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Extensions to the core ontology for robotics and automation

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ABSTRACT

The working group *Ontologies for Robotics and Automation*, sponsored by the *IEEE Robotics & Automation Society*, recently proposed a Core Ontology for Robotics and Automation (CORA). This ontology was developed to provide an unambiguous definition of core notions of robotics and related topics. It is based on SUMO, a top-level ontology of general concepts, and on ISO 8373:2012 standard, developed by the ISO/TC184/SC2 Working Group, which defines—in natural language—important terms in the domain of Robotics and Automation (R&A). In this paper, we introduce a set of ontologies that complement CORA with notions such as industrial design and positioning. We also introduce updates to CORA in order to provide more ontologically sound representations of autonomy and of robot parts.

1. Introduction

A well-structured *body of knowledge* for robotics and automation (R&A) is a crucial requirement not only for unambiguous communication and reasoning for robots, but also for knowledge and information sharing about robots among humans and for interaction between robots and humans. Recently, such bodies of knowledge have been successfully developed using ontologies. Ontologies are information artifacts that specify in a *formal* and *explicit* way the domain knowledge *shared* by a community [1]. The availability of well-founded methodologies allow us to develop ontologies in a principled way. The artifacts that result from this process ensure mutual agreement among stakeholders, increase the potential for reuse of the knowledge, and promote data integration.

In order to specify and clarify the meaning of the core notions common in R&A, the Working Group (WG) *Ontologies for Robotics and Automation* (ORA), sponsored by the *IEEE Robotics & Automation Society*, has proposed a *Core Ontology for Robotics and Automation* (*CORA*). This ontology is meant to be used by robots and roboticists in tasks that require explicit knowledge about robots, such as robot–robot and robot–human communication, robot design, and integration of data about robots. The aim of the ORA WG is to standardize knowledge representation in the R&A field [2]. Within this broad context, CORA is intended to provide the core conceptual structure that will integrate other specific ontologies developed for the domain of R&A.

CORA has been developed taking into account theories of the discipline of Formal Ontology [3]. In particular, many of our ontological choices were evaluated based on guidelines from known methodologies, such as METHONTOLOGY [4] and OntoClean [5]. Besides that, CORA was developed based on SUMO [6]; a top-level ontology that aims to define the main ontological categories describing the world. Such an approach is new in developing standards in R&A and has the advantage of producing

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a better founded standard, which requires less work to use, maintain and extend.

This work reports the recent developments within the ongoing CORA project, and provides an overview of its current state. The prior version of CORA [7] has been extended, implementing changes in modeling decisions and introducing new concepts and relations. Thus, this paper presents some changes in modelling decisions that have been implemented since the previous version. The major new contributions can be divided into two broad areas. First, we propose CORAX, an ontology that covers concepts too general to be part of CORA, and that are not covered by SUMO. These include knowledge about *design* (as in the case of product design), *physical environment*, *interaction*, and *artificial systems*. Second, we propose extensions and changes to CORA itself, in order to improve its ontological commitment to the domain. We are primarily concerned with representation of *operation modes* and *robot parts*. Finally, we discuss some directions regarding new, yet to be covered topics (such as control and planning).

2. Ontology Engineering

We developed CORA using several ontology tools and frameworks. The main methodology is based on METHONTOLOGY [4], which supports the development of ontologies either from scratch, by reuse, or by re-engineering existing ones. It consists of a set of guidelines about how to carry out the activities identified in the ontology development process, the kinds of techniques that are the most appropriate for each activity, and the resulting products.

We also based many of the underlying *ontological commitments* on *OntoClean* [5]. Ontoclean is a methodology for validating the ontological adequacy of taxonomic relationships, based on highly generic ontological notions drawn from philosophy, like *essence*, *identity* and *unity*. These notions are used to characterize relevant aspects of the intended meaning of the properties, classes, and relations that compose an ontology. OntoClean requires the ontology engineer to explicitly identify the ontological commitments underlying the concepts that are being modelled. As a result, OntoClean allowed us to identify ambiguities in the definitions of core notions provided by other standards of R&A (see [7] for more details).

In addition, as a result of an evaluation process carried out in [7], we selected the *Suggested Upper Merged Ontology* (SUMO)[1] [6] as the most suitable top-level ontology for supporting the development of CORA. SUMO was developed by an IEEE working group, and according to our analysis, it is flexible enough to fit the purposes of the project. It includes the main notions and distinctions we would like to introduce in our ontology, such as *agent*, *device* and *agent group*. All concepts in CORA and related ontologies are specializations of concepts in SUMO.

SUMO defines the basic ontological categories across all domains. The remainder of this section gives a brief overview of its main concepts, illustrated in Fig. 1. Detailed information can be found in [6].

The main SUMO category is *Entity*, which is a disjoint partition of *Physical* and *Abstract* entities. Physical represents entities that have a location in space-time. Abstract describes entities that do not have a location in space-time.

Physical is further partitioned into *Object* and *Process*. Object exists in space, keeping its identity in time, and has spatial parts but not temporal parts. Process is the class of instances that happen in time and have temporal parts or stages. This means SUMO follows an *endurantist* perspective instead of a *perdurantist* one. For a perdurantist, an object is composed of every temporal part it has at all times. On the other hand, for an endurantist, an object changes through time, but keeps the essential parts that define its identity. A good analogy is to think that perdurantists see objects as tunnel-like regions in a 4D space, while endurantists see them as a 3D region that travels through the time dimension.

Abstract is further partitioned into *Quantity*, *Attribute*, *SetOrClass*, *Relation* and *Proposition*. Quantity abstracts numeric and physical quantities. Attribute abstracts qualities that cannot or are chosen not to be considered as subclasses of Object. SetOrClass abstracts entities that have *elements* (in the case of sets) or *instances* (in the case of classes). Relation generalizes n-ary relations, functions and lists. Finally, Propositions are entities that express a complete thought or a set of such thoughts.

3. Overview of CORA

CORA aims to describe what a robot is and how its concept relates to other concepts. It defines three broad entities: *robot*, *robot group* and *robotic system* (Fig. 2). In this paper, we are not going to delve into the details of each concept, since they were presented in [7]. Instead, we provide a short description of each domain entity.

The term *robot* may have as many definitions as there are people writing about the subject. This inherent ambiguity in the term might be an issue when specifying an ontology for a broad community. We, however, acknowledge this ambiguity as an intrinsic feature of the domain, and therefore have decided to use a definition based purely on necessary conditions, without specifying sufficient conditions. Thus, our goal is to ensure that CORA's definition of robot includes most of the entities that the community actually considers as robots, at the cost of classifying as robots some entities that actually would not be considered as robots in the point of view of some roboticists. However, the concepts in our ontology could be extended according to the needs of specific sub-domains or applications of R&A.

More importantly, our definition of robot emphasizes its functional aspects. For our general purposes, *robots are agentive devices* in a broad sense, designed to perform purposeful actions in order to accomplish a task. In some cases, the actions of a robot might be subordinated to actions of other agents, such as software agents (bots) or humans. Robots are also *devices*, composed of suitable mechanical and electronic parts. Robots can form *social groups*, where they interact to achieve a common goal. A robot (or a group of robots) can be combined with other devices to form robotic systems. An environment equipped with a robotic system is a robotic environment.

A *robot* is a *device* in the sense of SUMO. According to SUMO, a device is an artifact (i.e., a *physical object product of making*), which participates as a tool in a process. Being a device, robot inherits from SUMO the notion that devices have parts. Therefore, CORA allows one to represent complex robots with robot parts.

A robot is also an *agent*. SUMO states that agent is "*something or someone that can act on its own and produce changes in the world*". Robots perform tasks by acting on the environment or themselves. Action is strongly related to agency, in the sense that the acting defines the agent. A robot can form robot groups. A *robot group* is also an agent in the sense that its own agency emerges from its participants. This notion can be used to describe robot teams, or even complex robots formed by many independent robotic agents acting in unison.

Robotic systems are systems composed of robots (or robot groups) and other devices that facilitate the operations of robots. A good example of a robotic system is a car assembly cell at a

[1] http://www.ontologyportal.org/