Use of Ontology to Model the Perception of the Environment by a Humanoid Robot

Helio Azevedo[1], **José Pedro Ribeiro Belo**[2], **Isaque E. de Souza**[1], **Roseli A. F. Romero**[2]

[1]Center for Information Technology Renato Archer (CTI)
Campinas – SP – Brazil

[2]University of São Paulo (USP)
São Carlos – SP – Brazil

{helio.azevedo,isaque.souza}@cti.gov.br

rafrance@icmc.usp.br, josepedroribeirobelo@usp.br

Abstract. *Social robotics is a research area that aims to develop models that allow robots and humans to interact naturally. One of the factors that compromises the evolution of social robotics is the difficulty in integrating cognitive and robotic systems, mainly due to the volume and complexity of the information existing in a dynamic environment. In this work, we are proposing an ontology, named OntPercept, for formalize the communication between the cognitive and robotic systems. Thanks to this ontology is possible to model the environment perception using the information captured by the sensors present in the robotic system. It will be shown that OntPercept simplifies the development, reproduction and comparison of experiments associated with social robotics.*

1. Introduction

Robots are capable of millimeter-precision movements by performing repetitive tasks operating in structured environments where objects are in known and predictable locations. Thus, it is not surprising that robots are used more in manufacturing operations, such as painting and welding, instead of operations where, diversity of actions, direct contact with humans and changes in the environment are part of the system requirements.

Despite its complexity, the demand for the use of robotic agents in environments other than manufacturing is a necessity of modern society. The *World Robotics 2017* report [IFR 2017] indicates a cumulative volume of around 27 billion U.S. dollars in the service robots sales forecast for the 2018-2020 biennium. This upward trend in the use of service robots requires a growth in research involving *Human-Robot Interaction* (HRI), in particular in the sub-area defined by Fong [Fong et al. 2003] as *Socially Interactive Robots* (SIR) or "Social Robotics", the term used in this article.

This work contributes in this process by developing an environment directed to social robotics involving the areas of ontology, HRI and cognitive science. For this, in our previous work, an architecture, named "Cognitive Model Development Environment (CMDE)" was proposed [Azevedo et al. 2017b] [Azevedo et al. 2017a]. The aim of CMDE was to accelerate the development of social robotic systems establishing a clear communication between the cognitive system and the robotic system responsible for generating the environment perception (in Fig. 1).

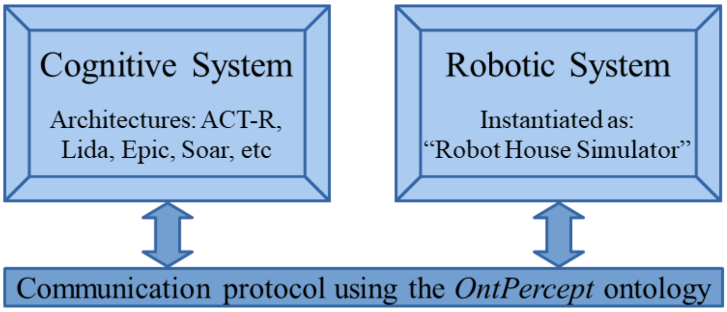

Figure 1. The CMDE architecture.

An important component of CMDE is the *OntPercept* ontology, that is responsible for formalizing the communication of the environment perception data from Cognitive to Robotic System. Since its first version in 2017 [1], two were the focus of evolution: optimization of objects access (bypassing performance issues of the producer-consumer information exchange model used with the triple store) and inclusion of the memory concept as a resource for robot long term interaction.

The organization of this article follows the steps used to create an ontology. The hierarchy, concepts and properties of the *OntPercept* are detailed in Section 2. In Section 3 is presented the test environment. In Section 4, the conclusion of this work is presented.

2. The *OntPercept* ontology

The ontology presented in this article emphasizes the need to formalize the information that transits between the processing nodes defined by CMDE architecture (Fig. 1). The idea is to enable the cognitive system to receive perception information from the environment with a high level of cognition.

The development of an ontology is accelerated by the use of appropriate modeling methodologies and tools. This work uses the *Ontology Development 101* methodology [Noy and Mcguinness 2001], which proposes seven steps for the construction of an ontology. In Table 1, the methodology steps instantiated in the context of *OntPercept* are shown. The Protégé editor [Protégé 2020] was selected to model *OntPercept*. After modeling, it is possible to identify anomalies using the Pellet reasoner [Stardog-Union 2017] tool, available as a plugin in the Protégé editor.

Table 1. Steps of the "Ontology Development 101" methodology

Step	Comments
1. Domain and Scope	Domain: social robotics, Scope: environment perception.
2. Reuse	SUMO and IEEE 1872-2015.
3. Concepts	Model for perception info.
4. Hierarchy	Combines top-down with bottom-up strategies.
5. Properties	Directly derived from robotic sensor data.
6. Facets	Refines the properties by defining: type, cardinality, and domain.
7. Instances	The instances are created by the environment perception.

[1] Initially the ontology was called *OntSense*, the name was changed to *ontPercept* to distance itself from the sensor notion and reflect the essence of this ontology: environment perception.

2.1. The *OntPercept* Development

An important feature of the *OntPercept* is adherence to the standards of international organizations with the aim of minimizing effort and providing a better dissemination of the results. In Fig. 2, the relationship with top-level ontologies is presented as well as the main concepts of the new ontology. The upper block of this figure presents the top ontologies, namely: SUMO [Pease 2019]and IEEE 1872/2015 [IEEE, R&A Society 2015]. namely: SUMO [Pease 2019], which provides a high-level view of existing objects in the world, and IEEE 1872/2015 [IEEE, R&A Society 2015], which provides specific objects associated with robotics and automation.

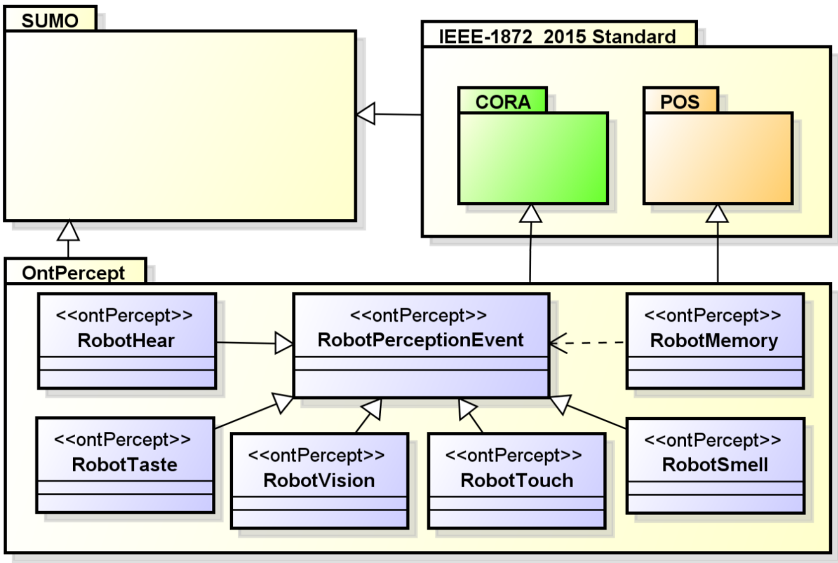

Figure 2. The *OntPercept* and two top level ontologies: SUMO and IEEE-1872.

In the lower block, the key concepts of *OntPercept* are presented. The concept *OntPercept:RobotPerceptionEvent* represents the super class used as a basis for defining the environment perception. All other concepts derive or maintain a relationship with this super class. Next, we will explore the *OntPercept:RobotMemory* concept. Details of the other concepts can be obtained at [Azevedo 2018].

***OntPercept:RobotMemory* concept:** Although not directly associated with environment perception, the *OntPercept:RobotMemory*[2] concept represents the initial step in the implementation of robotic long-term interaction systems. In this work, information retrieval is associated with the use of retrieval cues[3] stored together with the information content. The idea is to use association mechanisms similar to those used in the memorization process of humans [McLeod 2018]. To achieve this goal, the memory register is stored with information from the environment perception. The memory register is modeled by the *SUMO:Object* and *SUMO:Process* classes. The *SUMO:Object* class roughly corresponds to the class of ordinary objects and the *SUMO:Process* class models the class of things that happen and have temporal parts or stages [Pease 2019] (Fig. 3).

[2]In this work, the term "memory" represents the structures and processes associated with the storage and retrieval of information or experiences.

[3]A retrieval cue is a hint or clue that can help retrieval.

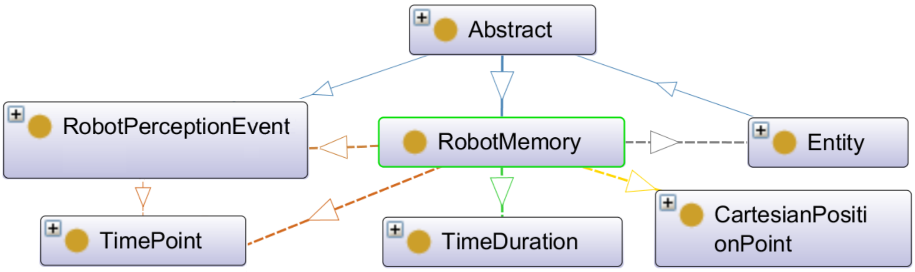

Figure 3. Relationship of *OntPercept:RobotMemory* concept.

Table 2. Properties of *OntPercept:RobotMemory* concept

Property	Description	Values
hasCaptureTime	The instant of memory capture.	Capture instant
hasDuration	The time during which the event exists.	Rational number
hasPerception	A set of perception objects.	RobotPerceptionEvent
hasContents	A *Object* or *Process* to be stored.	Entity class

In Table 2, it can be found the properties of the *OntPercept:RobotMemory* concept. Basically, the core is represented by a relationship with an instance of the *SUMO:Entity* class, which is super class of *SUMO:Object* and *SUMO:Process*. The other relationships represent cues that allow the retrieval of the memory register: capture time, event duration and the sensory environment perception at capture time.

An important memory concept feature is associated with the forgetting process. In humans the action of forgetting information from the *Long Term Memory* (LTM) can be explained using the following theories: interference, retrieval failure and lack of consolidation [McLeod 2018]. The *Interference Theory* states that forgetting occurs because of interference with other records, either by inhibition caused by an earlier record with similar characteristics or by overlapping the old record by the new one. The *Retrieval Failure Theory* states that a given record cannot be recovered because cues (e.g. smell, local, emotion and mood) are not present. In the *Lack of Consolidation Theory*, forgetting occurs due to biological failures in the record storage.

Unfortunately, robot memory is finite, and judicious use of memory is advisable. Two theories mentioned above may assist in the memory management process. The *Interference Theory* can be used to replace one robot's experience with another similar, where the robot has succeeded in its operation. On the other hand, the absence of pointers to the memory register can be used as a catalyst for garbage collector operations in the records, similarly to *Retrieval Failure Theory*. Note that by using ontology to formalize memory operations, axioms can be created to identify these obsolete records. Subsequently, reasoning tools[4] identify these records and triggers actions for their removal.

2.2. Building the *OntPercept* ontology

In Fig. 4, the relationships established between *OntPercept* classes and top-level ontologies are presented. Classes from SUMO are flagged in green and IEEE 1872-2105 in

[4] By reasoning we mean deriving facts that are not explicitly expressed in ontology or knowledge base [Obitko 2007].

blue. As an example, the properties *generateBy*, *hasCaptureTime* and *isSenseOf* associated with the class *OntPercept:RobotPerceptionEvent* represent relationships with top-level ontologies. Finally, it is also worth to mention the class *SUMO:Object* that models the elements present in the environment.

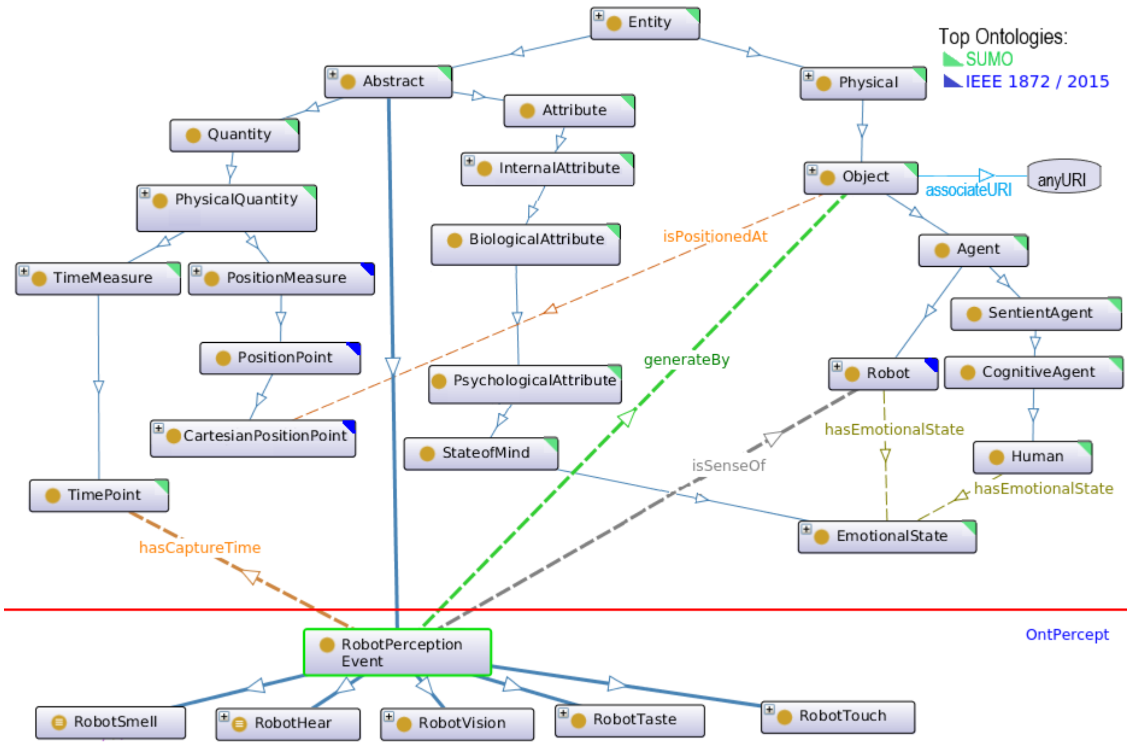

Figure 4. Example of *OntPercept* and top-level ontologies relationships.

2.3. Providing interfaces for *OntPercept*

The final step established by the "Ontology Development 101" methodology involves the generation, storage and retrieval of object instances. The strategy adopted to enable the handling of instances is presented in Fig. 5, with the definition of three processing nodes: *Cognition Node*, responsible for the implementation of the cognitive system, *SPARQL Server Node*, which implements a database with sensory information and *Robotic Agent Node*, which directly controls all sensors and actuators of the robotic agent.

Basically, the robotic agent obtains information from the environment and routes it to the cognitive system using a predefined communication protocol such as REST/HTTP. The cognitive system ("Cognition Node") processes the environment perception information, makes decisions and sends actions to the robotic agent via socket communication.

In order to reduce end-user effort, it was created two APIs to access the "SPARQL Server Node". These APIs provide a simpler interface for using the technologies mentioned here (see Fig. 5). The APIs implement insertion and retrieval operations of perception events captured by the robotic agent.

The use of a *triple store* for sending the environment perception represents a bottleneck in this deployment. In one cycle, dozens of information are stored in the *triple store* by the *Robotic Node* and then, they are read and immediately removed by the *Cognition Node*. In order to optimize this process only information associated with long-term

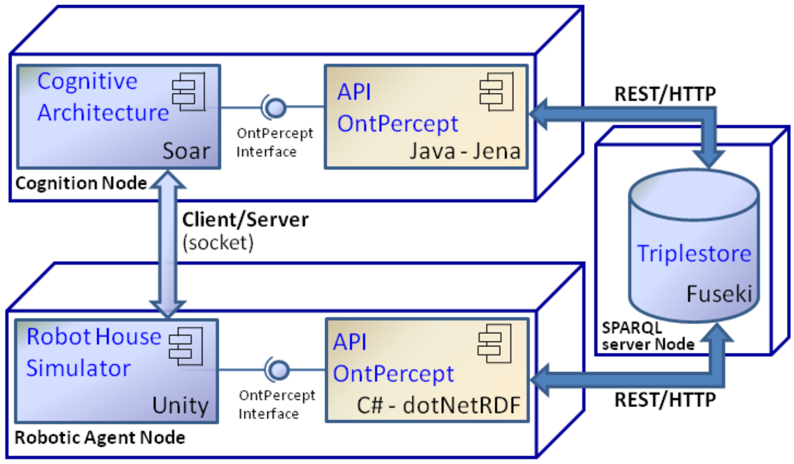

Figure 5. CMDE architecture processing nodes presented as a white box.

memory will be kept in the *triple store*, the other triples will be serialized and sent directly to the *Cognition Node*.

3. Using the Ontology

The test is accomplished by the exercise of the ontology in a controlled environment adhering to CMDE architecture. More specifically, given a usage scenario, the *OntPercept* must offers resources to represent the exchange of perception information between the cognitive and robotic systems.

Robot House Simulator (RHS) [Belo et al. 2017, Belo et al. 2018] was designed to test CMDE architecture and the *OntPercept* ontology. Another element involves the cognitive system that must control the robotic agent present in the simulator. In this instantiation, this control is performed using the Soar cognitive architecture [Laird 2012].

The steps to create an experiment involve: defining the desired behavior for the robotic agent, defining Soar production rules implementing the behavior, and finally, exercising the results in RHS simulator. The execution of a experiment can be visualized in the video available at `https://youtu.be/rPqfQvReXDo`.

4. Conclusion and Future Works

This article proposed an ontology to establish the communication between cognitive and robotic systems. This ontology was incorporated into CMDE architecture and a simulator for social robotics, called "Robot House Simulator" (RHS). All these elements are used together to design, develop and validate systems geared towards social robotics. All configuration items generated in this development are released into GitHub repository (`https://github.com/helioaz/OntPercept`) with the GNU GPL v3.0 license.

The results achieved represent a important step in the development of an integrated environment for the development of cognitive systems with application in social robotics. This framework is constantly evolving and, as such, a catalyst for future proposals, e.g.: inclusion of new elements in *OntPercept*; interface with others cognitive architectures [ACT 2015, Gudwin et al. 2018, Kotseruba et al. 2018]; improve the RHS simulator with new environments, buildings and streets and validation in a real environment.

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