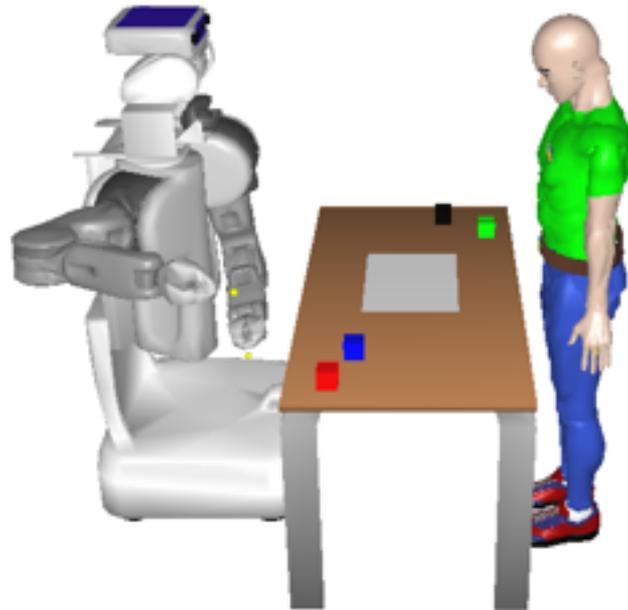
Situation assessment

perception



green cube position ???

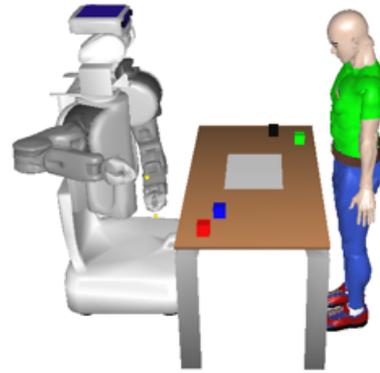
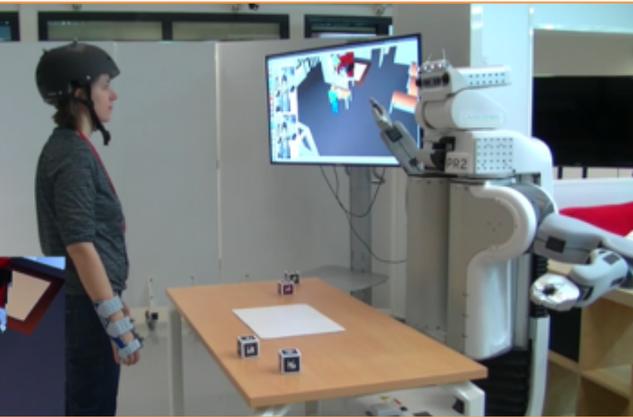
■
frame base_link
x -0.5
y 0.75
z 0.9
theta 0.0



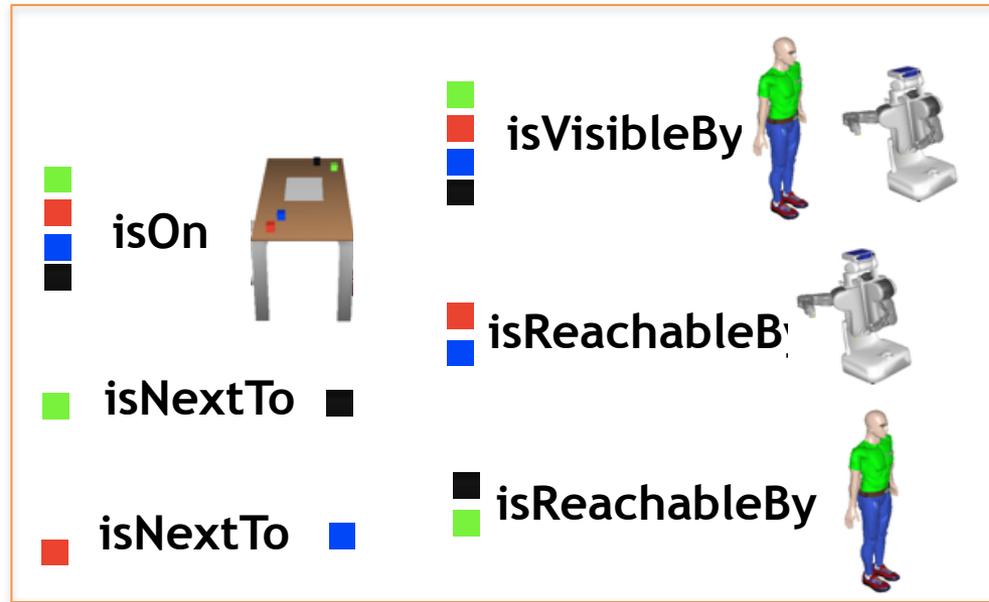
■ is on the table

Situation assessment

perception

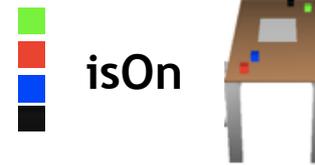
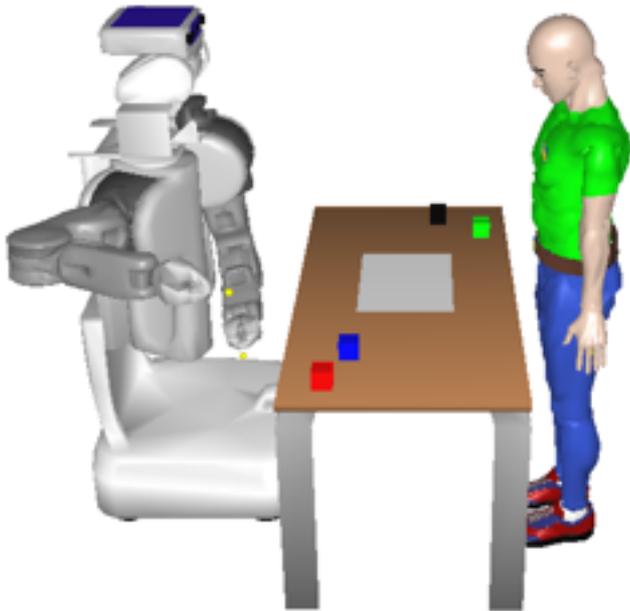


spatial reasoning



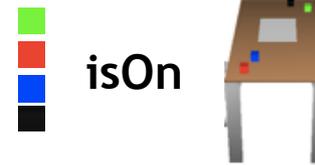
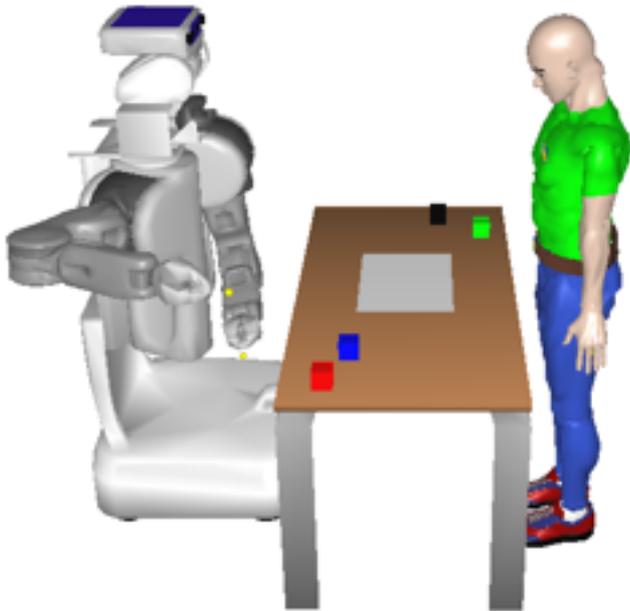
Situation assessment

spatial-reasoning



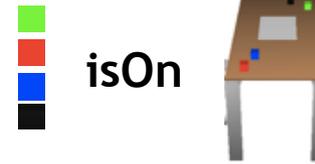
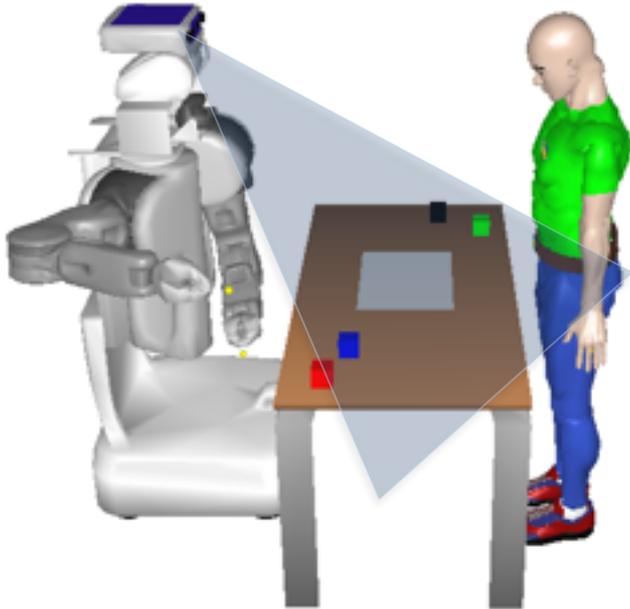
Situation assessment

spatial-reasoning



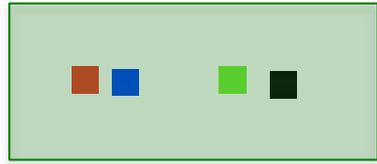
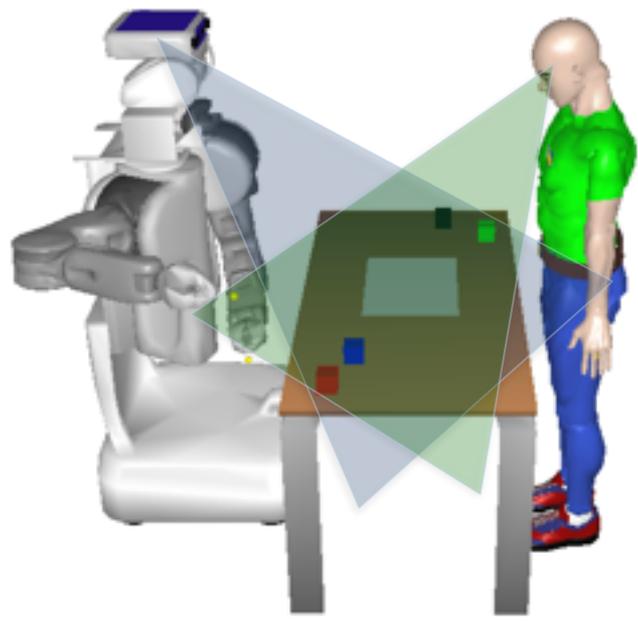
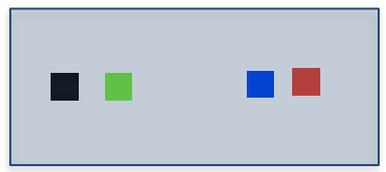
Situation assessment

mental state management



Situation assessment

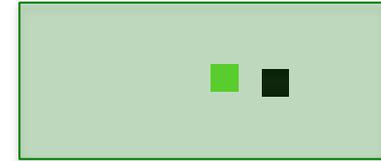
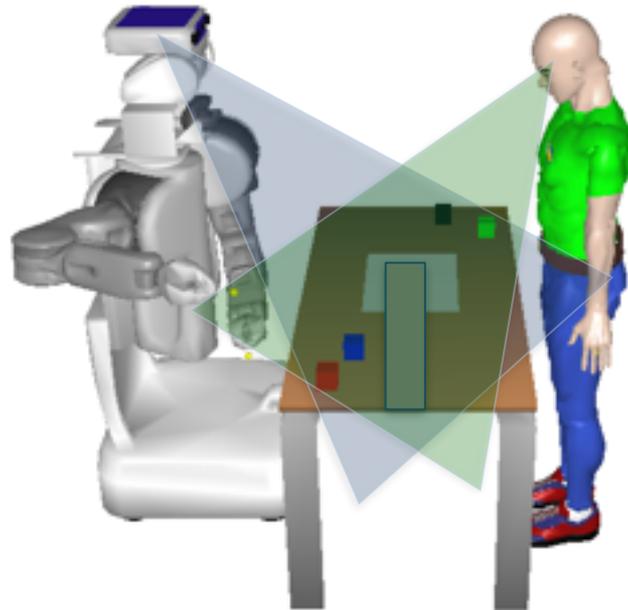
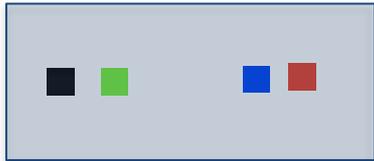
mental state management



order of the cubes on the table ???

Situation assessment

mental state management



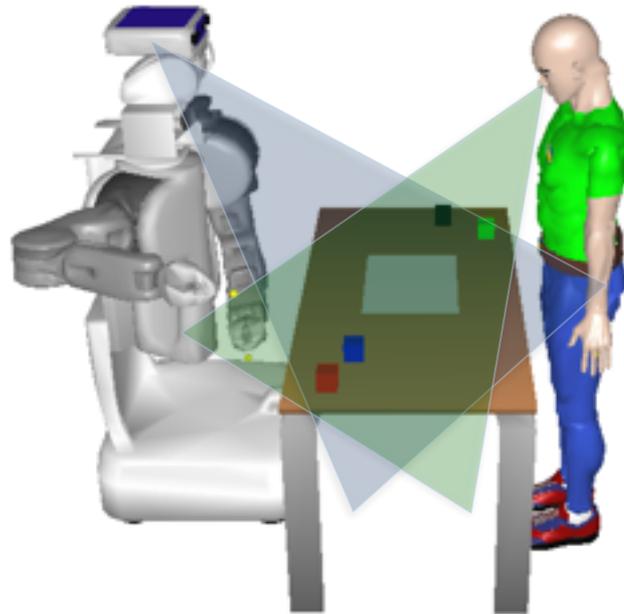
order of the cubes on the table
what if something is hidden ?

Situation assessment

mental state management



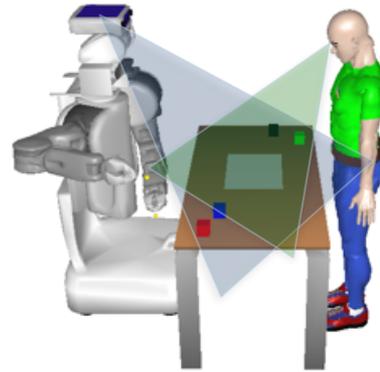
-    isOn 
-  isNextTo 
-  isNextTo 
-  isReachableBy 
-  isReachableBy 
-  isVisibleBy  



-    isOn 
-  isNextTo 
-  isNextTo 
-  isReachableBy 
-  isReachableBy 
-  isVisibleBy  

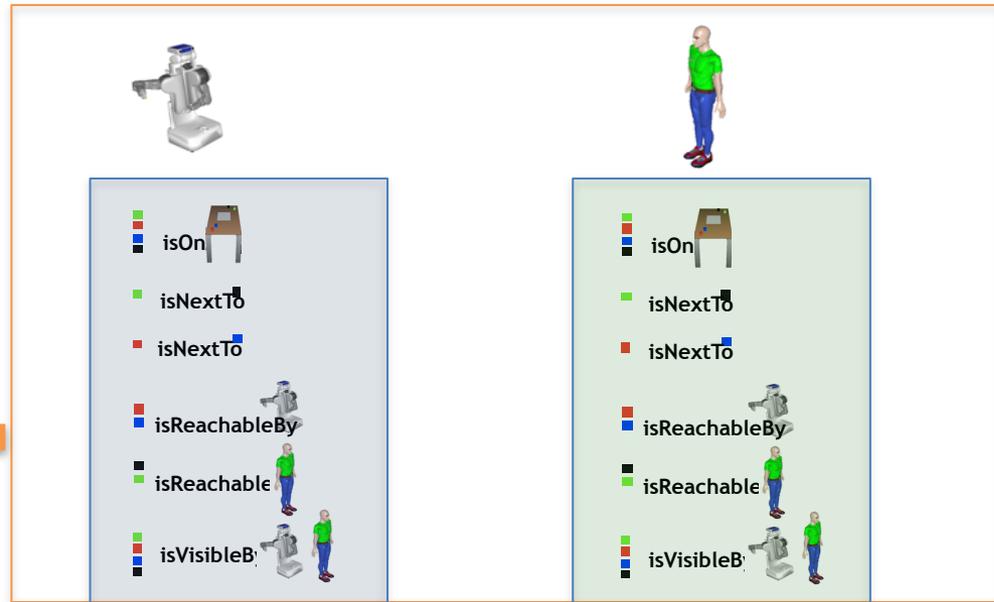
Situation assessment

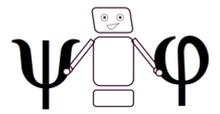
perception



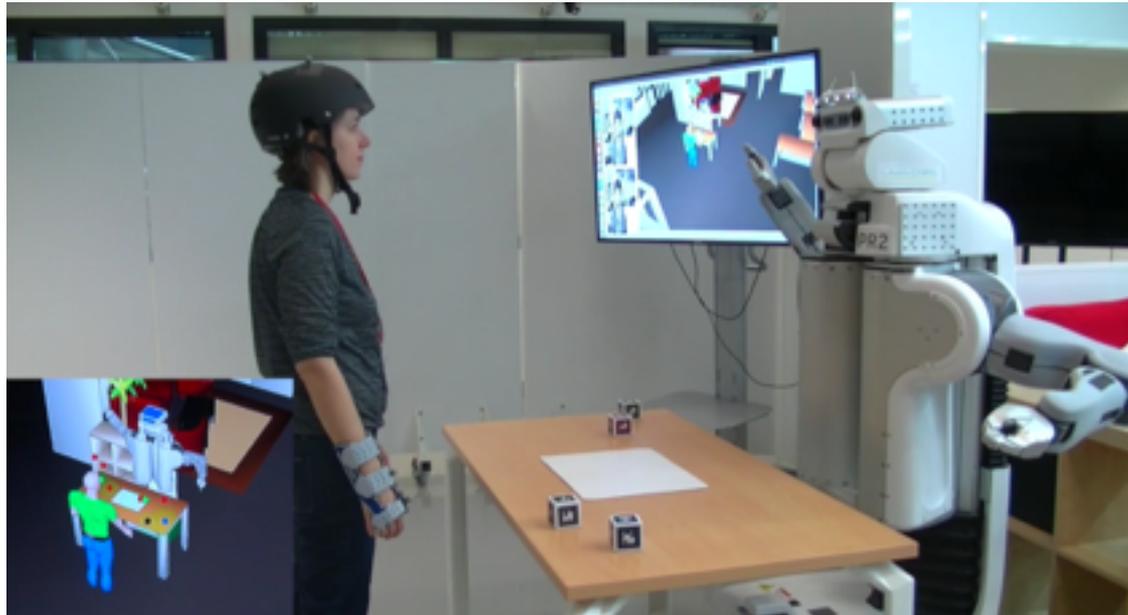
spatial reasoning

mental state management





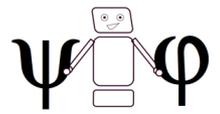
Joint attention



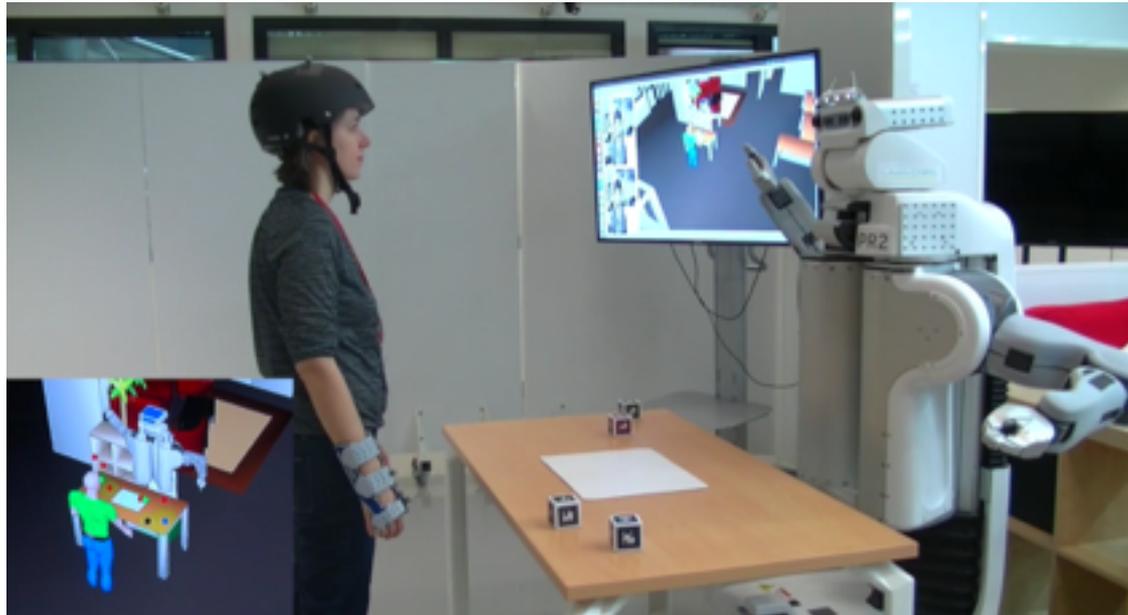
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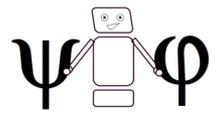
Are robot perception abilities readable ?



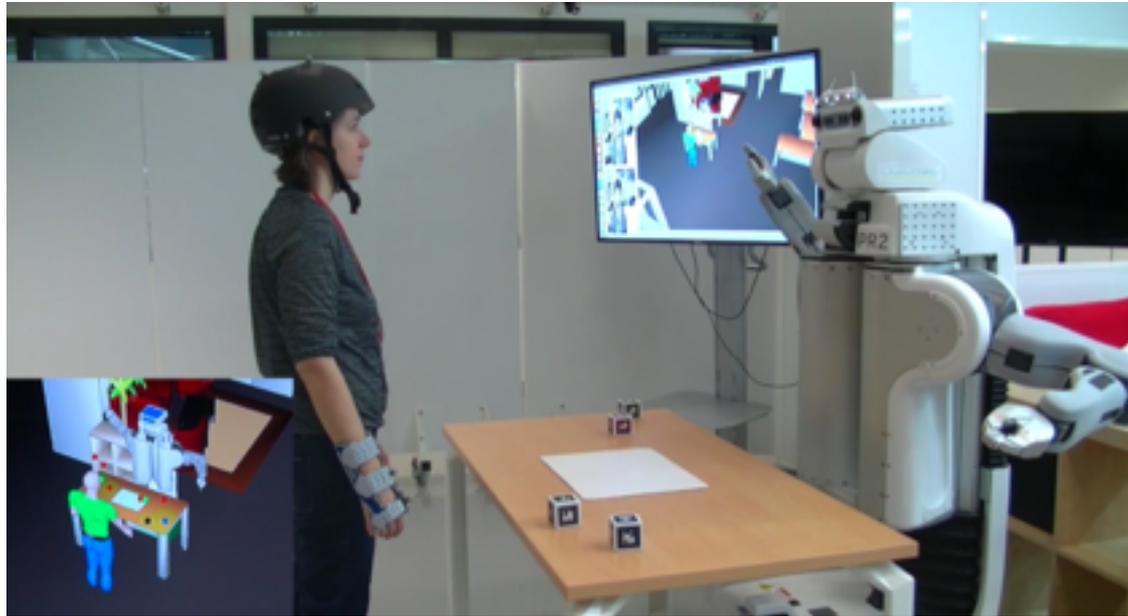
Joint attention



Mutual manifestness ?

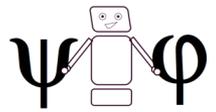


Joint attention



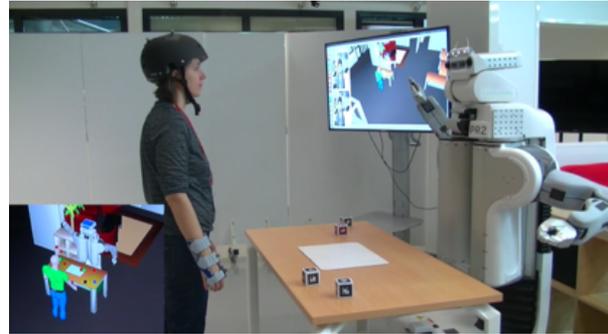
Mutual manifestness ?

" (...) 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 ?



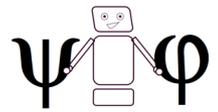
how can a robot know that the human it interacts with attended with him to the joint task ?

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

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

Mutual manifestness ?

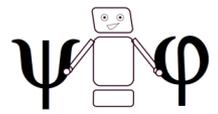
" (...) each subject must be aware in some sense, of the object as an object that is present to both; in other words the fact that both are attending to the same object or event should be open or mutually manifest..."



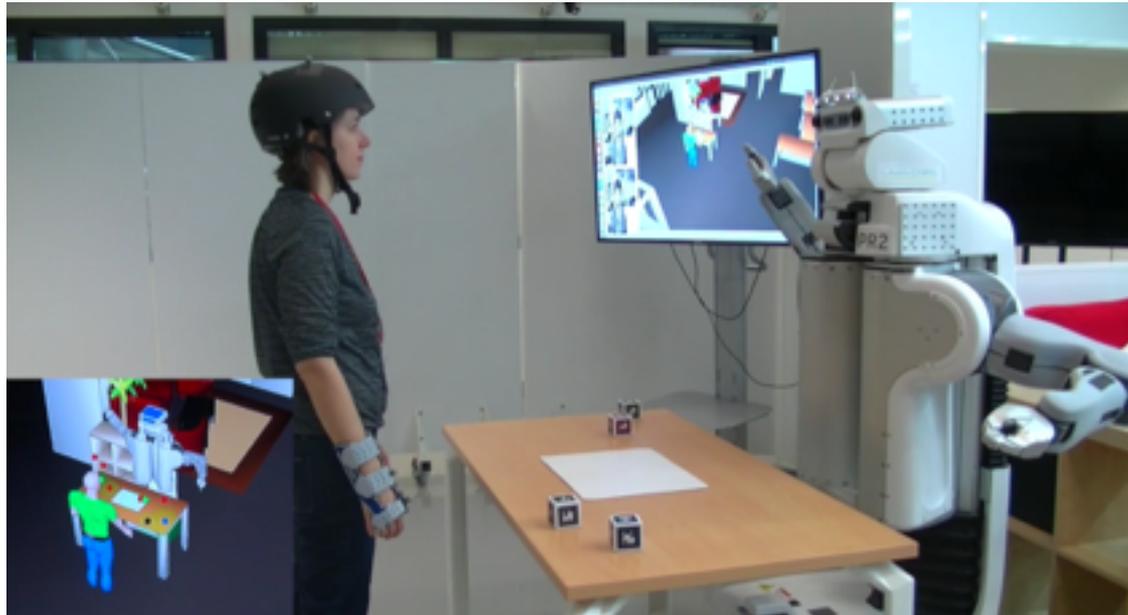
Intentional Action Understanding

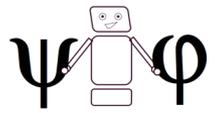
"... each agent should be able to read its partner's actions. (...) To understand an intentional action, an agent should, when observing a partner's action or course of actions, be able to infer their partner's intention" Tomassello 2005

* partner's intention = goal + plan

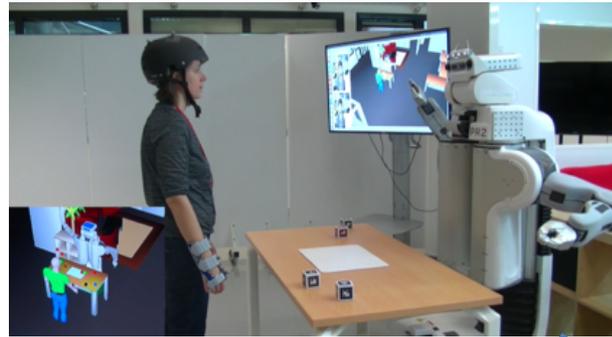


Intentional Action Understanding



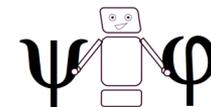


Intentional Action Understanding



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

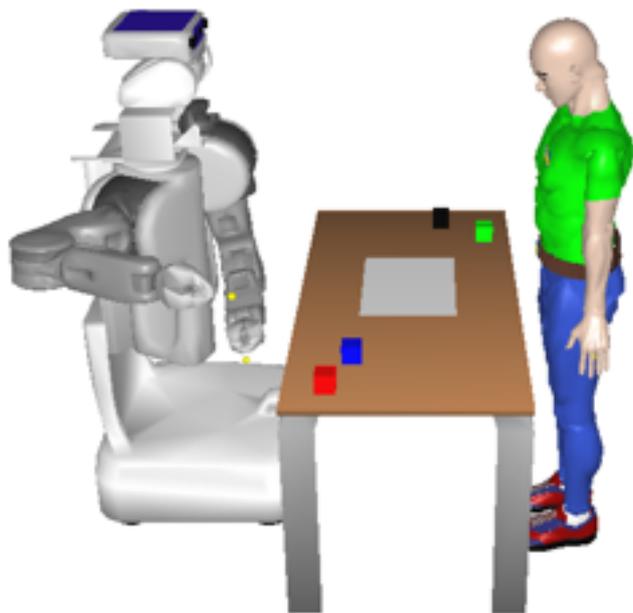


extended set of computed facts

agent/agent_joint is_moving

agent/agent_joint is_moving_toward agent/agent_jo

agent/agent_joint distance_to object far/medium/c



combined to detect actions

e.g.

agent_hand is_moving_toward■

+

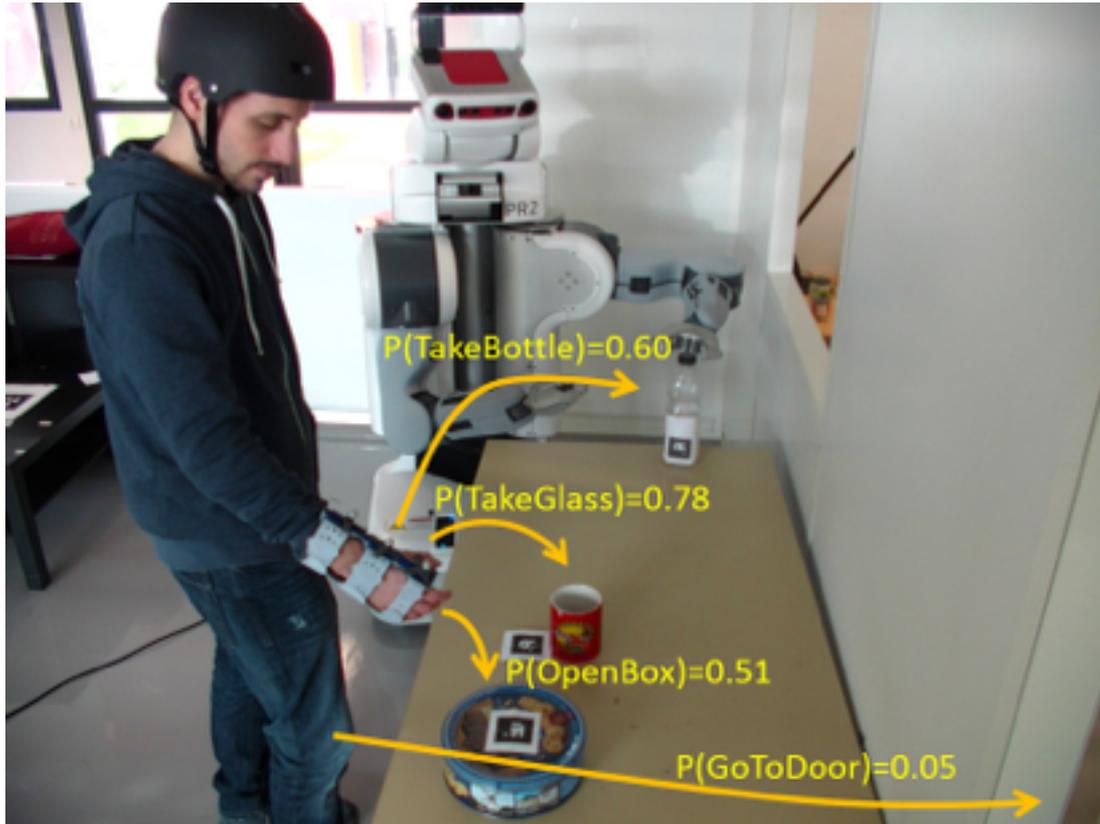
agent_hand distance_to■ close

+

■ isOn table

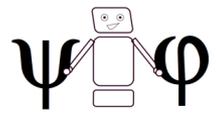
probability that agent will pick ■ soon is h

Intention detection/prediction

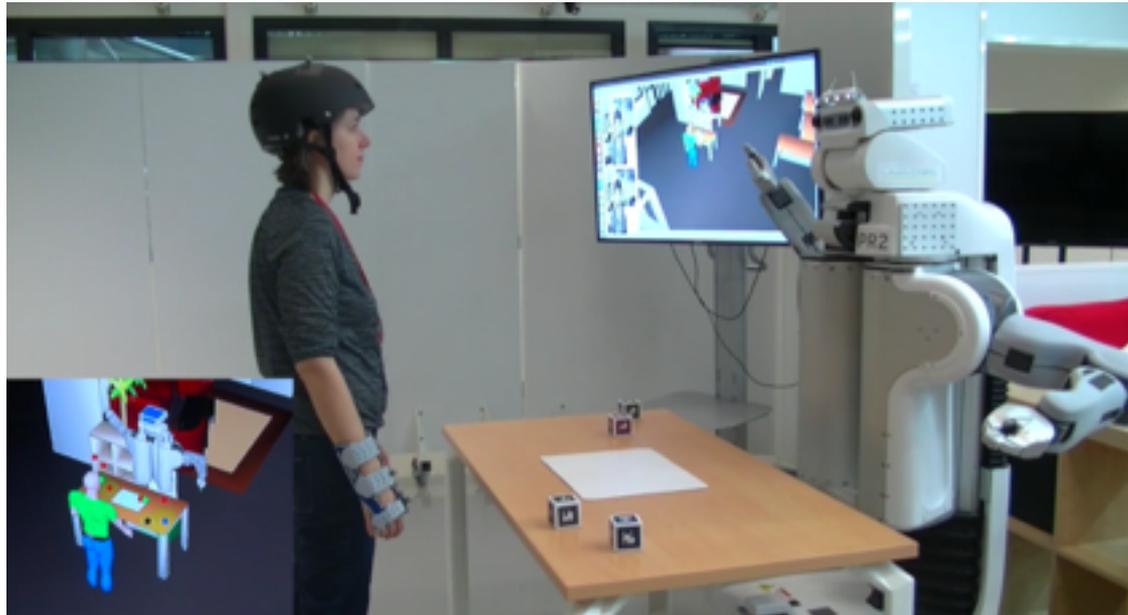


MDP linking intentions to human actions

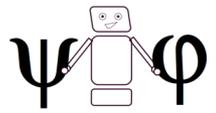
Humans mental state are used as current state for the MDP



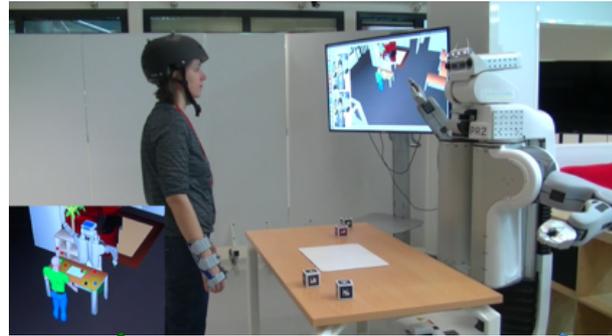
Intentional Action Understanding



???



Intentional Action Understanding



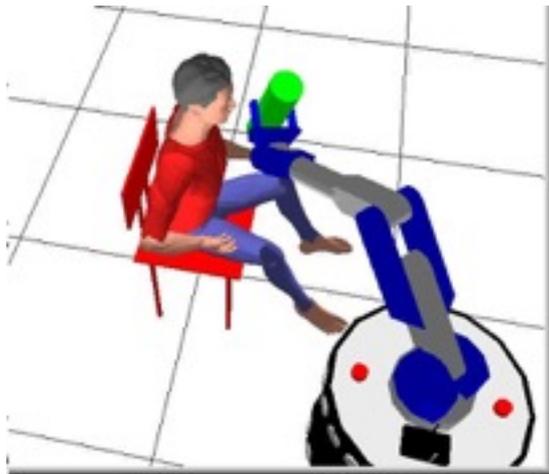
the human needs to be able to understand what the robot is currently doing and be able to predict the outcomes of robot actions

= viewing a movement, it must be able to infer what is the underlying action of the robot

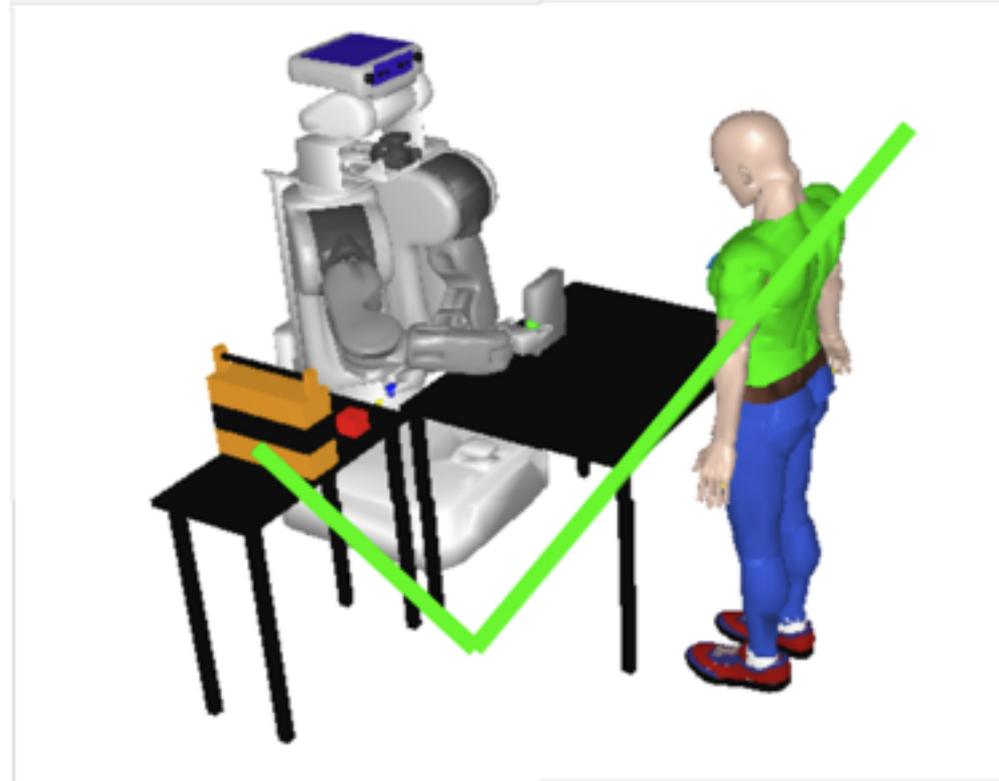
the robot needs to be able to understand what the human is currently doing and to be able to predict the outcomes of human's actions

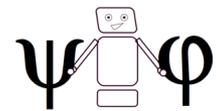
= it must be equipped with action recognition abilities

~~Human-Aware Motion Planning~~



Human-Aware Motion Planning

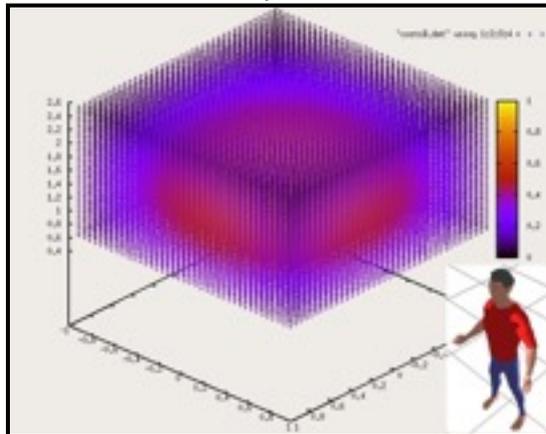




Human-Aware Motion Planning

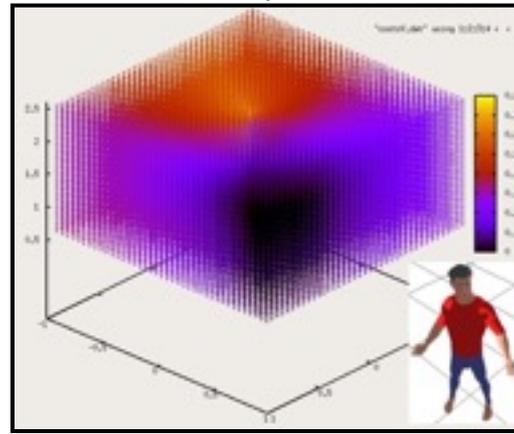
3 different HRI properties are defined and represented as 3D cost grids around the human

Safety



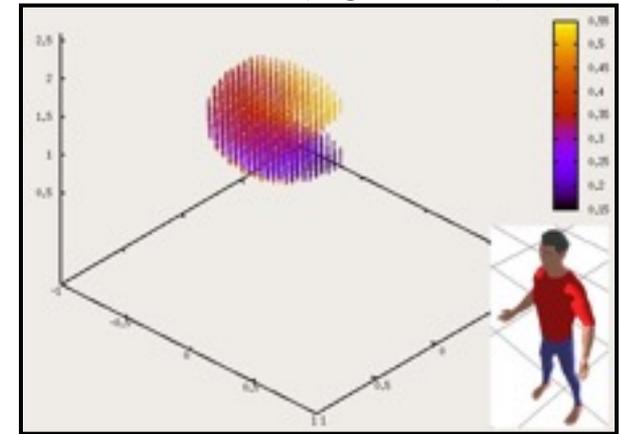
Proportional to the distance to human

Visibility

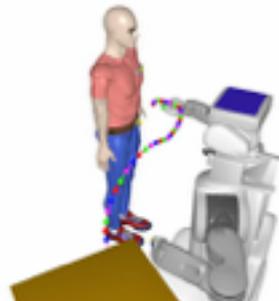


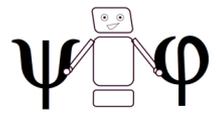
Reflects the effort to see a point

Arm Comfort(right/left)

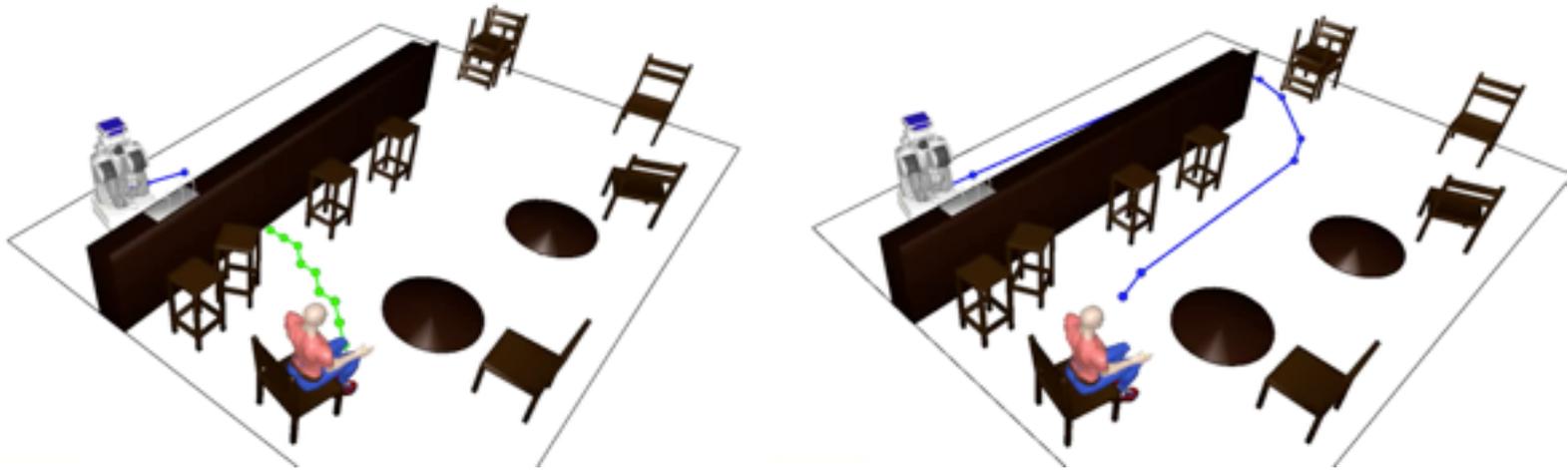


Combination of d.o.f difference and potential energy



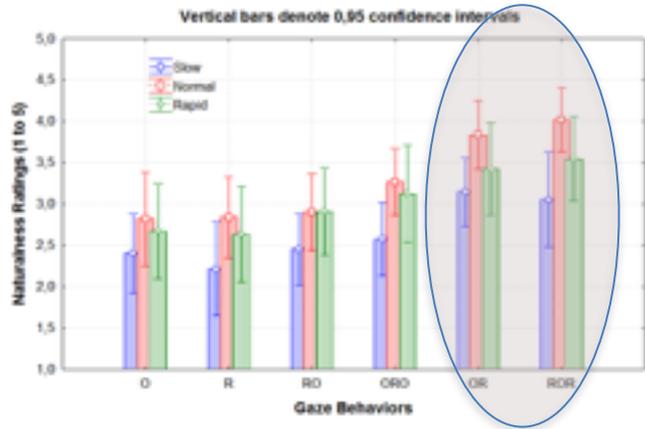


Human-Aware Motion Planning

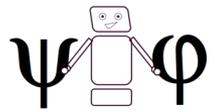


**Understandable ?
Readable?**

Human-Aware Motion Planning



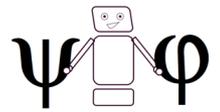
Gharbi, M., Paubel, P.-V., Clodic, A., Carreras, O., Alami, R., & Cellier, J.-M. (2015). Toward a better understanding of the communication cues involved in a robot-human object transfer. In *International Symposium on Robot and Human Interactive Communication (RO-MAN)*.



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.

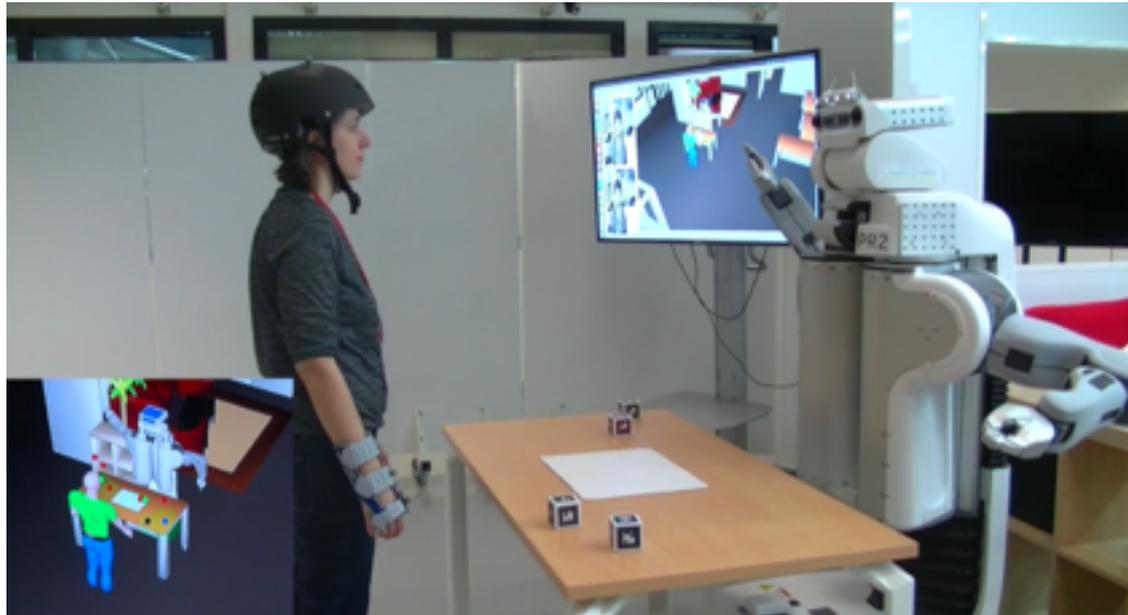
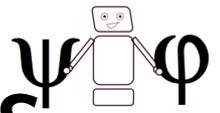


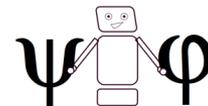
Shared Task Representations

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),

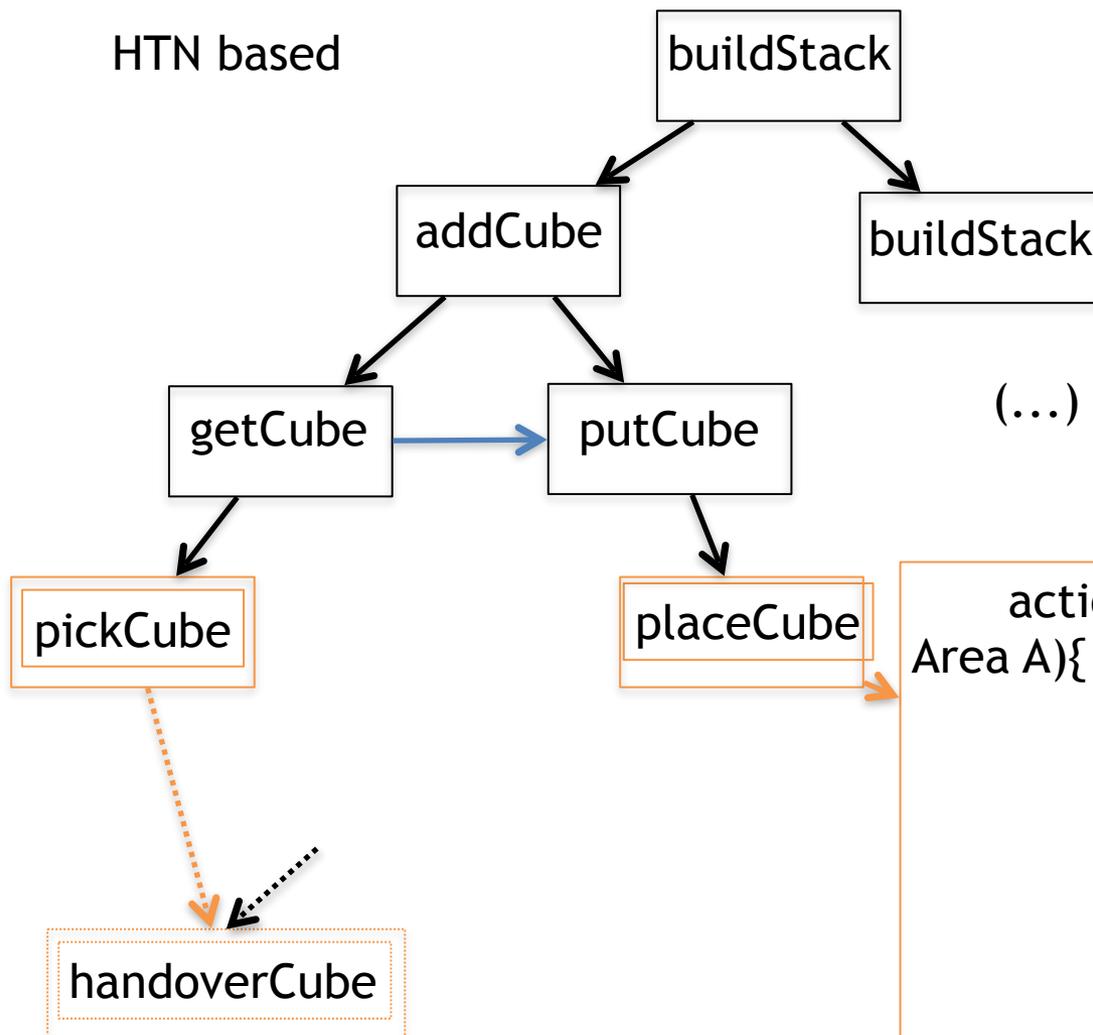
Shared Task Representations





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;  
  };
```

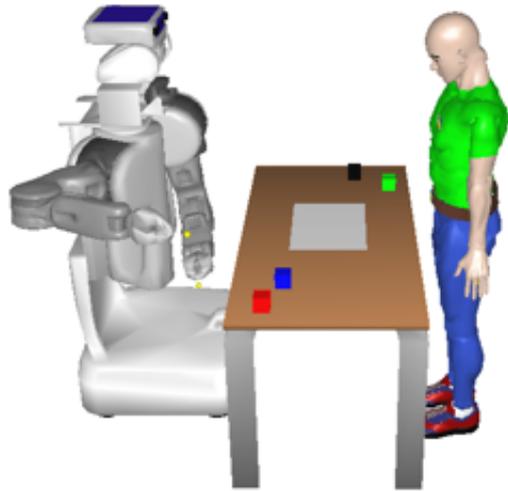
```
  cost{};  
  duration{};  
}
```

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

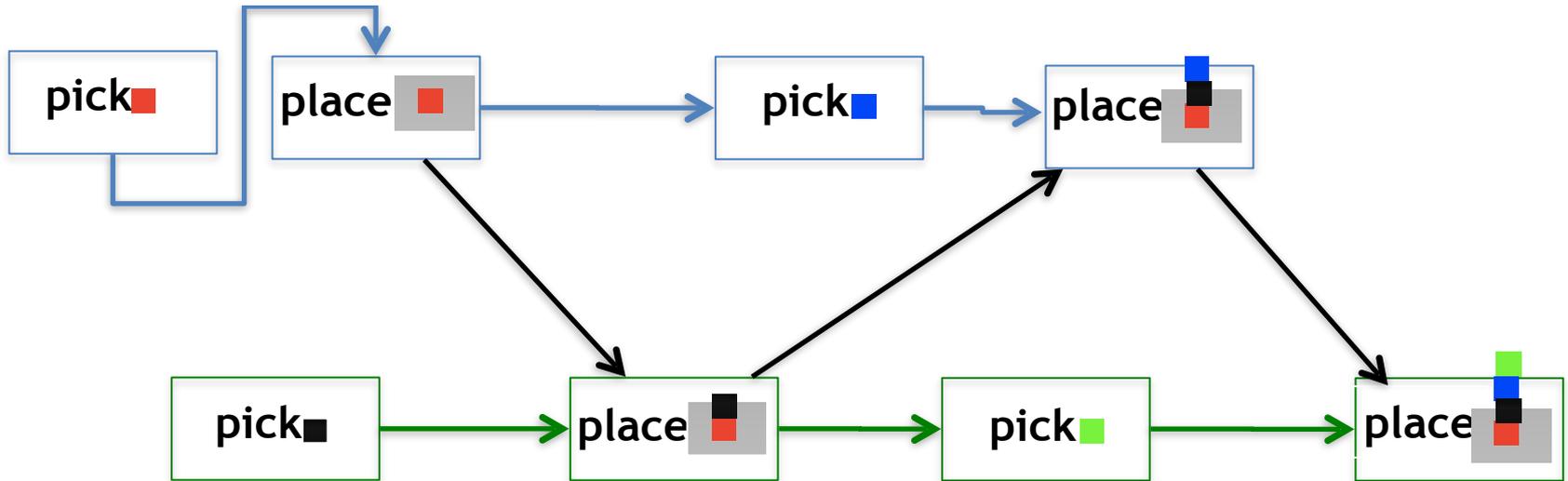
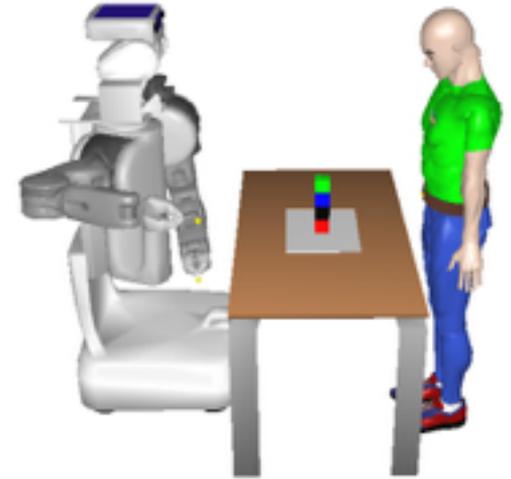
Allili, S., Alami, R., Montreuil V., A task planner for an autonomous social robot, Distributed Autonomous Robotic Systems 8

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

Human-Aware Task Planner

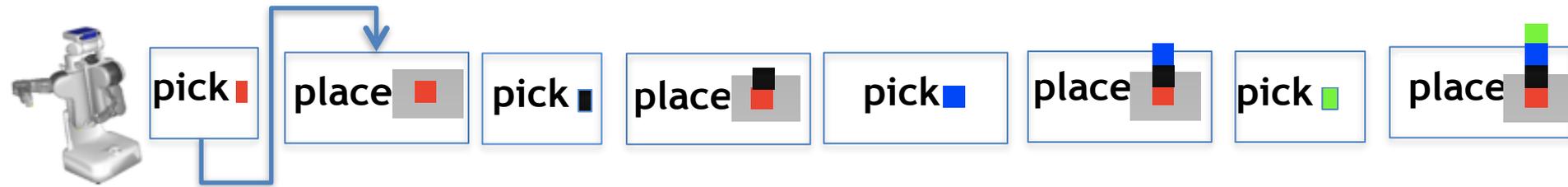
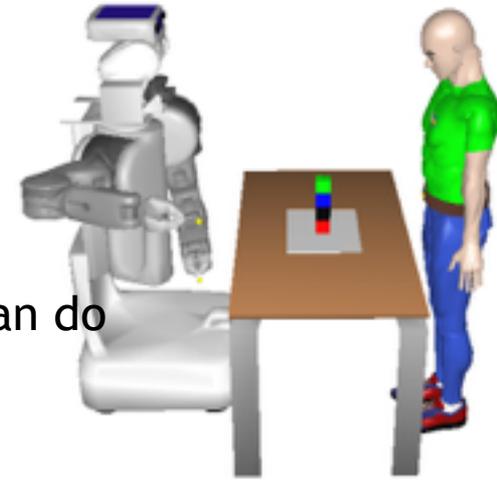


the planner plans for the robot **AND** the human it interacts with



Human-Aware Task Planner

possibility to add **social rules**,
e.g. imagine all the cubes are accessible by both agents,
we can set a rule to say that the robot has to do the most it can do



Human Adaptive Task Planner

we can also use human's knowledge on how to perform tasks !

Define a set of knowledge levels:

- 1 NEW: human has no knowledge on how to perform the task
- 2 BEGINNER: human may know how to perform the task
- 3 INTERMEDIATE: human knows how to perform the task
- 4 EXPERT: human knows how to perform the task and is able to teach it

Store human knowledge regarding each task:

<HUMAN, TASK, PARAMETERS, VALUE>

with

HUMAN: human having this knowledge

TASK: name of the task

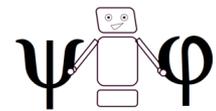
PARAMETERS: list of relevant parameters to describe the task

knowledge

VALUE: value (or level) of knowledge

e.g. human 1 has an expert knowledge on assembling A with B

<human1, assemble, [A,B], EXPERT>



Human Adaptive Task Planner

we can also use human's knowledge on how to perform tasks !

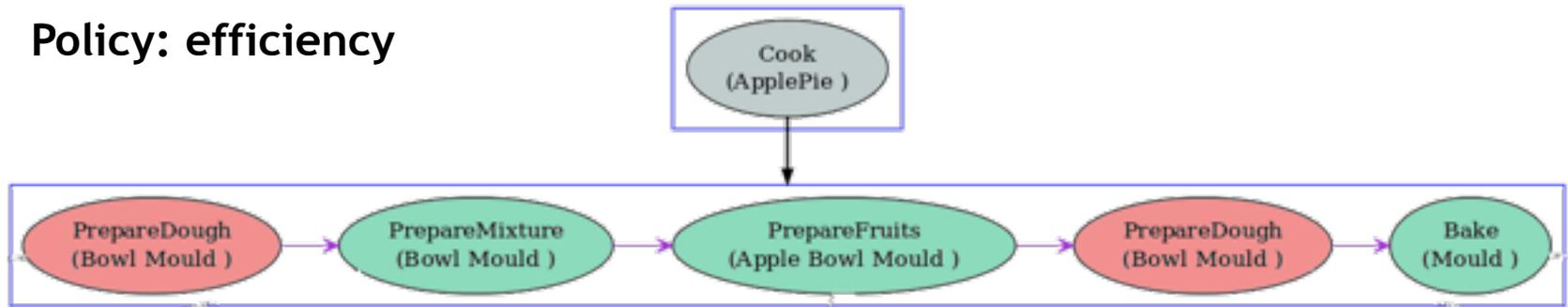
Human knowledge:

- <human1, PrepareDough, [], EXPERT>
- <human1, PrepareMixture, [], BEGINNER>
- <human1, PrepareFruits, [], BEGINNER>
- <human1, PrepareDough, [], BEGINNER>

Human request:

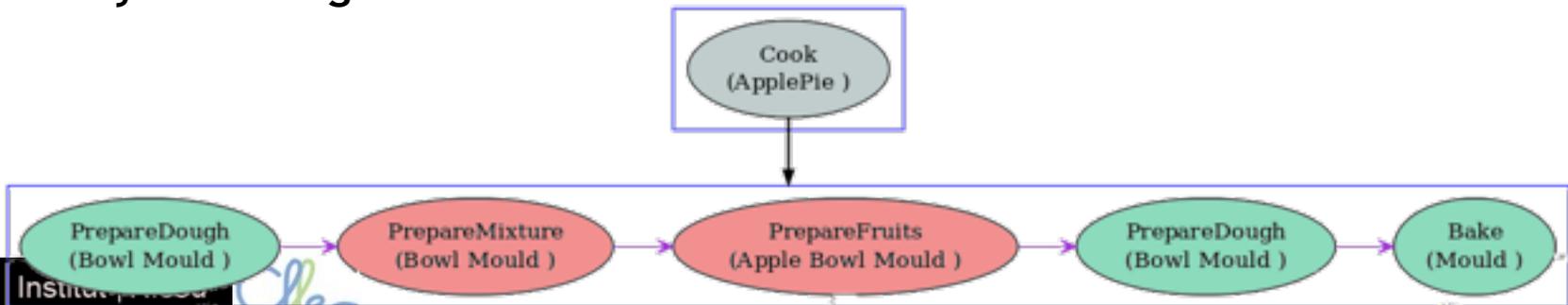
<human1, Bake, [Mould], Don't want>

Policy: efficiency



Robot Human

Policy: teaching



Human Adaptive Task Planner

it could be interesting to **negotiate** about this plan with the human before acting



Human Adaptive Task Planner

beginner<*human1*, *PrepareDough*, [],



expert<*human1*, *PrepareDough*, [],

EXPERT>



```

1: for n:=nodes.start to n:=nodes.end do
2:   if agents(n) = {robot} then
3:     if children(n) ≠ ∅ ∧ user_kn(n) = NEW
       ∧ teachPolicy then
4:       execute_tree(children(n))
5:       user_kn(n) := BEGINNER
6:     else
7:       execute(n)
8:     end if
9:   else if user_kn(n) = NEW then
10:    explain(n)
11:    if children(n) ≠ ∅ then
12:      execute_tree(children(n))
13:      user_kn(n) := BEGINNER
14:    else
15:      monitor(n)
16:    end if
17:   else if user_kn(n) = BEGINNER then
18:    if propose_explain(n) then
19:      user_kn(n) := NEW
20:      (...)           ▷ Same process as NEW
21:    else
22:      monitor(n)
23:    end if
24:   else if user_kn(n) = INTERMEDIATE
       ∨ user_kn(n) = EXPERT then
25:     monitor(n)
26:   end if
27: end for

```

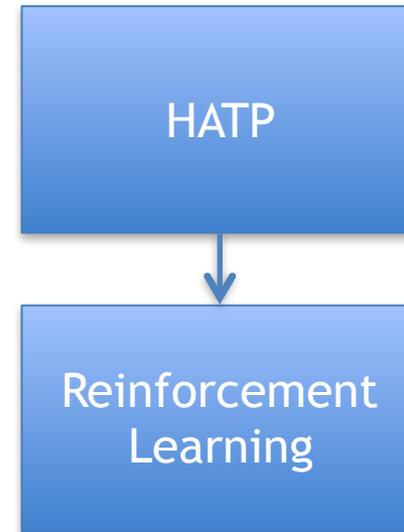


but the domain is static..., once written, it could not be enhanced online

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

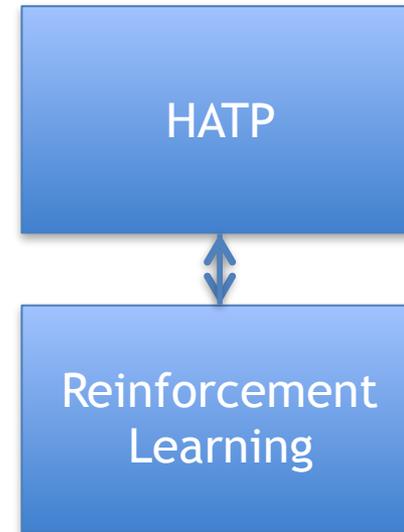


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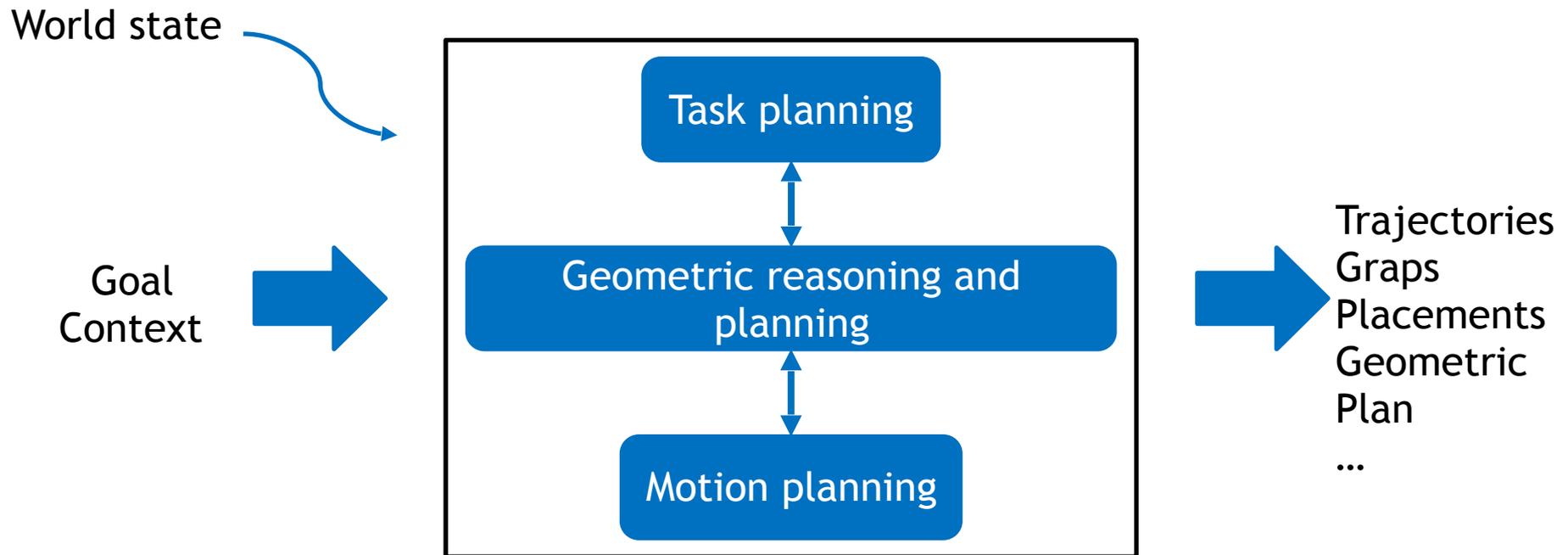


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RO-MAN'15 workshop on learning for Human-Robot Collaboration



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

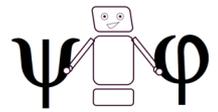
idea: link task planning to motion planning



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 human-aware plans: toward more efficient combined search. In *International Conference on Intelligent Robots and Systems (IROS)*



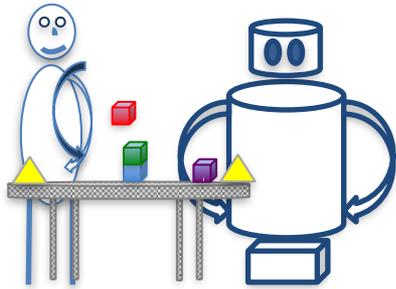


Shared Task Representations

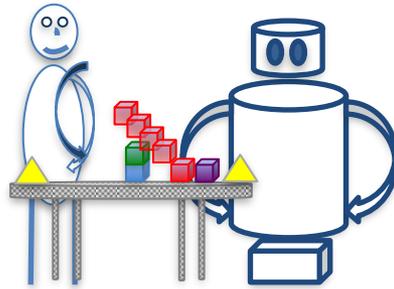
"Shared task representations do not only specify in advance what the respective tasks of each of the co-agents are, they also provide control structures that allow agents to monitor and predict what their partners are doing, thus enabling interpersonal coordination in real time."

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

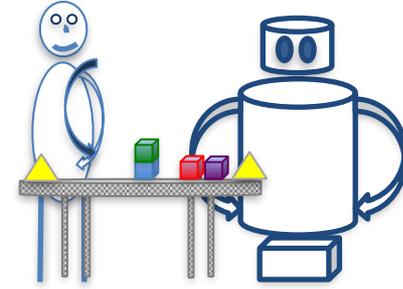
Knoblich, G., Butterfill, S., & Sebanz, N. (2011). Psychological research on joint action: theory and data. In B. Ross (Ed.), *The Psychology of Learning and Motivation*, 54 (pp. 59-101),



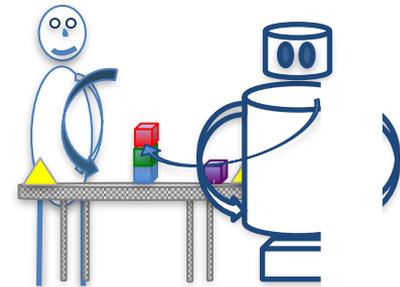
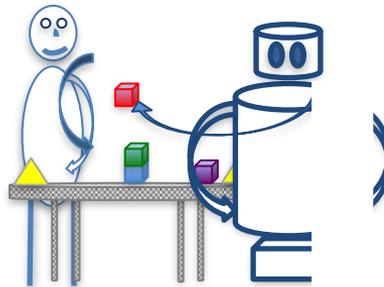
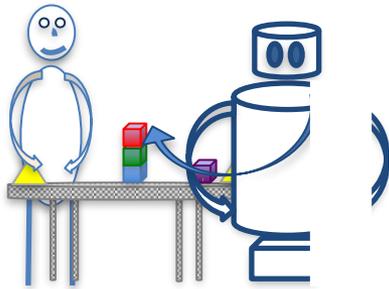
Triadic adjustment
i.e. adjustment toward
the joint goal



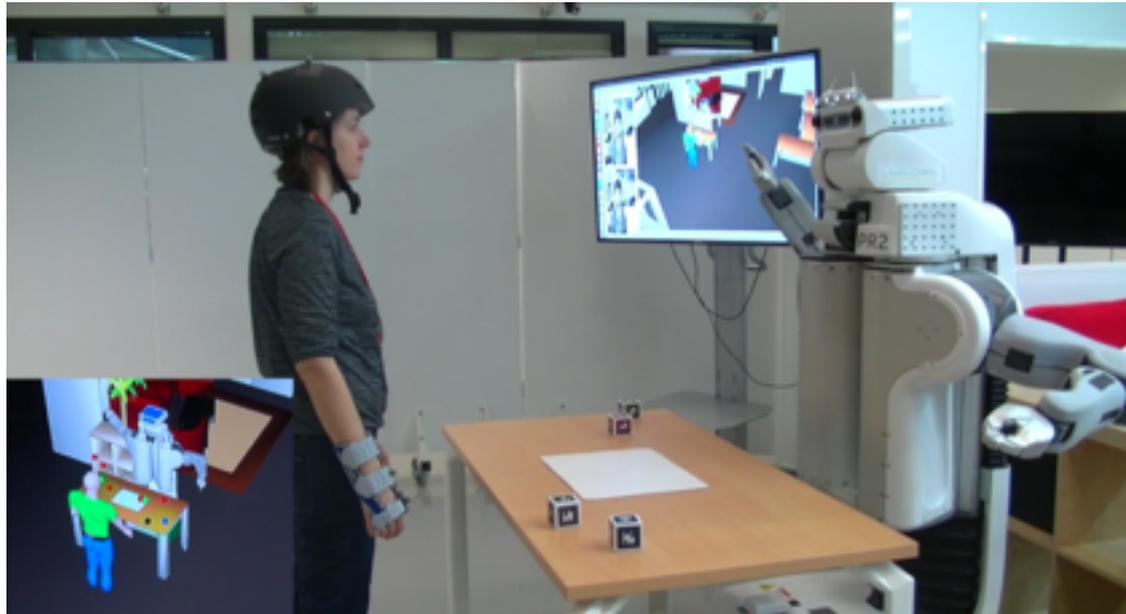
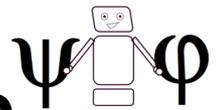
Dyadic adjustment
i.e. adjustment toward
the current action



Collaborative adjustment
(from Tomasello [30])



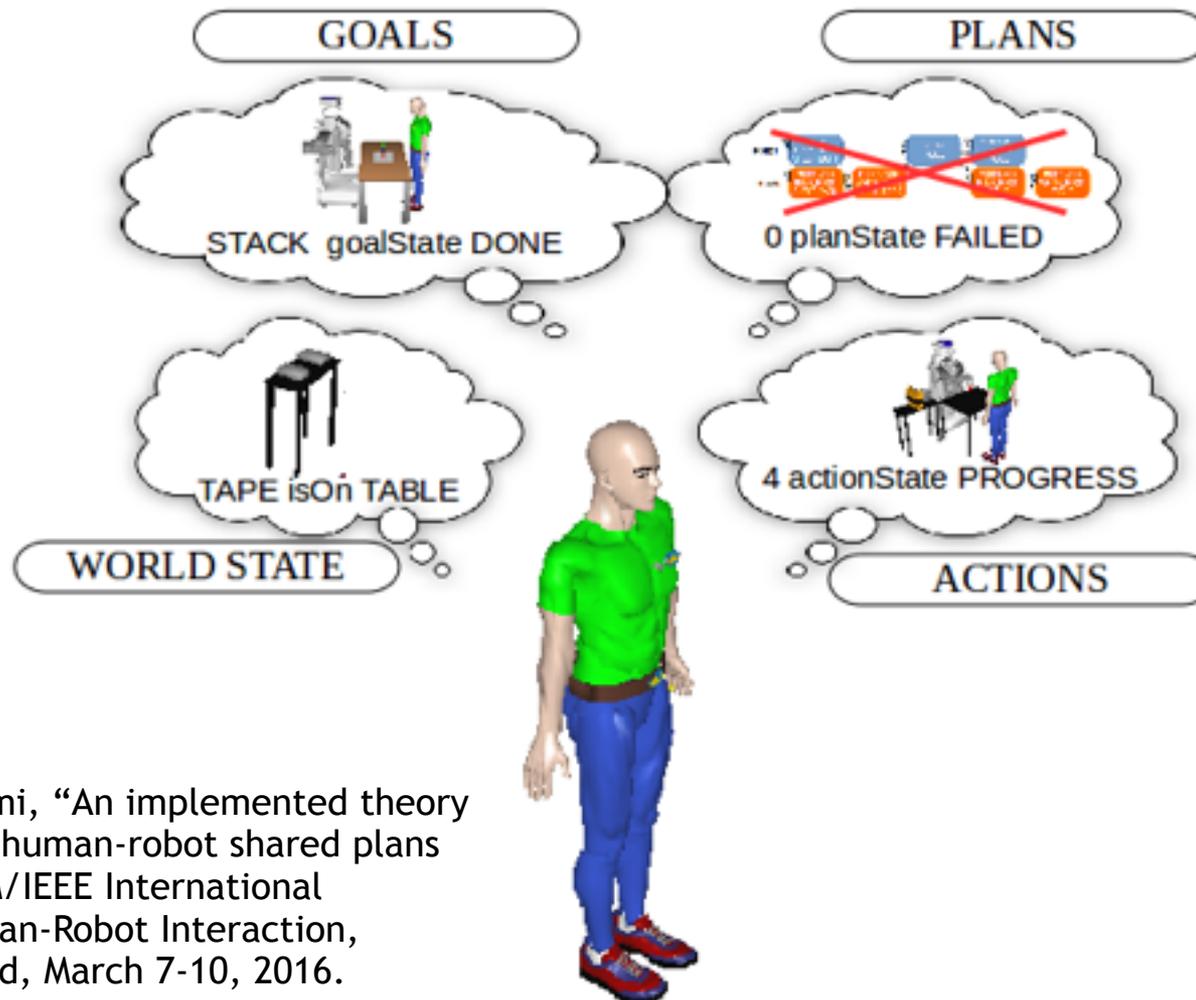
Shared Task Representation



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

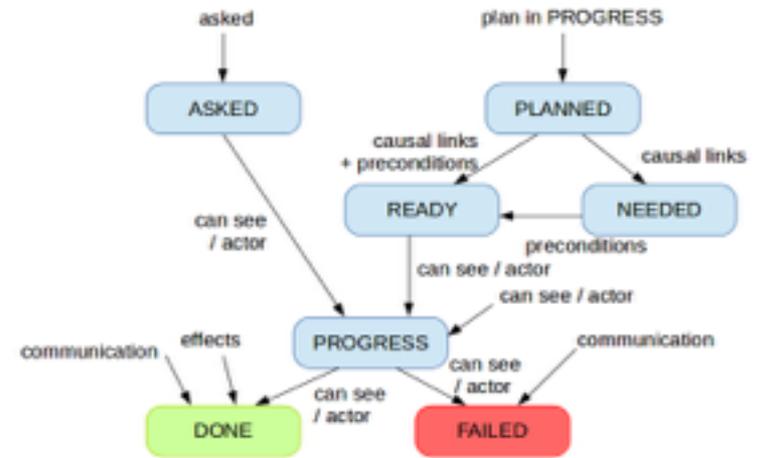
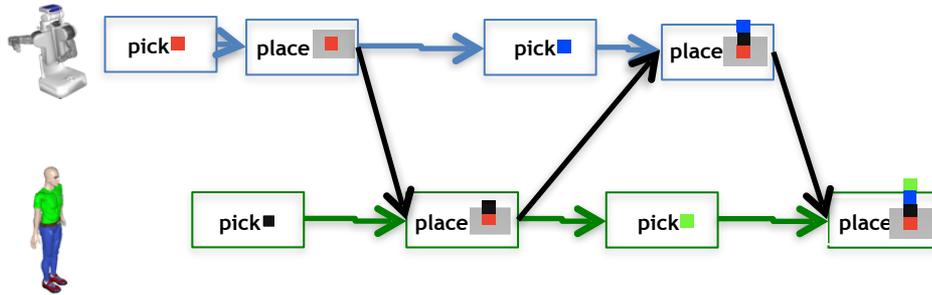
Shared Plan Management

Taking others mental state during execution

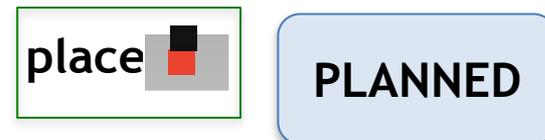
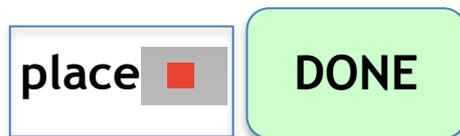


S. Devin and R. Alami, "An implemented theory of mind to improve human-robot shared plans execution.," in ACM/IEEE International Conference on Human-Robot Interaction, HRI'16, New Zealand, March 7-10, 2016.

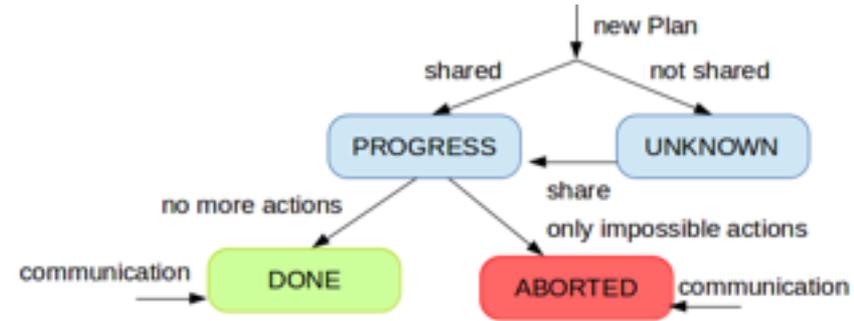
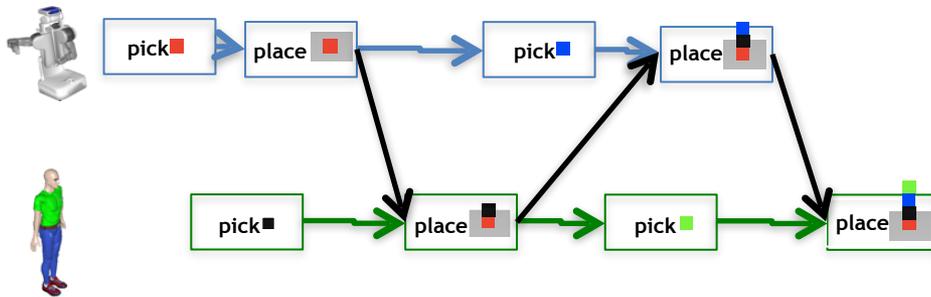
Shared Plan Management



action status



Shared Plan Management



plan status

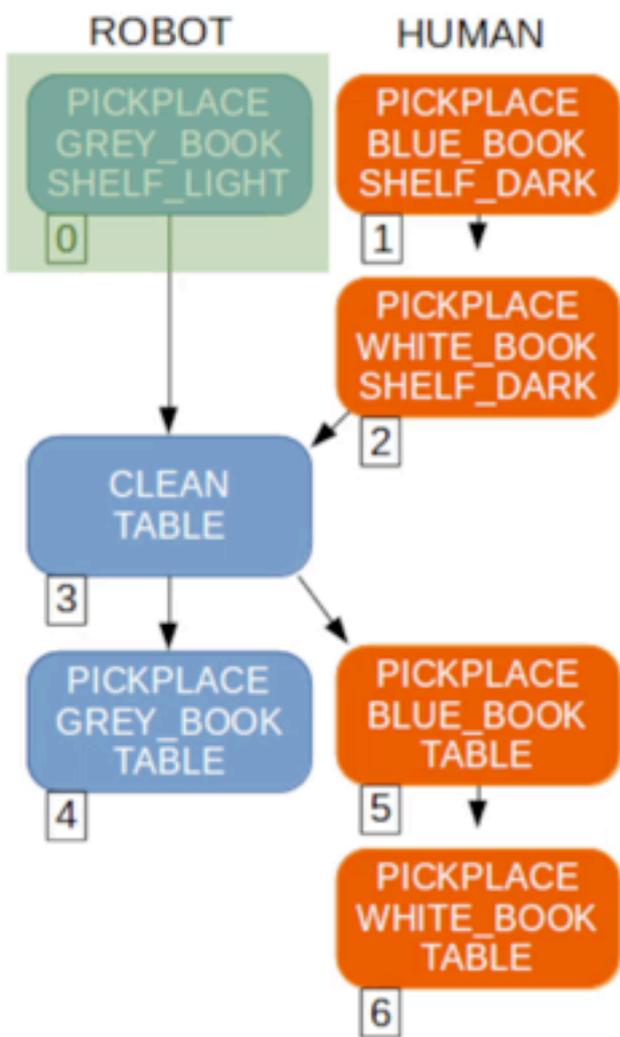


ABORTED



PROGRESS

Shared Plan Management



The robot starts to pick and place the grey book

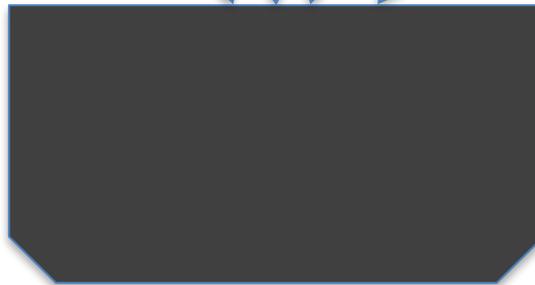
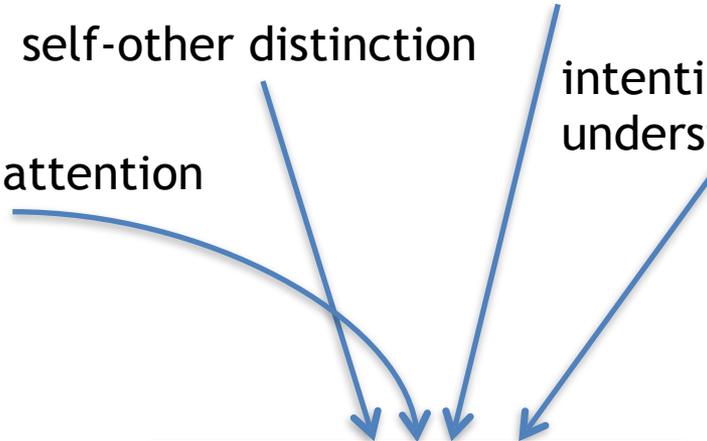


shared task representations

self-other distinction

intentional action
understanding

joint attention





shared task representation

self-other distinction

intentional action
understanding

joint attention

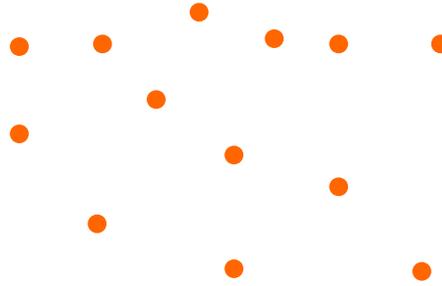
joint commitment

common ground

deliberation/negotiation



uncertainty powder



shared task representation

self-other distinction

intentional action
understanding

joint attention

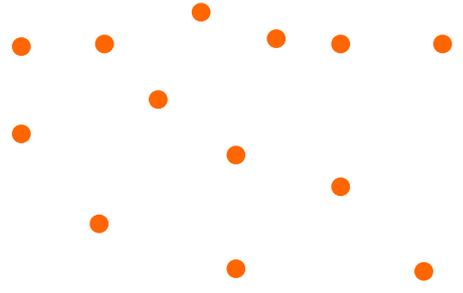
joint commitment

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shared task representation

self-other distinction

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Joint Action Mix