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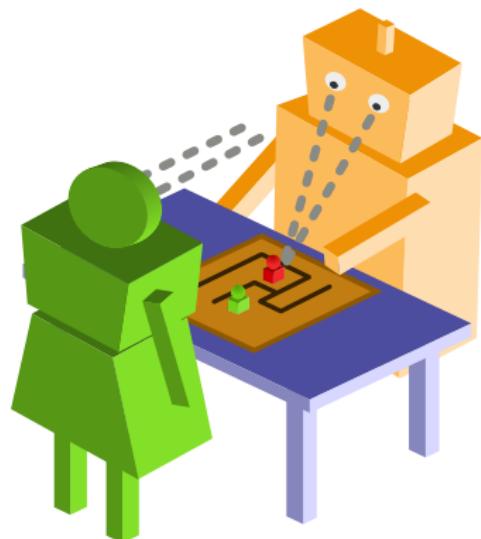
# Socially-driven Autonomous Robots for Real-World Human-Robot Interactions

KTH seminar | 06 Apr 2021

Séverin Lemaignan

**Bristol Robotics Lab**

University of the West of England



## SHORT BIO

- **2008–2012** Joint French (LAAS-CNRS)  
German (TU Munich) PhD  
AI & Cognitive Robotics
- **2013–2015** Post-doc at EPFL  
Child-robot interactions
- **2015–2018** Post-doc + lecturer at  
Plymouth University, UK  
EU Marie Curie fellowship  
Social Cognition in Robotics
- **2018–2021** Associate Prof. at Bristol  
Robotics Lab
- **2021– ...??!**



situation assessment

symbolic grounding

symbolic reasoning

## **SYMBOLIC SOCIAL COGNITION FOR ROBOTS**

ontologies

perspective taking

cognitive architectures

social situation assessment

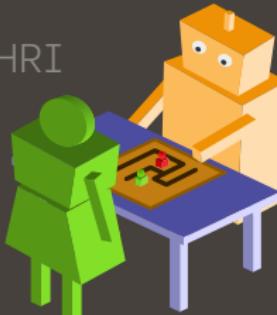
joint action

ROS4HRI

natural language processing

## **REAL-WORLD SOCIAL AUTONOMY**

learning of social policies



## **DATA-DRIVEN HRI**

large datasets

theory of mind

group dynamics

human-in-the-loop ML

robotics for  
learning

## **CHILD-ROBOT INTERACTION**

experimental robotics

trust

## **HUMAN FACTORS**

engagement

responsible AI

anthropomorphism

social robotics

participatory design

persuasion

Social Situations  
ooooo

Internal state  
oooooooooooo

Social policy learning  
oooooooooooo

Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

# SOCIAL ROBOTICS

Creating interactive robots that are **embedded and understand their (human) social context; generate and adopt appropriate social behaviours; have a positive impact on human society.**

⇒ designing and implementing the **assistant and companion robots** for tomorrow.

⇒ direct impact on ageing society, education, customer service; **major socio-economic challenge; European priority.**



Social Situations  
ooooo

Internal state  
oooooooooooo

Social policy learning  
oooooooooooo

Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

# SOCIAL ROBOTICS

## Major scientific challenges:

- Model open-ended, underspecified situations; rich semantics; complex social dynamics;



Social Situations  
ooooo

Internal state  
oooooooooooo

Social policy learning  
oooooooooooo

Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

# SOCIAL ROBOTICS

## Major scientific challenges:

- Model open-ended, underspecified situations; rich semantics; complex social dynamics;
- Close the interaction loop;



Social Situations  
ooooo

Internal state  
oooooooooooo

Social policy learning  
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Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

# SOCIAL ROBOTICS

## Major scientific challenges:

- Model open-ended, underspecified situations; rich semantics; complex social dynamics;
- Close the interaction loop;
- Understand and sustain long-term autonomous social interactions;



Social Situations  
ooooo

Internal state  
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Social policy learning  
oooooooooooo

Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

# SOCIAL ROBOTICS

## Major scientific challenges:

- Model open-ended, underspecified situations; rich semantics; complex social dynamics;
- Close the interaction loop;
- Understand and sustain long-term autonomous social interactions;
- Real-world algorithmic robustness;



Social Situations  
ooooo

Internal state  
oooooooooooo

Social policy learning  
oooooooooooo

Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

# SOCIAL ROBOTICS

## Major scientific challenges:

- Model open-ended, underspecified situations; rich semantics; complex social dynamics;
- Close the interaction loop;
- Understand and sustain long-term autonomous social interactions;
- Real-world algorithmic robustness;
- Complex ethical landscape;



Social Situations  
ooooo

Internal state  
oooooooooooo

Social policy learning  
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Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

# SOCIAL ROBOTICS

## Major scientific challenges:

- Model open-ended, underspecified situations; rich semantics; complex social dynamics;
- Close the interaction loop;
- Understand and sustain long-term autonomous social interactions;
- Real-world algorithmic robustness;
- Complex ethical landscape;
- ⇒ cross-disciplinary & holistic approach required



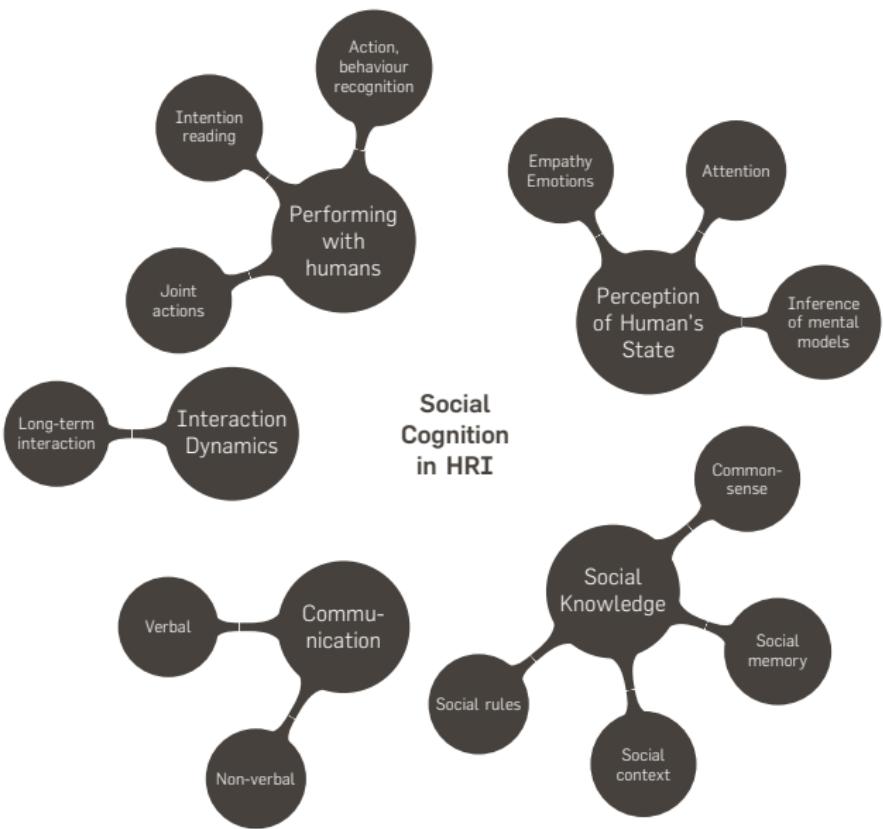
Social Situations  
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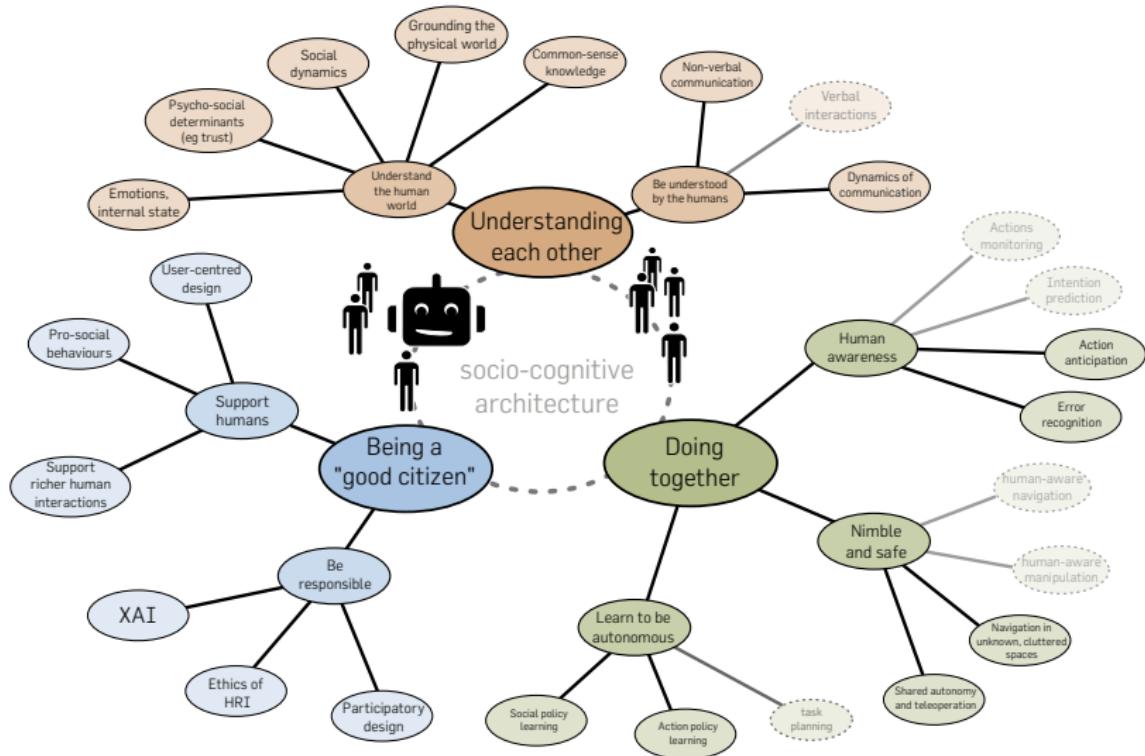
Internal state  
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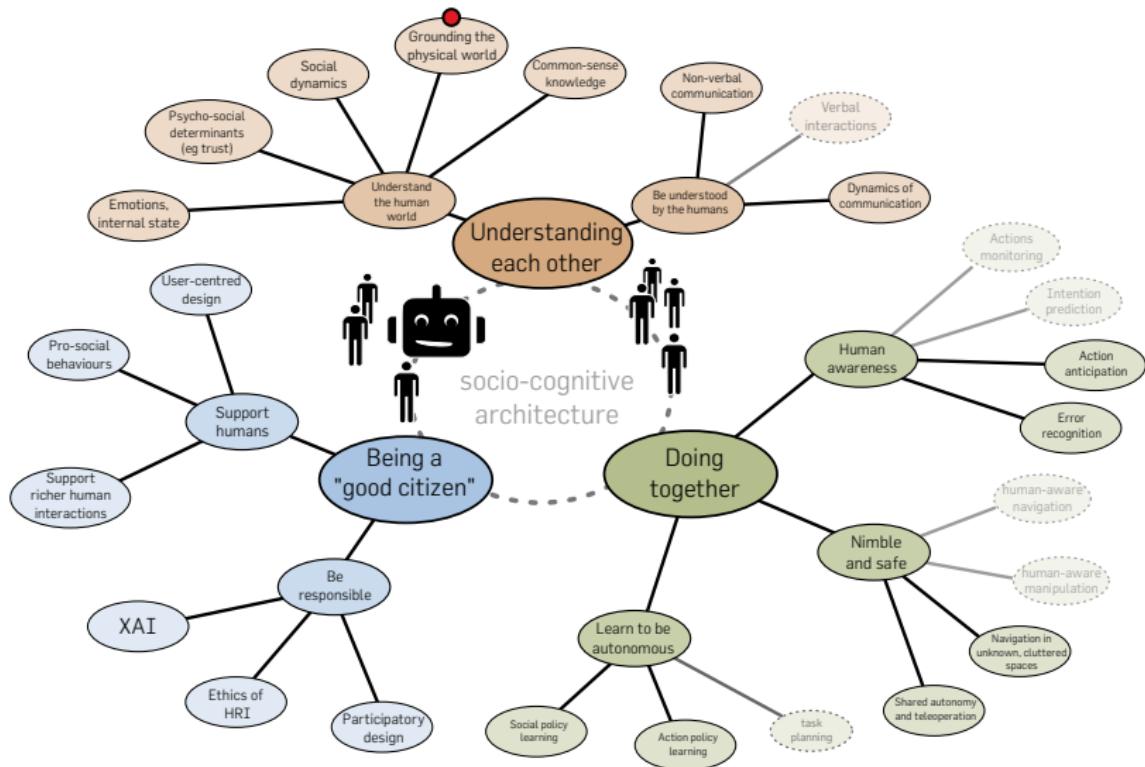
Social policy learning  
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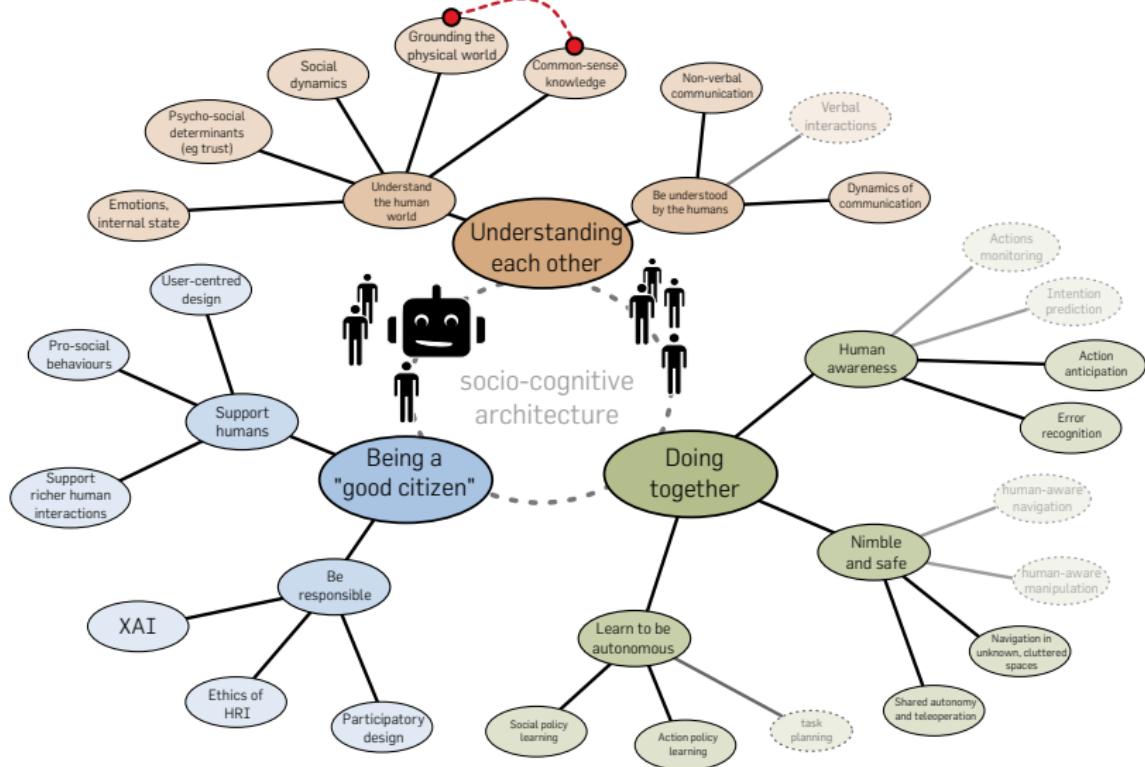
Generating behaviours  
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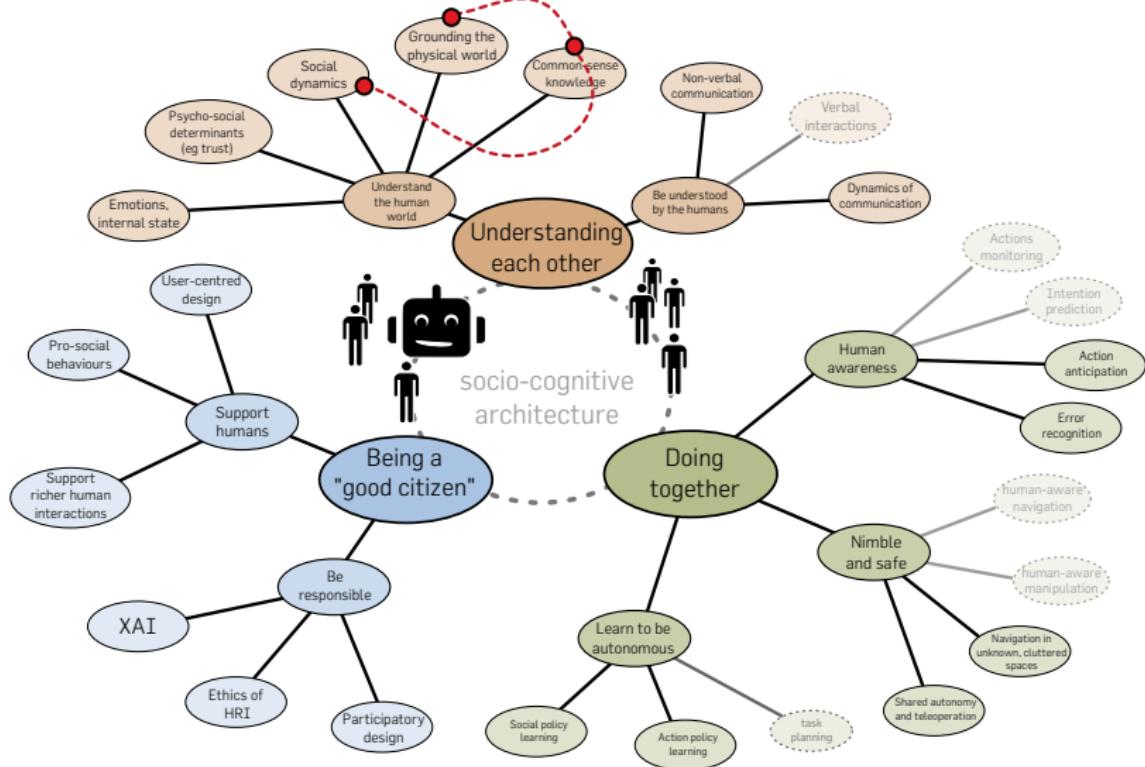
What next?  
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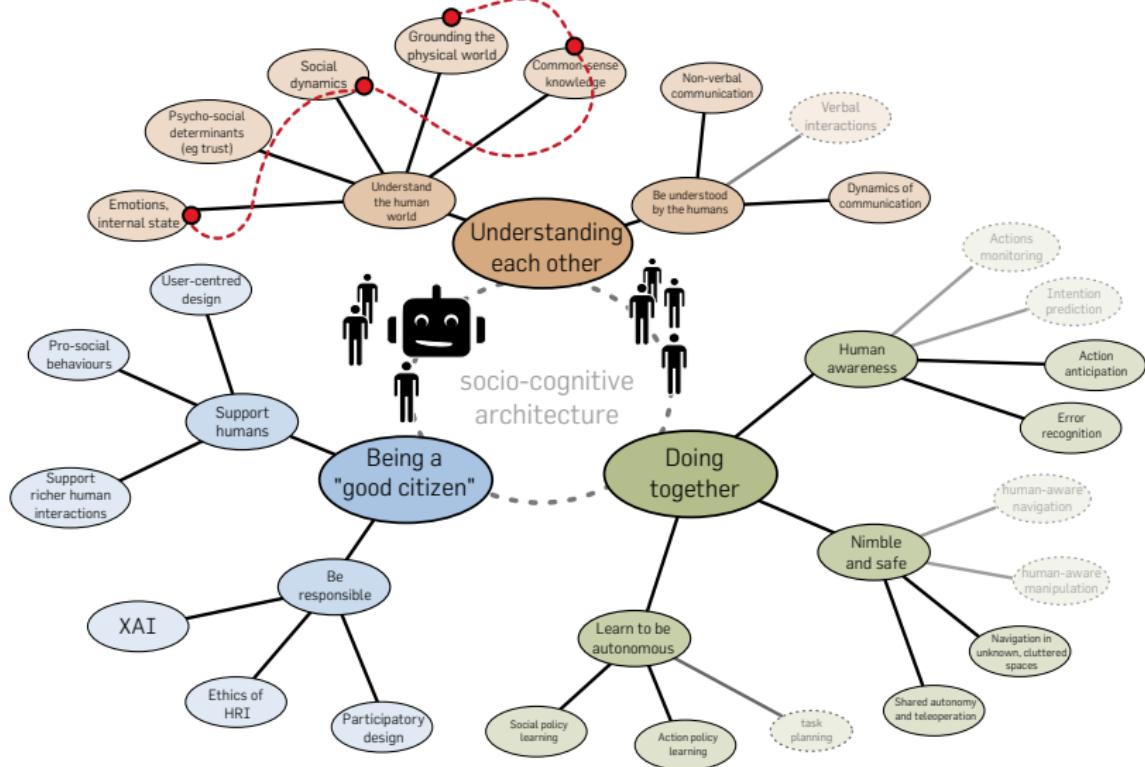


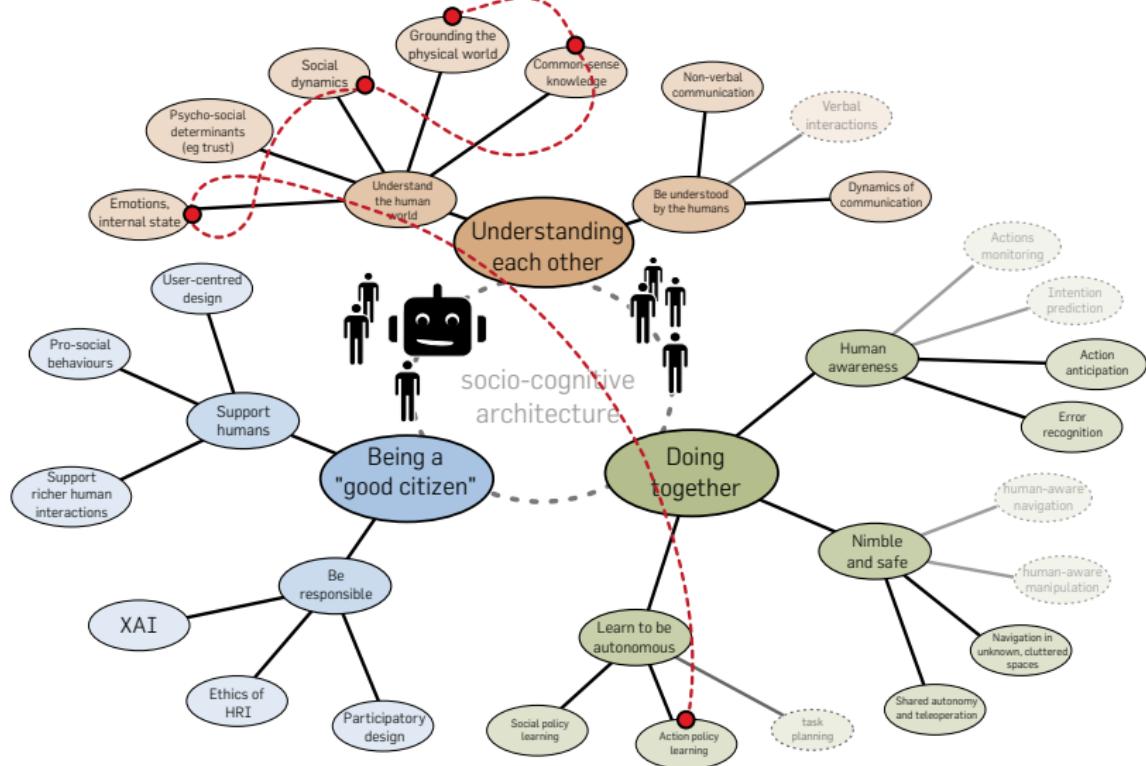


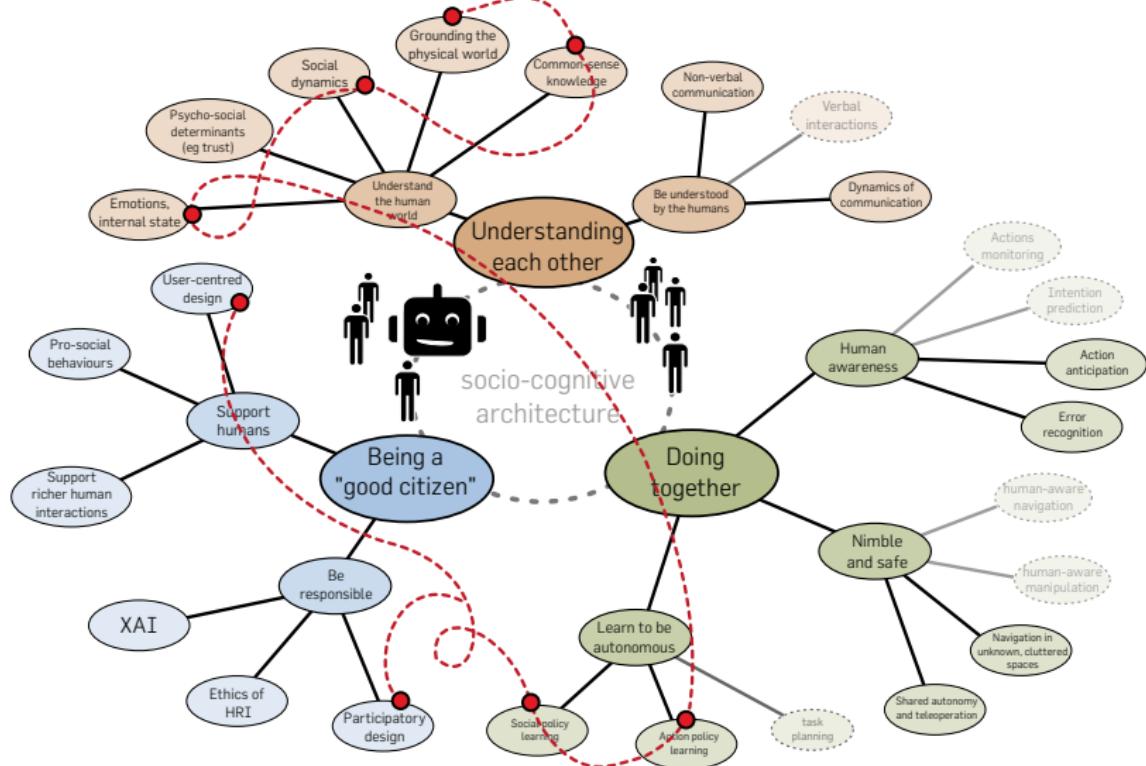


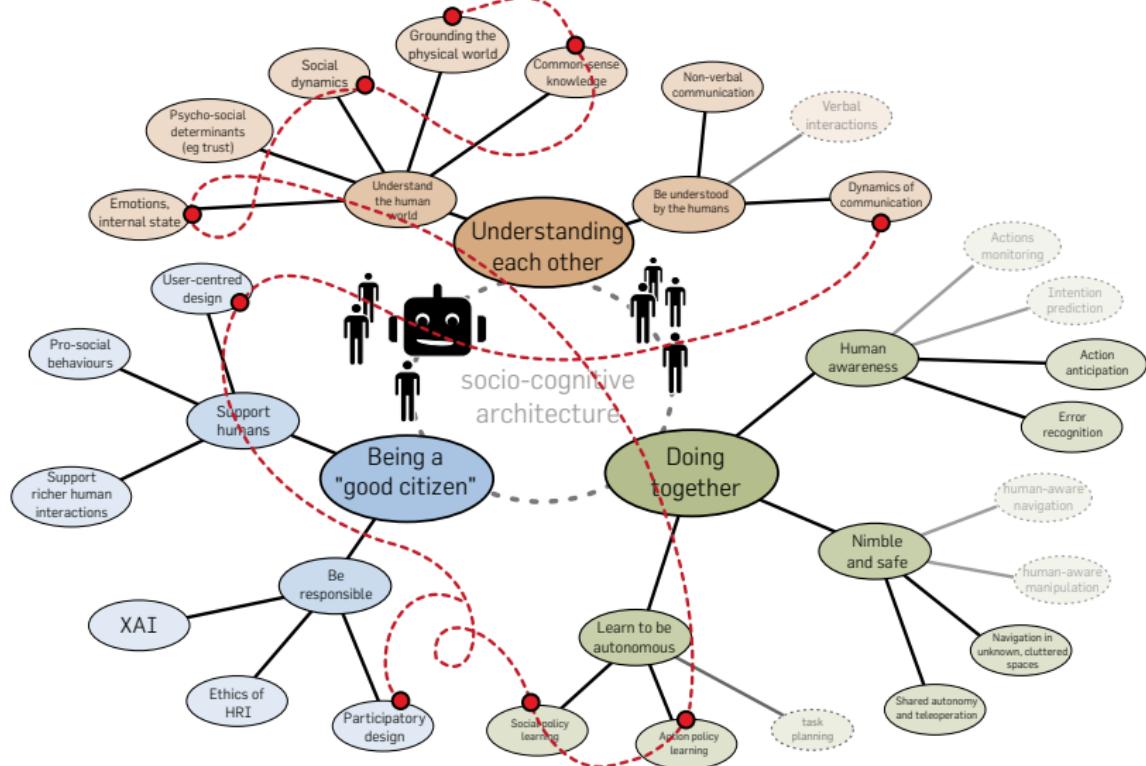


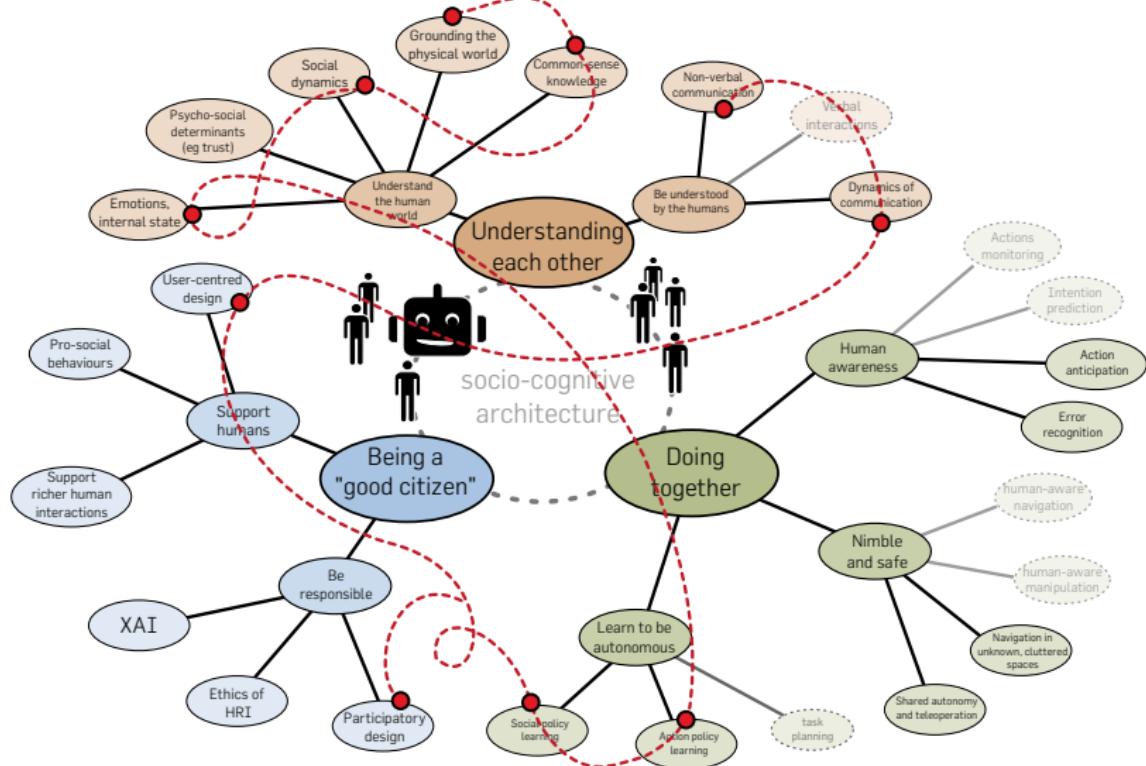


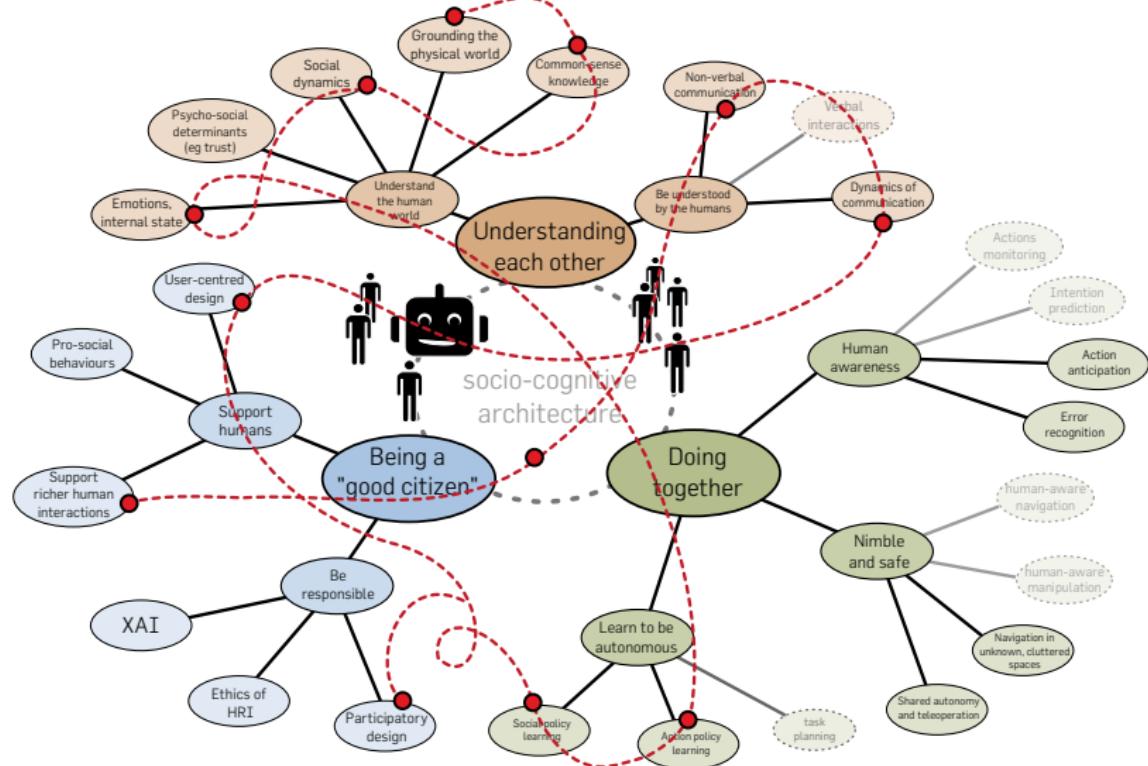












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FROM SOCIAL SITUATION  
ASSESSMENT...

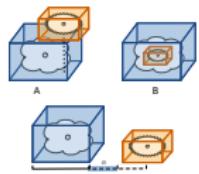
## SITUATION ASSESSMENT



## visibility



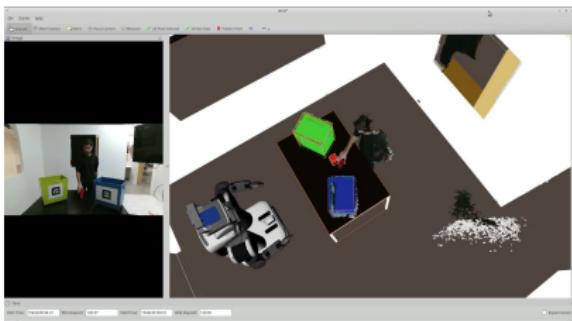
## reachability



## allocentric spatial relations



## egocentric spatial relations



Year Sales

Social Situations  
○○●○○

Internal state  
○○○○○○○○○○○○

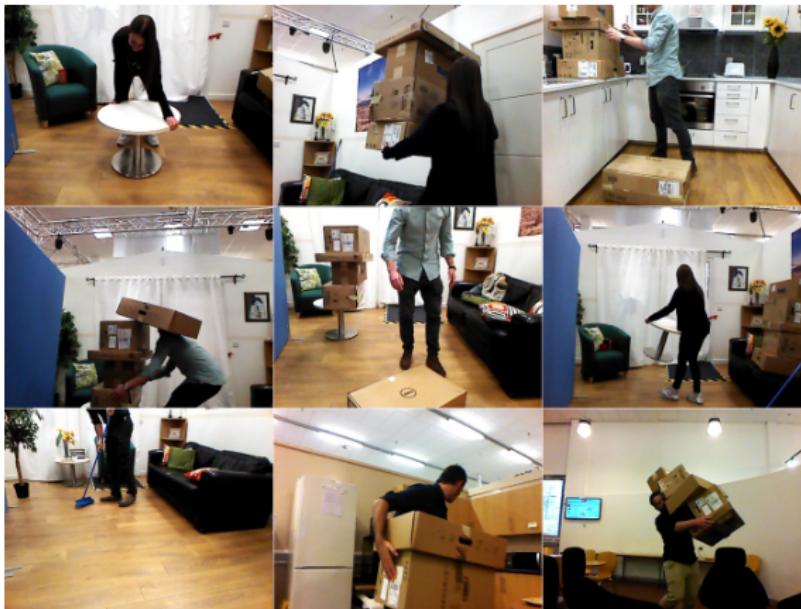
Social policy learning  
○○○○○○○○○○

Generating behaviours  
○○○

What next?  
○○○○○○○○○○○○○○○○

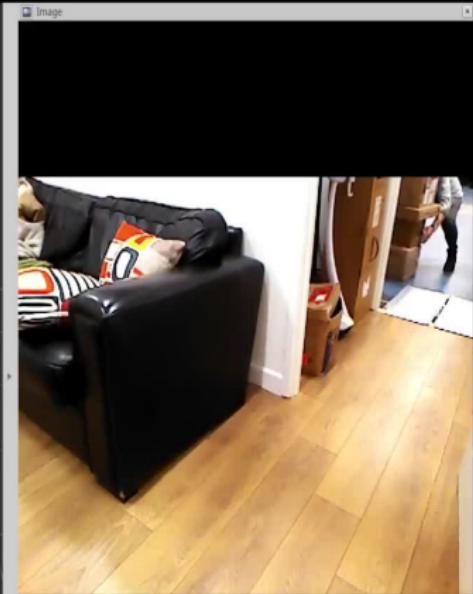
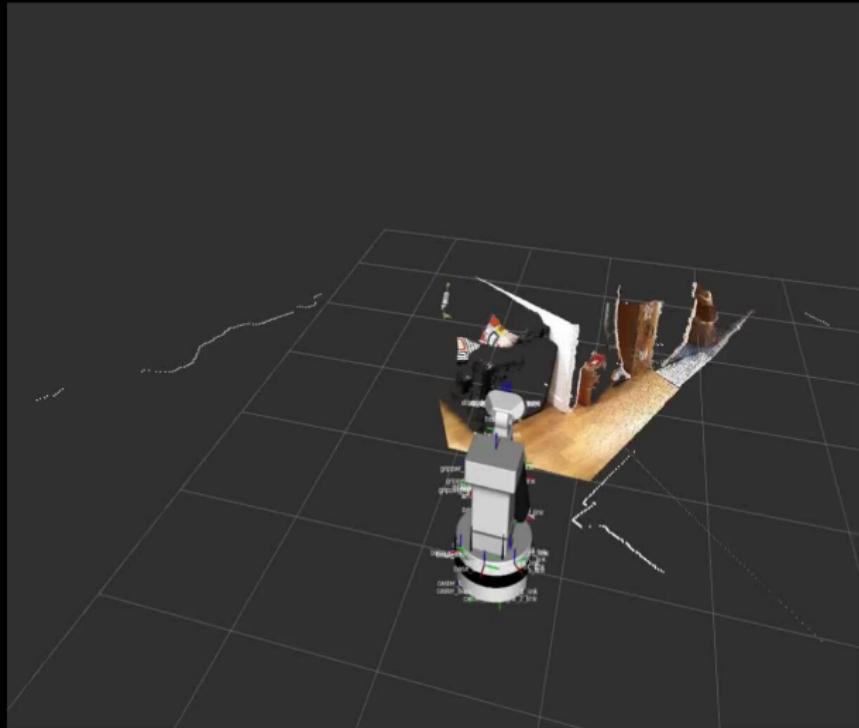
# COMMON-SENSE: UNEXPECTED SITUATIONS

## UDS: the Unexpected Daily Situations dataset



Yoan Sallami

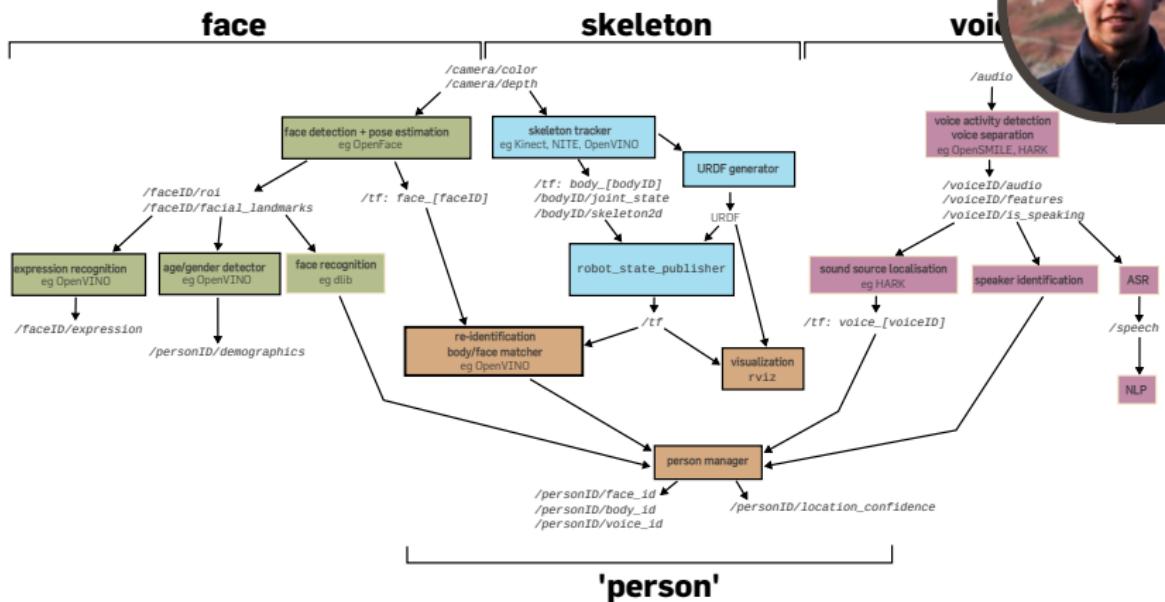
(idea borrowed from dev. psychologists Warneken and Tomasello)



## ROS4HRI



Youssef Mohamed



ROS4HRI: first integrated, multi-modal, ROS-based pipeline for social signal processing in robotics

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...TO INTERNAL STATE...

Social Situations  
ooooo

Internal state  
○●oooooooooooo

Social policy learning  
oooooooooooo

Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

# SOCIAL MODELING



Nicola Webb

Social Situations  
ooooo

Internal state  
○●oooooooooooo

Social policy learning  
oooooooooooo

Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

# SOCIAL MODELING



Nicola Webb

- multi-modal
- dynamic
- only partially observable
- complex pipeline; hard to make it robust

Social Situations  
ooooo

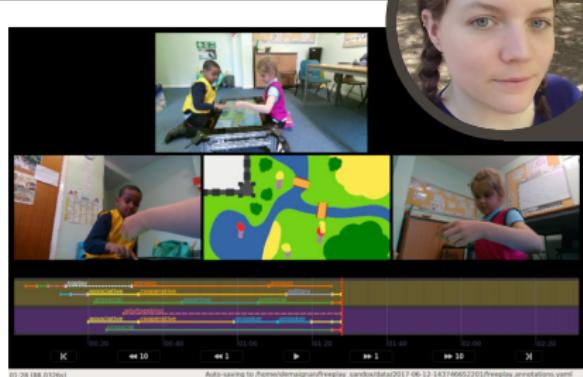
Internal state  
○○●oooooooooooo

Social policy learning  
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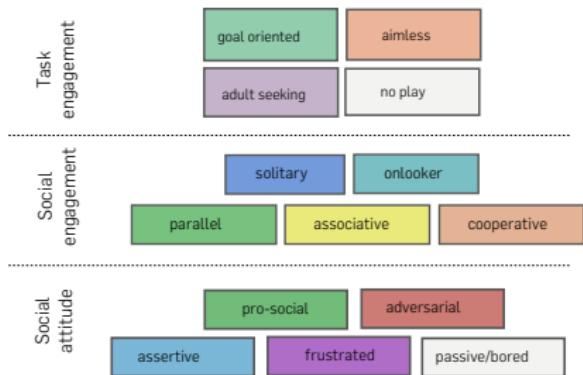
Generating behaviours  
ooo

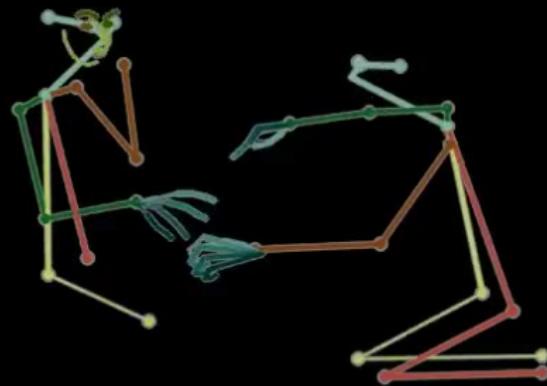
What next?  
oooooooooooooooooooo

# DECIPHERING INTERNAL STATE

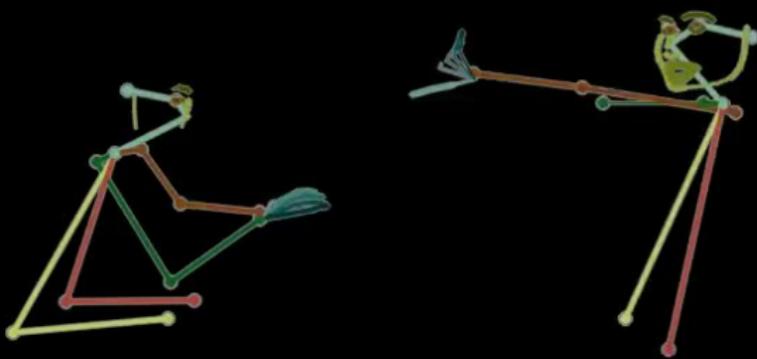


- PInSoRo dataset: 45h+ and 2M frames of annotated natural interactions.  
**[freeplay-sandbox.github.io](https://github.com/freeplay-sandbox)**
- first-in-kind dataset for data-driven study of social interactions in robotics
- new data analysis techniques to estimate internal state from body language













**Page 1 of 4.**

**How much do you agree with the following statements?**

The children were competing with one another.

Strongly Disagree

Disagree

Not Sure

Agree

Strongly Agree

200 participants, 4 clips each, on MTurk

The child on the left was sad.

Strongly Disagree

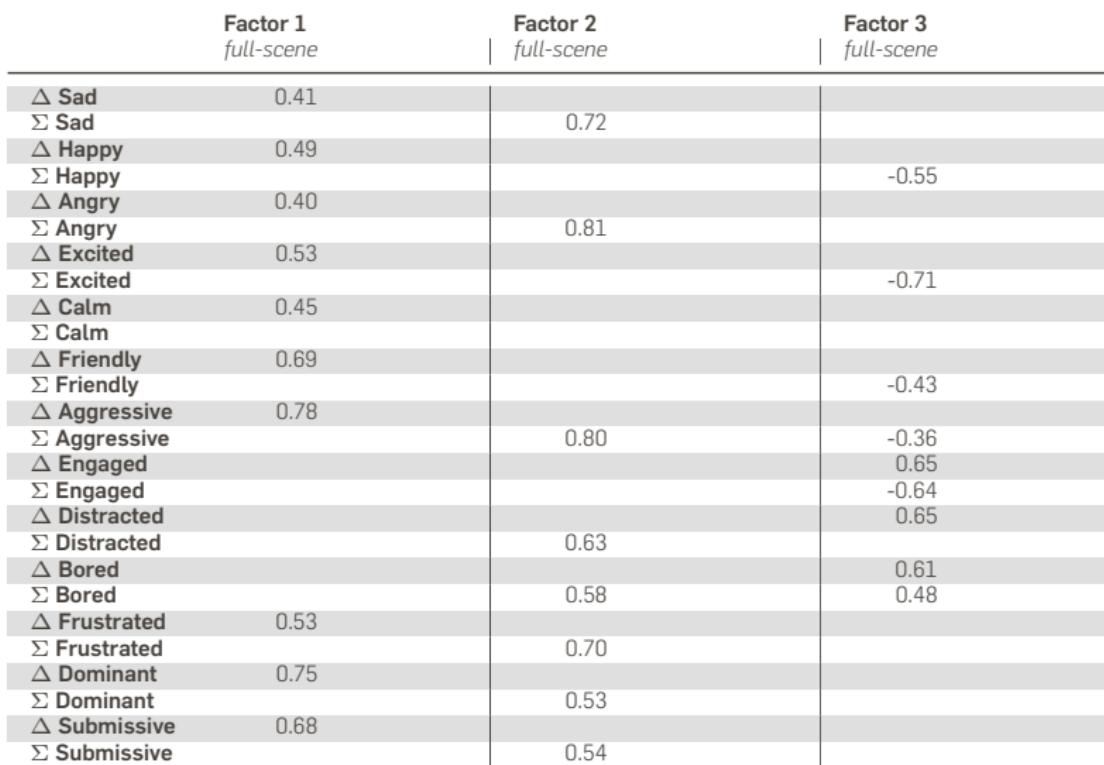
Disagree

Not Sure

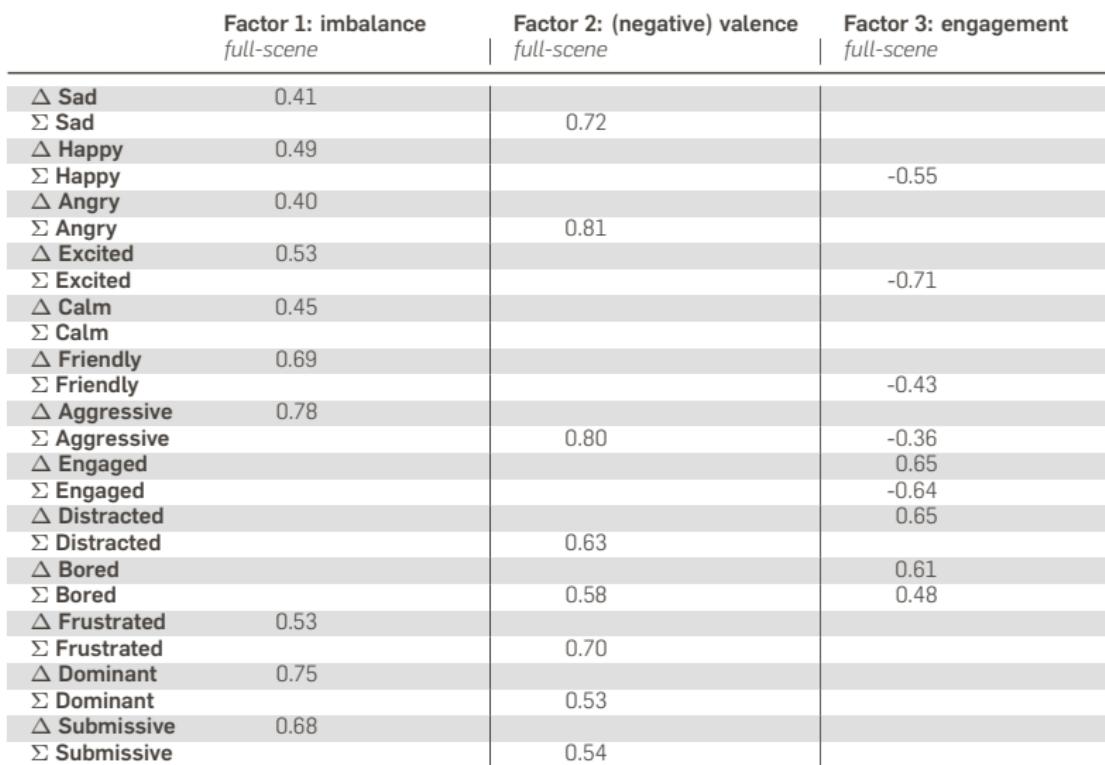
Agree

Strongly Agree

## EFA: EXPLORATORY FACTOR ANALYSIS



## EFA: EXPLORATORY FACTOR ANALYSIS



# EFA: EXPLORATORY FACTOR ANALYSIS

	Factor 1: imbalance full-scene      mov.-alone		Factor 2: (negative) valence full-scene      mov.-alone		Factor 3: engagement full-scene      mov.-alone	
△ Sad	0.41	0.52				
Σ Sad			0.72	0.53		0.49
△ Happy	0.49	0.53				
Σ Happy				-0.51		-0.55
△ Angry	0.40	0.62				
Σ Angry			0.81	0.85		
△ Excited	0.53	0.63				
Σ Excited					-0.71	
△ Calm	0.45	0.63				
Σ Calm				-0.45		
△ Friendly	0.69	0.56				
Σ Friendly				-0.60		-0.43
△ Aggressive	0.78	0.79				
Σ Aggressive			0.80	0.72		-0.36
△ Engaged		0.39				0.65
Σ Engaged					-0.64	-0.64
△ Distracted					0.65	0.63
Σ Distracted			0.63			0.82
△ Bored		0.44				0.61
Σ Bored			0.58			0.48
△ Frustrated	0.53	0.61				
Σ Frustrated			0.70	0.69		
△ Dominant	0.75	0.81				
Σ Dominant			0.53	0.52		
△ Submissive	0.68	0.72				
Σ Submissive			0.54			

Social Situations  
ooooo

Internal state  
oooooooo●ooo

Social policy learning  
oooooooooooo

Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

# THREE CONSTRUCTS TO RULE THEM ALL



Maddy Bartlett

Interaction imbalance

Interaction valence

Engagement

Social Situations  
ooooo

Internal state  
oooooooooooo●○

Social policy learning  
oooooooooooo

Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

## MEAN EFA PROJECTION OF CLIPS PER SOCIAL SITUATION

The 20 clips were labelled after their salient social features (*aggressive, excited, aimless, fun, cooperative, bored, dominant*).

What happens if we project the ratings for 'aggressive' clips, 'excited' clips, etc. onto the 3 EFA factors?

Social Situations  
ooooo

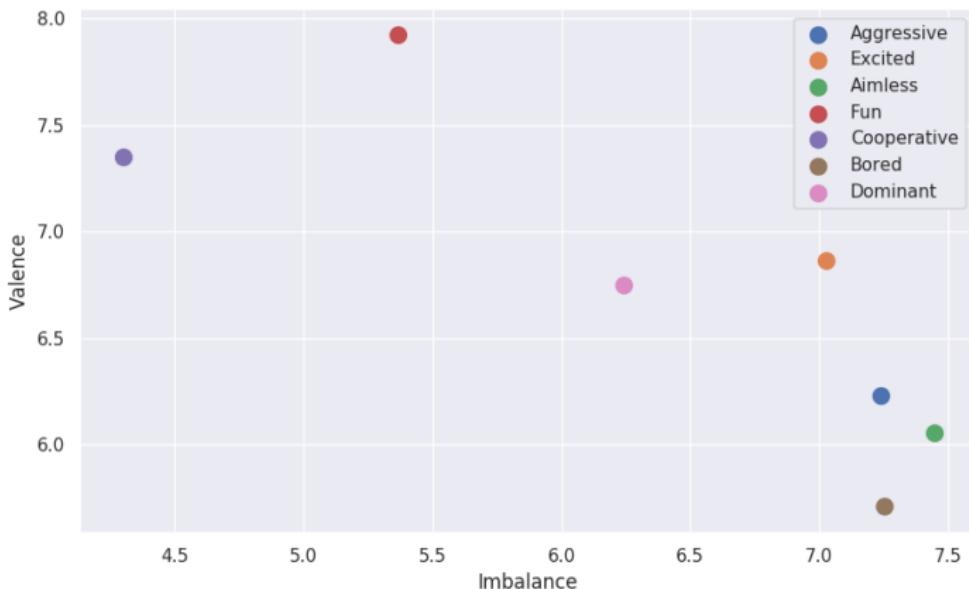
Internal state  
oooooooooooo●●

Social policy learning  
oooooooooooo

Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

## MEAN EFA PROJECTION OF CLIPS PER SOCIAL SITUATION



Social Situations  
ooooo

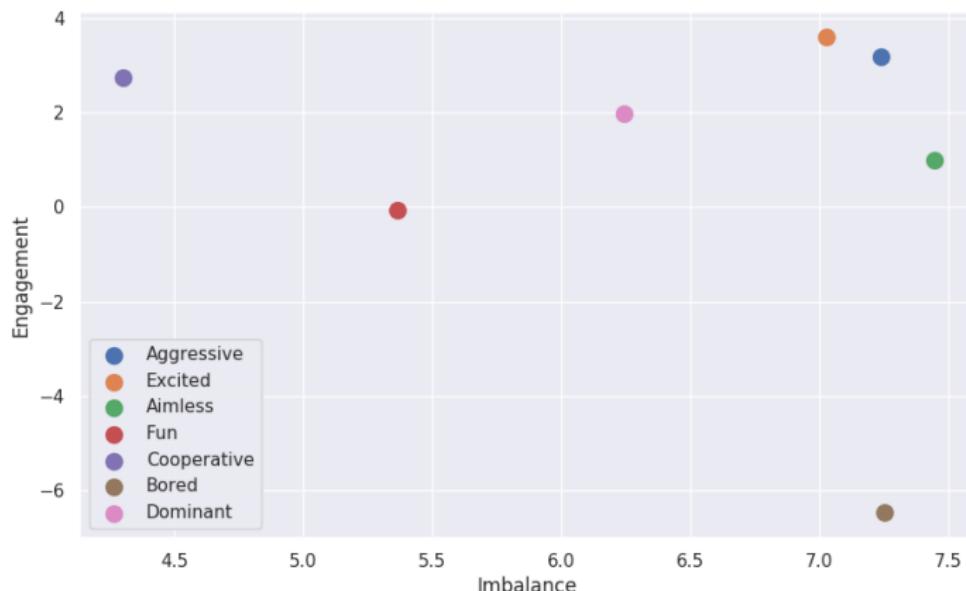
Internal state  
oooooooooooo●○

Social policy learning  
oooooooooooo

Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

## MEAN EFA PROJECTION OF CLIPS PER SOCIAL SITUATION



Social Situations  
ooooo

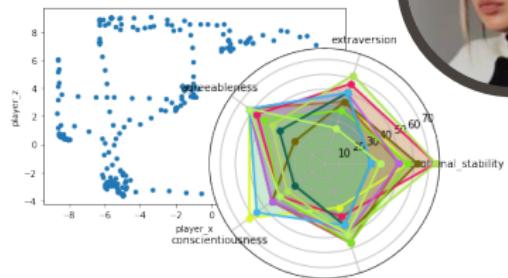
Internal state  
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Social policy learning  
oooooooooooo

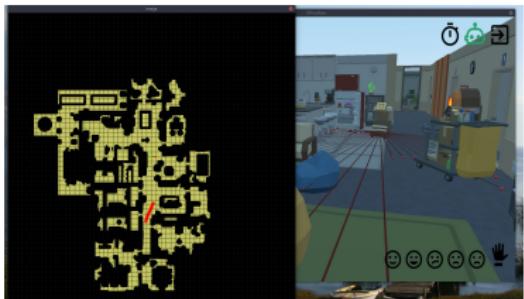
Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

# ONLINE GAMES & SOCIAL DATASETS



Nicola Webb



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...TO IN-SITU SOCIAL POLICY  
LEARNING

Social Situations  
ooooo

Internal state  
oooooooooooo

Social policy learning  
○●oooooooooo

Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

## LET SET OURSELVES A CHALLENGE

Design & run a study with:

- a real robot

Social Situations  
ooooo

Internal state  
oooooooooooo

Social policy learning  
○●oooooooooo

Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

## LET SET OURSELVES A CHALLENGE

Design & run a study with:

- a real robot
- a real interaction (...with a human!)

Social Situations  
ooooo

Internal state  
oooooooooooo

Social policy learning  
○●oooooooooo

Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

## LET SET OURSELVES A CHALLENGE

Design & run a study with:

- a real robot
- a real interaction (...with a human!)
- a continuous interaction

Social Situations  
ooooo

Internal state  
oooooooooooo

Social policy learning  
○●oooooooo

Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

## LET SET OURSELVES A CHALLENGE

Design & run a study with:

- a real robot
- a real interaction (...with a human!)
- a continuous interaction
- a realistic task (large state vector & action space)

Social Situations  
ooooo

Internal state  
oooooooooooo

Social policy learning  
○●oooooooo

Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

## LET SET OURSELVES A CHALLENGE

Design & run a study with:

- a real robot
- a real interaction (...with a human!)
- a continuous interaction
- a realistic task (large state vector & action space)
- also including social behaviours & social dynamics

Social Situations  
ooooo

Internal state  
oooooooooooo

Social policy learning  
○●oooooooooo

Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

## LET SET OURSELVES A CHALLENGE

Design & run a study with:

- a real robot
- a real interaction (...with a human!)
- a continuous interaction
- a realistic task (large state vector & action space)
- also including social behaviours & social dynamics
- ...and of course, the robot should be autonomous

# IRL APPLIED TO SOCIAL ROBOTICS



Emmanuel Sennft

The children plays a game about food chains; the robot learns to guide them (*task-specific action policy*) and encourage them (*social action policy*)

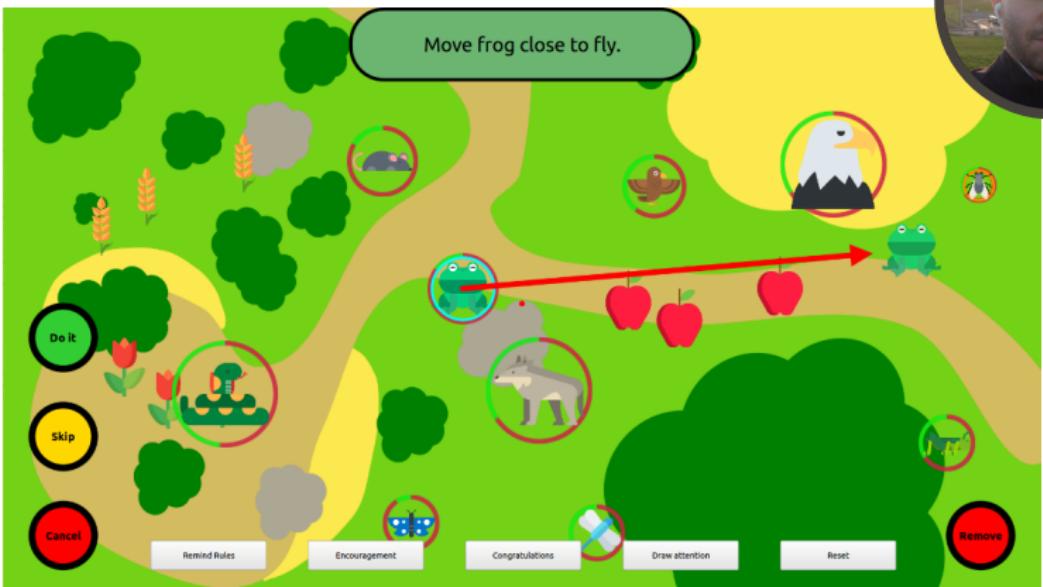
Complex problem:  $|state| = 210$   $|action\_space| = 655$



## TEACHER'S INTERFACE



Emmanuel Sennf



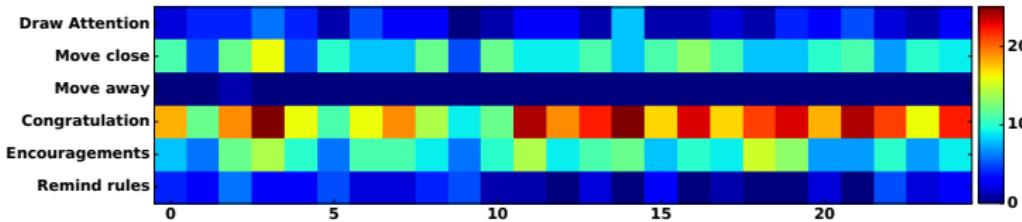
The robot's teacher (an end-user: might be the actual child's teacher) has a tablet interface that mirrors the child one, and adds robot's teleoperation and rewards.

# LEARNT ROBOT'S BEHAVIOUR



Emmanuel Sennft

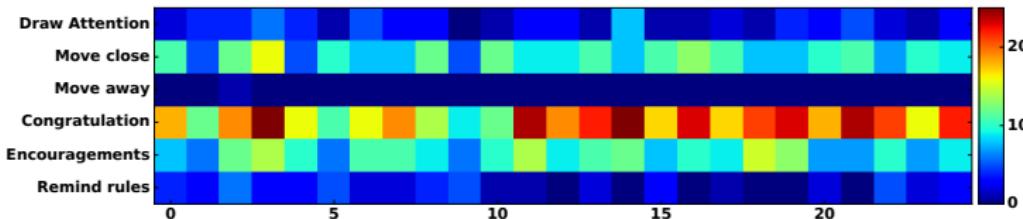
Distribution of actions for the 25 children participants:  
Supervised



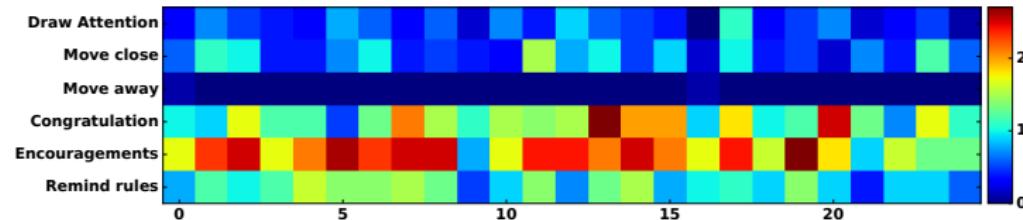
# LEARNT ROBOT'S BEHAVIOUR



Distribution of actions for the 25 children participants:  
Supervised



Autonomous



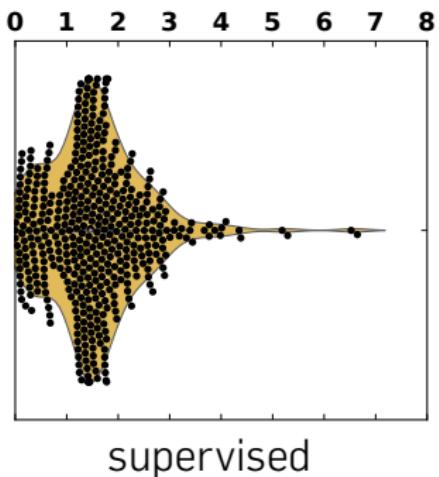
→ the robot personalises its action policies to the child's behaviour.

## LEARNT ROBOT'S BEHAVIOUR

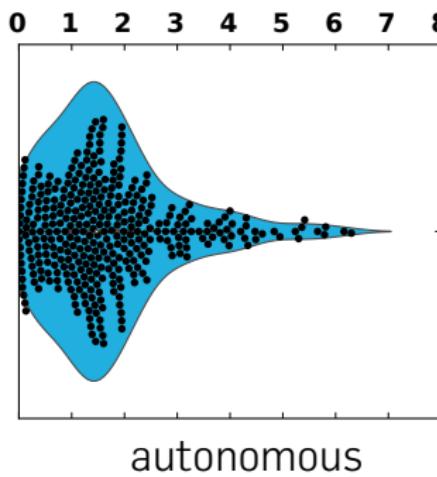


Emmanuel Sennf

Time between a child's successful action and a praise:



supervised



autonomous

→ the robot has also learnt an appropriate social timing.

Social Situations  
ooooo

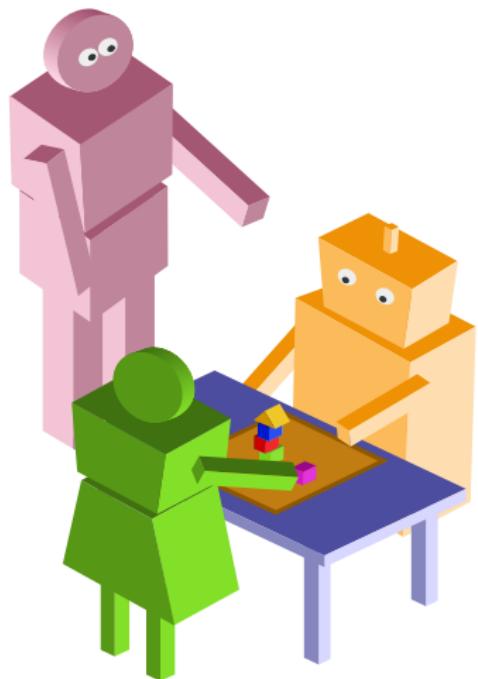
Internal state  
oooooooooooo

Social policy learning  
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Generating behaviours  
ooo

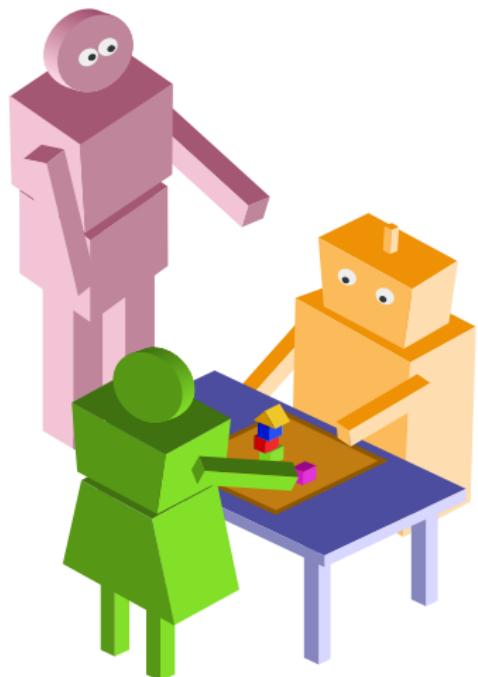
What next?  
oooooooooooooooooooo

## WHAT DOES THAT MEANS FOR THE EXPERT/TEACHER-END-USER?



- **Progressively transferring autonomy** demonstrably works in non-trivial tutoring scenarios
- (it also learns some elements of **social behaviours** and **social timing**)

## WHAT DOES THAT MEANS FOR THE EXPERT/TEACHER-END-USER?



### Key properties:

- **progressive autonomy** yet **transparency** of the behaviour;
- **observability** and possibility to **take over**;
- because the training takes place in-situ, the robot behaviours are **co-constructed** by the teacher and the child

Social Situations  
ooooo

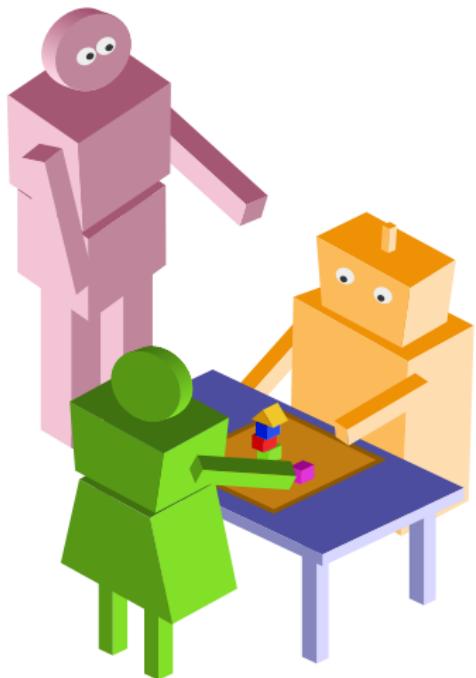
Internal state  
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Social policy learning  
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Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

## WHAT DOES THAT MEANS FOR THE EXPERT/TEACHER-END-USER?



Yet:

- Design of the input state tricky and largely task dependent;
- What about more complex social behaviours?
- Would that sustain long-term interactions?

Social Situations  
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Internal state  
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Social policy learning  
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Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

# CO-DESIGN FOR REAL-WORLD, LONG-TERM INTERACTION



Katie Winkle



Social Situations  
ooooo

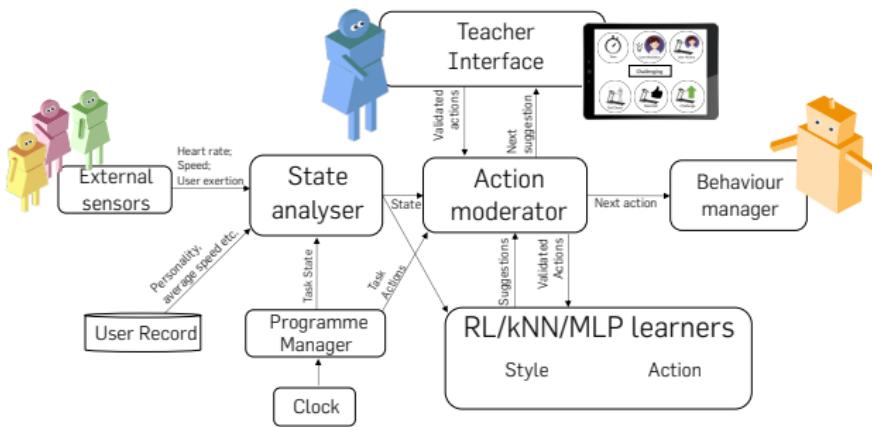
Internal state  
oooooooooooo

Social policy learning  
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Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

# EXPERT-IN-THE-LOOP MACHINE LEARNING



Social Situations  
ooooo

Internal state  
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Social policy learning  
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Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

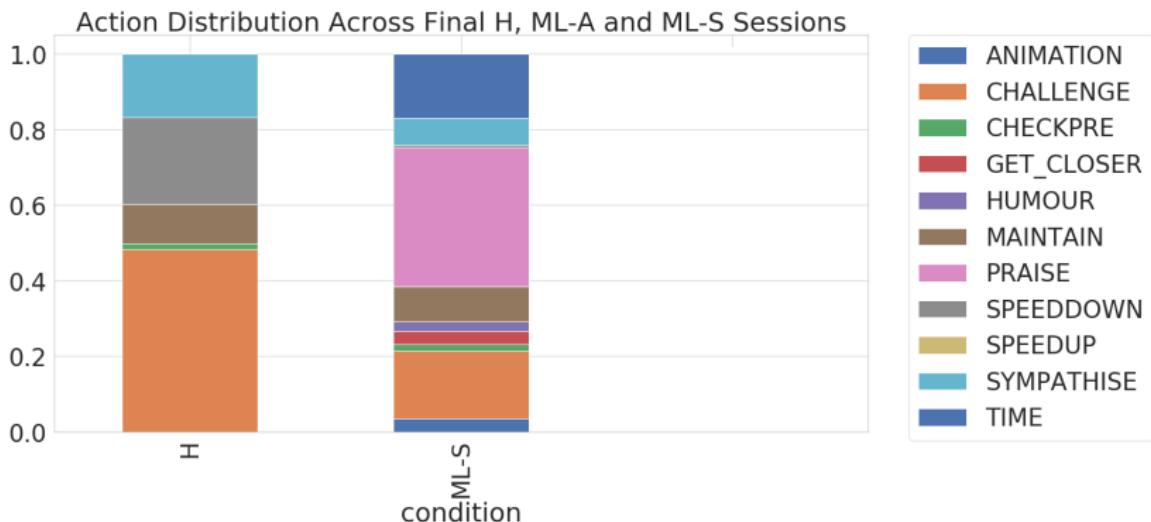
## COUCH TO 5KM STUDY



Katie Winkle

- 9 participants
- 3 months; 27 one-hour sessions per participants
- 20 input features; 11 actions (task-specific or social)
- human-in-loop design and machine learning
- robot evolving from full teleoperation to full task and social autonomy

# LEARNT POLICIES



Social Situations  
ooooo

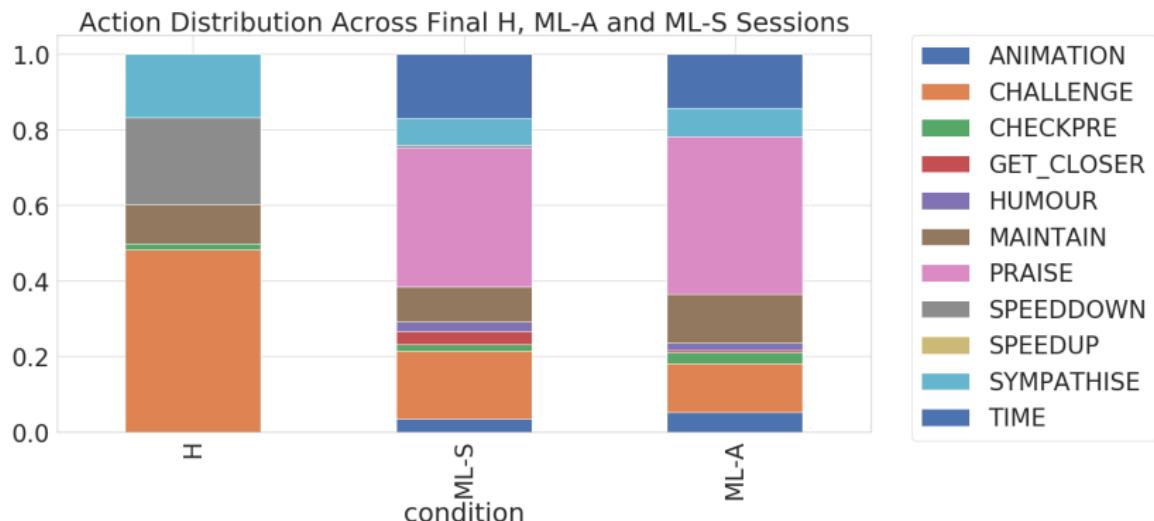
Internal state  
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Social policy learning  
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Generating behaviours  
ooo

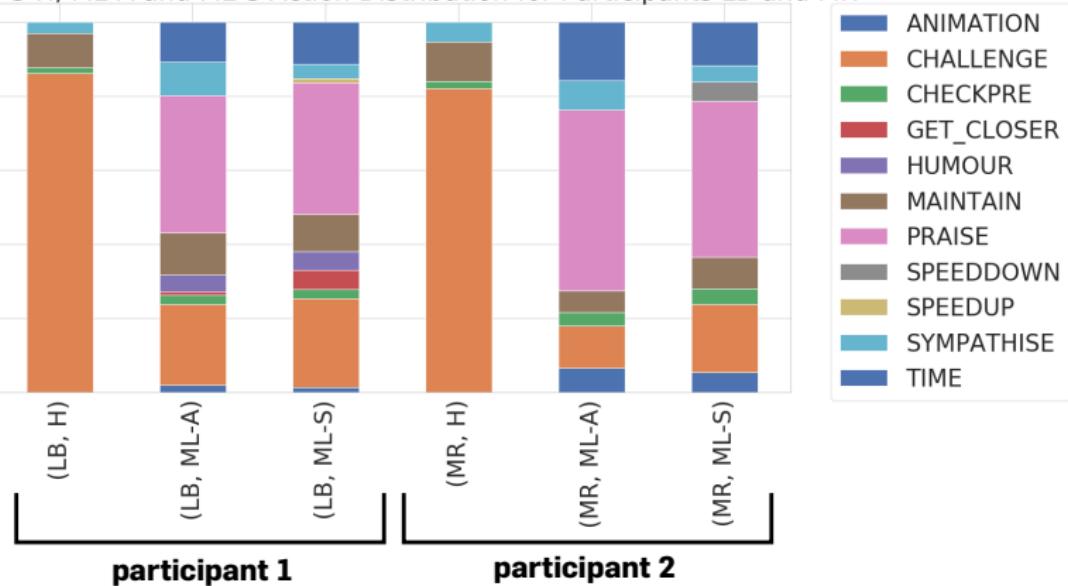
What next?  
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# LEARNT POLICIES



# LEARNT POLICIES

Phase 3 H, ML-A and ML-S Action Distribution for Participants LB and MR



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# GENERATING SOCIAILY-CONGRUENT BEHAVIOURS

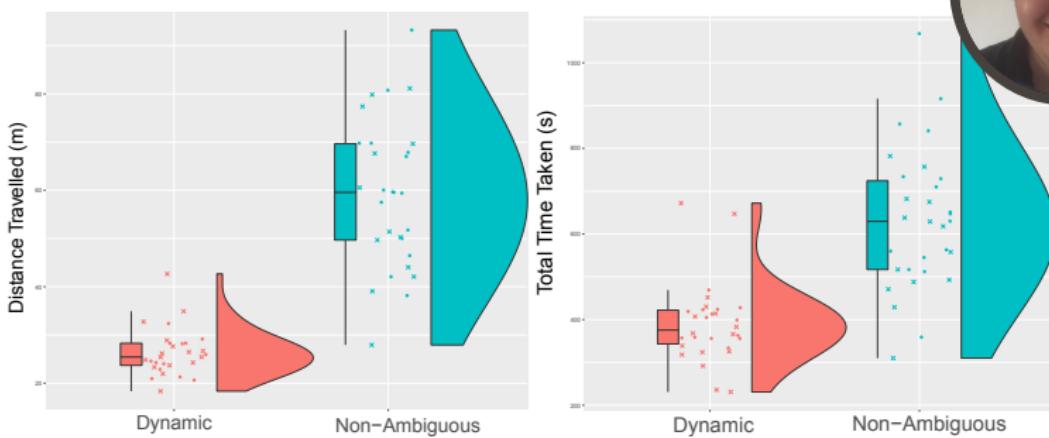
## DYNAMIC VS NON-AMBIGUOUS LANGUAGE



**Condition Non-ambiguous:** "A grey barrel is next to a grey barrel, next to a silver barrel and next to a green barrel."

**Condition Dynamic:** "Turn left about 90 degrees..." "Keep going"..." "Go forward"..." "The silver barrel next to the chrome barrel."

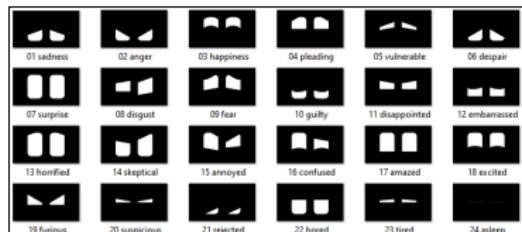
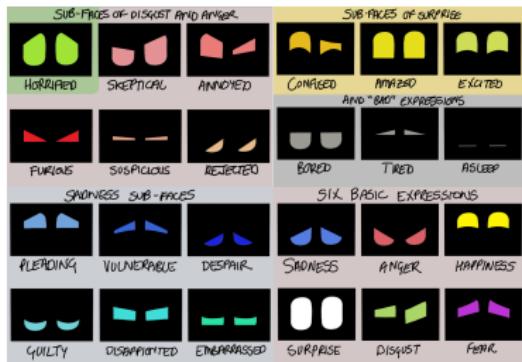
# DYNAMIC VS NON-AMBIGUOUS LANGUAGE



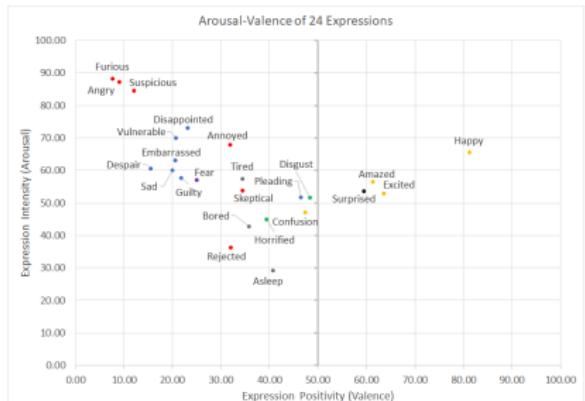
**Condition Non-ambiguous:** "A grey barrel is next to a grey barrel, next to a silver barrel and next to a green barrel."

**Condition Dynamic:** "Turn left about 90 degrees..." "Keep going"..."Go forward"..."The silver barrel next to the chrome barrel."

# EXPRESSIVE EYES

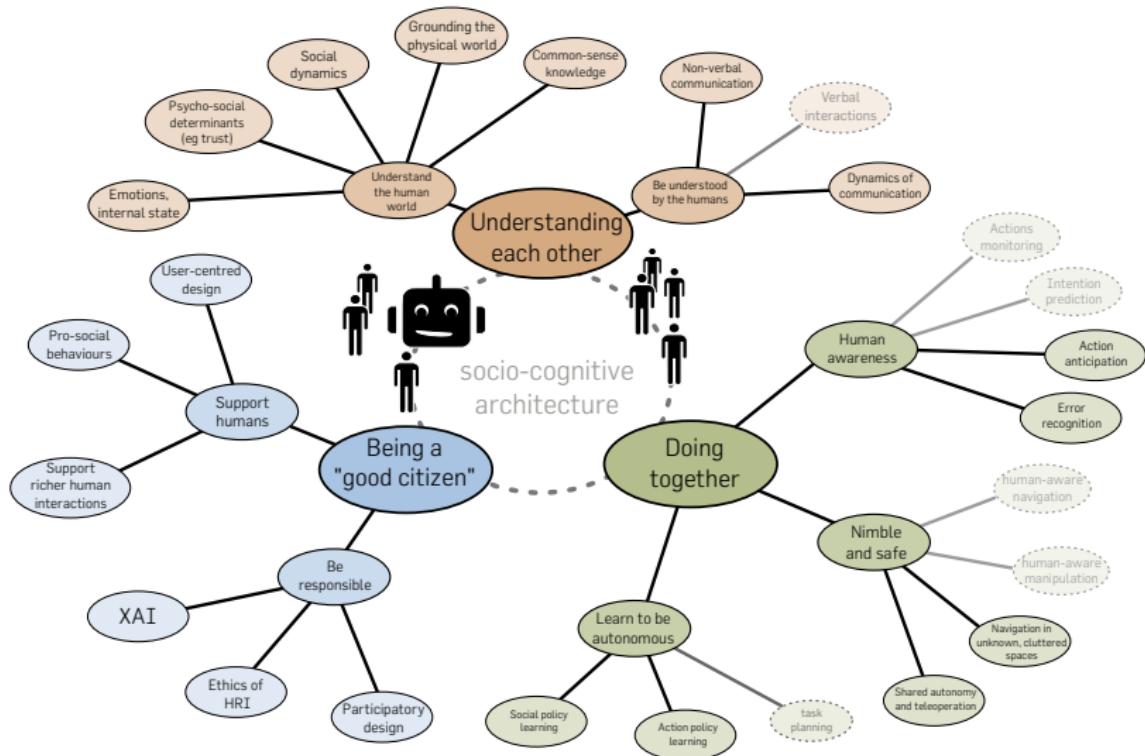


- inspired by Anki Cozmo/Vector
- expression interpretation validated online
- work by MSc student Catherine Chambers
- [git.brl.ac.uk/s-lemaignan/expressive-eyes](http://git.brl.ac.uk/s-lemaignan/expressive-eyes)



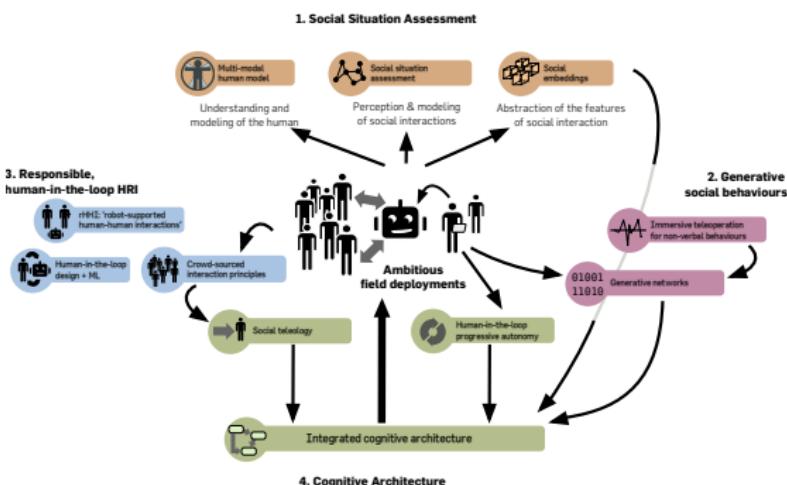
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WHAT NEXT?



# KEY SCIENTIFIC CHALLENGES

We want more real-world, long-term, autonomous interactions!



1. beyond state-of-art **robust real-world social modelling**; **social embeddings**
2. **public-in-the-loop** approach to design of **intrinsic social motivation**
3. **generative social behaviours** for robots
4. **cognitive architecture** for **long-term interaction**

Social Situations  
ooooo

Internal state  
oooooooooooo

Social policy learning  
oooooooooooo

Generating behaviours  
ooo

What next?  
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## IDEA: SOCIAL EMBEDDINGS



**social embeddings:** learning a compact, sub-symbolic representation of social interactions

- real-world social interactions are highly dynamic, noisy, multi-modal
- hard for the robot to model and reason about
- → **learn an embedding:** Attention nets, Deep graph nets
- can be used by the robot to **recognise social situation** and **generate congruent social behaviours**

Social Situations  
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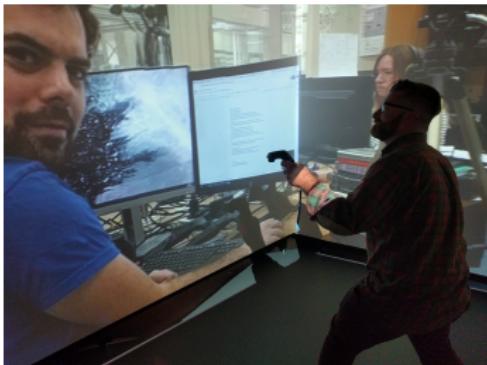
Internal state  
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Social policy learning  
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Generating behaviours  
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What next?  
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# IDEA: GENERATIVE NON-REPETITIVE SOCIAL BEHAVIOURS



- Cracking the '**non-repetitive, socially congruent**' behaviour generation problem
- Extend **Generative Adversarial Networks** à la AppGAN to complex behaviours  
(re-use *social embeddings*)
- **Immersive technologies** to build datasets
- **Transdisciplinary approach**, incl. arts: choreographer, sound expert

Social Situations  
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Internal state  
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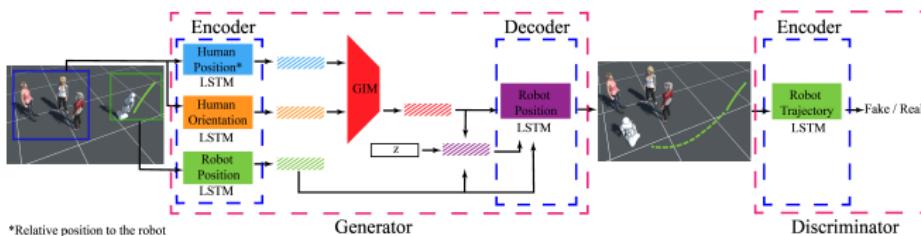
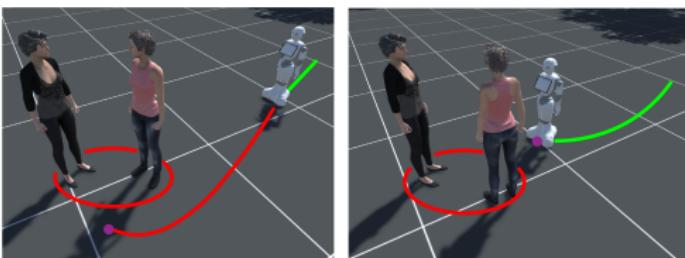
Social policy learning  
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Generating behaviours  
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What next?  
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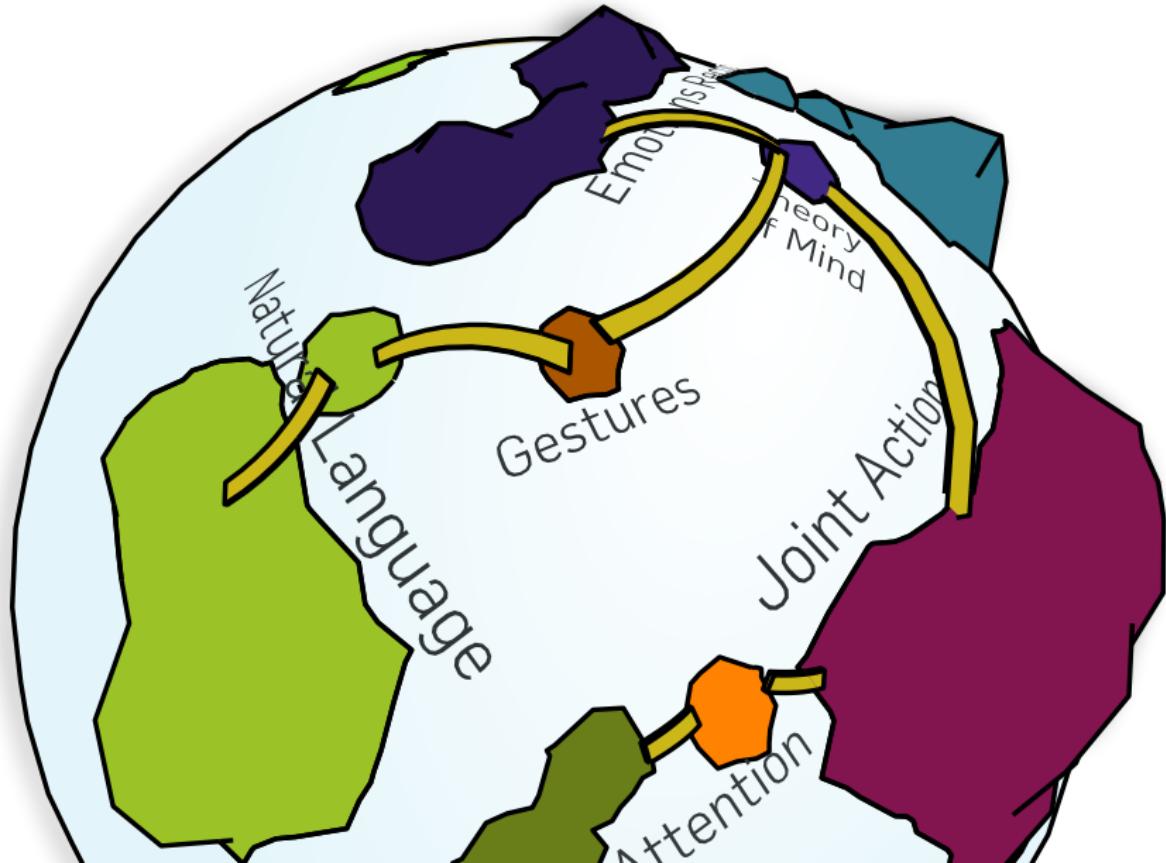
# GENERATIVE ADVERSARIAL NETS FOR BEHAVIOUR GENERATION

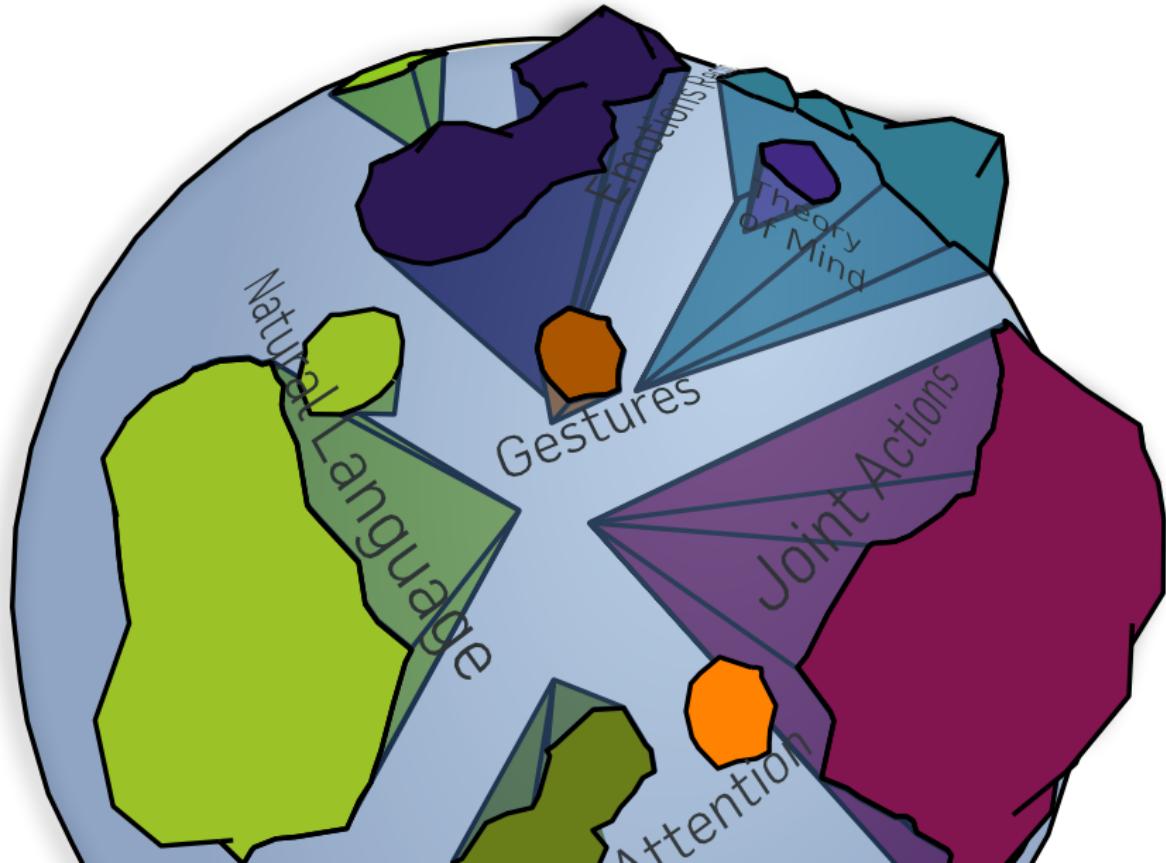
Some of the most exciting recent work in using ML for robot behaviour generation involve **Generative Adversarial Networks** (GANs):



Cognitive architecture?



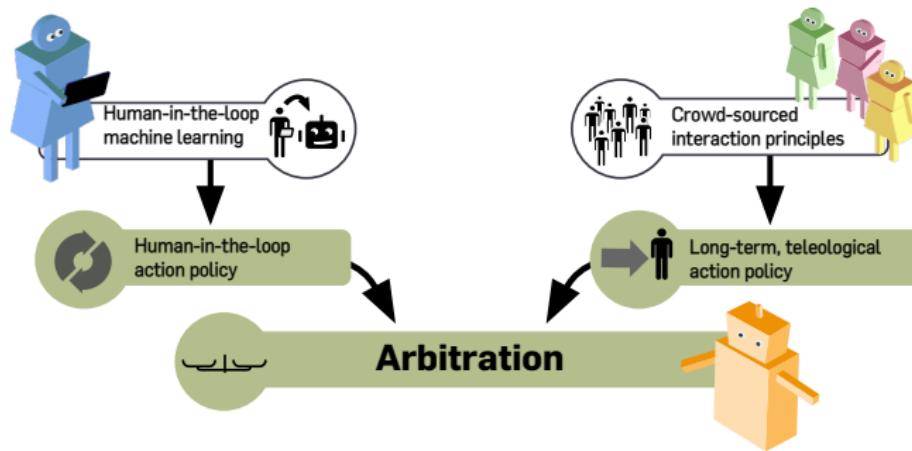






# IDEA: SOCIO-TELEOLOGICAL ARCHITECTURE

*Teleological* → **goal-oriented** architecture



- **end-users and public to play a key role:**
- **crowd-sourced pro-social goals** (eg 'show attention', 'appear alive') drives long-term behaviours
- **short-term/domain-specific policies learned** via interactive reinforcement learning (IRL)
- **cognitive arbitration** between the two, based on **experience transfer**

Social Situations  
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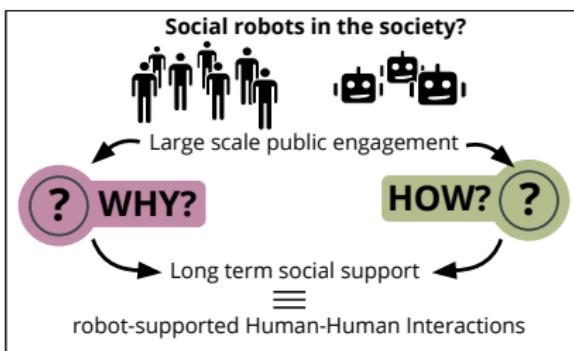
Internal state  
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Social policy learning  
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Generating behaviours  
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What next?  
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## IDEA: ROBOT-SUPPORTED HUMAN-HUMAN INTERACTIONS



Social robotics might need a paradigm shift from *Human-Robot Interaction* to **robot-supported Human-Human Interaction**:

- not so much: how to robot can interact with human
- instead: why robots? what positive impact can robots uniquely deliver? (and *then*: what technology is required)

Social Situations  
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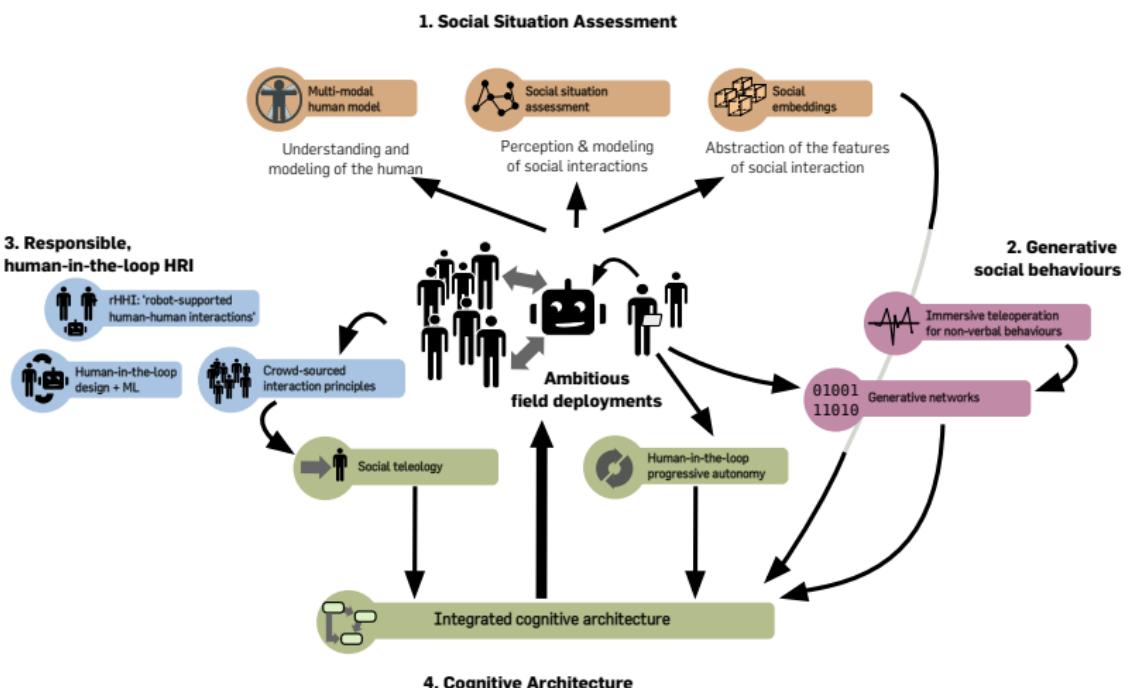
Internal state  
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Social policy learning  
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Generating behaviours  
ooo

What next?  
oooooooooooooooooooo

# A HOLISTIC APPROACH TO SOCIAL ROBOTICS



A PR2 robot is positioned on a stage. It has a white torso with "PR2" printed on it, two white arms with black grippers, and a white base. The robot is set against a dark background with red curtains on either side and a yellow rectangular backdrop behind it. The lighting is dramatic, highlighting the robot's metallic components.

Thank you!

(roboscopie 2012)