Modelling a bio-inspired architecture for Joint Action in human-robot interaction

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Keywords. Human-robot interaction, Joint Action, Joint Attention, Bio-inspired modeling, Neural robotics, Social cognition.

CONTEXT AND STATE OF THE ART

Social robotics is a multidisciplinary field dedicated to the study of robots that are able to interact and communicate among themselves, with humans, and with the environment, within the social and cultural structure attached to its role. In recent decades, the interest for social robots has increased considerably with applications in healthcare, education, assistance, and entertainment to mention a few. Although state of the art platforms have become more accessible and include diverse sensory and motor capabilities for engaging in interaction with humans, these robots generally perform poorly in social behavior when compared to the level of sophistication observed in humans, so significant challenges are faced in ensuring smooth interactions and maintaining human engagement [Belhassein et al. (2022)].

In this context, this project focuses on modeling intuitive forms of human-robot social interaction. These are situations based on rudimentary cognitive skills (e.g. gaze tracking, imitation, attentional sharing, working memory), in which action and decision-making emerge as hermeneutic processes in face-to-face interaction, which can be studied as a dynamical system. Thereby, the theoretical perspective adopted departs from traditional cognitivist approaches in artificial intelligence, and is situated within the scope of 4E cognition [Newen et al. (2018)] and *interaction theory* [Gallagher (2008)] research.

In particular, this project is interested in the study of *joint action*, which is according to [Fiebich and Gallagher (2013)] a complex form of social interaction characterized by the following three elements: a) a shared intention (i.e. aiming for a common goal), b) common knowledge of aiming for the same goal, and c) participation in cooperative patterns of behavior.

In the field of HRI, [Vesper et al. (2010)] proposed a minimal and modular architectural description of the types of dedicated processes enabling joint action. Inspired by this research, the main objective of this project is to propose an architectural model of joint action studied as a dynamical system for representing interaction context in HRI, allowing decision-making or behavior control control (e.g. action rhythmicity, synchronization with the human). Such integration will be pursued from the perspective of *free energy principle* theory, through the concept of *active inference* [Friston et al. (2013)] [Allen and Friston (2018)].

RELEVANCE, ORIGINALITY AND OBJECTIVES

This research project aims at studying the dynamics of joint action in human-robot interaction (HRI) through mathematical modeling, simulations, multi-scale signal processing and prototyping human-robot interaction experiments. Therefore, the main objective of the project is the proposal of an information fusion architecture allowing to represent and track in real time joint action context in HRI. This project can contribute to improving the quality of interaction in HRI. Given the foreseen intuitive nature of interaction, it can also contribute to the development of methods to study HRI with participants having particular psychological conditions (e.g. autism spectrum disorder, post-stroke rehabilitation, or psychopathological conditions such as schizophrenia), and to the development of several applications in HRI (educational, assistance, recreational, among others).

METHODOLOGY

Interaction scenario. Based on the literature, the first phase of the project will consist in proposing an intuitive HRI scenario eliciting joint action between the partners. Ideally, this activity will take the form of a fun game, capable of inducing human engagement.

Mathematical modeling. The second phase of the project will aim at the construction of the real-time interaction model from the definition of the data model. Several bio-inspired neural network architectures can be considered to develop the interaction model. Whitin *dynamic neural fields* theory research [Amari (1977)], previous works have considered two aspects directly related to the problem under study, such as modeling attention (at the individual [Chame et at. (2024)] and joint level [Chame et at. (2023)]), and motivation according to self-determination theory [Chame et al. (2019)]. Variational models could also be considered, based on the concept of *active inference* from free energy principle theory (e.g. [Chame and Tani (2020)], [Chame et al. (2020)]).

Experiment prototyping. Several sources of data could be considered in order to provide data to the interaction model, such that: behavioral (e.g. monitoring of position, direction of gaze), electrophysiological (e.g. electromyography, electroencephalogram), and data captured from the robot (proprioceptive and exteroceptive sensors). Ideally, the interaction prototype will consist of a distributed system, integrated to the Robot Operating System (ROS) middleware, and programmed in Python or C++.

Robotic platforms. Several robots are available, including: iCub (IIT), G1 (Unitree Robotics), Tiago (Pal Robotics), Panda (Franka), Pepper (Softbank Robotics), Furhat (Furhat Robotics).

SUPERVISION AND COLLABORATIONS

The thesis will take place at LORIA (Neurorhythms team). A collaboration with Dr Rachid Alami, member of LAAS-CNRS (RobotS and InteractionS - RIS) is envisaged for the experimental phase. The expertise of LORIA will be particularly required for the modeling and simulation aspects, in particular for the modeling of the biologically inspired interaction. While the expertise of LAAS-CNRS will be requested in the experimental phase.

This project is also situated in an international collaboration agreement between the Kyushu Institute of Technology (Kyutech), notably the lab Human and Social Intelligence Systems from Kitakyushu, Japan, and the University of Lorraine / LORIA-CNRS. Hence, PhD students' exchange and short international stays are foreseen between the participant institutions.

PROJECT DETAILS

- **Dates**: from September 2025 to August 2028.
- **Duration**: 36 months.
- **Laboratory:** LORIA-CNRS. *Campus Scientifique, 615 Rue du Jardin-Botanique, 54506 Vandœuvre-lès-Nancy, France*.
- **Department:** Complex Systems, Artificial Intelligence and Robotics.
- **Salary**: 2.200 € / month (gross salary)

PROFILE

- Equivalent degree to a French Master II diploma in robotics, computer science, mathematical modeling or cognitive science.
- Deep research interest in human-robot interaction, embodiment, cognitive sciences and bio-inspired modeling.
- Programming skills in Python language (skills in C++ would be a plus).
- Notions of classical geometric modeling and behavior regulation in robotics would be a plus.
- Level of French or English required: at least intermediate level. You can speak the language understandably, coherently and confidently on everyday topics that are familiar to you.

HOW TO APPLY

As soon as possible, and **before the 2nd of may 2025**, please send your application pack including a motivation letter, CV and the most recent transcript of your academic records to Prof. Hendry Ferreira Chame at the e-mail address hendry.ferreira-chame@loria.fr. In case your candidature is retained, you must apply online on the ADUM website. Please note that the latest is compulsory for your application to be officially taken into account.

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