Developing and Maintaining Sub-domain Ontologies

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I. GENERIC AND DOMAIN-SPECIFIC ONTOLOGY DEVELOPMENT

Ontologies are considered to be a winning modelling approach in human–machine collaboration, regarding cognition and knowledge-sharing. An ontology can serve as a communication middle-layer between humans and robots. Classically, core-level and sub-level ontologies are distinguished, and this latter can be built based on certain tasks or applications [1]. Most recently, the IEEE RAS Ontologies for Robotics and Automation Working Group (ORA WG) presented a notable effort to provide a consensus-based core ontology in the domain. Their aim was to link existing ISO, IEC, etc. standards and current research efforts and new regulatory frameworks to a generic Robotics and Automation Ontology [2]. The ORA WG is comprised of over 50 members, representing over twenty countries—a cross-section of industry, academia and government. The group has spent over three years to prepare a first version (P1872/D2 Draft Standard for Ontologies for Robotics and Automation) that is now being evaluated by invited experts, organizations and the IEEE SA Standards Board. The ontologies developed by the ORA WG are intended to be merged in a broad ontology that can be further extended for cover specific applications in R&A. The goal of the work group is also to coordinate the standardization efforts with other groups to facilitate more effective information sharing, while achieving wider impact and user-base [3].

To truly support the community, numerous sub-domain ontologies are planned by the ORA WG to be linked to the core ontology. These are developed by dedicated international teams. One existing sub-group is focusing on the service robotic domain and the relationship among concepts such that humans and robots can interact to perform tasks in any environment. The complete family of the ORA will ensure a common understanding among members of the community and facilitating more efficient integration and data transfer.

II. THE PROCESS OF ONTOLOGY DEVELOPMENT

The fundamental objective of domain-specific ontology development is to identify, develop and document the common terms and definitions within a sub-field, so that they can serve as a common reference for the R&D community. It needs to be completed at a very sophisticated way to fulfil its goals, since only high-quality ontologies can be hoped to become cornerstones of the community effort. High quality, high profile ontologies are called Exemplary Ontologies (http://ontologydesignpatterns.org/wiki/Ontology:Main). The general methodology for building ontologies specifies certain modelling principles that need to be followed in order to assure that the finished tool commits to the shared knowledge. It needs to ensure the mutual agreement among stakeholders, and increase the potential of reuse of the knowledge, allowing smooth data integration upward and downward as well. When it is targeted to develop exemplary ontologies, the following attributes need to be considered [4]:

- the ontology must be well designed for its purpose;
- shall include explicitly stated requirements;
- must meet all and for the most part, only the intended requirements;
- should not make unnecessary commitments or assumptions;
- should be easy to extend to meet additional requirements;
- it reuses prior knowledge bases as much as possible;
- there is a core set of primitives that are used to build up more complex parts;
- should be easy to understand and maintain;
- must be well documented.

An important issue towards a united robot ontology is the implementation of it, determined by its modularity, reusability and flexibility. The ORA WG thus decided to use Ontology Web Language (OWL, http://www.w3.org/TR/owl-features) because of its popularity in the community, and for the number of tools and reasoning engines available with it. Besides, OWL provides additional vocabulary, and facilitates greater machine interoperability of Web content. Accordingly, all sub-domain ontologies are expected to follow this convention.

Another important issue is the maintenance and curation of these ontologies, since the knowledge of each represented domain is expected to get enlarged
significantly over the next couple of years. For this, several methodologies exist, typically referred to as ontology life cycle management [5, 6].

III. BUILDING A SUB-DOMAIN ONTOLOGY

The next step of the community is to set up the teams, and define more precisely the concepts of the RAS knowledge representation in the sub-domains. These groups will be developing the sub-ontologies, e.g., for the field of surgical robotics. It is essential during the particular process affecting the medical domain to:

- ensure common understanding both among members of the engineering and clinical community;
- facilitate efficient data integration from medical ontologies (e.g., OGMS – Ontology for General Medical Science, or Open Clinical);
- facilitate efficient component integration;
- facilitate more efficient information transfer among medical electrical equipment and robotic systems.

There have been some examples of medical robotic ontologies, including the REHARROBO-ONTO (Sabanci University) [7], the Surgical Workflow Ontology (SWOnt) [8], the Surgical Ontologies for Computer Assisted Surgery (SOCAS) concepts (Leipzig University) [9] or the European Robotic Surgery FP7 project (http://eurosurge.eu/). To our knowledge, there are two narrower sub-domain ontologies within the field [10]:

- Neurosurgery Robotic Ontology (NRO)
  - Lead by Politecnico di Milano;
  - Both for pre-op and intra-op phases;
  - Definition of domain’s concepts (classes) by textbooks and interviews with surgeons;
  - Hierarchical organization of concepts, concept attributes, restrictions and relations among concepts (properties)
  - Definition of instances of concepts and population of the ontology.
- Total Hip Replacement Surgery Ontology
  - Coordinated by Polytechnic Institute of Castelo Branco / Technical University of Lisbon
  - Developed as part of HIPROB & ECHORD projects (www.echord.info/wikis/website/hiprob; www.echord.info/wikis/website/home).

Due to the sensitivity of the surgical domain, a more delicate ontology construction strategy is proposed, building on existing best practices [11]:

- Strategy with respect to the specialty of the application domain: taking into consideration the interdisciplinary domain requirements;
- Relying on the core ontology: identifying the interfaces and respecting the P1872 [12];
- Employing one overall strategy to identify concepts:
  - from the most concrete to the most abstract (bottom-up);
  - from the most abstract to the most concrete (top-down) or
  - from the most relevant to the most abstract and most concrete (middle-out);
- Life cycle proposal: choosing one best practice approach, e.g.:

- ontology development process based on IEEE 1075-1995 Standard for Software Development Process or

IV. FUTURE WORK

It is believed that the proper approach towards ontology engineering will lead to a set of mid-level and sub-domain ontologies truly useful and applicable to the current cognitive robotics research, particularly in the domain of service robots and medical robots within. The ORA WG is about to set up a dedicated WG to investigate and develop the relevant sub-domain ontology for surgical robot and computer-integrated surgical systems with the active support of the global research community.

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REFERENCES