In which context are we interacting? A Context Reasoner for interactive and social robots.

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***Abstract*— To effectively interact with others, one has to understand the context in which the interaction takes place. This understanding allows us to know how to act, how to interpret others' actions, and thus how to react. In this paper, we first present a basic formalism of the notion of context through the use of an ontology in order to integrate the new piece of information into a robot knowledge base in a coherent way. From there, we present a Context Reasoner integrated into the robot's knowledge base system allowing it to identify the context in which it is interacting but also to identify the current context of the surrounding humans. The effectiveness of this Context Reasoner and its underlying representation of the context is demonstrated in a simulated but dynamic situation where a robot observes an interaction between two humans.**

This work is an initial step to endow robots with the ability to understand the nature of interactions. We think that this basis will help to develop higher decisional processes able to adapt the robot's behaviors depending on the nature of the interaction.

***Index Terms*— Human-robot interaction, context awareness, social interaction, social robotics.**

Fig. 1. Representation of a situation where two humans interact. Here Bob (at left) is a theater teacher and Alice (at right) is a student. Depending if they play theater or teach, the nature of their interaction will change. This example highlights the fact that even if both humans are involved in several contexts at a time, their interaction will depend on the current context they are active in.

I. Introduction

The notion of context could be generally and intuitively defined in a simplistic way as the set of elements which for a given input of a system will impact its generated output. In social robotics, it could be refined as the set of elements impacting the way the robot should behave in a given situation. To better understand this deceptive simplicity, let us take the example of Fig. 1 with two humans interacting and the robot as a spectator. The man on the left is Bob, a drama teacher and the woman on the right is Alice, a student. Both agents could either play theater or teach. Depending on that, they will not interact in the same way. When they are playing theater, both agents have a role, theater actor for example, and could speak as friends or at the contrary enemies. In this situation, there is no more teacher or student. In the inverse, when they are teaching, a hierarchy exists between them. In some cultures, the student will have to adapt her language to speak with her teacher. With this simple example, we can thus see that two contexts exist at the same time but that each agent is active in one at a time and that its behavior will depend on it.

To continue with the importance but also the impact of these contexts, let us consider a pen in our example. When Bob is teaching, the pen is just a simple pen to write. However, when Bob is playing theater, this pen could be interpreted as a magic wand. Bob will thus not use the same object in the same way depending on the context he is active in. To go further, it could go the same for the locations. The left of the scene could be a garden and the right a castle while in the context of the course, the scene is just a scene without additional meaning.

To be anchored in more everyday-like situations, we could easily imagine the same effects in a museum where a painting could not be touched or moved while in your home you can. The same holds also when you meet the same person at his office or in the street, or when an object is in a store or in a house.

Through our example, we can see the importance to understand the context in which the robot interacts with others but also the context in which the others are involved to adapt the robot's behaviors and also to understand the meaning of the other's behaviors. With this paper, we aim at doing a first step toward this goal with two principal contributions: a basic **formalism of the notion of context** through the use of an ontology and a **Context Reasoner** integrated into the robot's knowledge base system allowing it to identify the context in which it is interacting but also to identify the current context of the surrounding humans.

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In §II we briefly discuss related work and how the notion of context is commonly used without precise definition. A basic formalism of the notion of context is then presented in §III before an explanation of the reasoning mechanism allowing the robot to determine the active context of each agent. Finally, §V presents results on a simulated but dynamic situation based on the theater course example and §VI concludes the paper.

II. Related Work

In robotics and especially in Human-Robot Interaction, the notion of context is often used but it can describe different underlying notions. In [1], the notion of context is used to talk about the displayed elements on a touchscreen. It could be compared to the use in [2] where this notion of context here corresponds to the surrounding physical elements of the environment to perform Referring Expression Generation. In addition to elements of the environment, [3] uses the position and orientation of the surrounding humans to detect groups of interaction and thus local social contexts.

Not focussing on the present elements and their location, [4] and [5] integrate qualities of the environment like the luminosity to adapt a perception algorithm, or the pressure and temperature to infer a device location.

Where the previous works focus on the environment, [6] and [7] aim at identifying the context of interaction through the detection of humans' actions. In other words, they use the notion of context as the performed activities.

In [8], the authors use another definition of the context where it is a set of facts they assume the robot and the human to already share during the interaction. In a Referring Expression Generation task, this allows the robot to not speak about these facts and thus ease communication. Even if it is not restricted to this use, at the difference of others it allows to integrate a kind of history in the notion of context.

Some projects like FrameNet [9] or ConceptNet [10] propose the use of knowledge graphs to extract information about a word or a phrase. To this end, they rely on common links between concepts in a sentence as the notion of context to understand them. An extension of FrameNet, presented in [11], proposes to take into account not only textual data but also visual data to provide more information about the current context. These works highlight the need for context to better understand a given situation.

Trying to extract the notion of context from all these works, we could say that it is composed of an environmental part which takes into account the objects' poses and natures as well as the humans' poses [1], [2], [3], and physical quantities of the environment [4], [5]. Activities could be another part of this context, taking into account the agents' actions [6], [7].

All these different uses of the concept of context highlight that the community does not have a unique definition of this notion and neither a unique way to use it. While all of the used notions are encompassed in the global notion of context, this latter is wider. This assertion is confirmed by surveys on context and some proposals of definitions.

Based on literature, Bisgaard et al. [12] identify two possible definitions. The first definition splits context into four categories: Location, Identity, Activity, and Time, and the second into six categories: User, Social Environnement, Task, Condition, Infrastructure, and Location. In this work, it's interesting to take into account the splits in the notion of context. For us, interesting parts can be Environment, Activity/Task, and Social. Without concrete implementations, this work is hard to apply.

[13] proposes to think of the notion of context as a holistic context which includes social and cultural aspects. To do so, they define three perspectives to take into account context in human-robot interaction. In this case, the social part is the main subject and helps to include it in HRI. This definition is very precise on the human aspect with the consideration of emotions and human expressions. However, this work does not take into account the activity and the environment.

Nikolakis et al. [14] work on a definition of context based on the spatial and temporal aspects of an interaction. For this, they based their definition on three categories: events (trigger), temporal ontology and spatial ontology. This work illustrates that the use of ontology is adapted to compute during interaction a notion of context for the robot. Moreover the temporal aspect here is interesting to take into account the history of the interactions. The social aspect is missing here to be used as it is.

Even if all these works want to propose a global definition of the notion of context, we find a lot of different definitions, each focusing on a specific aspect of this notion. None of these definitions is really usable for us because we need, in the same definition, the social aspect of an interaction but also the environment and the activity around this interaction. Our context representation must be usable during the interaction in order to integrate the decisional processes. That is why with this paper we want to propose a representation of the context for human-robot interaction through the use of an ontology.

III. Representing a context

To represent both the notion of context and to represent instantiations of contexts, we have chosen to use ontologies. Ontologies are more and more commonly used in robotics to represent agents' knowledge as they allow for a formalization of knowledge while allowing a representation of an instantiated situation. In addition, ontologies are suitable to perform reasoning to extract new knowledge from existing. An ontology can be defined as a set of classes representing general concepts and inheritance links between them, a set of individuals being instances of classes, and a set of properties allowing to link individuals together to create relations. Relations are in the form of triplets `<S, P, O>` where S and O are individuals and respectively the subject and object of the relation, and P is the predicate of the relation, being a property.

First of all, we represent the notion of context as a class of the ontology. This class is refined into four parts to classify the different kinds of contexts: the environmental context, the

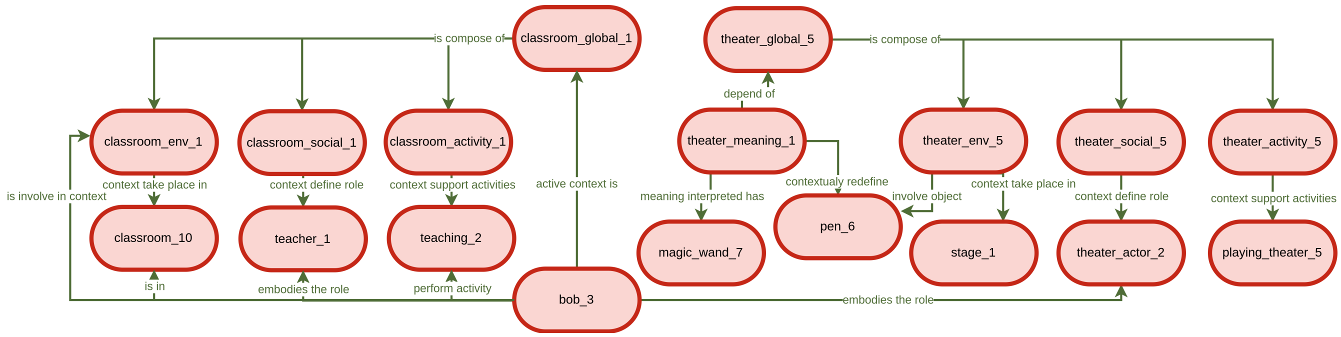

Fig. 2. Representation of the ontology used in our example. There are two possible global contexts, the classroom and theater. Two agents are involved in these two contexts, Alice and Bob, but at each time only one of the contexts can be active. With a focus on Bob, we can see all relations between contexts and this agent.

social context, the activity context, and the global context. The **environmental** context will be used to represent the localization where the context holds, the implied entities, or physical qualities like the luminosity used in [4]. The **activity** context will be used to represent the high-level activities or tasks realized in this context. We could also represent the activities' goals or the history of the actions. The **social** context will be used to represent the roles of the agents in a given context and could also be used to represent social rules for example. Finally, the **global** context will be used to gather the three kinds of context presented previously when they hold.

Here we do not propose any class definitions to represent the entities of the environment (i.e. the agents, objects, locations, etc) as they does not impact the context representation. Nevertheless, to represent the context dependent meanings, we introduce the class `MeaningInContext` which can be refined into `ObjectMeaningInContext` and `LocationMeaningInContext`. These classes will be used as reification of relations [15] allowing to represent links between more than two individuals.

A simplified use of these classes is presented in Fig. 2 with properties not detailed in this paper. This instantiation is the representation of the contexts existing in our example with a focus on the agent Bob. We can note here the representation of two contexts (i.e. two global contexts), each owning an environmental, social, and activity context. However, a global context is not mandatory to instantiate all three sub-contexts. Here the activity contexts are only defined by one activity which can be performed in these contexts but they could be enriched with the activity goal or even a Hierarchical Task Network rather than an activity. Regarding the environmental contexts, they are composed of a single location and for the theater context an involved object. Nevertheless, one could add the representation of physical quality like the luminosity used in [4] if needed. Concerning the social contexts, we focus on the agent's roles but we could add social rules for example.

Taking a closer look at the theater context (i.e. `theater_global_5`), one can note that it is linked to a context-dependent meaning individual. As explained earlier, this entity is used as a relation reification to link an object (here a pen) to a given meaning in a given context. Indeed, the same object could have different meanings in different contexts. Here, being used in the theater context, this pen should be considered as another individual being a magical wand. Knowing the context in which an agent is active, thanks to this representation the robot could thus re-interpret the nature of an individual.

To represent the agents' active context, a dedicated property is used. Here we can see that Bob has for active context the classroom context. This relation has not to be mismatched with the relation that an agent is involved in a context. The fact that an agent is involved in a context represents the notion that the agent is in a location where a context exists but this does not necessarily mean that the agent is active in it.

IV. DETERMINING THE ACTIVE CONTEXT

Now that we are able to represent contexts in an ontology, our goal is to give the robot an understanding of the current active context of each agent. First of all, we assume that an agent is automatically implied in a context if he is at the location where a context holds. To do so we used chain axioms in the ontology stating that if an agent is at a location which is implied in a context, then the agent is implied in this context. In our running example, if Bob goes on the stage, as the context `theater_global_5` exists on the stage, then Bob is implied in this context. However, this does not mean that he is active in this context. Since the stage is in the classroom, then Bob is still implied in the context `classroom_global_1`. In this way, an agent can be implied in several contexts at a time. We thus have to find the context in which the agent is active among the ones he is involved in.

To implement our Context Reasoner, we have chosen the software Ontologenius [16]. It maintains the robot's semantic knowledge base allowing to dynamically modify it while keeping it continuously consistent thanks to a set of reasoners. Ontologenius has been chosen since these reasoners are in the form of plugins allowing us to easily integrate our own reasoning mechanism. Three types of reasoners are available in Ontologenius:

1) Pre-reasoner: runs before calculating the response to a query.
2) Post-reasoner: runs each time the knowledge base is modified.
3) Periodical reasoner: runs at a fixed period defined by Ontologenius.

As we want to detect a switch of active context based on modifications related to the agents, our Context Reasoner is implemented as a post-reasoner. It is thus activated each time the knowledge base is modified by external processes like the robot's perception system. More precisely, since we assume for now that the contexts already exist in the knowledge base, we only activate the reasoning process when the modifications are related to an agent. This means that if, for example, an agent changes of location, the reasoner will be run to check if this modification has an impact on the agent's active context.

First of all, we verify if the activity performed by the agent is applicable in the contexts he is involved in. If the agent holds an activity in the ontology and that a context also holds an activity which is different and which is not a refinement of the agent activity, this context is directly discarded. If a context does not imply any activity or if the agent has no current activity, the reasoner cannot discard the context as the possibly active one.

If after this first step, several contexts still hold as the possibly active one, we do the same as for the activity with the roles. If both the agent and the context hold roles that mismatch and are not included, the studied context is discarded. Finally, if several contexts still hold, we select one with the more precise location. In our example, if Bob goes on the stage, he will be located on the stage but also in the classroom. However, since the stage is described as being in the classroom, the stage is the more precise location.

If at any moment during the reasoning process all the contexts in which the agent is involved are discarded to be the active context, the reasoner creates a new context having as a location and activity the agent ones.

V. Use-case scenario

To illustrate the use of this reasoner, let's take the example described before with Bob and Alice. Now in this example, Bob goes on stage. Consequently, a new relation is created in the ontology and the reasoner is triggered. Because of the chained axiom and the existance of a context linked to the stage, Bob is automatically represented as involved in the theater context. Nevertheless, because his activity does not correspond to the one performed in this context, his active context is not modified (i.e. Bob is still in the teaching context).

After this, let's now assume that Bob stops teaching and starts to play theater. With this, his activity change and a mismatch with the one of his on-going active context appears. The reasoner will try to resolve this mismatch. Here the activity of playing theater is not allowed in the classroom context but is in theater context where Bob is involved due to his location. With this match between the activity realised by Bob and the activity allowed in a context that involves Bob, the reasoner switch Bob's current active context from the one of the classroom to the one of the theater. Now Alice can interact with Bob as a friend or something else because both are in the theater context.

Take now the case where we lose the information of Bob's activity or we cannot obtain this information. In this case, the relation between Bob and activities in the ontologies doesn't exist. Here without this relation, Bob keeps as current active context (the theater context) due to his location. Indeed the stage is a more precise location because it is included in the classroom. The reasoner maintains Bob in the more precise context here, the theater context.

After this Bob will go off the stage, at this moment his location changes from the stage to the classroom so he is no longer involved in the theater context because his location doesn't match. That's why Bob has now as an active context the context of classroom. This is due to the reasoner which attaches Bob's active context to the classroom context because it's the only context available for Bob in this situation.

This set of examples allows us to illustrate the algorithm behind the reasoner and the fact that all relations aren't needed to keep the active context on an agent.

VI. Conclusion

In the current work, we have presented a context representation in an ontology and a Context Reasoner that is able to determine the active context of an agent using the perceived activity, location, and role of the agent. This work is the first step to obtain robots that can understand the context and use it to react better to our interactions with them. In addition, we have demonstrated the correct behavior of our algorithm using an example, where it has extracted the true active context of each agent in an example where two contexts coexist.

For the moment, activities are only taken into account by single task instead of a set of tasks that create an activity represented in a Hierarchical Task Network. Another limitation is the lack of consideration of chronology which can help to understand and provide a richer context.

In the future, we plan to evolve with more complex cases and integrate this Context Reasoner in a whole robotic system to allow the task planning and the supervision parts of this system to use the knowledge provided by this Reasoner. In addition, we plan to implement a context refiner aiming to automatically represent contexts in the knowledge base using the current perceptions of the environment, without knowing it previously.

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