CNRS Research Project

Socially-Driven Autonomous Robots

for

Real-world Human-Robot Interactions

Pr. Séverin Lemaignan

Host laboratory:
Laboratoire d'Analyse et d'Architecture des Systèmes
(LAAS-CNRS)

Summary

AI is already part of our daily life, and robots are increasingly part of our everyday lives, supporting our ageing society, and assisting teachers in classrooms. In this context, how to ensure 'by-design' that these social robots have a positive social impact? This question is the backbone of my research project, and my specific objective is that, within 5 years, we create a socially-intelligent and responsible robot, that (1) will have recognised social utility, and (2) will see long-term acceptance by its users.

I formulate two main hypotheses: (1) this objective can only be achieved if the robot is socially-driven: the robot's behaviours must be driven by the intention to support positive human-human interactions. How this general principle translates into specific guidelines and algorithms – while taking into account the principles of a responsible AI – is a central contribution of the project.

(2) Long-term acceptance requires genuine involvement of the end-users at every step of the design process. To this end, my project introduces a novel methodology involving 'public-in-the-loop' machine learning: the large scale participation of end-users, over extended periods of time, to teach the robot how to become a good and responsible social helper.

My research tests these two hypotheses with an ambitious work programme. It includes basic research and conceptual framing; extensive, beyond-state-of-art, technical developments; and an ambitious experimental programme, with a combined two years of field deployment of social robots in public spaces.

This research project opens a unique window into the positive role social robots can play in our future societies; it will provide a lasting legacy, paving the way forward for a better understanding of the design of socially-intelligent robots that are socially useful and acceptable in the long-term.

Contents

Long-term vision and ground-breaking nature of the project

This research project is about designing and delivering a ground-breaking embodied AI for socially intelligent robots, with long-term social utility and demonstrated acceptance in the real world.

This breakthrough is made possible by a combination of novel methodologies and the principled integration of complex socio-cognitive capabilities:

- **crowd-sourced social interaction patterns;**
- **'public-in-the-loop' machine learning;**
- **a novel spatio-temporal and social model of the robot's environment;**
- **novel, non-repetitive, social behaviour production based on generative neural networks;**
- **and finally, an integrative cognitive architecture, driven by long-term social goals.**

In addition, I will deliver the conceptual and ethical framework required to further support the public debate and policy making process around social robots, and concretely demonstrate lifescale applications of this technology with ambitious, long-term deployments of autonomous robots in high impact, social environments.

The Laboratoire d'Analyse et d'Architecture des Systèmes (LAAS), part of the Artificial and Natural Intelligence Toulouse Institute (ANITI), would be an ideal host laboratory to successfully conduct this programme: its strong track-record in autonomous interactive robots, combined with the breadth of expertise available within the ANITI institute, would prove instrumental in scaffolding and accelerating several of the key science breakthrough I target with this project.

Closely aligned with the national and European research priorities (see *National and International Importance* section), this research project creates a unique opportunity to establish myself a key leader in Intelligent Social Robotics, as well as asserting the CNRS and European worldwide leadership in AI and robotics.

State of the art: real-world social robots and impact on the society

Social robotics is a disruptive field, with a profound impact on society and economy [1]. A recent report from the United Nations about the impact of the technological revolution on labour markets stated that AI and robotics are expected to radically change the labor market world-wide destroying some job categories and creating others [2]. Social robotics, however, is still an young, emerging, research-active field. The expectations are high, in multiple application domains: elderly care, customer service (in airports and shopping malls, for instance), education, child development, and autonomous vehicles to name a few [3]. However, whereas both computer-based AI applications, and traditional industrial robots already have a significant economic impact, social robots have not reached that point yet. Significantly, the recent failures of several companies investing in social robotics, like Jibo, Kuri, Willow Garage and Anki, and the major setbacks of companies like SoftBank, who designed and deployed hundreds of Pepper robot in their shops, before renouncing a few months later due to the poor reception by the customers, show that these technologies are not yet mature [4].

Indeed, understanding *why* these robots have failed, is one of the active debate within the Human-Robot Interaction community [5], with only a handful of qualitative studies on this question [6, 7]. Proposed explanations include the lack of perceived usefulness (robot seen purely as a toy); the limited liveliness of the robot that become rapidly predictable and repetitive [8]; the poor management of expectations, where user over-ascribe cognitive capabilities that do not match the reality. The community agrees however that the crux of the issue is achieving long-term social engagement [9, 5]

Research is however seemingly hitting a wall to further progress towards socially meaningful long-term interactions. For instance, in their large review of research in robotics for education, Belpaeme et al. [10] point to the shortcomings that prevent further development of effective, long-term social robotics in educative settings: the need for a correct interpretation of the social environment; the difficulty of action selection; the difficulty of pacing generated behaviours: three issues that underpin long-term engagement.

Attempts at long-term human-robot interactions are nevertheless becoming more common [11, 12], with a number of studies involving social robots deployed in real-world settings (for instance in schools [13, 14, 15, 16], homes [7] and care centres [17, 18]) over relatively long periods of time (up to 2 or 3 months at a time). Even though these robots are typically not fully autonomous, they do exhibit a level of autonomy, either by handling autonomously a relatively broad range of shallow tasks (eg, a butler-like robot answering simple questions, like in [17] or in the H2020 MuMMer [19] and FP7 Spencer [20] projects), or a narrow, well-specified complex task (for instance, supporting exercising in a gym, as I did in [18]). However, general purpose, long-term interaction is still an open question.

Novely, context, timeliness, relevance

The service and companion robots that we are set to interact with in the coming years are being designed and built today in labs and startups all over the world. Indeed, we already envision close and long-term human-robot interactions in a range of sensitive domains like education, elderly care and health care. Critically, we as a society, need to develop in parallel the underpinning principles that will ensure the future roles of social robots are collectively defined, in a responsible and ethical manner – in particular in the context their interactions with vulnerable populations.

<u>Progressing this question requires real-world evidence</u>. However, because autonomous social robots lie at the forward edge of science and engineering, the real-world, long-term deployments required to gather such evidence are extremely rare. As a consequence, we currently have limited insights into the factors that determine the utility and acceptability of social robots.

change approaches this important and timely question in a **novel and ambitious** manner: the project will define and implement **a vision of AI and social robotics that places the human at the centre of these emerging technologies, to foster novel social dynamics that are acceptable and beneficial to society**.I propose to create a **state-of-the-art autonomous social robot** that not only learns social behaviours **with and from** the public and end-users, but is also **co-designed from the ground-up to be acceptable, responsible and useful** to the humans it will serve.

Ambition, adventure, transformative aspects

This research is ground-breaking: **This resaerch programme will lead to the design, implementation and real-world demonstration of the AI engine of a socially-intelligent robot. My aim is to create, sustain and better understand the dynamics of responsible long-term social human-robot interactions, in order to build robots that (1) have an effective, demonstrable social utility, and (2) will see long-term acceptance by their end-users**.

The project is **ambitious**: in the next 5 to 10 years, I will have brought together two emerging AI paradigms (teleological architectures and human-in-the-loop machine learning); I will have them integrated into a state-of-the-art cognitive architecture for autonomous social robots, relying on multidisciplinary approaches where relevant (eg. a choreographer to create a novel 'body language' for social robots); I will have created the conditions for a unique, large-scale, 'public-in-the-loop' participatory design approach that will transform how we think about public engagement with technology design; finally, I will have deployed co-designed autonomous robots in several real-world, highly social settings, for significant periods of time.

Combining scientific ambition, engineering ambition and methodological ambition, my research programme sets a high bar for excellence, which leads to a fourth ambition: establishing myself as one of the key leaders in social robotics. Surprisingly few groups worldwide have achieved full autonomy for a complex social robot – the LAAS is one of them.

By joining the laboratory, I would create the conditions to 'future-proof' this scientific know-how, while developing a wide-ranging set of new research directions that promise to have a transformative impact on our digital future.

Methodology and approach to achieve impact

The overall aim of my research programme is to **create, sustain and better understand the dynamics of responsible, long-term social human-robot interactions**. This translates into three overarching, long-term research questions:

RQ1: What are the public expectations with respect to the role of social robots, and how can we collectively design principles ensuring responsible, beneficial, socially acceptable robots?

RQ2: What are the conceptual, algorithmic and technical prerequisites to design and implement such an embodied AI? in particular, what AI is required to **sustain long-term engagement** between end-users and a robot?

RQ3: What new ethical questions are raised by long-term social interaction with an artificial agent, and in particular, how to balance **autonomy** of the robot with **behaviour transparency** and **human oversight**?

From these questions, I derive the following five objectives that are the guiding principles of my research programme:

O1: conceptual framing To construct a solid conceptual framing around the multidisciplinary question of responsible human-robot interactions, answering questions like: What should motivate the robot to step in and attempt to help? or: What social norms are applicable to the robot behaviours? I will investigate the basic principles of responsible social interactions, that must form the foundations of a socially useful robot, accepted and used in the long run. Using user-centred design and participatory design methodologies, I will identify the determinants and parameters of a responsible social intervention, performed by a socially-driven robot, and formalise them in guidelines.

O2: real-time social modeling To create the novel cognitive capability of artificial *social situation assessment* and enabe the robot to represent real-time social dynamics in its environment, I will significantly extend and integrate the current state-of-art in spatio-temporal modeling (so-called *situation assessment*) with my recent research in social state modeling.

O3: congruent social behaviours production To create a novel way of producing non-repetitive, socially-congruent, expressive motions using the state of the art in generative neural networks, combined with data acquired from an expert choreographer. This will be integrated with novel *sound landscapes* to create a beyond-state-of-art, non-verbal (yet highly expressive) action and communication system for the robot.

O4: embodied AI breakthrough To create robot behaviours that are perceived as purposeful and intentional (long-term goals), while being shaped by a user-created and user-controlled action policy. I will integrate long-term social goals, arising from the interaction principles of **O1**, with the social modeling capability of **O2** and the behaviours production of **O3** into a principled, goal-driven cognitive architecture. The breakthrough will come from combining these long-term social goals with bottom-up action policies, designed and learnt from the end-users using human-in-the-loop reinforcement learning.

I want to specifically test the following two hypotheses: first, that long-term social goals, if suitably co-designed with the public and stakeholders and properly integrated into the robot as a *social teleology*, will create the perception that the robot is intentional and purposeful. This will in turn elicit sustained engagement from its human users.

Second, that human-in-the-loop machine learning can be used to ensure an additional layer of human oversight and a level of behavioural transparency. Human-in-the-loop reinforcement learning – as implemented in the SPARC approach that I have developed and already used in complex social environments [21, 22, 23] – relies on an end-user 'teacher'. This teacher initially fully controls the robot (via teleoperation) while it learns the action policy, and then progressively relinquishes control up to a point where the robot is effectively autonomous. As I previsouly argued [22], this approach leads to increased control and ownership of the system, and as a result, increased trust on the part of end-users.

This objective also raises one additional question: how to *arbitrate* between a top-down action policy arising from the long-term goals and the bottom-up action policy learnt from the end-users? This question leads to objective **O4'**: To design a policy arbitration mechanism that preserves the robot's long-term intentional behaviour while effectively guaranteeing human control, ownership and oversight.

O5: ambitious field research Finally, the last major objective of my research project is to demonstrate the effectiveness of my approach in complex, real-world conditions. This means deploying the socially interactive robots in existing social eco-systems that are sufficiently complex and open to explore novel social interactions. My objective is also to show that this real-world deployment can be successfully driven by the 'end-to-end' involvement of all the end-users and stakeholders: from defining the robot's role, from the different perspective of each end-user, to actually designing and 'teaching' the robot what to do.

Together, these five objectives build a coherent and realistic pathway towards addressing the overall aim of my research programme: creating, sustaining and better understanding the dynamics of responsible long-term social human-robot interactions.

Implementation of the work programme

The five scientific objectives presented in the previous section underpin my research vision and scientific programme. This section presents how I intend to *implement* these objectives, i.e. what are the major research directions that I will research, develop and establish as active research fields in the coming years.

I intend to organise my research along **4+1 main research strands**:

- **Strand 1** focuses on advancing the **perception of complex social situations**, including modeling the complexity of humans and human group dynamics;
- **Strand 2** investigates the **intelligent generation of social behaviours**, exploring novel techniques mixing immersive teleoperation and adversarial generative networks;
- **Strand 3** aims at significantly progressing the state-of-art in **cognitive architectures** for robots, also accounting for and integrating end-users in the generation of cognitive behaviours.
- **Strand 4** focuses on framing and practically advancing what responsible and safe AI means in the context of social robots. Critically, I propose a methodology enabling the co-construction of these guidelines with both the general public and ethics expert. This work will pave the way for an international framework and concrete guidelines for **responsible human–robot interactions**.

Those four research strands are all underpinned by one additional research activity, the transversal **Strand 5**. As a research scientist, I will build-up an ambitious **experimental capacity** at LAAS-CNRS, that will significantly improve upon the current, mostly lab-based, experimental work conducted to date. Building on my extensive experience in real-world deployments of autonomous social robots (see section **??**), I will establish an ambitious experimental programme, in close partnership with local institutions, based on the field's best practices that I have contributed to establish [24].

Overview and coherence of the research programme

These five strands are tightly coupled, and together will enable a major scientific and technical breakthrough in autonomous, socially-intelligent, robots.

Figure 1 gives an overview of how the research directions interact with each other. Fieldwork (**Strand 5**) plays a central role in my research programme, and appears in the centre of the figure. Indeed, the deployment of autonomous social robots in real-world, meaningful social spaces (eg. in schools, Toulouse's Purpan hospital, Toulouse's science centre 'Le Quai des Savoirs', etc) will be integral to my research methodology, and will enable the development of 'public-in-the-loop' experiments (4.2): the public, by co-designing interventions, interacting and, at time, taking direct control of the robots, will shape what a useful and socially acceptable interaction looks like, and lead to the *definition of core interaction principles*. Using machine learning to learn from these field experiments (3.2), these core principles are in turn translated into algorithmic models, guiding the *social teleology* of the cognitive architecture (3.1).

The regular fieldwork I intend to conduct will also provide the source of data to feed into to Strand 1: **Strand 1**, focusing on *social situation assessment*, researches, develops, and integrates all the components pertaining to the assessment of the spatio-temporal and social environment of the robot. Reference interaction situations and the interaction

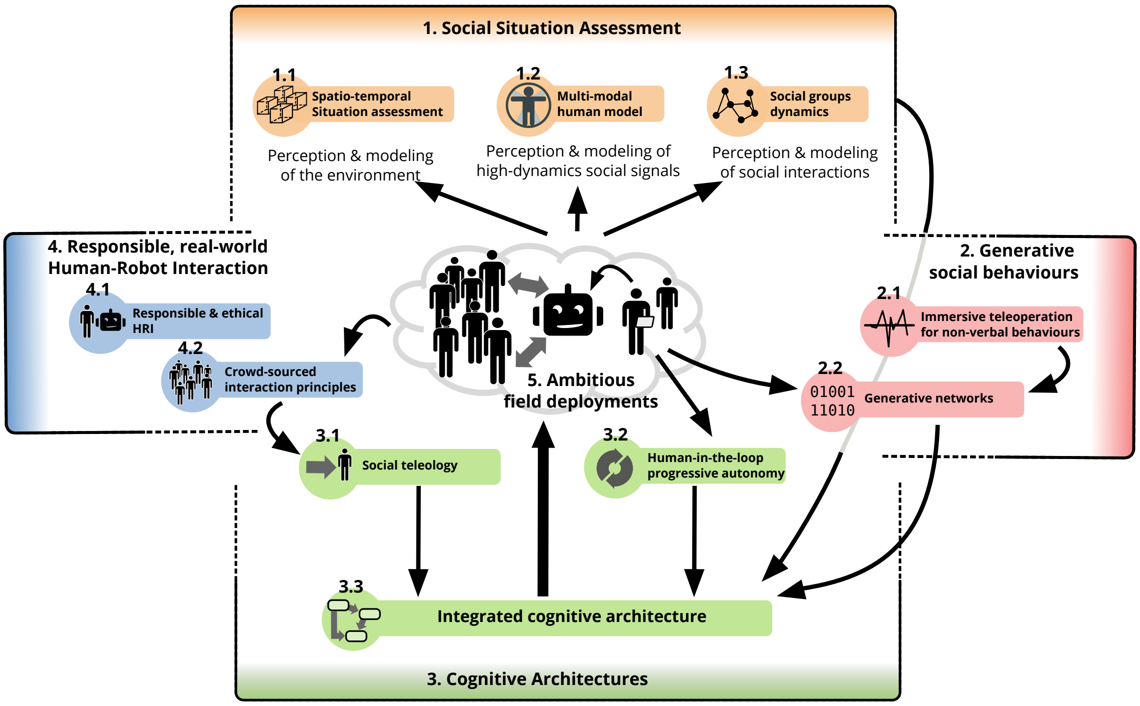


Figure 1: Overview of the research strands that I intend to develop as a CNRS research scientist.

datasets required to support this research is directly drawn from the experimental field-work, as well as an additional, focused experimental programme on mental states modeling that I detail in the following sections.

These perceptual capabilities are both (1) continuously integrated into the robot's cognitive architecture (3.3), iteratively improving the socio-cognitive performances of the robot, (2) disseminated to the broader community through standardisation and integration to the ROS ecosystem.

Strand 2 looks into behaviour generation using immersive teleoperation to investigate novel non-verbal interaction modalities (2.1), combined with new developments in machine learning to learn and automatically generate them (2.2). In this research strand, I will focus on researching new way of automatically generating rich behaviours (including eg expressive gestures, expressive motions) that are non-repetitive and socially congruent. I intend to apply state-of-the-art deep generative networks to achieve this; as such, the research strand is data-intensive, and will use datasets acquired during the field deployments, as well as lab-recorded dataset of social interactions, using novel immersive techniques presented below. Similar to Strand 1, the newly developed capability of generating socially congruent behaviours is continuously integrated in the robot architecture.

My research project includes an ambitious, beyond-state-of-art, technical work programme, and **Strand 3** investigates the *principled* integration of a cognitive architecture for autonomous social robots. Indeed, in addition to the integration of the results of Strand 1 and Strand 2, Strand 3 is also researching and developing the socio-cognitive principles, or *drives* of the architecture. They will be identified both from the 'public-in-the-loop' research and end-user engagement conducted in **Strand 4**, and an novel research on intrinsic social motivation that I detail below.

Towards building a principled cognitive architecture

As such, an important part of my research programme contributes to the design and implementation of a novel, complete cognitive architecture for socially intelligent robots. While I detail in a following section the scientific underpinnings of this research, Figure 2 illustrates how my different research strands combine towards that goal.

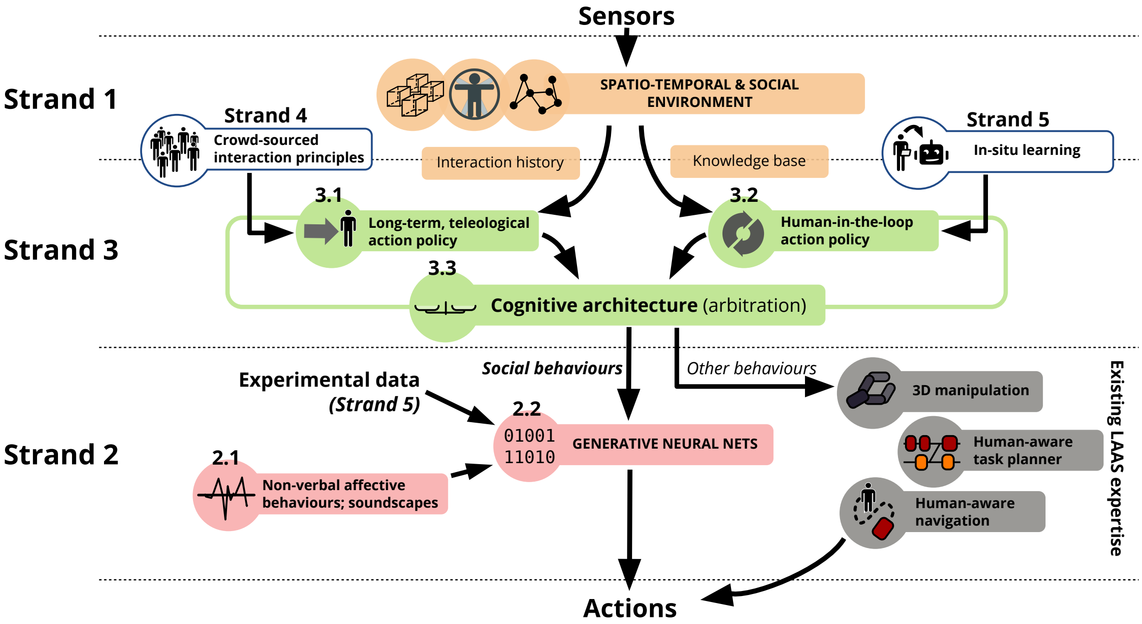


Figure 2: Contributions of my research strands to the AI architecture at the core of the research programme. Some capabilities already developed at the host lab (grey blocks) will directly contribute to the practical realisation of autonomy.

Strand 1 (top) focuses on creating a novel, integrated model of the social environment of the robot; it will build on the current state of art in spatial modeling, semantic modeling and interaction history representation, and augment it with representations of the social dynamics around the robot, introducing the idea of *social embeddings*. Strand 2 (bottom) significantly improve upon techniques for non-repetitive, socially-congruent behaviour production, combining behaviour design and data acquisition using immersive teleoperation with recent advances in generative neural nets. Strand 3 (centre) integrates the robot cognitive capabilities in a new cognitive architecture for long-term social autonomy. It introduces a novel arbitration mechanism between action policies, to enable both long-term, goal-driven autonomous behaviours, and direct in-situ learning from the robot's end-users, to ensure transparency and human oversight.

The following sections describe in greater detail each of these research strands, in the context of the current state-of-the-art.

Strand 1: Perception for robust real-world Social Situation Assessment

My first research direction will look into integrating a full representation system for the social environment of the robot. It builds on existing state of art in *situation assessment* and *knowledge representation*, and extend it to the social sphere. I plan to organise my work along the following five initial directions:

1.1 – Hybrid situation assessment and knowledge representation

Knowledge representation and grounding is a fundamental building block for cognitive architectures[25, 26]. This task builds on existing work on symbolic knowledge representation (eg. [27] or my own work [28]) and my work on situation assessment [29] (that includes for instance object recognition and physics simulation [30]), to create a coherent system of representations for the cognitive architecture that extends the underworlds spatio-temporal representation tool [29] with with recent advances in symbolic (eg. data-driven semantic labelling, like the 4D convolution network MinkowskiNet [31]) and hybrid (like *conceptors* [32]) representations capabilities.

> **Research strand 1.1 – targeted outcomes:**
>
> An extensible multi-modal software platform, that robustly tracks and represents the spatio-temporal environment of the robot (including the locations and objects in the robot vicinity).

1.2 – Multi-modal human model

This workpackage focuses on the acquisition, processing and modelling of social signals [33] to build a multi-modal model of the humans in the robot's vicinity. I have recently introduced a dataset of social interaction [34] that enables for the first time a quantitative, data-driven investigation of social dynamics. Promising initial results led me to uncover three latent constructs that underpin social interactions [35]. This dataset and the related methodologies on data-driven social modeling will form the basis of this research workpackage, and will exploit the natural interaction data collected in Strand 5.

> **Research strand 1.2 – targeted outcomes:**
>
> A data-driven social signal processing pipeline to model the surrounding humans.

1.3 – Interaction and group dynamics

Building on 1.2, 1.3 investigates the automatic understanding and modelling of group-level social interactions [36], including f-formations [37], sociograms (as done in [38] for instance), and inter-personal affordances [39]. This task builds on literature on on social dynamics analysis (eg [40, 41, 42]) to apply it to real-time social assessment by a robot, itself embedded into the interaction.

> **Research strand 1.3 – targeted outcomes:**
>
> The software pipeline required for the automatic analysis of social dynamics at group-level, able to model in real-time the social context of the robot.

1.4 – Social situation assessment

In 1.4, I integrate the social cues from 1.2 and 1.3 into the representation platform developed in 1.1. It will result in a socio-cognitive model of the social environment of the robot that I term *social situation assessment*. It effectively extends the representation capabilities of implemented in 1.1 to the social sphere, and covers the development of a complete social assessment pipeline, from social signal perception (like automatic attention tracking, face recognition, sound localisation, etc.) to higher-level socio-cognitive constructs,

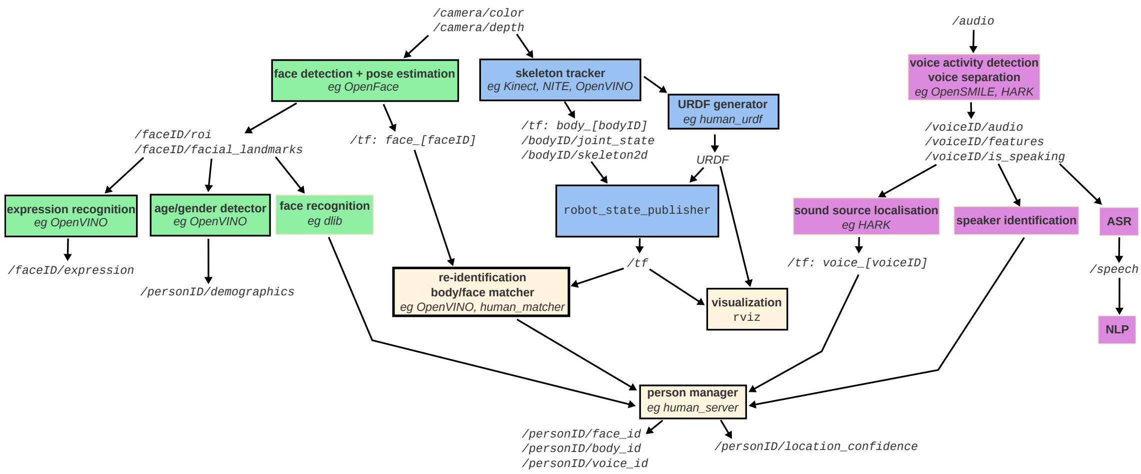


Figure 3: Overview of the 'ROS4HRI' pipeline that I currently develop.

including group dynamics and perspective taking [43] (as I previously framed in [44, 45]).

Research strand 1.4 – targeted outcomes:

A novel cognitive sub-system for social situation assessment, released as an open-source set of integrated ROS modules ("*ROS4HRI*", Figure 3). This set of tools will enable the robot to represent its physical and social environment, and perform queries about it, including queries about past events (temporal model) and queries requiring higher socio-cognitive perceptual capabilities like perspective taking.

1.5 – Social embeddings

One of the key novel scientific idea that I will research in this workpackage is the construction of the **social embedding** of the robot: a compact, low-dimensional representation of the full social environment, inspired from word embeddings (eg. [46]). If fruitful, this approach would significantly simplify the application of neural networks to automatically recognise social situations and social dynamics (something notoriously difficult to achieve with the current state-of-art [35]), and potentially *generate* plausible social situations, that the robot could use to eg. predict the next states of an interaction.

Research strand 1.5 – targeted outcomes:

The investigation of *social embeddings* as a general, sub-symbolic representation of the social environment of interactive robots.

Experimental programme of Strand 1

In complement to the large-scale experimental work described in Strand 5, a focused experimental programme accompanies Strand 1, to demonstrate (in relative isolation) the resulting socio-cognitive capabilities. I will implement a subset of the experimental protocols identified by Frith and Happé [47] to investigate theory of mind with autistic children, as it offers an excellent experimental framework for social robotics, as I argued in [44].

Indeed, experimental protocols in research on autistic spectrum disorders are often striking by their apparent straightforwardness because of the careful choice of interaction modalities: since autistic children frequently exhibit impairments beyond social ones (such as motor or linguistic ones), the experiments must be designed such that they require only basic cognitive skills beyond the social abilities that are tested. The Sally and Anne task, for instance, requires the observing child to be able to visually follow the marble, to remember the true location of the marble, to understand simple questions ("Where will Sally look for her marble?" in Baron-Cohen's protocol [48]) and eventually to give an answer, either verbally or with a gesture – the two first points being actually explicitly checked through questions: "Where is the marble really?" (reality control question) and "Where was the marble in the beginning?" (memory control question).

Likewise, current social robots have limited cognitive skills (no fast yet fine motor skills, limited speech production and understanding, limited scene segmentation and object recognition capabilities, etc.) and such tasks that effectively test a single cognitive skill (in this case, mentalizing) in near isolation are of high relevance for experimental social robotics [44], offering rich experimental opportunities, early on in the development process of the complete cognitive architecture.

No mentalizing required	Mentalizing required
Ordering behavioural pictures	Ordering mentalistic pictures[49]
Understanding see	Understanding know[50]
Protoimperative pointing	Protodeclarative pointing[51]
Sabotage	Deception[52]
False photographs	False beliefs[53]
Recognizing happiness and sadness	Recognizing surprise[54]
Object occlusion	Information occlusion[55]
Literal expression	Metaphorical expression[56]

Table 1: Tasks requiring or not mentalizing to pass, listed by Frith and Happé in[47]

Frith and Happé's list (Table 1) is in that regard especially interesting in that it mirrors pairs of task (ones which do not require mentalizing with similar ones which do require mentalizing), thus providing control tasks. *Object occlusion* vs. *Information occlusion* is one example of a pair of tasks which evidence representation-level perspective taking through *adaptive deception*. Adapting such a protocol for a human-robot pair would demonstrate *second-order*, *representation-level* perspective taking capabilities, which is beyond the state-of-the-art in an artificial cognitive system.

Strand 2: Generative social behaviours

Mirroring Strand 1's focus on understanding the social interactions, Strand 2 addresses the question of social behaviour *generation*: how to create natural behaviours, engaging over a sustained period of time (eg not simply picking scripted behaviours from a library, that are rapidly perceived as repetitive).

The focus of my research will be in the first instance on *non-verbal* behaviours (however, see Section for planned collaborations on *verbal* behaviours). This is a purposeful interaction design choice, that ensures we can more effectively manage what cognitive capabilities are ascribed to the robot by the users (expectation management). I seek however to significantly push forward the state-of-the-art of behaviour generation for robots, both in term of technique to generate the behaviours, and in term of the nature of the non-verbal behaviours (including expressive gestures and motion, non-verbal utterances using sounds, gaze, joint attention).

This strand of research will build upon the long expertise of the LAAS-CNRS on developing social robots interacting with humans in complex environments [57, 58, 59]**add additional/better references**, as well as the existing literature on current behaviour generation methodologies, covering techniques like curiosity-driven behaviours[60], Learning from Demonstration[61, 62], human-in-the-loop action policy learning[63, 22].

Collaborating with Nicholas Asher, IRIT, ANITI

Dr. Nicholas Asher is a leading figure in natural language processing. Collaborating with him would open strong mutual opportunities to develop and apply language processing for physical, embodied agents. the LAAS would enable me to

2.1 – Immersive teleoperation to design richer non-verbal interactions

As part of Strand 2, I also intend to lead research on novel non-verbal interaction modality for social robots. This direction of research, tightly related to the previous one, will pursue an interdisciplinary approach: from creating a novel body language for social robot with choreographers, to investigating new forms of sound expressions like soundscapes with sound experts: soundscapes are about creating a sound environment that reflects a particular situation; they also have been shown to be an effective intervention technique in the context special needs treatments (eg [64]). The soundscapes that we will research and create, are 'owned' by the robot, and it can manipulate it itself, eg to create an approachable, non-threatening, non-judgmental, social interaction context, or to the establish the interaction into a trusted physical and emotional safe-space for the children.

Complete the 'immersive teleoperation for behaviour design' part

with a dataset co-created with artists (for instance, a choreographer): during a period of time, a choreographer would join the lab and remotely 'puppet' a robot which would be itself interacting with the lab members (Figure 4)

Collaborating with Olivier Stasse, LAAS–CNRS

Olivier Stasse is an expert in humanoid motion, and has past experience in working with dancers to inform the design of complex motions. I have a track-record of collaboration with him on art-driven design methodologies [66].

Research strand 2.1 – targeted outcomes:

The research, development and implementation of novel non-verbal communication modalities, including for instance a robot 'body language' for social interactions and soundscapes; a large dataset of such interactions, recorded in immersive conditions, and suitable for machine learning.

2.2 – Generative neural network for social behaviour production

Designing behaviours that enable sustained, long-term engagement in a social human-robot interaction is essentially an open research question. The specific challenge of producing non-repetitive social behaviours is particularly difficult: social robots typically rely on *off–*

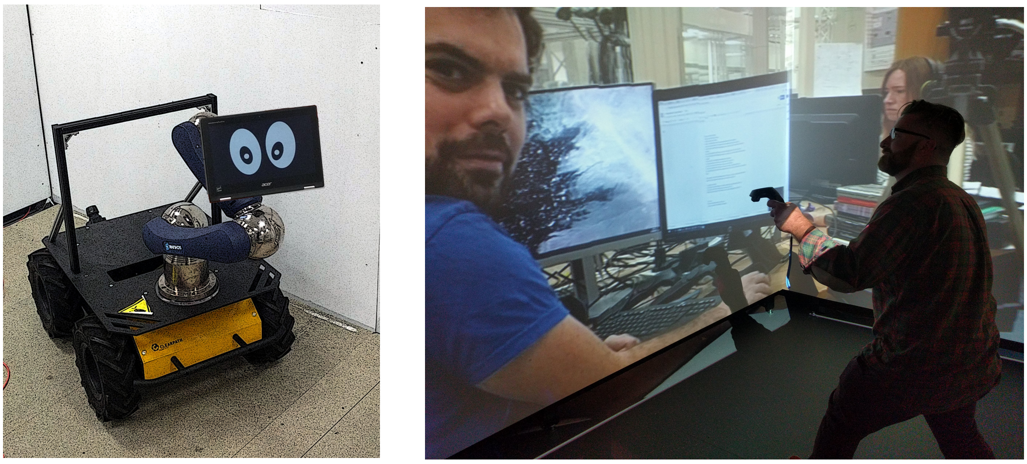


Figure 4: (left) Possible appearance of a puppet-robot that I will use to collect data. A tablet, displaying facial animations, is mounted on a robotic arm. It can freely orient its 'gaze' and use expressive movements. The robot is effectively teleoperated in realtime by an artist (eg choreographer, right) who 'sees through the robots' eyes' [65] and who is tasked with designing and acting a novel 'body language' for social interactions.

the-shelf behaviours, where the robot effectively picks from a set library of behaviours (that might be individually relatively complex). The approach can elicit a strong initial social response from the user, but this social response tends to vanish rapidly once the 'tricks' of the robot have been all discovered and become repetitive. Besides, as the robot does not typically maintain a long-term socio-cognitive plan of the interaction, the behaviours are typically perceived as fun, yet pointless, leading to disengagement. This is often observed in toy-like robots (eg Vector, Dot & Dash) [5].

The LAAS-CNRS has played a pioneering role in this field with eg the development of HATP as a hybrid task-planner for human-robot interaction [67, 57] or human-aware motion planning [58, 59]. While effectively enabling the robot to store and manage long-term plans, symbolic task planners still rely on mostly static libraries of 'canned', repetitive actions. Also neither of these planners are well-suited to rapid, dynamic behaviours generation, especially in situations requiring performing parallel, blended actions.

Building on these solid foundations, I aim at significantly advancing the state of the art in this regard, by combining two recent machine-learning techniques: (1) generative neural networks for affective robot motion generation [68, 69, 70]; (2) interactive machine learning in high-dimensional input/output spaces, where I have shown with my students promising results for generating complex social behaviours [22, 23] that fully involve the end-users [71].

In [70], a Generative Adversarial Network (GAN) is trained to generate expressive motions; the generation being modulated by a feature encoding an emotion. I will extend this idea in two ways: (1) I will train the GAN on multiple interaction modalities (motions, but also facial expressions, gaze, sounds) using the data acquired in 2.1. The aim will be to collect a large amount of data to train a GAN from, effectively creating a new multi-modal 'grammar' for the robot expression. (2) Instead of using emotions to modulate the generation stage, I will use the social embedding constructed in 1.5: the generated behaviours will be shaped by the current, complex social state of the interaction instead of simply emotions.

> **Research strand 2.2 – targeted outcomes:**
>
> A generative neural network able to produce non-verbal yet multi-modal social behaviours. They will combine expressive gestures, gazing behaviours, facial expressions, and expressive sounds.

Strand 3: Goal–driven socio–cognitive architecture

Strand 3 investigates the principled integration of a cognitive architecture for autonomous social robots. It binds together the socio-cognitive perceptual capabilities of the robot developed in the Strand 1, the action production mechanisms developed in the Strand 2, and includes key elements from my 'human-in-the-loop' methodology to isolate and model the interaction principles and social goals of the robot.

3.1 – A social teleology for robots

Teleological systems (ie goal-driven) have been investigated in robotics for being a way of providing long-term drives to an autonomous robot. This has been successfully applied to relatively simple cognitive systems [60, 72] or virtual agents [73]. This first basic research activity in Strand 3 aims to significantly progress this line of research, and to look into *complex* interactive cognitive systems. The key objective of this work package 3.1 is to define and implement a novel *social teleology*: the **algorithmic encoding of long–term social goals** into the robot.

This work will directly draw from the participatory, 'human-in-the-loop' methodological paradigms that present in Strand 5. Indeed, before being transposed into algorithms, these long-term social goals will first be co-defined and co-created by the end-users and the public in terms of *interaction principles for useful and responsible social robots*.

> **Research strand 3.1 – targeted outcomes:**
>
> The algorithmic translation of interaction principles into long-term social goals for the robot; eg a long-term, socially-driven action policy for the robot.

3.2 – Learning from humans to achieve by–design responsible & trustworthy AI

I have recently obtained promising results on human-in-the-loop social learning [22, 23]: non-expert end-users teach in-situ (eg at school, at the gym, etc.) a robot, which progressively learns to be autonomous, eventually reaching full task- and social autonomy. This approach, that I developed with one of my students [21], holds a lot of promise in term of field acceptance of social robots as it entrust the end-user with a high level of control during the learning phase, leading to a feeling of ownership of the resulting robot behaviours. I will further develop this idea, applying in-situ interactive reinforcement learning to more complex, real-world, situations.

In addition, I will study through qualitative methods (thematic interviews and questionnaires) whether (and how) human-in-the-loop machine learning enables a more trustworthy AI system, by involving the end-users in the creation of the robot behaviours, thus offering a level of behavioural transparency to the end-users.

Research strand 3.2 – targeted outcomes:

A human-in-the-loop reinforcement learning paradigm, suitable for in-situ teaching of the robot by the end-users themselves, demonstrated in complex social environments.

3.3 – Integrating a socially-driven architecture for long-term interaction

This research strand builds on the state of art in cognitive architectures (disembodied ones [74, 75, 76, 77, 78, 79, 80], as well as ones specifically developed for robotics: ACT-R/E [81], HAMMER [82], PEIS Ecology [83, 84], CRAM/KnowRob [26, 27], Ke-Jia [85], POETICON++ [86], and the LAAS Architecture for Social Interaction [25], to which I have been a key contributor during my PhD). The overall purpose of this socio-cognitive architecture is to integrate in a principled way the spatio-temporal and social knowledge of the robot (Strand 1) with a decision-making mechanism, to eventually produce socially-suitable actions (Strand 3).

The decision-making mechanism is critical, and lay at the heart of my research project. The robot will rely on it to generate action decision that are purposeful, legible and engaging on the long run, something that none of the existing architectures have been able to successfully demonstrate to date. I aim at a breakthrough, and will introduce a novel approach: drawing from the interaction patterns identified (Strand 4), I will combine long-term, socially-driven goals (the *social teleology*, 3.1), and human-in-the-loop machine learning (3.2) using a novel arbitration mechanism.

The arbitration mechanism itself will build on research on reinforcement learning for experience transfer [87] that enables the re-assessement of a policy (here, our long-term social teleology) based on specific experience (here, the end-user-taught policy).

Research strand 3.3 – targeted outcomes:

A cognitive architecture, implemented on the LAAS social robots, that enables long-term social engagement, by combining long-term goals with domain-specific action policies, taught by the end-users themselves.

Strand 4: Framing responsible human-robot interactions

The basic, long-term ambition of my research programme is to re-investigate the underpinnings of human-robot interaction by taking a **strong human-centered perspective**. I frame this as a shift from *human-robot interaction* to *robot-supported human-human interactions* (r-HHI). This last major strand of research operationalises this objective in term of a basic contribution: examining the interplay between r-HHI, responsible AI, and ethics. This will be directly influenced by the experiemental work described in Strand 5.

Conceptual framing of r-HHI and ethical framework

The first task in Strand 4 is to research and define the framework that will provide the conceptual frame around questions like: what role should social robots have? Where to set the boundaries of artificial social interactions? What does 'ethical-by-design', 'responsible-by-design' mean in the context of social human-robot interactions?

Indeed, my research project involves social robots, interacting in repeated ways and over long period of time, with human end-users, including vulnerable children. This raises complex ethical issues, both practical ones (how to design the experimental work in a such a way that they are safe and ethically sound), and more fundamental ones (what is the ethical framework for robots intervening in socially sensitive environment?).

The ethical questions raised by social robotics have been actively studied over the last 5 years, attempting to address issues like:

- how to ensure that social robots are not used to simply replace the human workforce to cut costs?
- can we provide guarantees that the use of social robots will always be ethically motivated?
- further on, can we implement some ethical safeguarding built-in the system (like an ethical *black-box* [88])?
- what about privacy? how to trust robots in our home or school or hospital not to eavesdrop on our private lives, and, in the worst case, not be used *against* us?

These questions are indeed pressing. The recent rise of personal assistants like Amazon Alexa or Google Home, with the major privacy concerns that accompanies their deployments in people home, shows that letting the industry set the agenda on these questions is not entirely wise – and robots can potentially be much more intrusive than non-mobile smart speakers. The EU is positioning itself at the forefront of those questions. The recent release of operational **Ethics Guidelines for Trustworthy AI** by the EU High-level Expert Group on Artificial Intelligence [89] is a strong sign of this commitment. These guidelines identify seven requirements of trustworthy AI:

R1 **Human agency and oversight**, including fundamental rights, human agency and human oversight

R2 **Technical robustness and safety**, including resilience to attack and security, fall back plan and general safety, accuracy, reliability and reproducibility

R3 **Privacy and data governance**, including respect for privacy, quality and integrity of data, and access to data

R4 **Transparency**, including traceability, explainability and communication

R5 **Diversity, non-discrimination and fairness**, including the avoidance of unfair bias, accessibility and universal design, and stakeholder participation

R6 **Societal and environmental wellbeing**, including sustainability and environmental friendliness, social impact, society and democracy

R7 **Accountability**, including auditability, minimisation and reporting of negative impact, trade-offs and redress.

The design methodologies and techniques employed in my research programme naturally implement most of these requirements: interaction co-design and human-in-the-loop machine learning ensures human agency oversight over the robot's behaviours (R1); Privacy and data governance (R3) is addressed in the project's data management plan and facilitated by the design decision of performing all data processing on-board the robot, avoiding the dissemination of personal information; the transparency of the robot behaviour (R4) stems from the machine learning approach that we advocate: the robot's behaviours primarily originate from what the end-users themselves taught the robot; diversity and non-discrimination (R5) is supported by the large-scale involvement of the public at the science centre, ensuring a broad diversity of backgrounds and profiles; societal wellbeing (R6) is the core research question of the project, and I intend to contribute in realising this requirement in the context of social robots.

Technical robustness (R2) and accountability (R7) are important design guidelines for the robot's cognitive architecture (WP4), and will be addressed there as well.

The Ethics Guidelines for Trustworthy AI form a solid foundation for the project. However, personal and social robots raise additional questions regarding what ethical and trustworthy systems might look like, and while the principles of responsible design are somewhat established [90, 91], the reality of robot-influenced social interactions is not fully understood yet, if only because the technology required to experience such interactions is only slowly maturing.

Social robots have indeed two properties that stand out, and distinguish them from smart speakers, for instance. First, they are fully embodied, and they physically interact with their environment, from moving around, to picking up objects, to looking at you; second, willingly or not, they are ascribed *agency* by people. This second difference has far-reaching consequences, from affective bonding to over-trust, to over-disclosure of personal, possibly sensitive, informations [92, 93]. As an example, a common objection to human-robot interaction is the perceived deceptive nature of the robot's role. It has been argued [94] that the underlying concern is likely the lack of an adequate (and novel) model of human-robot interactions to refer to, to which the project will provide elements of response. This needs nevertheless to be accounted for in depth.

Ethical framing of social robotics has started to emerge under the term **roboethics**: the "subfield of applied ethics studying both the positive and negative implications of robotics for individuals and society, with a view to inspire the moral design, development and use of so-called intelligent/autonomous robots, and help prevent their misuse against humankind." [95]. Specific subfields, like assistive robotics [96], have seen some additional work, but social robotics is still not equipped with operational guidelines, similar to the EU guidelines on trustworthy AI.

This is my ambition that my research will significantly contribute to the framing and the building of guidelines and recommendations for responsible human-robot interactions, enabling a safe and trustworthy digital future in our society.

I intend to develop this line of research by adopting the same open-science approach, involving the general public in the process: my field work experiments (Strand 5) will both *build on* and *feed into* the framework developed in this research strand.

In addition, I will also structure this framing effort through international workshop. During these workshops, invited ethics experts (from both robotics and AI backgrounds) will be invited to engage with field practitioners, including local institutions where the experimental work will have taken place. These regular forums will be coordinated with the European Commission (I am already acting as an Expert Collaborator on ethics for the European Joint Research Centre), and will create a public opportunity to debate and iterate over ethics guidelines for responsible long-term social interactions with robots.

Research strand 4 – targeted outcomes:

A conceptual framework that clarify and organise together the questions raised by long-term social interactions; ethical guidelines for such interactions, aimed at informing future policy making.

Strand 5: Experimental programme: long-term deployments in sensitive social spaces

I have the ambition to demonstrate long-term, co-designed social interactions in two complex, socially sensitive spaces.

Revisit this section to adapt to local environment

The first one involves the deployment of social robots in special needs schools (SEN schools) in Bristol (T5.1). Building on a rigorous participatory approach involving the school teachers, as well as the parents, we will seek to integrate the robot in the daily life of the school, supporting the development of the students' physical and social skills. The second one takes place in Bristol's Children's Hospital (T5.2), supporting isolated children who suffer long-term conditions, in close cooperation with the hospital staff. In both cases, a social robot will be deployed on premises, for one un-interrupted year. It will integrate the daily routines of the institutions, under supervised autonomy [21], and *without* requiring the presence of a researcher at all time.

These two experiments raise specific practical and ethical questions, as they target vulnerable populations. This is an however informed choice: first, I already have established partnerships with Bristol's children hospital on one hand, and a network of Bristol-based SEN schools on the other hand. As such, and from a practical perspective, I do not foresee any institutional issues – on the contrary, our partners are excited at the prospect of taking part to the project. Besides, convincingly demonstrating the importance and positive impact of socially-driven, socially-responsible robotics does accordingly require complex social situations, and complex social dynamics. The two scenarios, which complement each other, provide both. These scenarios also put the project in the unique position of actually delivering high societal impact: we anticipate 30+ hospitalised children with long-term conditions, and 250+ SEN-educated children to directly benefit of the project, showing how robots can have a lasting, beneficial impact on the society, alongside human carers: it will establish the idea of *robots supporting human interactions* instead of dehumanising our social relationships.

Both these deployments will take place within the strict ethical framework established in T1.1, the ethical considerations pertaining to these experiments are further discussed below, in the section on ethics, and in the separate annex on ethics, uploaded alongside this proposal.

5.1 – Crowd-sourced patterns of robot-supported social interactions

In order to broadly engage the public with defining what future robots should do to be perceived as responsible, beneficial, and engaging, I intend to create and deploy a novel investigation methodology that I term 'experimental crowd-sourcing'. For one year, in close partnership with local institutions (like Toulouse's "Le Quai des Savoirs"), the general public will be invited to teleoperate my robots, with the objective of interacting and assisting other visitors. The participants will remotely control the robot through a tablet interface (similar to the setup I created for [22] and [23]), and interviews of both the teleoperators and the visitors interacting with the robot will be conducted in parallel, collecting in a structured manner the interaction patterns and social norms that will emerge over the course of the study. Additional focus groups will be organised with the public to reflect and iterate on these principles.

finish that During the duration of the study, one researcher will be permanently based at the science museum, and the museum staff themselves will be trained to communicate about the aims of the study. Anonymous interaction data (eg, body postures) will be collected as well, and feed into WP2 and WP3.

Collaborating with Toulouse Science Centre *Le Quai des Savoirs* & local science charities

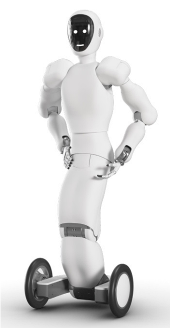
This work will only be successful if it reaches out to a broad and diverse public. I have an established network of contact in the local science communication community (eg local science charities *Planète Sciences*, *Les Petits Débrouillards*) and intend to establish a solid collaboration with Toulouse Science Centre *Le Quai des Savoirs* where field studies could be run.

Research strand 5.1 – targeted outcomes:

A set of crowd-sourced interaction patterns and principles, that will inform the long-term social goals of the robot (4.1); a large dataset of social interactions to feed into Strands 2 and 3.

Experimental approach

My experimental approach has two phases. First, I will co-design and co-construct the robot's social role and behaviours through large-scale public engagement. For a whole year, I will deploy the **change** robot within the Open City Lab of Bristol Science Centre *WeTheCurious*, relinquishing its control to the visitors themselves. Tasked with remotely operating the robot to assist fellow visitors, a researcher will accompany them in 'inventing by doing' a new grammar of social interactions to develop answers to the questions: what does it mean for a robot to help? How to do so in the dynamic, messy, environment of a science centre? What are acceptable behaviours? Can we see new social norms emerge? At the end of this experiment, we expect 1000s of people to have experienced – and co-designed – how robots should interact with humans in a positive, helpful way. Each of these experiences will contribute to uncovering and designing the basic principles of social interaction for robots. This work is the focus of WP1.



While most of the interactions in the science centre will be short-lived, a follow-on, long term (one year) experiment will take place in one of Bristol's Special Education Needs (SEN) school where I currently run pilots, helping 250+ children with psycho-social impairments (autism) to develop their social skills and to engage into playful social activities: telling stories, triggering group activities with other children, providing additional social presence. Similar to the science museum experiment, the robot behaviours will be co-designed with, and learnt from the end-users themselves: teachers, parents, and as much as possible, the children themselves.

Importantly, **change** focuses specifically on the AI engine of the robot: I will use an existing robotic platform (Halodi's EVE, pictured on the left) and develop and train the algorithms required to achieve autonomy and responsible, long-term social utility. Indeed, after an initial training period, the robot will be autonomous: while the users will be provided with tools to override the robot's decisions at any time (via both an app and touch sensors on the robot itself), it will otherwise move and act on its own, without the need for constant supervision.

Risk/gain assessment; risk mitigations

Tasks 1.1, 1.2 develop a novel methodology, 'public-in-the-loop' machine learning, for large-scale co-design of social interactions with the public. If successful, this will be of great value, well beyond the project. The proposed experimental setup (science centre visitors 'taking control' of the robot) might however lead to interactions that are either too short or to artificial to create meaningful, generalisable social interaction. In addition, the messy and complex nature of the science centre environment is also currently beyond-state-of-the-art in term of extracting the useful social features required to train a classifier.

However, the interaction principles that we want to uncover in T1.1 and T1.2 (and that are feeding into WP2 and WP4) will principally come from a qualitative analysis of the interactions, carried in parallel to the machine learning approach. This well within the expertise of the PI, and, as such, is low-risk. T1.1 can thus be described as a **medium–risk, high–gain** component of **change**.

Task 2.1 develops a novel situation assessment component, that integrates spatio-temporal modeling with knowledge representation. The resulting component is beyond-state-of-the-art, and would be highly relevant to a large range of robotic applications. This component relies on integrating tools that are independently relatively mature and well understood, and the principles of the integration itself is already well researched. Besides, it falls well within the PI expertise [29, 30, 28]. As such, T2.1 can be described as **low–risk, medium–gain**.

Tasks 2.2, 2.3, 2.4 Work on real-time modeling of social dynamics in real-world environments are only begining to be studied in robotics. While the underpinning are well understood in neighbouring academic fields, a very significant work remain to be done to integrate disparate or partial approaches into one framework. These tasks also require the acquisition of novel datasets that focus on natural human-human social interactions. The PI has extensive experience in building and acquiring such datasets [34, 97], and does not foreseen major difficulties. The resulting components have however the potential to unlock a new class of social robots, aware in real-time of their social surroundings and dynamics. These tasks are thus considered **low–risk, high–gain**.

Task 3.1 The behavioural baseline implements the current state-of-the-art, and as such is **low–risk, low–gain**. T3.1 will guarantee early on in the project a 'working' robot, yet with predictable/repetitive behaviours.

Task 3.2 The neural generation of complex social behaviours is a **medium–risk, high–gain** task: while it builds on solid existing state-of-the-art, it relies on very significant progress in both the modeling of the social dynamics (WP2) and the capacity of designing a machine learning approach to learn and generate these complex behaviours. While the former falls well within the PI expertise, machine learning for social motion generation is essentially a novel field. The success of this task will rely to a large extend on the quality of the post-doctoral researcher recruited to lead this effort. The main mitigation to the risk associated to T3.2 is the behavioural baseline created in T3.1: the behavioural capabilities generated in T3.2 can be complemented by ad-hoc behaviours whenever required.

Task 3.3 Non-verbal communication is a well established subfield of HRI research, well known to the PI. The creation of the novel interaction modality based on soundscape is novel, with potential for impact beyond the project. This new modality will be co-developped with an expert of sound design for interaction, and we do not foresee major risks. Overall, the task is **low–risk, medium–gain**.

Task 4.1 The conceptual framing of a *socially–driven architecture* (social teleology) and its translation into decision-making algorithms are to a large extend open questions. This task might however lead to uncover a fundamental mechanism to enable long-term engagement of users with social robots. Building fundamentally on blue-sky research, this task is **high–risk, high–gain**. If not successful, I will instead rely on the decision-making strategy of T4.2, which is much lower risk.

Task 4.2 The techniques developed in T4.2 have been previously used and tested by the PI in two different real-world environments [22, 18]. While they will require significant adjustments for this project, the task is overall **low–risk, low–gain**.

Task 4.3 The integration of the different cognitive functions of the robot into one principled cognitive architecture, that include cognitive redundancy, is one of the core expertise of the PI [25]. This task however includes significant novel elements (cognitive mechanisms for long-term autonomy; decision arbitration) that bear unknowns. Besides, this task is a critical pre-requisite for WP5. As a result, T4.3 is considered as **high–risk**. The task is focused on integration to meet the requirements of the WP5 experiments, and parts of the resulting software architecture might be project-specific. However the overall aims of endowing the robot with long-term social autonomy would be a significant breakthrough, and as such, T4.3 is **high–gain**. The main mitigations comes from (1) the iterative development process of the architecture, that will start from the existing state-of-the-art, to which the PI has previously contributed [25]. By doing so, a decisional architecture for the robot will be available early on in the project. While that architecture might be a scaled-down version of the initial ambition, it will still enable the fieldwork proposed in WP5, possibly with a lesser level of autonomy; (2) the possibility of using only one of the two action policies (T4.1 or T4.2), thus removing the need for complex arbitration.

WP5: Experimental deployments

The two application scenarios (at the children hospital and in the SEN school) are ambitious and inherently risky, as they target vulnerable populations. However, first, demonstrating the importance of advanced social modelling, and convincingly proving the effectiveness of our approach does require accordingly complex social situations, and complex social dynamics. The two scenarios, which complement each other, provide both.

Second, working with vulnerable populations, in constrained and complex environments (children hospital and SEN schools) adds significant risks to the project. But it is also what make the project in the unique position of delivering a high societal impact: a direct positive impact on children's lives (we anticipate 100+ hospitalised children and 50+ children with psycho-social impairements interacting over long periods of time with a robot over the course of the project), and a broader impact on the society, showing how robots can have a lasting, strong, positive impact on the society, also establishing the idea of *robots supporting human interactions* instead of dehumanising our social relationships.

Together, Task 5.1 and 5.2 are high–risk, high–gain.

The two main mitigations are (1) early and continuous engagement with the stakeholders, and (2) the decoupling of the two applications, meaning that the risks associated to each of them do not impact the other one.

Early engagement will be ensured by relying on a participatory design methodology, involving all the stakeholders from the onset of the project; the methodology will involve regular joint workshops; on-site (hospital and SEN schools) research stay including engagement with the staff/charities and the children themselves; early field testing and prototyping, relying if necessary on provisional, yet well-known, robot platforms available at the host institution (for instance, Softbank Nao and Pepper). This user-centered approach will be championed by the post-doc recruited on the project on WP4 and WP5, who will have to have a strong expertise in user-centered design.

It is also important to note that, while preparing this bid, initial discussions have been held with all the partners involved with the experimental fieldwork (WeTheCurious science centre, Bristol's Children Hospital, the network of SEN schools): each of these institutions is enthusiastic about the project, already contributing ideas to integrate the robots in their daily routines, and ready to dedicate time and effort for its success.

Research plan for the first five years

T5.1: A robot companion to support physical, mental and social well-being in SEN schools

Inspired by a similar large-scale deployment of social robots in Hong-Kong's SEN schools[98], the first study investigate whether a socially assistive robot can effectively support the development, social interactions and well-being of children with a long-term mental condition. This study will take place within the network of Bristol-based SEN schools, with which I already have an on-going collaboration. Specifically, the two main questions we seek to investigate are: What are the social underpinnings of the successful integration of a social robot in the school ecosystem? Can ambitious co-design with the end-users (teachers) deliver a 'net gain' for the learning, social interaction and well-being of the students?

The core of the study consists in deploying the R1 social robot in one of Bristol-based SEN school (Mendip Primary School, with possible extensions to other schools), to investigate how the robot can help shaping a social school ecology that fosters mental well-being, while effectively supporting teachers and students in their learning.

The study will adopt a strong participatory design approach, inspired by Patient and Public Involvement methodologies (PPI[99]), with 3 one-day focus groups organised with the school teachers; two evening focus group with the school parents, prior to the study; and several preparatory workshop at the school premises to involve the students as well.

The school study itself will take place during Y3, with the robot permanently based at the school. The robot will take part in the regular teaching and other daily routines of the school, and will directly interact with the children, learning its action policy ('when to do what') from initial co-design with the teachers, followed by progressive in-situ teaching (see T4.2).

During selected 'observation days', observations will be conducted by the research team, and regular semi-structured interviews will be conducted with the teachers, parents, and where possible, the children themselves (using engagement metrics like the Inclusion of Other in Self task and Social-Relational Interviews[14]), to understand how the robot impacts the school dynamics (both positively and potentially negatively).

The task will be jointly supervised with local colleague and expert Dr.Nigel Newbutt, who has a long track record of working with special needs schools.

T5.2 – A robot companion to support isolated children during their hospital stay

The second experiment will take place within the paediatric ward for long-term conditions at the Bristol Children's Hospital. The ward has 8 beds, with children staying from a few weeks to several years. Over the course of the one-year deployment, we expect the robot to interact with about 30 children, their parents, and the hospital staff (nurses, doctors).

Similar to the first experiment, we will be using a *mutual shaping* approach[71] to design the role of the robot with the different stakeholders (nurses, doctors, parents, children), in order to experimentally investigate how a social robot can support hospitalised children with long-term conditions. The robot's role will revolve around facilitating social interactions between (possibly socially isolated) children, by fostering playful interaction within the paediatric ward.

This second experiment complements the first one by evidencing the commonalities and divergences in terms of social interactions when the robot is moved to a different environment. While the hospital eco-system is comparatively smaller that the SEN school one, people 'live' at the ward day and night; it becomes *de facto* the second home of the children, and the children will have more interaction opportunities than at the SEN school (where the robot is shared amongst a larger group). As a consequence, we expect to observe different interaction patterns, with potentially deeper affective engagement between the robot and the other ward's 'inhabitants'. Specific safeguarding measures will be put in place with the hospital team, and resulting observations will feed into the ethical guidelines of T1.1.

Importance and Integration in the scientific landscape

National and International Importance

This research project addresses the questions of how to design socially assistive robots that are both effective autonomous social agent, and useful, acceptable and responsible vis-à-vis their end-users.

Update that section for France/CNRS/Europe/ANITI

These questions are of prime societal importance, and this research closely aligns with the **EPSRC Delivery Plan *Connected Nation* and *Healthy Nation* priorities**. Specifically, the project investigates and will significantly advance the questions of Trustworthy autonomous AI, Multidisciplinary approaches to technology acceptability and Technology for the public good[1].

The project is also closely aligned with UKRI Healthcare Technology Grand Challenge: *Transforming Community Health and Care*[2] by significantly advancing our capabilities in term of socially assistive robotics.

More broadly, and as a multidisciplinary project, **change** relates to several themes of the EPSRC portfolio. The main ones are: *Human-computer interaction* and *Social computing/interactions* within the *Digital Economy* theme, *Assistive technology* within the *Healthcare technology* theme, and *Artificial Intelligence* and *Robotics* within the Engineering theme.

From an academic perspective, the UK and the European Union currently enjoy a 2-3 years leadership on research and deployment of socially interactive robots (mainly built through the several large-scale European projects on that topic, which took place over the last decade). The UK did play a key role in several of these projects (eg FP6-Cogniron, FP7-CHRIS, FP7-STRANDS, FP7-Poeticon++), and has built a solid reputation. It is now critical that this expertise is maintained and further developed, as to ensure the future academic leadership of the UK.

In addition, my project would create the opportunity for France and Europe to establish themselves at the forefront of the emerging research on the complex ethical questions arising from the development of social robots. Indeed, my research will significantly contribute to the pressing issues around Responsible AI applied to robotics: the creation of the High-level Expert Group on Artificial Intelligence by the European Union, and the subsequent release in 2019 of their *Ethics guidelines for trustworthy AI*, evidences the importance of framing and defining the adequate policies to enable and support the future development of a safe and trustworthy AI. It however does not address any of the emerging challenges raised by social robots.

My work will in effect pave the way for similar guidelines to be extended to social robotics, eg, *embodied, physical* AI. In line with the UK's strong societal values, the task T1.1, which continues throughout the project, will specifically address and frame the ethical underpinnings of social robots and deliver the guidelines that we need to inform our future policies on social robotics. Combined with beyond-state-of-the-art technological developments, **this research programme will make a major contribution in securing a safe and responsible digital future in France, the European Union, and beyond**.

[1] EPSRC Delivery Plan 2019: https://epsrc.ukri.org/about/plans/dp2019/

[2] https://epsrc.ukri.org/research/ourportfolio/themes/healthcaretechnologies/strategy/grandchallenges/

Interdisciplinary nature of the research programme

change paves the way for a better understanding of the societal challenges raised by the rapid development of AI and robotics. Grounded in both the psycho-social literature of human cognition, and the latest technological advances in artificial cognition and human-robot interaction, the project delivers major conceptual, technical and experimental contributions across several fields: AI, ethics, sociology of technology, intelligent robotics, learning technology. As such, **change builds bridges across multiple disciplinary boundaries**.

change delivers this programme by building on a range of multidisciplinary methods, including user-centered design; ethnographic and sociological investigation; expressive non-verbal communication, including dance and puppetering; embodied cognition; symbolic AI; neural nets and sub-symbolic AI; interactive machine learning.

Accordingly, the project builds on a **strong interdisciplinary team**: the post-docs directly recruited on **change** will have backgrounds in sociology of technology (PD1), cognitive modeling (PD2), machine learning (PD3), cognitive robotics (PD4). Additional expertise will be recruited to provide specific support: the **change** Ethics Advisory Board will contribute expertise to guide the work on ethics; Dr. Newbutt will provide expertise in learning technologies and cognitive impairment; Dr. Meckin will provide expertise in sound-based expressive communication; the WeTheCurious science centre will provide training in large-scale public engagement; the Bristol Children's hospital will bring the required expertise in working with young patients; the RustySquid company will provide expertise in expressive arts and puppetering.

Integration with the local research landscape

TODO, in particular connections to ANITI

- verbal behaviours -> collaboration within ANITI? - collaboration with Rafaelle
- experimental work: partnerships/institution in Toulouse

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