

WITH PLYMOUTH UNIVERSITY

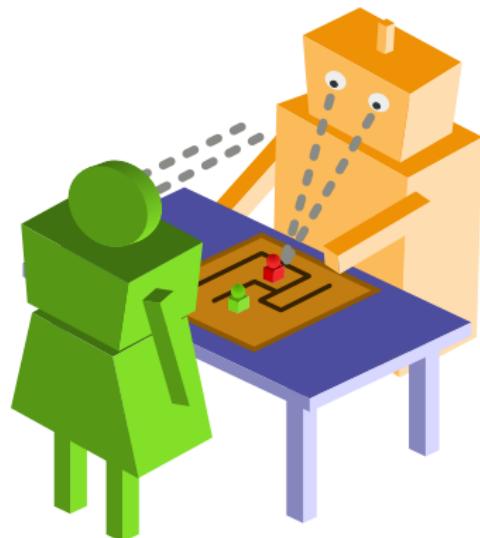


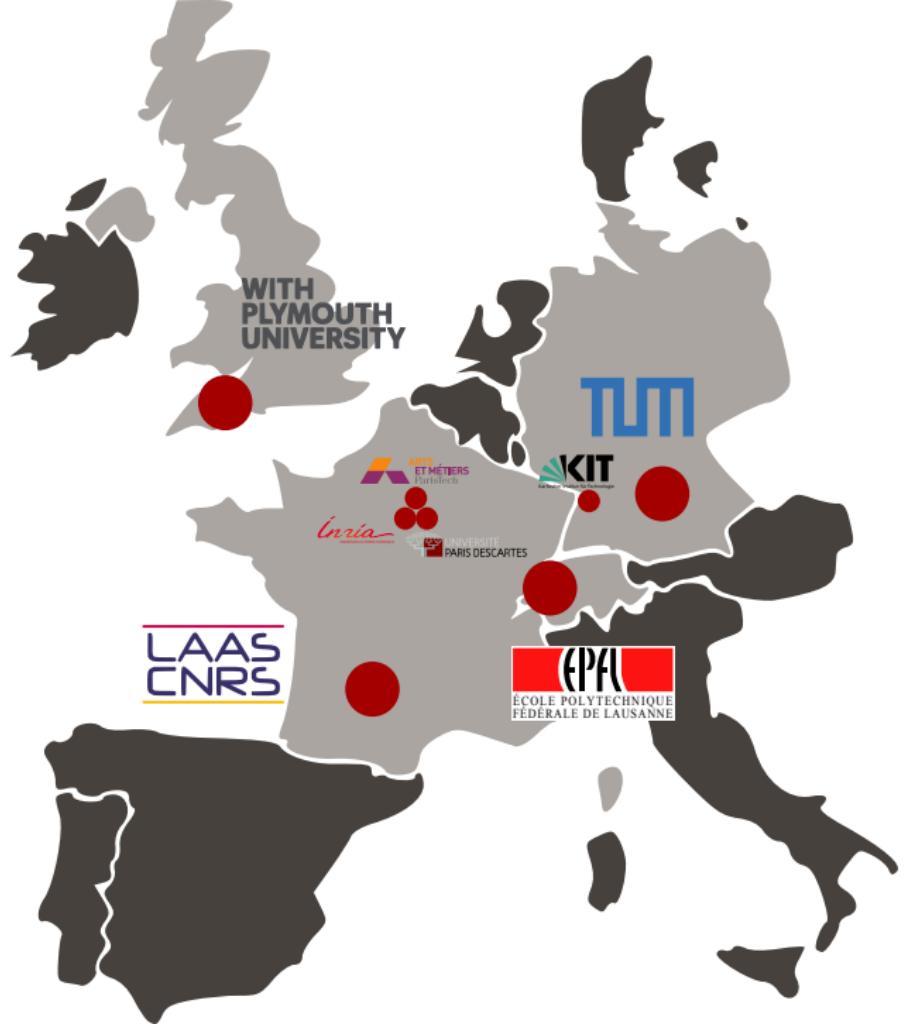
Of Cognition and Social Robots a vision for artificial social cognition in HRI

Plymouth University – **14 February 2017**

Séverin Lemaignan

Centre for Robotics and Neural Systems
Plymouth University

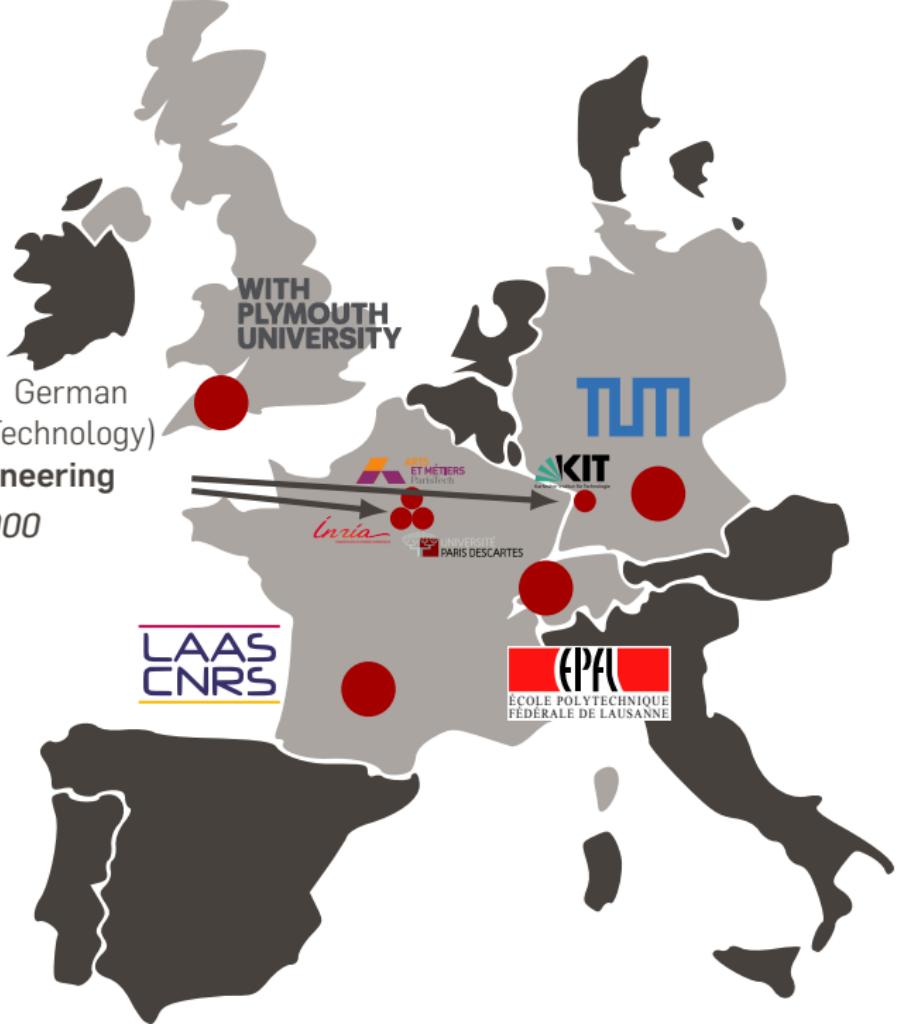






Joint French (ParisTech) German
(Karlsruhe Institute of Technology)
MSc in **Mechanical Engineering**

top ten student out of 1000



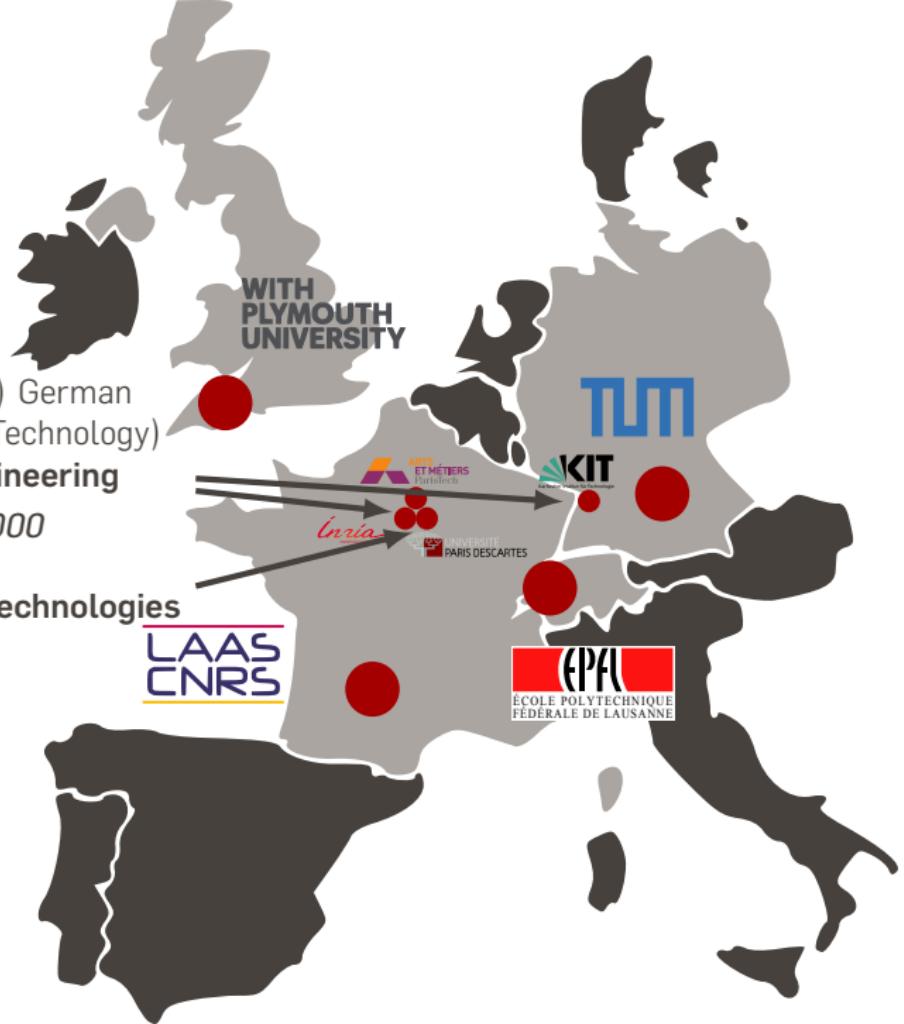


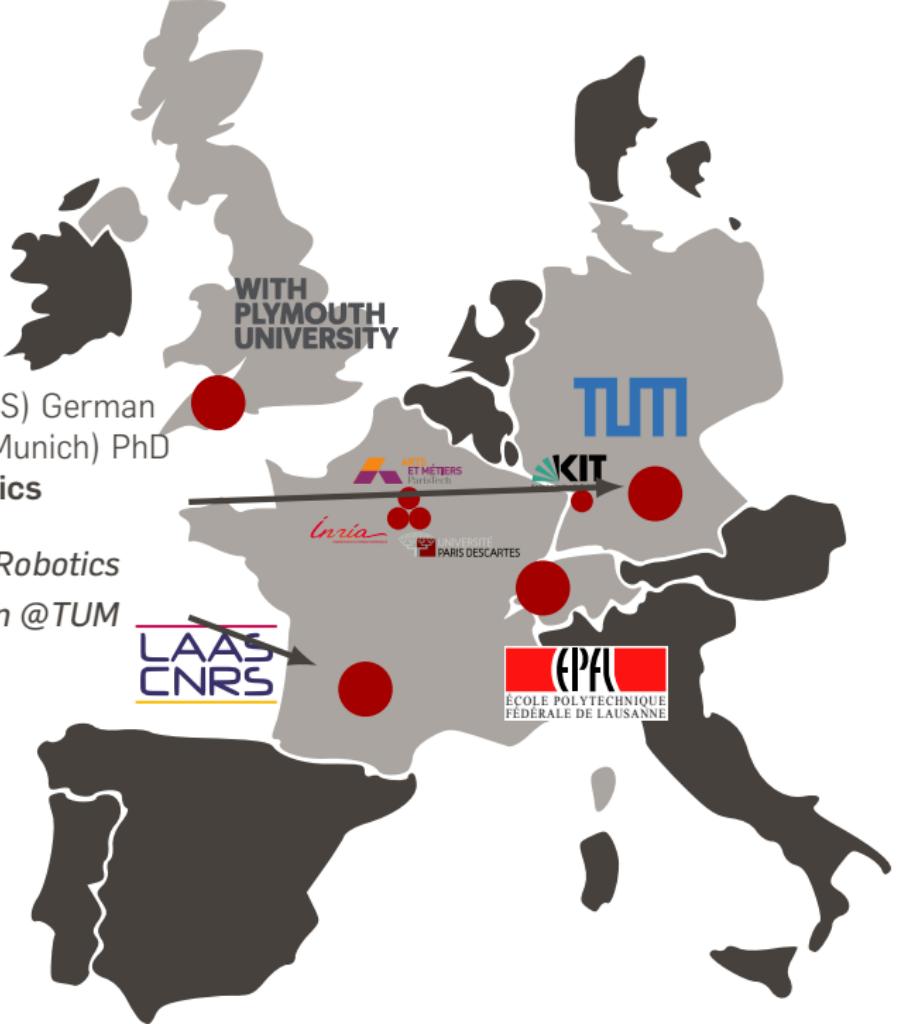
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MSc in **AI for Learning technologies**
(Paris 5)

top student of the year





Joint French (CNRS LAAS) German
(Technical University of Munich) PhD
in **AI & Cognitive Robotics**

Best 2012 CNRS PhD in Robotics
PhD with High Distinction @TUM

SINCE MY PHD

2013–2015 Post-doc at EPFL

- built up a leading group in child-robot interaction

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2015–2017 **EU Marie Skłodowska-Curie fellow** at Plymouth University on **Theory of Mind & Social cognition for robots**

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50+ publications; 900+ citations; H-index=15

PLYMOUTH
UNIVERSITY

ROCO318
Mobile and Humanoid Robots
Part 1 – Introduction

Sébastien Lemaignan

Centre for Neural Systems and Robotics
Plymouth University



SOFT252

EVENT-ORIENTED PROGRAMMING

Event-oriented programming is a possible way of implementing a behavioural control paradigm.

```
def on_start(robot):
    robot.Look_at_Joystick()
    robot.blade()

def on_joystick(robot):
    Pulse = robot.pulse_axe[0]
    while abs(robot.state.v) > 0.05:
        robot.Lightbar(RGB(255,0,0))
        sleep(0.05)
        robot.Cancel()

def on_shoot(robot):
    robot.Light_bar.colors.set(0)
    robot.Axe(0, 4, v = 0.8)
    robot.Lightbar(RGB(0,255,0))
    sleep(0.1)

def on_top_reached(robot):
    robot.Light_bar.colors.set(1)
```

SOFT561

GRASSFIRE ALGORITHM

	A	B	C	D	E	F	G	H	I	J	K	L
1	13	12	11	10	9	8	7	8	9	10	11	10
2	12	11	10	9	8	7	6	5	4	5	6	7
3	11	10	9	8	7	6	5	4	3	4	5	6
4	10	9	8	7	6	5	4	3	4	5	6	7
5	11	9	8	7	6	5	4	3	2	3	4	5
6	10	9	8	7	6	5	4	3	2	1	2	3
7	11	10	11	12	13	14	15	16	17	18	19	20
8	10	9	8	7	6	5	4	3	2	1	2	3
9	8	7	6	5	4	3	2	1	2	3	4	5
10	9	8	7	6	5	4	3	2	1	2	3	4
	10	9	8	7	6	5	4	3	2	1	2	3

SOFT561

ROCO503

CORRECT STEP EQUATIONS (MEASUREMENT UPDATING)

$$K_k = P_{k|k-1} \cdot H^T \cdot (H \cdot P_{k|k-1} \cdot H^T + R)^{-1}$$

The Kalman gain, this needs to be calculated first

$$\hat{X}_{k|k} = \hat{X}_{k|k-1} + K_k \cdot (z_k - H \cdot \hat{X}_{k|k-1})$$

The a posteriori estimated state

$$P_{k|k} = (I - K_k \cdot H) \cdot P_{k|k-1}$$

The a posteriori covariance of our state

EVENT-ORIENTED PROGRAMMING

SOFT252

Event-oriented programming is a possible way of implementing a behavioural control paradigm.

```
def on_start():
    robot.LookAt(Home())
    robot.blade()
    robot.Move(0, 0, 0, 0)
    robot.Lightbar(RADBON), wait()
    sleep(0.5)

def on_shoot_ready():
    robot.Lightbar(HOTBON).on()
    robot.Lightbar(RADBON).off()
    sleep(0.5)
    robot.Lightbar(RADBON).on()
    sleep(0.5)

def on_shoot():
    robot.Lightbar(HOTBON).off()
    robot.Lightbar(RADBON).on()
    sleep(0.5)
    robot.Lightbar(RADBON).off()
    sleep(0.5)
```

GRASSFIRE ALGORITHM

SOFT561

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1	13	12	11	10	9	8	7	6	5	4	3
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4	10	9	8	7	6	5	4	3	2	1	0
5	11	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0
7	11	10	11	12	13	14	15	16	17	18	19
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CORRECT STEP EQUATIONS (MEASUREMENT UPDATING)

ROCO503

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The Kalman gain, this needs to be calculated first

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The a posteriori estimated state

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The a posteriori estimated covariance of our state

REBASING BRANCHES

SOFT152

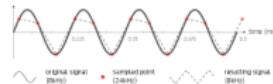
git checkout cool-idea
git commit

SAMPLING RATE

ROCO222

Nyquist theorem

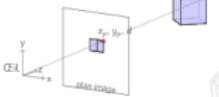
- The sampling rate has to be at least **twice as high** as the fastest changes. If not, you are going to miss relevant information.



- e.g. If sound signal changes at 3kHz, you have to sample at at least 6kHz to not miss anything of the signal.

EN 3D

SOFT153



$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \oplus \begin{bmatrix} \frac{dx}{dt} \\ \frac{dy}{dt} \\ \frac{dz}{dt} \\ 1 \end{bmatrix}$$



EVENT-ORIENTED PROGRAMMING

SOFT252

Event-oriented programming is a possible way of implementing a behavioural control paradigm.

```
def on_start():
    robot.lock()
    robot.set_arm_stance()
    robot.blade()
    robot.set_color("full_stance")
    robot.Lightbar(RADIOMAX).on()
    sleep(0.1)
    robot.set_color("idle")
    sleep(0.1)

def on_chop_reached():
    robot.Lightbar.set_color("stand")
    robot.set_color("idle")
    robot.set_v(0.4, v=0.8)
    sleep(0.1)
    robot.set_color("idle")
```

GRASSFIRE ALGORITHM

SOFT561

A	B	C	D	E	F	G	H	I	J	K	L	
1	13	12	11	10	9	8	7	8	9	10	11	10
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12	11	10	11	12								
13	12	11	10	9	8	7	6	5	4	3	2	1

CORRECT STEP EQUATIONS (MEASUREMENT UPDATING)

ROC0503

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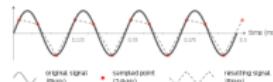
```
git checkout cool-idea
git commit
```

SAMPLING RATE

ROC0222

Nyquist theorem

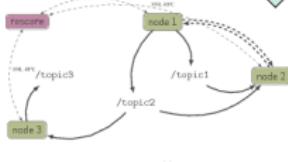
The sampling rate has to be at least twice as high as the fastest changes. If not, you are going to miss relevant information.



e.g. if sound signal changes at 3kHz, you have to sample at at least 6kHz to not miss anything of the signal.

MIDDLEWARES' CORE PRINCIPLE: TALKING NODES

NET302

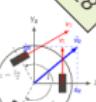


KINEMATICS OF AN OMNIDIRECTIONAL ROBOT

ROC0318

$$\begin{aligned} V_x &= \dot{\varphi} \cdot r \\ &= -x_0 \cdot \sin(\alpha_0) + y_0 \cdot \cos(\alpha_0) + l \cdot \dot{\theta} \\ \dot{\varphi} \cdot r &= \begin{bmatrix} x_0 & y_0 & r \end{bmatrix} \cdot \begin{bmatrix} 0 & -\sin(\alpha_0) & \cos(\alpha_0) \\ 0 & \cos(\alpha_0) & \sin(\alpha_0) \\ 1 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} \dot{x}_0 \\ \dot{y}_0 \\ \dot{\theta} \end{bmatrix} \\ &= \begin{bmatrix} -x_0 \cdot \sin(\alpha_0) & y_0 \cdot \cos(\alpha_0) & r \\ 0 & x_0 \cdot \cos(\alpha_0) & y_0 \cdot \sin(\alpha_0) \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \dot{x}_0 \\ \dot{y}_0 \\ \dot{\theta} \end{bmatrix} \end{aligned}$$

∴ we can determine the wheels angular velocities to obtain a specific robot velocity.



GLOBAL VS LOCAL PATH PLANNING

AINT252

Global path planning

- long distances (i.e. large map, slower calculations)
- dynamic environment (use of sensors)

Local path planning

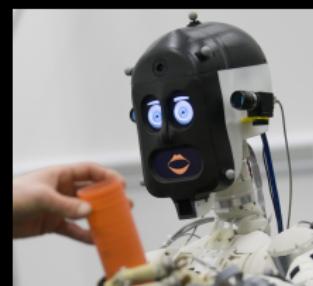
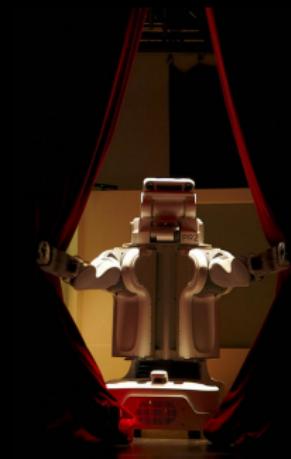
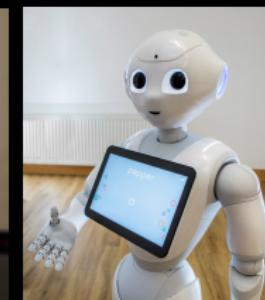
- short horizon
- static environment

CS EXPERTISE

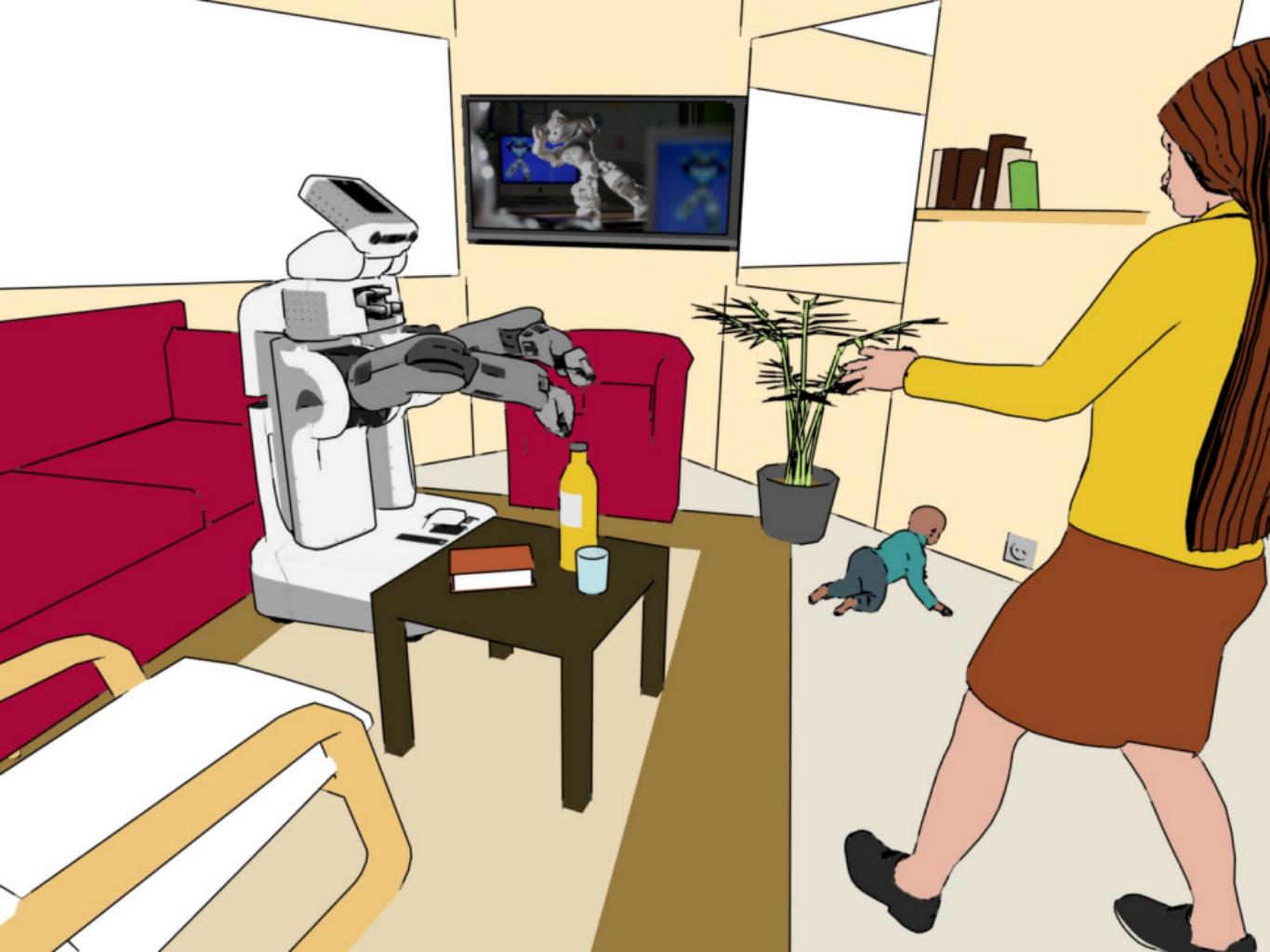
Strong track record in core computer sciences

- **advanced C++** (C++11/14, STL, meta-programming)
- **advanced Python** (meta-programming)
- **software engineering** (GIT expertise, coding best practises)
- logic programming (Prolog, ontologies)
- distributed systems (middlewares)
- computer vision & 3D rendering (OpenGL)
- algorithms & data structures

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



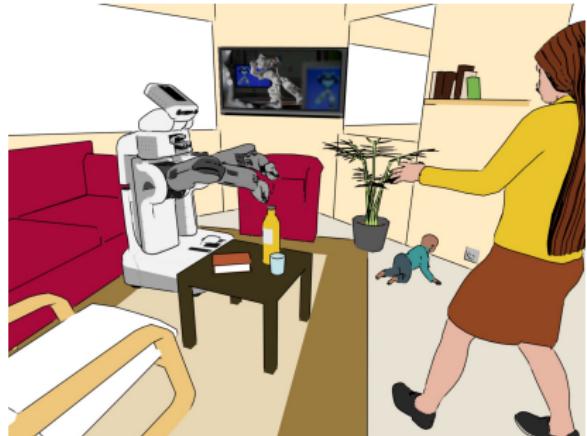
RESEARCH BACKGROUND SYMBOLIC SOCIAL COGNITION



Situated dialogue effectively evidences the challenges

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

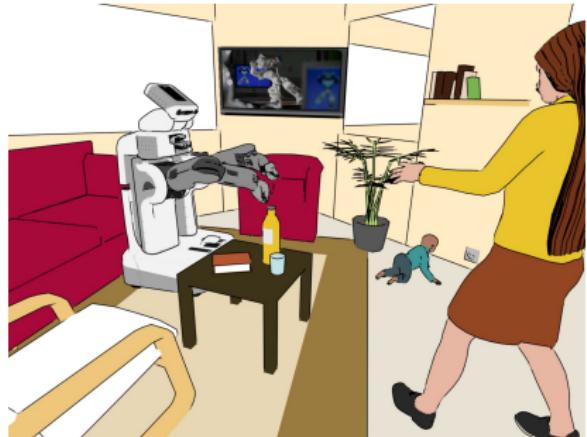
“Can you give me that book?”



Situated dialogue effectively evidences the challenges

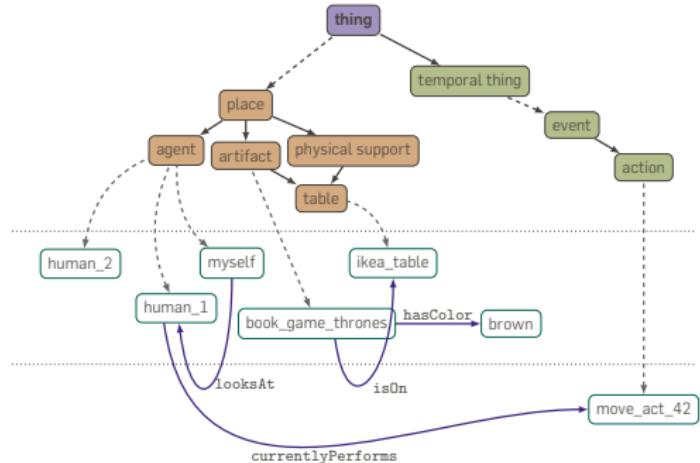
How can the robot make sense
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My PhD: a symbolic approach to this problem

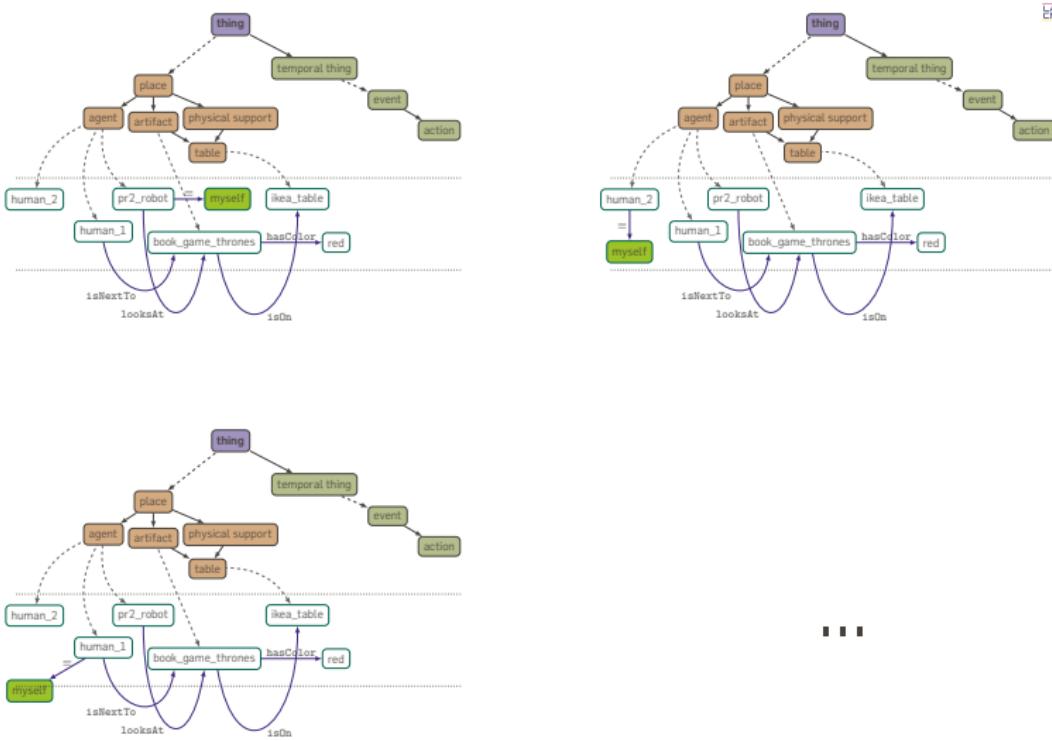
MULTI-MODAL SYMBOLIC SITUATION ASSESSMENT

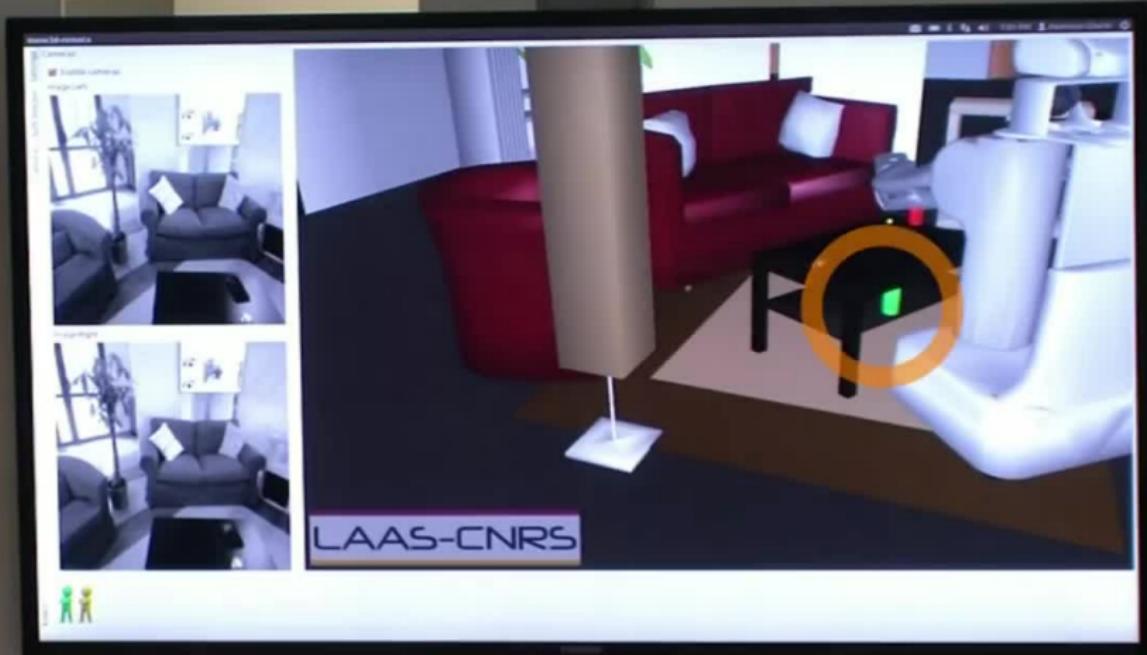


LAAS-CNRS

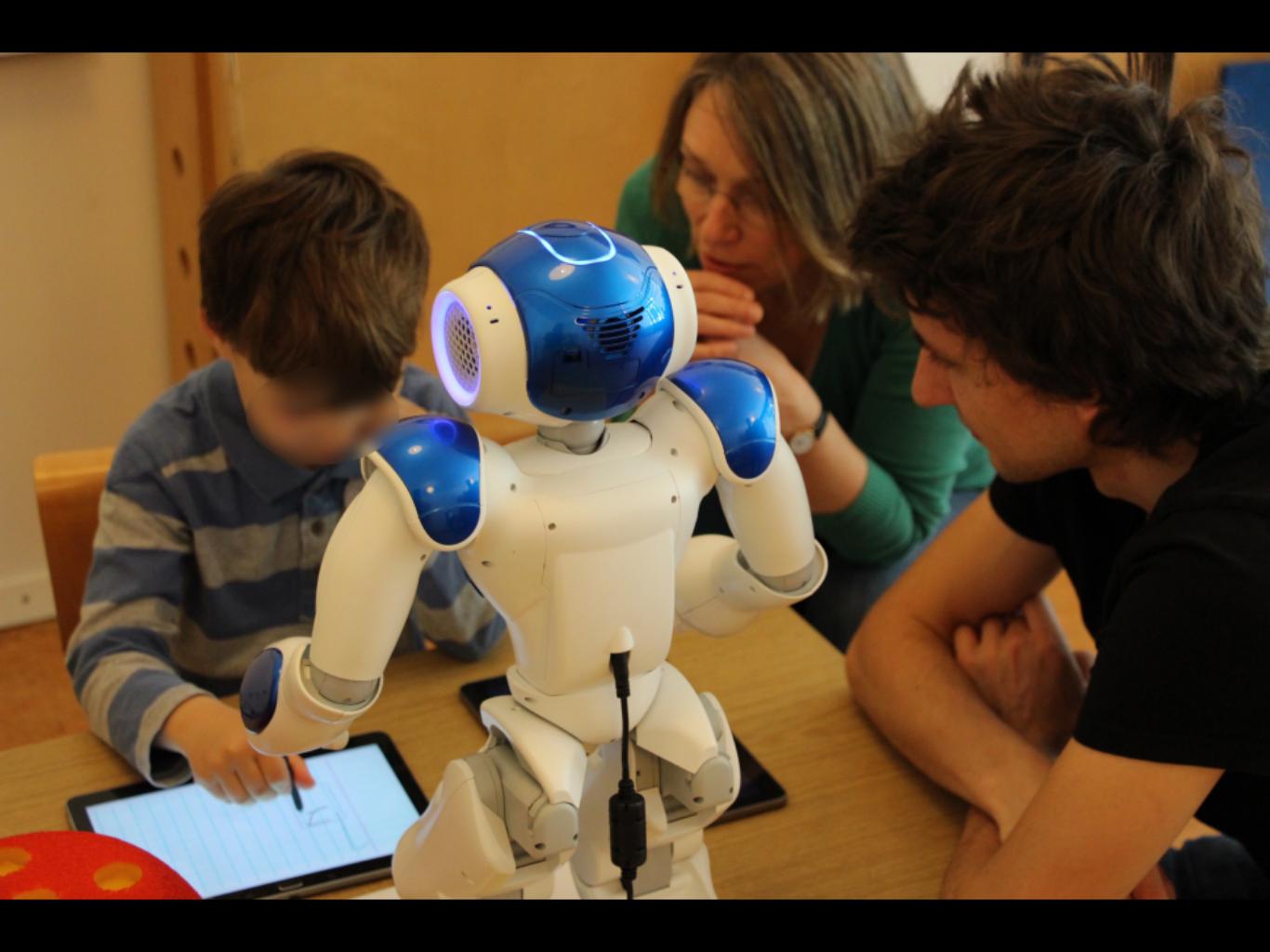


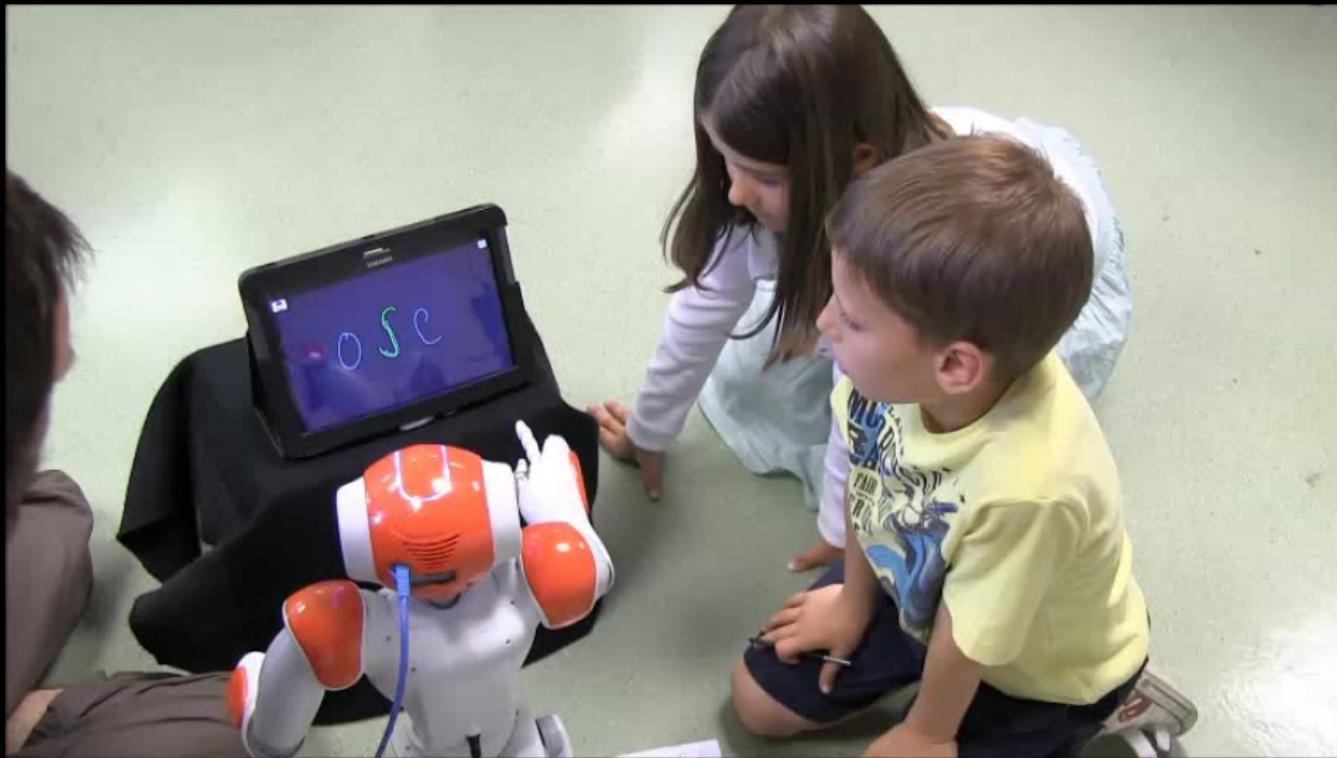
PARALLEL MODELS: TOWARDS THEORY OF MIND



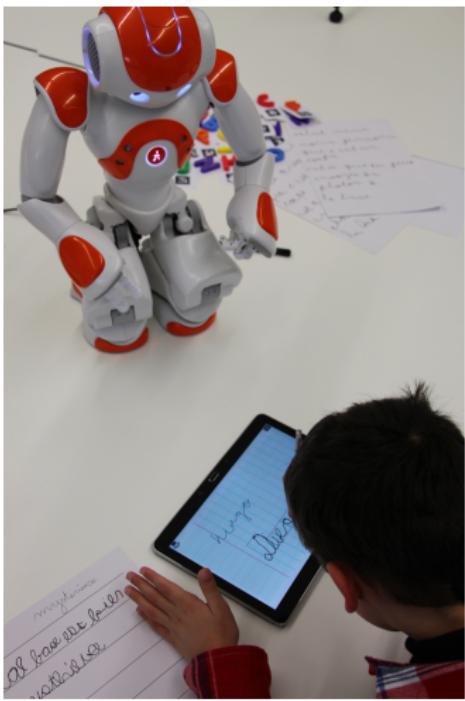








THE ROBOT AS A SOCIAL AGENT

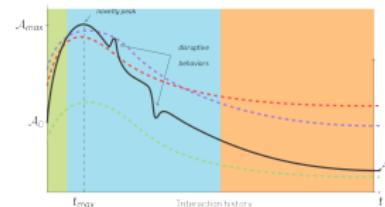


**The robot as a cognitive agent
is key here**

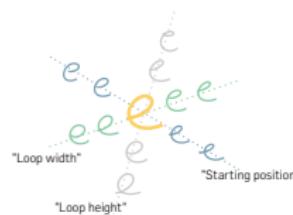
- Protégé effect
- metacognition

OTHER EXPERIMENTAL WORK

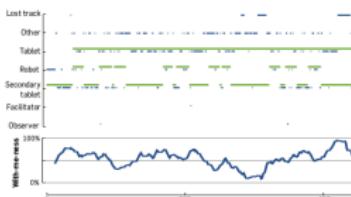
Social HRI in the field



Robots for Learning



Methodology



Expectations

- How do you imagine a robot?
What could it look like?
Have you ever seen a robot before?

Do 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 get out the door all by itself?
Does R always obey / does it ever break?
Does R always get things right?
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 it be happy or sad sometimes?

Social acceptance

- Do you like R? Why (not)?

- Would you like to have R at home?

Compassion

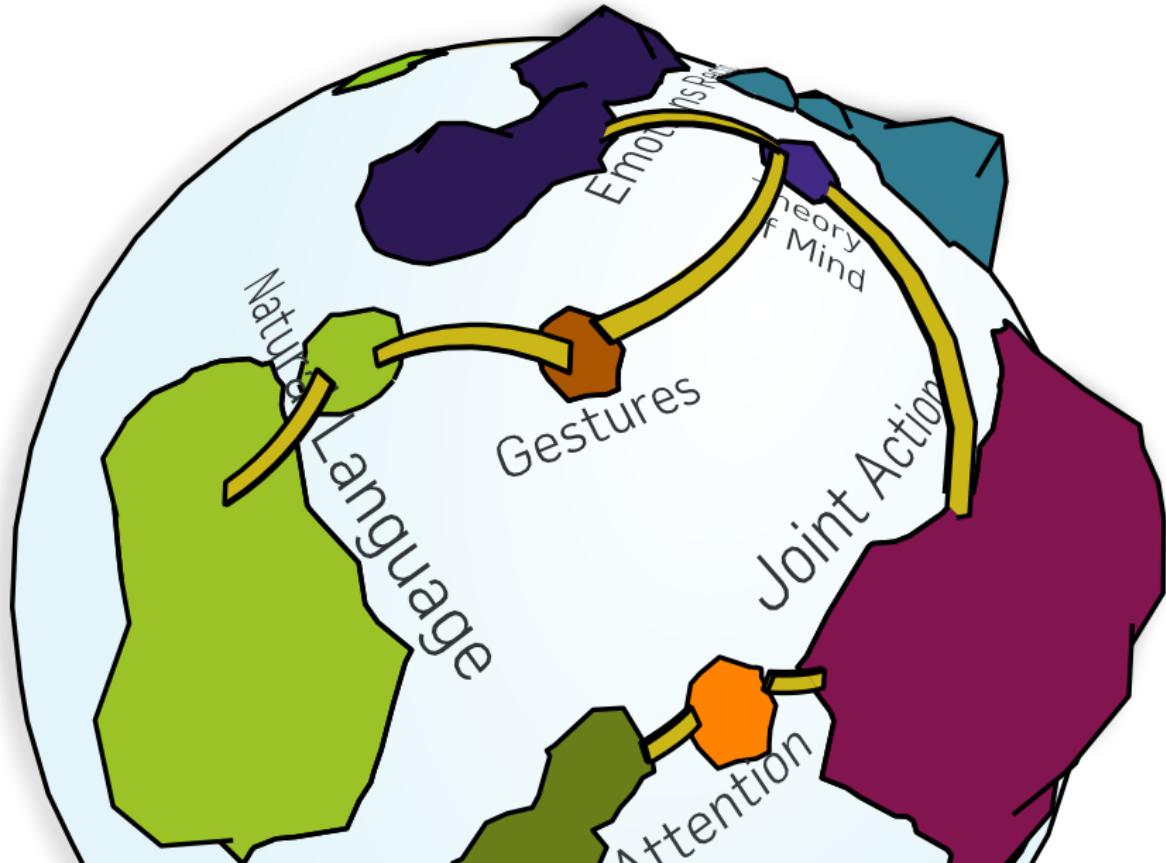
- Could R be your friend? Why (not)?

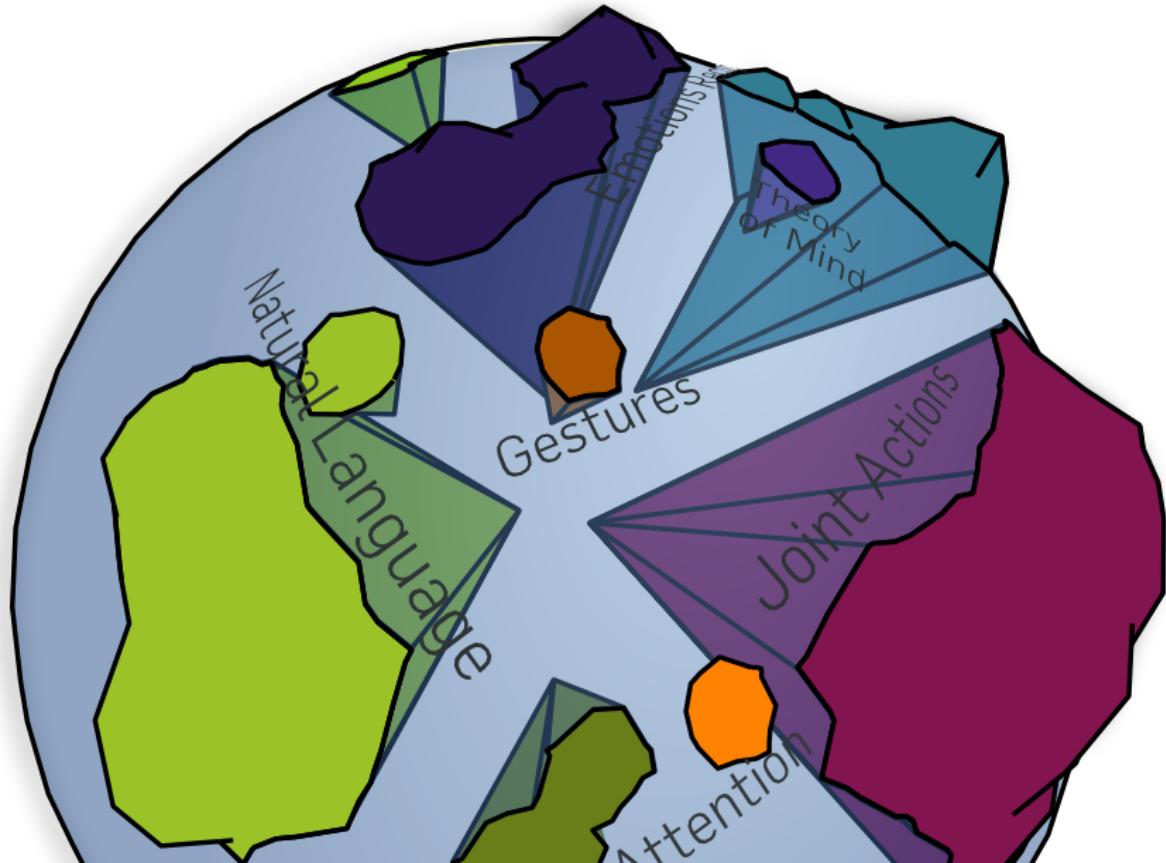
Ascribe moral standing

- Assume you go on a holiday for two weeks. Is it ok to leave R alone at home? Why (not)?

RESEARCH VISION









(Deep) learning of socio-cognitive human-robot interactions

(Deep) learning of socio-cognitive human-robot interactions

Working hypothesis: **Sociality emerges from interaction**

(Deep) learning of socio-cognitive human-robot interactions

Working hypothesis: **Sociality emerges from interaction**

- Instrumental role of **attention**
- Unsupervised **recurrent neural networks** to model others' minds → a **connectionist theory of mind**



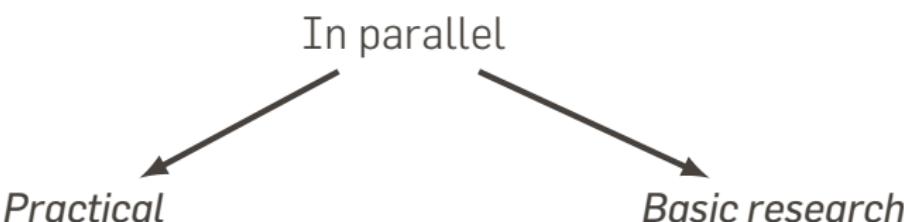


Free-play: challenging yet incredibly rich

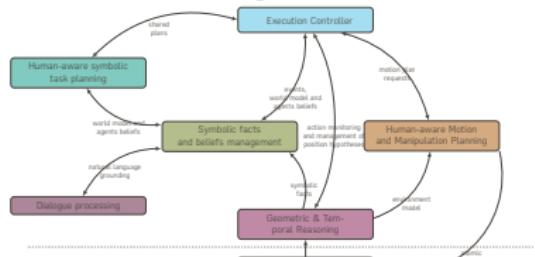
KEY MILESTONES FOR HRI

- **behavioural alignment**
- **'natural' (i.e. emergent) turn-taking**
- **'natural' protodeclarative pointing**
- ability to pass non-perceptual **false-belief tasks**
- **replication of Parten's stages of play**

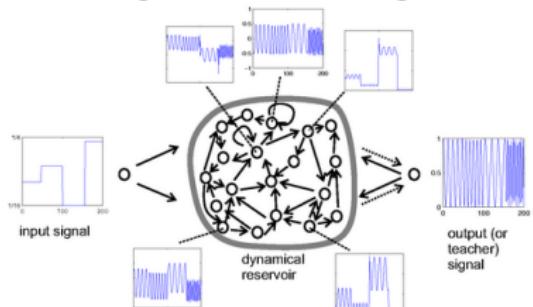
RESEARCH APPROACH



The “Plymouth Architecture for Socio-Cognitive Robots”



Emergent Social Cognition



→ RNNs; deep learning

SCAFFOLDING THE RESEARCH



Build up Plymouth's **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
 - funding for the **KidsLab** project
 - equipment + one post-doc

- **EPSRC Early Career Fellowship**

- max 5 years
 - focus 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

Within 2-3 years

- **Co-Investigator on a H2020 project**
 - close contacts with IST Lisbon, LAAS-CNRS, EPFL, INRIA
Bordeaux, Bristol BRL
- Submit a **EPSRC Standard Research** proposal
 - reaching independence
 - 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
 - within 7 years of PhD completion, i.e. before 2019
 - project on **Emergence of artificial social cognition**



Thank you!

SUPPLEMENTARY MATERIAL

3. Performing in Human Environments

4. pyRobots Example

5. Dialogue Grounding

6. Child-Robot Interaction for Learning

7. Child-Robot Interaction: the Practical Side

8. Reframing the research

9. Sketching a model

10. Experimental investigation

11. Theories on theory of mind

12. Dynamics of Interaction

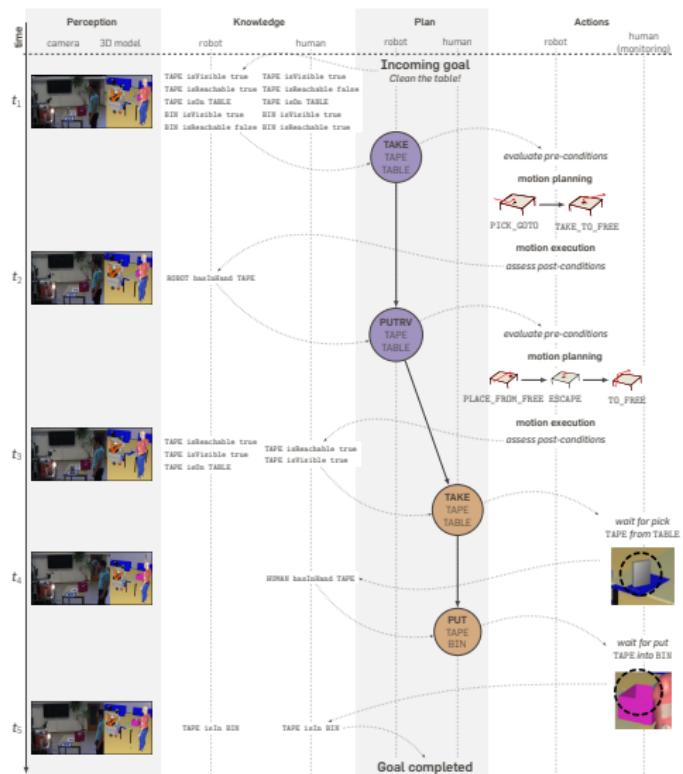
13. Cognitive Architectures

PERFORMING IN HUMAN ENVIRONMENTS

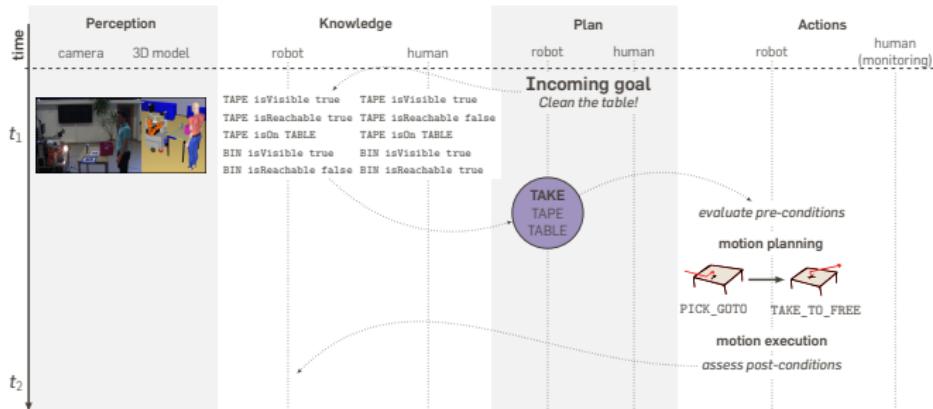


LAAS-CNRS

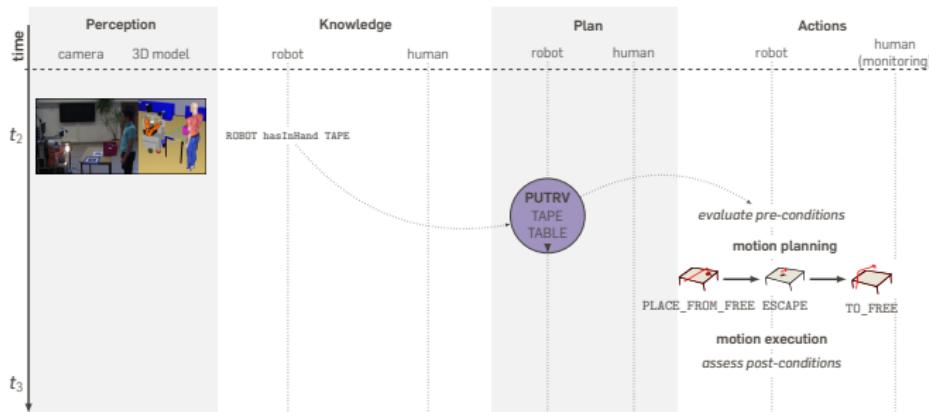
"CLEANING THE TABLE"...



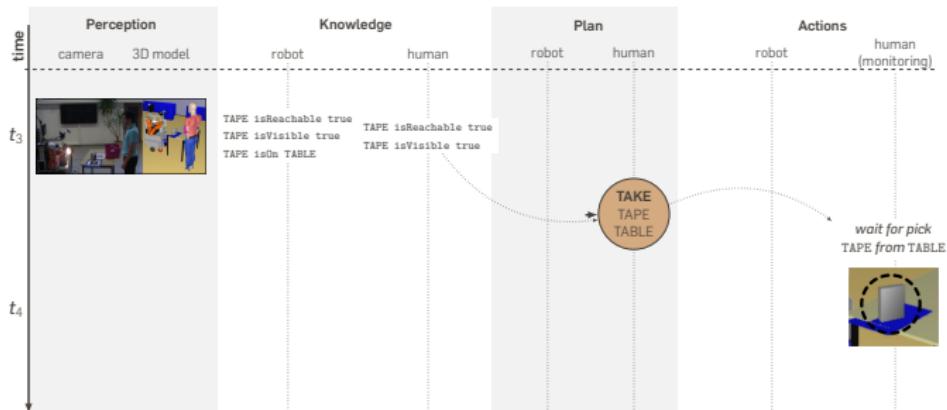
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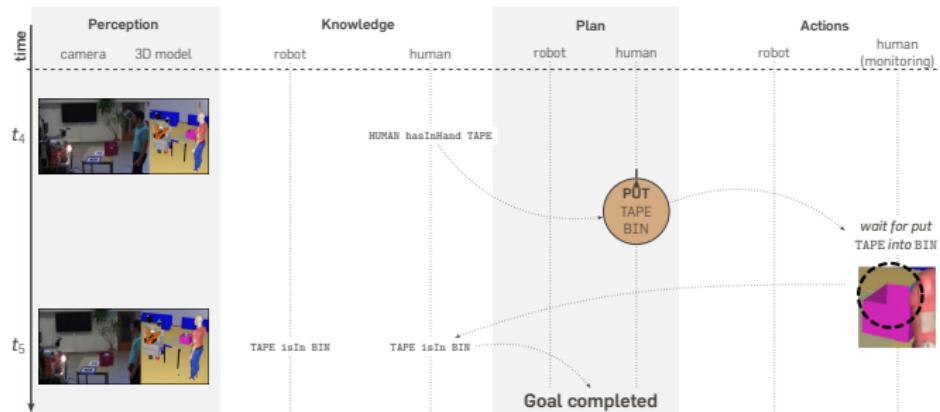
"CLEANING THE TABLE"...



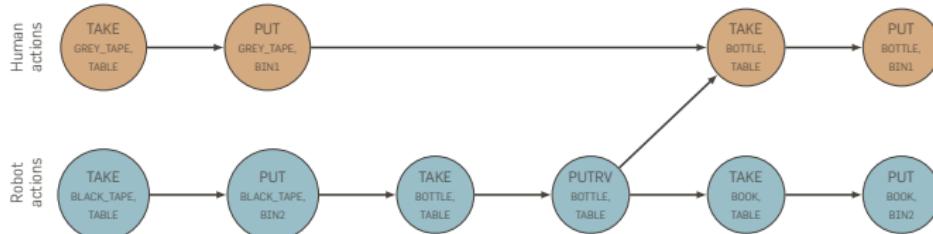
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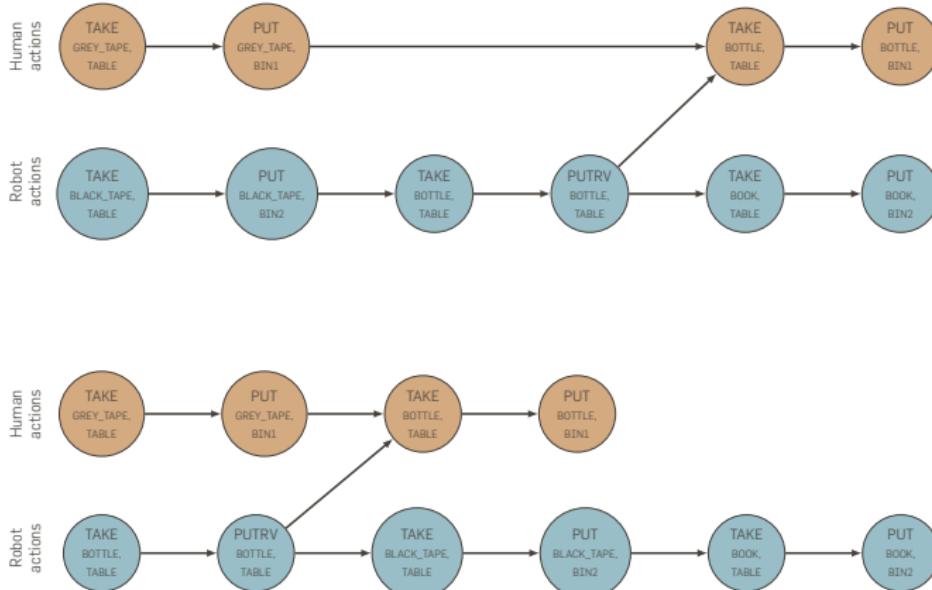
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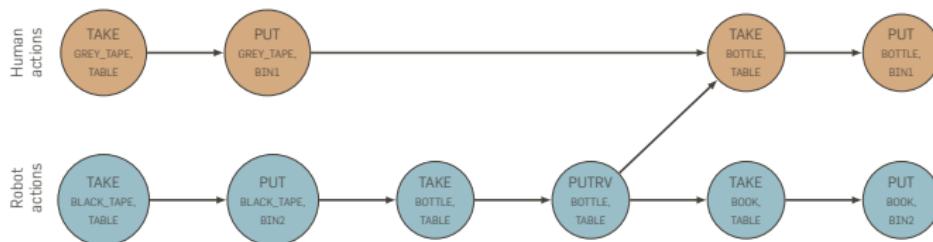
PLANNING FOR THE HUMAN



PLANNING FOR THE HUMAN



PLANNING FOR THE HUMAN







LAAS-CNRS

roboscopie

A Theatre Performance for a Robot and a Human

HRI 2012

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

PYROBOTS

```
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()
```

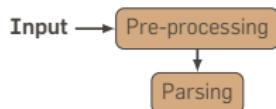
```
with MyRobot() as robot:

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

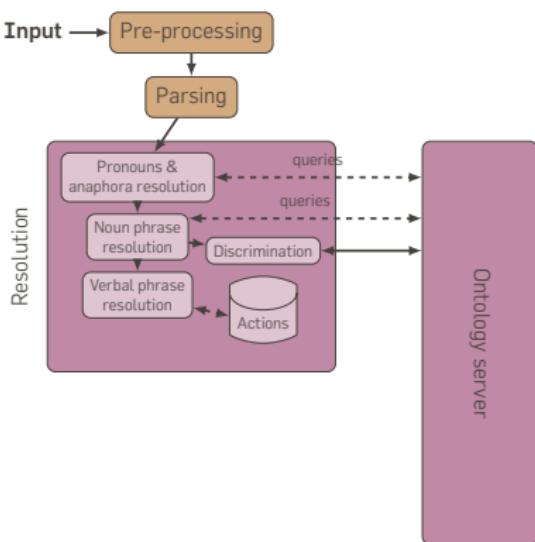
    try:
        while True:
            time.sleep(0.5)
    except KeyboardInterrupt:
        pass
```

DIALOGUE GROUNDING

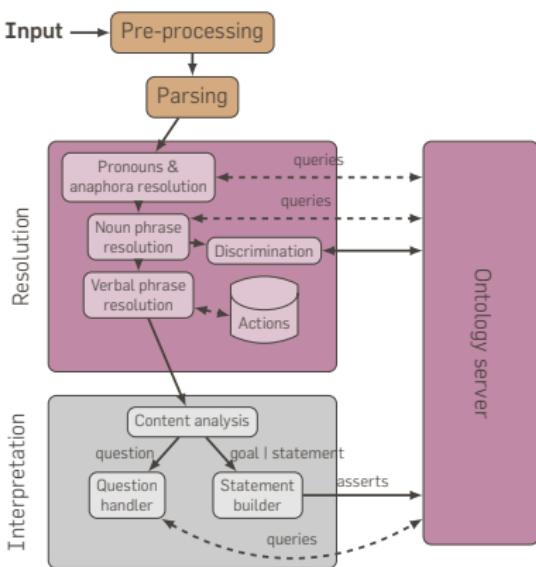
DIALOGUE GROUNDING



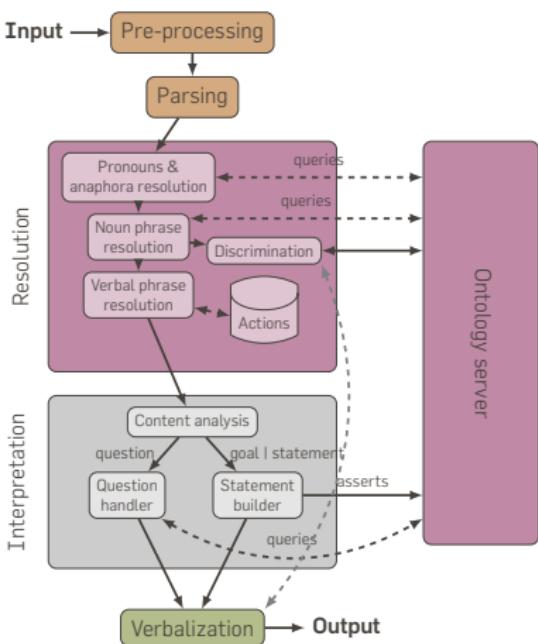
DIALOGUE GROUNDING



DIALOGUE GROUNDING



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DIALOGUE GROUNDING



"Give me the book on the table"

DIALOGUE GROUNDING



"Give me the book on the table"

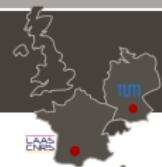


$\text{me} \rightarrow \text{baby_1}$

$\text{find}(\text{?obj type table}) \rightarrow \text{ikea_table}$

$\text{find}(\text{?obj type book, ?obj isOn ikea_table}) \rightarrow \text{harry_potter}$

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,

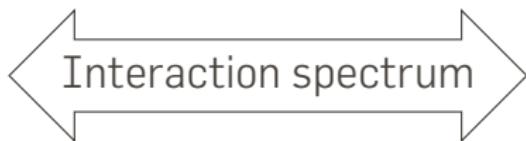
action1 receivedBy baby_1

CRI FOR LEARNING

SOCIAL OR NOT SOCIAL?



Non-social



Social

SOCIAL OR NOT SOCIAL?



Cellulo



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?

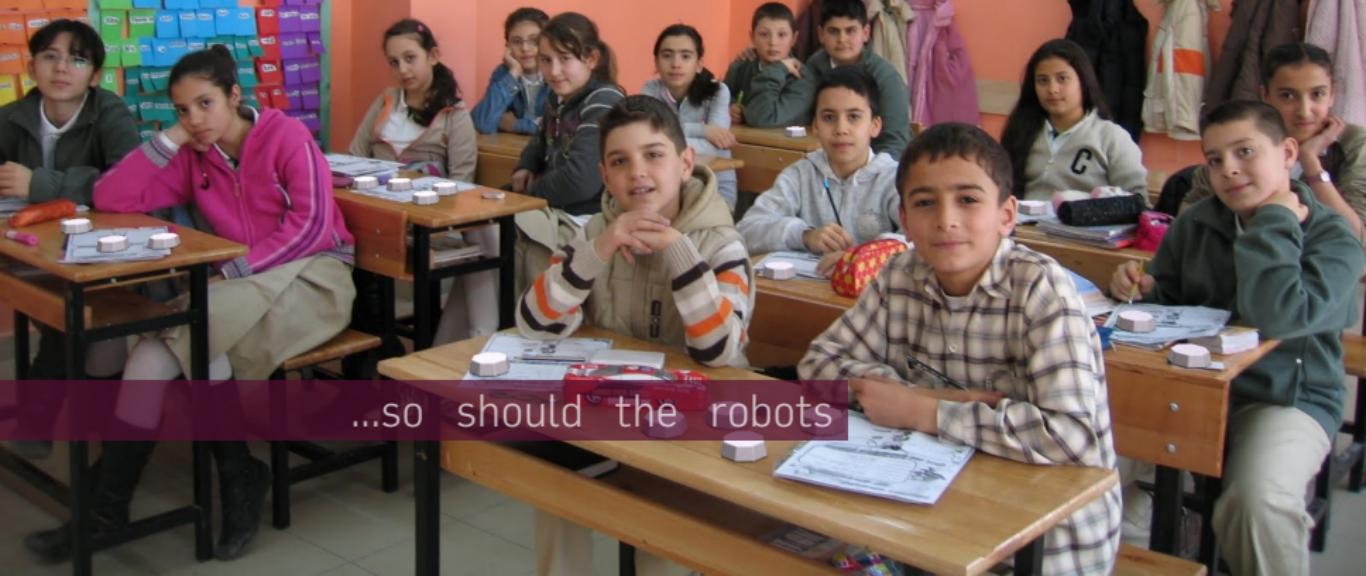




Pens and paper are pervasive...



WORDMANIA



...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)

CELLULO: DESIGN PRINCIPLES



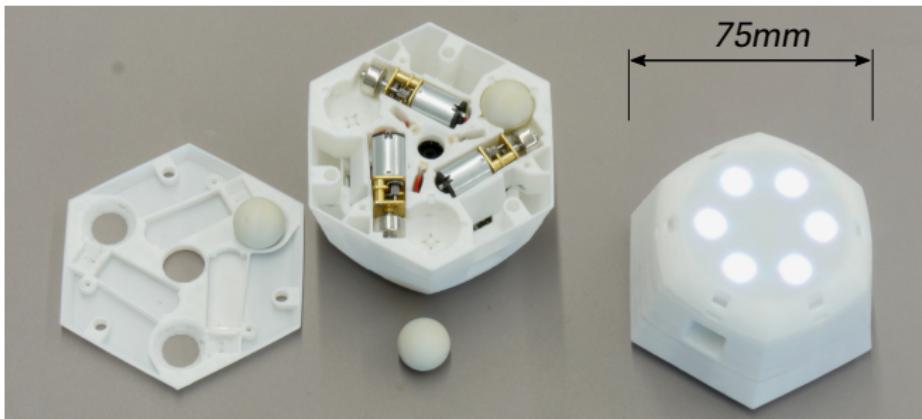
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- **versatile:** applicable to a broad range of learning scenarios; the robots' hardware, appearance and interaction modalities must not imply or be constrained to specific use cases

CELLULO: DESIGN PRINCIPLES



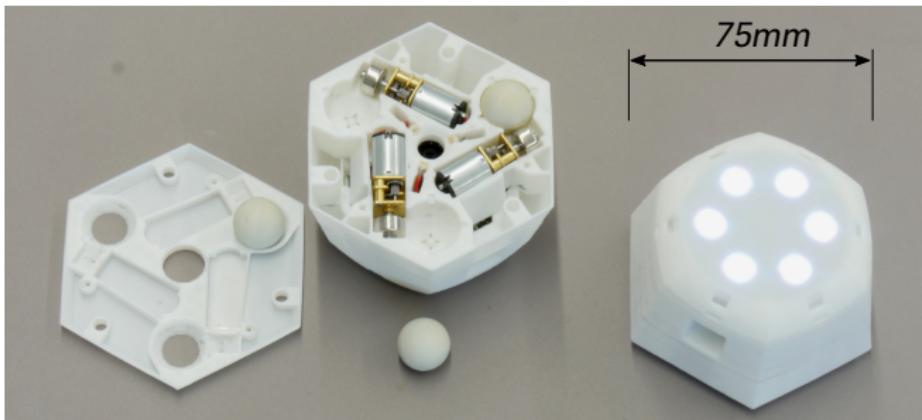
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- **versatile:** applicable to a broad range of learning scenarios; the robots' hardware, appearance and interaction modalities must not imply or be constrained to specific use cases
- **practical:** to gain field acceptance in the classrooms, educative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

CELLULO: HARDWARE



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

CELLULO: HARDWARE



- Holonomic motion
- Sub-mm absolute localisation (no external hardware)
- 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**.

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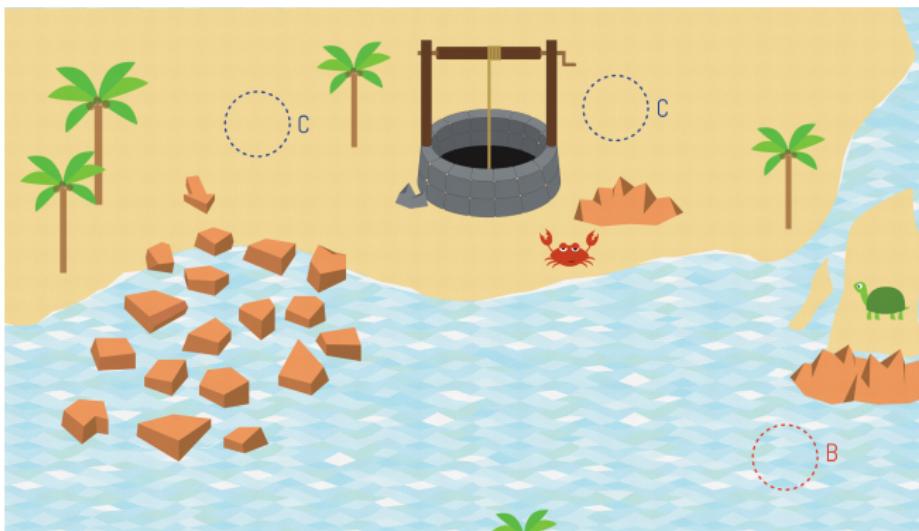
Achieved through a **paper-based absolute localisation system**

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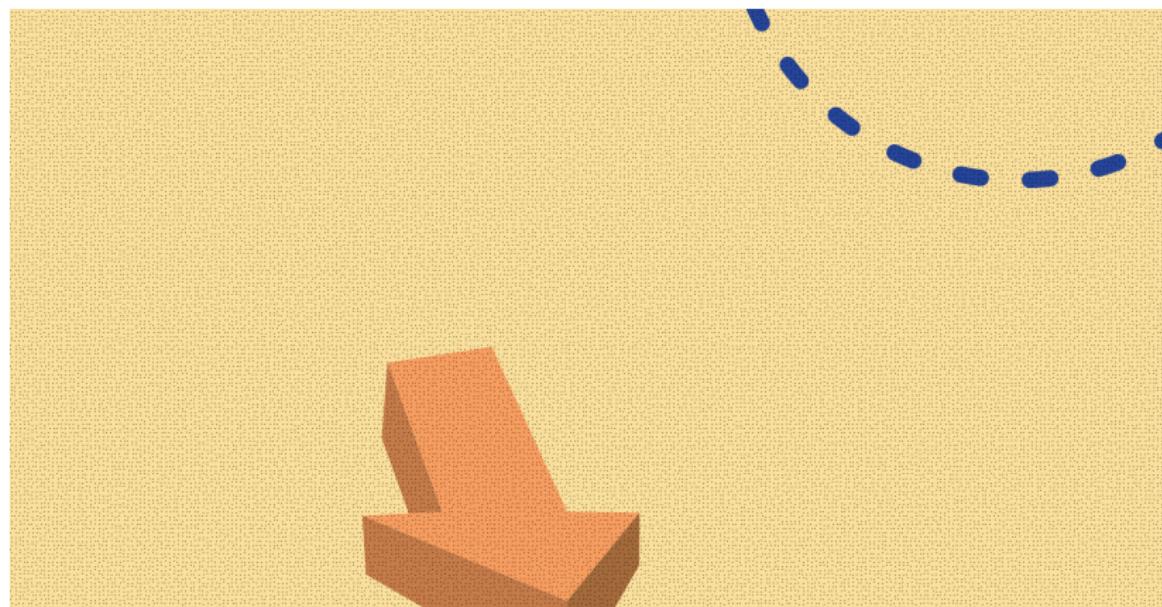


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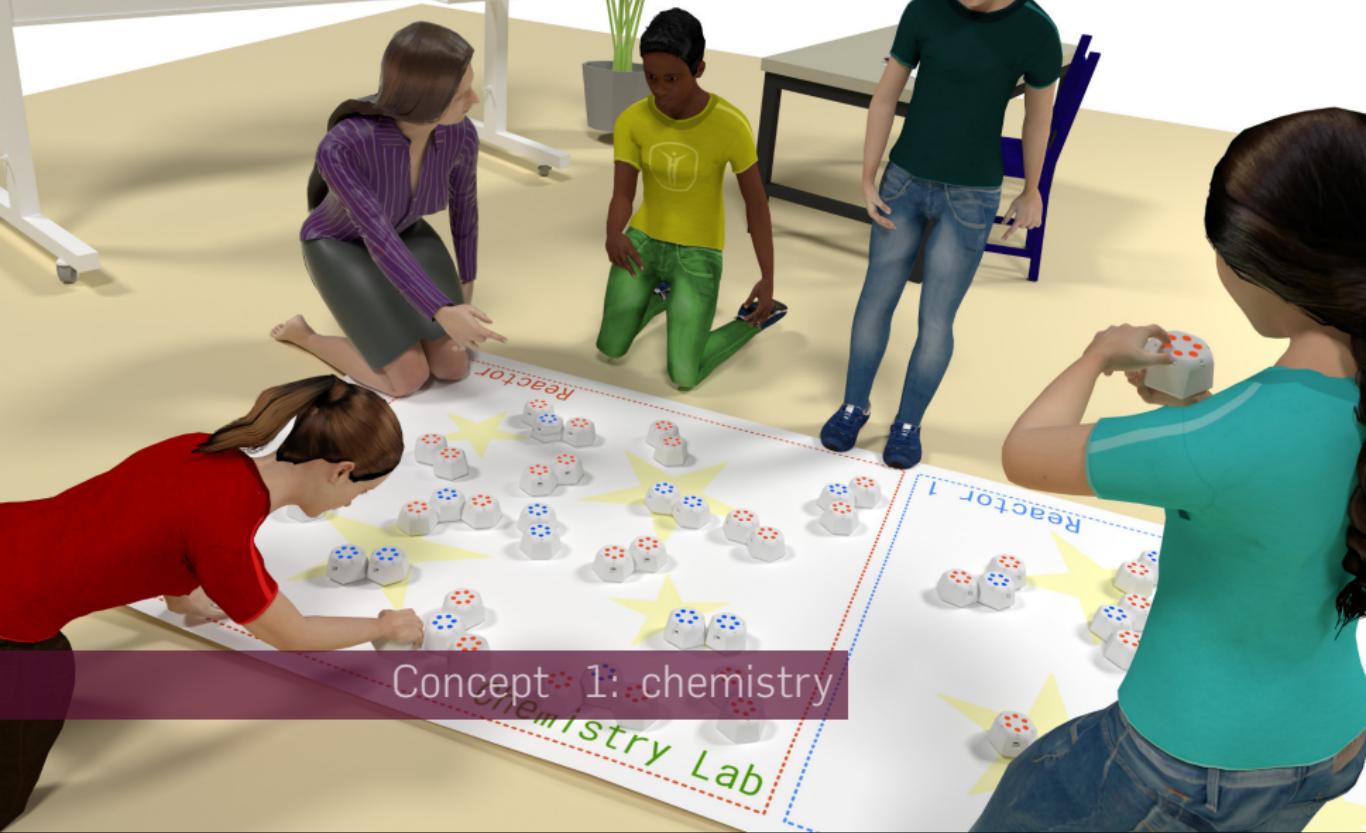
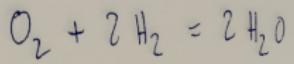
INTERACTION WITH THE PAPER



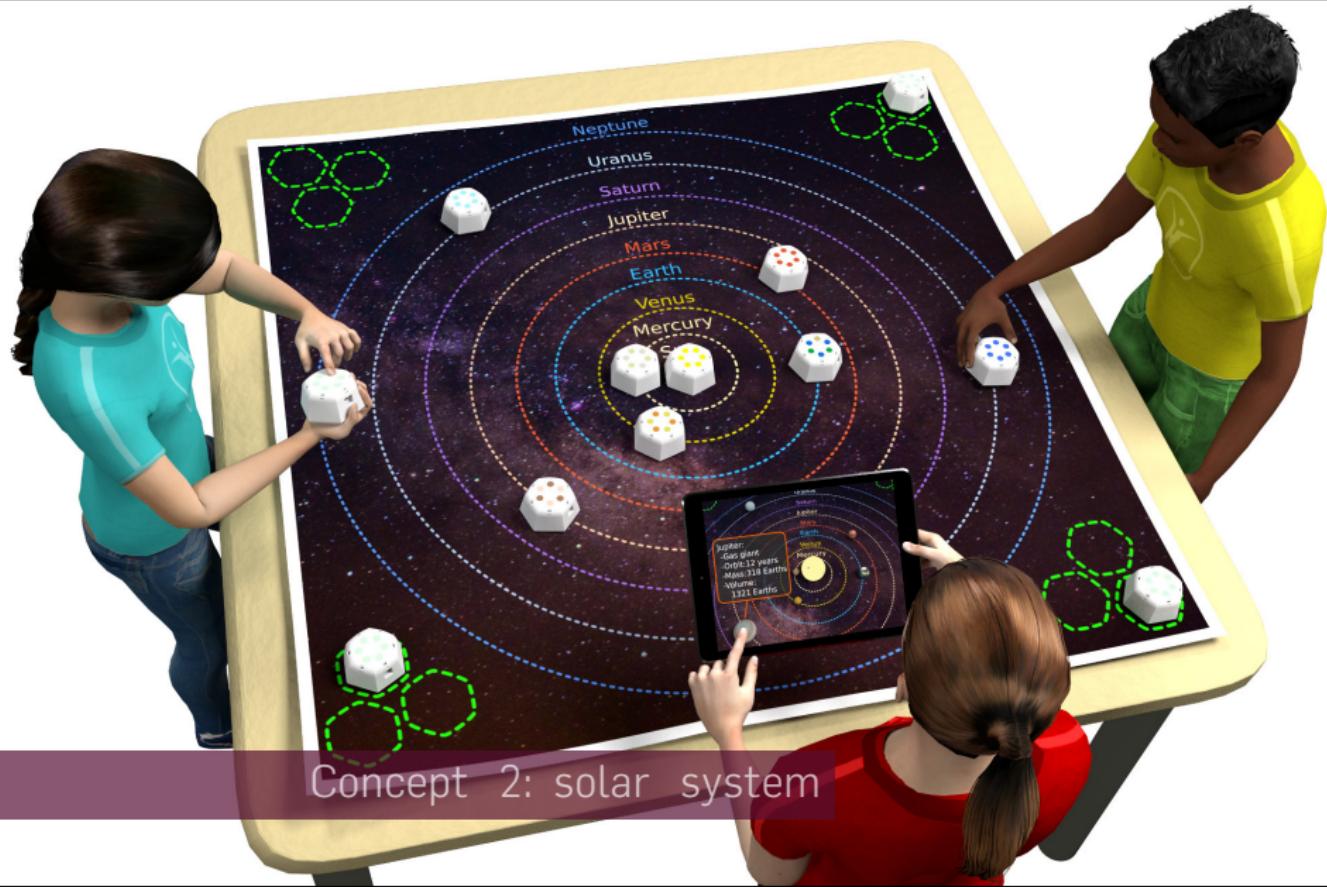
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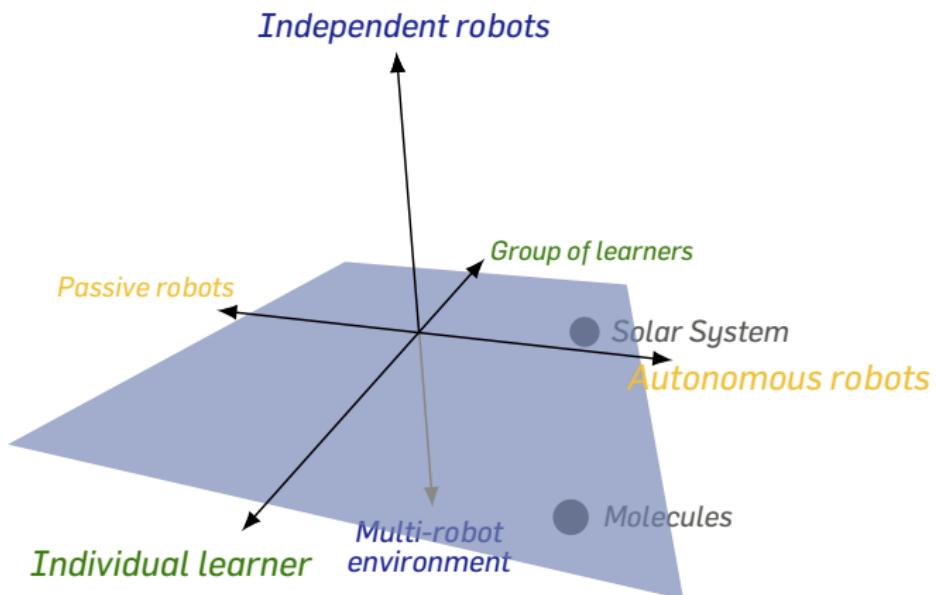
- even more than 'classroom-friendly', paper is 'teacher-friendly'
- easy to manipulate, copy, print, cutout, dispose...
- unique activity IDs: drop the robots onto the sheet, it recognizes the activity



Concept 2: solar system



INTERACTION DESIGN SPACE



...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

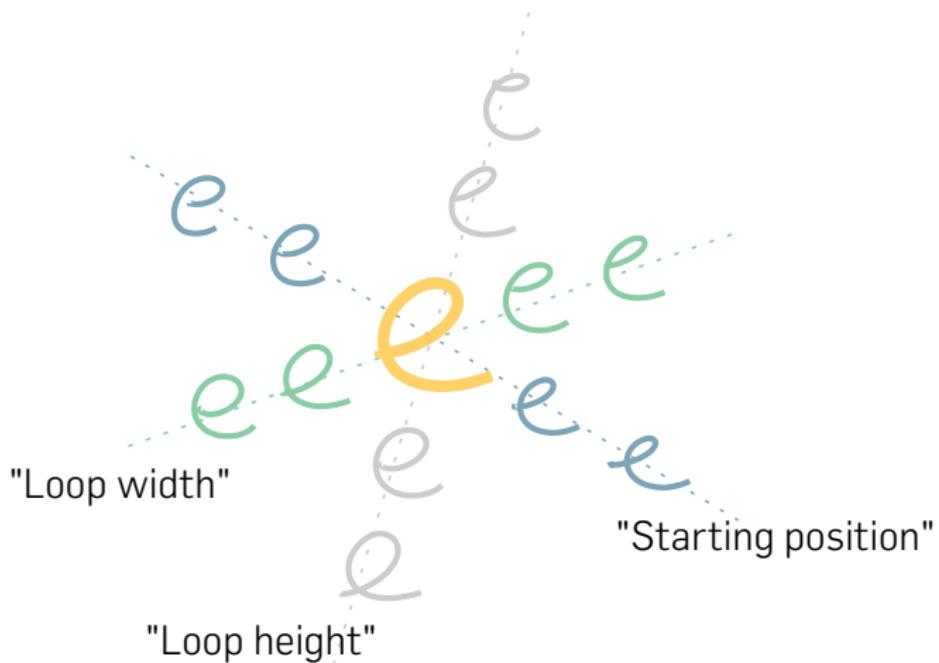


- Get a child-proof robot to write...
- ...badly...
- Make it able to learn...
- ...with the help of children

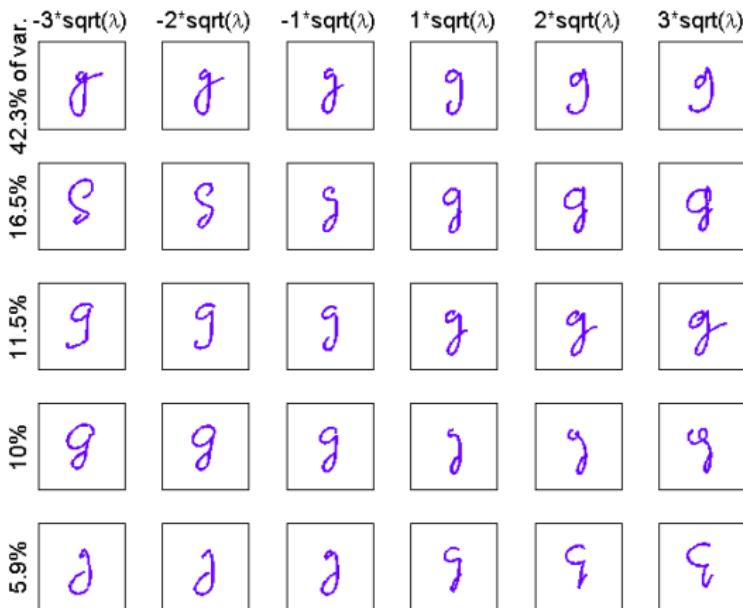
COWRITER IMPLEMENTATION



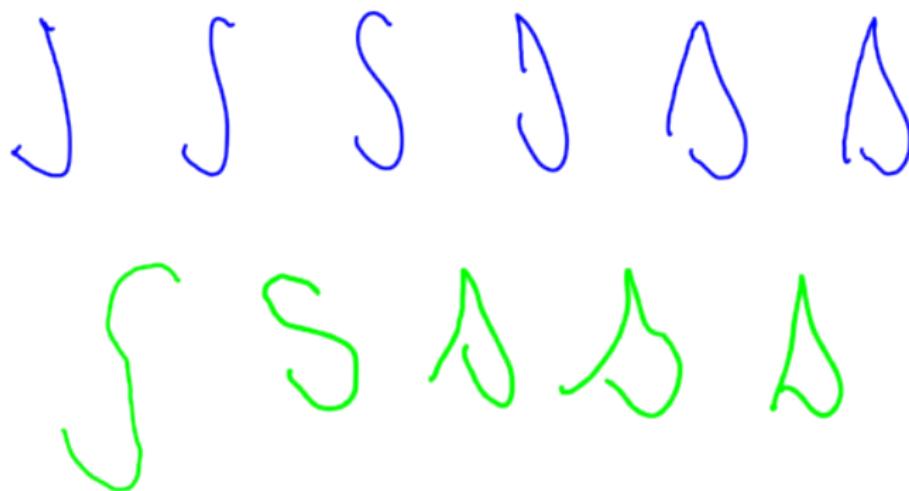
COWRITER IMPLEMENTATION

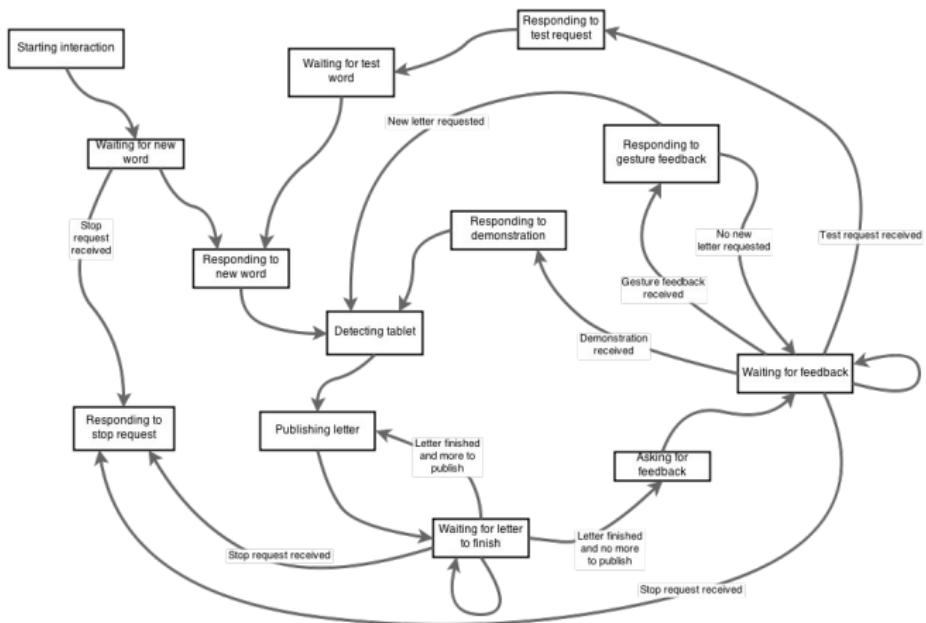


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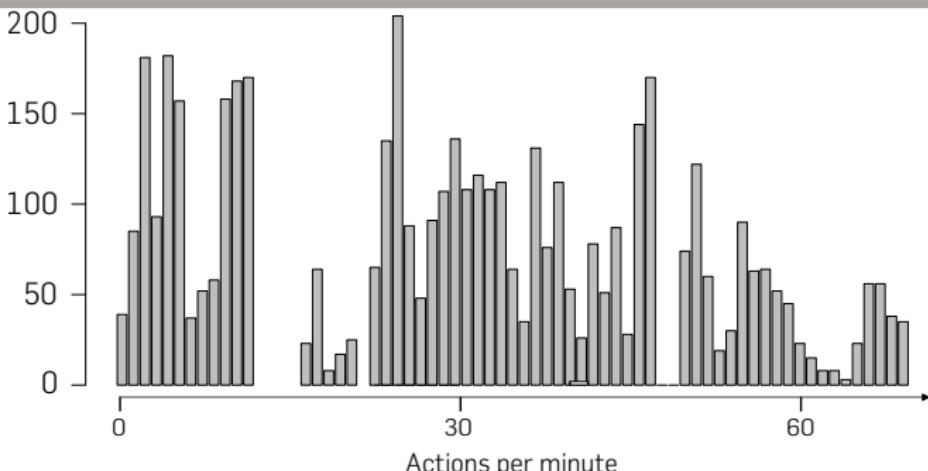
COWRITER IMPLEMENTATION





PRACTICAL CRI





lightbox	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	

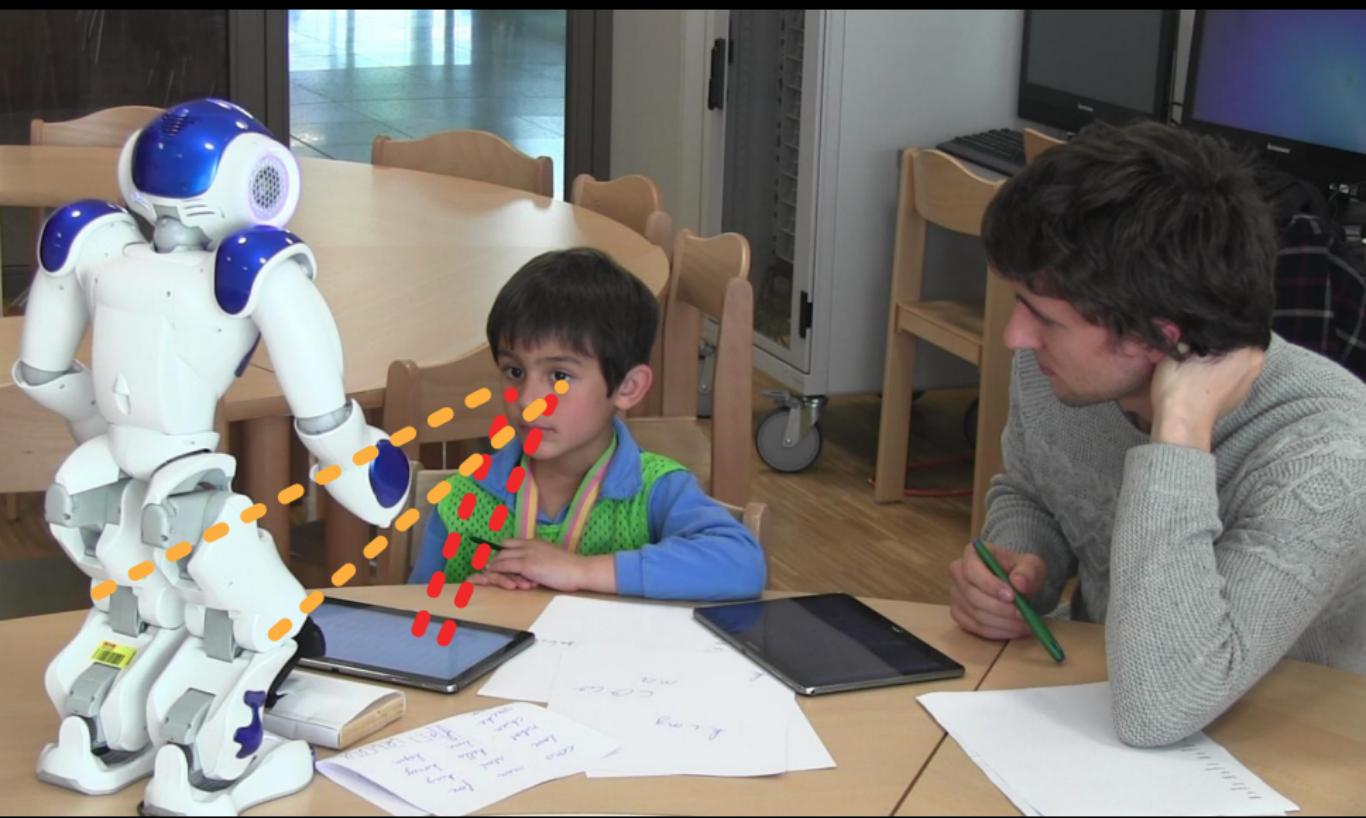
Can we make the analysis of child-robot interaction **practical**?

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

WITH-ME-NESS

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



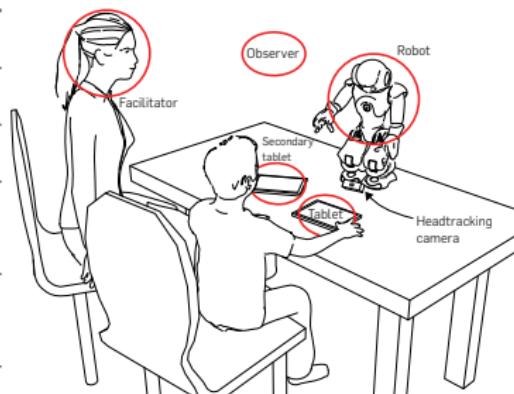


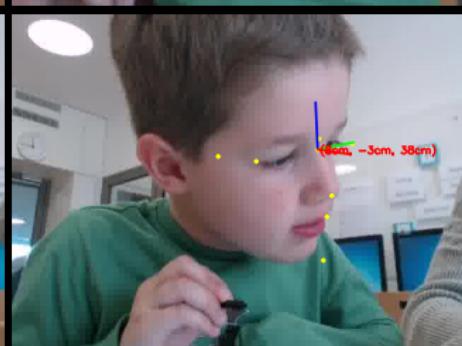
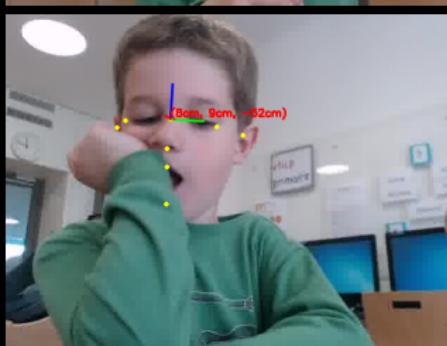
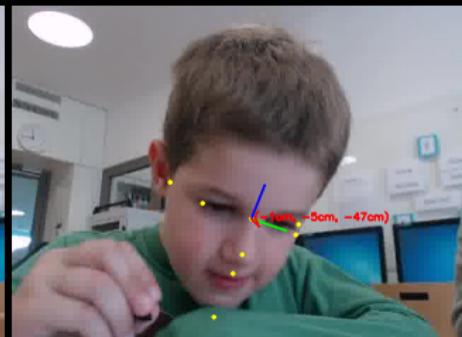
EXPECTED FOCUS



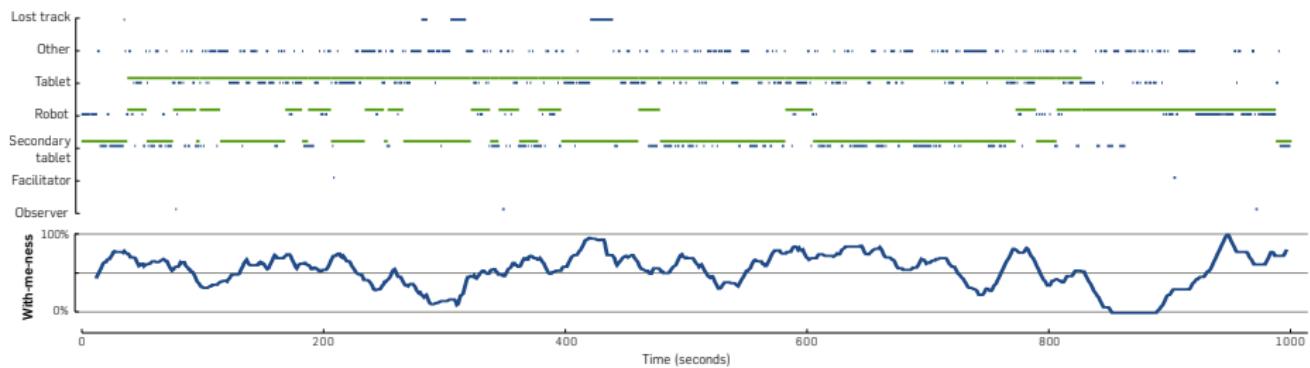
Example for the CoWriter task:

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





WITH-ME-NESS



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

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)?

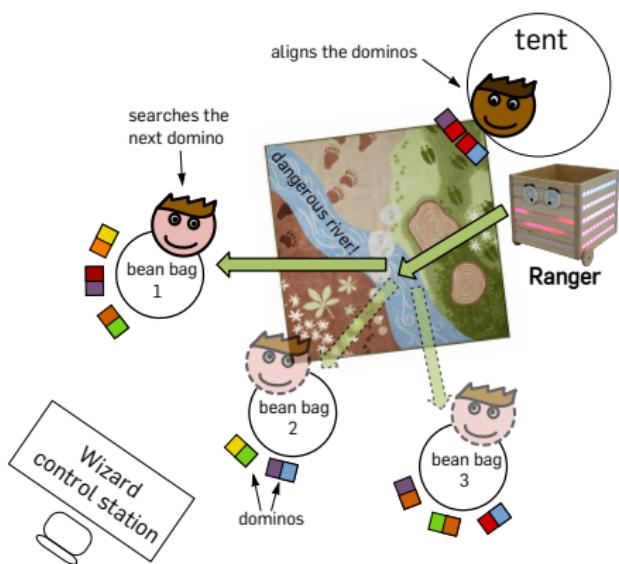
Ascribe moral standing

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?



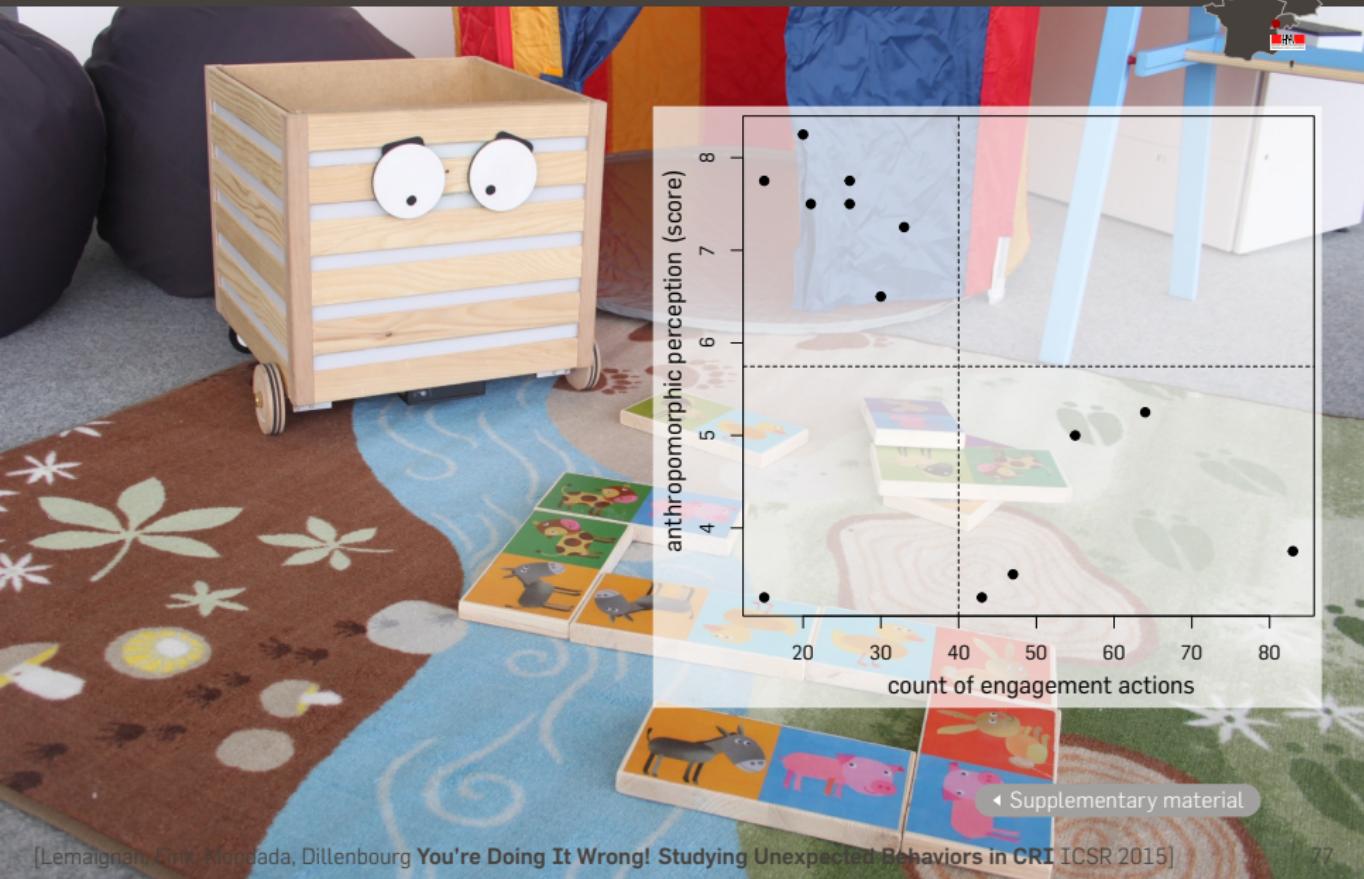
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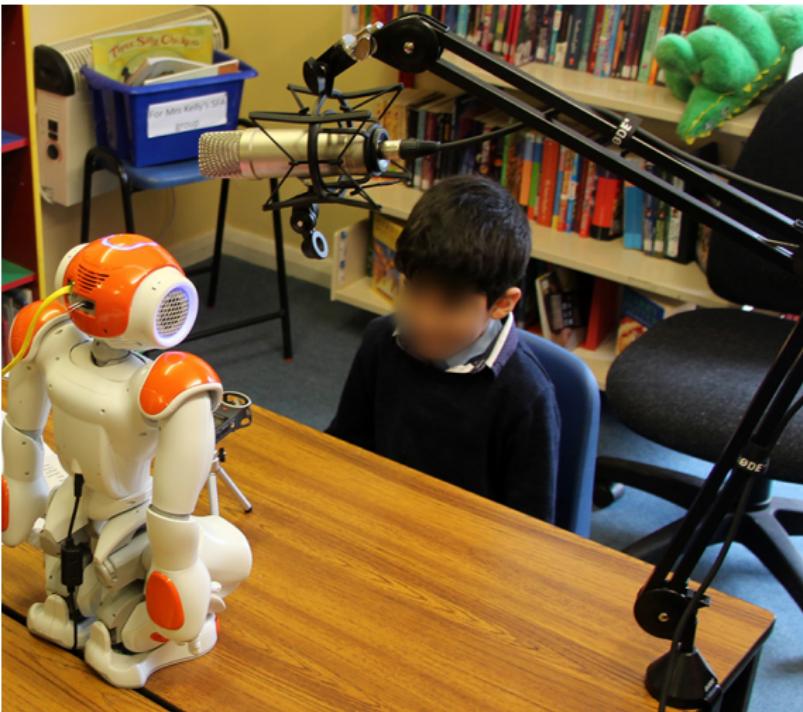


We can compute for each pair an “anthropomorphic perception” score based on the cognitive ascriptions, and...

ANTHROPOMORPHISM != ENGAGEMENT



AUTOMATIC SPEECH RECOGNITION WITH CHILDREN



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	<i>11.8 [38]</i>	0.64	<i>0 [0]</i>	0.68	<i>0 [0]</i>	0.76	<i>0 [0]</i>
spontaneous (n=222)	0.39	<i>6.8 [17.6]</i>	0.64	<i>0.5 [2.4]</i>	0.80	<i>0 [0]</i>	0.80	<i>0 [0]</i>
spontaneous clean only (n=83)	0.40	<i>6.0 [16.9]</i>	0.63	<i>1.2 [1.2]</i>	0.78	<i>0 [0]</i>	0.78	<i>0 [0]</i>

M LD: mean Levenshtein distance, at word level.

◀ Supplementary material

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!**

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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, 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!*

ONE QUESTION

Can sociality emerge from interaction?

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"

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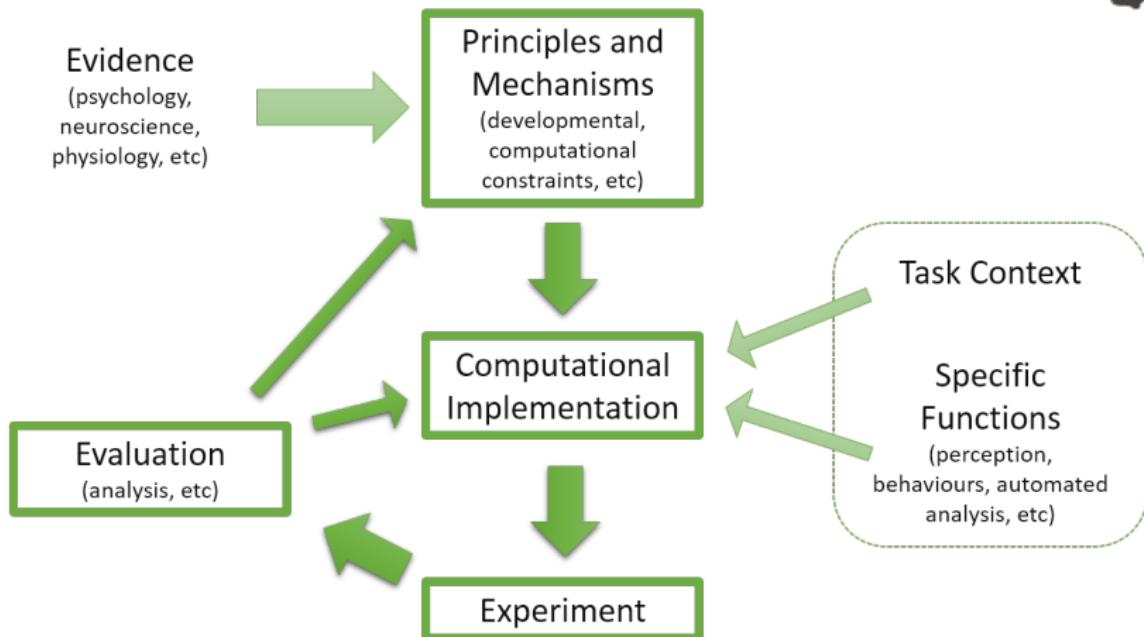
"unifying disparate phenomena"

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

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

COGNITIVE ARCHITECTURE AS A METHODOLOGY



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 joint goals
 - ultimately, performing joint actions

→ Social analogs of *perception & action*

COGNITIVIST VS EMERGENT PARADIGMS

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

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Possible 'emergent paradigm' rephrasing:

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 consciousness”.

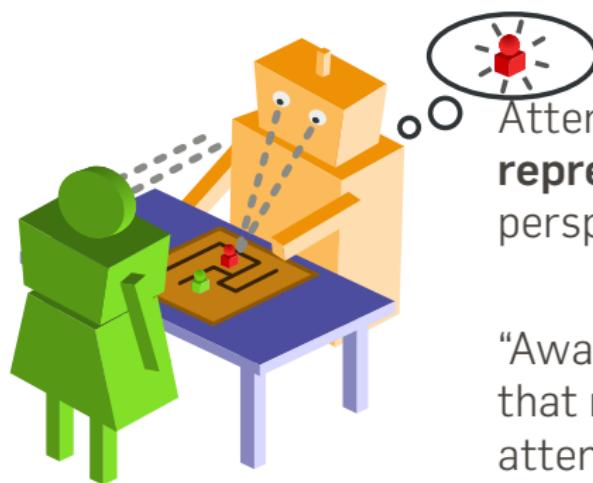
MODELING OTHERS' MIND?

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



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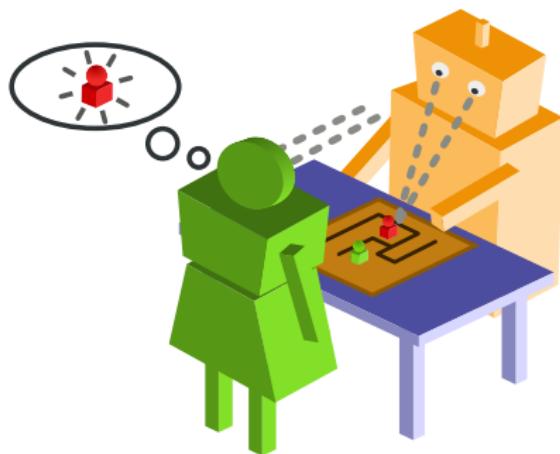


Attention is more about
representation than visual
perspective

“Awareness is a construct
that represents the
attentional state of a brain”

MODELING OTHERS' MIND?

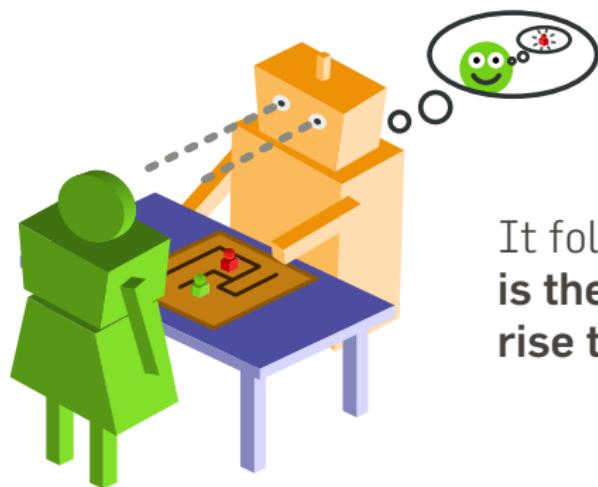
In cognitive neurosciences: Graziano's *Attention Schemata Theory*



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

MODELING OTHERS' MIND?

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



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

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 hypothesise 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**

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4. modelling **others' mental representations** is taking snapshots of their own current state of awareness

IN MORE DETAILS

1. **mental representations** are **snapshots of what we are aware of**
2. **awareness** is the label we conveniently put on the **process of attention**
3. attention at time t is the label we put on the set of the **activated units** in a (biased) **associative memory network**
4. modelling **others' mental representations** is taking snapshots of their own current state of awareness
5. modelling other's state of awareness, i.e. their current attentional process, is **mediated by one's own attentional system**, typically through **joint attention** mechanisms

IN MORE DETAILS

1. **mental representations** are **snapshots of what we are aware of**
2. **awareness** is the label we conveniently put on the **process of attention**
3. attention at time t is the label we put on the set of the **activated units** in a (biased) **associative memory network**
4. modelling **others' mental representations** is taking snapshots of their own current state of awareness
5. modelling other's state of awareness, i.e. their current attentional process, is **mediated by one's own attentional system**, typically through **joint attention** mechanisms
6. Points 1 to 5 essentially refer to a *phenomenal* awareness (a *raw* inner experience). *Phenomenal* awareness can be turned into *access consciousness* (the abstract, cognitive ability to reflect on the inner experience)

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6. Points 1 to 5 essentially refer to a *phenomenal* awareness (a *raw* inner experience). *Phenomenal* awareness can be turned into *access consciousness* (the abstract, cognitive ability to reflect on the inner experience)
7. In AI, *phenomenal awareness* maps to connectionist approaches, while *access consciousness* maps to **symbolic representations**

AN HYBRID MODEL OF COGNITION

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

⇒ bottom-up, from raw percepts to *accessible* representations

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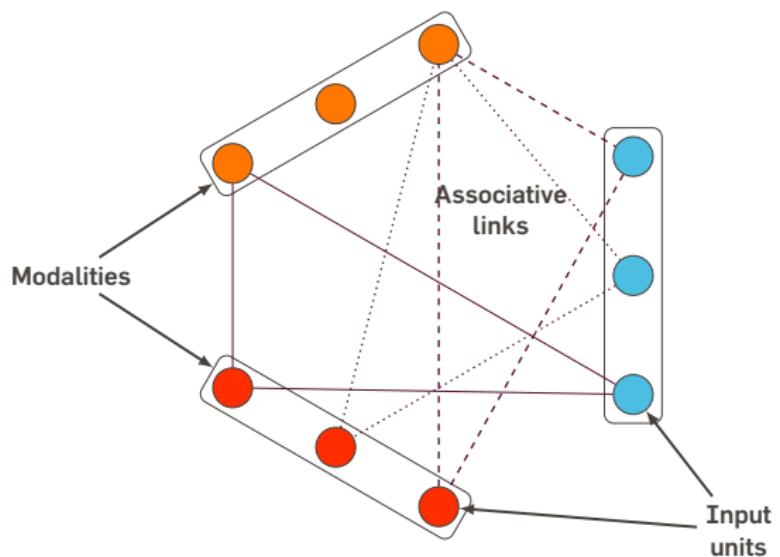
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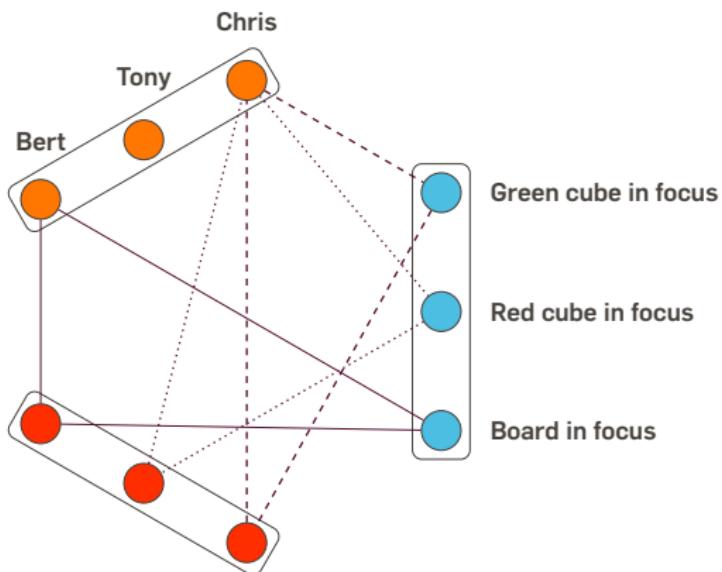
The *Biased Competition Model of Attention* supports bottom-up as well as **top-down biasing mechanisms**:

- *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



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MANY GAPS CALLING FOR INVESTIGATION!

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- what is the **social motivation** for the robot to carry over this modeling? What social drives?
- 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

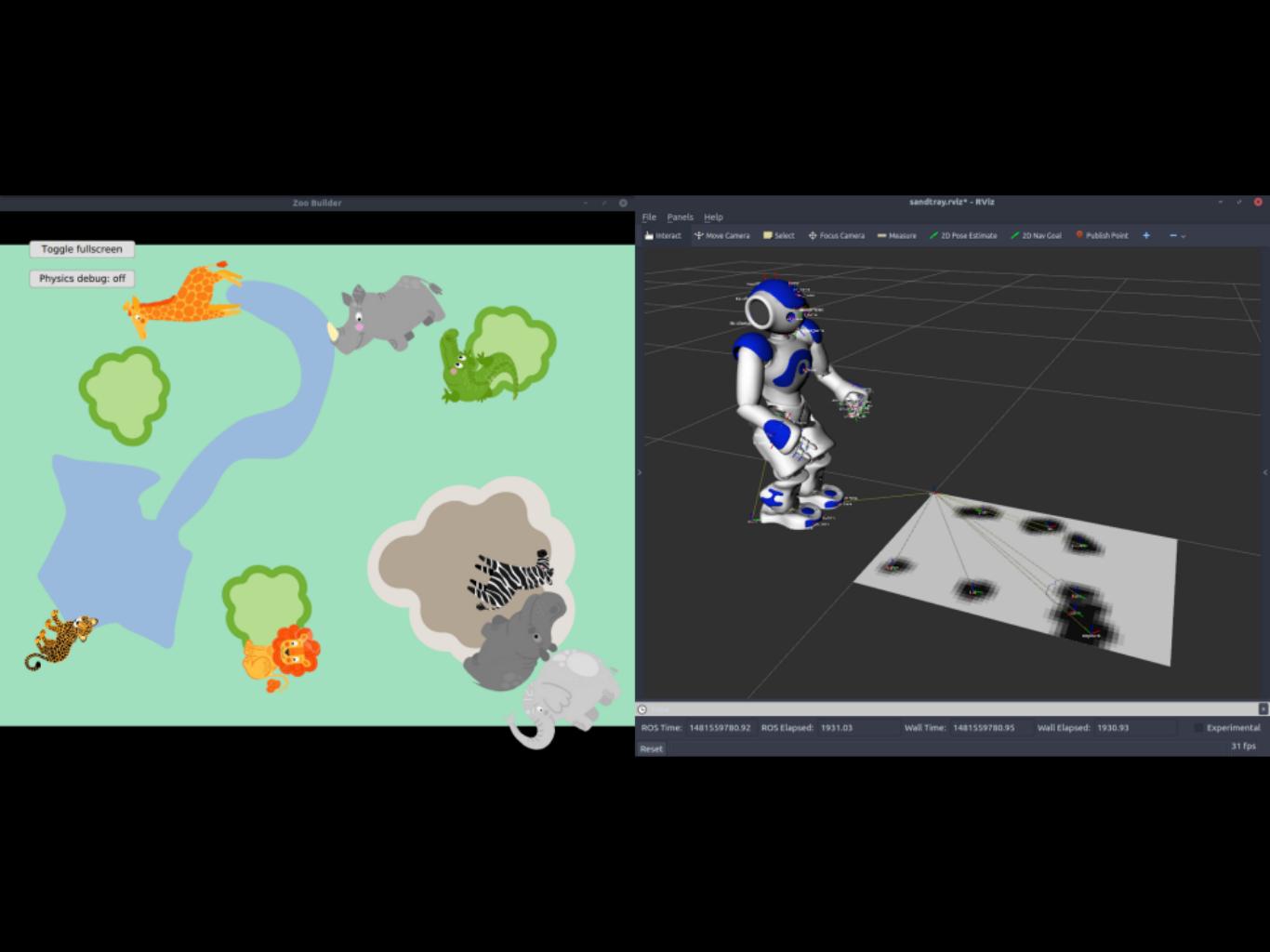
AN EXPERIMENTAL FRAMEWORK

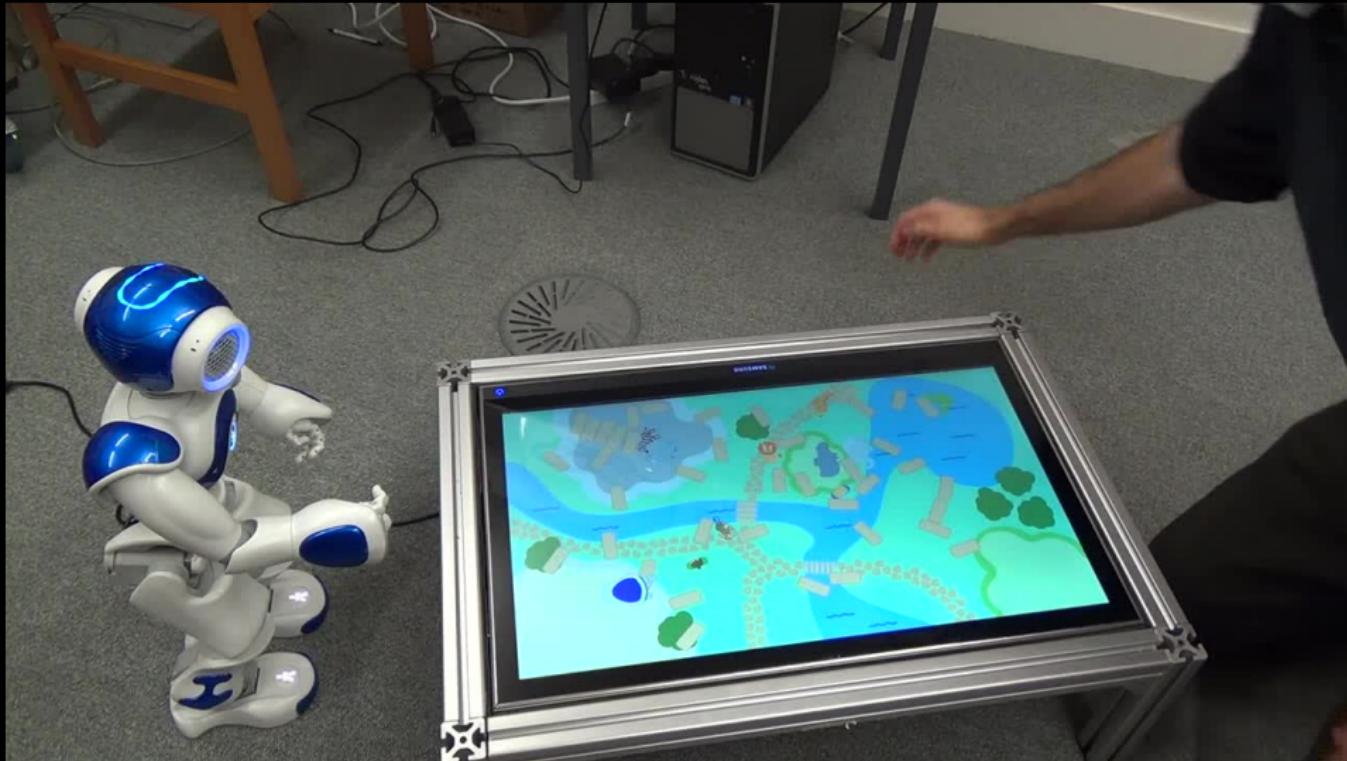
- The “Zoo design” play situation
- **Free play** with the following constraints:
 - initial prompt (“Let’s build a zoo!”)
 - limited set of tokens (cubes, Lego animals)
 - spatially limited playground

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- 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
- 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







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

ONLY THE START OF IT!

Which cognitive model? which cognitive architecture?

→ 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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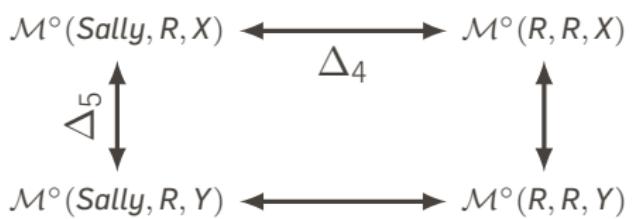
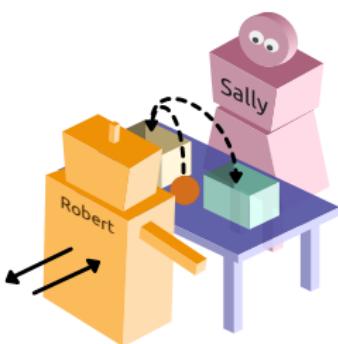
What inputs for a connectionist take on social interactions?

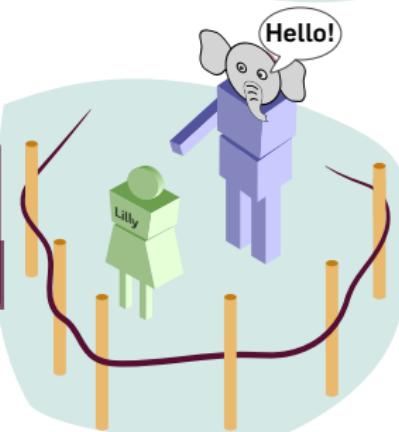
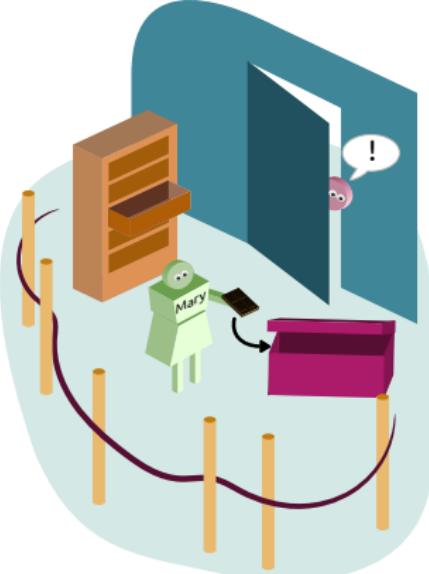
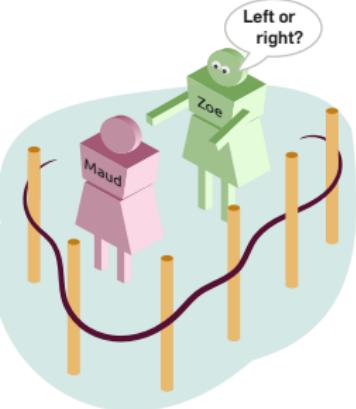
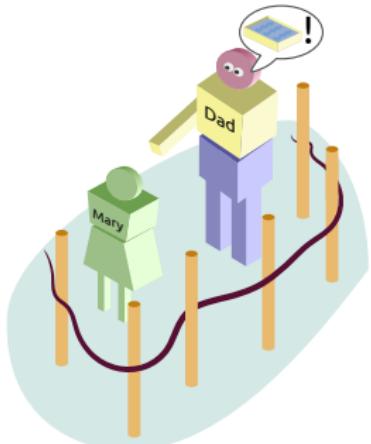
low-level? high-level? To reconstruct someone else's attentional state, Graziano suggests:

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

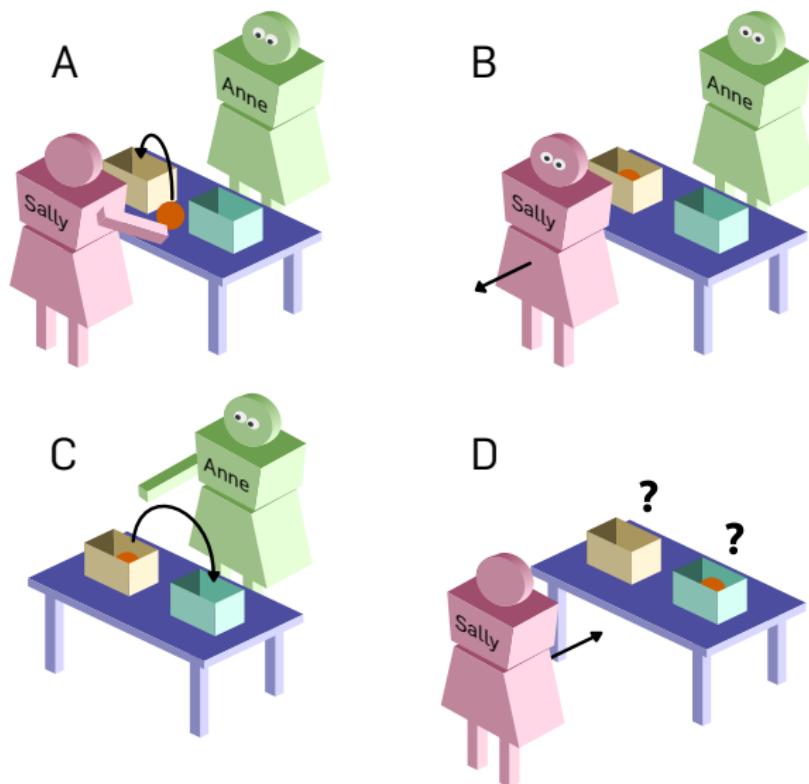
Probably not the end of it, though!

THEORIES ON THEORY OF MIND



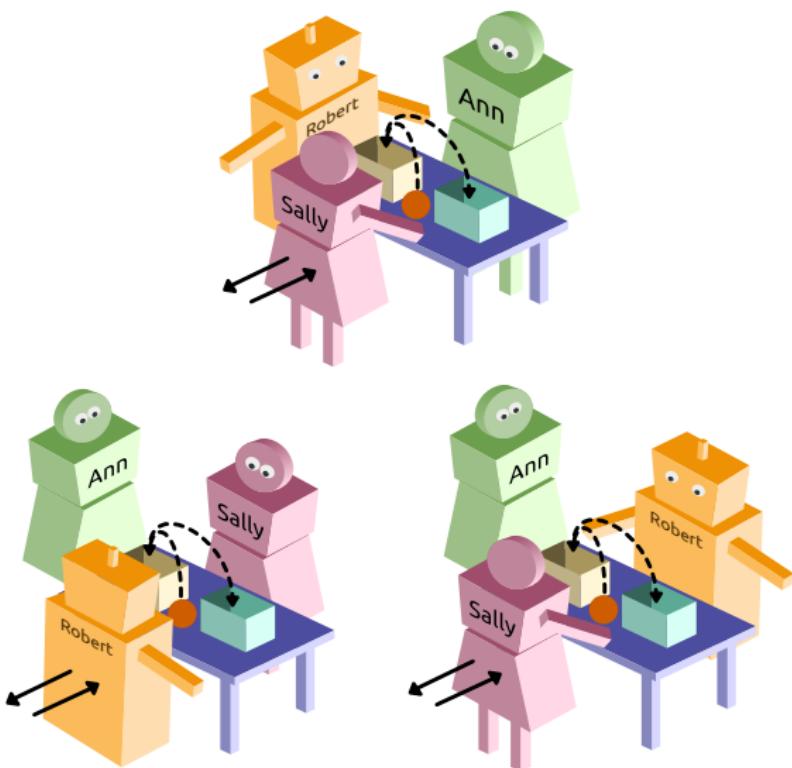


1ST ORDER TOM: THE FALSE-BELIEF EXPERIMENT

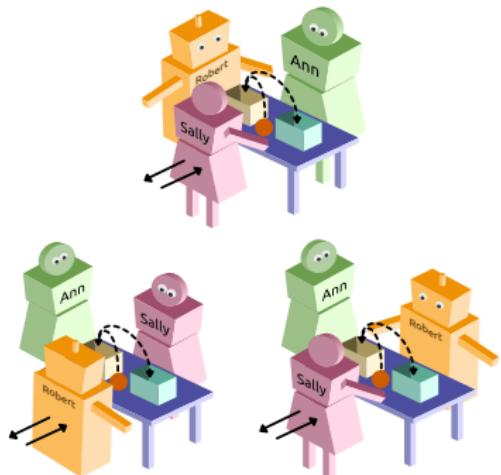


[Wimmer and Perner, **Beliefs about beliefs: Representation and constraining function [...]**, Cognition, 1983]
[Lemaignan, Dillenbourg **Mutual Modelling in Robotics: Inspirations for the Next Steps – HRI 2015**]

THE FALSE-BELIEF EXPERIMENT, RELOADED



THE FALSE-BELIEF EXPERIMENT, RELOADED



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

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

THE FALSE-BELIEF EXPERIMENT, RELOADED



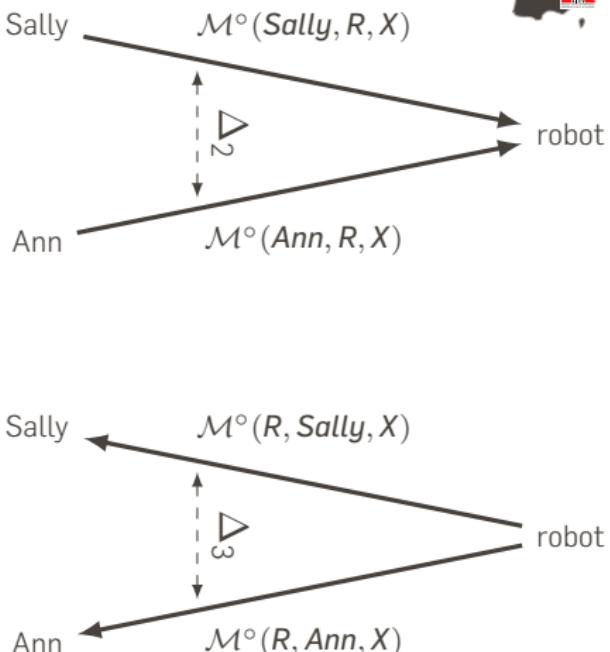
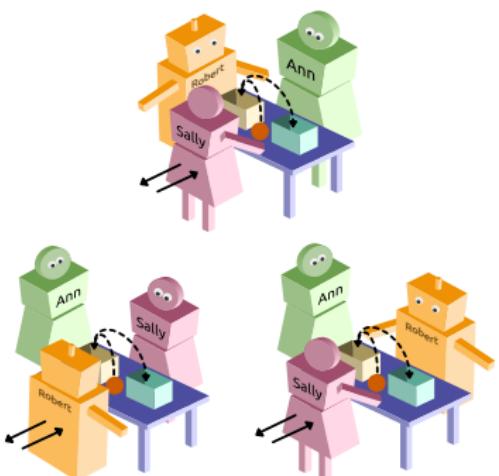
- **Robot is the observer**

$\mathcal{M}^\circ(R, \text{Sally}|\text{Ann}, \textit{plans})$? 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?

THE FALSE-BELIEF EXPERIMENT, RELOADED



THE FALSE-BELIEF EXPERIMENT, RELOADED



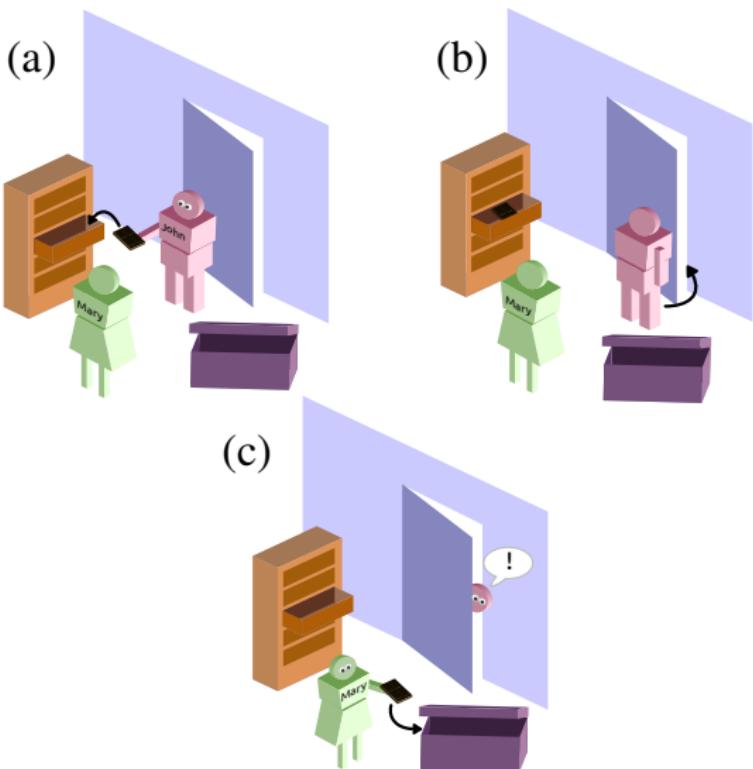
Do Sally and Ann have the same accuracy when modelling the robot?

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

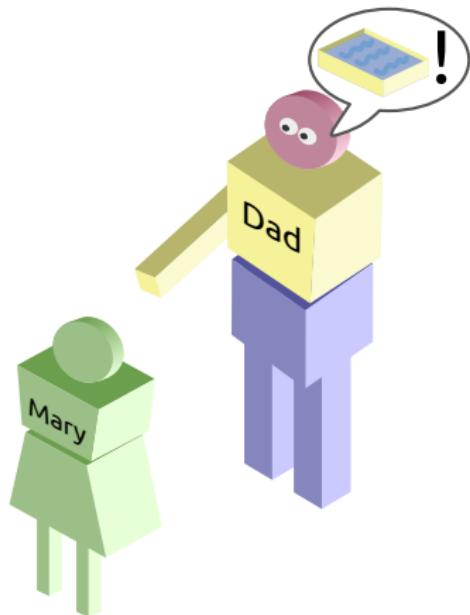
Conversely, what may lead the robot to model more accurately Sally or Ann?

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

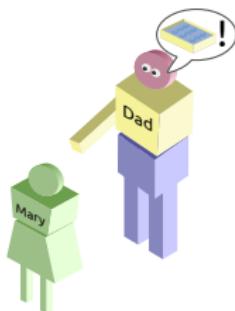
2ND ORDER TOM: THE CHOCOLATE BAR EXPERIMENT



AGREEMENT AS ∞ -ORDER TOM



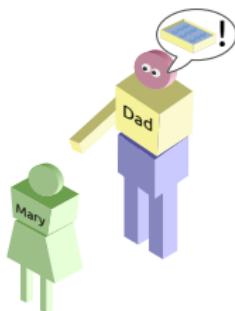
AGREEMENT AS ∞ -ORDER TOM



Shared knowledge

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

AGREEMENT AS ∞ -ORDER TOM



Shared knowledge

$$\text{EK}_J\varphi \leftrightarrow \bigwedge_{i \in J} K_i\varphi$$

Common knowledge

$$\text{CK}_J\varphi \leftrightarrow \text{EK}_J\varphi \wedge \text{EK}_J\text{EK}_J\varphi \wedge \text{EK}_J\text{EK}_J\text{EK}_J\varphi \wedge \dots$$

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

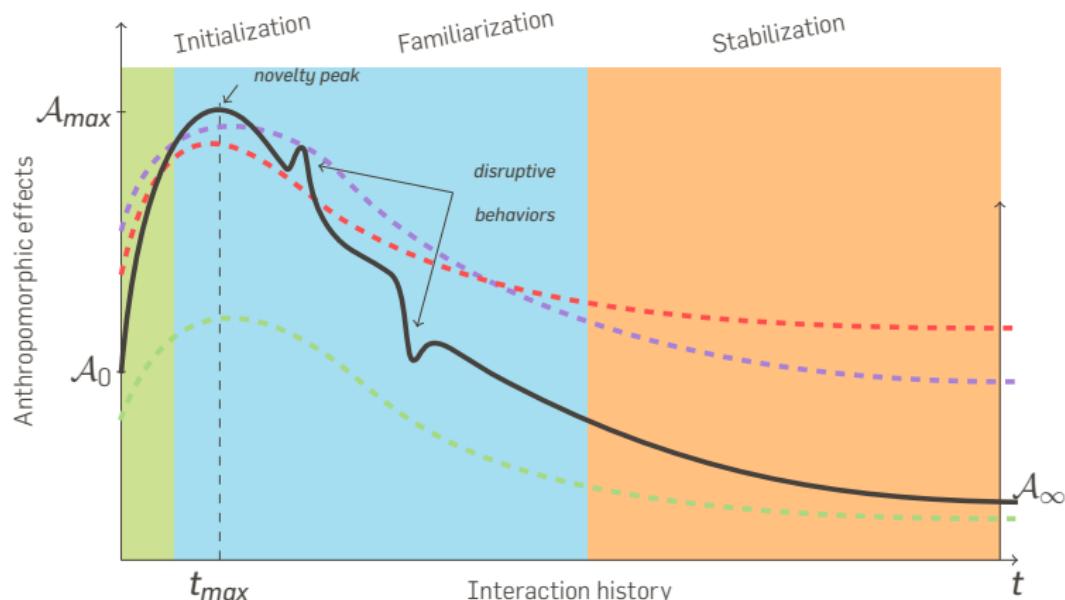
AUTISTIC ASSETS AND DEFICITS OBSERVED IN REAL LIFE



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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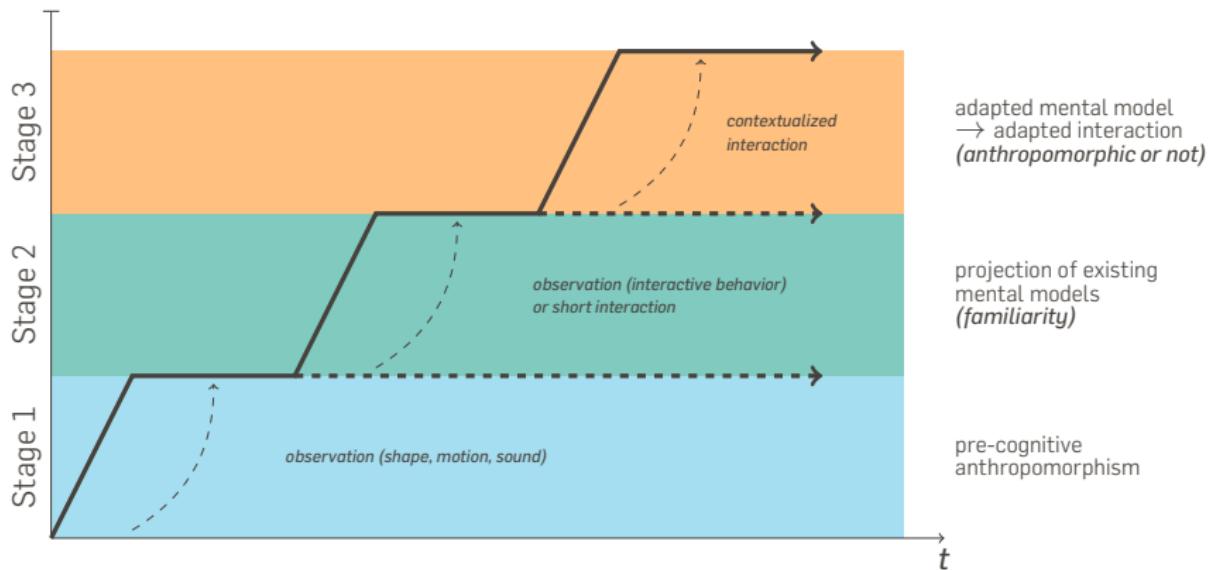
DYNAMICS OF INTERACTION

HOW DO WE PERCEIVE ROBOT OVER TIME?



◀ Supplementary material

COGNITIVE INTERPRETATION?



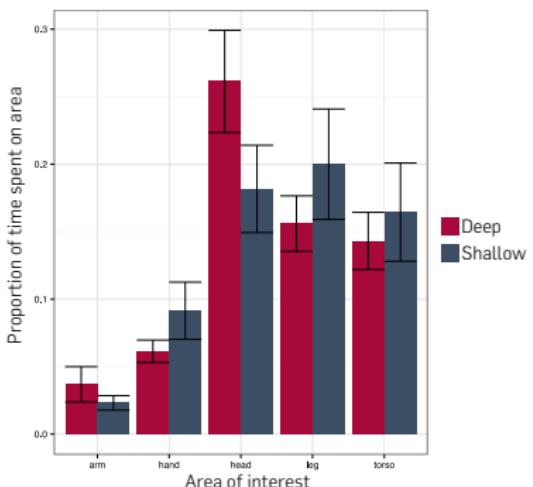
UNEXPECTED BEHAVIOURS



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

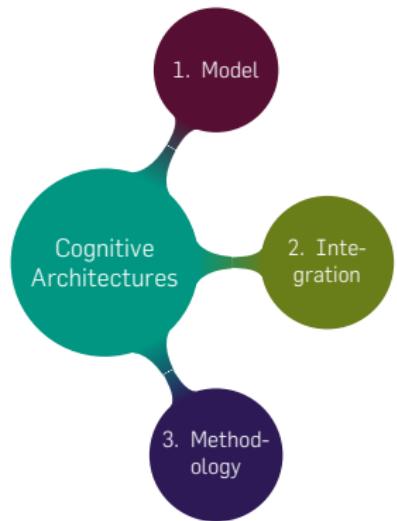


COGNITIVE CONTEXT AND ANTHROPOMORPHISM



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

"MODELING OF HUMAN COGNITION"...

