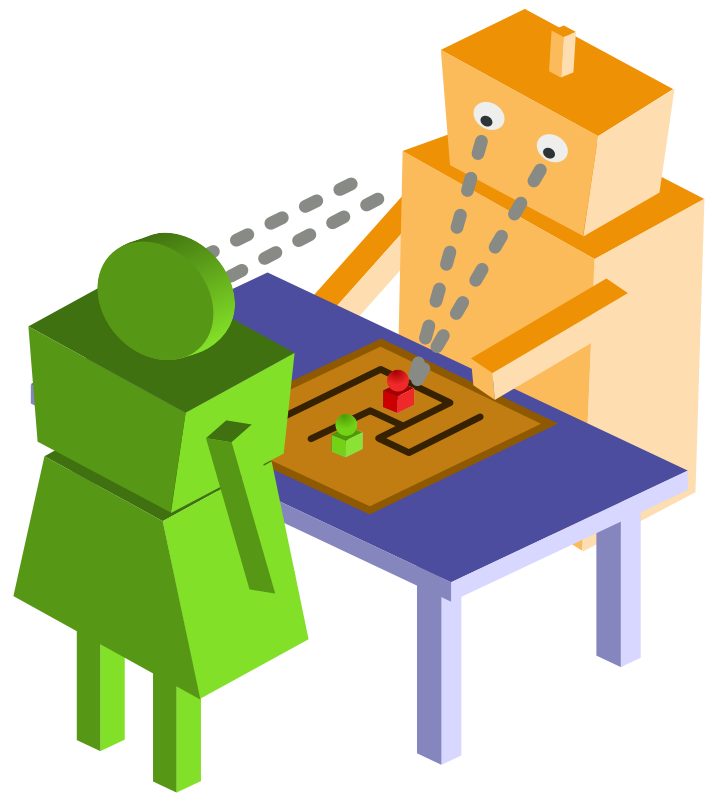
WITH PLYMOUTH UNIVERSITY

MARIE CURIE ACTIONS

Of Cognition and Social Robots

towards a theory of artificial social cognition

Plymouth University – **14 February 2017**



Séverin Lemaignan

Centre for Robotics and Neural Systems
Plymouth University

MARIE CURIE ACTIONS

ACADEMIC CURRICULUM OVERVIEW

- Joint French (ParisTech) German (Karlsruhe Institute of Technology) MSc in mechanical engineering

  top ten student out of 1000

- MSc in AI for Learning technologies (University Paris 5)

  top student of the year

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  Best 2012 CNRS PhD in Robotics
  High Distinction in Germany

2013: post-doc at **EPFL**, establishing there a new leading group in Child-Robot interaction

2015: **EU Marie Skłodowska-Curie fellow** at Plymouth University on **social cognition for robots**

TEACHING EXPERIENCE

- Formal teaching position during PhD
  - java, prolog, ontologies, ada, databases
- Guest lectures at undergraduate & postgraduate level
  - ROS, GIT, Python for robotics, robotic simulation, 3D modelling…
- Autumn term 2016: ***Lecturer at Plymouth University***
  - ROCO318 – Mobile and Humanoid Mobile Robots

TEACHING EXPERIENCE

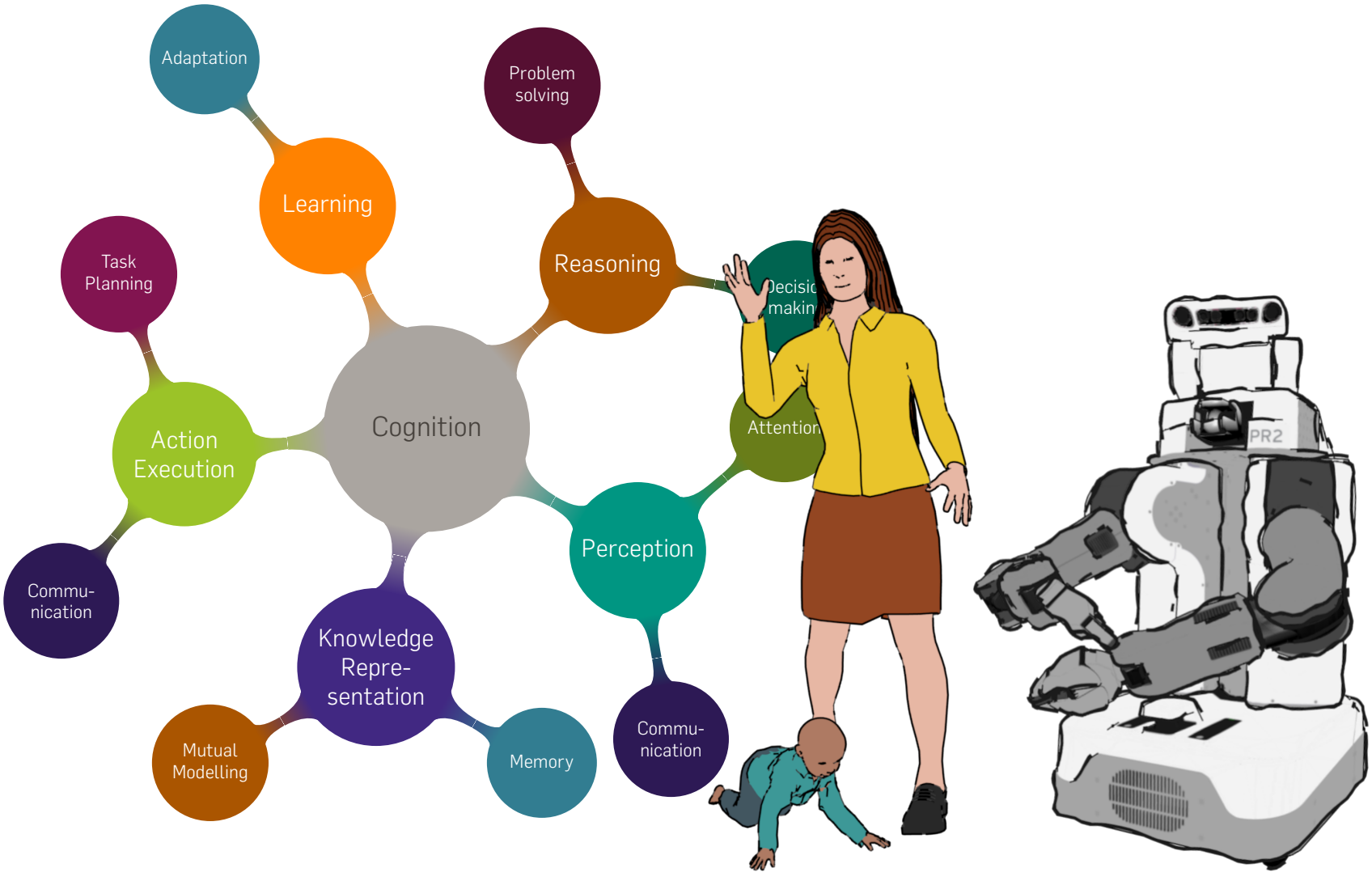
Strong track record in “core” computer sciences

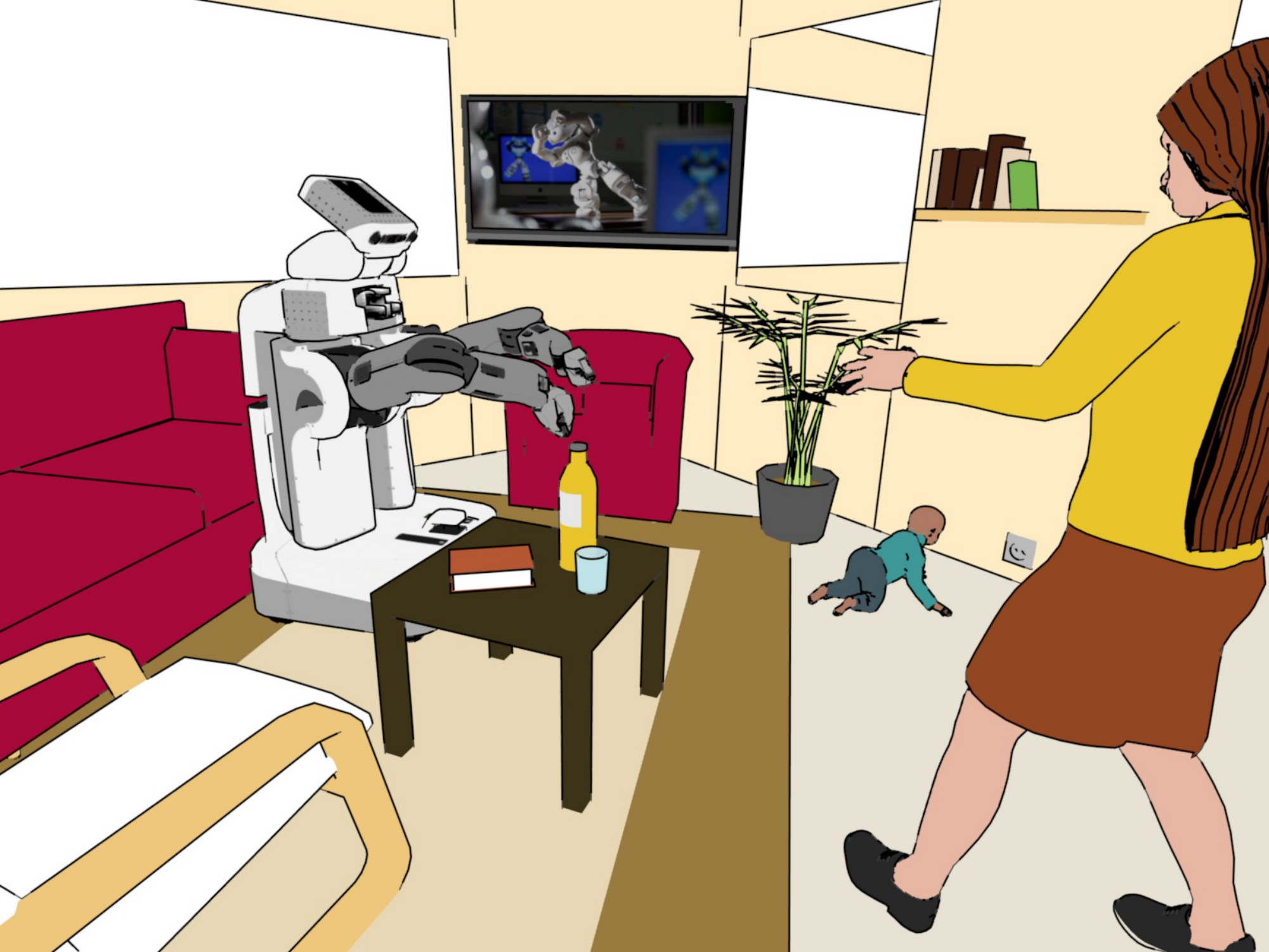
- algorithms & data structures
- advanced C++ (C++11, STL, meta-programming)
- advanced Python (meta-programming)
- logic programming (Prolog, ontologies)
- distributed systems (middlewares)
- software engineering (GIT expertise, coding best practises)
- computer vision & 3D rendering (OpenGL)

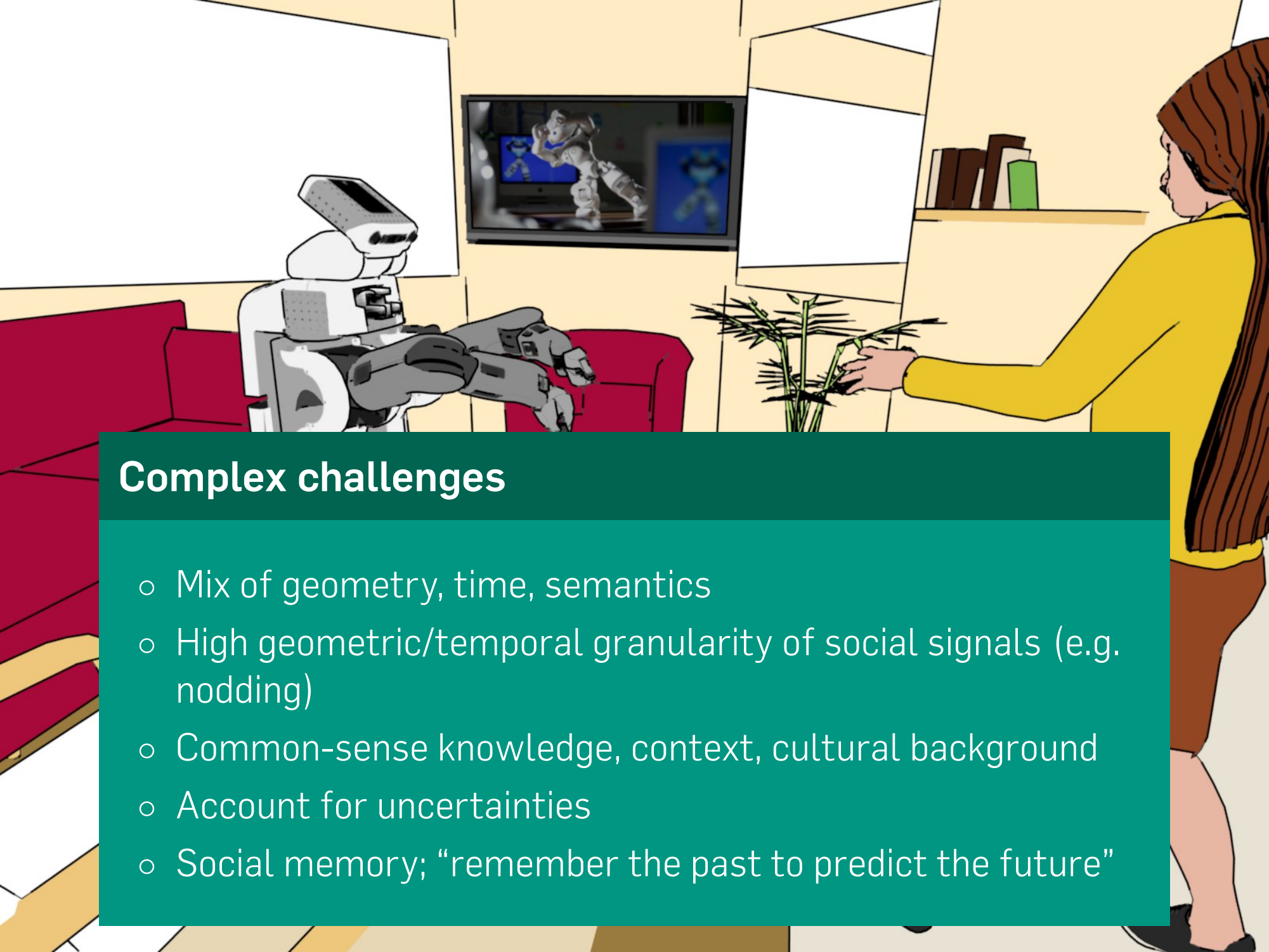
\+ **robotics**!

120+ open-source repositories on GitHub; contributor to major open-source projects like ROS, OpenCV

RESEARCH BACKGROUND: SYMBOLIC SOCIAL COGNITION


Adaptation
Learning
Problem solving
Reasoning
Task Planning
Action Execution
Cognition
Attention
Perception
Commu-nication
Knowledge Repre-sentation
Mutual Modelling
Memory
Commu-nication
PR2





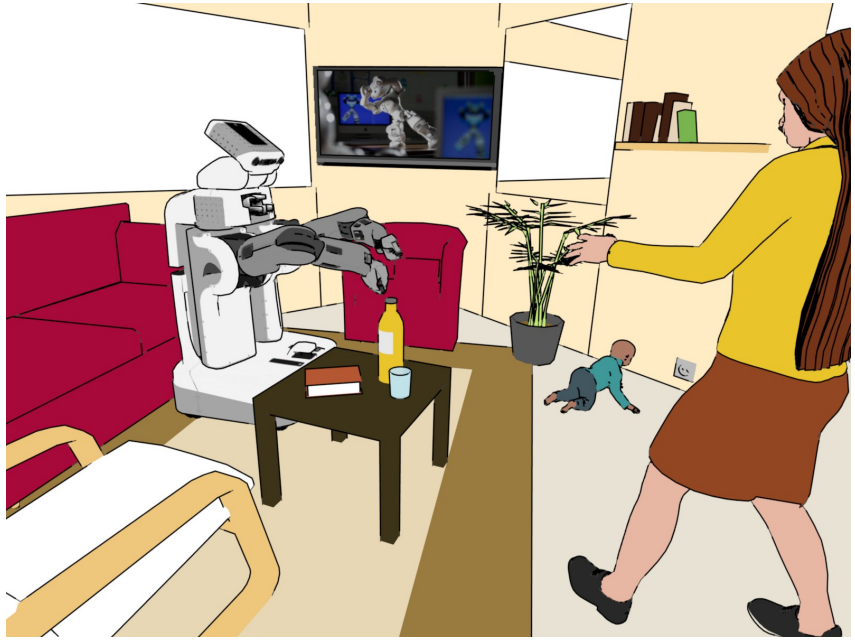
Complex challenges

- Mix of geometry, time, semantics
- High geometric/temporal granularity of social signals (e.g. nodding)
- Common-sense knowledge, context, cultural background
- Account for uncertainties
- Social memory; “remember the past to predict the future”

Situated dialogue effectively evidences these challenges

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

“Can you give me that book?”



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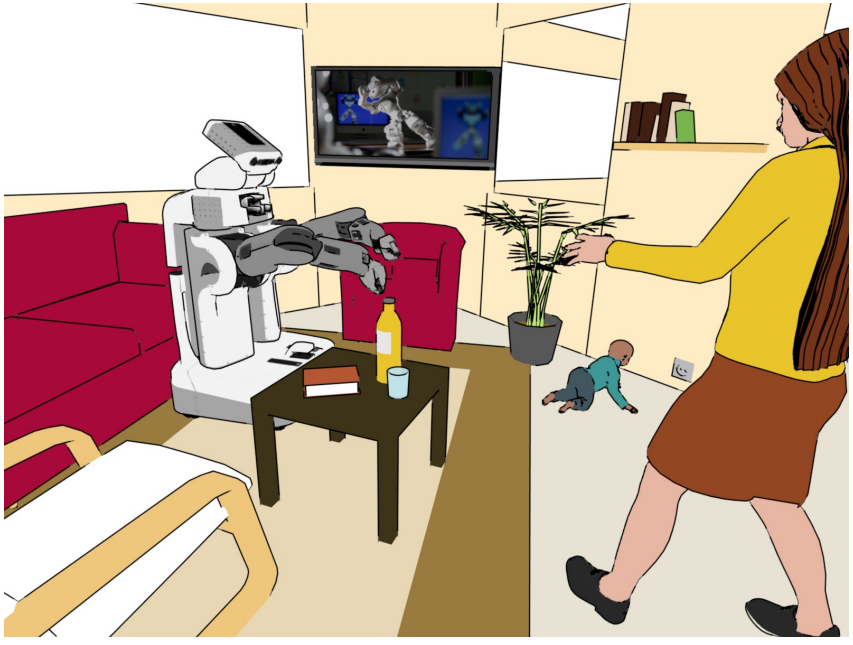
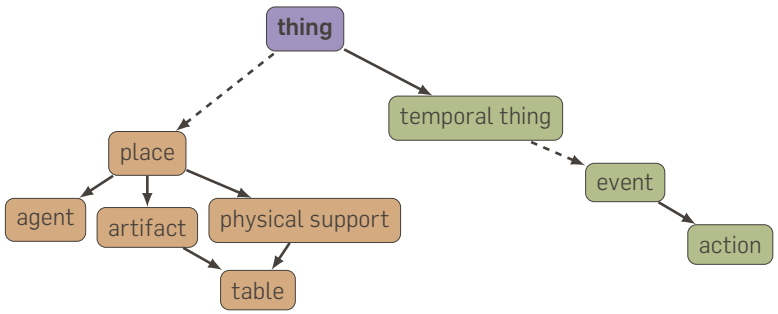


My PhD: a symbolic approach to this problem

SYMBOLIC SITUATION ASSESSMENT



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

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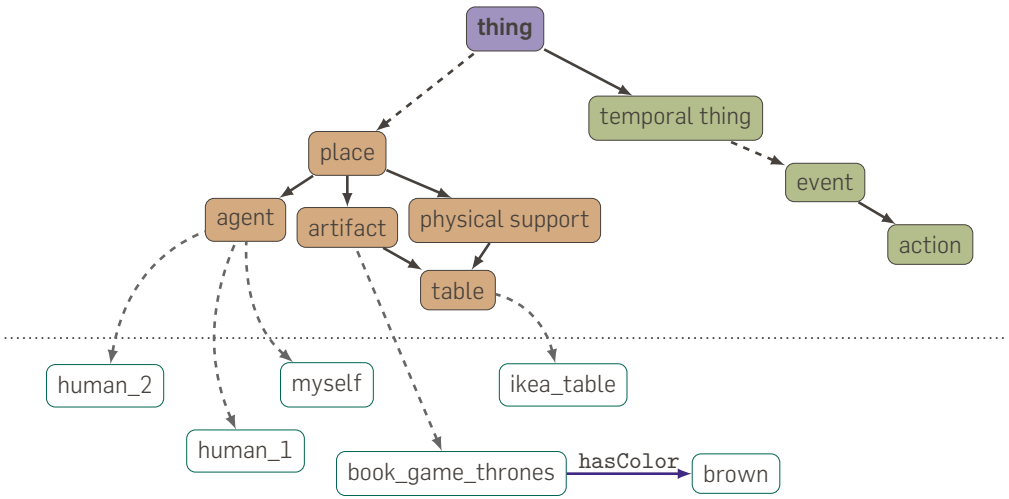

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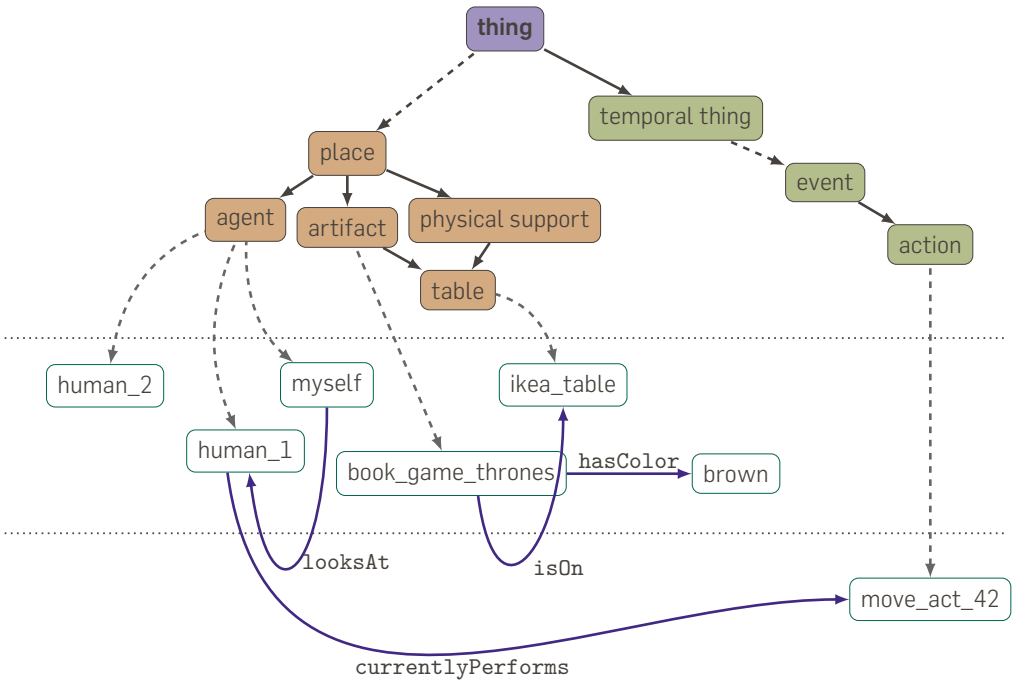

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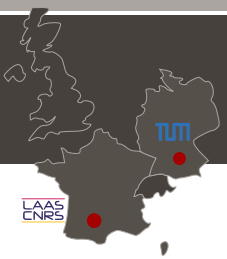
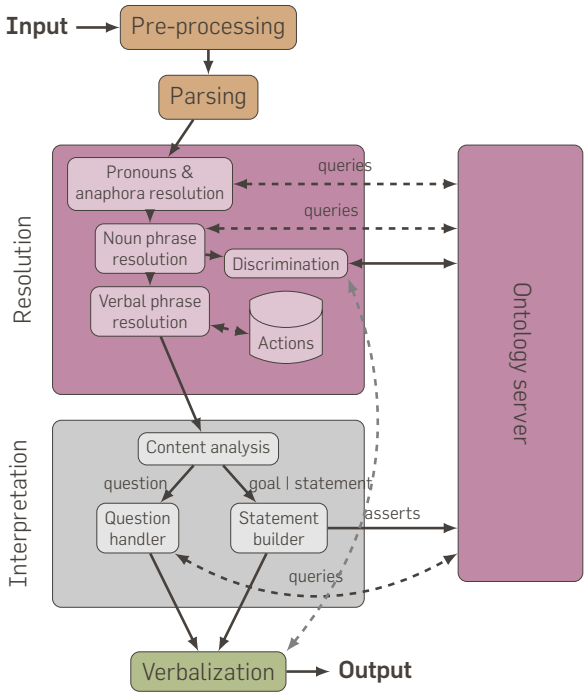
DIALOGUE GROUNDING



I keep the NLP details for the questions, but:

“Give me the book on the table”



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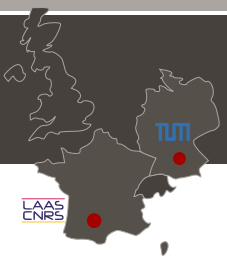

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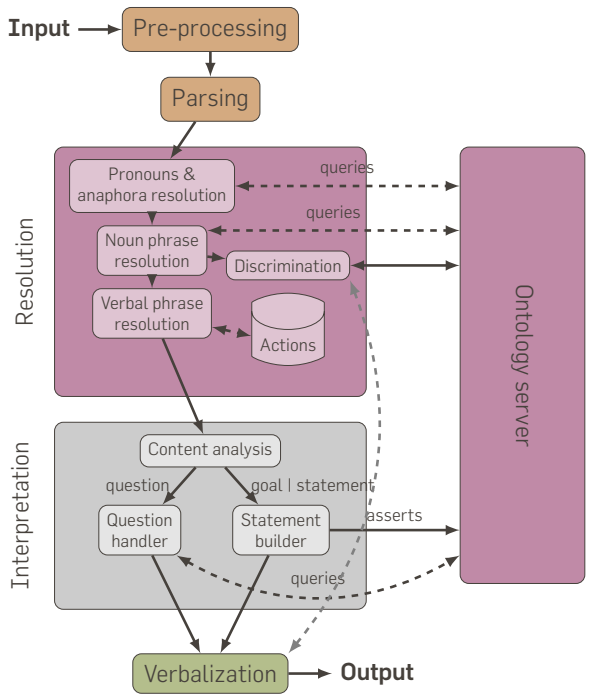
“Give me the book on the table”

↓

`me` → `human_1`

find(`?obj type table`) → `ikea_table`

find(`?obj type book, ?obj isOn ikea_table`) → `book_game_thrones`



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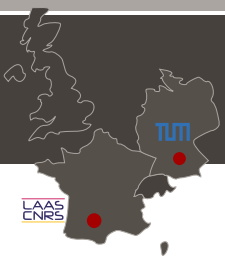

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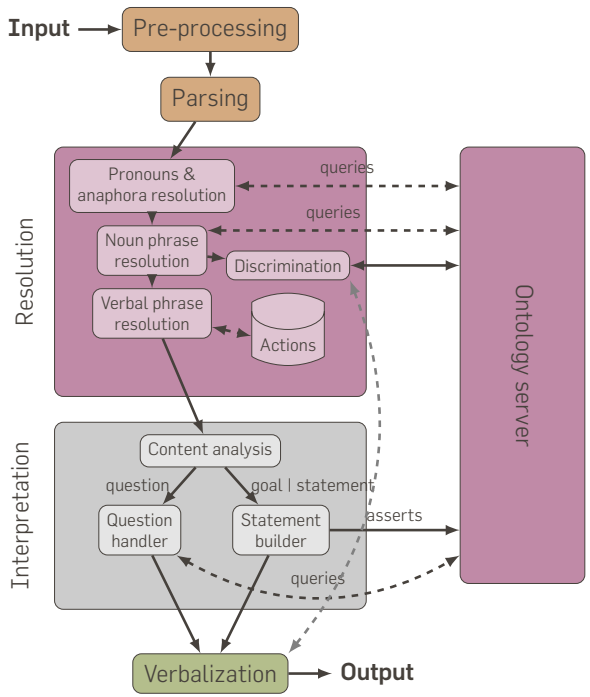
↓

```
human_1 desires give_act_1,
give_act_1 type Give,
give_act_1 performedBy myself,
give_act_1 actsOnObject book,
give_act_1 receivedBy human_1
```



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

MULTI-MODAL INTERACTION

What about
“Give me that book”?
(or even: **“Give me that!”**)

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


LAAS-CNRS

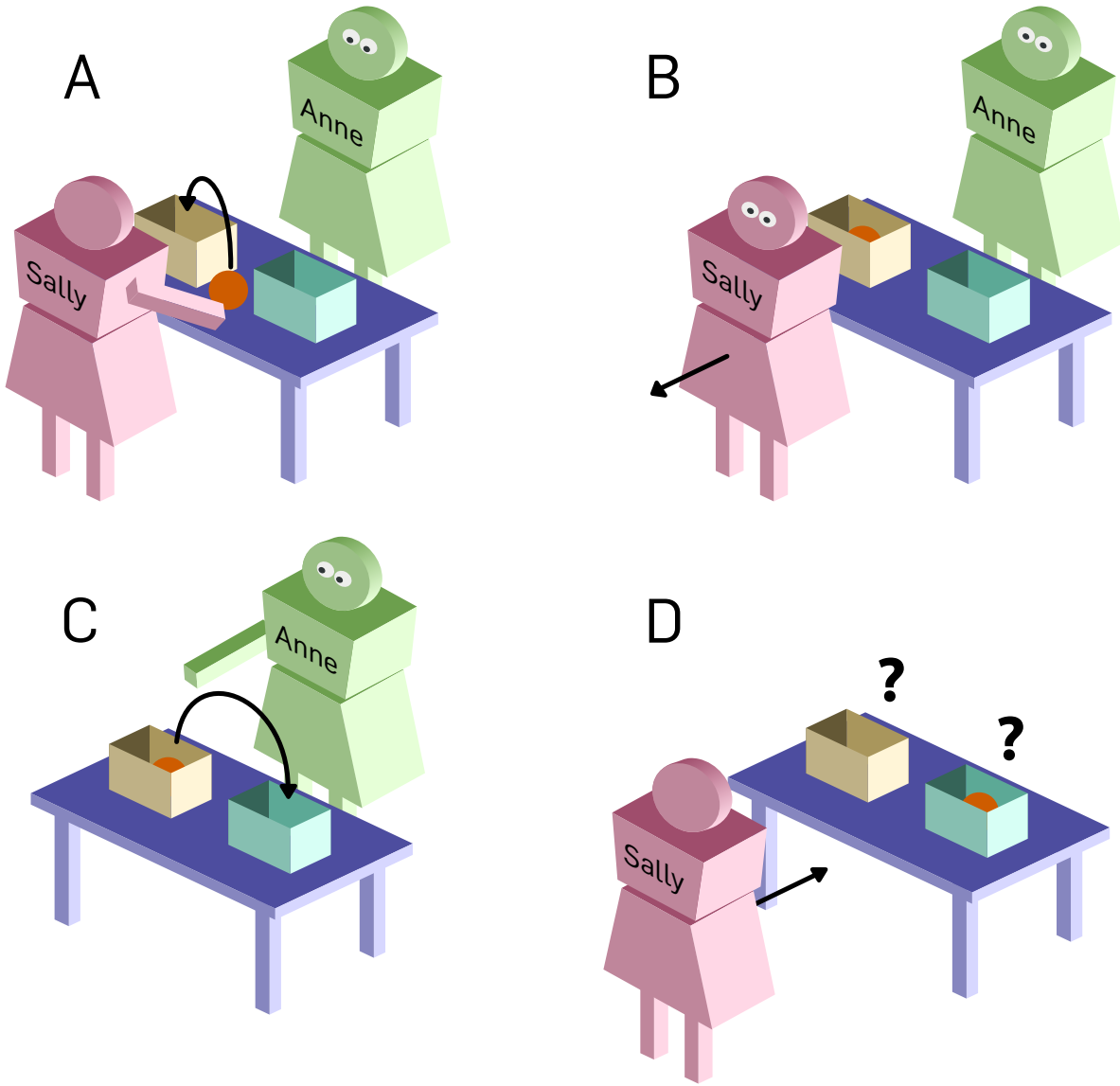
ONE STEP FURTHER: THEORY OF MIND

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

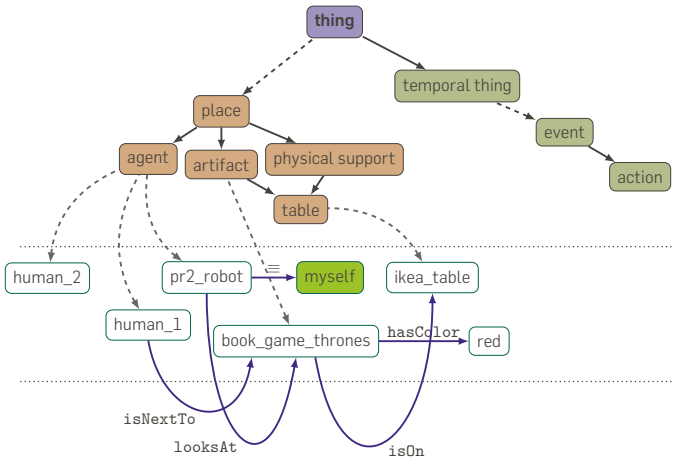
What if I ask for the video tape in the box, but the robot previously moved it somewhere else?

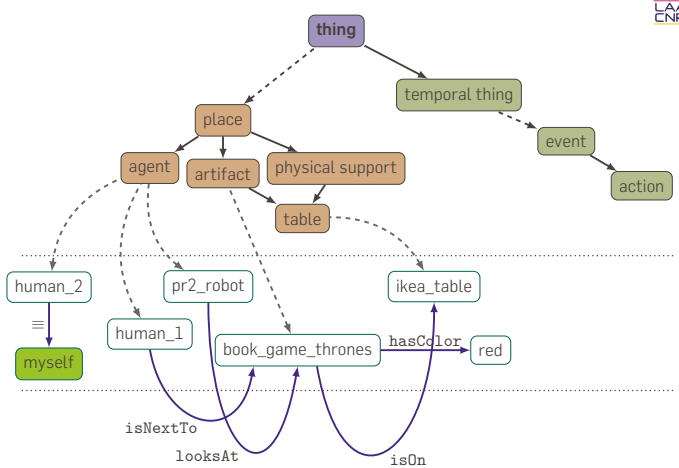
False-belief situation

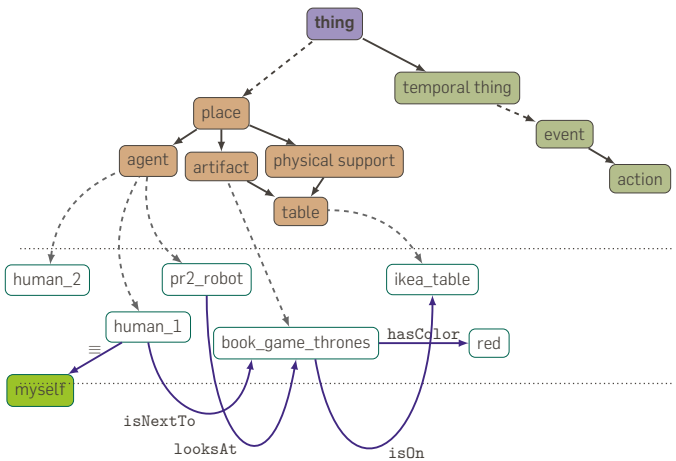
THE FALSE-BELIEF EXPERIMENT



MULTIPLE SYMBOLIC MODELS







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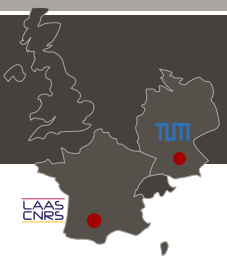
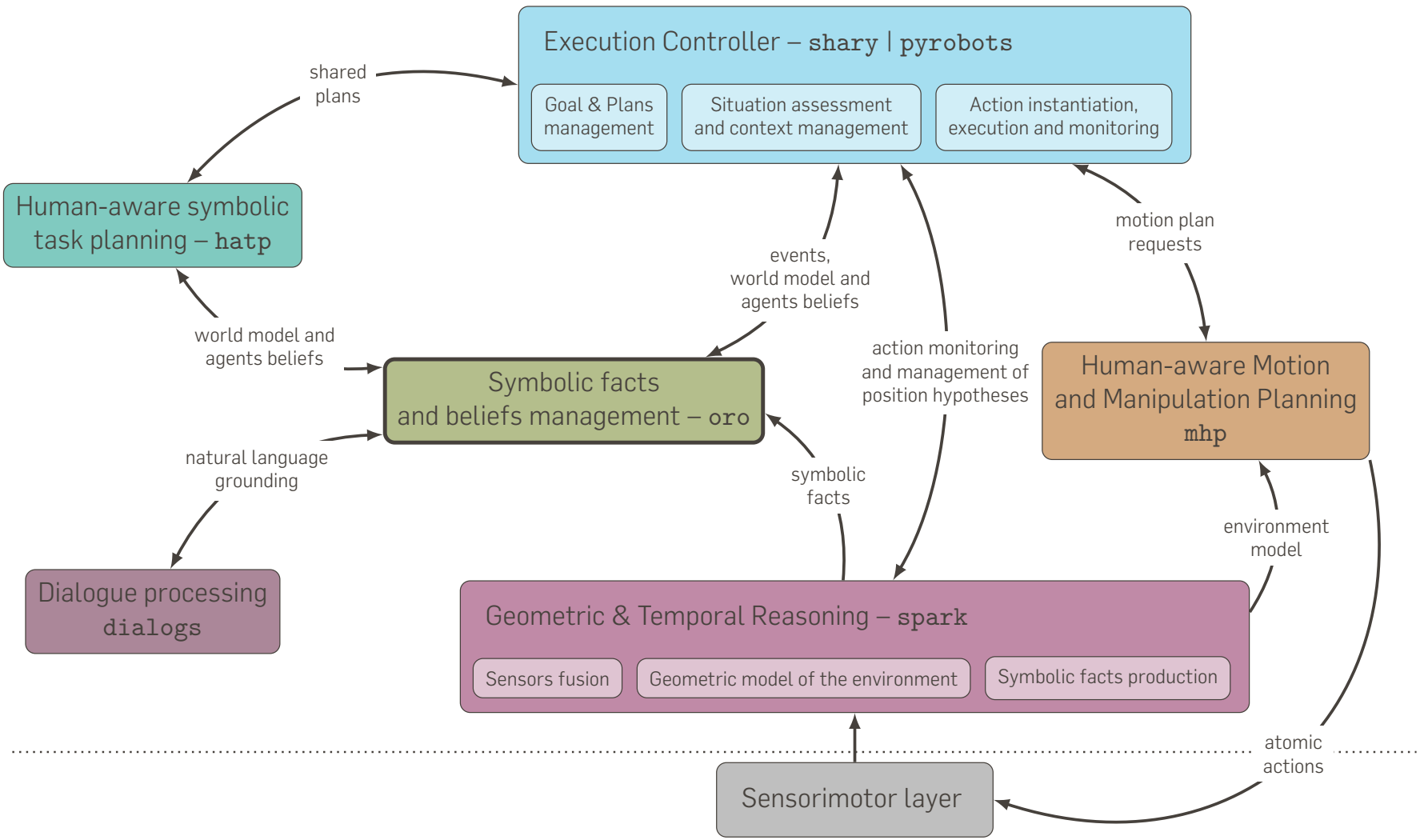
[Ros, Lemaignan et al., **Which One? Grounding the Referent Based on Efficient HRI**, ROMAN 2010]


LAAS-CNRS

INTO AN CONTROL ARCHITECTURE





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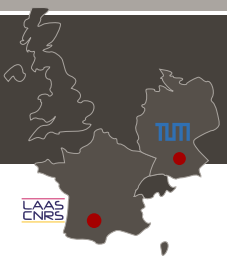

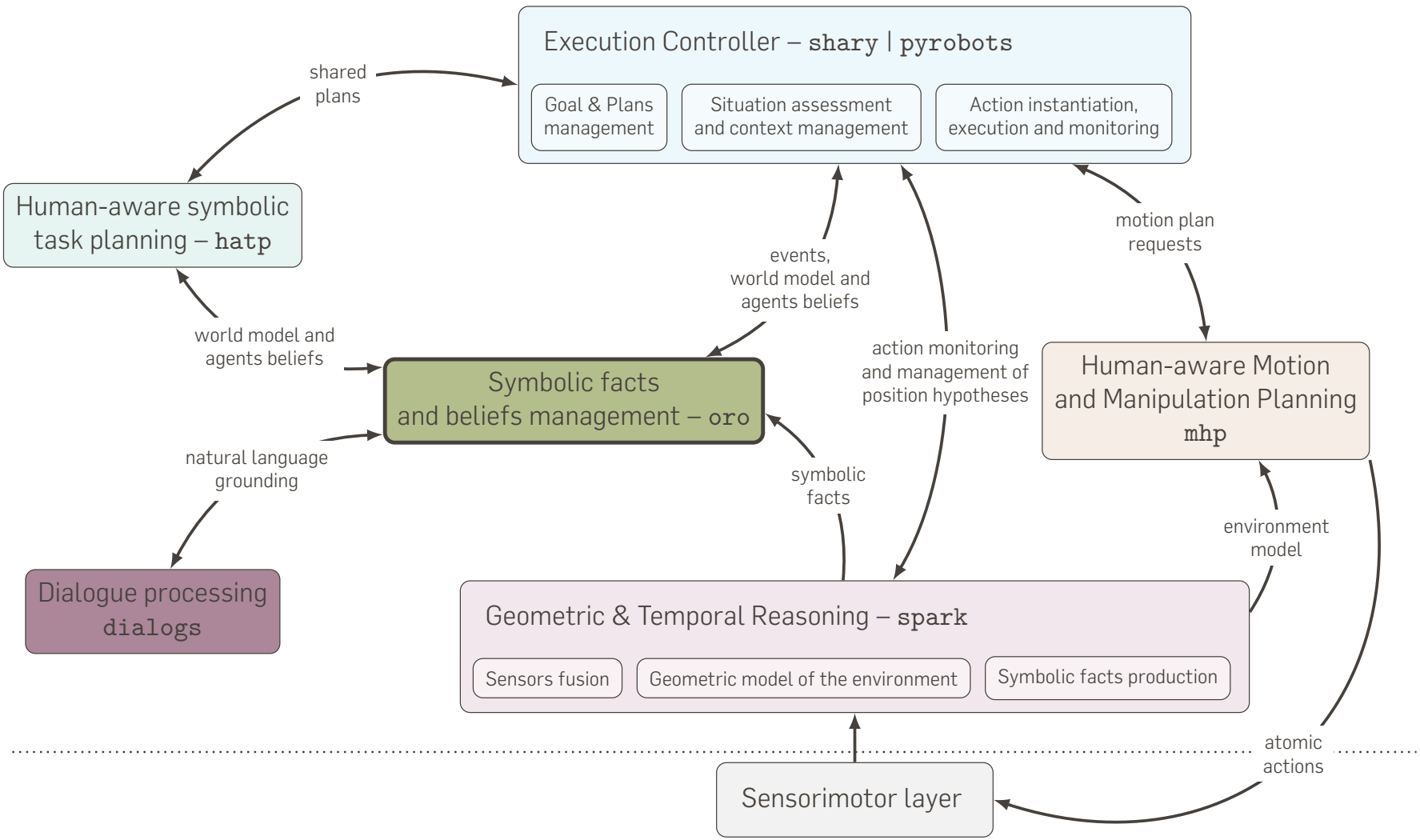

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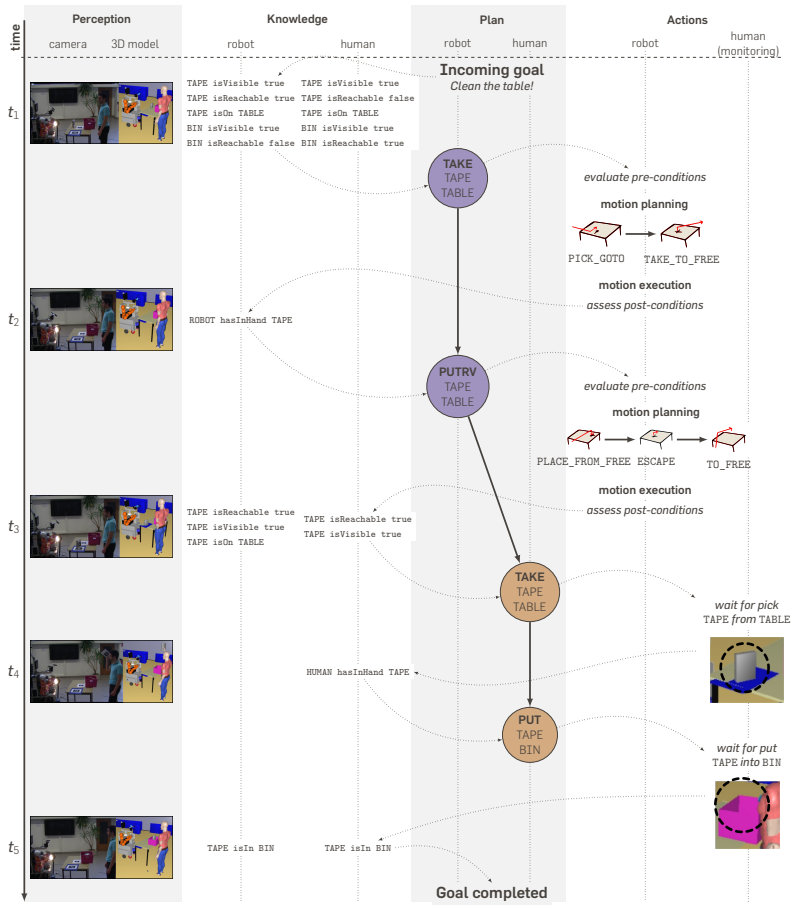
ONE EXAMPLE

Walkthrough one full-stack example in the question



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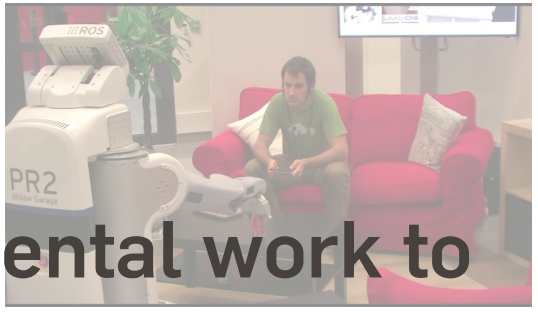
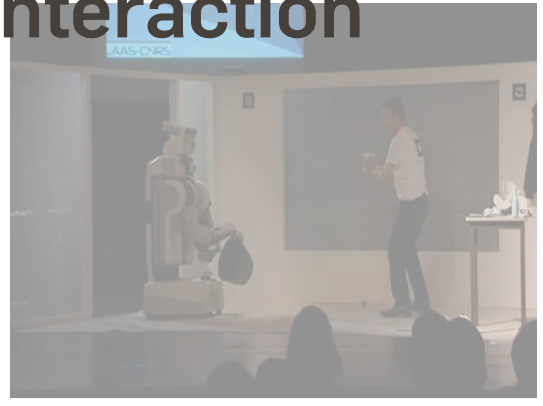
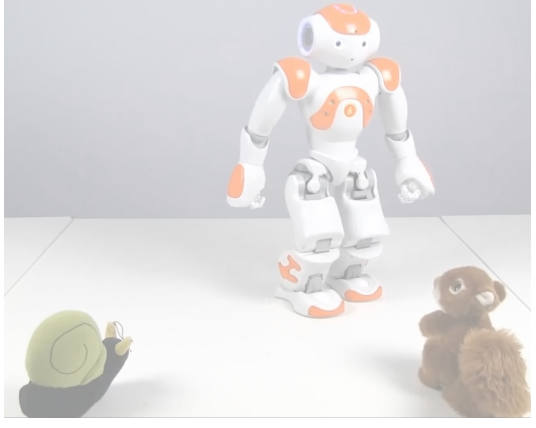
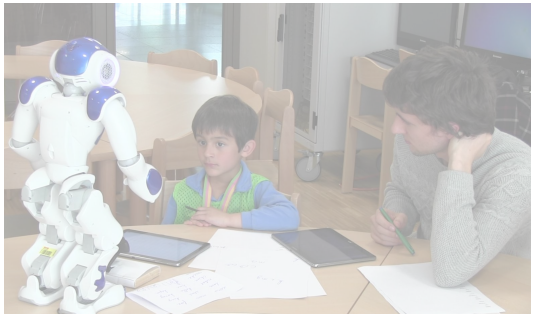
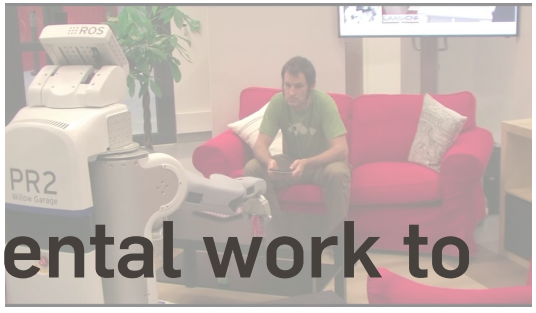
EXPERIMENTAL WORK

Since my PhD, further experimental work to characterise human-robot interaction

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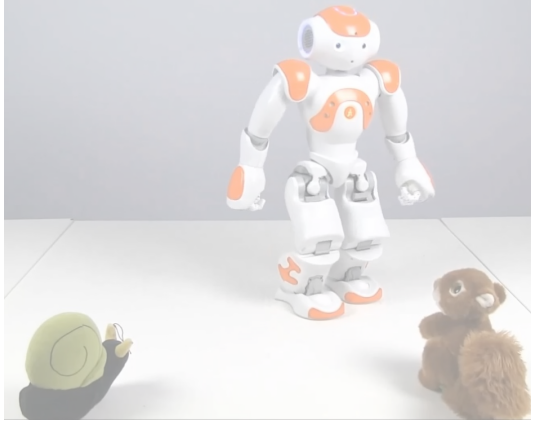
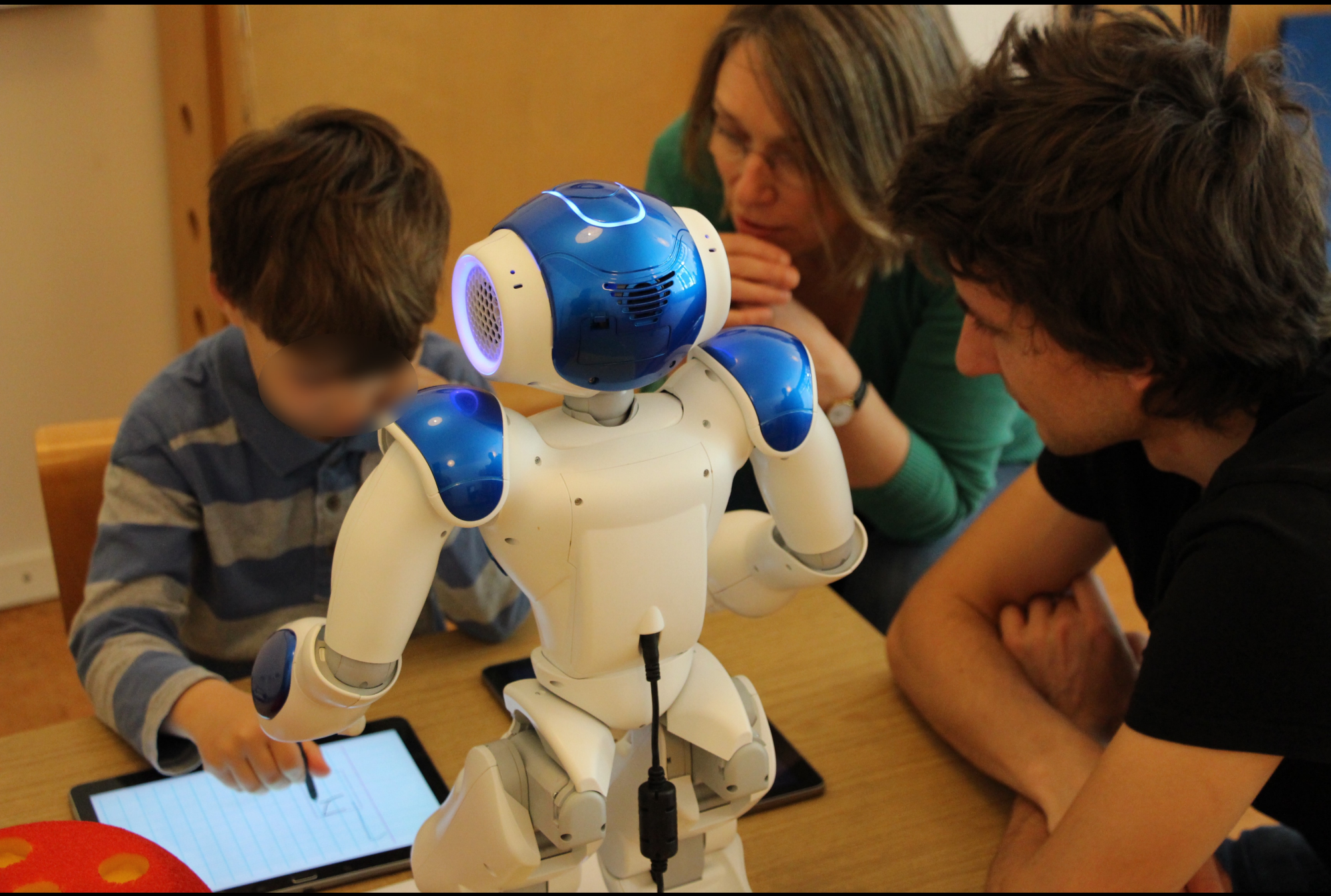
One example to evidence the importance of a **socio-cognitive approach** to HRI: the *CoWriter* project

THE COWRITER PROJECT

Can we address children' hand-writing impairments with robots?

[Lemaignan et al. **Learning by Teaching a Robot: The Case of Handwriting** – Robotics and Automation Magazine 2016]

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Can we address children' hand-writing impairments with robots?

- Robots do not know how to write!
- Learning by Teaching
- (nice side-effect: we can adapt to each child and each disabilities)

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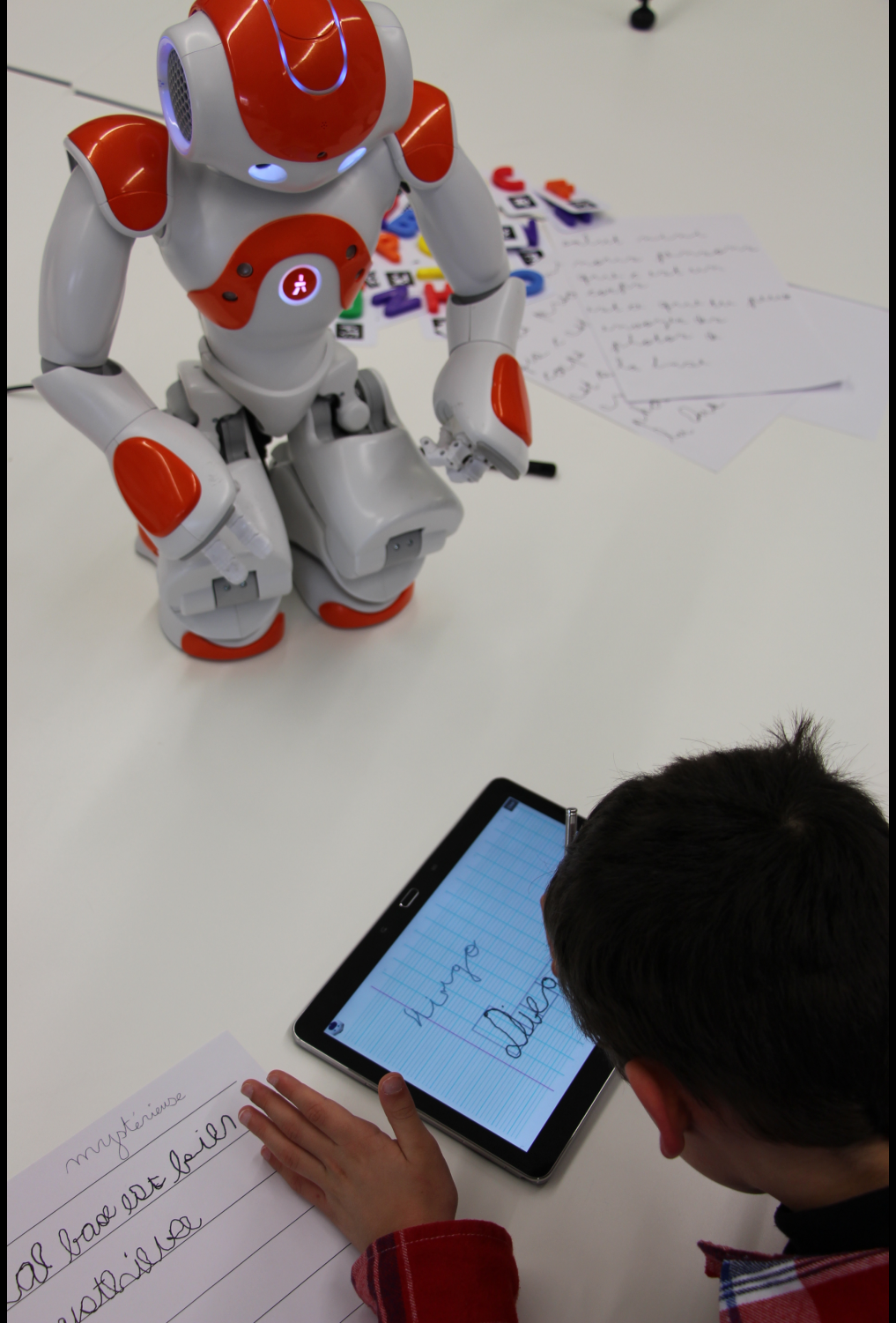
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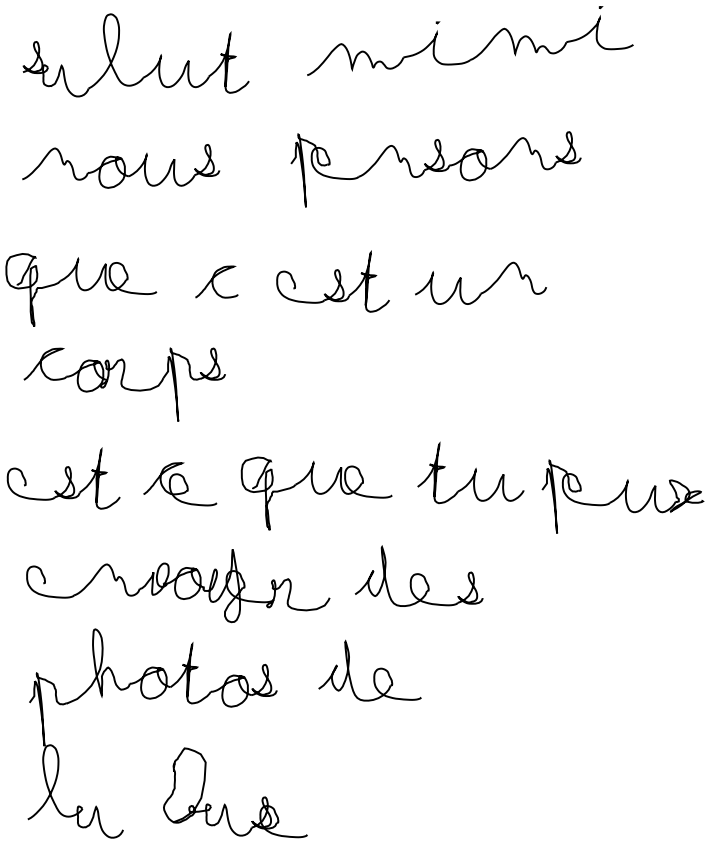
BEFORE – AFTER



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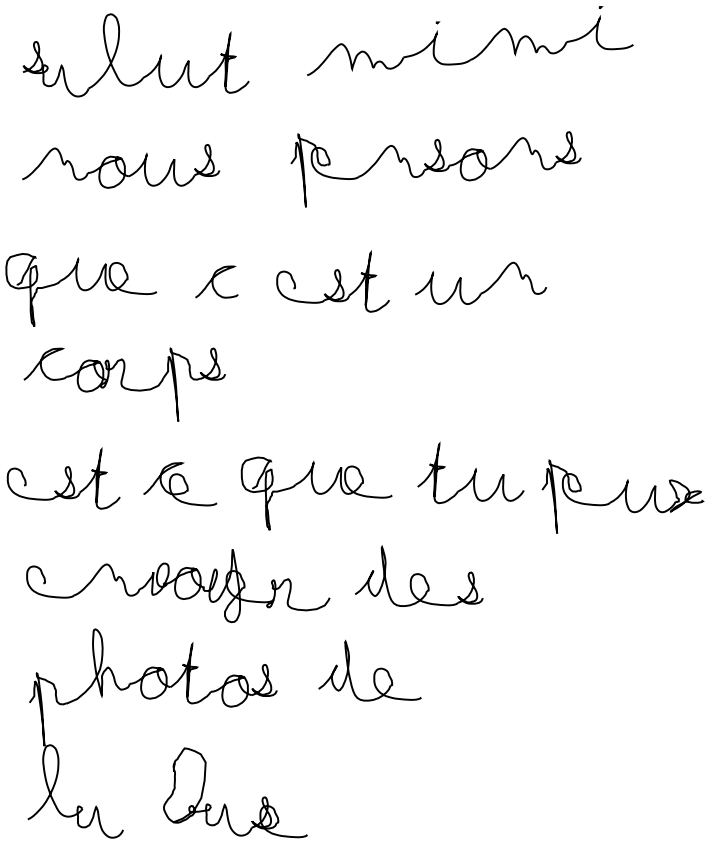

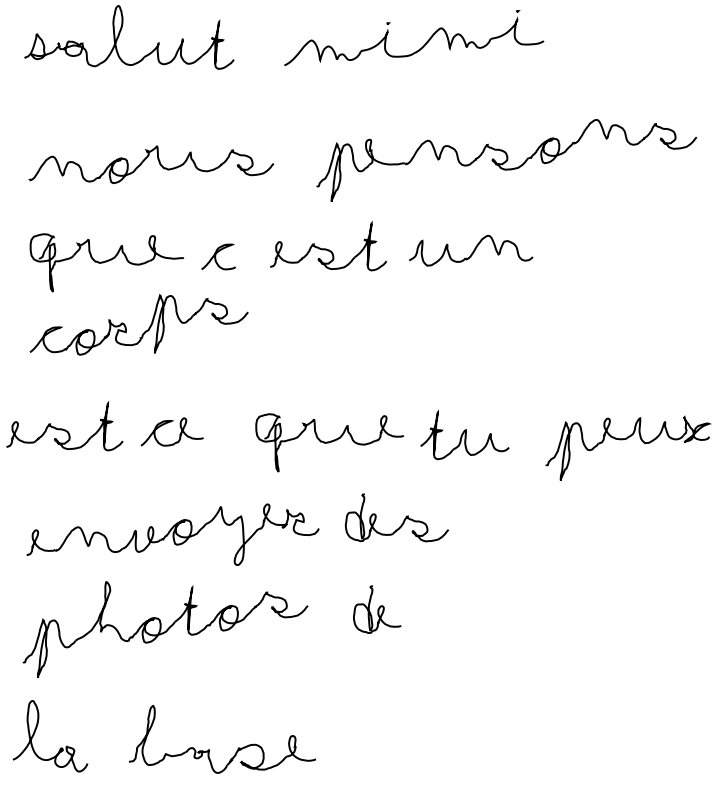

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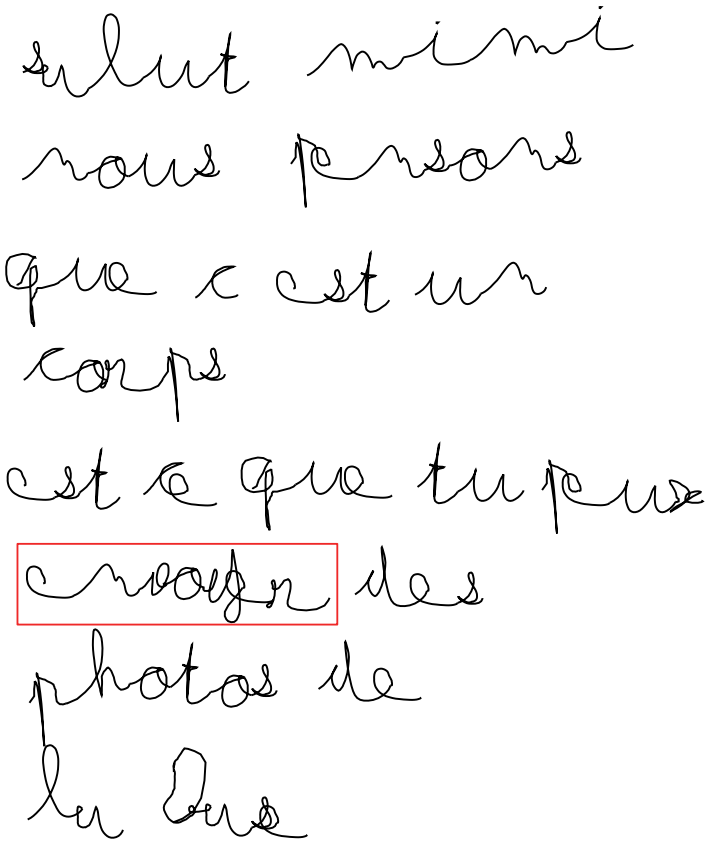

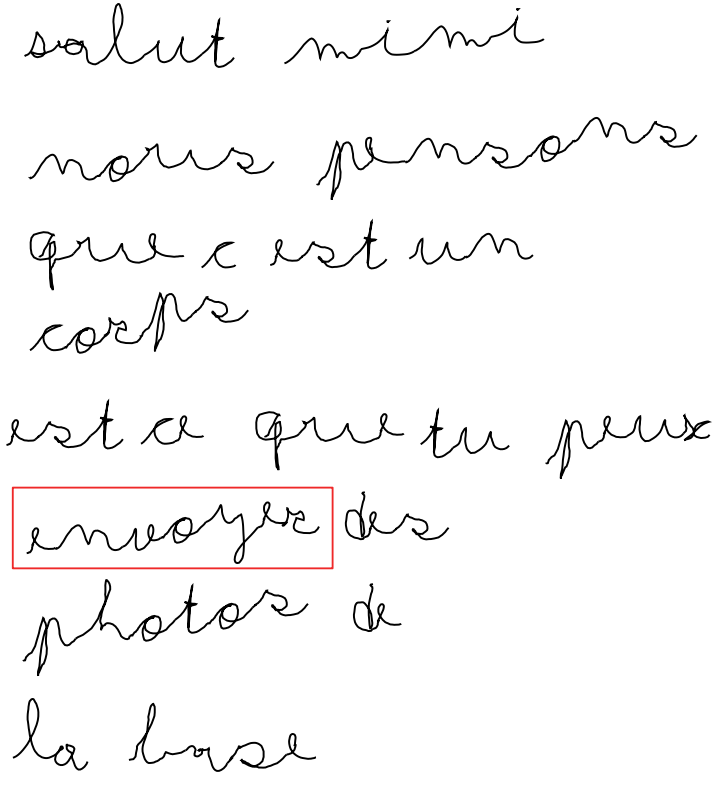

THE ROBOT AS A SOCIAL AGENT

- **The robot as a cognitive agent is key here**
  - Protégé effect
  - metacognition

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- **New role**: not a 'tool to teach robotics', not a facilitator
  (note: a tool for the teacher vs a social agent for the child!)

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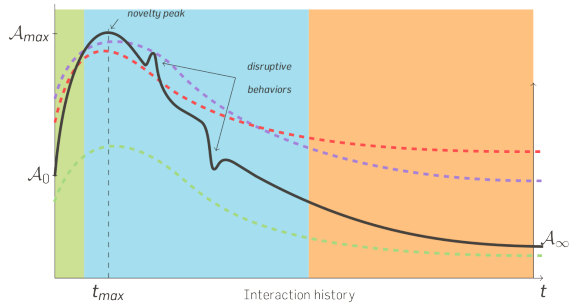
THE ROBOT AS A SOCIAL AGENT

- **The robot as a cognitive agent is key here**
  - Protégé effect
  - metacognition
- **New role**: not a 'tool to teach robotics', not a facilitator (note: a tool for the teacher vs a social agent for the child!)
- Could we replace it by someone else? Not easily

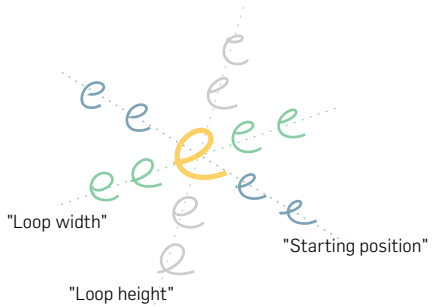
[Lemaignan et al. **Learning by Teaching a Robot: The Case of Handwriting** – Robotics and Automation Magazine 2016]

WHAT ELSE?

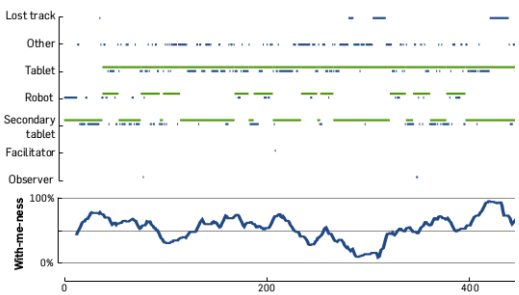
Social HRI on the field

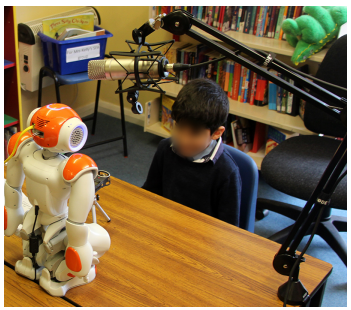


Robots for Learning



Methodology



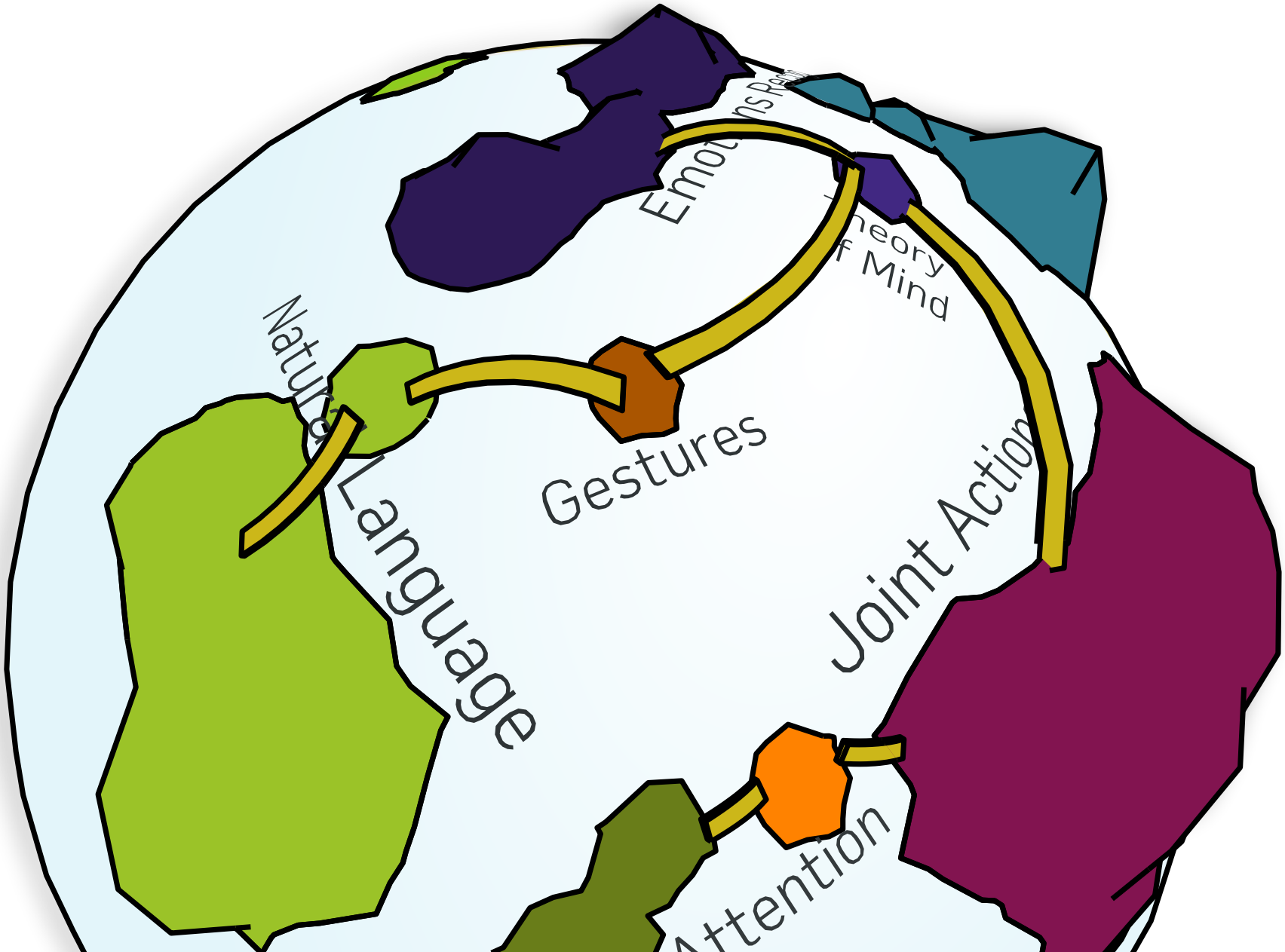


Expectations
How do you imagine a robot? *What could it look like?* *Have you ever seen a robot before?*
Impression
When you first saw R, what did you think? *Is R a robot? How do you know?* *Did you expect R would come over to you when you call it?* *What happened when you put the domino in the box?*
Ascribe intention
Do you think R could go out the door all by itself? *Does R always obey / come over to you?* *Could R do something silly?* *Why did R not come over to you when you called it?*

Ascribe perceptual capabilities
Here is a domino. Do you think R can see it? *When I say "Hello R!", do you think R can hear it?*
Ascribe emotional state
Does R have feelings? Can R be happy or sad sometimes?
Social acceptance
Do you like R? Why (not)? *What do you (not) like about it?* *Would you like to have R at home?*
Companionship
Could R be your friend? Why (not)?
Ascribe moral standing
Assume you go on a holiday for two weeks. Is it alright to leave R alone at home? Why (not)?

THE NEXT STEPS


Emotions
Theory of Mind
Natural Language
Gestures
Joint Actions
Attention


Emotions
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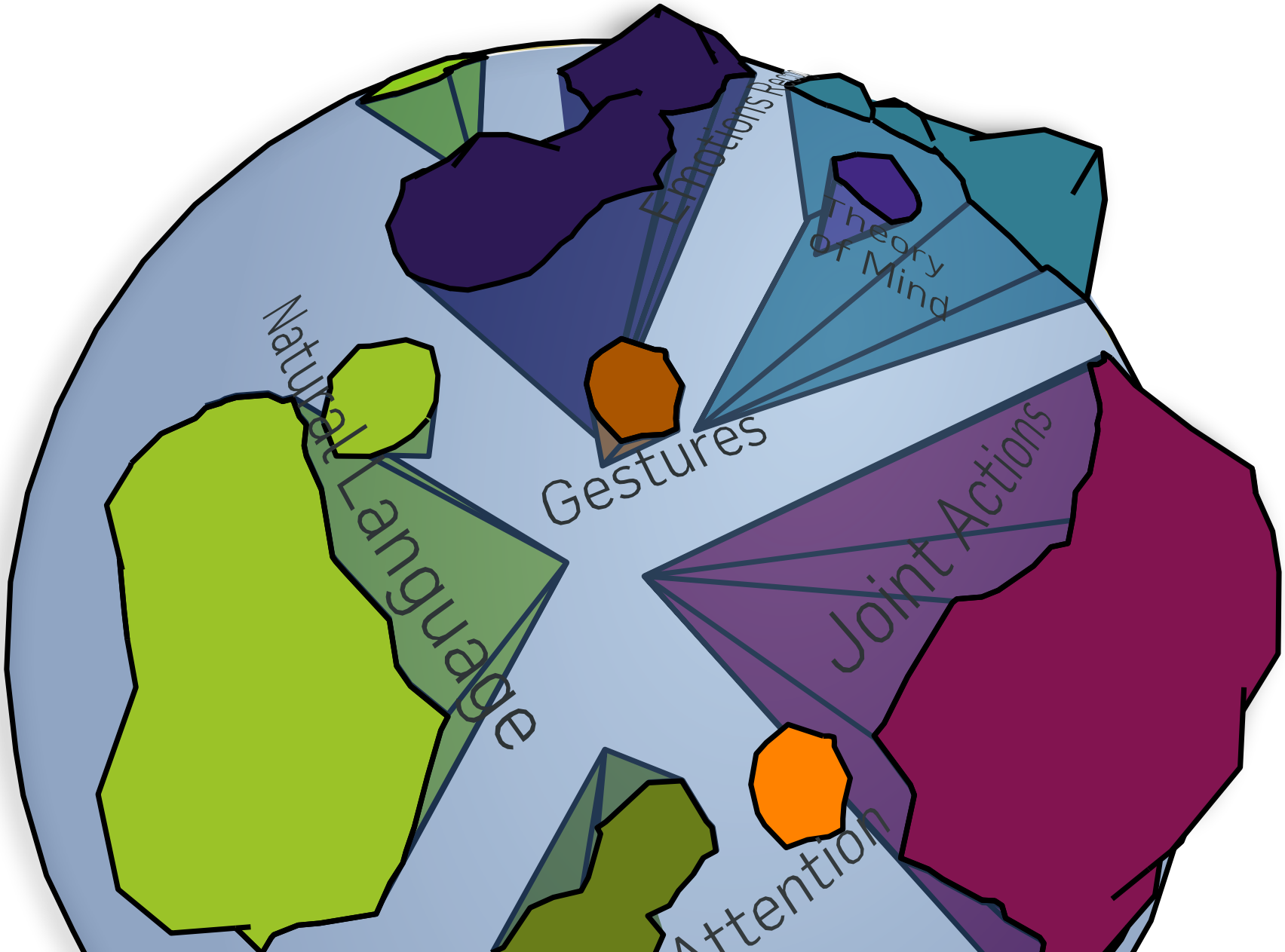
Joint Action
Attention


Emotions
Theory of Mind
Gestures
Natural Language
Joint Actions
Attention

TOWARDS A COGNITIVE ARCHITECTURE

Guiding research question: **What are the principles that underpin social cognition?**

[Graziano **Consciousness and the Social Brain** – 2013]

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One working hypothesis: **Sociality emerge from interaction**

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- **Social interaction is mediated by attention**
- **Modelling other's attention is building a theory of their mind**

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Fine, but… testable predictions?

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OPERATIONALISING THE RESEARCH

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- ⇒ **free play as our next horizon**: *rich set of cognitive and social dynamics*; importance of motivation/drive; forces us to deal with uncertain and unexpected situations
- But challenging as well! What is the action policy? Focus instead on the **social policy**

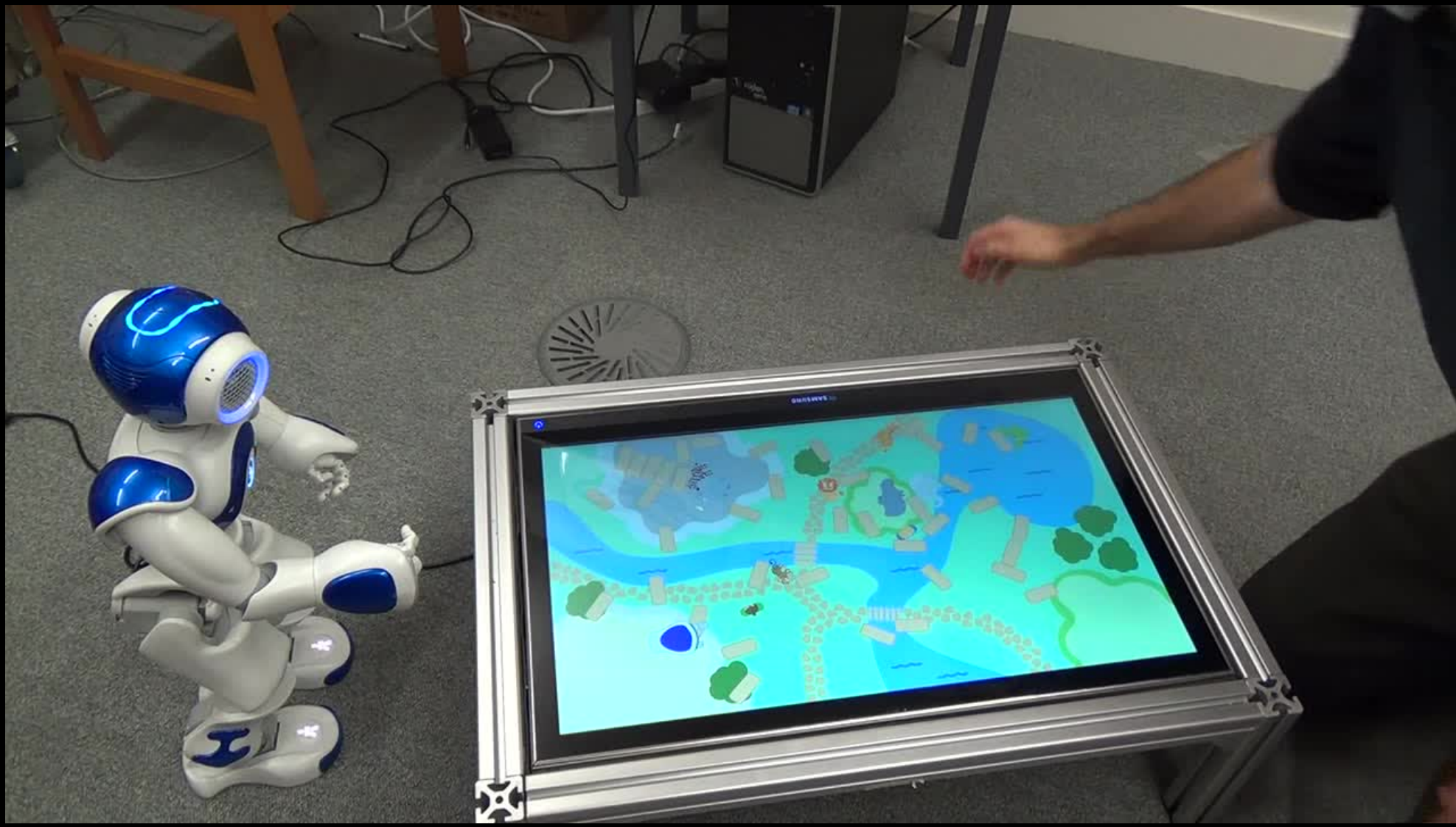
THEORETICAL FRAMEWORK: STAGES OF PLAY

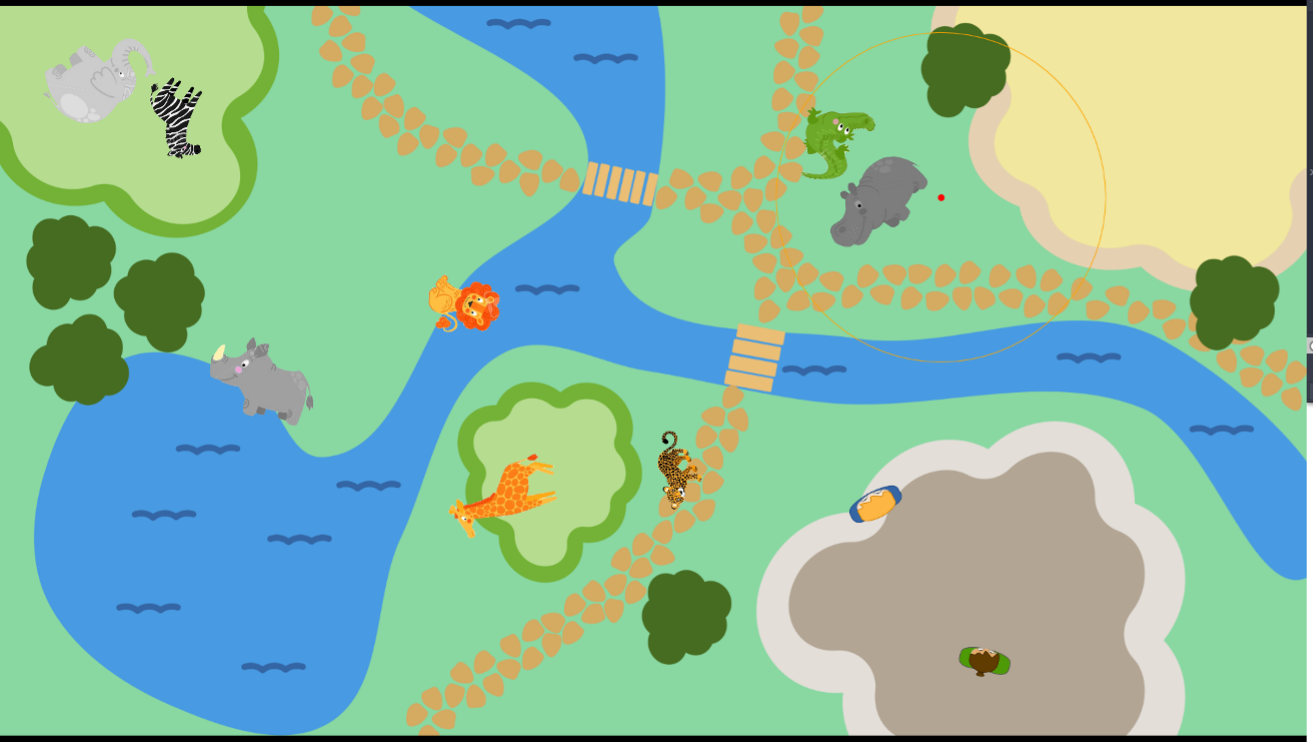
In developmental psychology, Parten's **stages of play**:

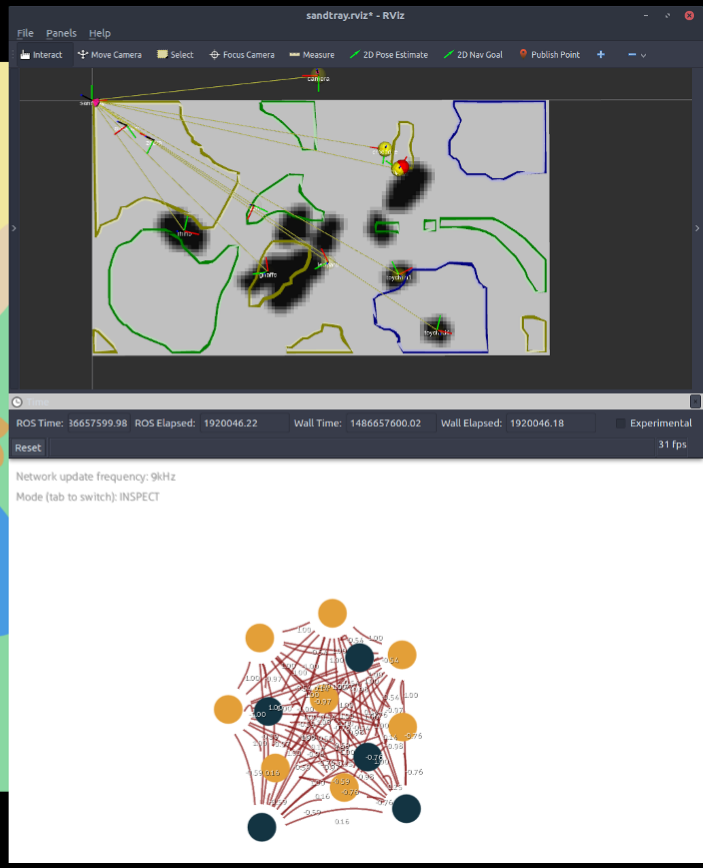
1. **Solitary (independent) play**: Playing separately from others, with no reference to what others are doing.
2. **Onlooker play**: Watching others play. May engage in conversation but not engaged in doing. True focus on the children at play.
3. **Parallel play** (adjacent play, social coaction): Playing with similar objects, clearly beside others but not with them (near but not with others.)
4. **Associative play**: Playing with others without organization of play activity. Initiating or responding to interaction with peers.
5. **Cooperative play**: Coordinating one's behavior with that of a peer. Everyone has a role, with the emergence of a sense of belonging to a group. Beginning of "team work."

[Parten, **Social participation among preschool children** Journal of Abnormal and Social Psychology 1932]


A framework for artificial socio-cognition





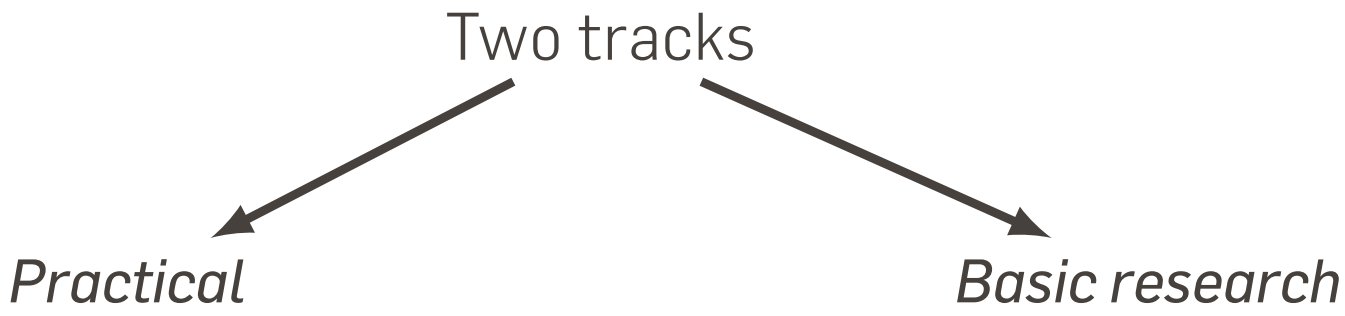

sandtray.rviz* - RViz
File Panels Help
Interact Move Camera Select Focus Camera Measure 2D Pose Estimate 2D Nav Goal Publish Point
ROS Time: 36657599.98 ROS Elapsed: 1920046.22 Wall Time: 1486657600.02 Wall Elapsed: 1920046.18 Experimental
Reset 31 fps
Network update frequency: 9kHz
Mode (tab to switch): INSPECT

KEY PREDICTED SOCIAL BEHAVIOURS

- **behavioural alignment**: each time we play together, our interaction flow improves, becomes more natural
- **'natural' (i.e. emergent) turn-taking**: I 'just' know when it is my turn to act
- **'natural' protodeclarative pointing**: I 'just' know when I really need to draw your attention on something
- ability to pass **false-belief tasks**, including non-perceptual, non-physical, abstract ones,
- **replication of Parten's hierarchy** $\leftarrow$ ambitious!

$\Rightarrow$ significant scientific targets for human-robot interaction

RESEARCH APPROACH



- symbolic approach
- complete with respect to cognitive capabilities
- focus on long-term autonomy
- cross-hardware

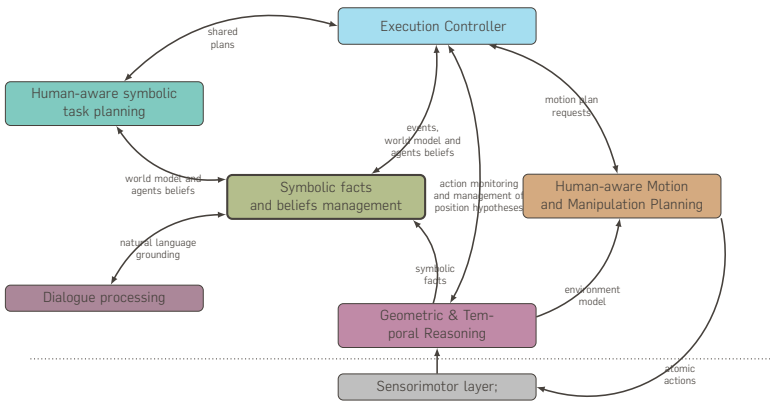
- principled approach
- emergent paradigm
- initially based on the ***attention schemata theory***
- associative memory networks

cross-pollination

RESEARCH APPROACH

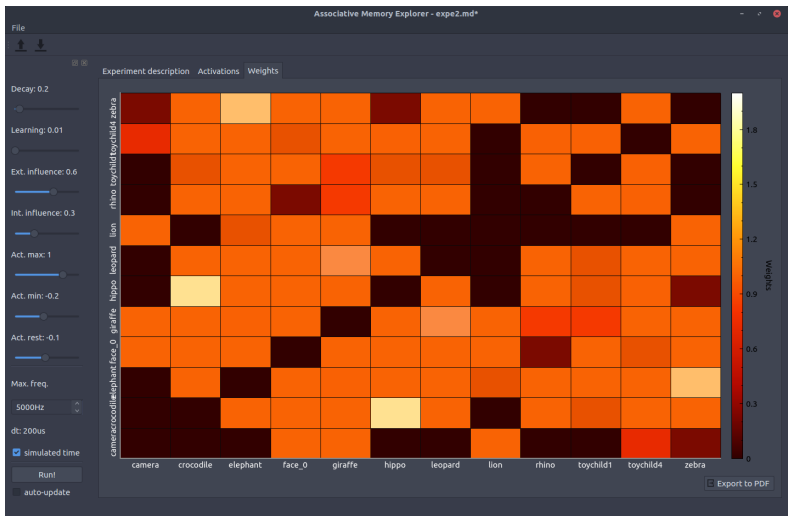
Two tracks

Practical



The “Plymouth Architecture for Socio-Cognitive Robots”

Basic research



Emergent Artificial Social Cognition

DEVELOPING CHILD-ROBOT INTERACTION AT PLYMOUTH

Create a **KidsLab**

- experimental space suited for 5 to 13 years old
- fully equipped (recording, tracking, touch tables)
- in close cooperation with Caroline Floccia & the BabyLab

FUNDING

Short term

- **EPSRC First Grant**

  up to £125,000
  max 2 years, no closing date to submit
  funding for the **KidsLab** project
  covers equipment + one post-doc

- **EPSRC Early Career Fellowship**

  max 5 years, no closing date to submit
  covers equipment and staff
  project on **Emergence of artificial social cognition**
  possible partnerships: developmental robotics (e.g. INRIA Flowers), cognitive neurosciences (e.g. Graziano lab), learning technologies (e.g. EPFL CHILI Lab)

FUNDING

Mid-term (within 2-3 years)

- **Co-Investigator on a H2020 project**
  close contacts with IST Lisbon, LAAS-CNRS, EPFL, INRIA Bordeaux
- Submit a **EPSRC Standard Research** proposal
  aimed at reaching independence (1 PhD, 1 post-doc)
  focus on socio-cognitive architecture + long-term field deployment
  multi-proposal submission, possibly with Lincoln U. (expertise on Cognitive Architectures)
- **ERC Starting Grant**
  up to €1.5m
  max 5 years
  within 7 years of PhD completion, i.e. before 2019
  project on **Emergence of artificial social cognition**

Thank you!

Séverin Lemaignan
severin.lemaignan@plymouth.ac.uk

SUPPLEMENTARY MATERIAL

5. Performing in Human Environments

6. pyRobots Example

7. Dialogue Grounding

8. Child-Robot Interaction for Learning

9. Child-Robot Interaction: the Practical Side

10. Reframing the research

11. Sketching a model

12. Experimental investigation

13. Theories on theory of mind

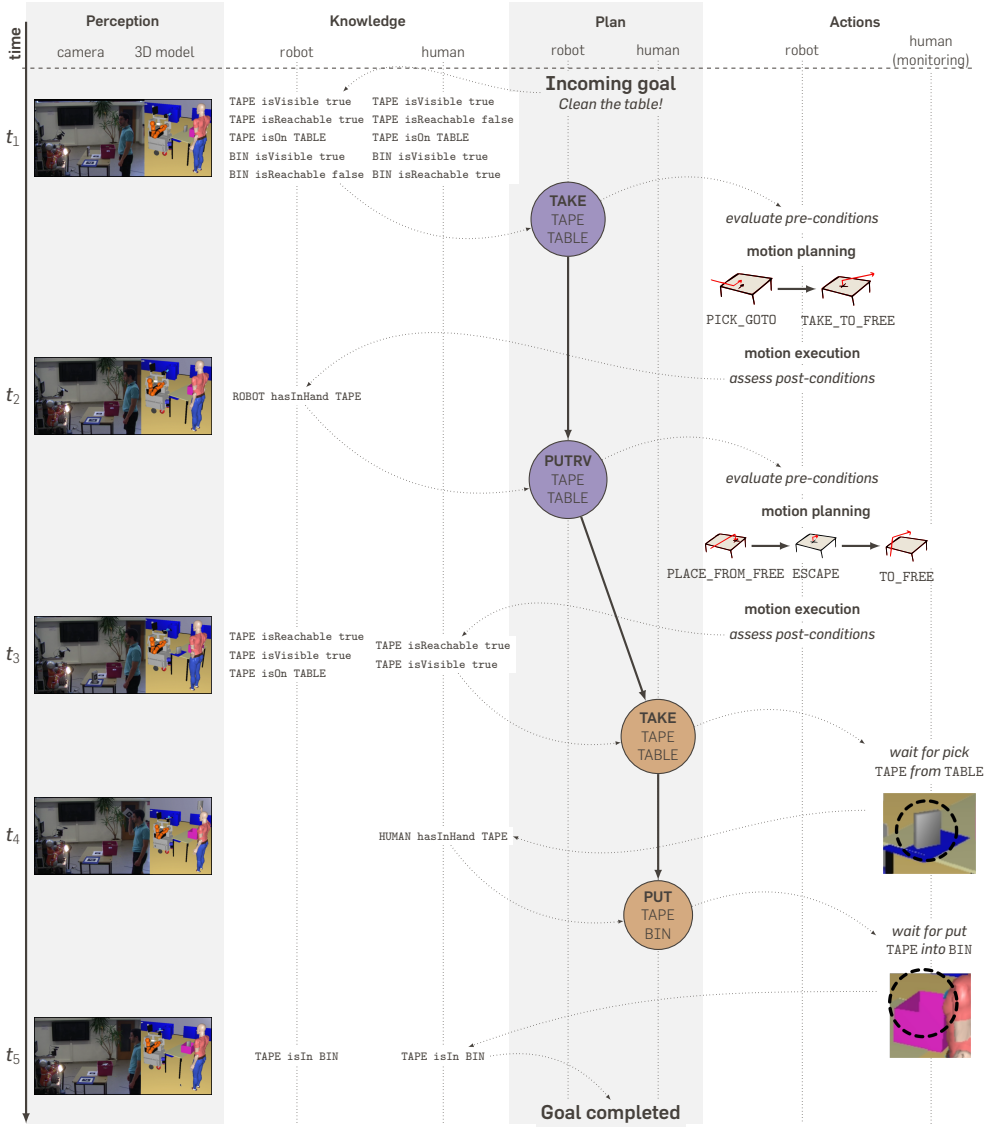
14. Dynamics of Interaction

15. Cognitive Architectures

PERFORMING IN HUMAN ENVIRONMENTS


LAAS-CNRS

"CLEANING THE TABLE"...



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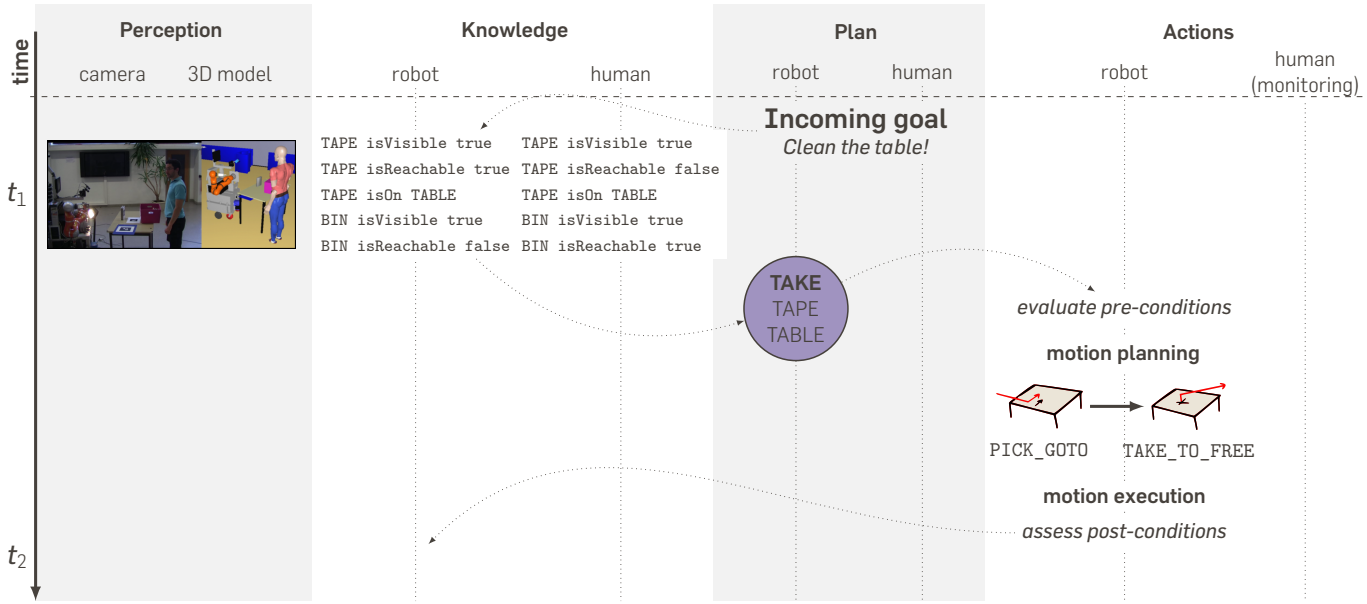

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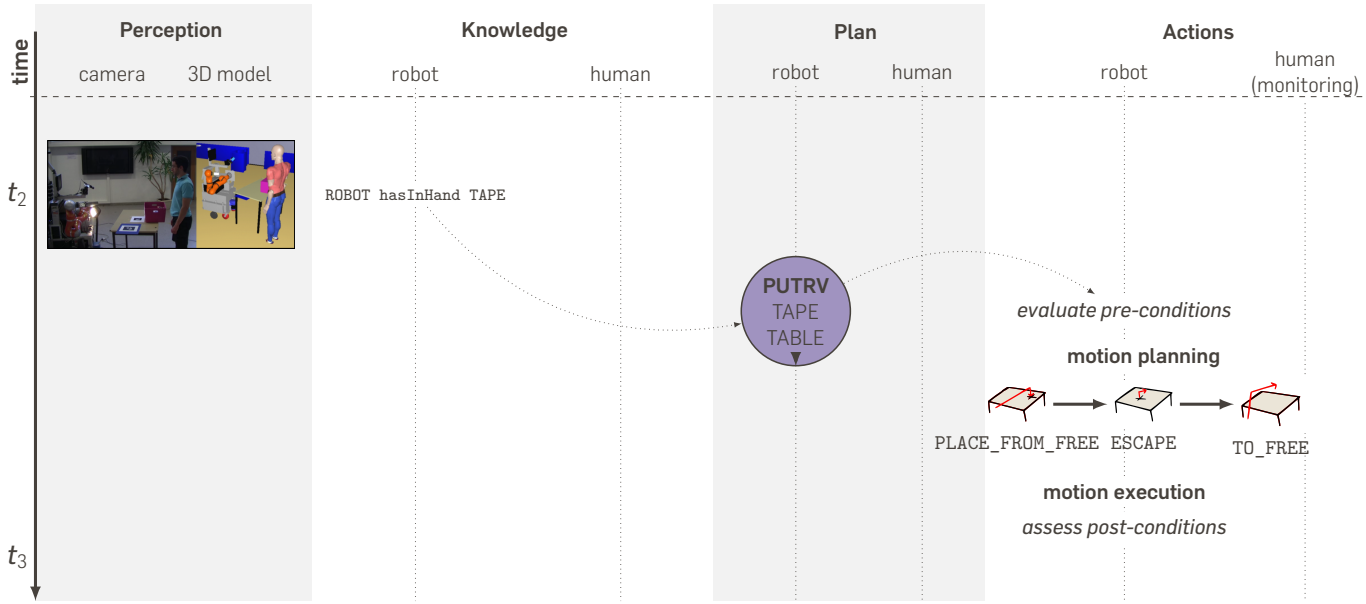

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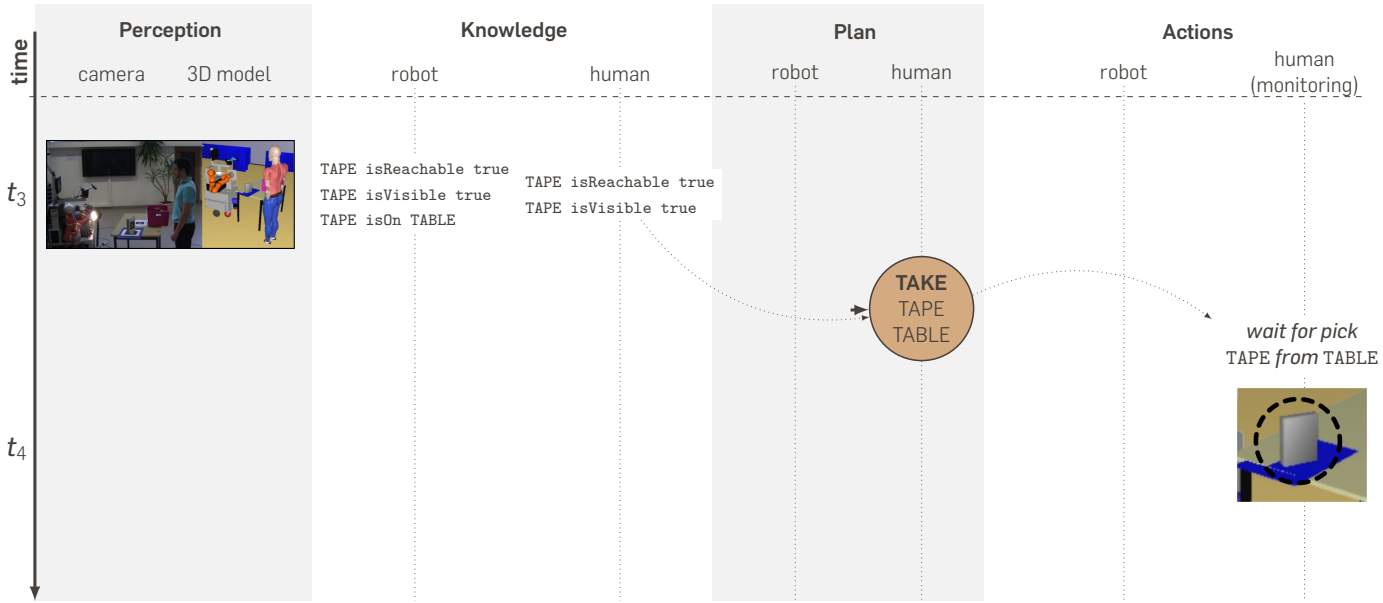

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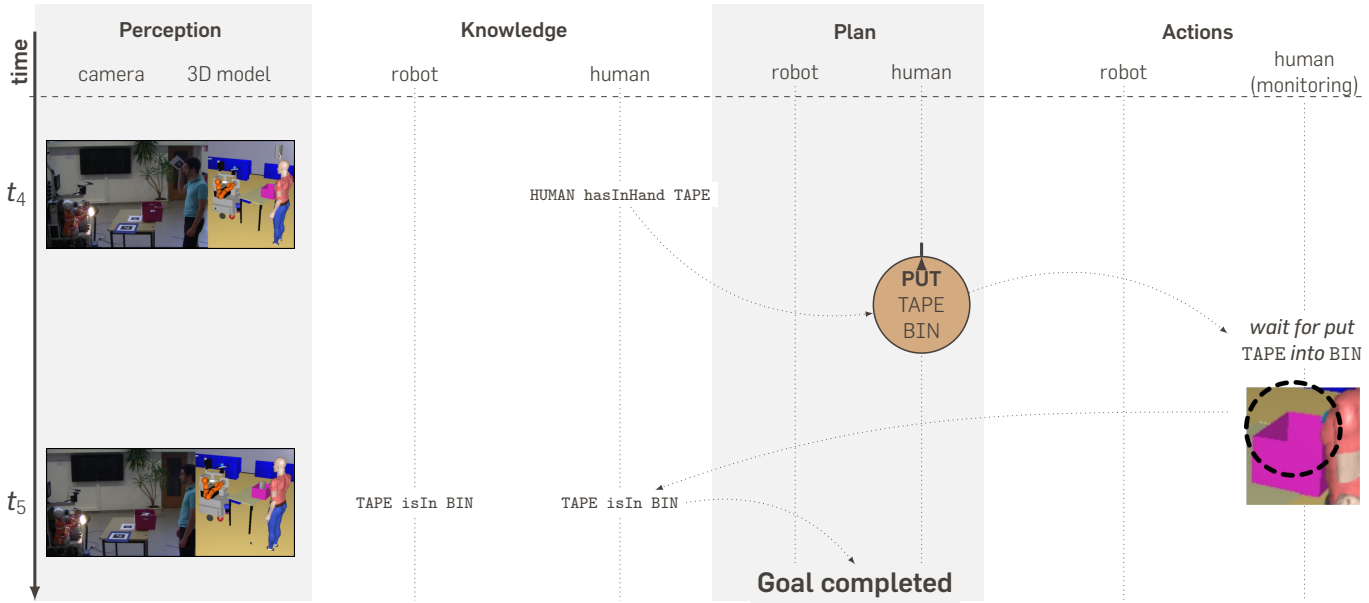

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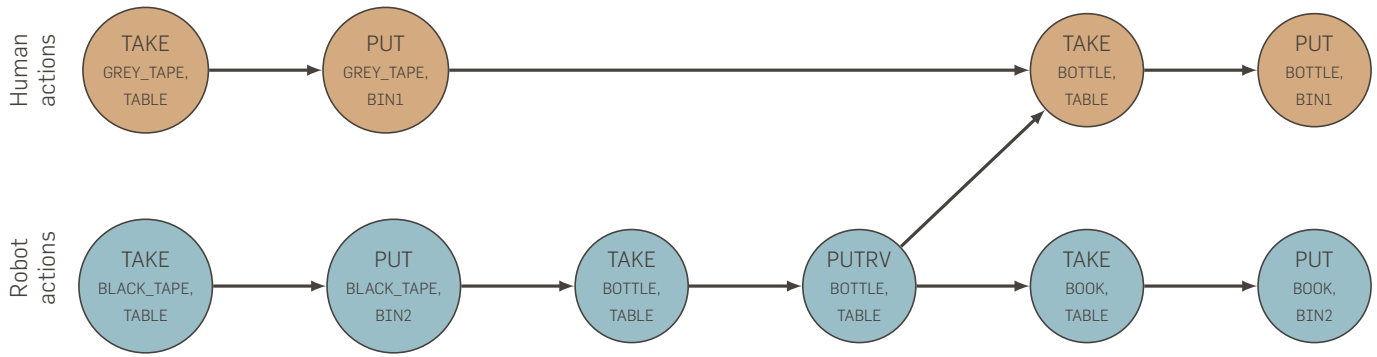
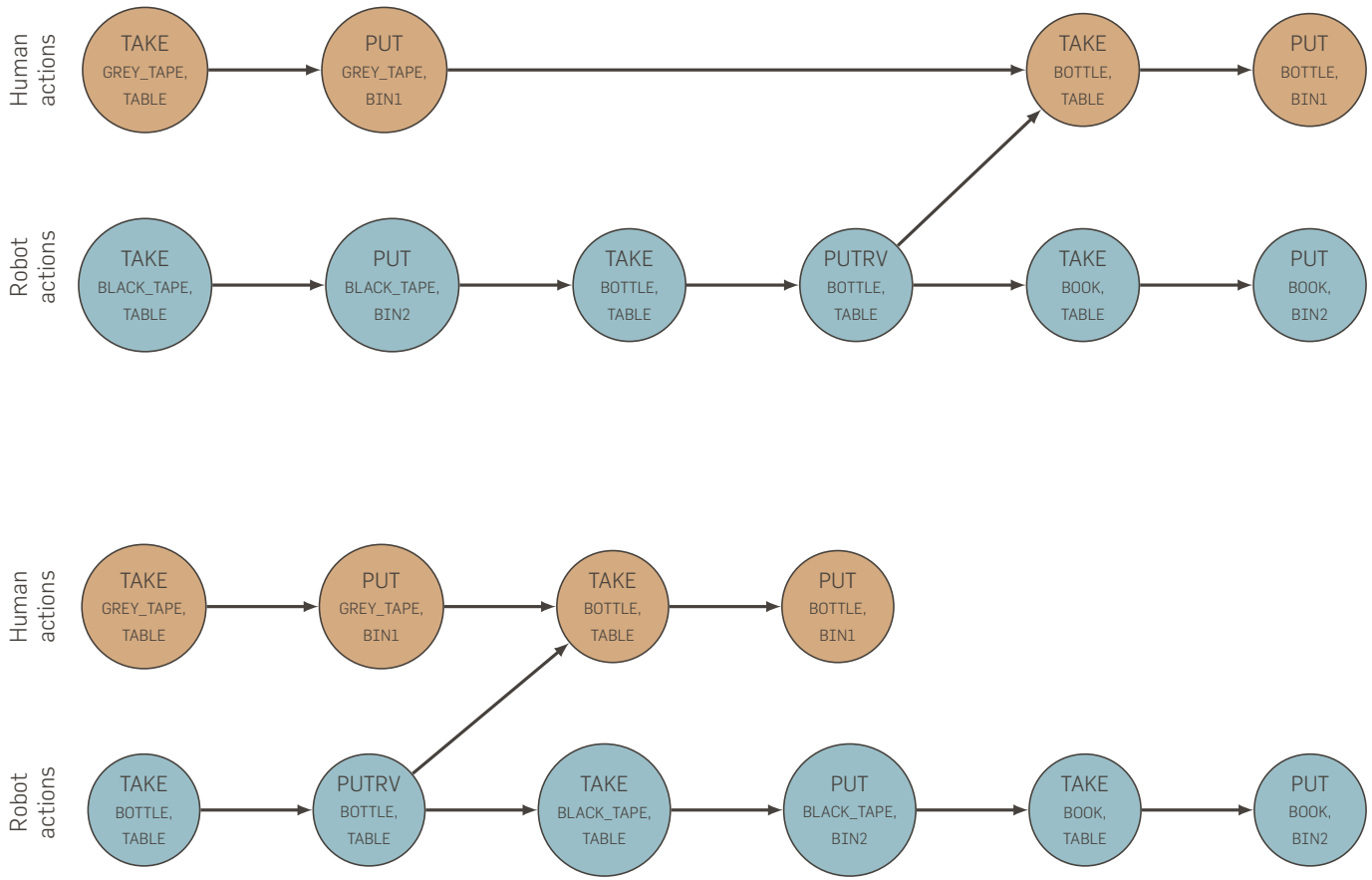
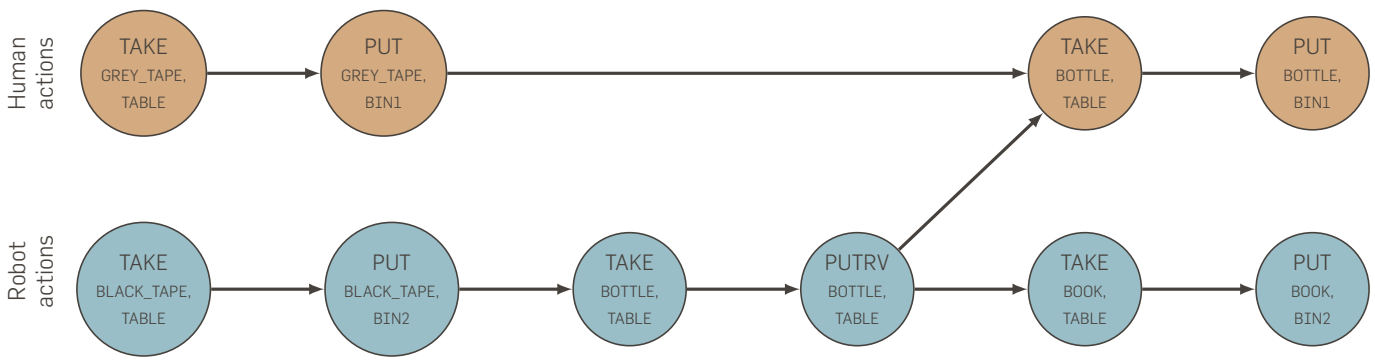
PLANNING FOR THE HUMAN



PLANNING FOR THE HUMAN



PLANNING FOR THE HUMAN




PR2
PR2

roboscopie

A Theatre Performance for a Robot and a Human

HRI 2012

```
amit_give
arms_against_torso
attachobject
basicgive
basicgrab
basictake
basket
cancel_follow
cancel_track
cancel
carry
close_gripper
configure_grippers
detect_and_grab
detect
disabledevileye
display
dock
enabledevileye
extractpose
follow
glance_to
goto
grab_gripper
grab
gym
handover
handsup_folded
handsup_folded2
handsup_folded3
handsup
hide
idle
init
larm_swinging
lock_object
look_at_ros
look_at_xyz
look_at
looksat
manipose
move_head
movearm
moveclose
open_gripper
pick
place_agent
place_object
pointsat
put_accessible
put
rarm_swinging
release_gripper
release
restpose
rotate
satisfied
say
setpose
settorso
setup_scenario
show
slow_arms_swinging
sorry
speed_arms_swinging
sweep_look
sweep
switch_cameras
take
track_human
track
translate
tuckedpose
unlock_object
wait
waypoints
```

PYROBOTS

```python
from robots import GenericRobot
from robots.concurrency import action, ActionCancelled
from robots.resources import Resource, lock

class MyRobot(GenericRobot):
    # ... state + lowlevel action

WHEELS = Resource("wheels")

@lock(WHEELS)
@action
def move_forward(robot):
    target = [1.0, 0., 0., "base_link"]

    try:
        robot.goto(target)

        while(robot.dist_to(target) > 0.1):
            robot.sleep(0.5)

    except ActionCancelled:
        robot.stop()
```

```
with MyRobot() as robot:

    robot.whenever("my_bumper", True).do(move_forward)

    try:
        while True:
            time.sleep(0.5)
    except KeyboardInterrupt:
        pass
```

DIALOGUE GROUNDING

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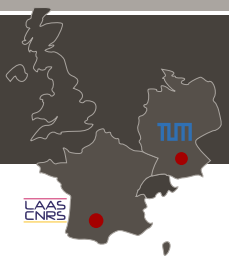

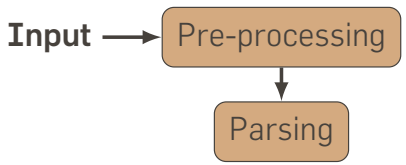

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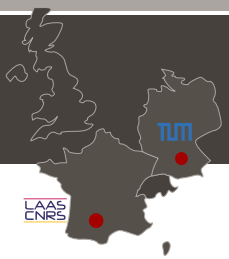

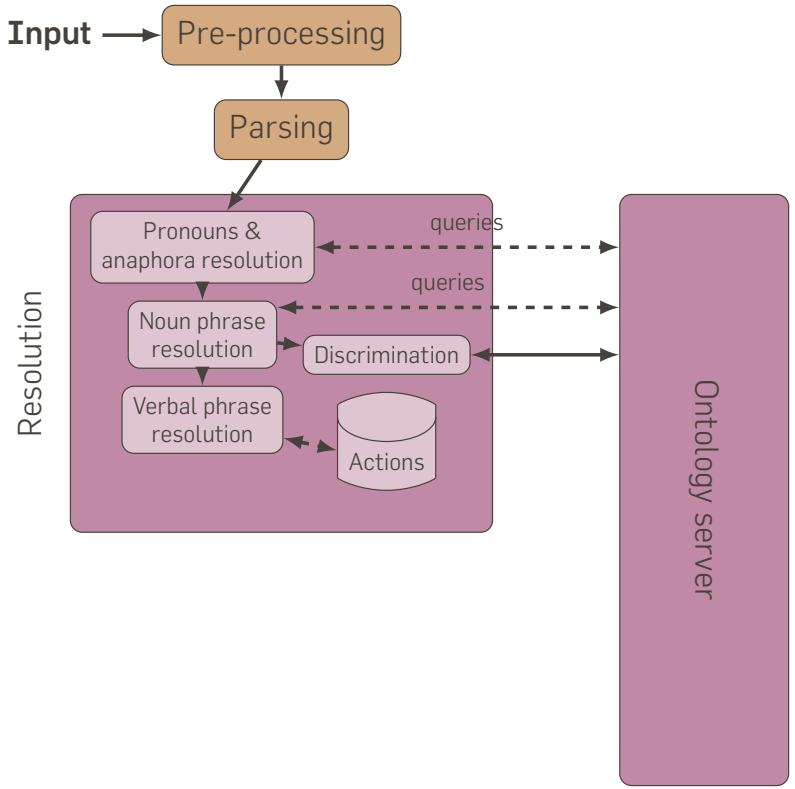

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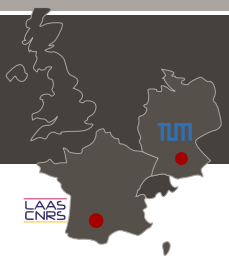

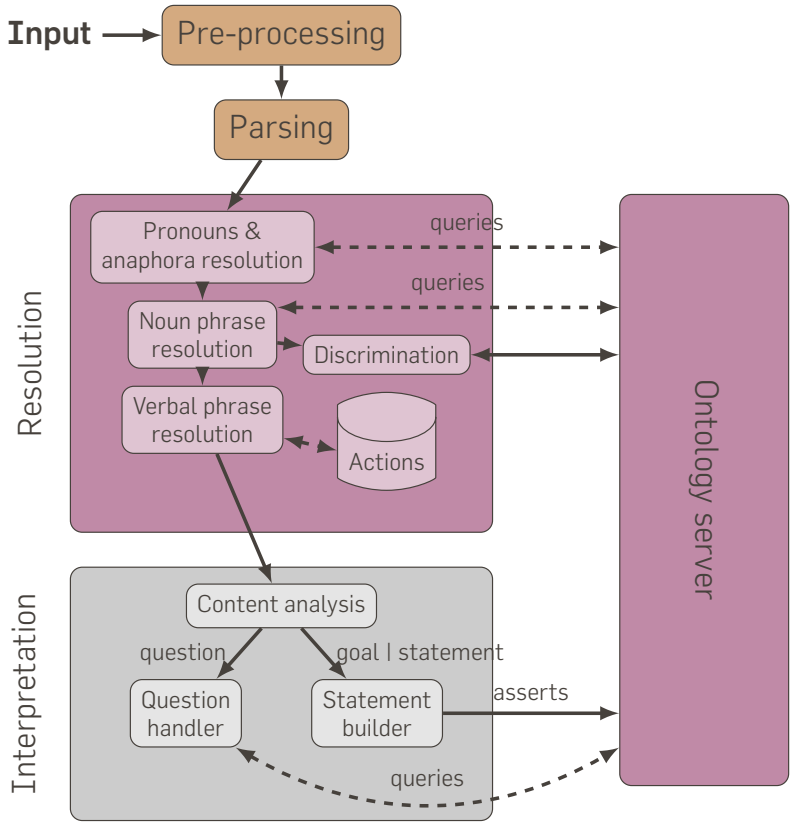

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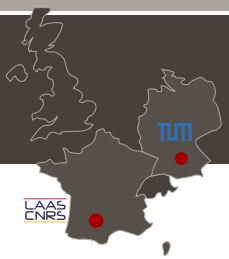

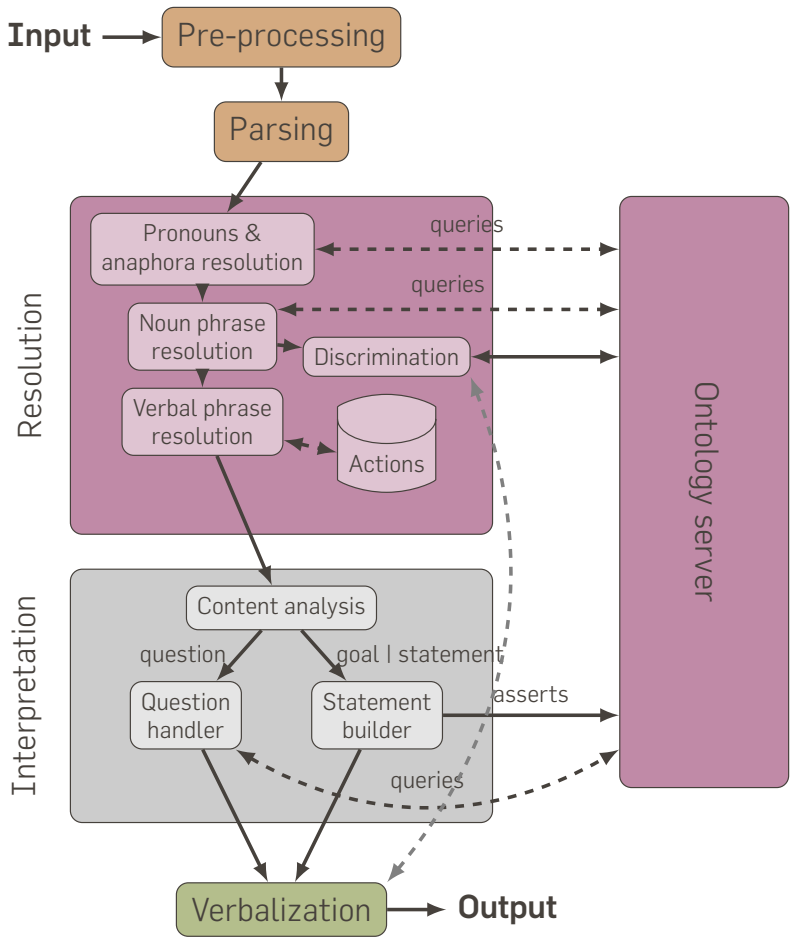

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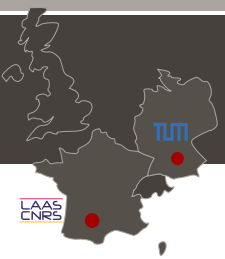
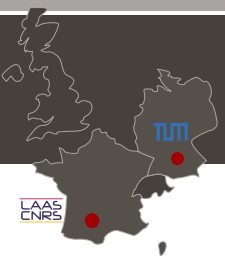


"Give me the book on the table"

DIALOGUE GROUNDING



"Give me the book on the table"

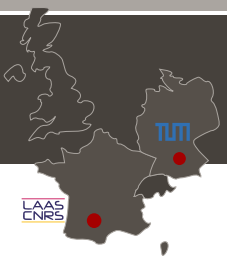
$$\downarrow$$

$$\texttt{me} \rightarrow \texttt{baby\_1}$$

$$\text{find}(\texttt{?obj type table}) \rightarrow \texttt{ikea\_table}$$

$$\text{find}(\texttt{?obj type book, ?obj isOn ikea\_table}) \rightarrow \texttt{harry\_potter}$$

DIALOGUE GROUNDING



"Give me the book on the table"

↓

`me` → `baby_1`

find(`?obj type table`) → `ikea_table`

find(`?obj type book, ?obj isOn ikea_table`) → `harry_potter`

↓

```
baby_1 desires action1,
action1 type Give,
action1 performedBy myself,
action1 actsOnObject harry_potter,
action1 receivedBy baby_1
```

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

CRI FOR LEARNING

SOCIAL OR NOT SOCIAL?

SOCIAL OR NOT SOCIAL?

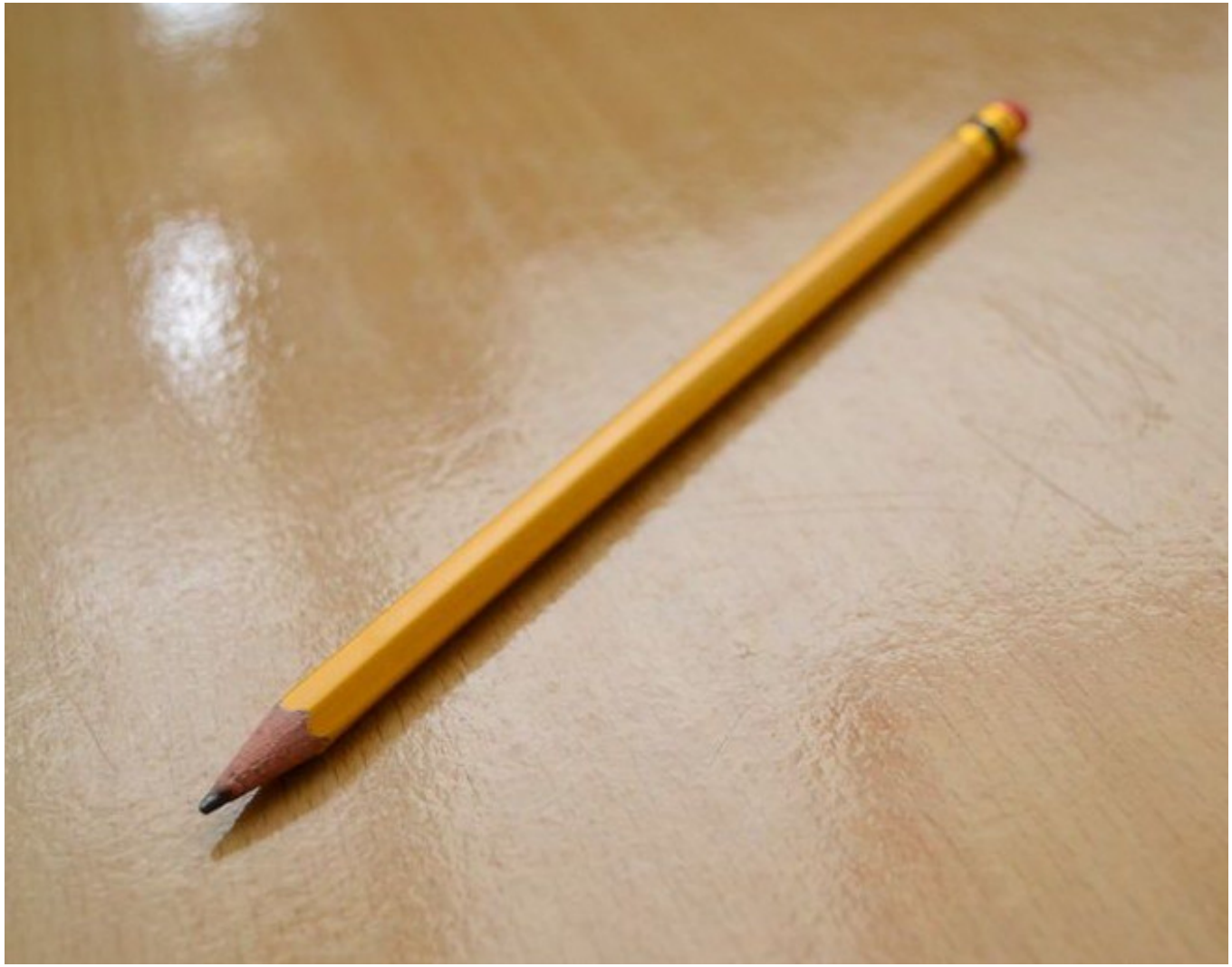
Cellulo Interaction spectrum **CoWriter**

NON-SOCIAL INTERACTION

What is the most effective learning tool in a classroom?

NON-SOCIAL INTERACTION

What is the most effective learning tool in a classroom?



Pens and paper are pervasive...

...so should the robots

CELLULO: DESIGN PRINCIPLES

- **ubiquitous**: a pervasive yet unremarkable tool that blend into the daily learning routine; has to be trustworthy (i.e. reliable), readily replaceable (i.e. cheap, no affective bonding), intuitive (i.e. few simple affordances)

[Özgür, Lemaignan et al. **Cellulo: Versatile Handheld Robots for Education** – HRI 2017]

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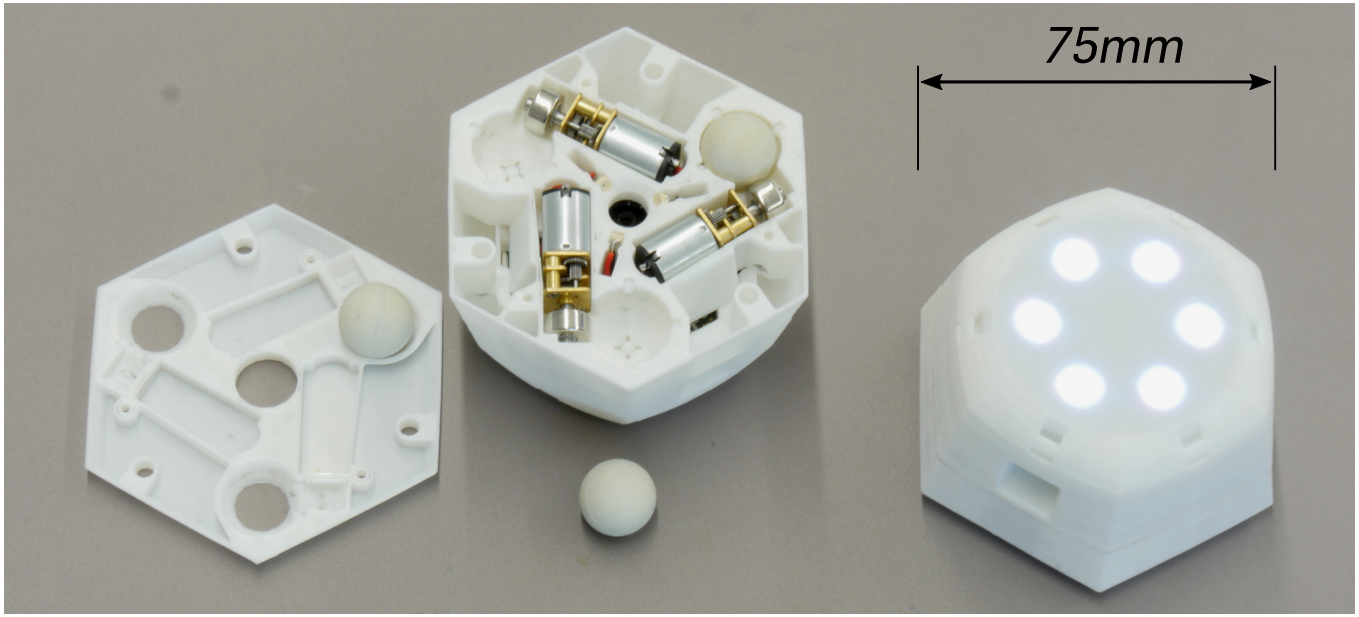
- **versatile**: applicable to a broad range of learning scenarios; the robots' hardware, appearance and interaction modalities must not imply or be constrained to specific use cases
- **practical**: to gain field acceptance in the classrooms, educative robots must critically represent a net educative gain and must not incur higher workload for the teachers

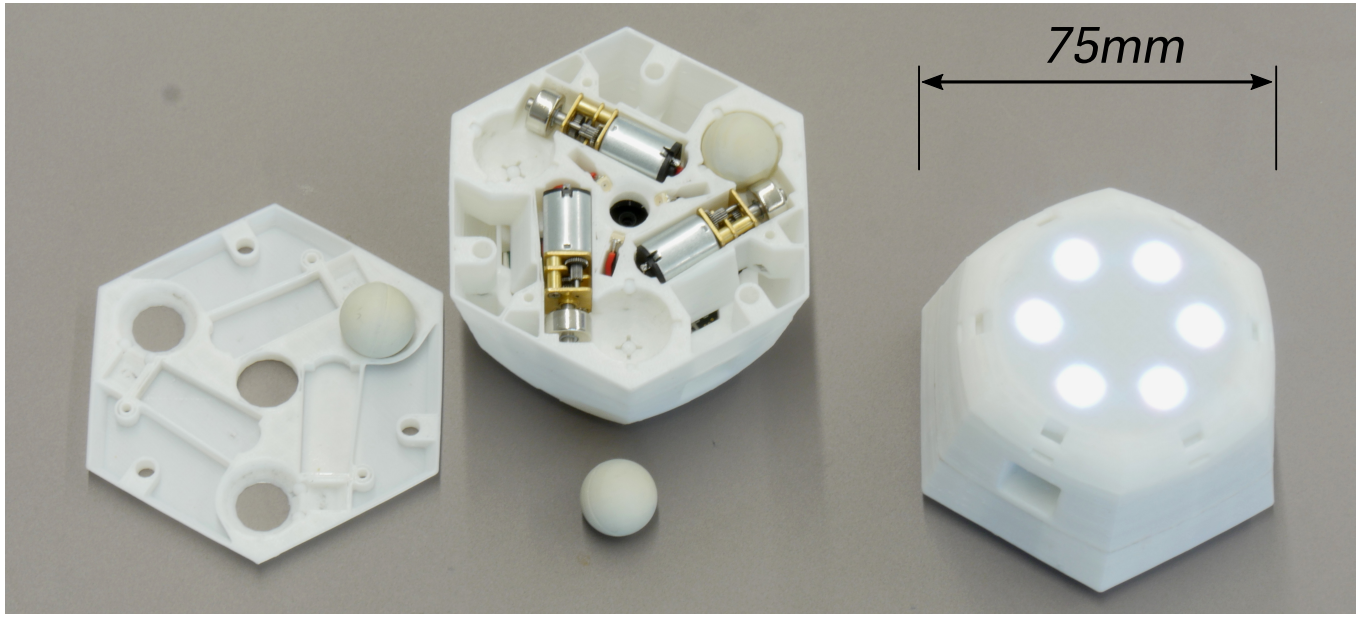
[Özgür, Lemaignan et al. **Cellulo: Versatile Handheld Robots for Education** – HRI 2017]

CELLULO: HARDWARE



- Holomonic motion
- Sub-mm absolute localisation (no external hardware)
- Haptic feedback + tactile RGB LED buttons
- Bluetooth

CELLULO: HARDWARE



- Holomonic motion
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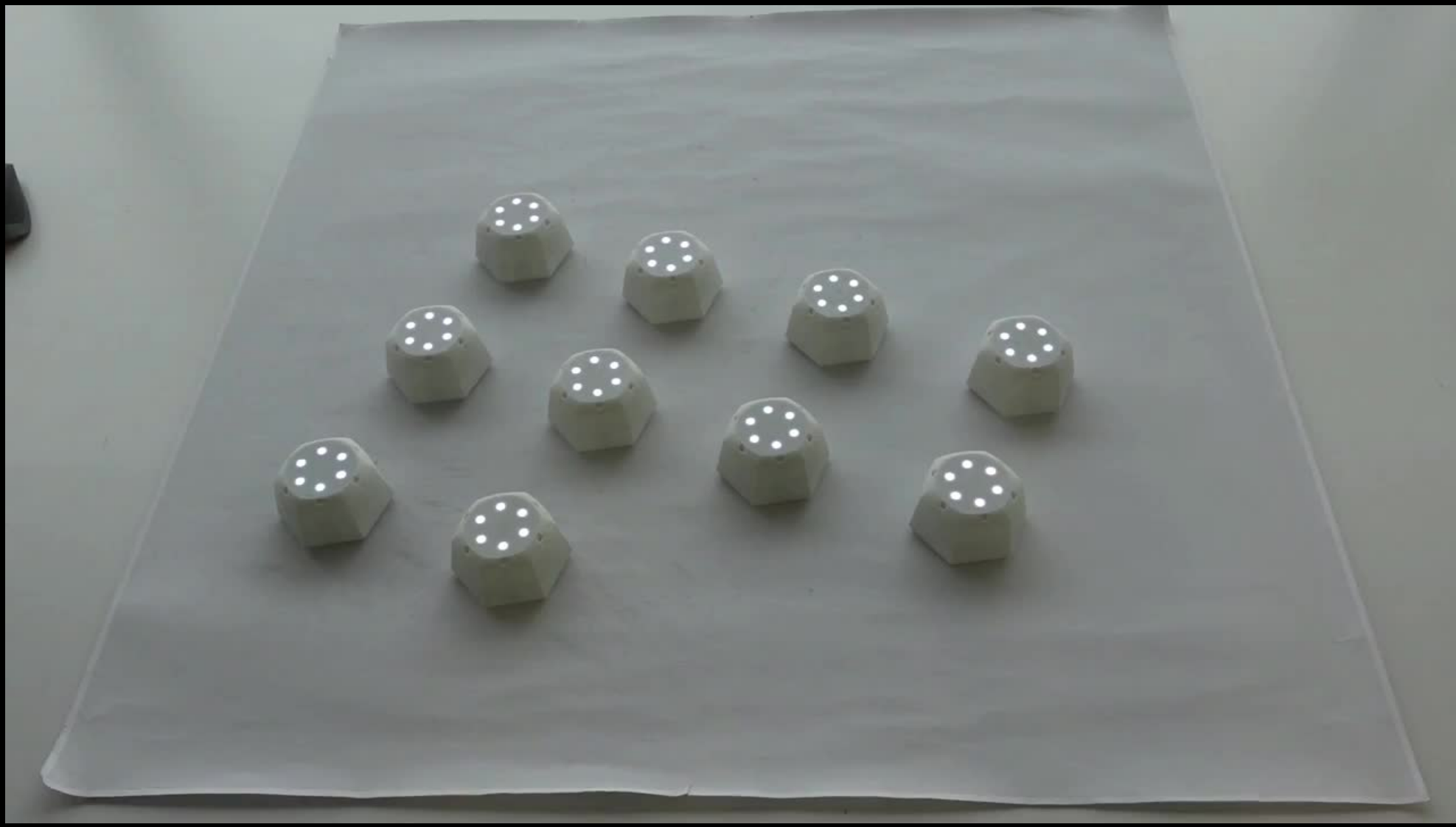
- Haptic feedback + tactile RGB LED buttons
- Bluetooth
- Affordable (prototype: €125)



INTERACTION WITH THE PAPER

Critically, Cellulo is meant as an **interaction between (classroom-friendly) paper and the robots**.

[Hostettler, Özgür, Lemaignan et al. **Real-Time High-Accuracy 2D Localization with Structured Patterns** – ICRA 2016]

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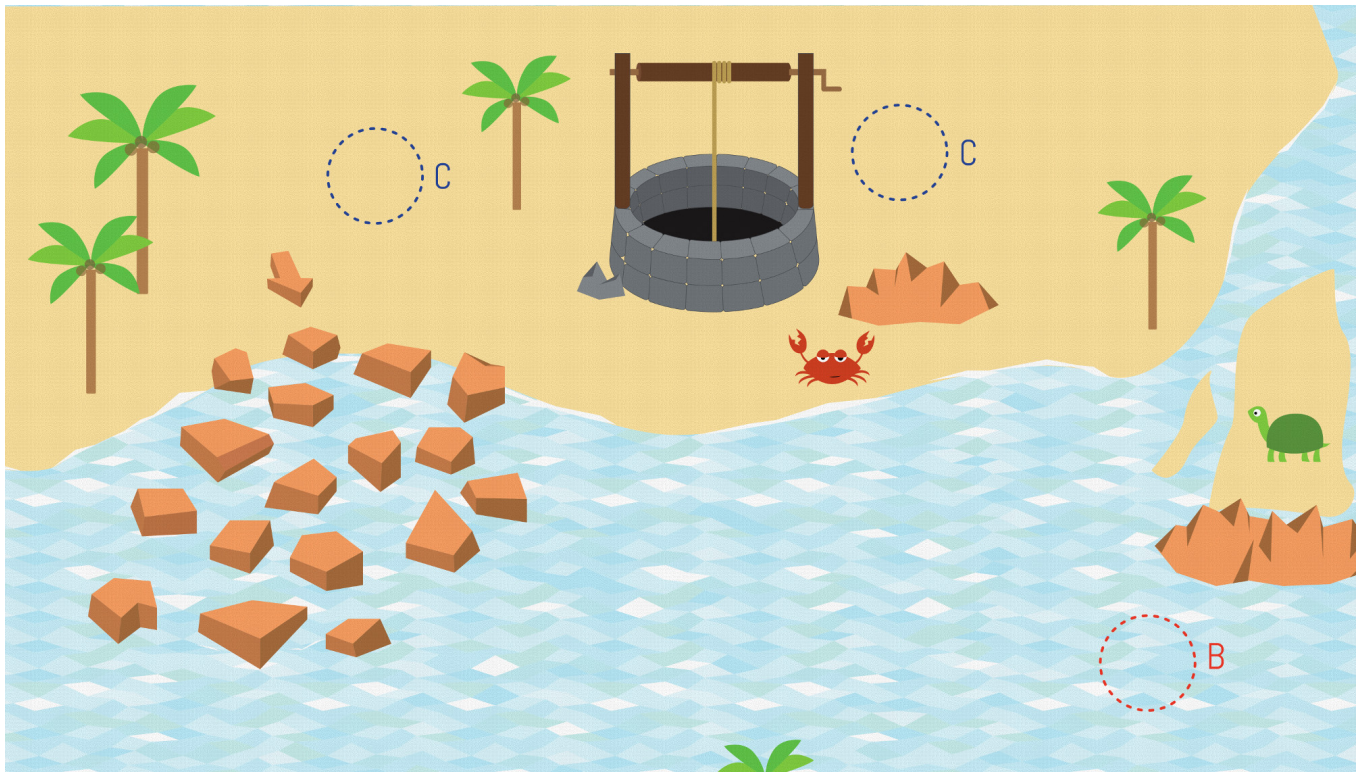

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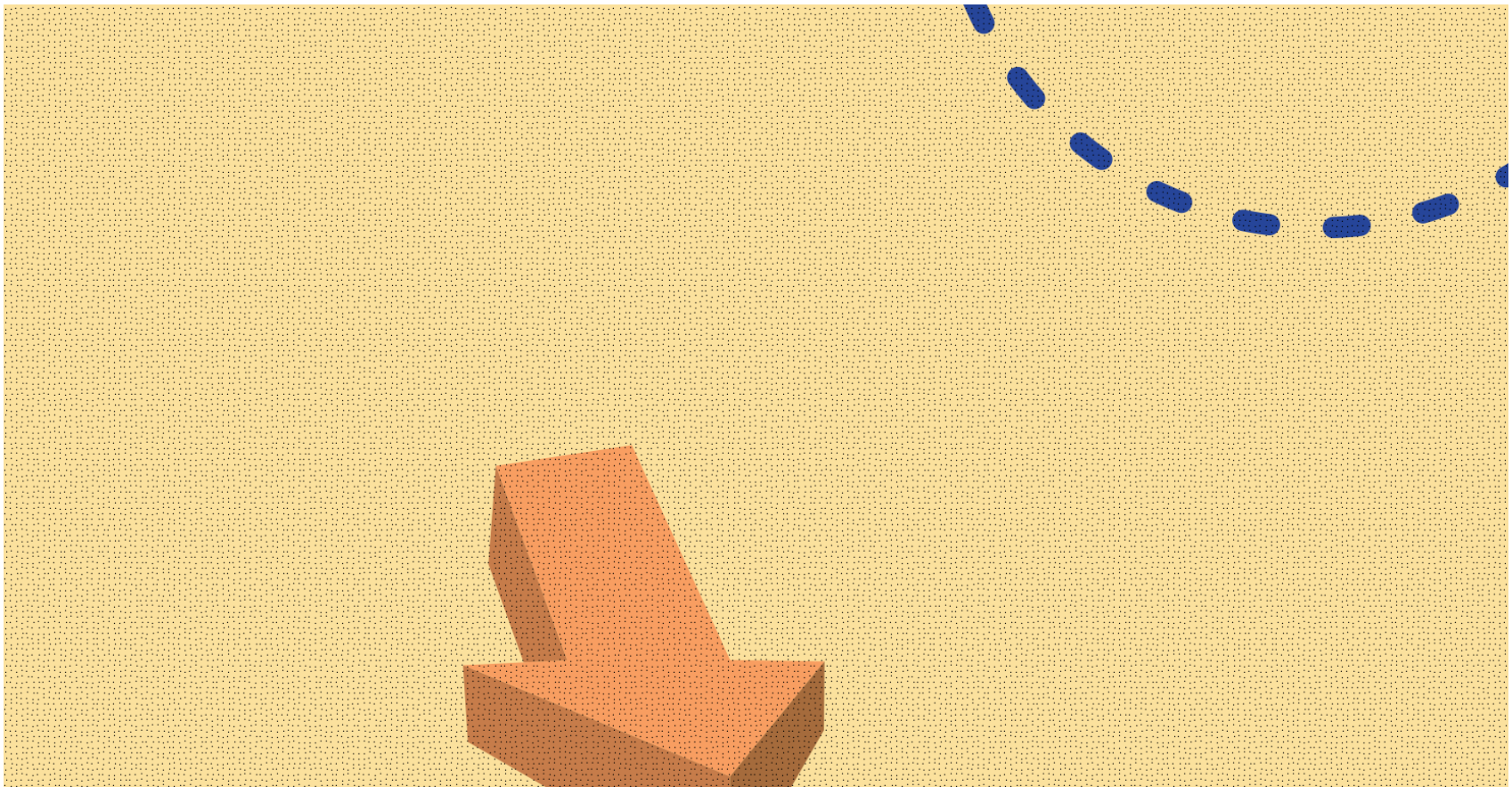


[Hostettler, Özgür, Lemaignan et al. **Real-Time High-Accuracy 2D Localization with Structured Patterns** – ICRA 2016]

INTERACTION WITH THE PAPER

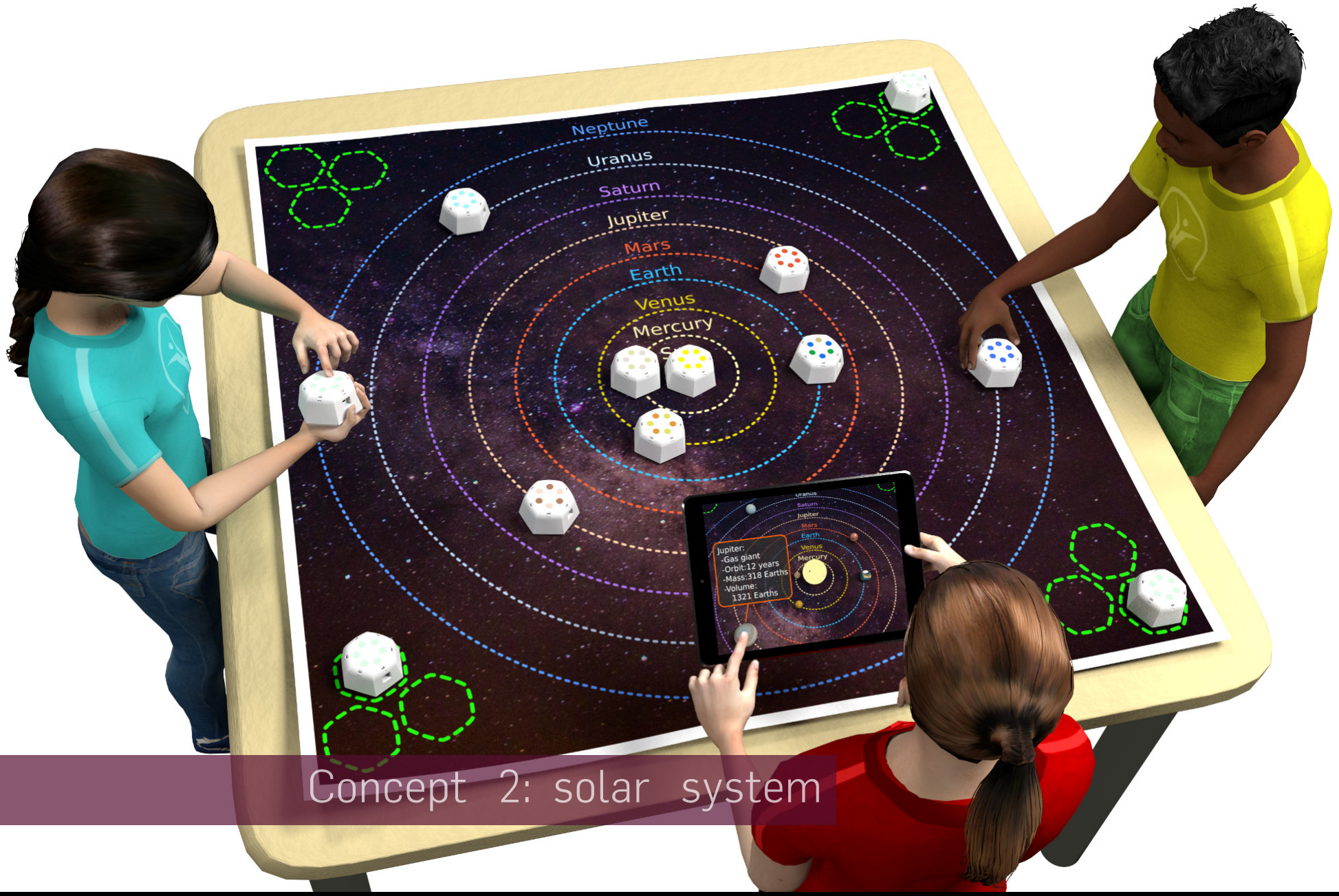
Critically, Cellulo is meant as an **interaction between (classroom-friendly) paper and the robots**.

Achieved through a **paper-based absolute localisation system**

- even more than 'classroom-friendly', paper is 'teacher-friendly'
- easy to manipulate, copy, print, cutout, dispose...
- unique activity IDs: drop the robots onto the sheet, it recognizes the activity

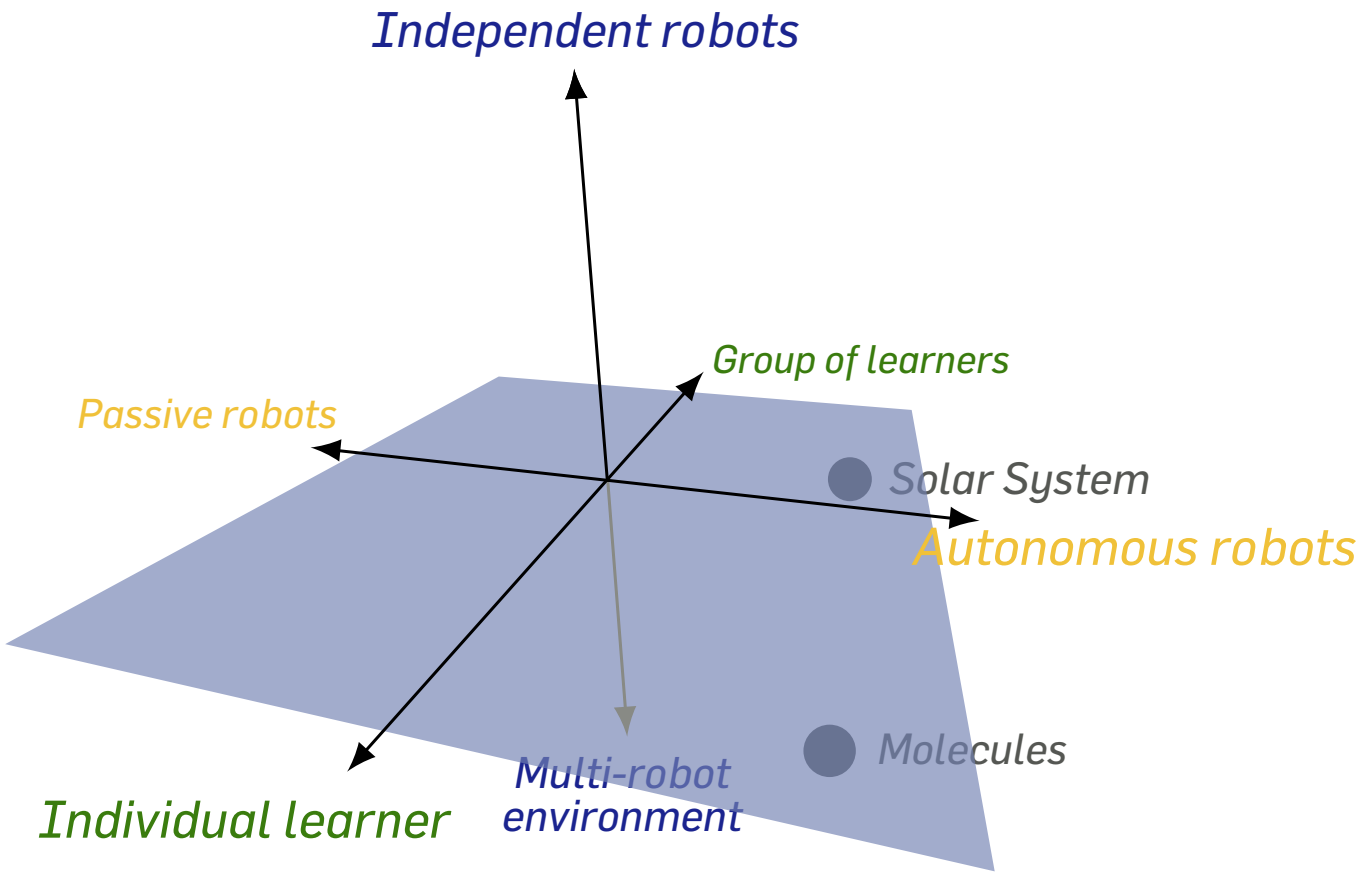
[Hostettler, Özgür, Lemaignan et al. **Real-Time High-Accuracy 2D Localization with Structured Patterns** – ICRA 2016]


$O_2 + 2H_2 = 2H_2O$
Reactor
Reactor 1
Chemistry Lab
Concept 1: chemistry



Concept 2: solar system

INTERACTION DESIGN SPACE



[Özgür, Lemaignan et al. **Cellulo: Versatile Handheld Robots for Education** – HRI 2017]

...at the other end of the spectrum...

TECHNICAL CHALLENGES

- Get a child-proof robot to write...

TECHNICAL CHALLENGES

- Get a child-proof robot to write...
- ...badly...

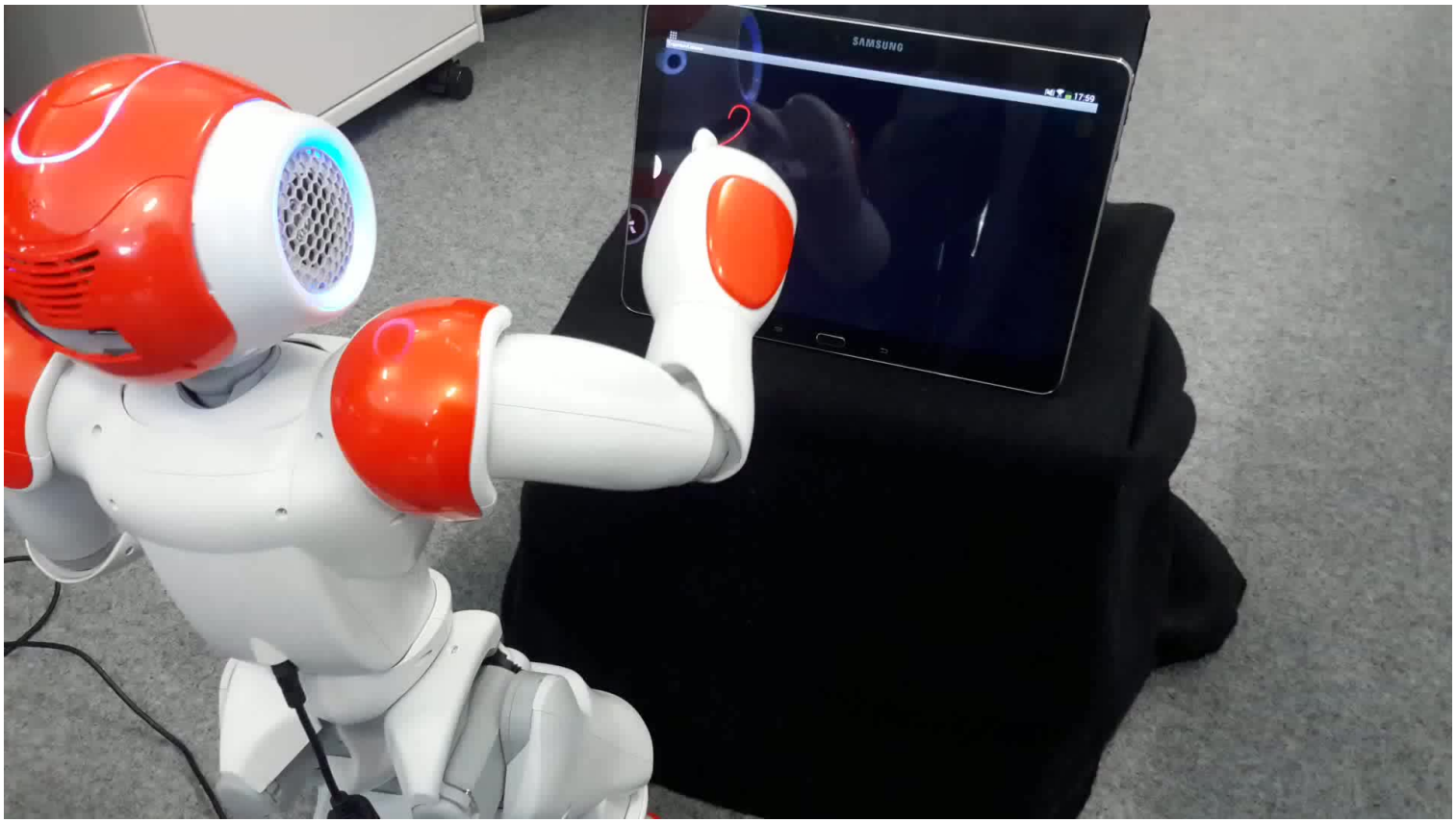
TECHNICAL CHALLENGES

- Get a child-proof robot to write...
- ...badly...
- Make it able to learn...

TECHNICAL CHALLENGES

- Get a child-proof robot to write...
- ...badly...
- Make it able to learn...
- ...with the help of children

COWRITER IMPLEMENTATION



[Hood, Lemaignan et al. **When Children Teach a Robot to Write: An Autonomous Teachable Humanoid [...]** – HRI 2015]

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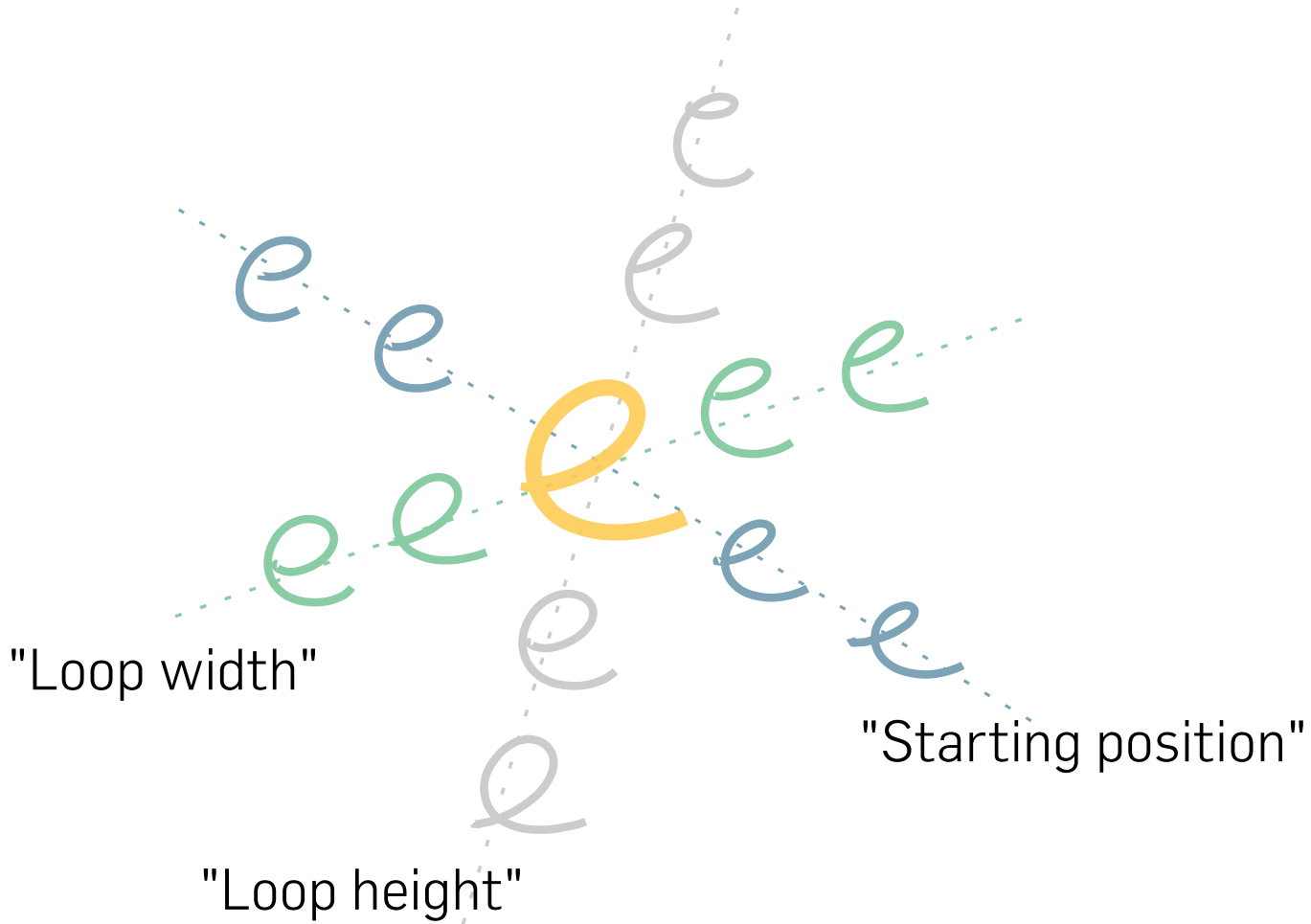

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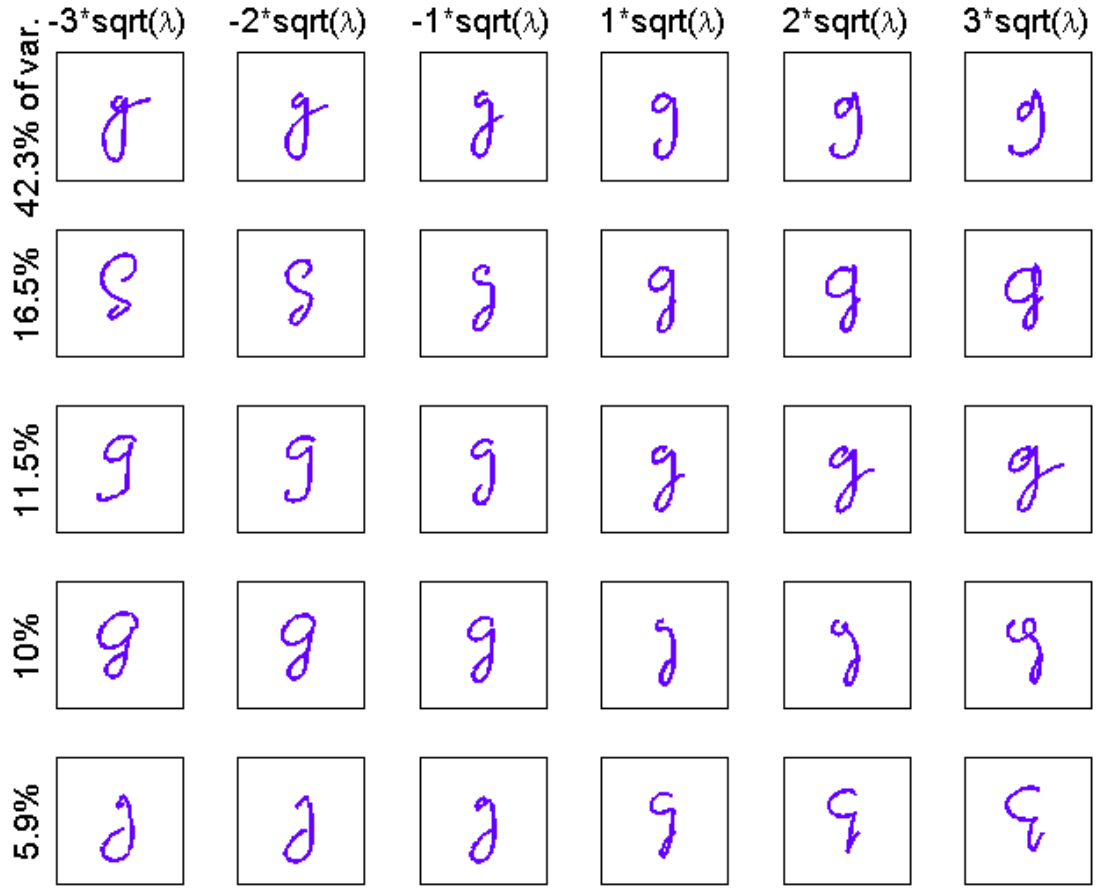

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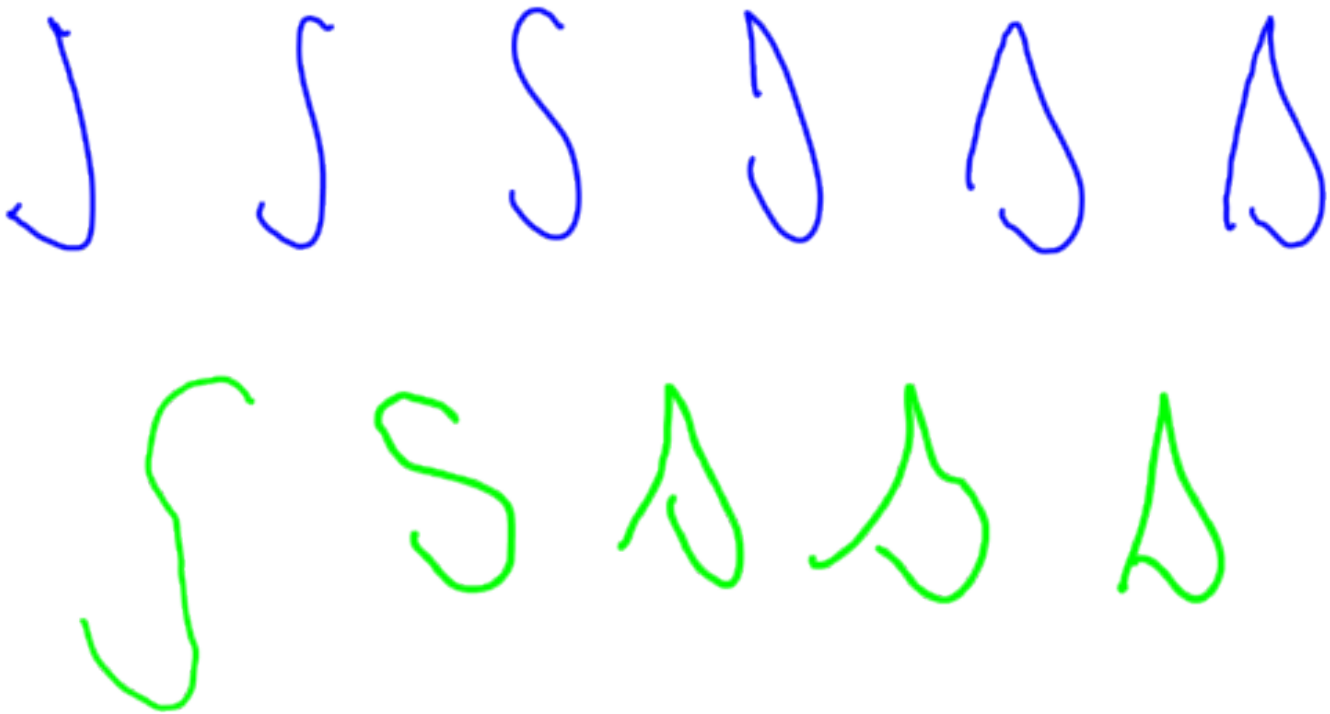

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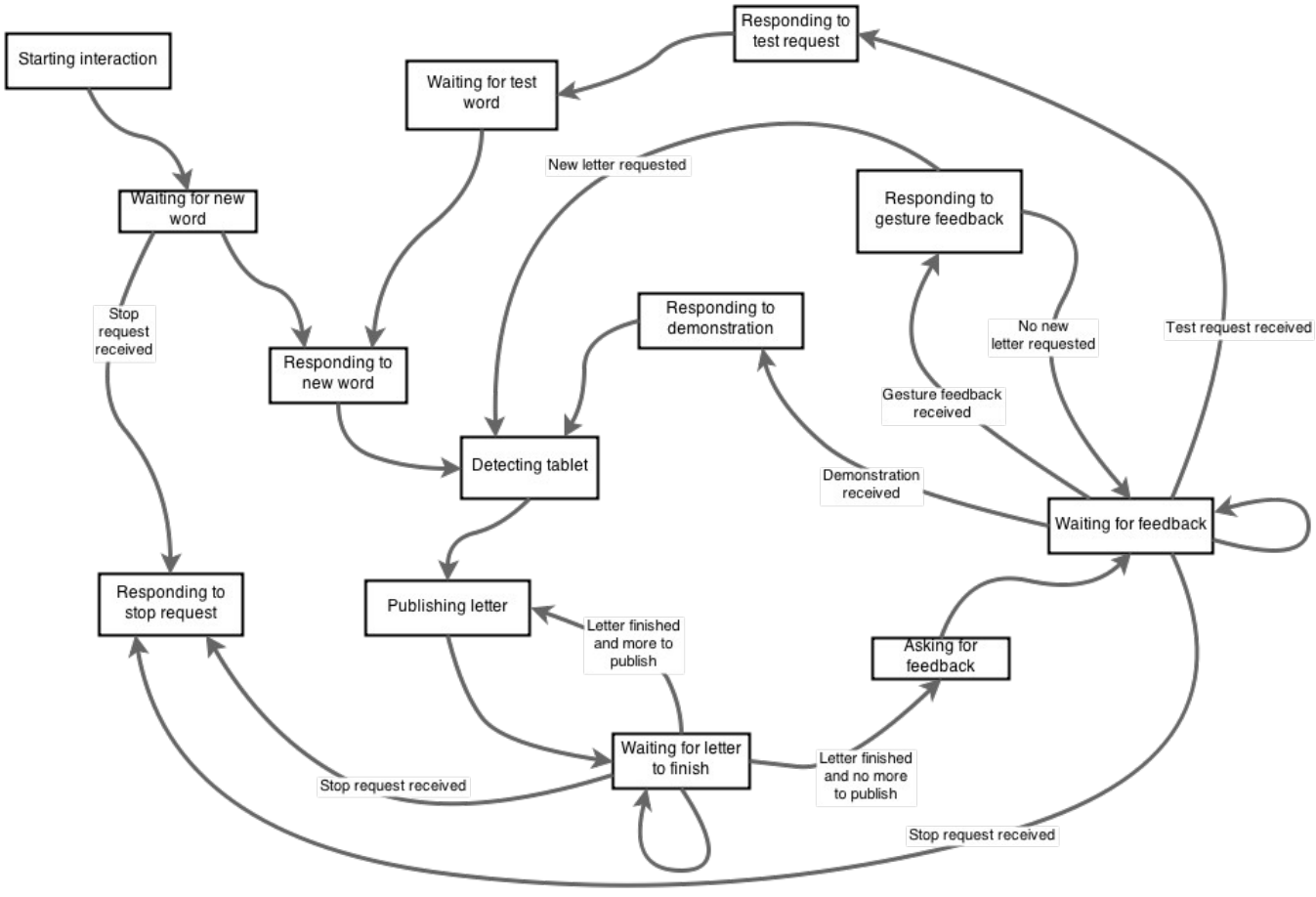
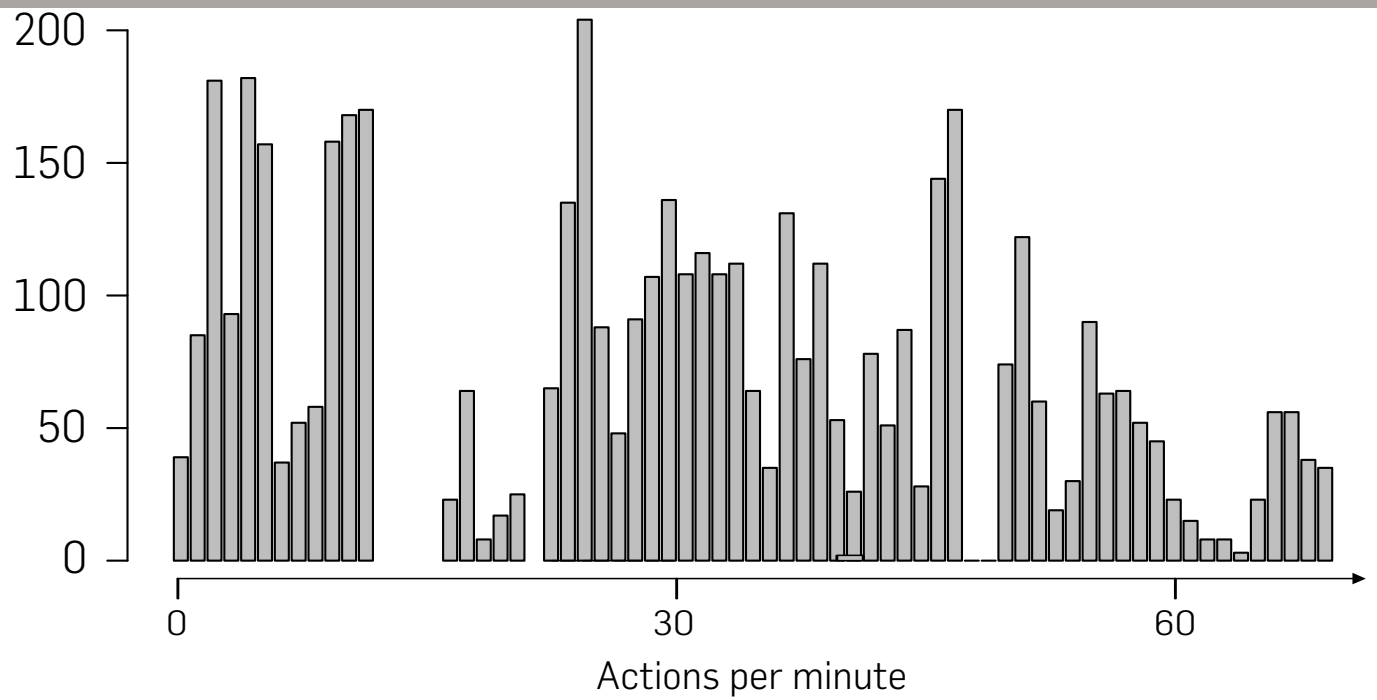

Starting interaction
Responding to test request
Waiting for test word
Waiting for new word
New letter requested
Responding to gesture feedback
Stop request received
Responding to demonstration
No new letter requested
Test request received
Responding to new word
Gesture feedback received
Detecting tablet
Demonstration received
Waiting for feedback
Responding to stop request
Publishing letter
Letter finished and more to publish
Asking for feedback
Waiting for letter to finish
Letter finished and no more to publish
Stop request received
Stop request received

PRACTICAL CRI



lightbar	on_bumped	active_wait
on_toy_added	up_down_row	closeeyes
move	wakeup	lightpattern
background_blink	look_at_caresses	turn
undock	on_toy_removed	idle
pulse_row	sneak_in	playsound
blink	on_lolette_removed	blush
on_lolette	fall_asleep	
placeeyes	look_at_lolette	

◂ Supplementary material

Can we make the analysis of child-robot interaction **practical**?

- (surface) engagement
- cognitive perception/anthropomorphism
- child speech recognition

WITH-ME-NESS

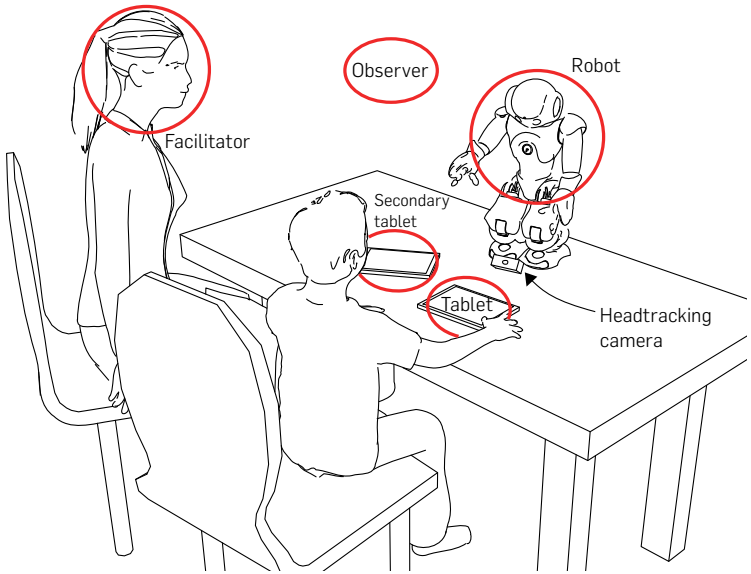
“With-me-ness”: real-time estimation of surface engagement

[Lemaignan et al. **From Real-time Attention Assessment to “With-me-ness” in Human-Robot Interaction** HRI 2016]

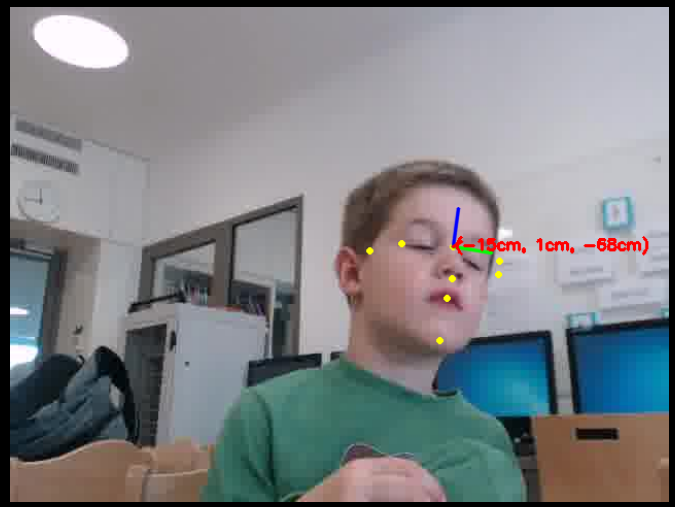
EXPECTED FOCUS

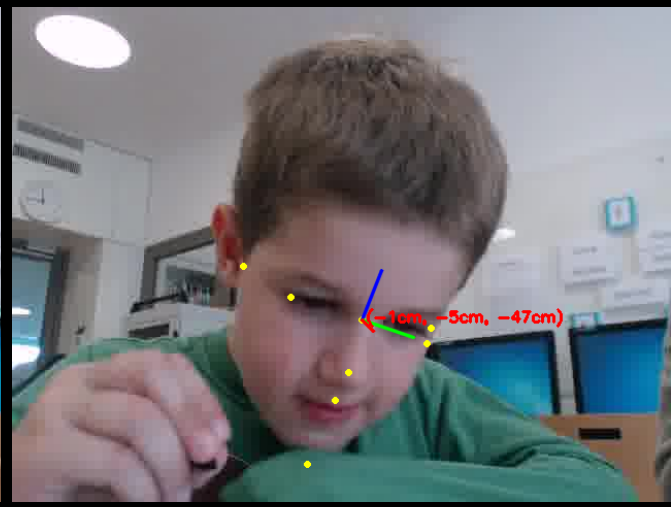
Example for the CoWriter task:

Interaction Phase	Expected targets
Presentation	robot
Waiting for word	secondary tablet
Writing word	tablet robot
Waiting for feedback	tablet secondary tablet
Story telling	robot
Bye	robot

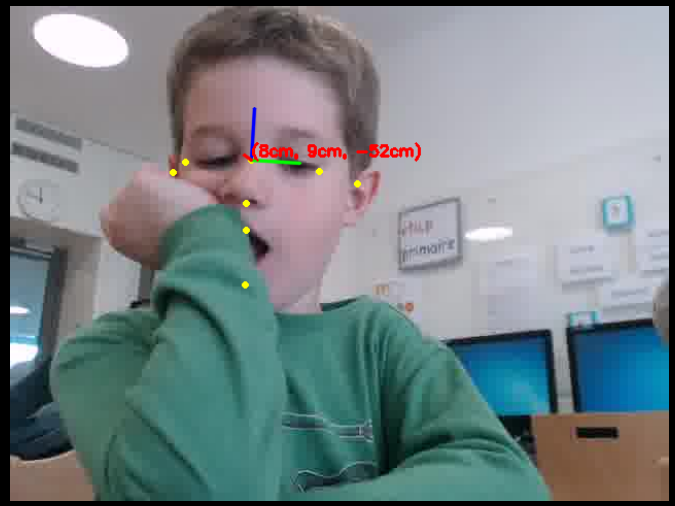


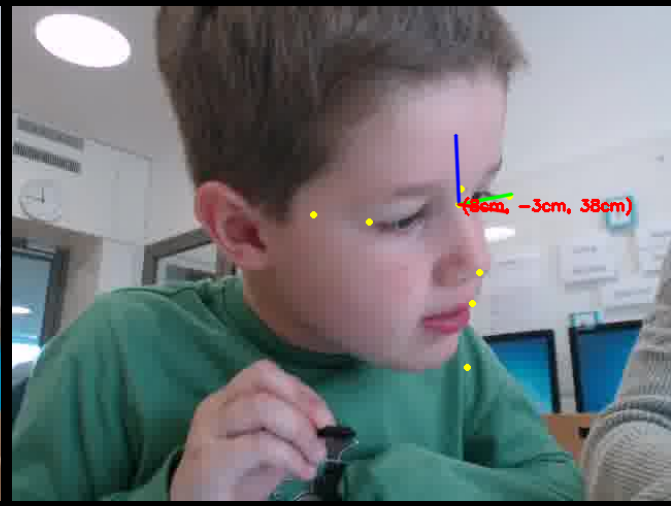

(−6cm, −7cm, −76cm)


(−15cm, 1cm, −68cm)

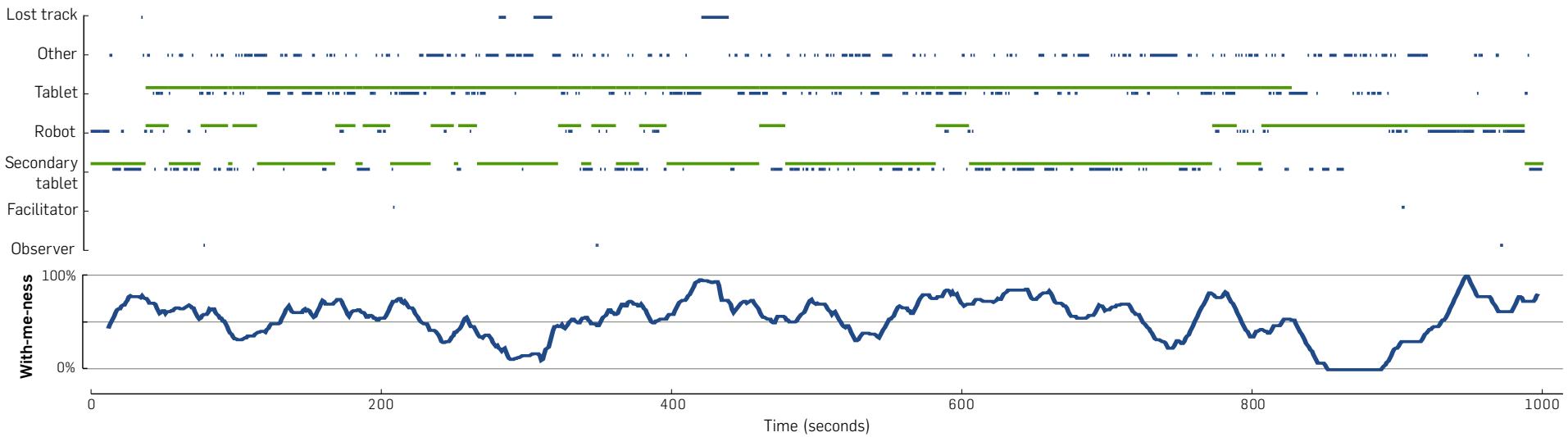

(−1cm, −5cm, −47cm)


(0cm, 8cm, −49cm)


(8cm, 9cm, −52cm)


(8cm, −3cm, 38cm)

WITH-ME-NESS



[Lemaignan et al. **From Real-time Attention Assessment to "With-me-ness" in Human-Robot Interaction** HRI 2016]

WITH-ME-NESS IS…

With-me-ness is…

- An **objective** & **quantitative** precursor of engagement…
- …based on matching the **user's focus of attention** with a set of **prior expectations**
- Can be computed **on-line** by the robot…
- …and **sensitive to** the (task-dependent) **set of expectations**
- ⇒ **relative** metric!

◂ Supplementary material

[Lemaignan et al. **From Real-time Attention Assessment to "With-me-ness" in Human-Robot Interaction** HRI 2016]

CONSTRUCTS FOR COGNITIVE PERCEPTION ANALYSIS

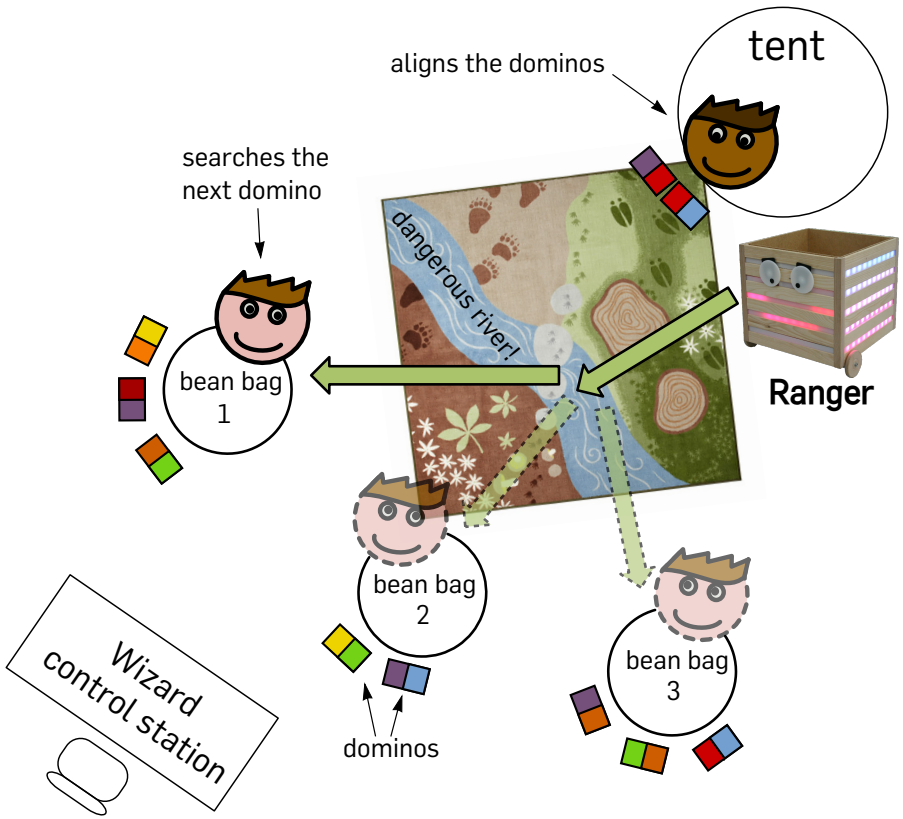
Expectations
How do you imagine a robot? *What could it look like?* *Have you ever seen a robot before?*
Impression
When you first saw R, what did you think? *Is R a robot? How do you know?* *Did you expect R would come over to you when you call it?* *What happened when you put the domino in the box?*
Ascribe intention
Do you think R could go out the door all by itself? *Does R always obey / come over to you?* *Could R do something silly?* *Why did R not come over to you when you called it?*

Ascribe perceptual capabilities
Here is a domino. Do you think R can see it? *When I say "Hello R!", do you think R can hear it?*
Ascribe emotional state
Does R have feelings? Can R be happy or sad sometimes?
Social acceptance
Do you like R? Why (not)? *What do you (not) like about it?* *Would you like to have R at home?*
Companionship
Could R be your friend? Why (not)?
Ascribe moral standing
Assume you go on a holiday for two weeks. Is it alright to leave R alone at home? Why (not)?

◂ Supplementary material

BEHAVIOUR VS PERCEPTION?

Any relation between the behavioural and perceptual measurements?



[Lemaignan, Fink, Mondada, Dillenbourg **You're Doing It Wrong! Studying Unexpected Behaviors in CRI** ICSR 2015]

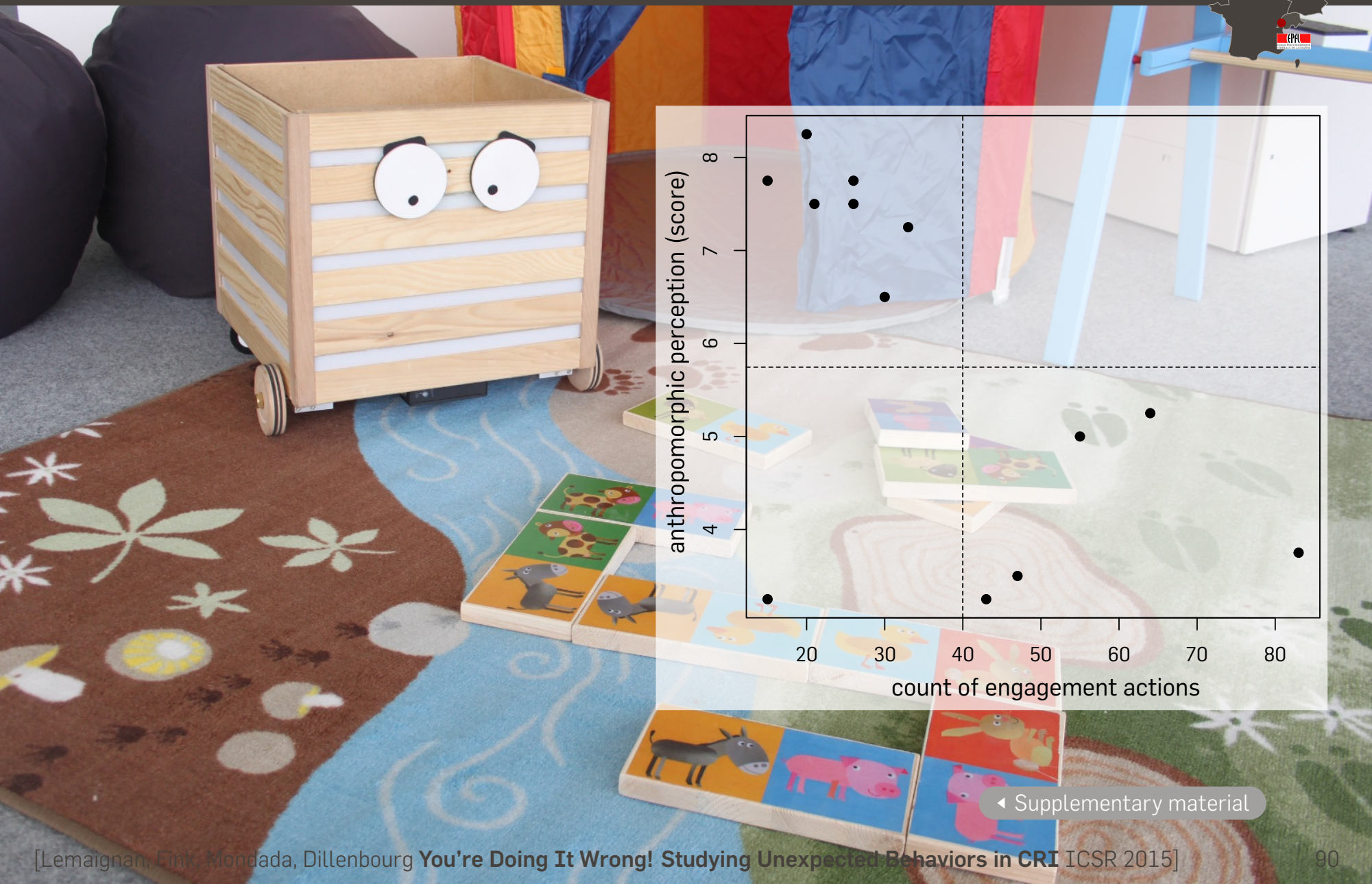
BEHAVIOUR VS PERCEPTION?

Any relation between the behavioural and perceptual measurements?

We can compute for each pair an “anthropomorphic perception” score based on the cognitive ascriptions, and…

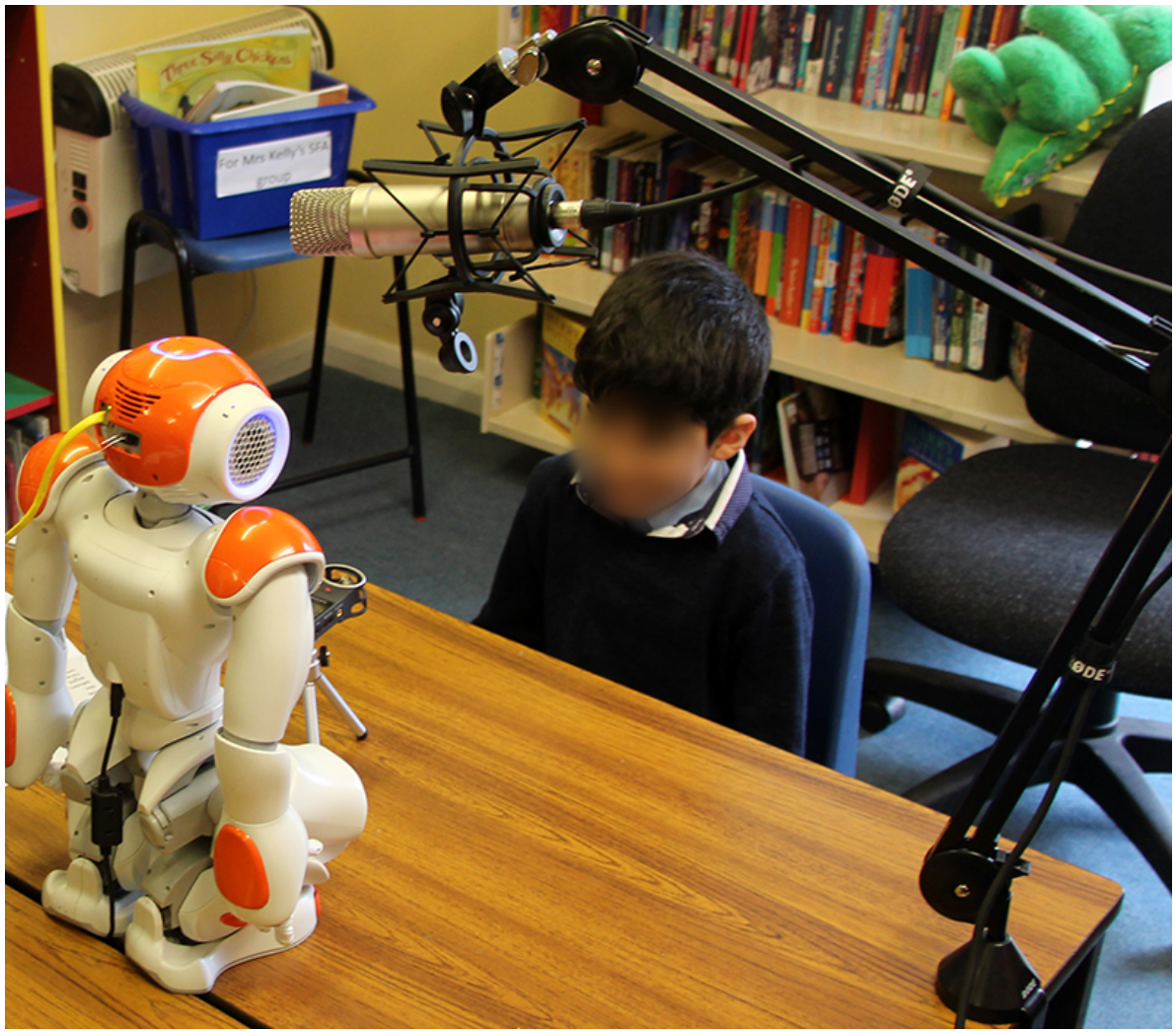
[Lemaignan, Fink, Mondada, Dillenbourg **You’re Doing It Wrong! Studying Unexpected Behaviors in CRI** ICSR 2015]

ANTHROPOMORPHISM != ENGAGEMENT



◂ Supplementary material

AUTOMATIC SPEECH RECOGNITION WITH CHILDREN



[Kennedy, Lemaignan et al. **Child Speech Recognition in Human-Robot Interaction[...]** HRI 2017]

AUTOMATIC SPEECH RECOGNITION WITH CHILDREN

	Google		Bing		Sphinx		Nuance	
	M LD	*% rec.*	*M* LD	*% rec.*	*M* LD	*% rec.*	*M* LD	*% rec.*
fixed (*n*=34)	**0.34**	*11.8 [38]*	0.64	*0 [0]*	0.68	*0 [0]*	0.76	*0 [0]*
spontaneous (*n*=222)	**0.39**	*6.8 [17.6]*	0.64	*0.5 [2.4]*	0.80	*0 [0]*	0.80	*0 [0]*
spontaneous clean only (*n*=83)	**0.40**	*6.0 [16.9]*	0.63	*1.2 [1.2]*	0.78	*0 [0]*	0.78	*0 [0]*

M LD: mean Levenshtein distance, at word level.

◂ Supplementary material

[Kennedy, Lemaignan et al. **Child Speech Recognition in Human-Robot Interaction[...]** HRI 2017]

REFRAMING THE RESEARCH

OUR STARTING POINT

Symbolic artificial social cognition: works rather well as long as:

- we know what we want to do (in terms of task domain & declarative knowledge)
- interaction mostly relying on symbolic *perceptual inputs* (including visual perspective taking) rather abstract or less explicit representations

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Good for any practical HRI purposes? **mostly**!

However, intuitively, social modeling goes beyond computing what the human perceives or does not perceive → Flavell's ***cognitive connections*** vs ***mental representations***.

Symbolic cognition **does not explain much about how social cognition actually work**. We need a **principled approach** to social cognition for robots

A LONG-TERM DIRECTION

Adapting and unifying the large and disparate set of theories on social cognition to **build a theory of social cognition for robots**

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...or rather, **a computational model of social cognition for robots**

...or rather, an **embodied** computational model of social cognition?

ONE QUESTION

Can sociality emerge from interaction?

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Both “emerge” as ***arise from*** and “emerge“ as in ***emergent paradigm of cognition***!

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Both “emerge” as ***arise from*** and “emerge“ as in ***emergent paradigm of cognition***!

“Social cognition arising in interaction”? certainly looks like a situated & embodied view on cognition

A MODEL?

Models attempt to ***explain***:

> *"identifying the causes for an event or phenomenon of interest"*
>
> *"unifying disparate phenomena"*

A model's value is gained from

> *"predicting facts that, absent the theory, would be antecedently improbable"*

[cited in Lewandowsky and Farrell, **Computational Modeling In Cognition**, 2011]

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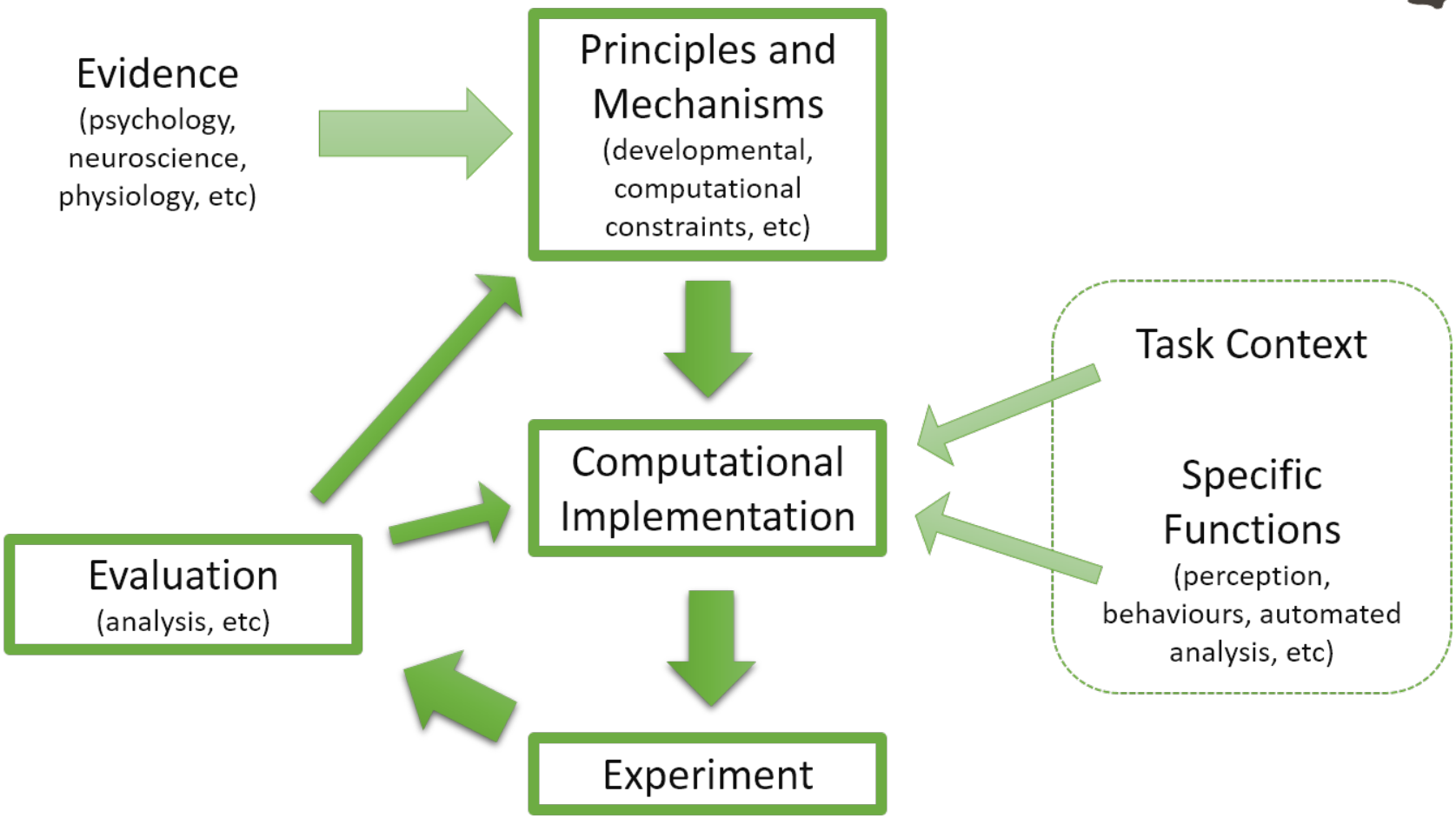
...we will come back to the predictive power of a model of artifical social cognition.

[cited in Lewandowsky and Farrell, **Computational Modeling In Cognition**, 2011]

COGNITIVE ARCHITECTURE AS A METHODOLOGY



[Baxter, Lemaignan, Trafton **Workshop on Cognitive Architectures for Social Human-Robot Interaction** HRI 2016]

SKETCHING A MODEL

A MODEL OF ARTIFICIAL SOCIAL COGNITION

I postulate **two stages**:

1. building models of others' minds
2. exploiting these models to socially act:
   - prediction, reading others' intentions
   - adapting own behaviour, alignment
   - establish join goals
   - ultimately, performing joint actions

→ Social analogs of *perception* & *action*

COGNITIVIST VS EMERGENT PARADIGMS

"building", "exploiting", "reading", "establishing"... my terminolgy denotes a cognitivist approach ('I, the designer of the system, explicitly implement these capabilities')

[see discussion in Vernon, **Artificial Cognitive Systems: A Primer** 2014]

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1. developing internal states ***connoting*** others' minds
2. perturbing (influencing) actions synthesis with these states

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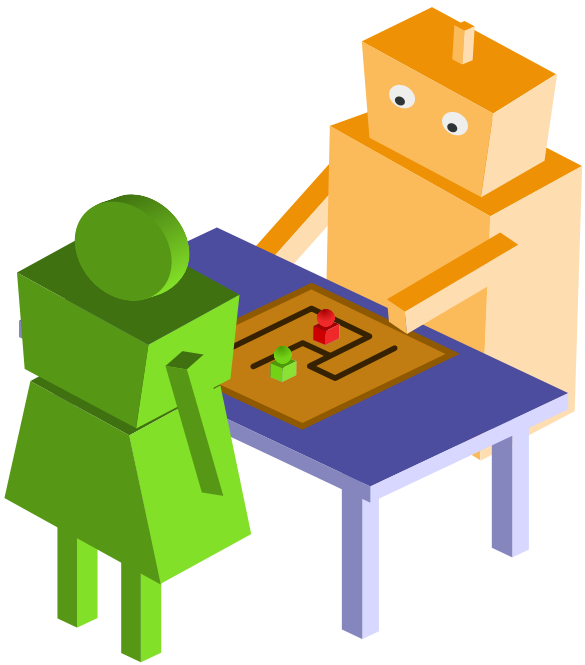
Hybrid approaches are possible – mapping to "raw phenomenal experience" vs "access counciousness".

[see discussion in Vernon, **Artificial Cognitive Systems: A Primer** 2014]

MODELING OTHERS' MIND?

In cognitive neurosciences: Graziano's *Attention Schemata Theory*



[Graziano **Consciousness and the Social Brain** – 2013]

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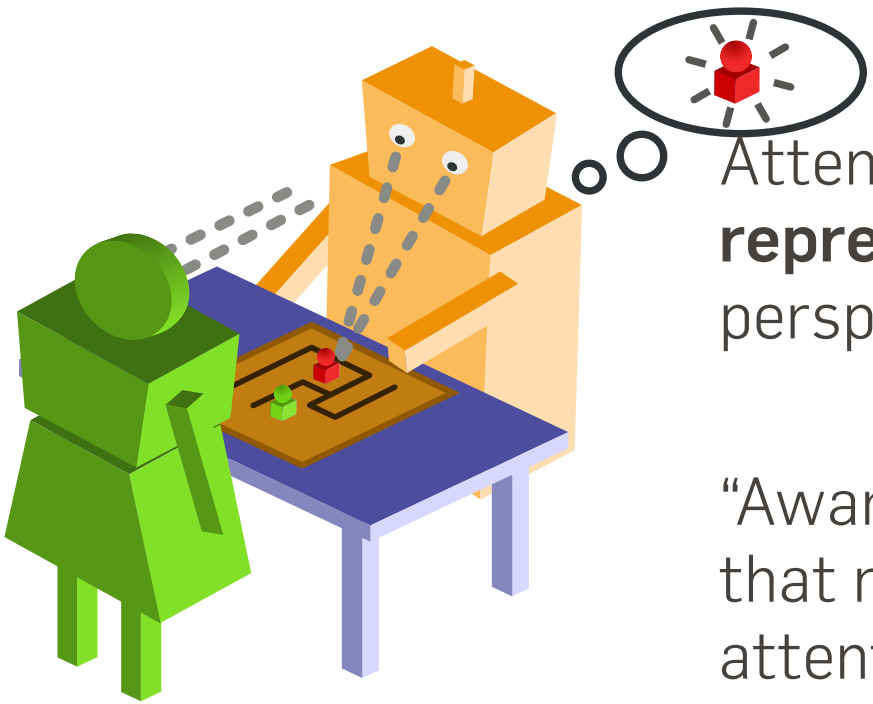

Attention is more about **representation** than visual perspective

"Awareness is a construct that represents the attentional state of a brain"

[Graziano **Consciousness and the Social Brain** – 2013]

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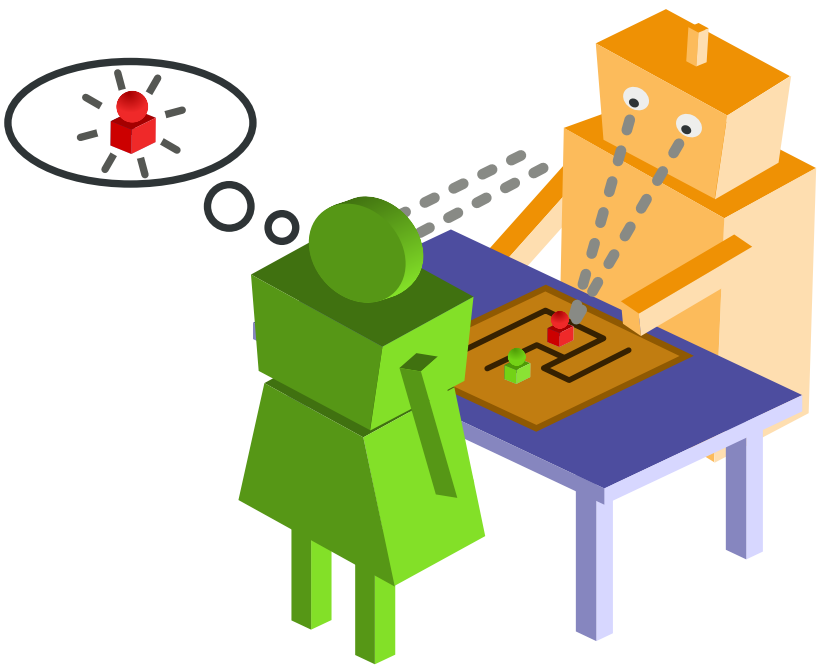

Graziano's postulate that modelling other's state of awareness is **mediated by one's own attentional system**, through joint attention

[Graziano **Consciousness and the Social Brain** – 2013]

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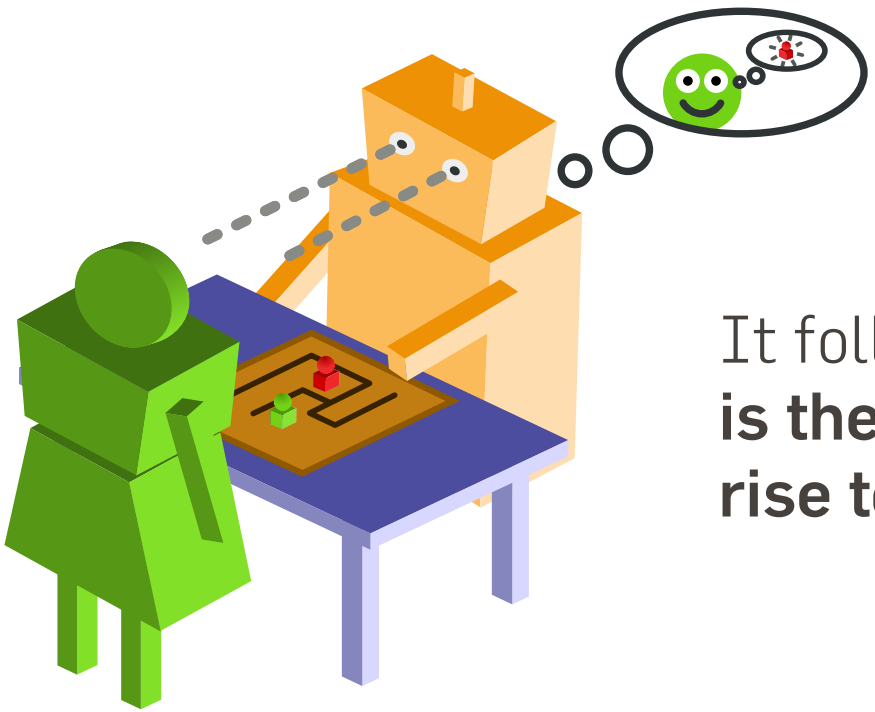

It follows that **joint attention is the process that gives rise to social awareness**

[Graziano **Consciousness and the Social Brain** – 2013]

SKETCHING A PATH FORWARD: MENTALIZING

Hypothesis 1: Graziano is right: mental representations are snapshots of *awareness*, *awareness* being itself a label for the *memory-mediated process of attention*.

SKETCHING A PATH FORWARD: MENTALIZING

Hypothesis 1: Graziano is right: mental representations are snapshots of *awareness*, *awareness* being itself a label for the *memory-mediated process of attention*.

Hypothesis 2: this can be extended to social cognition. **Modeling one other mental representations equates to taking snapshots of their current state of awareness**.

As we do not have direct access to others' process of attention, it has to be mediated. Following Graziano, we hypotesise that **modelling other's state of awareness is mediated by one's own attentional system, through joint attention mechanisms**.

IN MORE DETAILS

1. **mental representations** are **snapshots of what we are aware of**

[Graziano's Attention Schemata Theory; Desimone and Ducan **Biased Competition Model of Attention** 1995; Block 1996]

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7. In AI, *phenomal awareness* maps to connectionist approaches, while *access consciousness* maps to **symbolic representations**

[Graziano's Attention Schemata Theory; Desimone and Ducan **Biased Competition Model of Attention** 1995; Block 1996]

AN HYBRID MODEL OF COGNITION

- ***phenomenal experience*** modelled in a connectionist (sub-symbolic) fashion (associative memory network)
- ***access conciousness*** in a cognitivist (symbolic) fashion (typically, an ontology or epistemic logics)

$\Rightarrow$ bottom-up, from raw percepts to ***accessible*** representations

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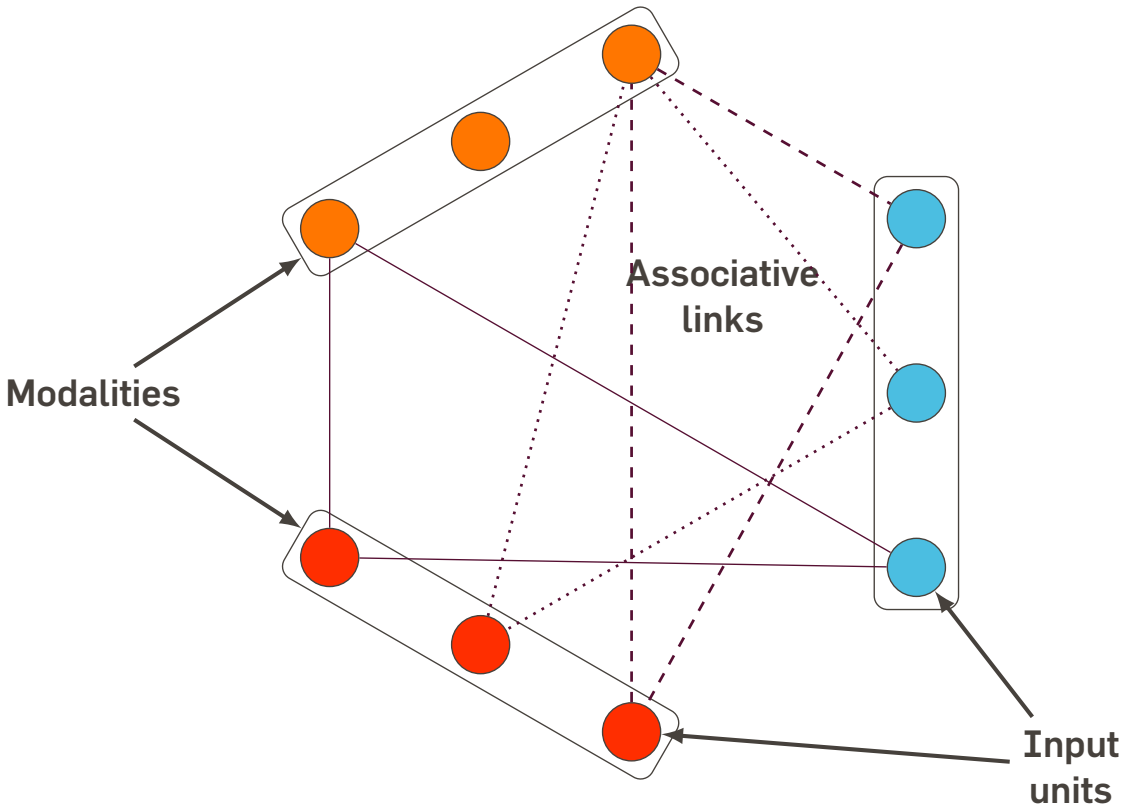
$\Rightarrow$ bottom-up, from raw percepts to *accessible* representations

The *Biased Competition Model of Attention* supports bottom-up as well as **top-down biasing mechanisms**:

- *bottom-up*: if a unit is activated longer/stronger, it biases the resulting attention to this unit.
- *top-down*: abstract cognitive processes can influence the memory network at symbolic level to bias the attention process. Practically less clear, but also potentially very interesting as it **closes the loop between the emergent and cognitivist paradigms**

ASSOCIATIVE MEMORY NETWORK



[Baxter et al., Cognitive Architecture for HRI: Towards Behavioural Alignment, 2013]

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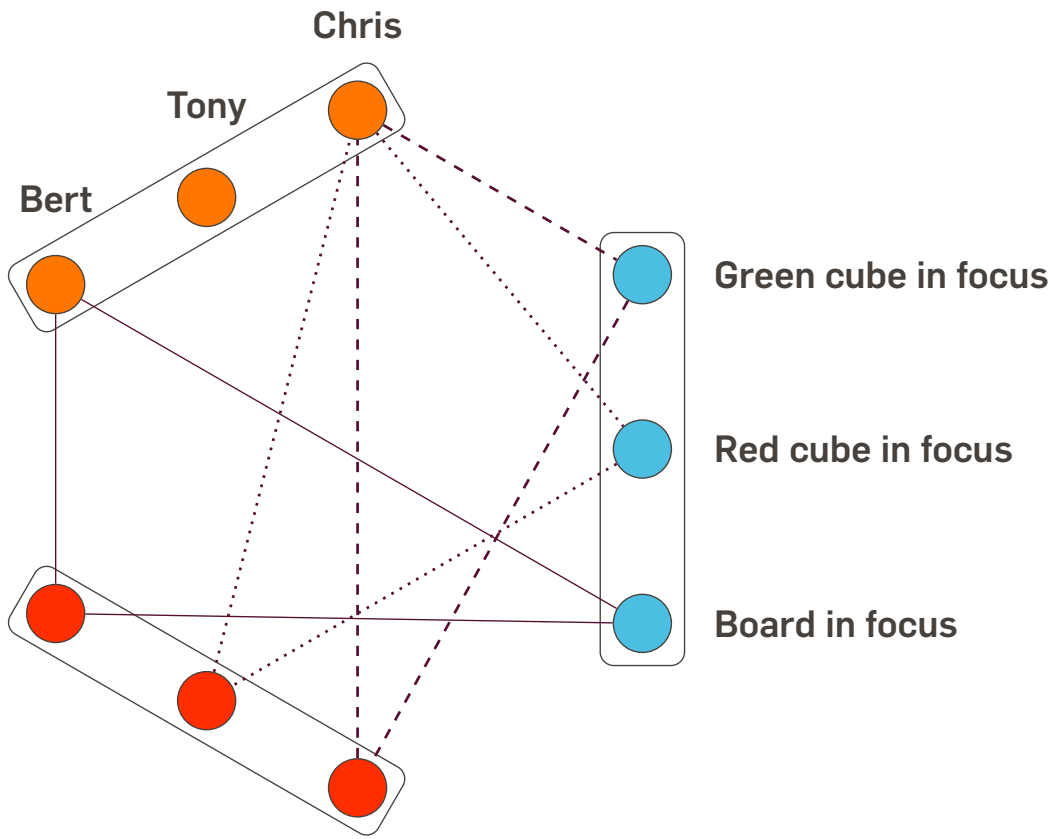

[Baxter et al., Cognitive Architecture for HRI: Towards Behavioural Alignment, 2013]

MANY GAPS CALLING FOR INVESTIGATION!

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- at epistemic level, if access to other's mental representations is *mediated* by one's own attentional system, these mental representations are subjective. **Can we equate humans' and robots' subjectivities?**

SKETCHING A PATH FORWARD: SOCIAL BEHAVIOURS

Hypothesis 3: together, representations of one's and others' minds are *necessary* and *sufficient* for social behaviours to emerge

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How? ...recruit me to discover ;-)

EXPERIMENTAL INVESTIGATION

AN EXPERIMENTAL FRAMEWORK

- The “Zoo design” play situation
- **Free play** with the following constraints:

  initial prompt (“Let’s build a zoo!”)
  limited set of tokens (cubes, Lego animals)
  spatially limited playground

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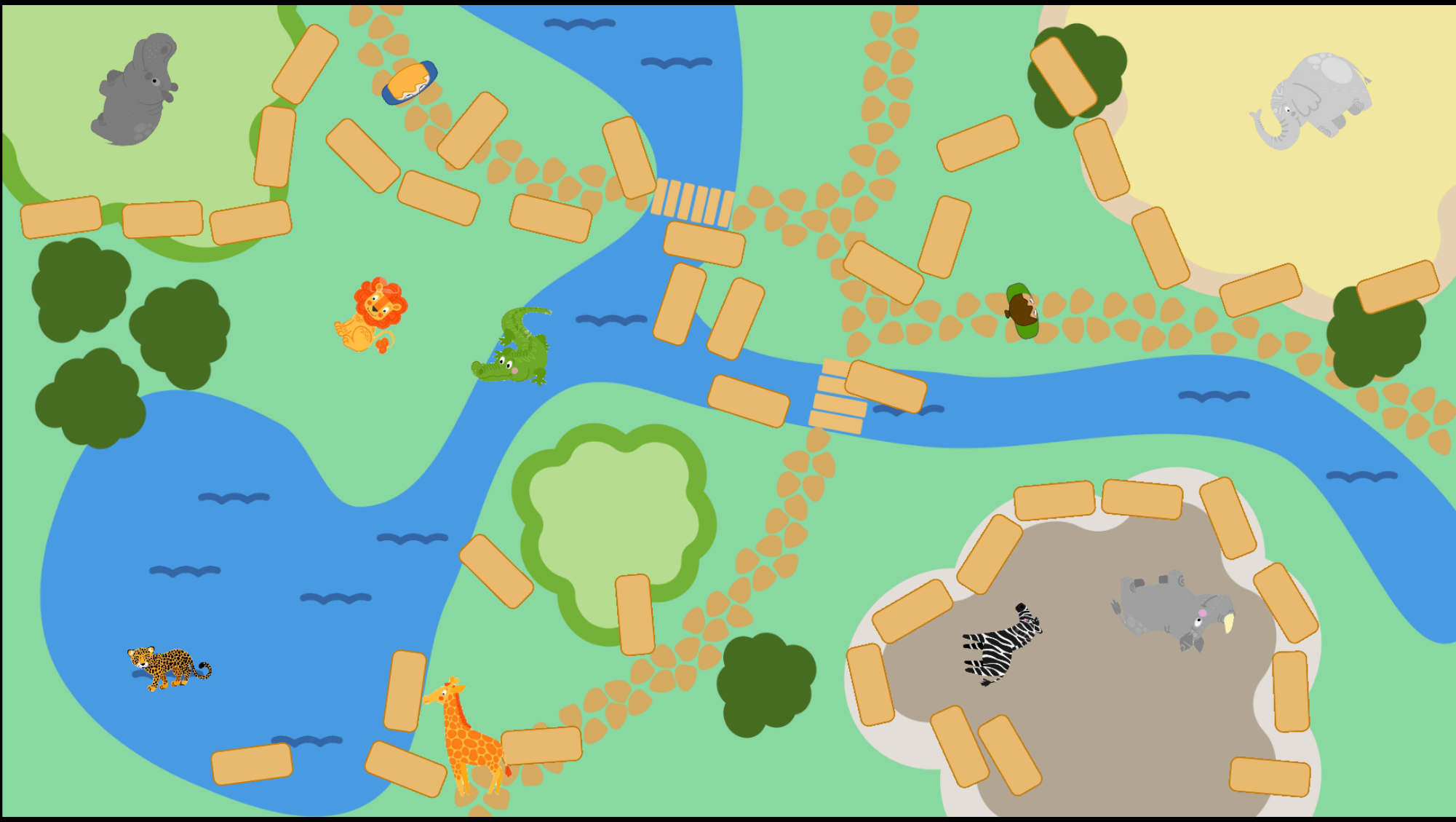
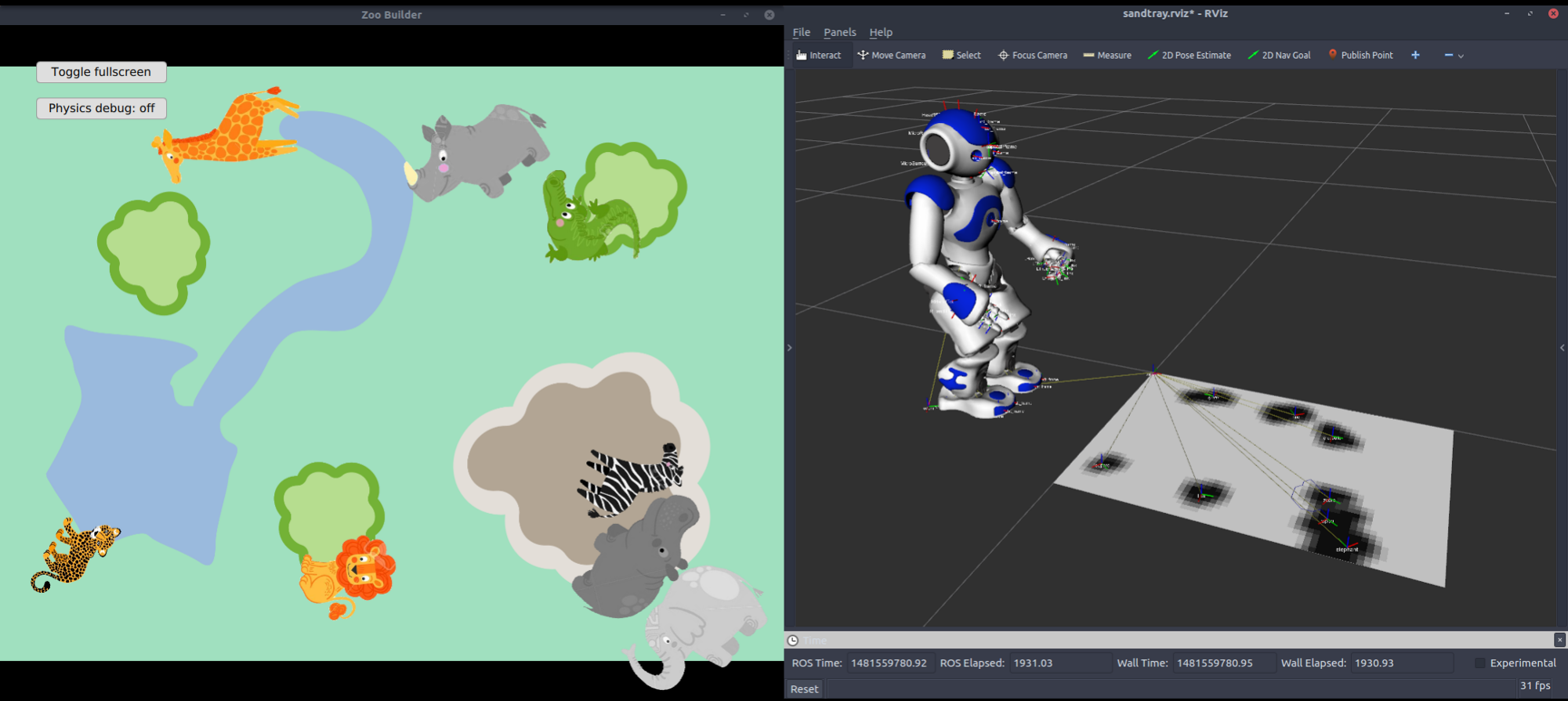
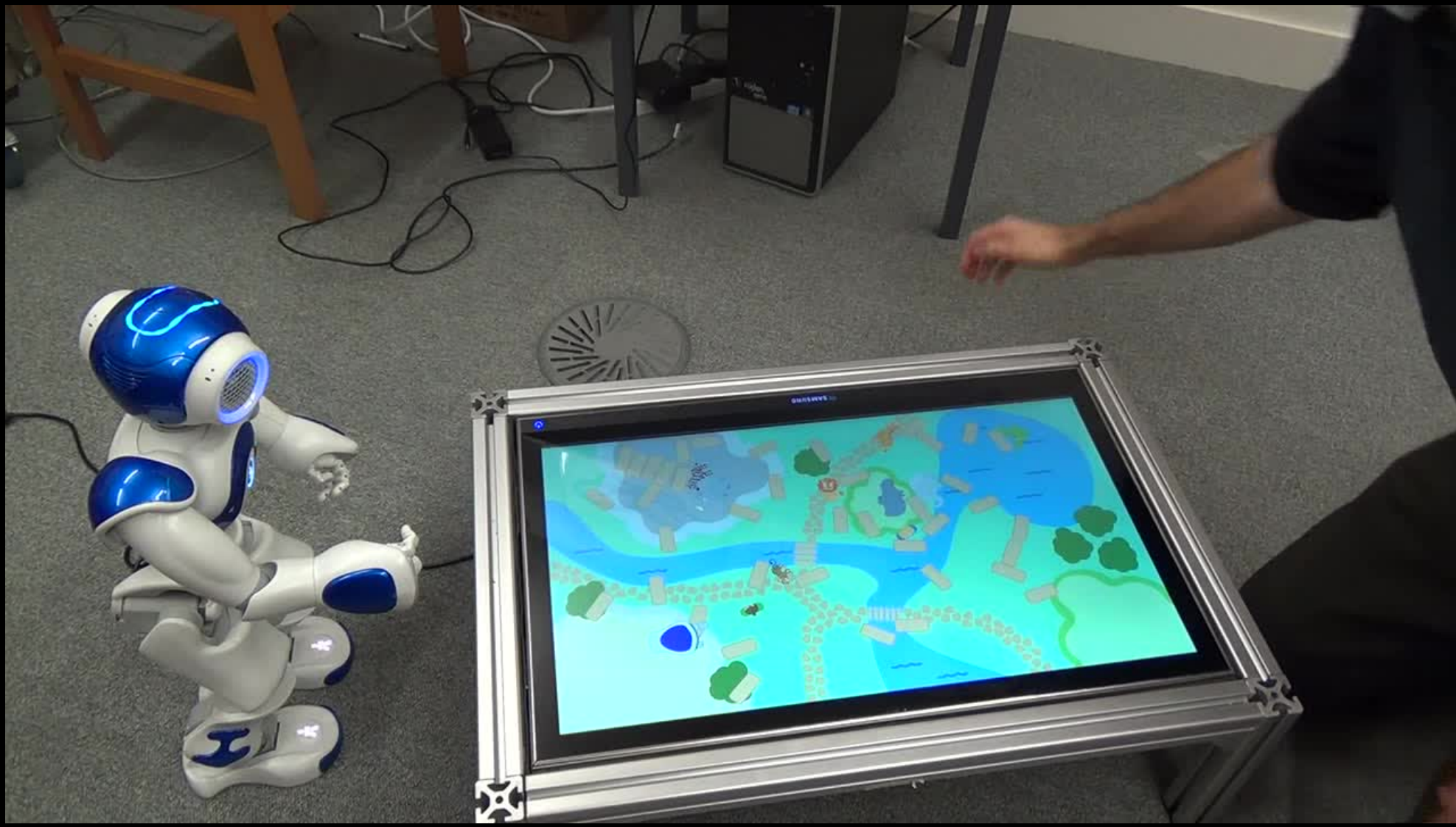
  - initial prompt (“Let’s build a zoo!”)
  - limited set of tokens (cubes, Lego animals)
  - spatially limited playground
- to make it technically tractable with robots, the physical playground is **replaced by a large touchscreen** (sandtray): entirely skips the difficult problem of perception and manipulation in a dense & cluttered scene
- the touchscreen strictly replace the perception of objects on the playground (exports ROS TF frames of each object) and their manipulation (receives virtual ’touches’ from the robot)
- importantly, perception of the partner and of the global scene geometry is genuine




Zoo Builder
Toggle fullscreen
Physics debug: off
sandtray.rviz* - RViz
File
Panels
Help
Interact
Move Camera
Select
Focus Camera
Measure
2D Pose Estimate
2D Nav Goal
Publish Point
Time
ROS Time: 1481559780.92
ROS Elapsed: 1931.03
Wall Time: 1481559780.95
Wall Elapsed: 1930.93
Experimental
Reset
31 fps



AN EXPERIMENTAL FRAMEWORK

Open-ended task: more an **experimental framework** than a task.

- free play, yet sufficiently well-defined to be reproducible
- focus on abstract socio-cognitive facets (perception is simplified; manipulation is mostly avoided)

Besides, well suited for interaction analysis, with tools like:

- behavioural alignment between partners: for instance, using Słowinski's *Individual Motor Signature*
- Ballard's (and Anderson's extension) coding of children's free-play interactions
- *With-me-ness* as a metric of co-engagment

[Lemaignan et al., **From Real-time Attention Assessment to "With-me-ness" in Human-Robot Interaction** HRI 2016]

ONLY THE START OF IT!

Which cognitive model? which cognitive architecture?

$\rightarrow$ will likely draw from hybrid architectures (CLARION), internal simulation (HAMMER), sub-symbolic cognitive architecture (ERA)

...but not many cognitive architectures model social interactions! (on BICA website, about 0 actually!)

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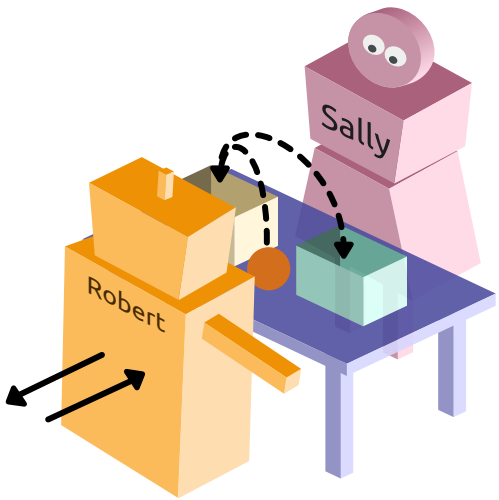
What inputs for a connectionist take on social interactions? low-level? high-level? To reconstruct someone else's attentional state, Graziano suggests:

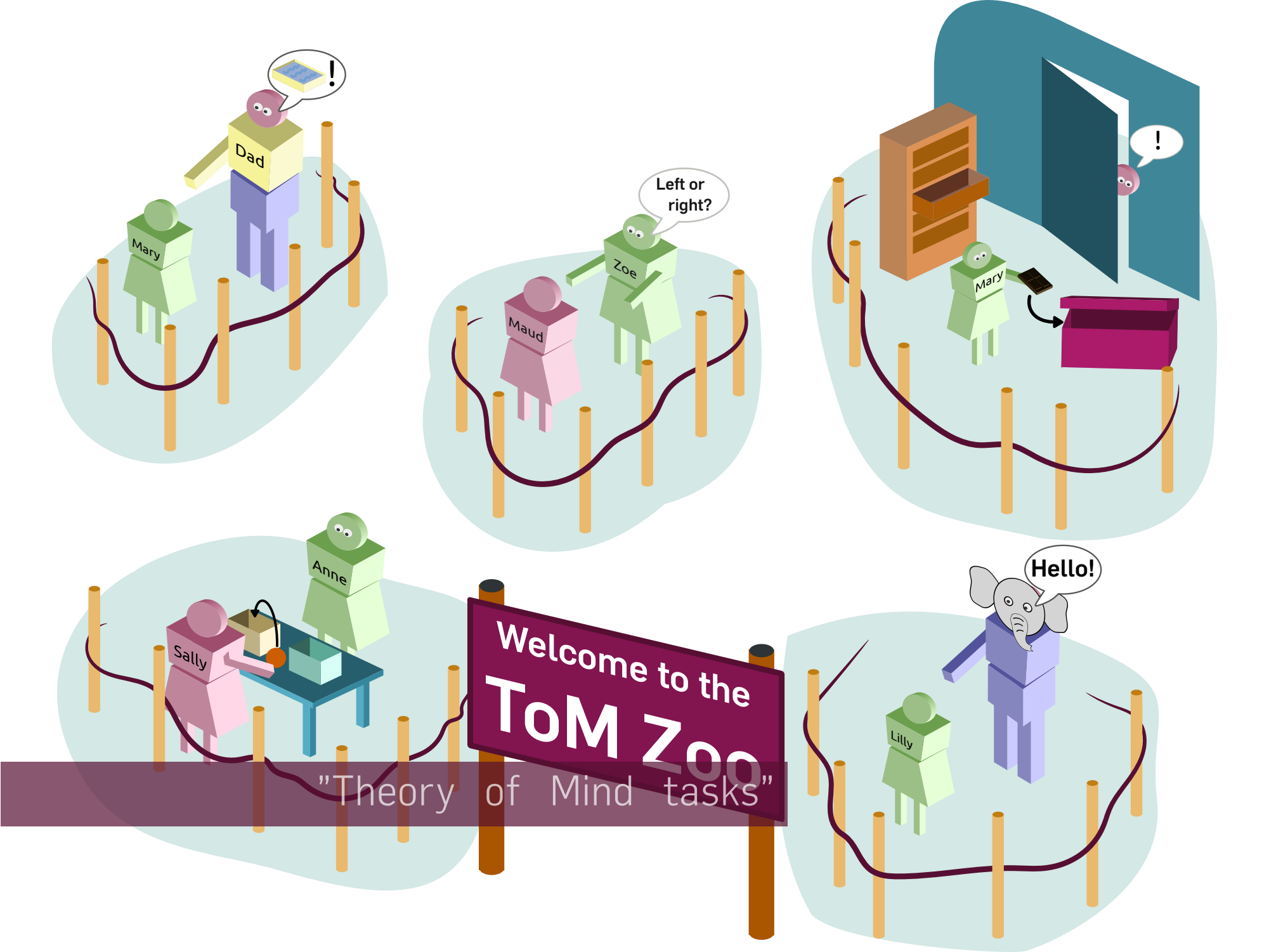
- gaze direction
- facial expression
- body language
- prior knowledge of person
- location of salient objects

Probably not the end of it, though!

THEORIES ON THEORY OF MIND

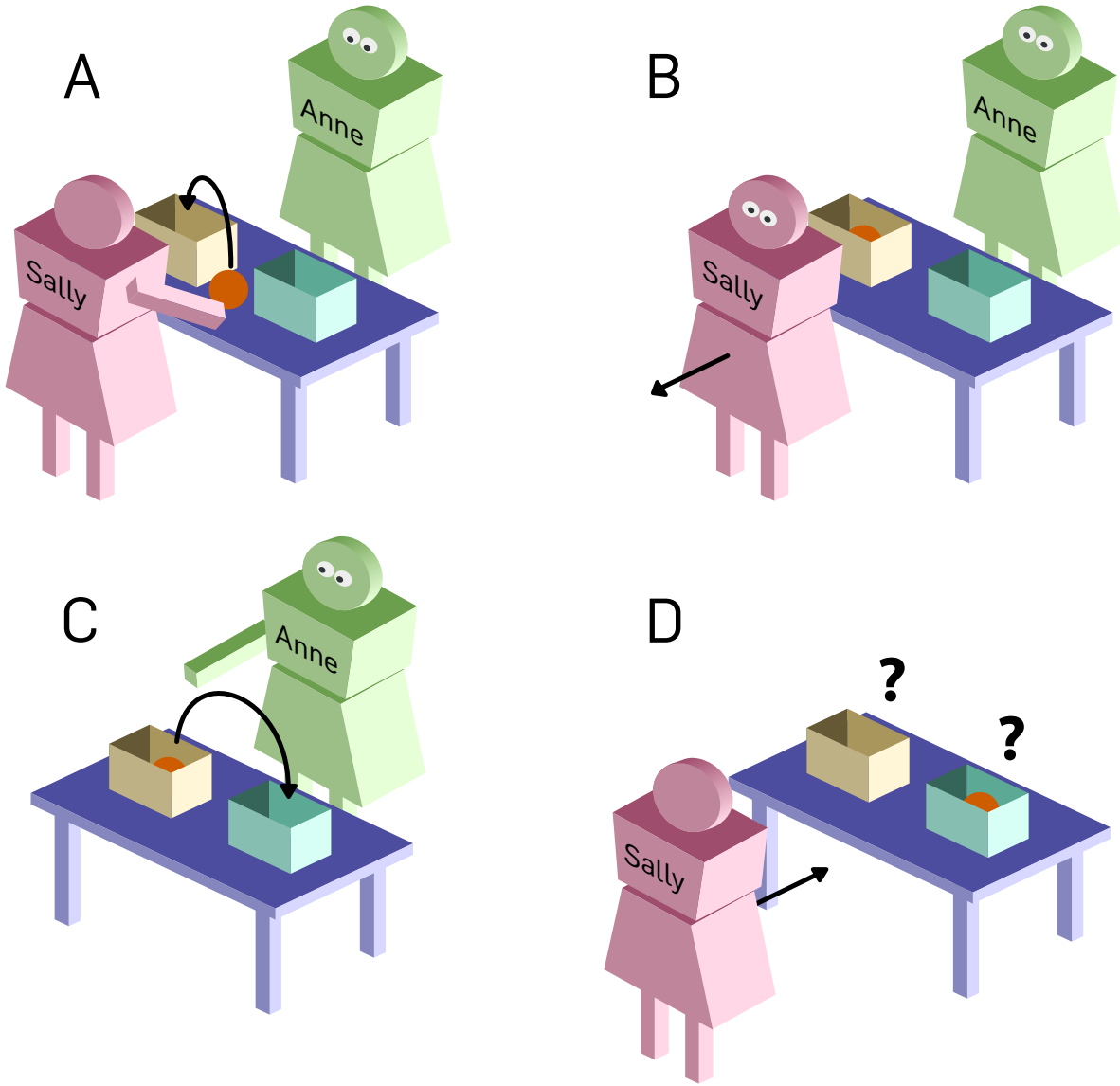


$$\begin{array}{ccc} \mathcal{M}^{\circ}(Sally, R, X) & \xleftrightarrow{\Delta_4} & \mathcal{M}^{\circ}(R, R, X) \\ \Delta_5 \updownarrow & & \updownarrow \\ \mathcal{M}^{\circ}(Sally, R, Y) & \longleftrightarrow & \mathcal{M}^{\circ}(R, R, Y) \end{array}$$



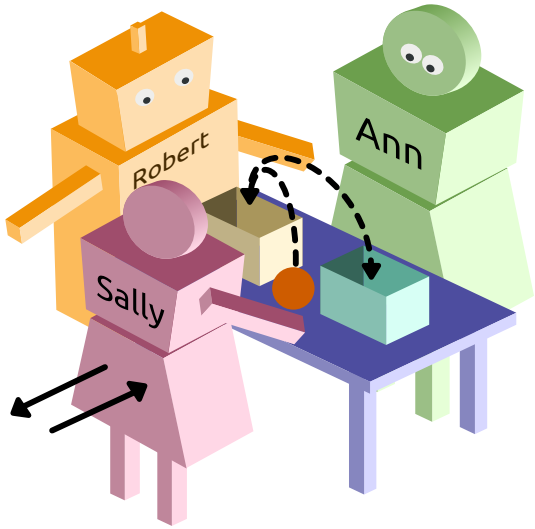
"Theory of Mind tasks"

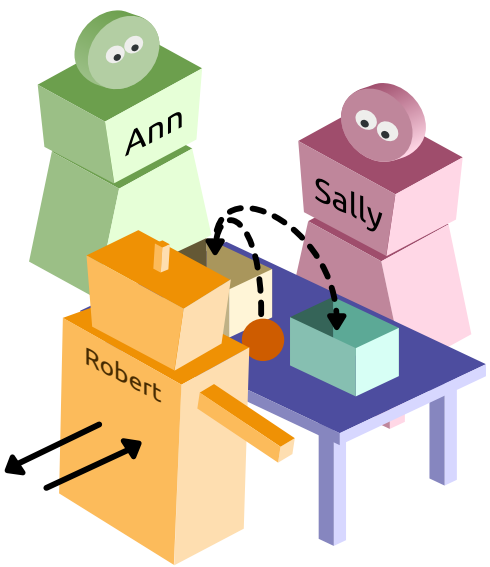
1ST ORDER TOM: THE FALSE-BELIEF EXPERIMENT

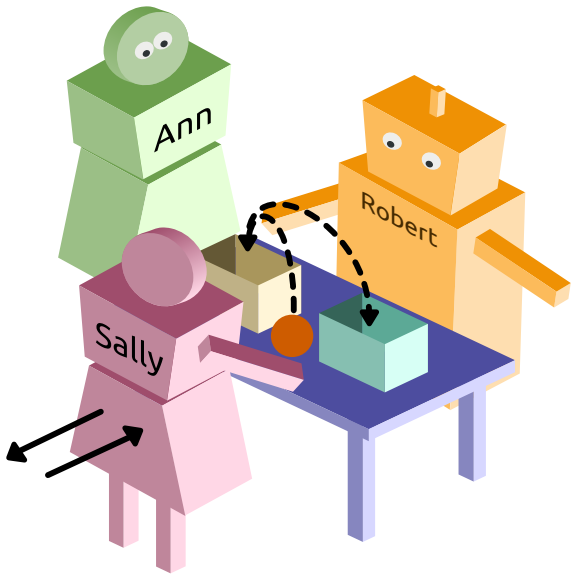


[Wimmer and Perner, **Beliefs about beliefs: Representation and constraining function [...]**, Cognition, 1983]
[Lemaignan, Dillenbourg **Mutual Modelling in Robotics: Inspirations for the Next Steps** – HRI 2015]

THE FALSE-BELIEF EXPERIMENT, RELOADED

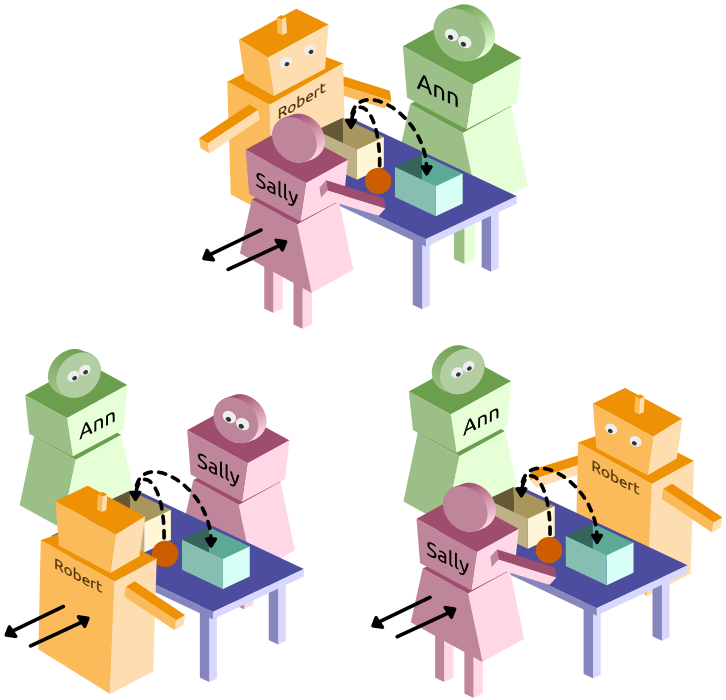






[Dillenbourg, Lemaignan et al., **The Symmetry of Partner Modelling**, Intl. J. of Computer Supported Collaborative Learning 2016] 119

THE FALSE-BELIEF EXPERIMENT, RELOADED



- $\mathcal{M}(A, B, X)$
- $\mathcal{M}^{\circ}(A, B, X)$

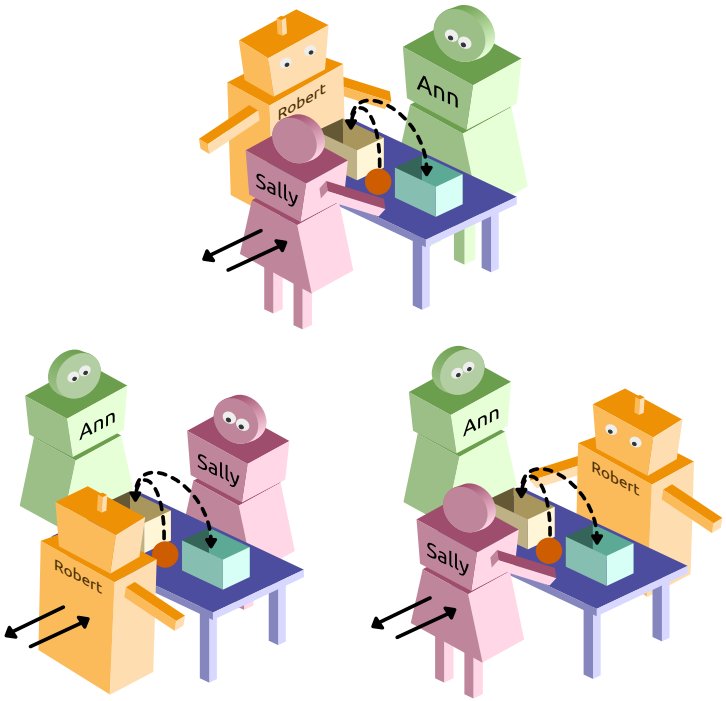
e.g. $\mathcal{M}(\text{robot}, \text{Sally}, \textbf{\textit{plans}})$

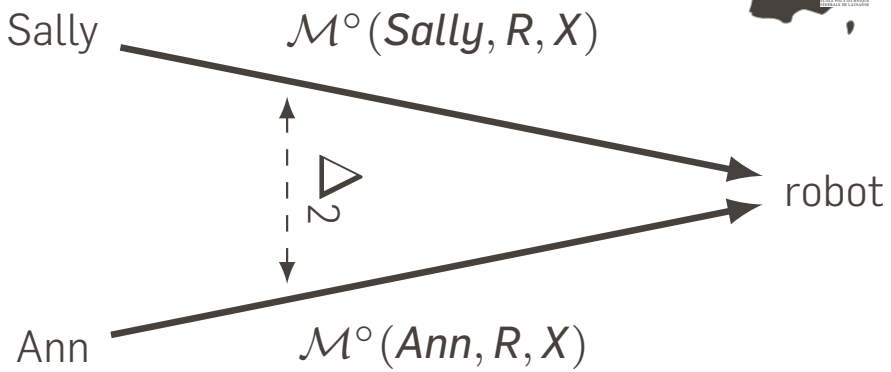
THE FALSE-BELIEF EXPERIMENT, RELOADED

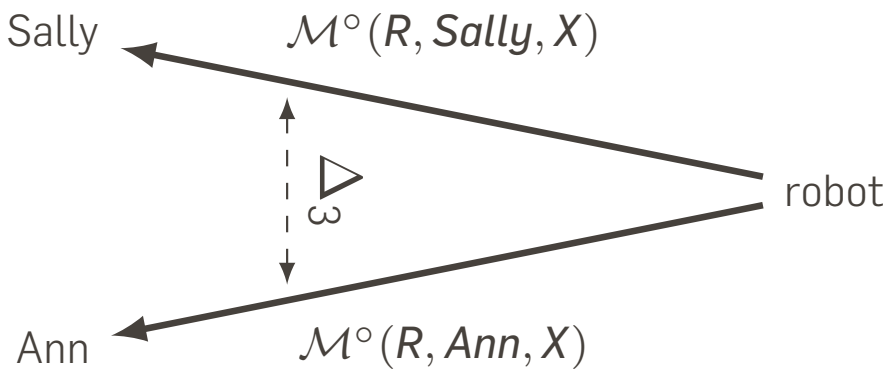
- **Robot is the observer**
  $\mathcal{M}^{\circ}(R, \text{Sally}|\text{Ann}, \textit{plans})$? can the human verbalise it? i.e. $\mathcal{M}(H, R, \mathcal{M}(R, H, \textit{plans}))$?
- **Robot is an active participant**
  $\mathcal{M}(H, R, \textit{knowledge}|\textit{plans}|\textit{goals})$? i.e. How Ann interprets the behaviour of a robot who moves the ball from the beige box to the blue box while Sally is away?

[Dillenbourg, Lemaignan et al., **The Symmetry of Partner Modelling**, Intl. J. of Computer Supported Collaborative Learning 2016]

THE FALSE-BELIEF EXPERIMENT, RELOADED







THE FALSE-BELIEF EXPERIMENT, RELOADED

Do Sally and Ann have the same accuracy when modelling the robot?

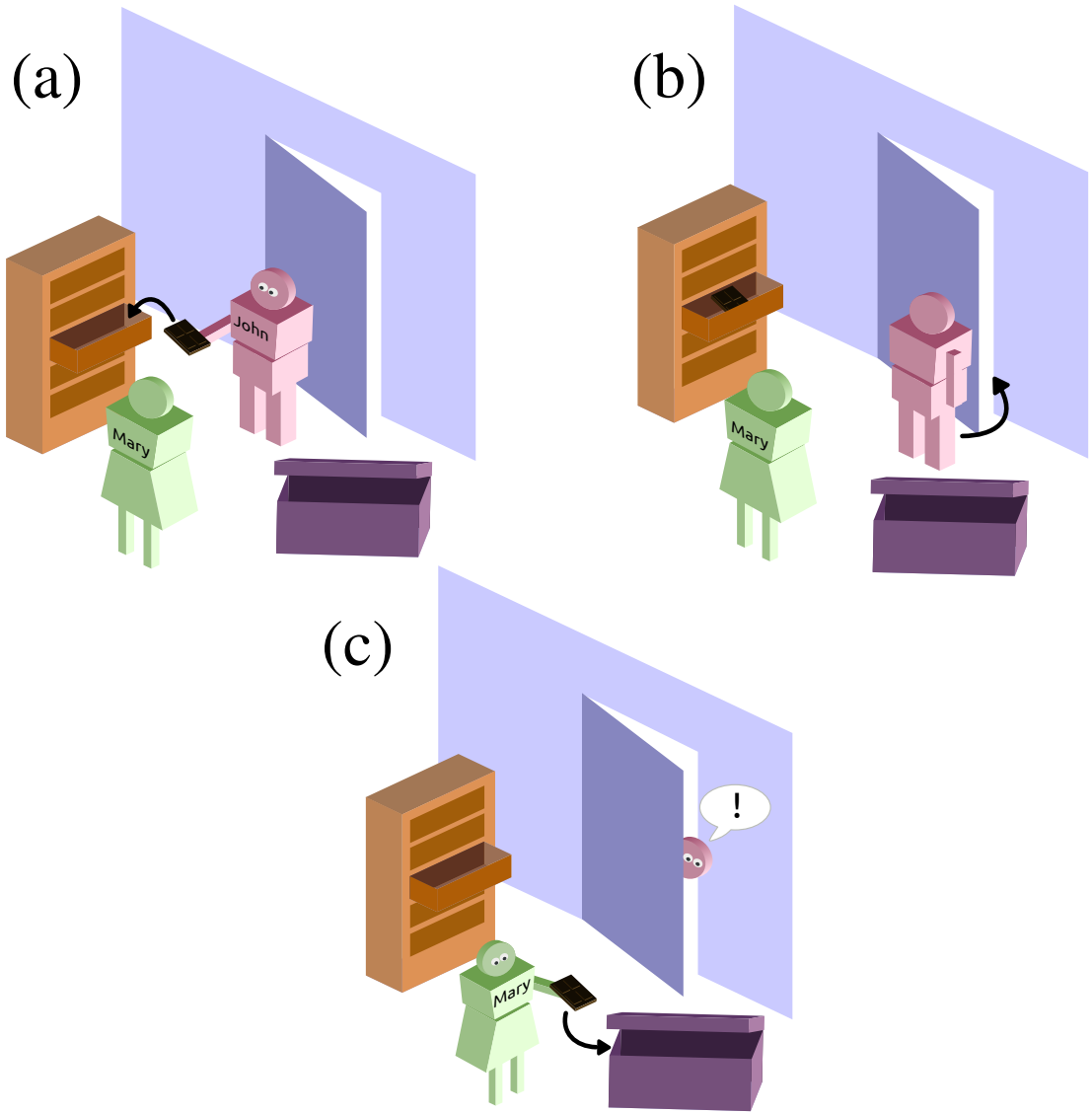
$$\Delta_2 = \Delta(\mathcal{M}(\text{Sally}, R, X), \mathcal{M}(\text{Ann}, R, X))$$

Conversely, what may lead the robot to model more accurately Sally or Ann?

$$\Delta_3 = \Delta(\mathcal{M}(R, \text{Sally}, X), \mathcal{M}(R, \text{Ann}, X))$$

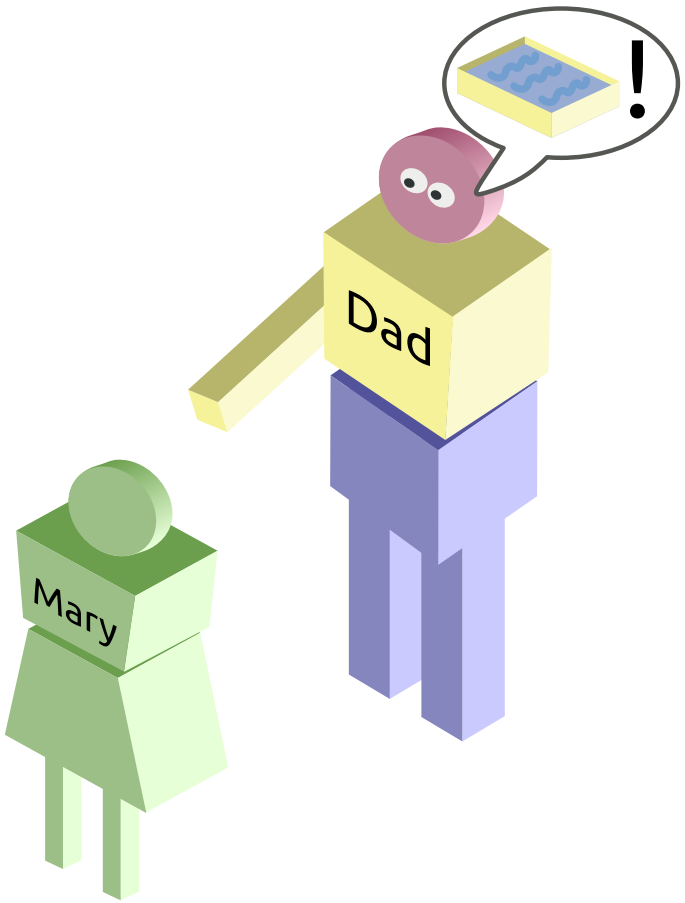
[Dillenbourg, Lemaignan et al., **The Symmetry of Partner Modelling**, Intl. J. of Computer Supported Collaborative Learning 2016]

2ND ORDER TOM: THE CHOCOLATE BAR EXPERIMENT



[Flobbe et al. **Children's application of theory of mind in reasoning and language**, J. of Logic, Language and Information, 2008]
[Lemaignan, Dillenbourg **Mutual Modelling in Robotics: Inspirations for the Next Steps** – HRI 2015]

AGREEMENT AS ∞-ORDER TOM



[Verbrugge, **Logic and social cognition**, Journal of Philosophical Logic, 2009]
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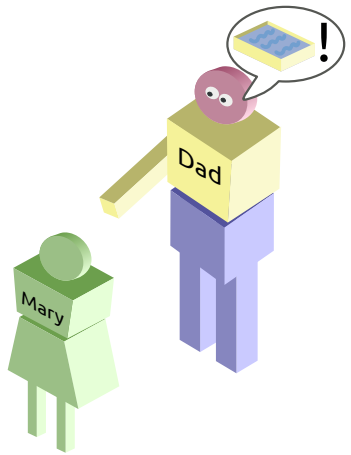

Shared knowledge

$$EK_J\varphi \leftrightarrow \bigwedge_{i \in J} K_i\varphi$$

[Verbrugge, **Logic and social cognition**, Journal of Philosophical Logic, 2009]
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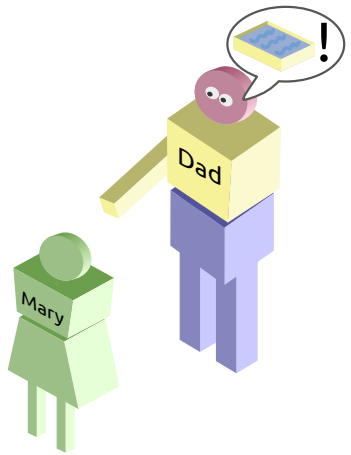

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Common knowledge

$$CK_J\varphi \leftrightarrow EK_J\varphi \wedge EK_JEK_J\varphi \wedge EK_JEK_JEK_J\varphi \wedge \ldots$$

[Verbrugge, **Logic and social cognition**, Journal of Philosophical Logic, 2009]
[Lemaignan, Dillenbourg **Mutual Modelling in Robotics: Inspirations for the Next Steps** – HRI 2015]

SHOPPING LIST FOR HRI?

Already in the HRI fridge	To buy...
Instrumental gestures	Expressive gestures
Using person as tool	Using person as receiver of information
Talking about desires and emotions	Talking about beliefs and ideas
Showing "active" sociability	Showing "interactive" sociability
Elicited structured play	Spontaneous pretend play

[Frith and Happé **Autism: Beyond "theory of mind"** – Cognition, 1994]
[Lemaignan, Dillenbourg **Mutual Modelling in Robotics: Inspirations for the Next Steps** – HRI 2015]

AUTISTIC ASSETS AND DEFICITS OBSERVED IN REAL LIFE

Assets	Deficits
Instrumental gestures	Expressive gestures
Using person as tool	Using person as receiver of information
Talking about desires and emotions	Talking about beliefs and ideas
Showing "active" sociability	Showing "interactive" sociability
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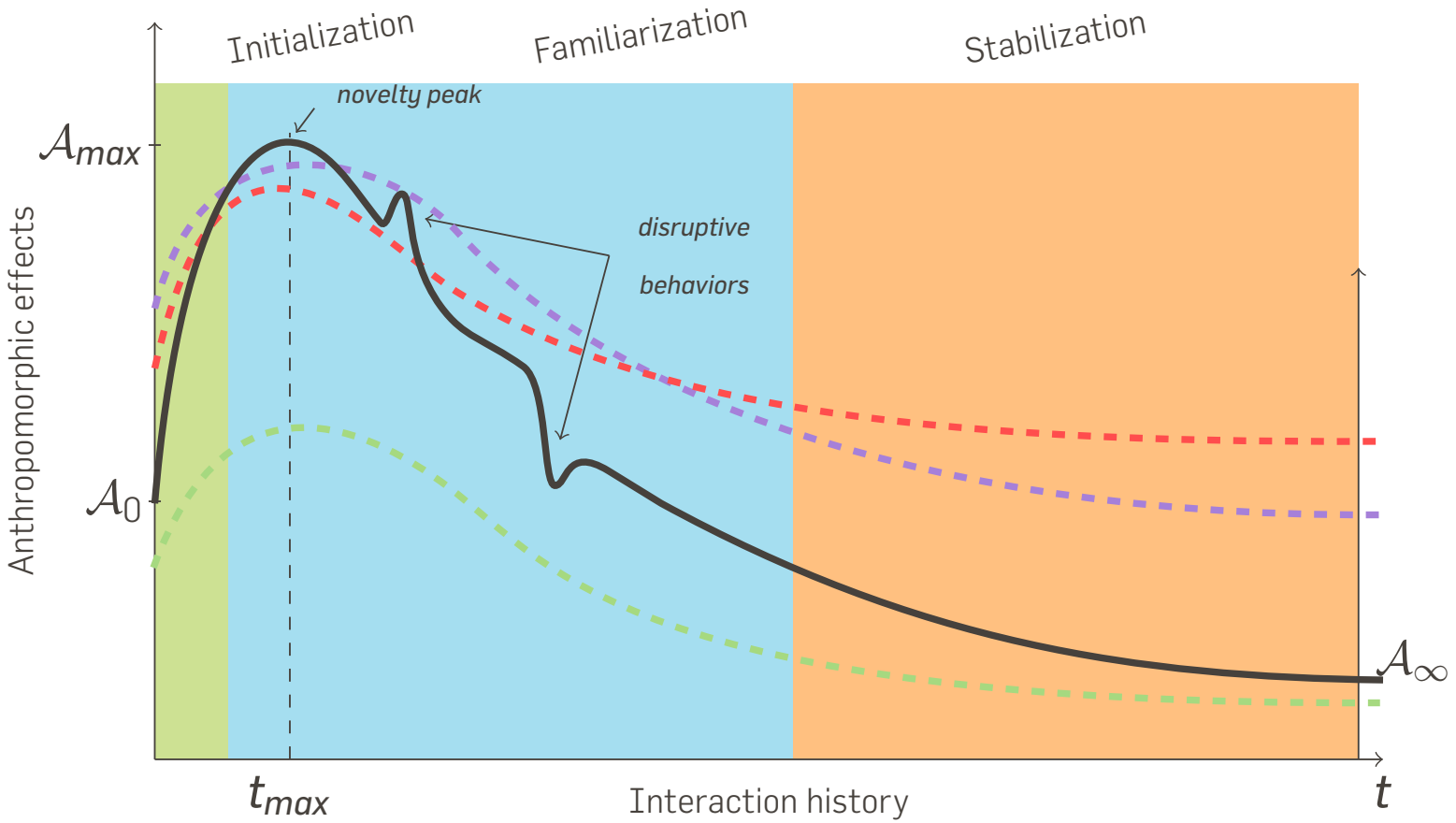
DYNAMICS OF INTERACTION

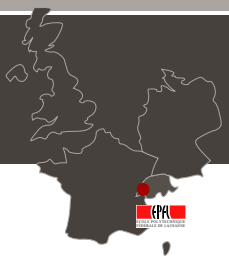
HOW DO WE PERCEIVE ROBOT OVER TIME?

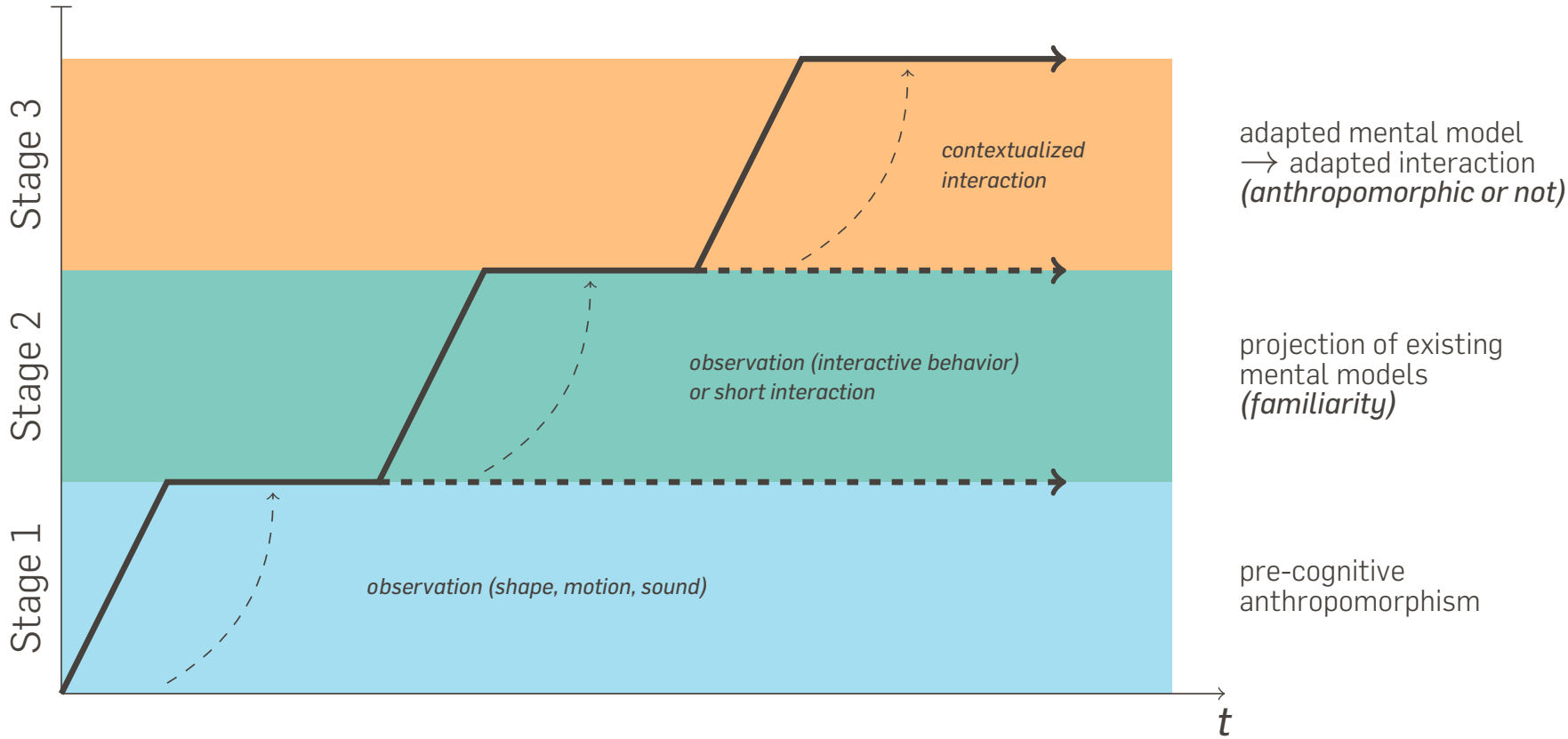


◂ Supplementary material

[Lemaignan, Fink, Dillenbourg, Braboszcz **The Cognitive Correlates of Anthropomorphism**, HRI 2014]

COGNITIVE INTERPRETATION?





adapted mental model
⟶ adapted interaction
(anthropomorphic or not)

projection of existing mental models
(familiarity)

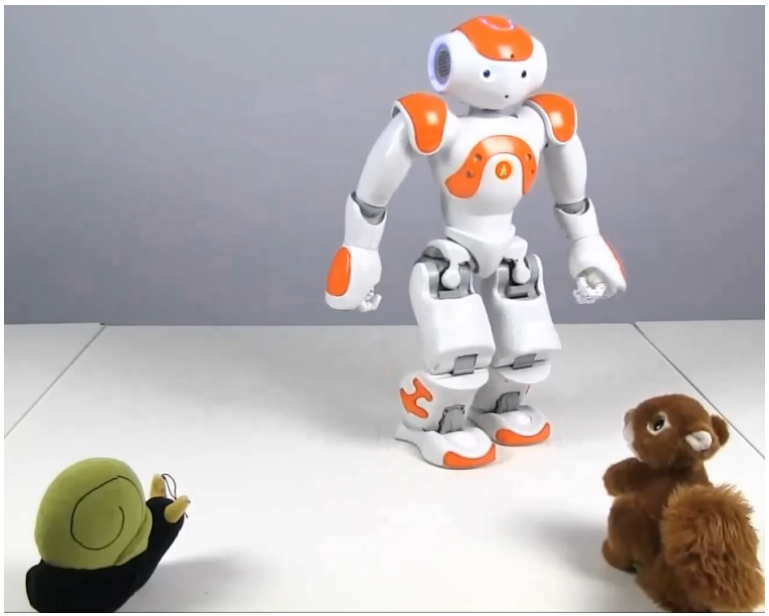
pre-cognitive anthropomorphism

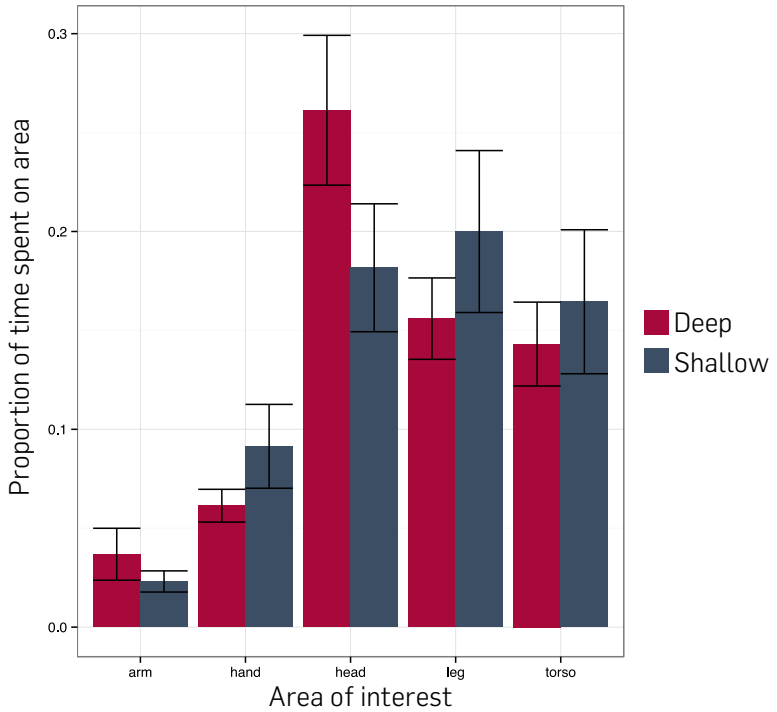
[Lemaignan, Fink, Dillenbourg, Braboszcz **The Cognitive Correlates of Anthropomorphism**, HRI 2014]

UNEXPECTED BEHAVIOURS

	Unplanned by the robot	Planned by the robot
Perceived as non-intentional	A	B
Perceived as intentional	C	D

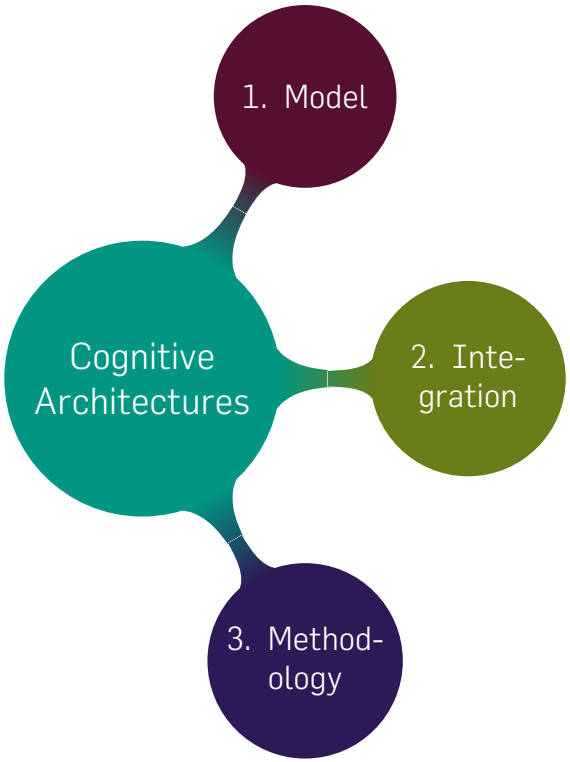
COGNITIVE CONTEXT AND ANTHROPOMORPHISM





COGNITIVE ARCHITECTURES

COGNITIVE ARCHITECTURES FOR SOCIAL HRI



1. Models of Human Cognition

– Modelling (aspects of) human cognition

– Subsequent application to robots

2. Technical Integration

– Define required functionality of robots

– Implement algorithms (etc) necessary

3. A Methodology

– Formalising assumptions

– Integrating knowledge from multiple disciplines

– Iteratively updating architecture

[Baxter, Lemaignan, Trafton **Workshop on Cognitive Architectures for Social HRI** – HRI 2016]

"MODELING OF HUMAN COGNITION"...