Human-Robot Teaming: Perspective on Analysis and Implementation Issues

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Abstract. Interaction in a human-robot team in a changing environment is a big challenge. Several essential aspects that deserve investigation are at the base for efficient interactions. Among them the ability to produce a self-model and to apply elements from the theory of mind. This case is much more cumbersome than just implementing a system in which the various parts have to co-operate and collaborate to achieve a common goal. In the human-robot team, some factors that cannot be known before the execution phase intervene. Our goal is to investigate how a human-human team works and replicate it on the robot by defining a new cognitive architecture which attempts to model all the involved issues. This means enabling the robot with the capability to understand the world around, itself and the other, human or robot as well. In this paper, we present the first step towards the creation of a multi-agent architecture to realize human-robot teaming interaction.

1 Introduction

The long-term research goal of the described research focuses on the analysis and development of teams where humans and robots are mates, and they collaborate at the same level in a human-like fashion.

A team member, first and foremost, knows the overall goal of the team. She knows what she wants to do. Hence, she intentionally decides which purpose to commit. She is also aware of what she can do, i.e., of her capabilities; accordingly, she selects the goals she can reach and the corresponding plan of actions.

A team member is also aware of the surrounding environment: she can associate any new element in the situation with the content of her knowledge base. A team member owns a knowledge base that includes a large number of items; only a few of them are of interest for what she was doing. A team member can communicate with the other teammates to update her knowledge base on the environment. A teammate explicitly or implicitly delegates action to other mates; she asks how to do something she is not able to do. She observes what other members are doing and, if the case, she anticipates actions or cooperates with other teammates.

She observes what the other teammates are doing and decides what to do, and whether to do something by her emotional and stress state, on the trust level she has on the other teammates and herself. A team member understands if the operative condition for pursuing actual objectives changes. In this case, she can re-plan or create a new plan from experience. She can explain to the other team members what she is doing and why and, if the case, why she is not able to do something. Finally, she learns from experiences and stores all the information about the continuous changing world.

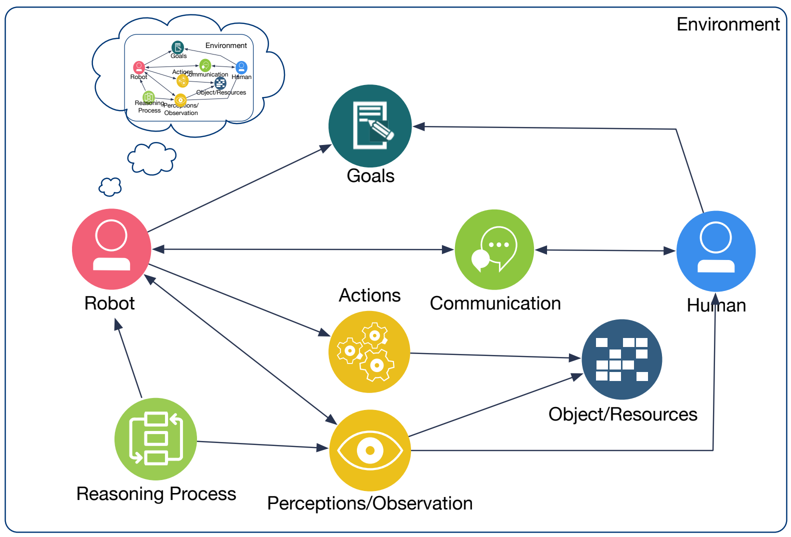

Fig. 1. Human-Robot teaming scenario in an environment composed of cognitive agents, objects and resources.

During each one of the previous activities, each team member performs different processes concerning vision, speech understanding, learning, state of mind, decision making that account for a description of the world in real time.

Taking into account these aspects in human-robot teaming means to analyze and implement the processes of: *(i)* knowledge acquisition and representation, including memory management; *(ii)* representation of the external environment; *(iii)* plans selection and creation; *(iv)* learning. Moreover, we take into account a simplified process of introspection to allow the robot mate to be aware of itself and its capabilities.

Fig. 1 sketches this scenario. The environment the robot is plunged in is made of humans that interact/communicate with him and resources to use and to act on. The robot, so as human, can reason about perceptions and observations and about the situation he has in his mind of the world around and himself.

This paper focus on knowledge and we propose an agent-oriented architecture for robot knowledge acquisition and representation.

2 From the Standard Model of Mind to the BDI architecture

In [9], authors propose a standard model of mind. The standard model is intended to be a reference point and a driving theoretical approach for developing and implementing cognitive architectures in several research areas. The core of the standard model is the cognitive cycle - perception, working memory, and action - that allows realizing complex behaviors.

Taking inspiration from the standard model of mind we hypothesize a set of modules of a cognitive architecture for a robot teammate [6]: the *knowledge* and *memory* module, the *perception module*, the *communication system* and the *reasoner* that allows the robot to choose by taking into account the retrieved data. The behavior of the robot is deliberated by the *planner* module which interacts with the context in which the robot is plunged. Thus, we got inspiration from the standard model to create an agent-oriented architecture for robot knowledge acquisition and representation.

We employ the agent-oriented technology and the BDI paradigm for knowledge representation and acquisition with a robot able to generate a simplified model of introspection. Fig. 2 illustrates the agent architecture we propose; here we employ the multi-agent systems paradigm to implement each *module* as an *agent* which interacts with all the others for achieving its objectives and at the same time the overall system objective.

Agents employ inputs from the environment perception and from memory for choosing which action to execute. The agent decides actions to perform after a reasoning process, and it completes and continuously observes the results of its work on the environment. To integrate self-consciousness aspects in the architecture, we use specific agents for decision and memory modules.

We represent knowledge by including the objects in the environment, the goals to be pursued and the motivations to execute a specific action. The knowledge representation allows us considering the situation as composed of objects, other cognitive agents and also the agent inner state (see Fig. 1). All these elements are parts of the agent's self-consciousness that triggers the agent decision process. Continuous observation and perception allow the agent to update knowledge during the execution phase [5].

We model and update the agent knowledge base at runtime. Knowledge is necessary for the decision process and for communicating and interacting with other agents. Besides, knowledge representation lets the agent be able to understand what it does not know.

We employ multi-agent theoretical and technological aspects to implement the reasoning cycle at the core of the decision process. We also employ the *Belief-Desire-Intention model* (BDI) [11] to describe the reasoning process of each agent. We employ Jason [2] as a programming language that implements

BDI agents. The decision-making model underpinning BDI systems is known as *practical reasoning*, a reasoning process to do actions, where agents' desires and agents' beliefs supply the relevant factor [3]. Practical reasoning consists of the activities of deliberation and intentions and means-ends reasoning.

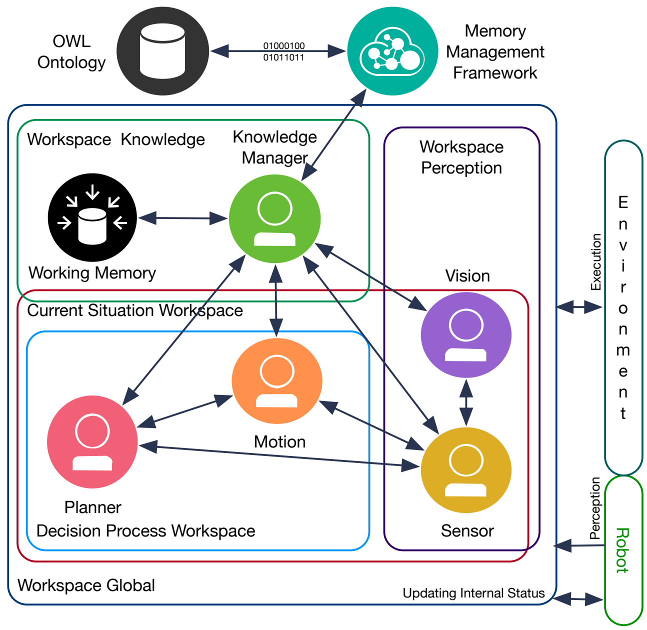

Fig. 2. BDI multi-agent architecture for human-robot teaming interaction.

In our approach (Fig. 2), each agent is orchestrated, regarding knowledge and memory access, by the *controller* agent *Knowledge Manager*, implementing the planning and reasoning functions. The module ensures the knowledge necessary to allow collaboration among the agents.

Across the extended reasoning cycle, each agent employs its experience to perform the action and to reason on the situation by analyzing inner states and external perceptions. Once the plan selects a response, it is executed by changing the state of the environment and also the internal state of the robot.

With the aim to endow the robot with self-consciousness abilities, we model tasks through sets of beliefs and intentions. The robot can identify failures in executable plans and actions and to explain and justify the incompleteness of its performances. Perception and external stimuli are modeled in the knowledge ontology of the robot. When a goal is detected, the related beliefs are generated from the ontology by allowing the robot to select the appropriate plan. Each action modifies the state of the environment and the robot inner state.

Our approach involves knowledge allowing the robot to identify the motivations for which a plan could fail [7][4]. We keep a separation between the reasoning component and the environmental managing tools; these two components are implemented respectively by Jason [2] and CArtAgO [12]. Jason implements the BDI agents, and it manages the interactions among them, whereas CArtAgO manages the interaction with all the resources and the objects in the environment. Beyond simple actions, each plan involves *context variables* representing the preconditions to be satisfied to perform the steps of the plan. When one of these variables, instantiated by the perception module, does not meet the prerequisites (i.e., it has an unexpected value, or it is false), then the plan execution fails, and the robot can infer the motivations of the failure, thus implementing a simple form of self-consciousness. The motives of failures are then sent to the other members of the team which may solve the situation by enforcing collaboration.

3 Conclusions

In this paper we propose a cognitive architecture for human-robot teaming interactions in changing and partially known environment. An efficient interaction may be performed on the basis of several factors among which we stress the role of self-modeling and theory of mind that we claim to be a way for resembling human-human interactions.

We also propose to use of the multi-agent system paradigm for filling the gap between design and system level. The power of BDI paradigm let us to implement an high modular framework that may be scaled by simply adding agents to the whole system. Indeed, the strength of our approach is the extension of the BDI reasoning cycle, we did not perform any change but simply added portion of Jason code for implementing the modules of the architecture.

The part of the architecture we detail in this paper is related to the knowledge management and is inspired by a well established standard model of mind such as to several cognitive architectures of the literature [1][8][10].

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