What a robot needs to assist humans or collaborate with them

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« From Human-Human Joint Action to Human-Robot Joint Action and vice-versa ! »
April 4/5 2016, LAAS, Toulouse

Robots among us

- Service and assistive robots
- Teammate robot in a factory

- Need to study role and abilities of a robot involved in a joint activity with humans

Integrative approach for a robot that acts in interaction with humans

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- Work on Collaborative / Interactive task achievement
  - based on a study of human-robot interaction
  - inspired from Joint activity / Teamwork
  - concretized as a set of robot decisional abilities

- Aim to progressively elaborate a coherent framework for **Joint Human-Robot Activity**

Integrative approach for a robot that acts in interaction with humans

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- Work on Collaborative / Interactive task achievement
  - inspired from Joint activity / Teamwork
  - based on a study of human-robot interaction
  - concretized as a set of robot decisional abilities
- Related Work:
  - Inspiration
    - Multi-agent: Cohen P. R., Levesque H. J. (1991), Tambe (Teamwork)
    - Dialog: H. Clark (Joint Activities, Dialogue)
    - Philosophy: Bratman (1992). Shared cooperative activity.
  - Collaboration
    - Developmental Psychology: Tomasello M. Warneken F. et al (2005 - ..)
    - CLLE Toulouse: Developmental Psychology, Ergonimics: H. Cochet, M. Guidetti, JM Cellier, O. Carreras
  - New Inspiration ..
    - Pacherie, E. (2012 - ..)
    - Knoblich G. Sebanz N. et al. (2009 - ..), Vesper (2013)

Approach

- Elaboration of an Architecture: components / ingredients and their articulation
- Investigation on models (representations, schemes) and how they can be acquired
- Elaboration of Decisional and interactive processes

A task-oriented architecture for a collaborative robot

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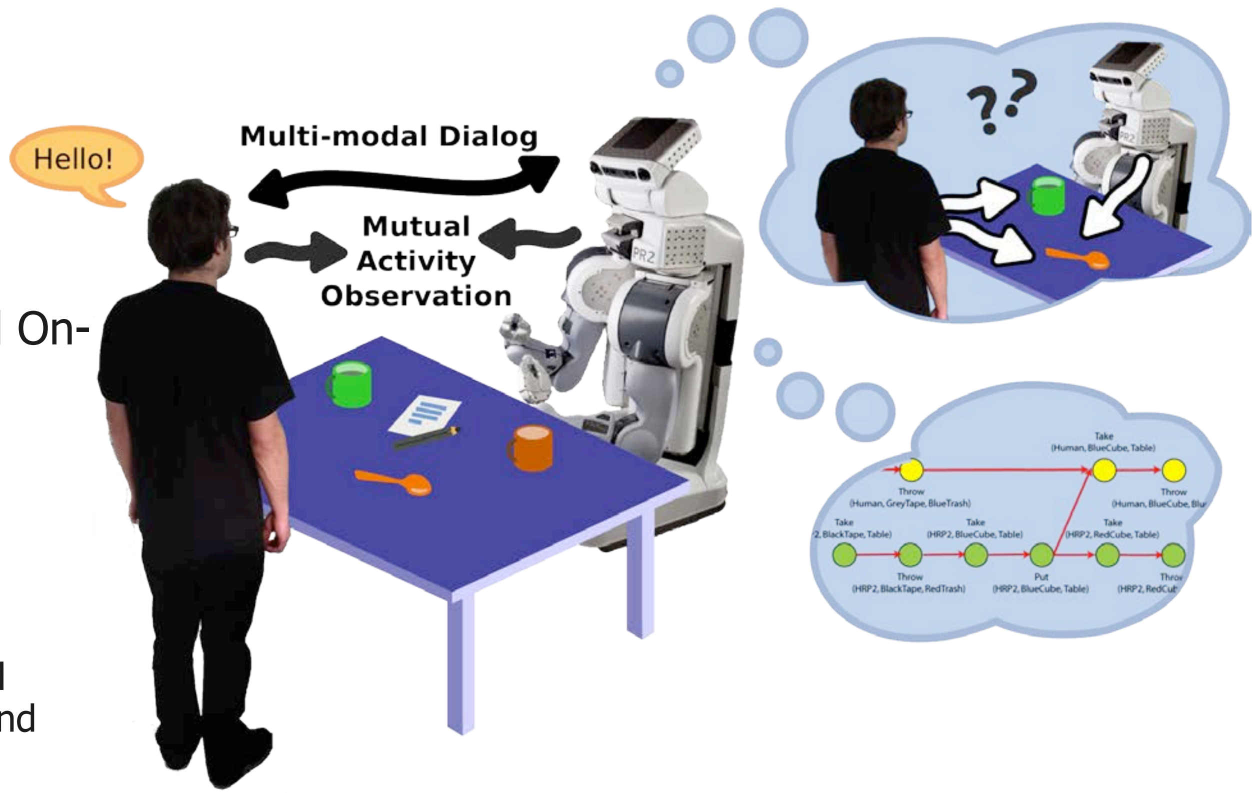
H&R Sharing Task and Space

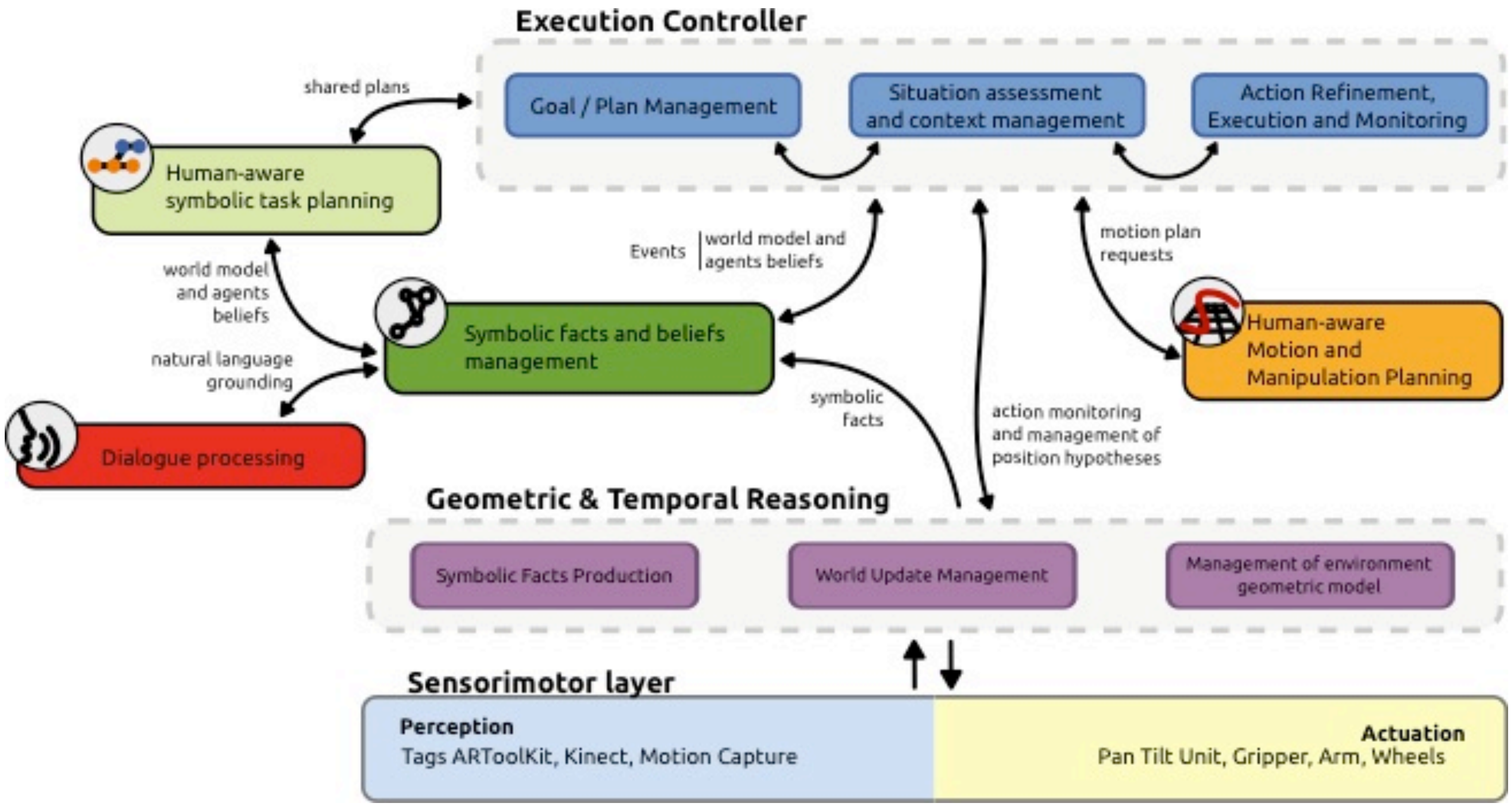
- **Task-Oriented:** How to perform a task, in presence or in interaction with humans, <u>in the best possible way</u>
  - Efficiency
  - Safety
  - Acceptability
  - Intentionality, Legibility

- **Plan-Based:** Planning and On-Line Deliberation
  - Reasoning
  - Anticipation
  - Pro-active behaviour

- **Theory of Mind** – Predicting and reasoning about human activity and mental state



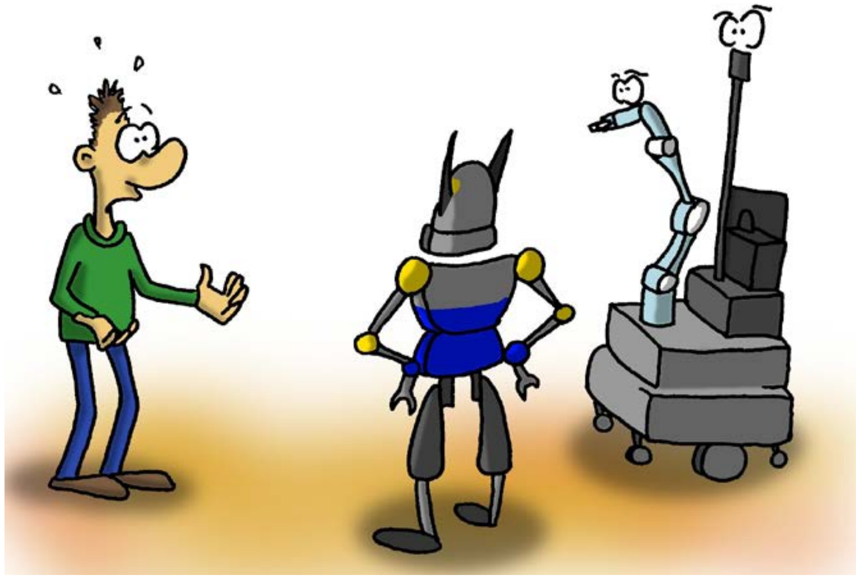
Robot Decisional Architecture: a constructive approach



Questions for a robot which collaborates with humans

what, who, where, when, how?

- At various levels of abstraction
- With various time horizons



→ In the quest of models

Outline

1. Situation assessment, Theory of Mind, Perspective-Taking and affordances
2. Plan elaboration based on each agent abilities
3. Action refinement taking into account human preferences and needs
4. Managing Commitment in Joint task achievement

1 - Perspective-taking and affordances in interactive contexts

One key robot capability: reasoning about placements and perspectives

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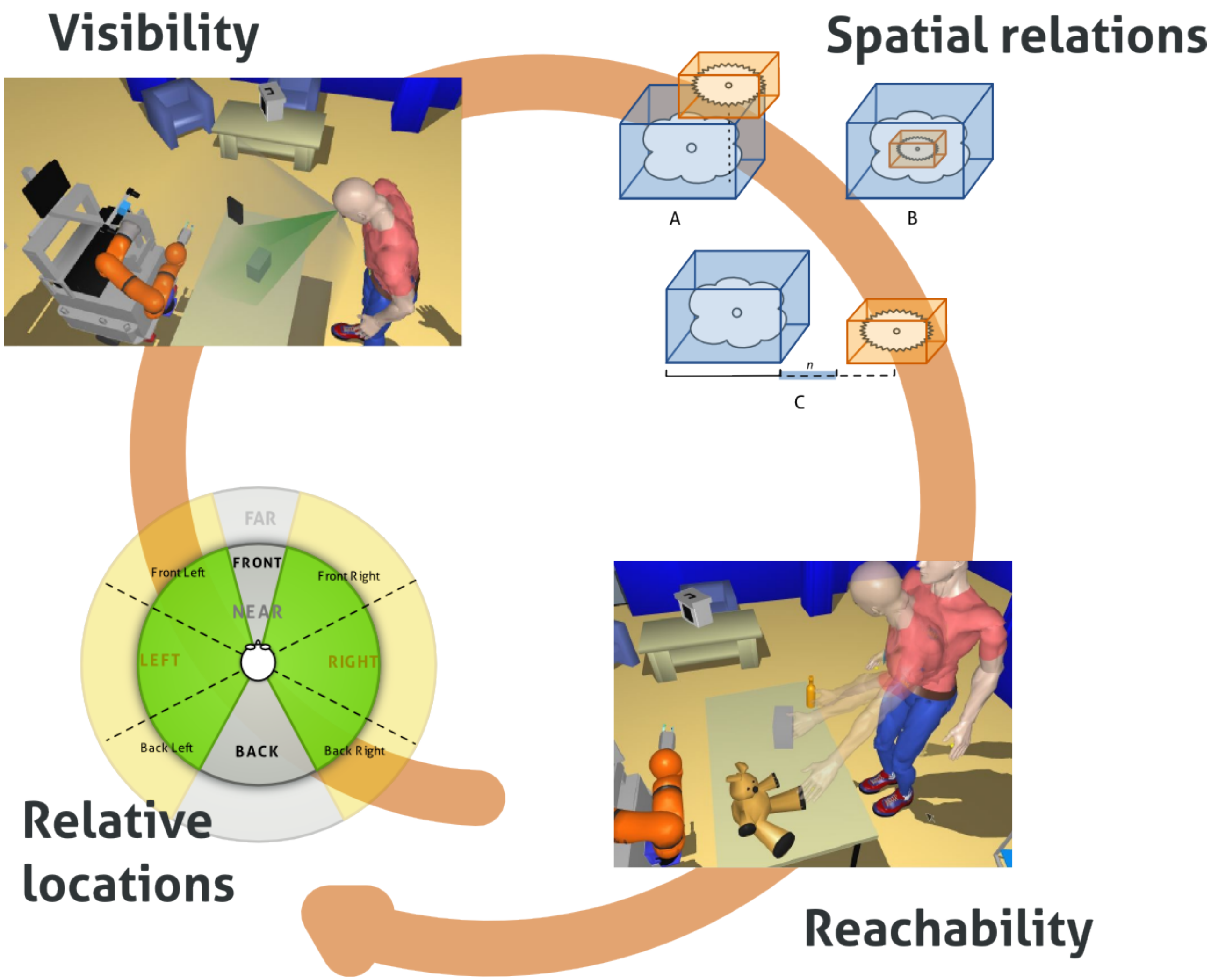
- **Situation Assessment** for Human-Robot Interactive Object Manipulation: reasoning on the human (and the robot) perception and manipulation abilities

- **Compute** relative **Placement** and **Motion** with respect to humans and objects in an environment

- In order to answer questions such as:
  - Can the human see that object ? Can the human see the a given part of the robot ? **(perspective)**
  - Can human reach an object **(grasp)**
  - Where to place the robot in order to be able to see simultaneously an **object, the hand and the face** of a human partner

Perspective-taking and geometric reasoning for anchoring facts on human-robot object manipulation



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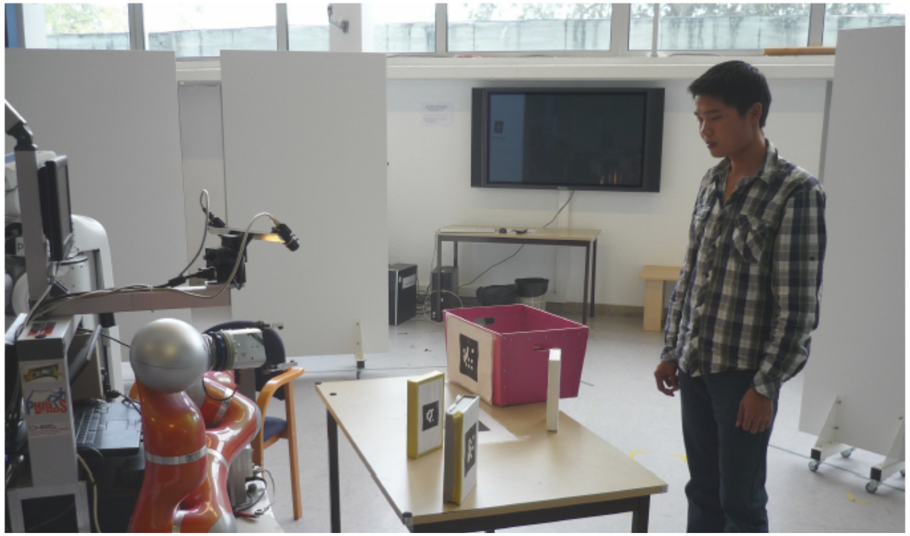
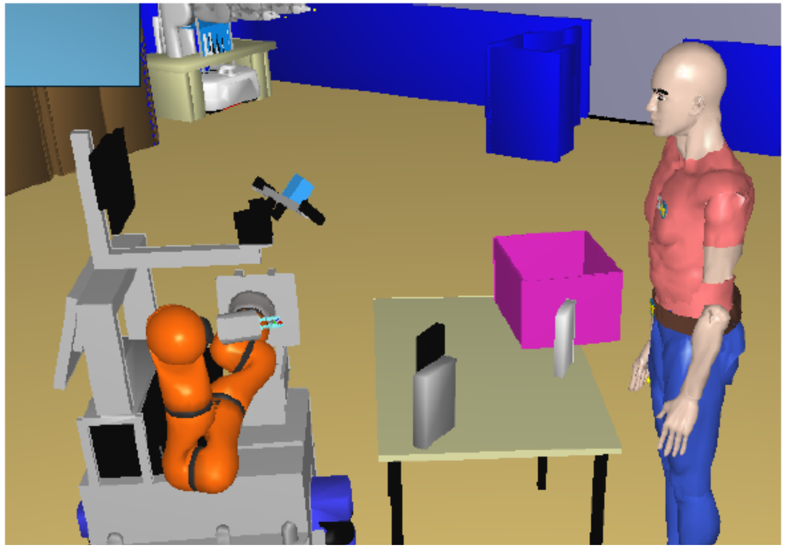
Relevant robot and human beliefs (from the robot perspective)





ROBOT

PINK_TRASHBIN isReachable false
WALLE_TAPE isReachable false
LOTR_TAPE isReachable true
GREY_TAPE isReachable true
WALLE_TAPE isVisible true
LOTR_TAPE isVisible true
GREY_TAPE isVisible true
WALLE_TAPE isOn TABLE
LOTR_TAPE isOn TABLE
GREY_TAPE isOn TABLE

HUMAN1

PINK_TRASHBIN isReachable true
WALLE_TAPE isVisible true
LOTR_TAPE isReachable false
GREY_TAPE isReachable false
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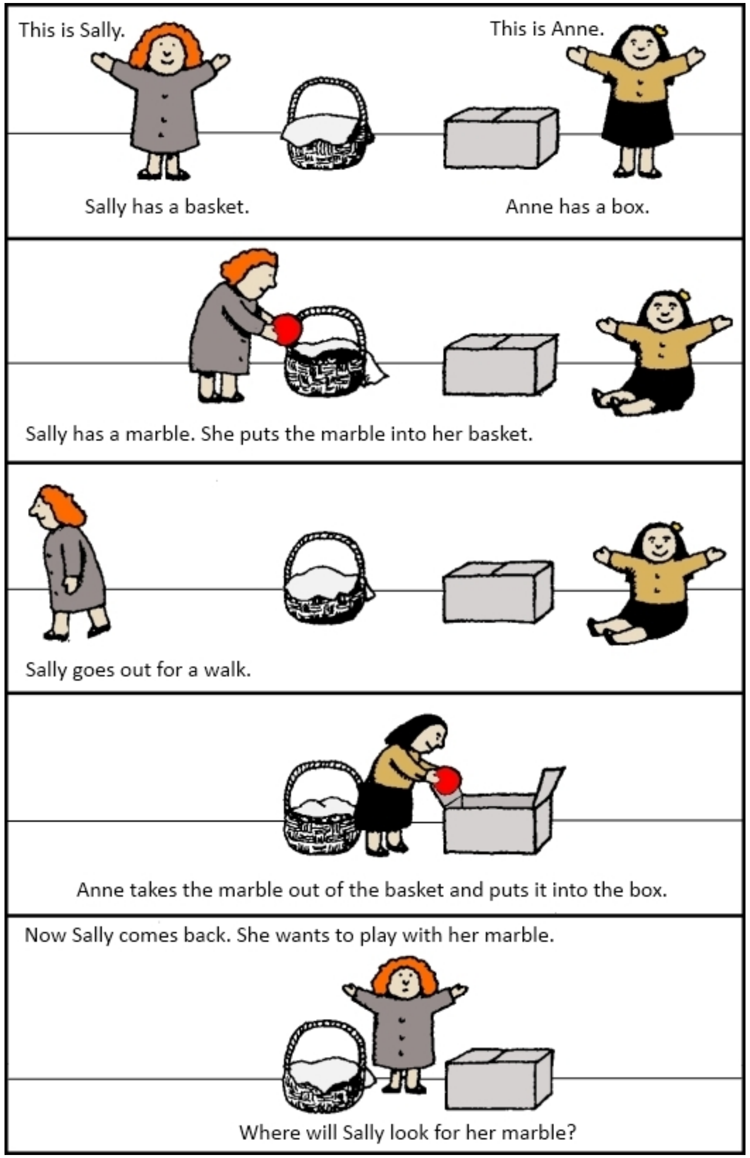
Mind reading for Robot's Social Intelligence

- Theory of mind
- Developing means to estimate mental state
  - Situation assessment
  - Comfort, Acceptability of robot behaviour
  - State of Joint Goals and Shared Plans

-> Perspective taking based on geometric and temporal reasoning, Affordances estimation

Sally and Anne



Dealing with Divergent beliefs

Building, maintaining mental models and using them for planning:

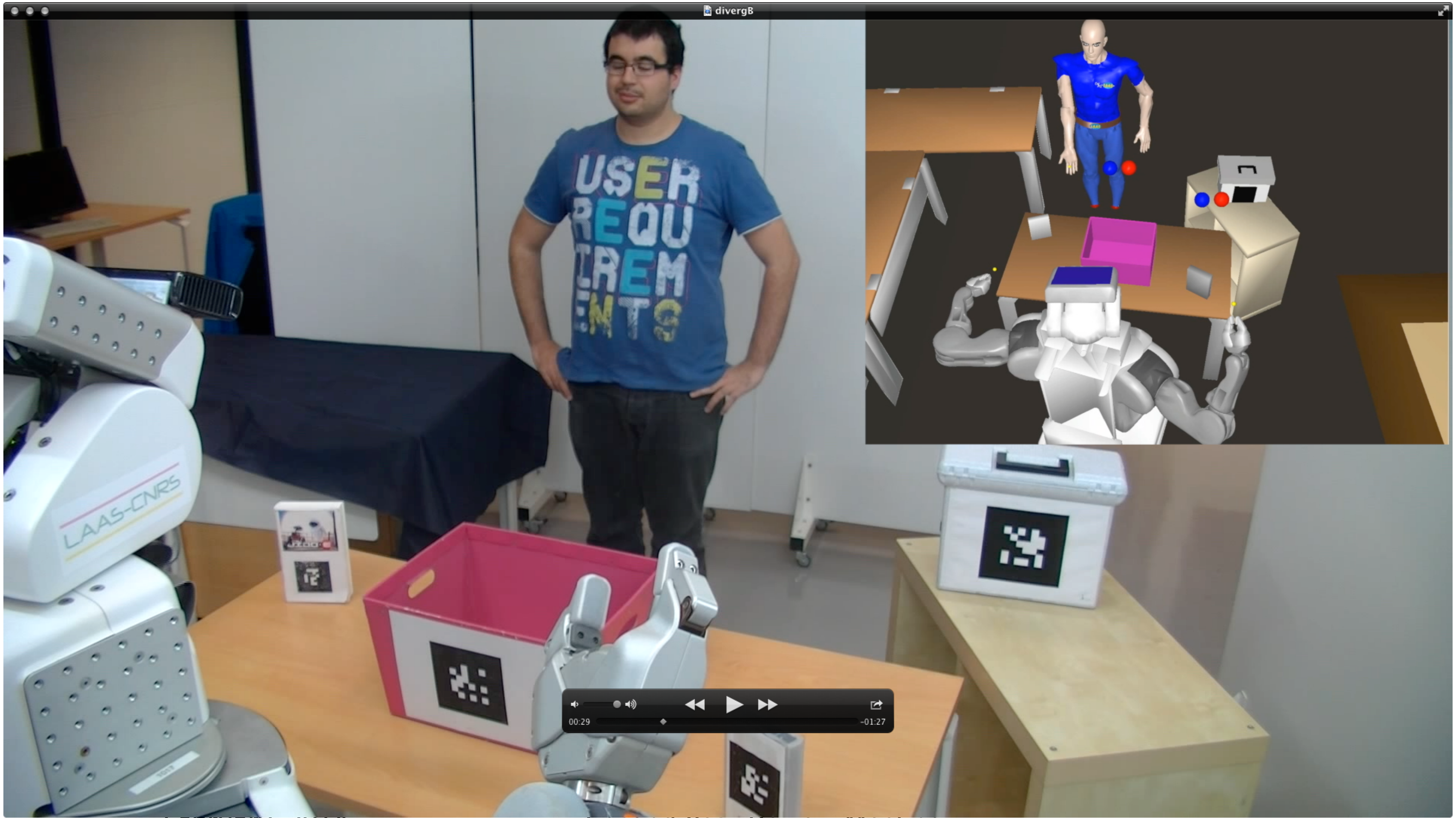
- Situation assessement
- Tracking of human beliefs (possibly divergent)
- Elaboration of shared plans integrating communication acts

Mental models and management of divergent beliefs

Robot and two humans: **Blue** and **Green**:

- Keeping track of distinct beliefs for each agent and managing divergent beliefs
- Planning if necessary communication actions
- Similar to the “Sally & Anne False Belief Test”

Blue is here
(**Robot** is an observer …)



Green comes in

Robot computes that **Green** does not know (yet) about the objects

Robot infers that now Green knows about the objects (since they are visible to him)

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Green leaves … Blue moves the white box

Robot computes the new situation

Blue leaves – **Green** is back

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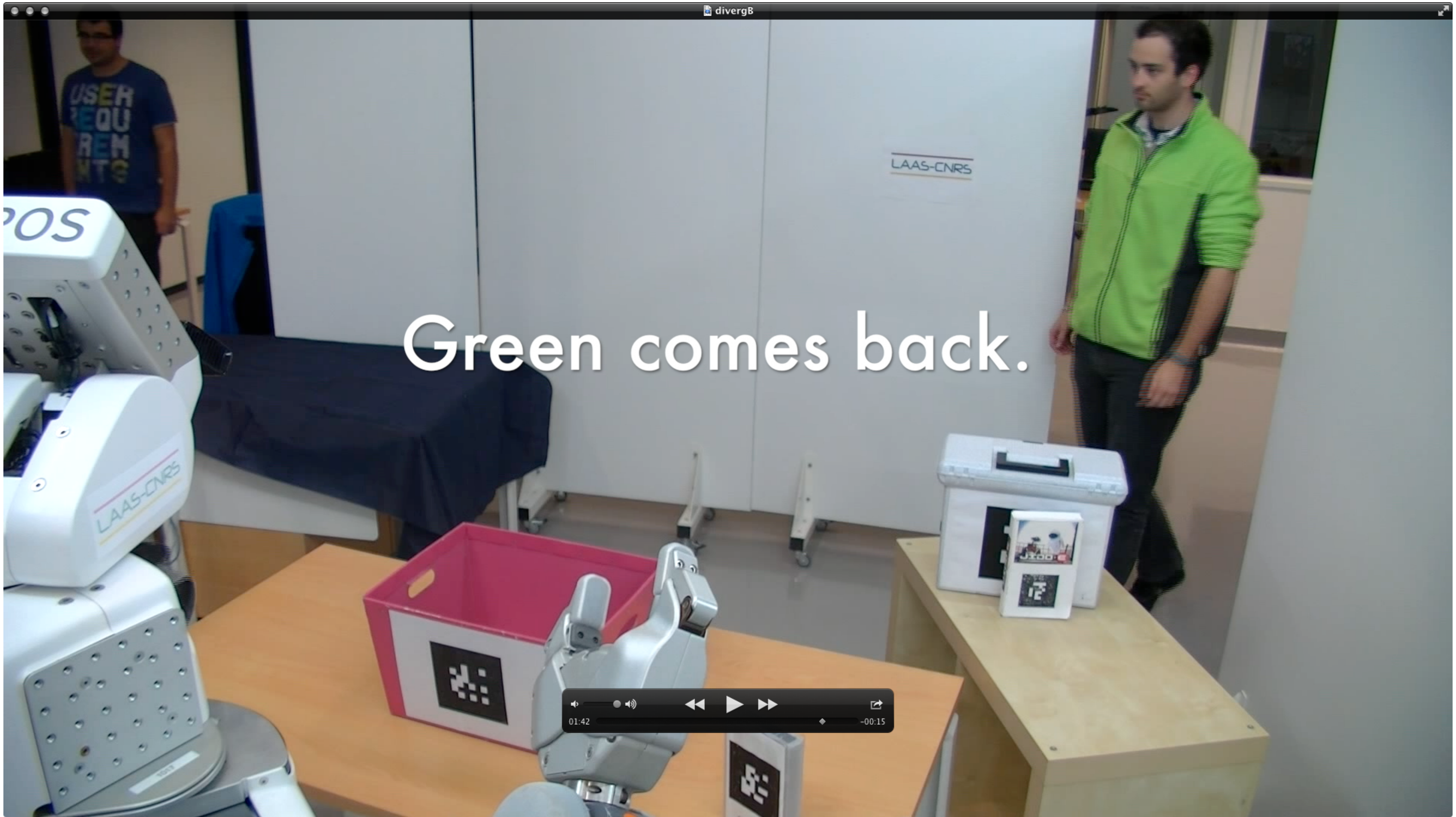


Robot infers that **Green** does not know now where is the white box (it has been moved and it is not visibile to **Green**)

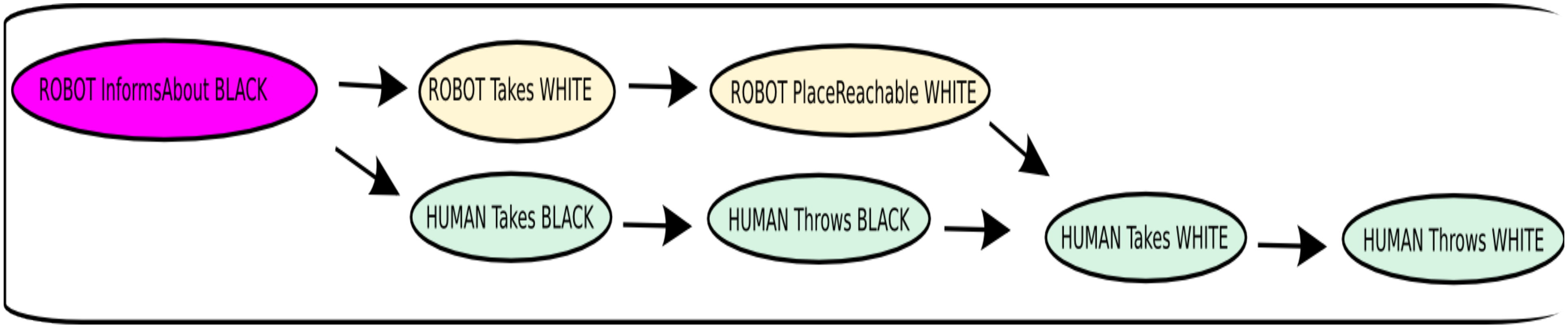
If the goal is to clean the table ….

Robot can synthesize a shared plan based on:

- its current knowledge of the state
- its estimation of the beliefs of its human partners

and provide information (**adds in the plan communication actions**) to its human partners when necessary

Robot has computed that BLACK object **reachable** but **not visible** by **Green**



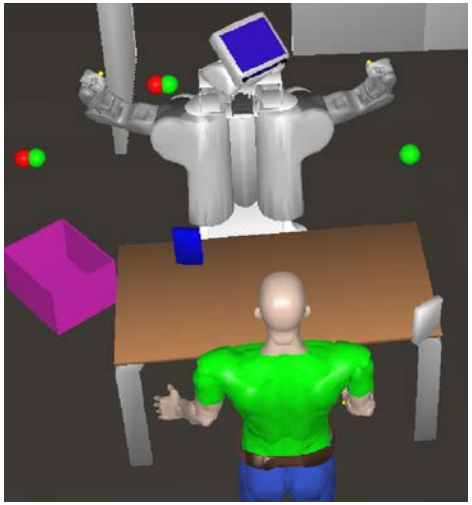
2- Elaborating a shared plan

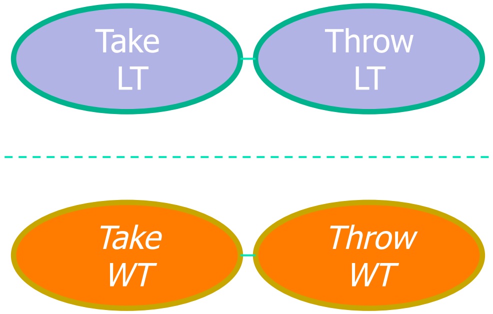
From Shared Cooperative Activity

- From a (shared) goal to a (shared) plan
- Need to elaborate and agree on how to achieve a goal: the plan (also called « recipe »)

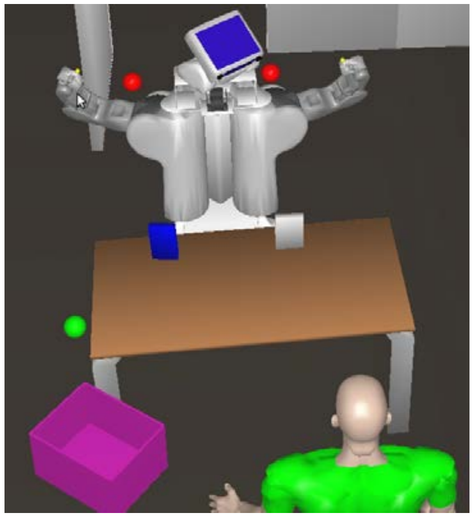
- Robot selects a stereotypical or known plan / build a plan based:
  - on the goal to satisfy
  - on the current state (as it is perceived and inferred)
  - on its knowledge of the capacities of each agent (itself and the human)
  - on its estimation of the belief of its human partner

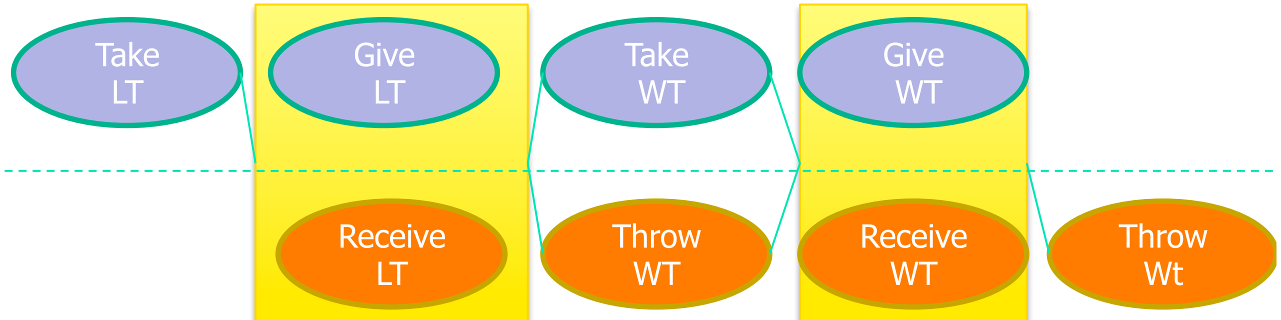
Human Aware Planning





Meshing sub-plans





HATP (Human-Aware Task Planner)

- Hierarchical planner (HTN) [Alili et al., 2008]
- Multi-agent / H and R plan
  - From the point of view of the robot
  - 1 stream of actions per agent
  - Synchronization (causal links)
- Setting of the level of cooperation
  - Cost functions
  - Social rules

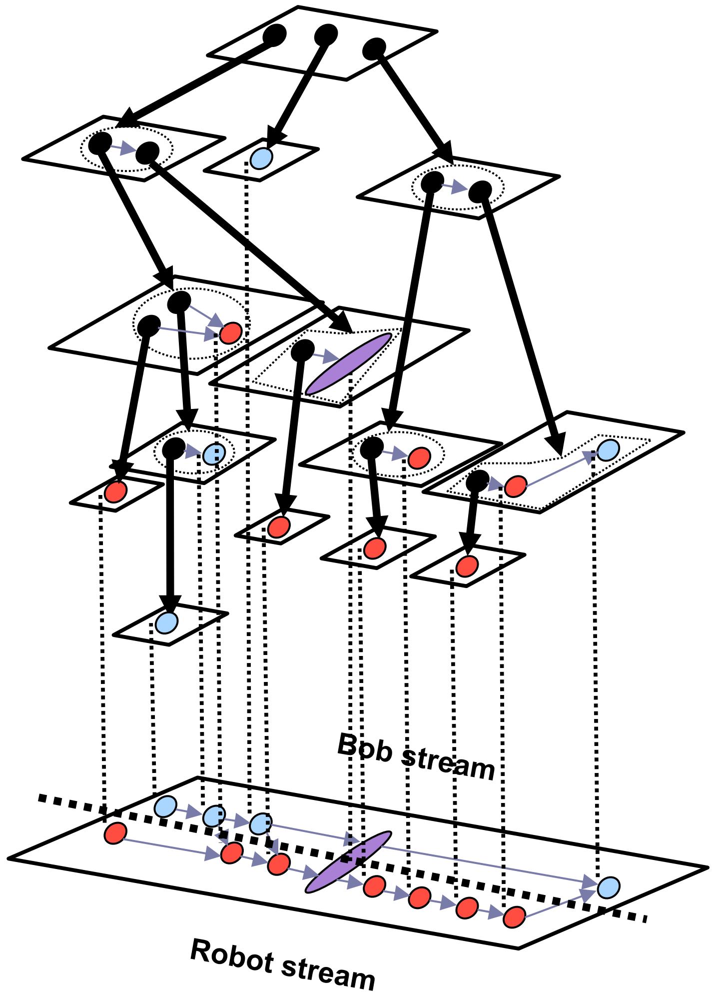
HATP plan construction

- A plan = tree + projection
  - HTN (Hierarchical task Network)
  - temporal plan projection on Directed Acyclic Graph

- **Maximizing plan utility to help assist human / minimize human effort:** partner, teammate, assistant

- **Agent abilities and preferences:** costs associated to each action he can perform.

- **Social rules:**
  - Avoid undesired states or undesired sequences of actions
  - Satisfy social conventions
  - Promote fluency, legibility…



HATP example: Implementation of the concept of shared plans

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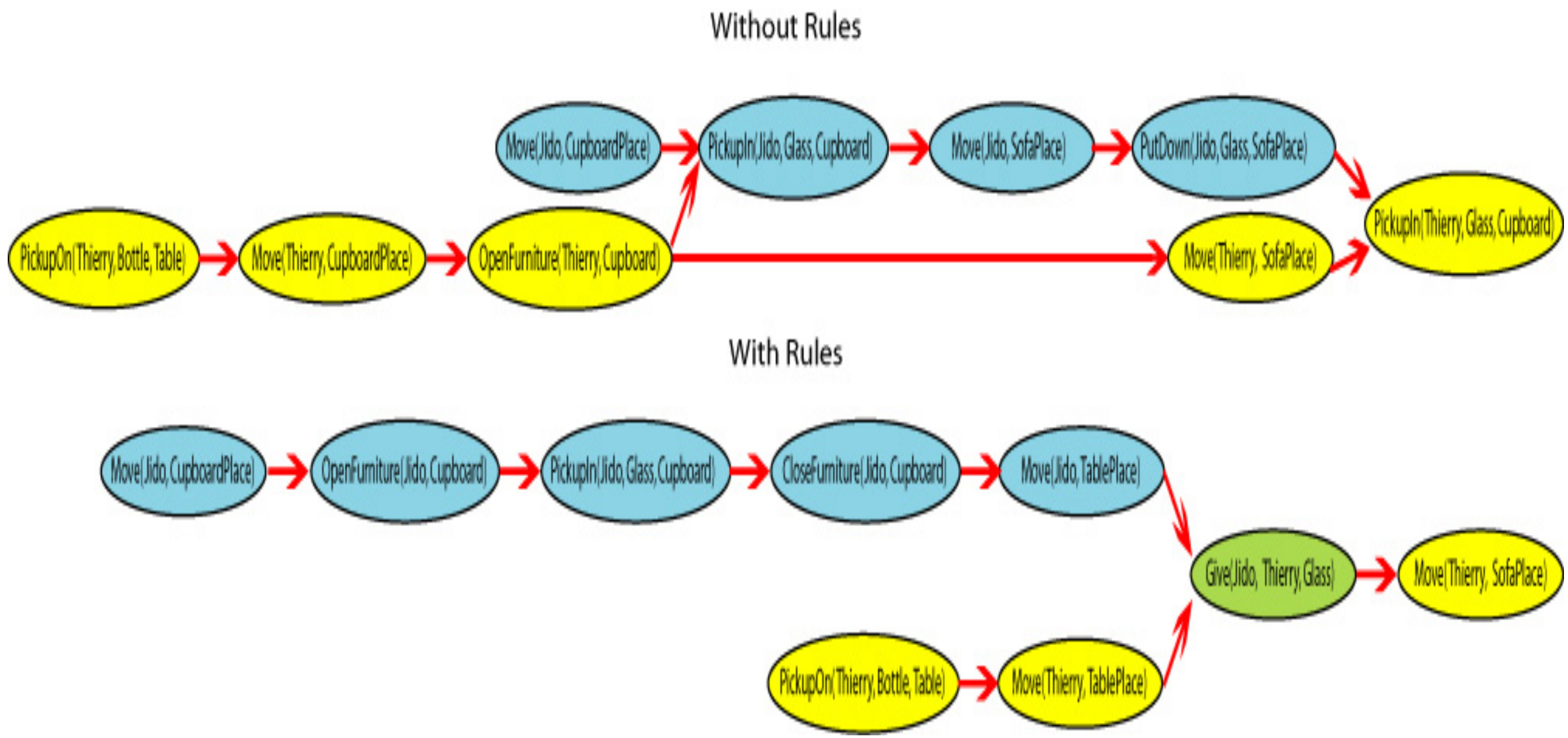
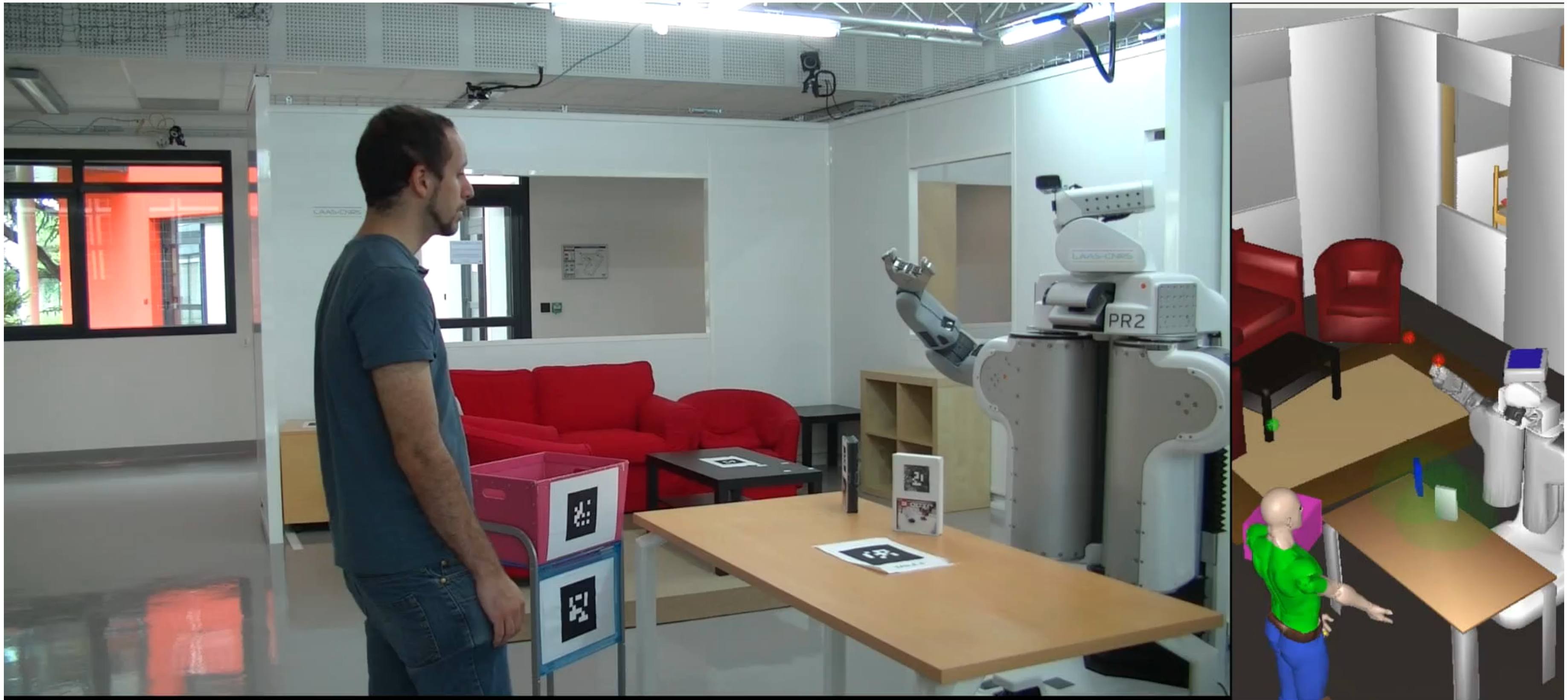


Promoting plans with less intricacies

Work of S. Alili and J. Guitton



First, I take the lord of the rings tape
and give it to you.

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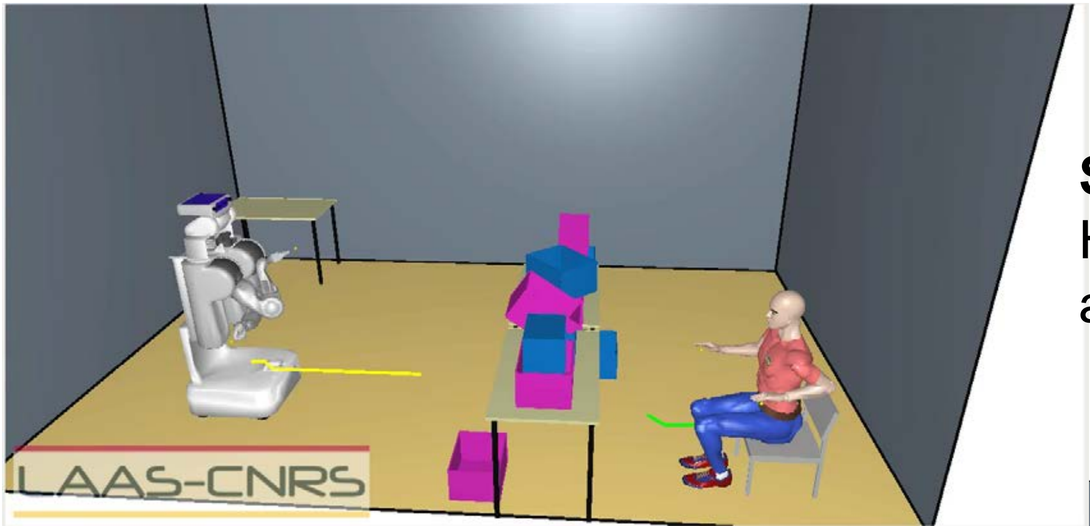
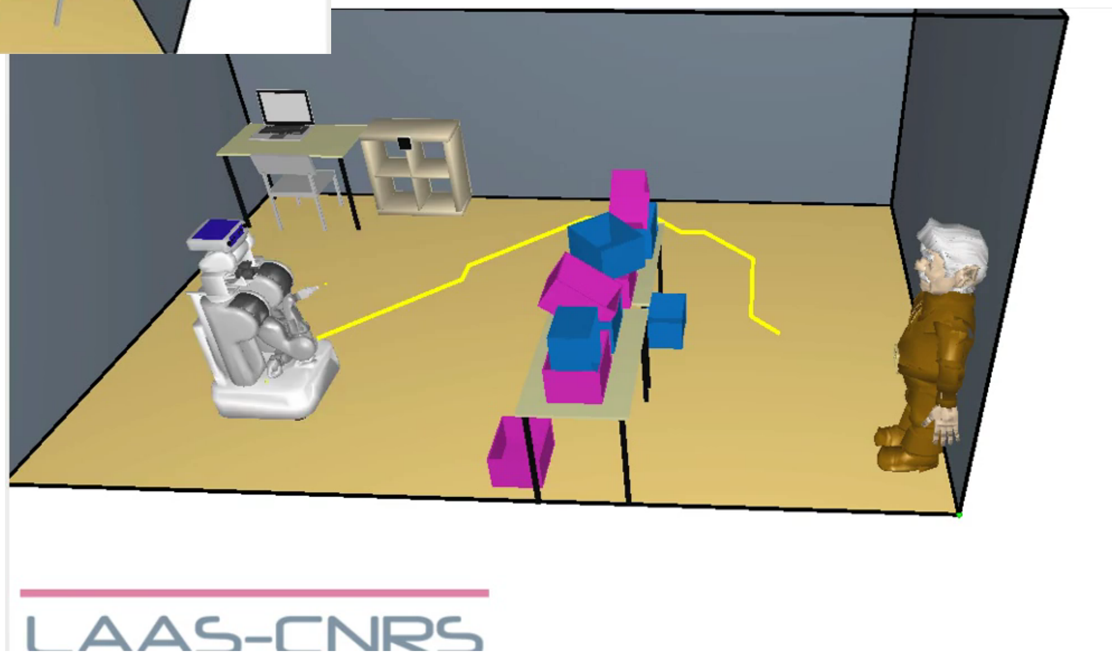
Planning for human and robot



Robot behaviour can be tuned and adapted to human preferences

Sharing the load for efficiency :
Human needs the task to be achieved quickly

Elderly people prefer the robot to do more

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PR2

3 - Synthesizing a good / pertinent behavior

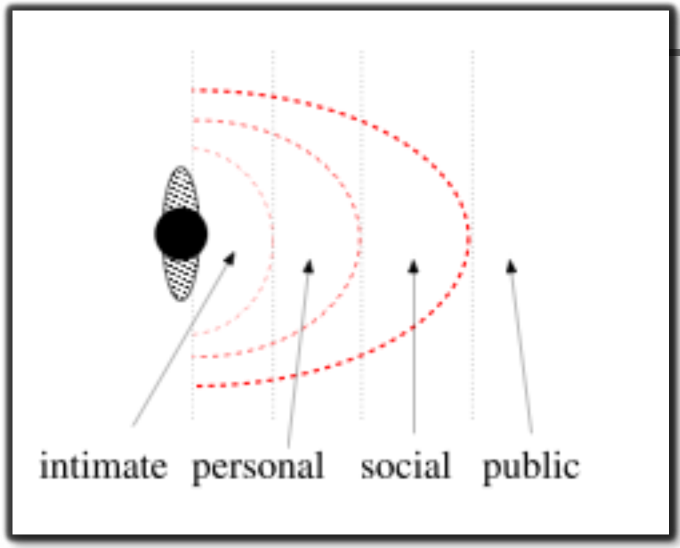
Building a « good » plan

- Managing Joint task achievement
- Legibility of robot actions and intentions (intentionality)
- Acceptability of robot actions
- Compliance with "conventions"
- Coherent attitudes and behaviors

Constraints on robot plans

Sharing space

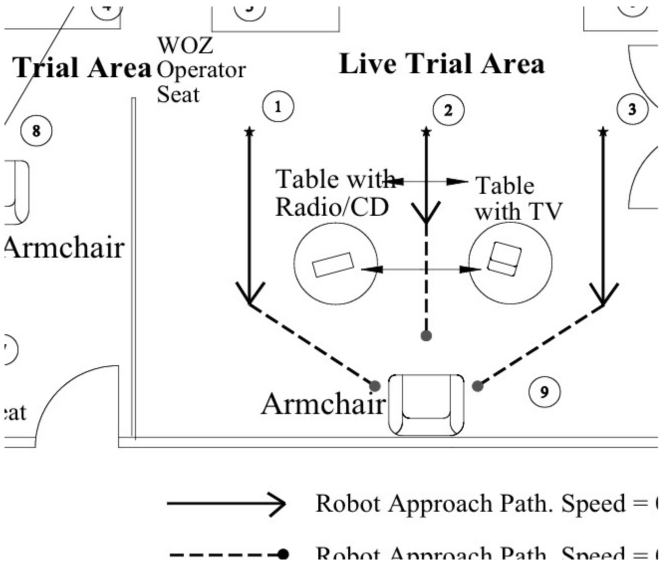
Robot motion and placement deduced from user trials

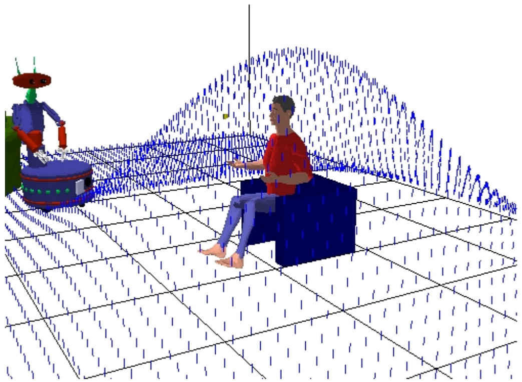


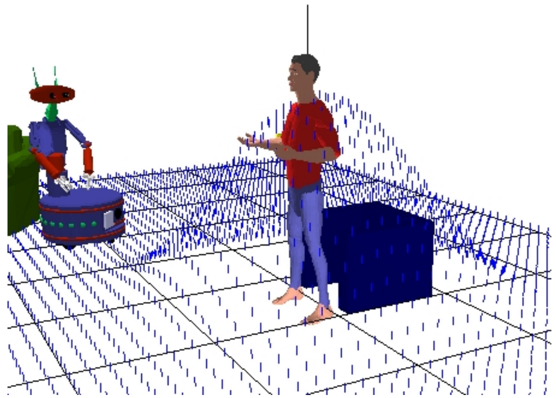
Proxemics (Hall 66)

User trials performed at Univesity of Hertfordshire

K.L.Koay et Al "Exploratory Studies of a Robot Approaching a Person in the Context of Handing Over an Object »AAAI Spring Symposium - 2007

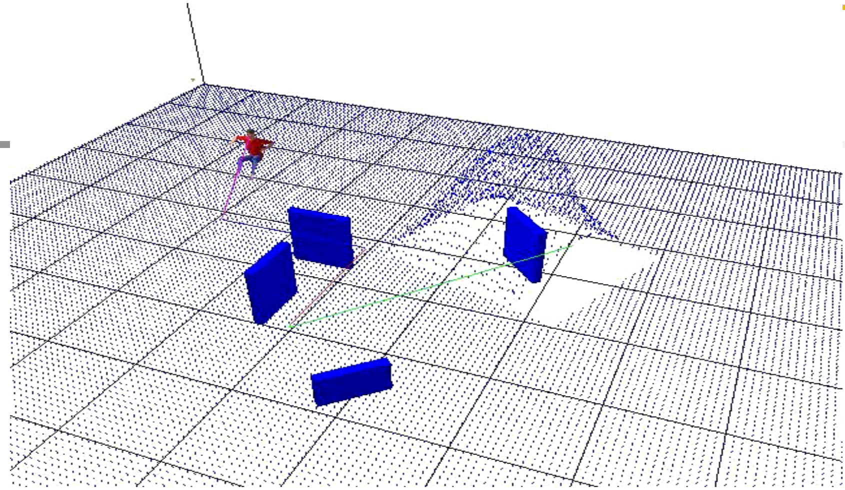


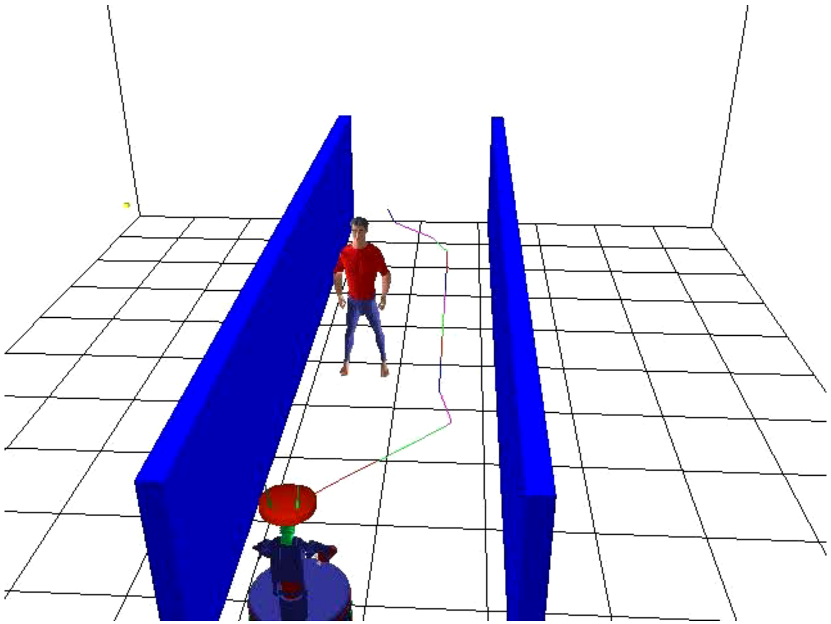




Real-time cost evaluation:
distance, posture, visibility

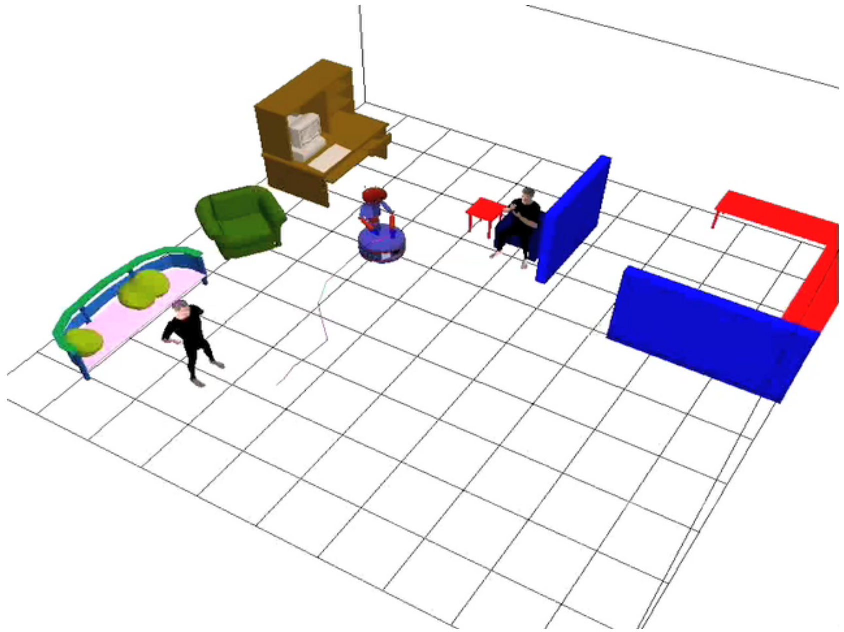
E.A.Sisbot , L. F.Marin Urias , R.Alami , T.Simeon
"A human aware mobile robot motion planner" ,
IEEE Transactions on robotics, Vol.23,N°5, 2007





Hallway Crossing

Catenary-like trajectory



Replanning in dynamic environment

Take the mug … and Give it to me

or (simply)

Give me the mug

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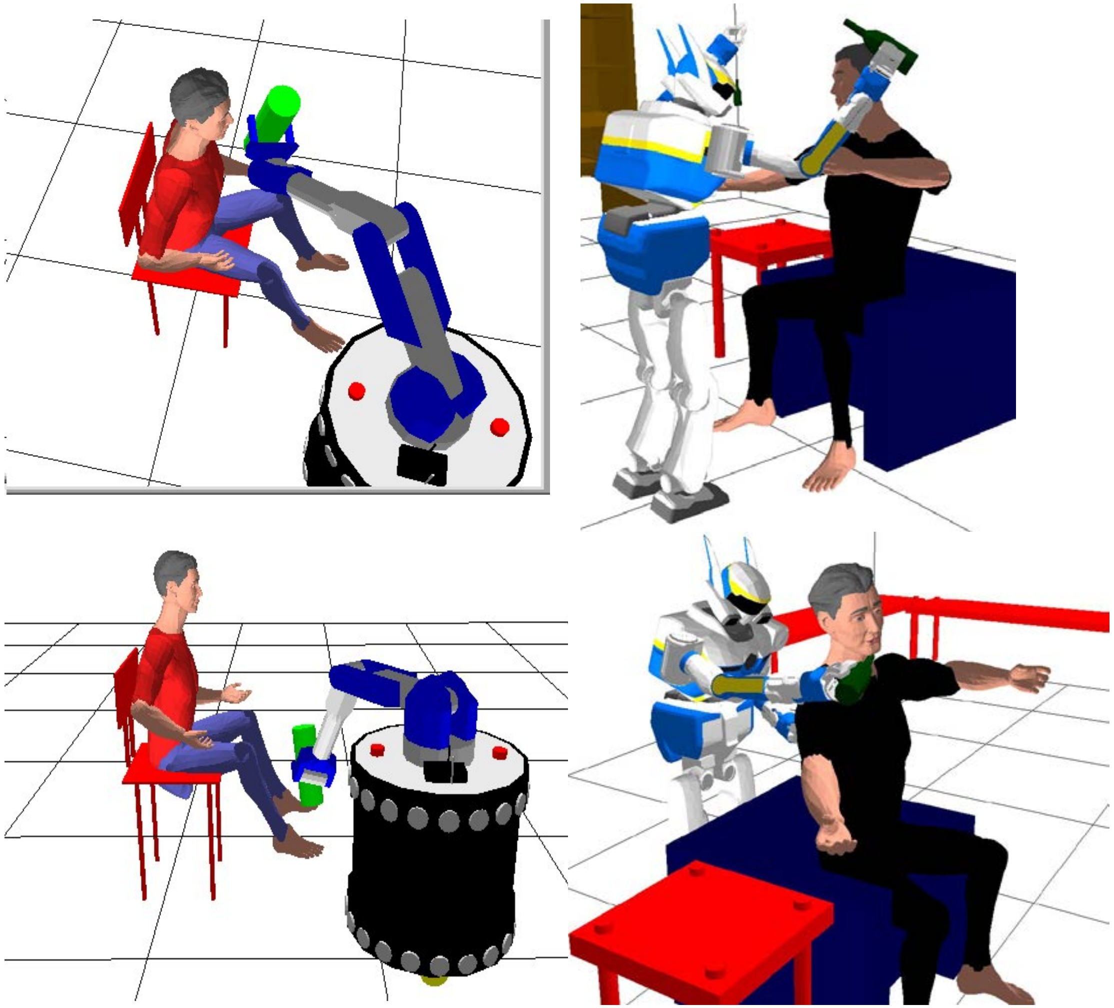
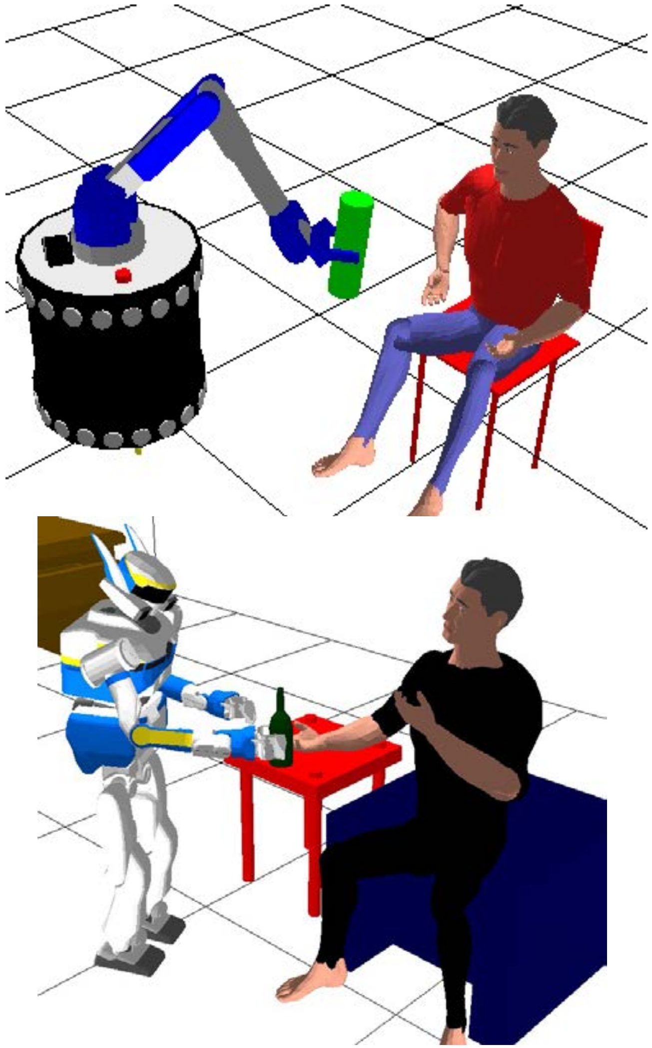
How to hand an object to a person?



Undesirable Placements /Motions

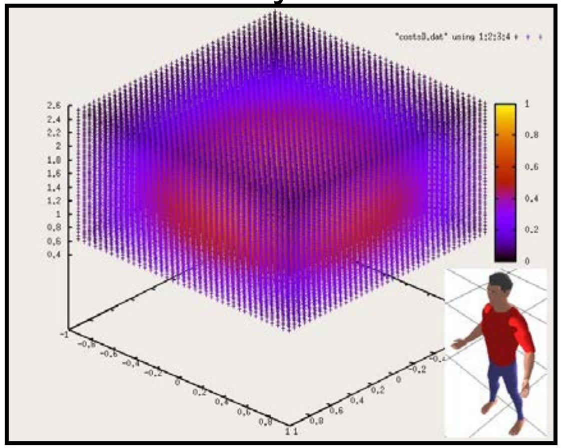


"acceptable" placements

Handing an object to person

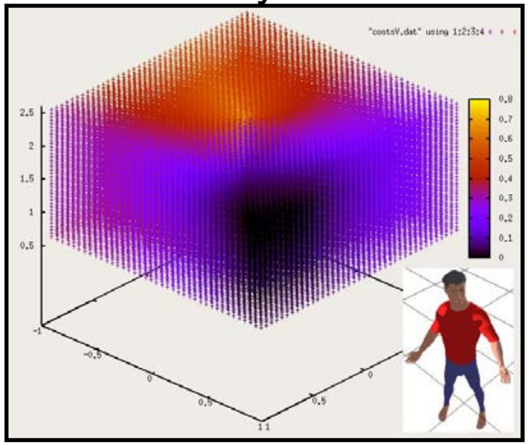
- The object should be placed in a safe and comfortable position.
- 3 different HRI properties are defined and represented as 3D cost grids around the human

Safety



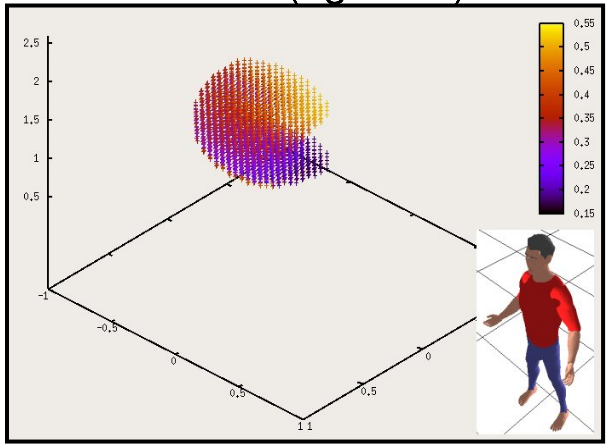
Proportional to the distance to human

Visibility



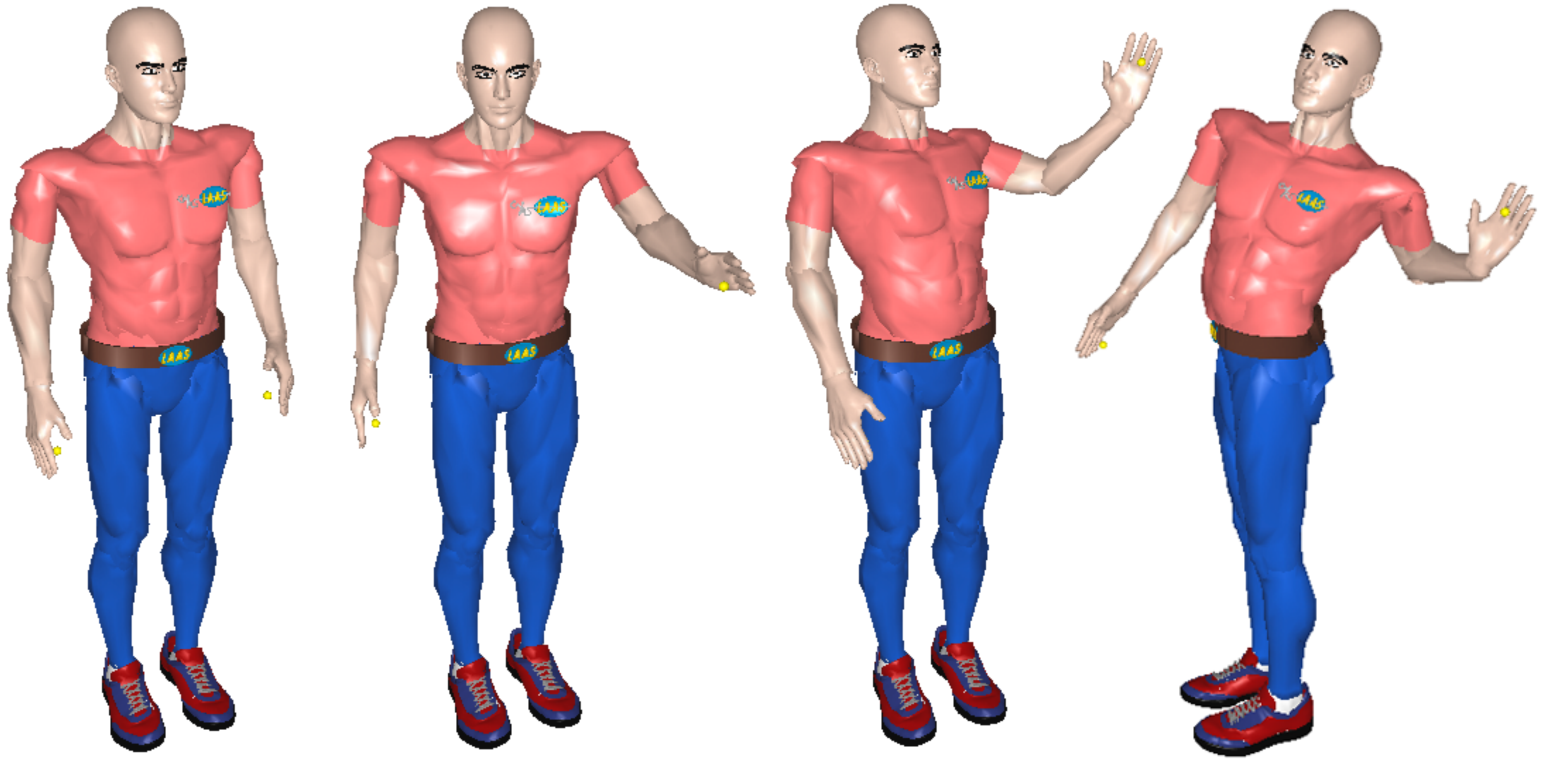
Reflects the effort to see a point

Arm Comfort(right/left)



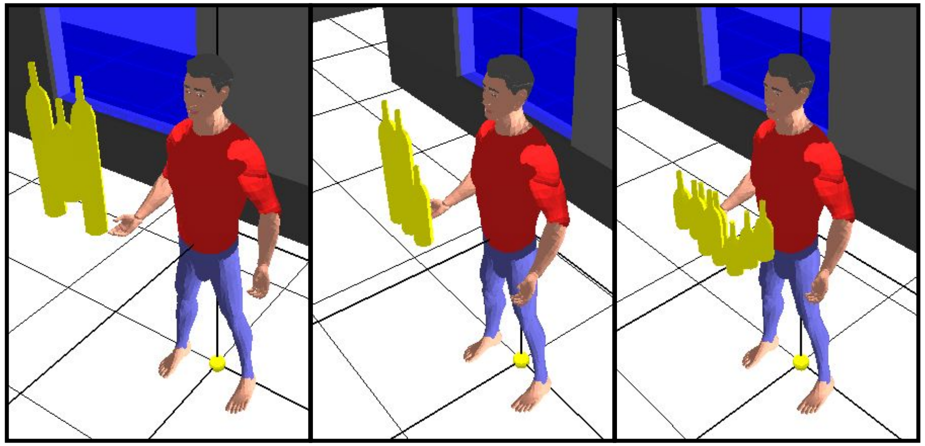
Combination of d.o.f difference and potential energy

The comfort criteria

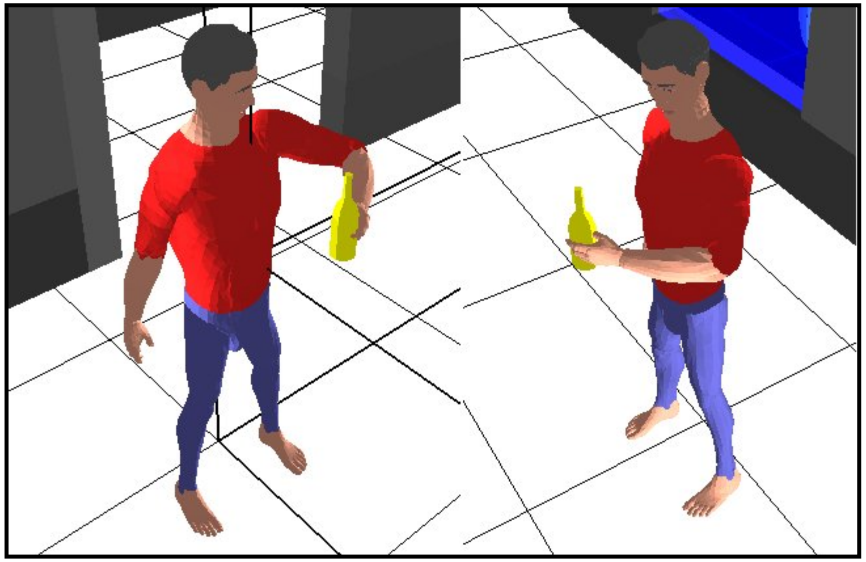


Calculating object transfer position

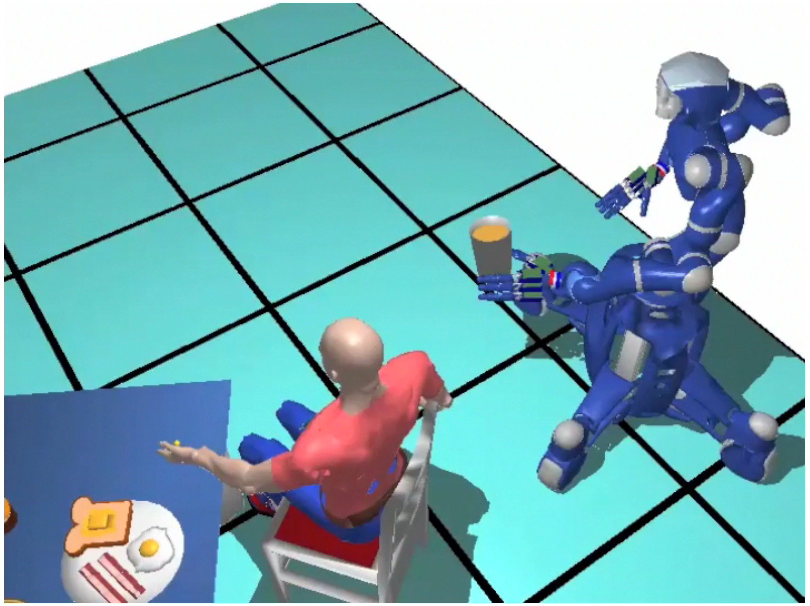
- 3 grids are combined to form a final grid that merges all these properties.
- The cell with minimum cost is chosen to be the place where robot will place the object.

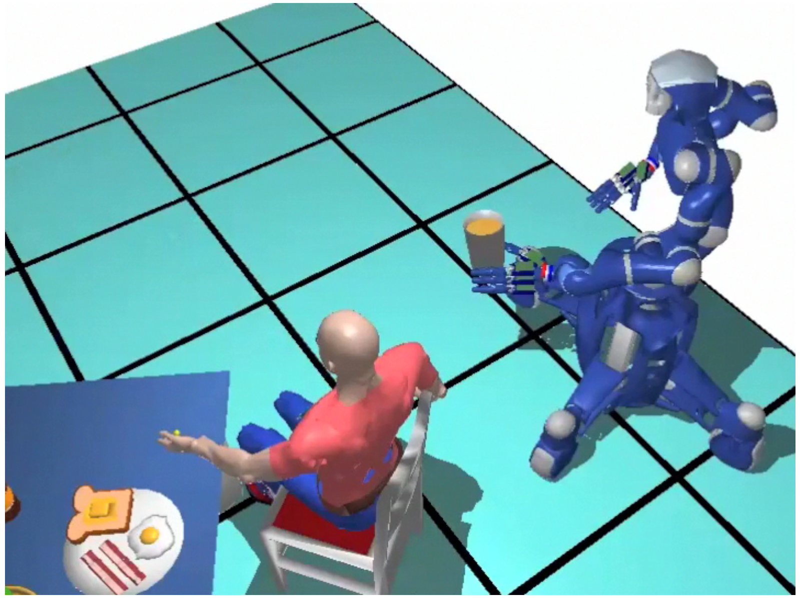


Dist > Vis >AC   Vis > Dis > AC   AC > Vis > Dis



Intrusive Better





E.A.Sisbot , L. F.Marin Urias , R.Alami , T.Simeon "A human aware mobile robot motion planner" ,
IEEE Transactions on robotics, Vol.23,N°5, 2007

4 – Managing Commitment in Joint task achievement: Shary

SHARY
Supervisor for Human Aware Robot « Ynteraction »

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- Continuous planning: Context dependent task refinement
- **Joint tasks achievment**
- Maintains common ground through **a set of communication acts that support the interactive task achievement**:
  - deciding when to speaks
  - establishing facts that must be agreed upon ..
  - dealing with signals produced by the human partner
- **Monitors human** performance and **commitment:**
  - "signals" exchanged between agents
  - Situation assessment
- Thesis of Aurélie Clodic (2007)

A robot guide that monitors commitment of its “customers”

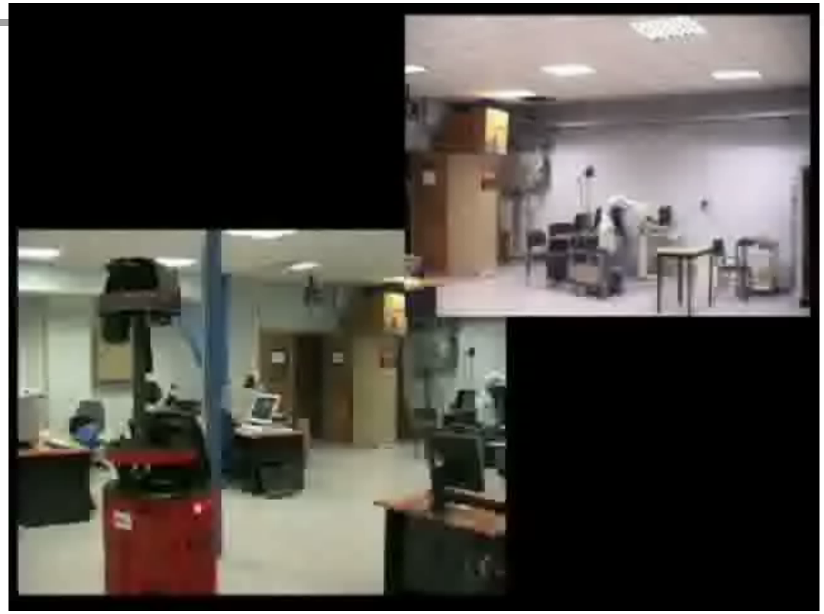
Robot Searches for interaction when left alone

Establishes a common task

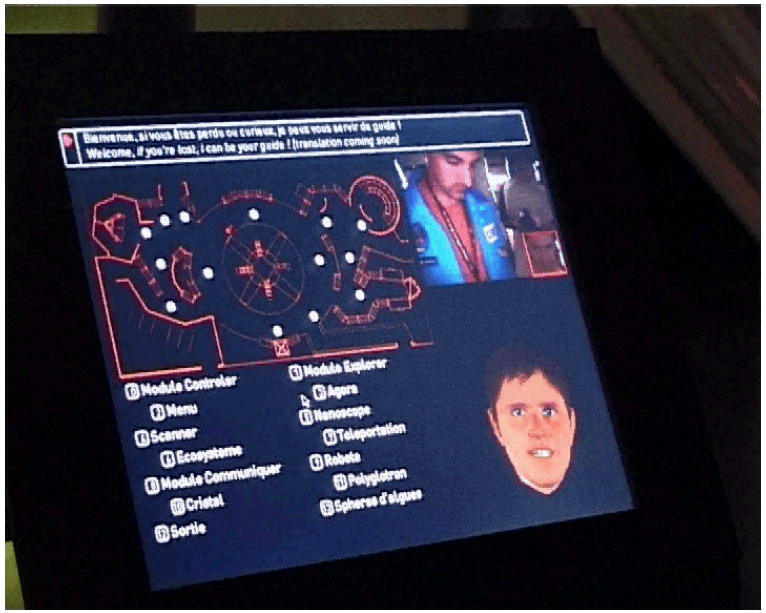
Programming a H/R task involving several perception and interaction modalities

Monitors (and even **tries to influence) human commitment** to the task

Abandons mission if guided person stops following



Rackham at « Cité de l’Espace »:



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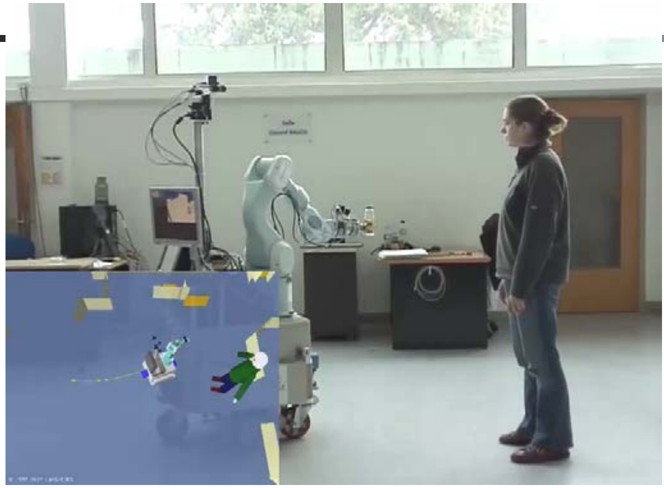
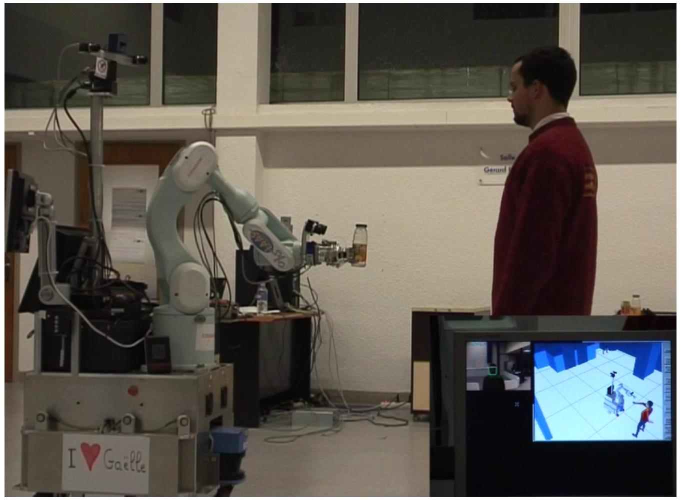
Handing an object to a person / various situations



Tout va bien

Where is Thierry ?

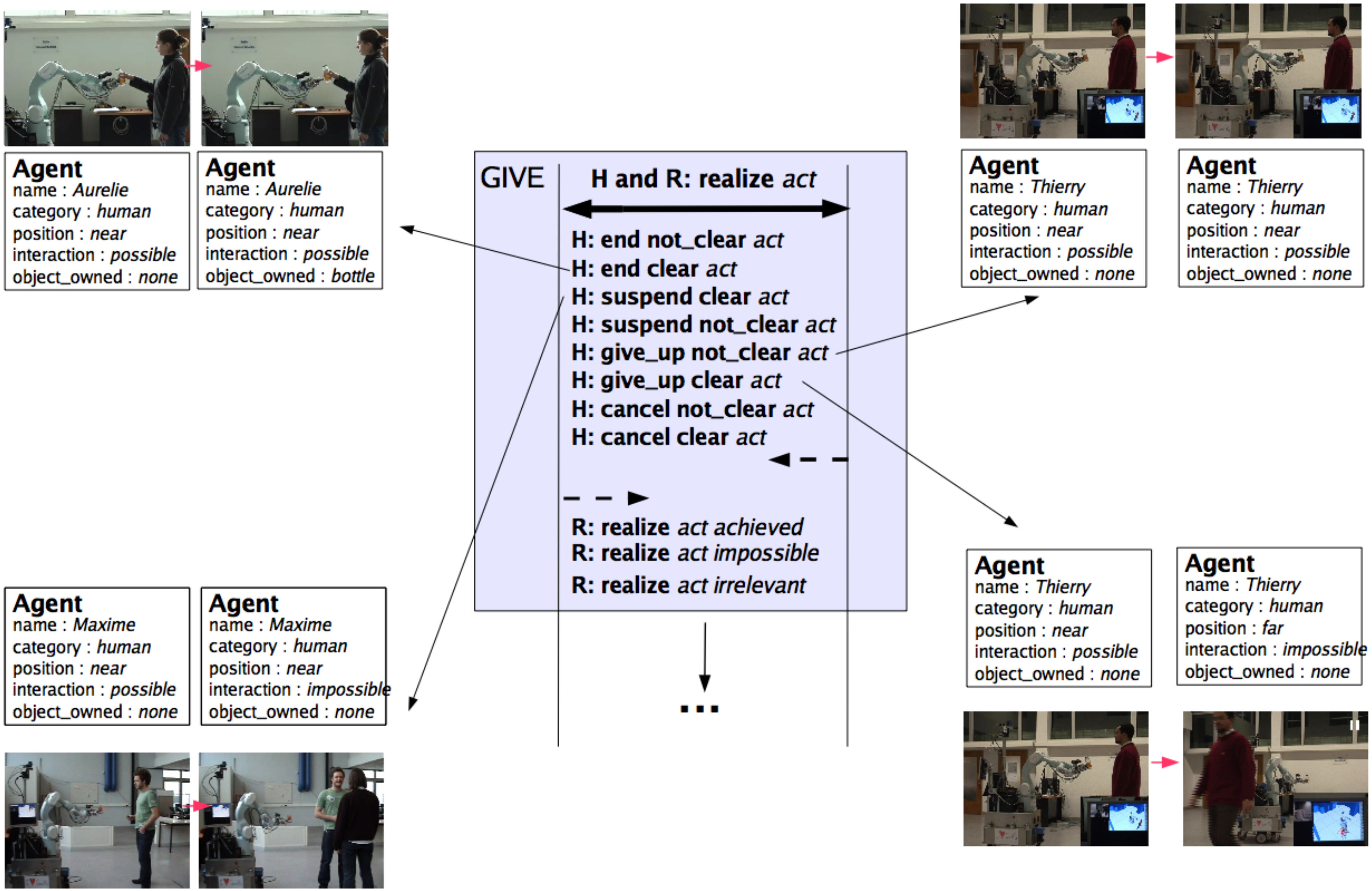


Thierry does not take the bottle

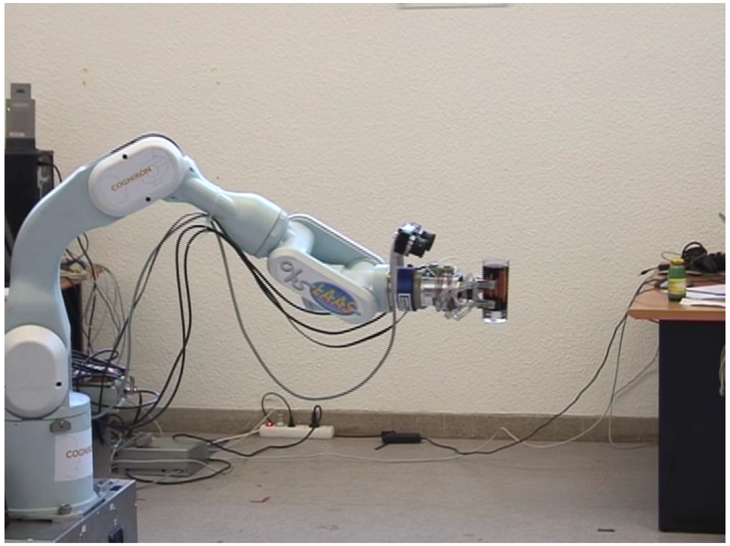
« Disturbed » attention

Handing a bottle to a person

Predictability, Common Ground, Responsiveness



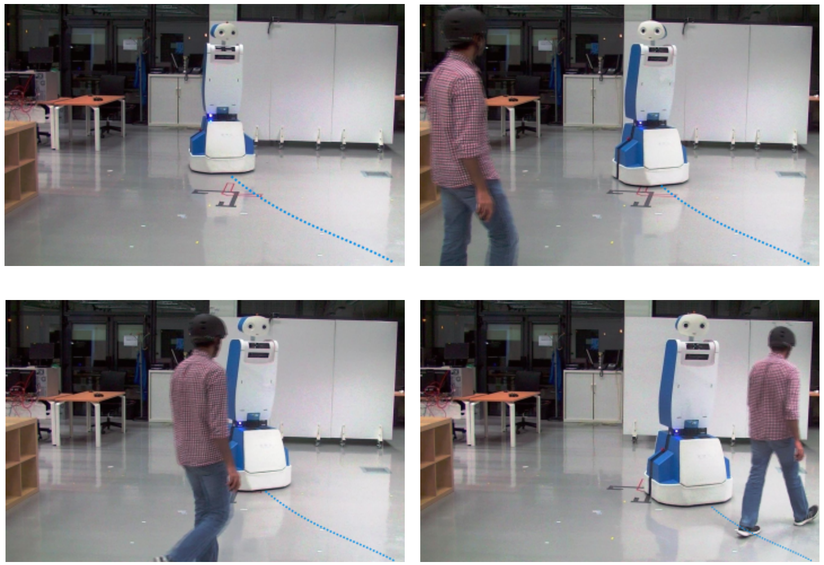
Cooperative action: When to release the object ?



Always leave the opportunity to the person to act.

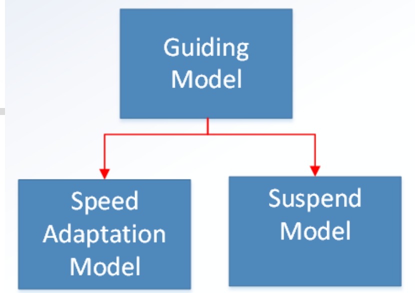
Making robot intent legible

- We have proposed a 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**



Submitted to IROS 2016: "Head-Body Motion Coordination for Human Aware Robot Navigation" Harmish KhambhaitaJorge Rios-Martinez, and Rachid Alami .

SPENCER: Task Planning and Control



- **Examples of Adaptive behaviors**:
  - The robot accelerates or decelerates based on an estimation of the group's intentions.
  - The robot cancels mission if guided human abandons.
- **Examples of Proactive Behaviors:**
  - The robot proposes a new speed based on task or environmental related stimulus.
  - The robot proactively tries to engage the group (e.g. by offering information) when it detects that the guiding task is momentarily suspended.

Implementation based on hierarchical Mixed Observability Markov Decision Models

Robot adaptive and proactive behaviour

« standard » robot guide behaviour

Robot adapts by slow walk

Robot adapts to person willing to walk faster

Proactive robot behaviour

M. Fiore, H. Khambhaita, G. Milliez R. Alami**, « An Adaptive and Proactive Human-Aware Robot Guide »**, ICSR-15

Theory of Mind to Improve Human-Robot Shared Plans Execution

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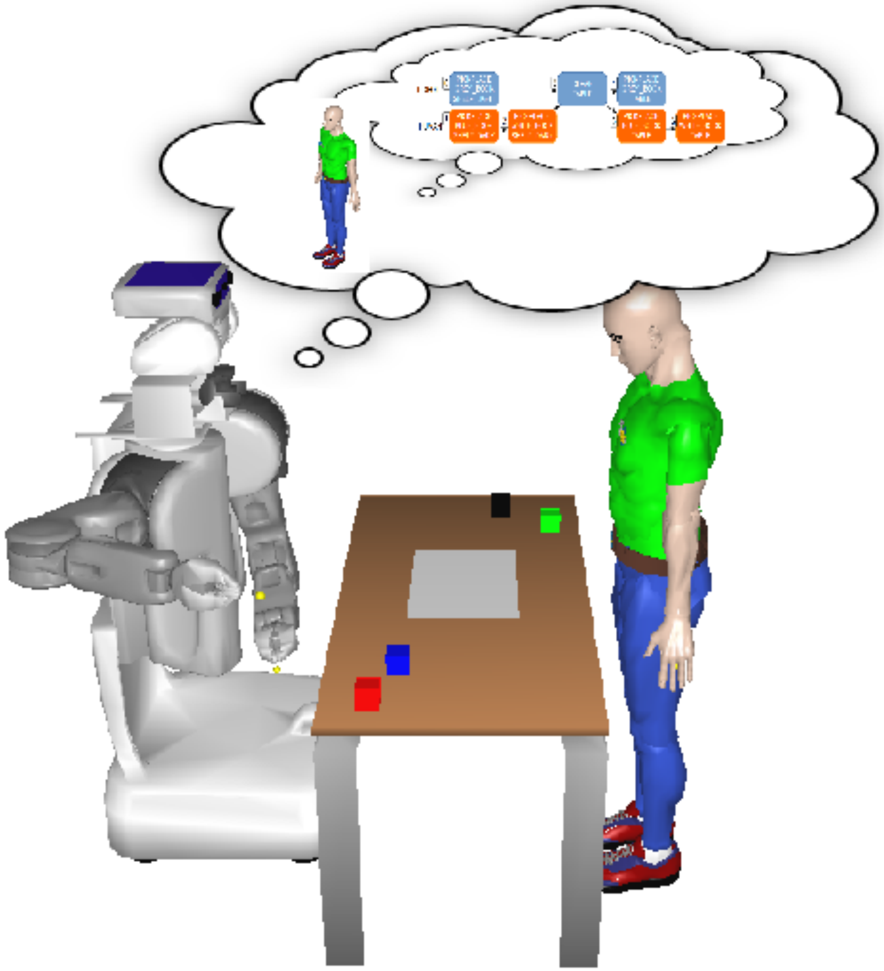
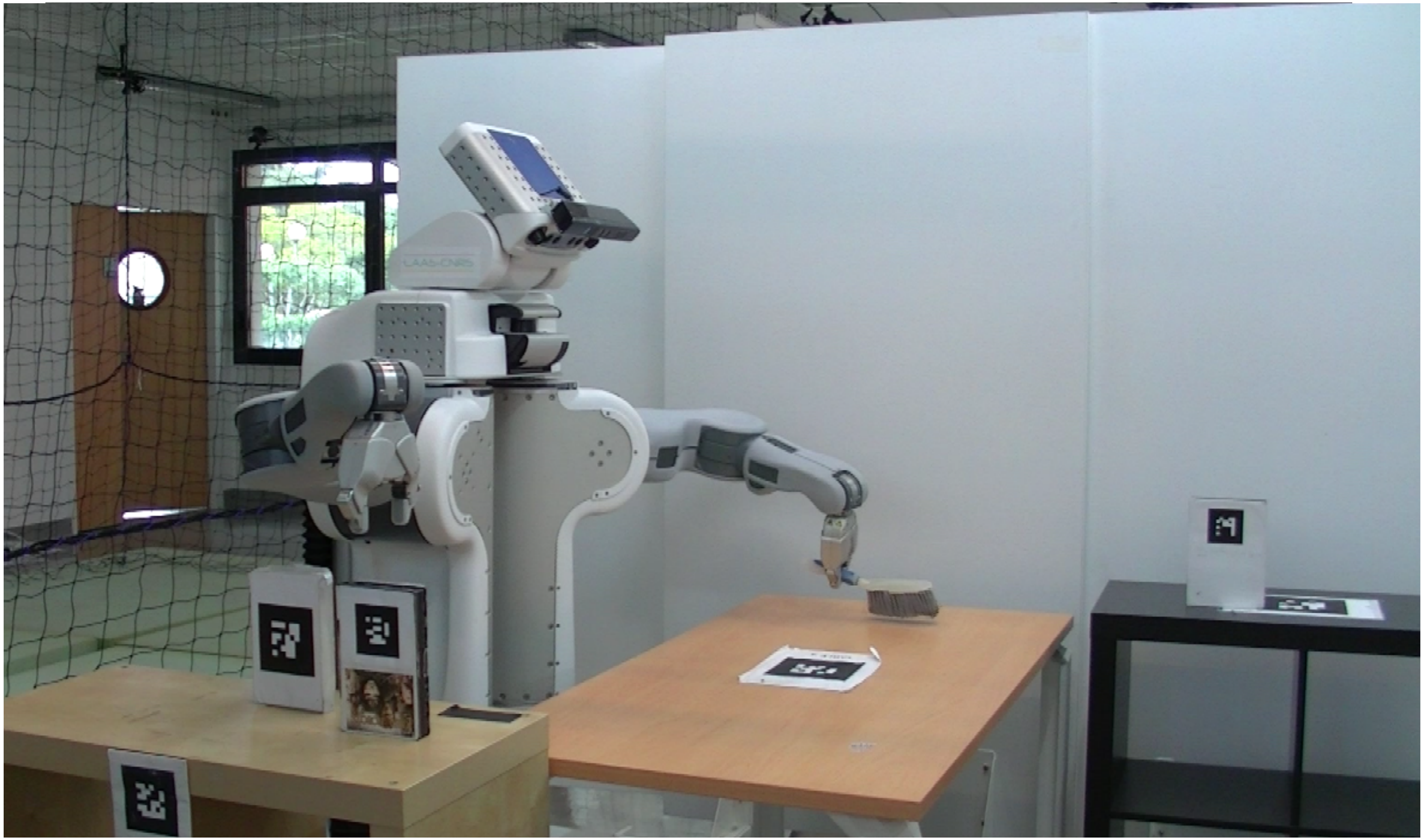
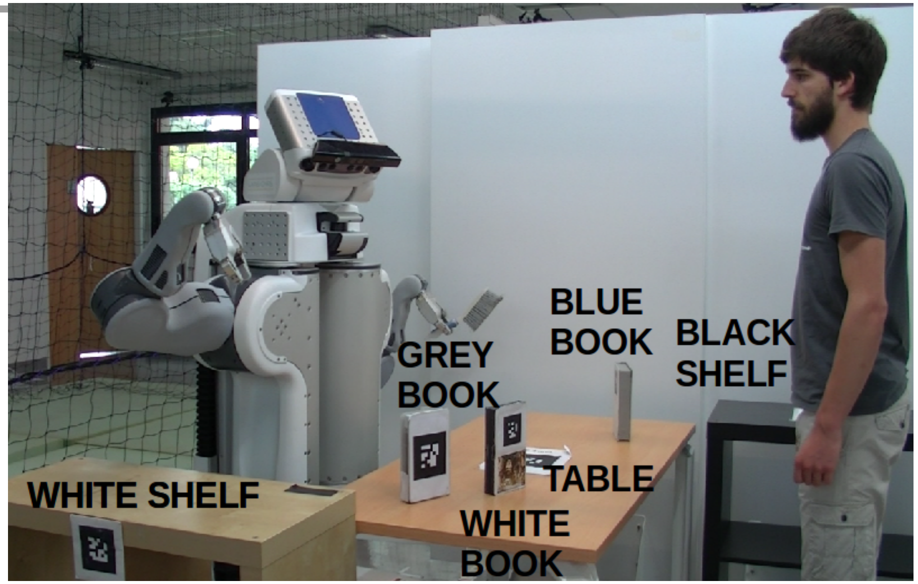
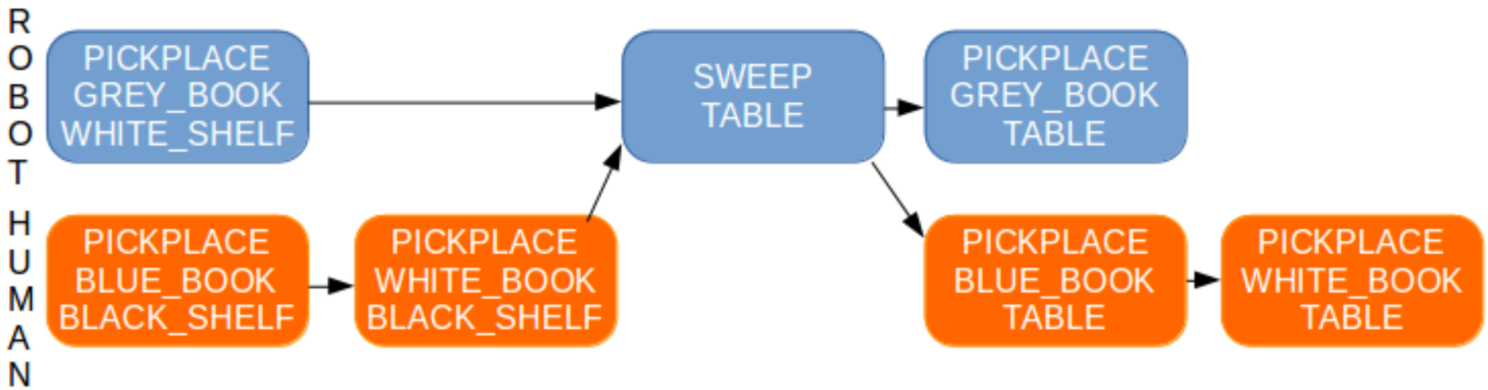


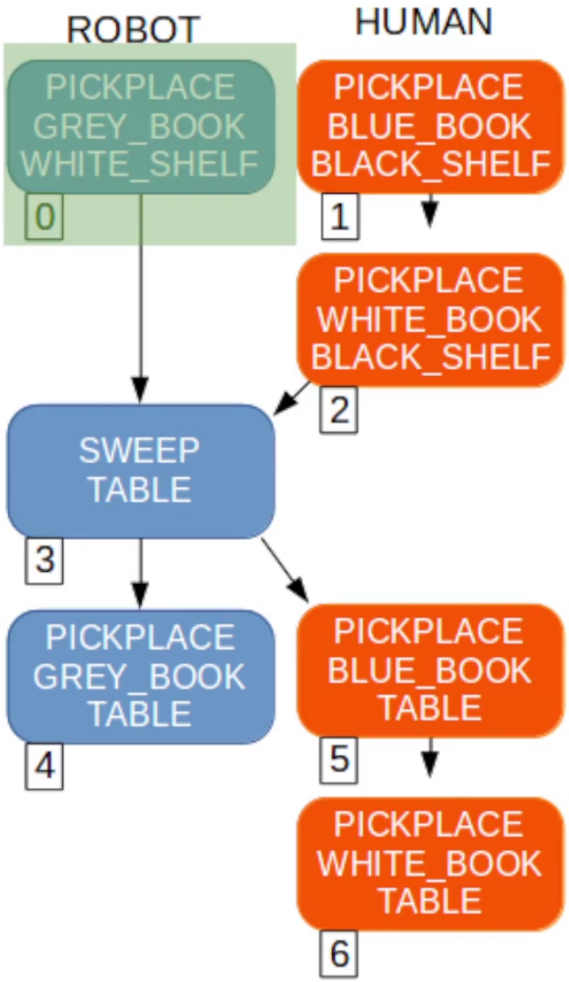
Sandra Devin - HRI16



✓ Already established shared plan



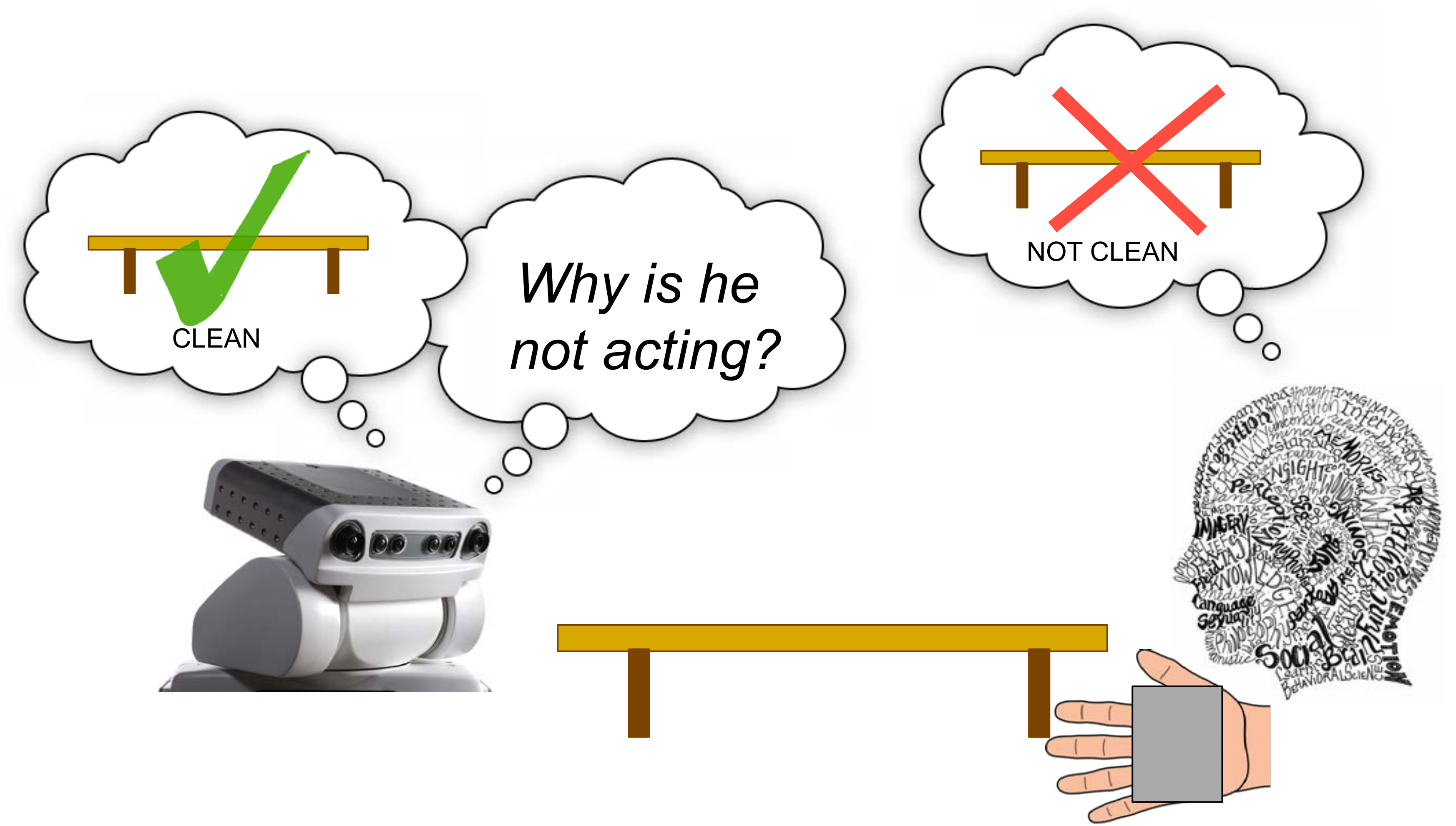




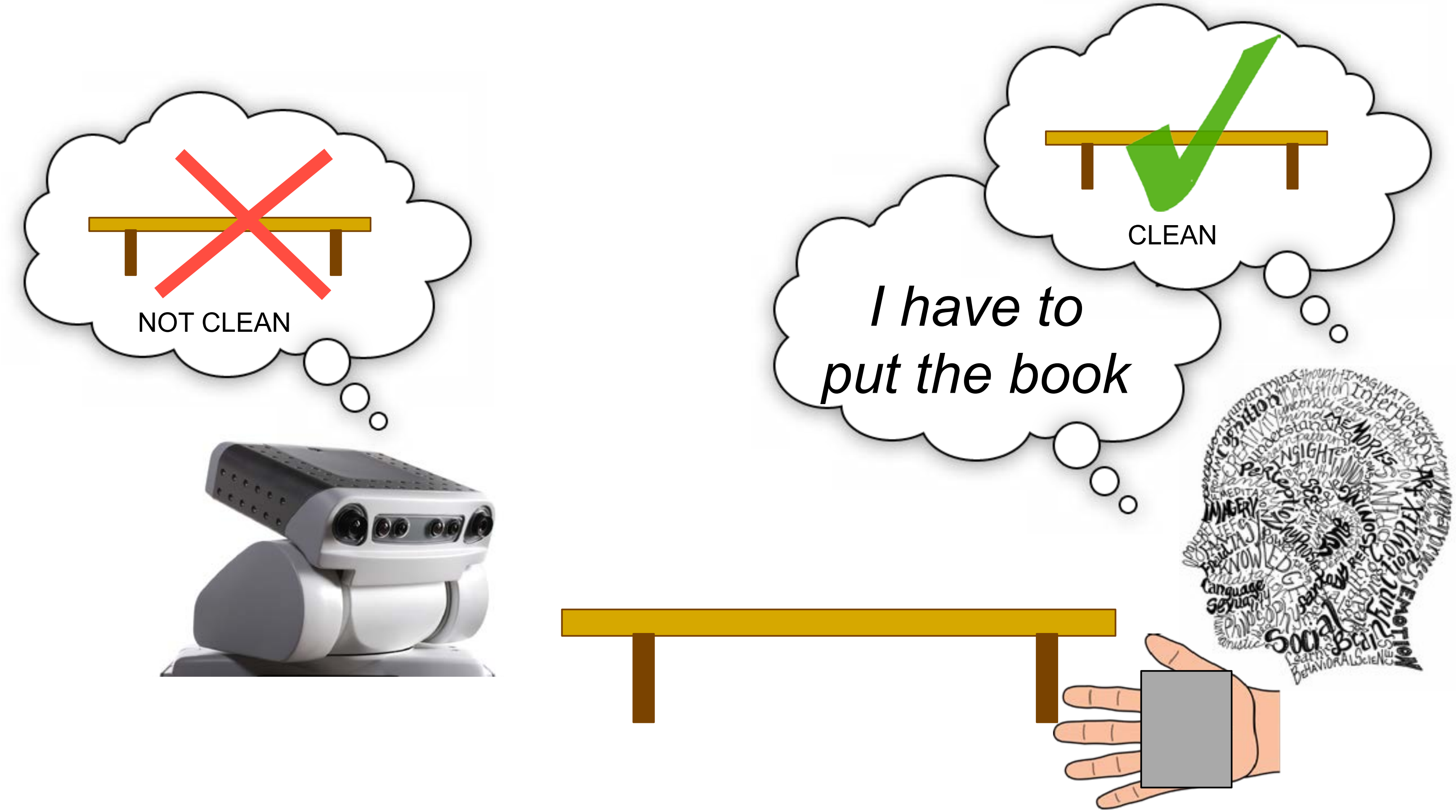
The robot starts to pick and place the GREY_BOOK

What should the robot do?

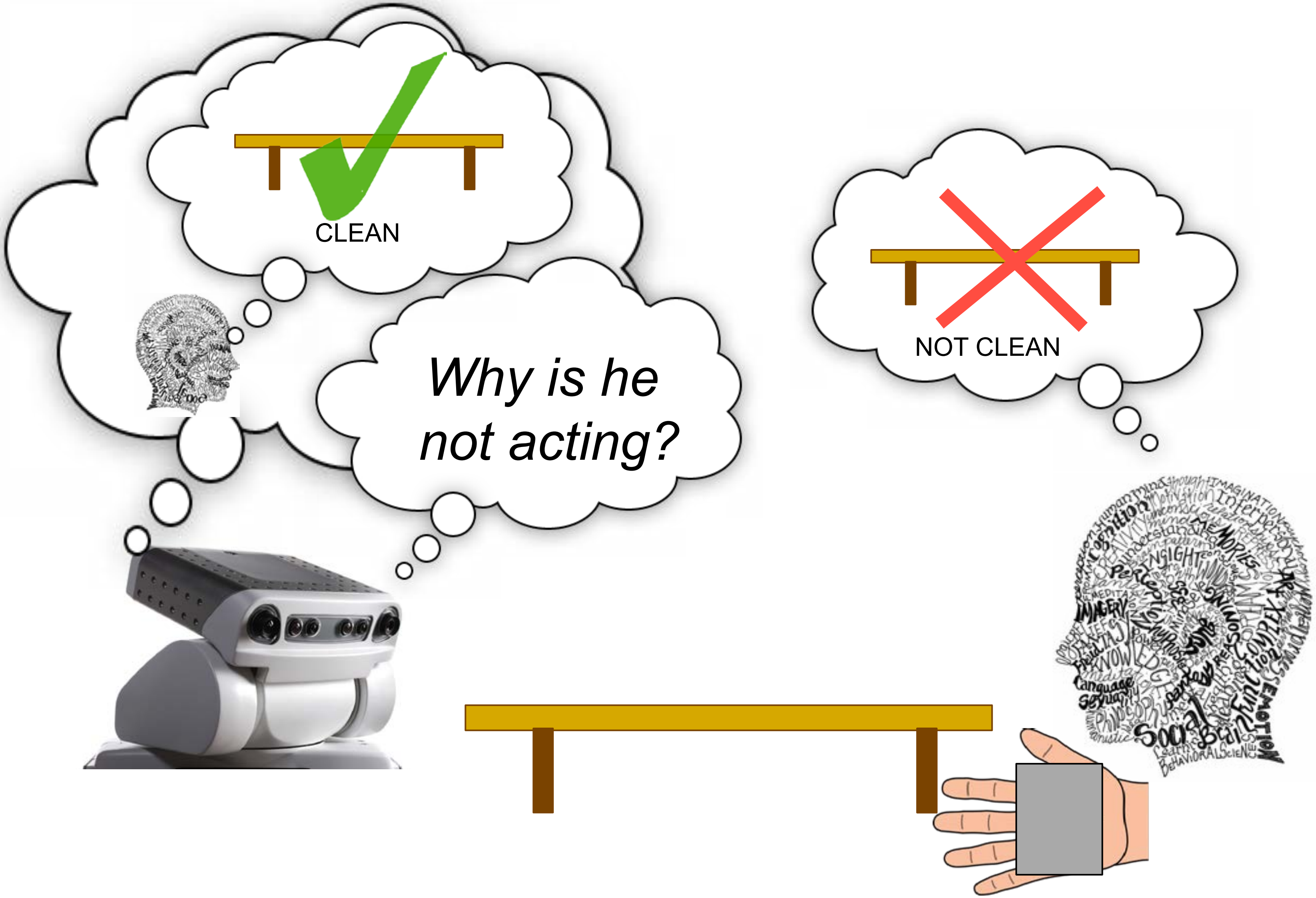
Before humans' actions

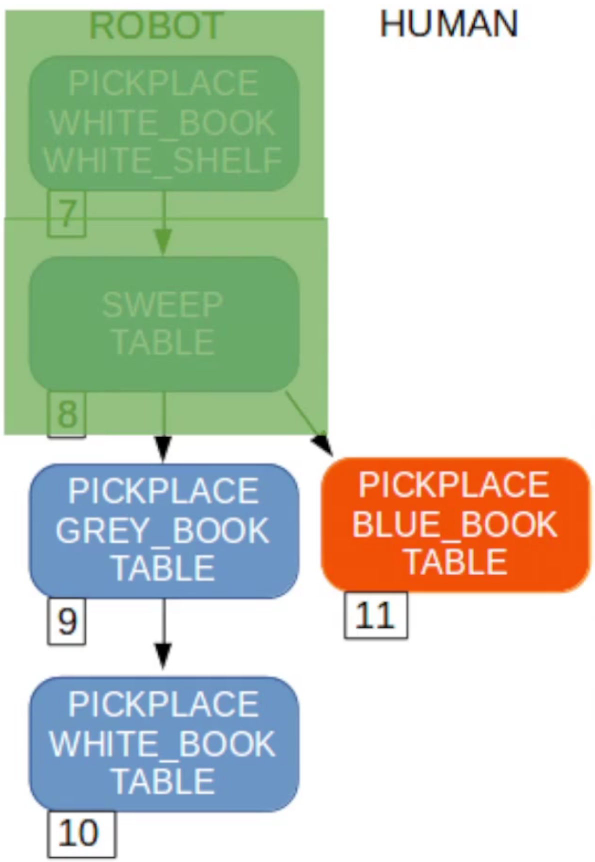


Preventing mistakes



Inaction and uncertainty





The human comes back

Conclusion

List of co-authors

LAAS-CNRS

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Development and articulation of some abilities involved in shared activity

LAAS-CNRS

- Architecture and decisional components for a robot to participate in collaborative activities with shared goals and intentions

- Robot « tries » to do its « share » in the process
  - Mutual responsiveness -- behavioral coordination
  - Elaboration of a shared plan to satisfy a shared goal
  - Commitment to the shared goal – mutual support
  - Consideration of Human needs and preferences (Human-aware behavior synthesis)

- **Specific, limited context:** fetch&carry, interactive manipulation and associated tasks

Planning - Decisional processes

- **Cost based search**
  - Proxemics
  - Visibility
  - Effort
- **Constraints**
  - Relative placements
  - Postures
  - Grasps
  - Reach
  - Mutual visibiilty
- **Properties that a plan should satisfy:**
  - Protocols
  - Standard / known procedures
  - Interaction modalities, social signals
  - Rhythms
  - « social » rules
  - Compliance to social norms
- **Criterias**
  - Comfort
  - Acceptability
  - Legibility
  - Intentionality
  - Predictability
  - Robustness
  - Efficiency
  - Time

But still …

- Besides advances in general robot capabilities …

- We need far more refined models, based on solid grounds, and evaluated in realistic situations

Thanks... Questions ?