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Toward the use of upper level ontologies for semantically interoperable systems: An emergency management use case

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Abstract. In the context of globalization and knowledge management, information technologies require an ample need of unprecedented levels of data exchange and sharing to allow collaboration between heterogeneous systems. Yet, understanding the semantics of the exchanged data is one of the major challenges. Semantic interoperability can be ensured by capturing knowledge from diverse sources by using ontologies and align these latter by using upper level ontologies to come up with a common shared vocabulary. In this paper, we aim in one hand to investigate the role of upper level ontologies as a mean for enabling the formalization and integration of heterogeneous sources of information and how it may support interoperability of systems. On the other hand, we present several upper level ontologies and how we chose and then used Basic Formal Ontology (BFO) as an upper level ontology and Common Core Ontology (CCO) as a mid-level ontology to develop a modular ontology that define emergency responders' knowledge starting from firefighters' module for a solution to the semantic interoperability problem in emergency management.

Keywords: Semantic Interoperability, Ontology, Upper Level Ontology, BFO, Mid-Level Ontology, CCO, Emergency Management.

1 Introduction

Today, the more information systems are becoming connected, the more the word is getting smaller and smaller. To manage the integration and interaction of these linked complex systems and the evolution of the amount of data that should be exchanged and shared, interoperability is considered as the key feature. It refers to the "Ability for two (or more) systems or components to exchange information and to use the information that has been exchanged" [1]. From this definition, it is possible to decompose interoperability into two distinct components: 'syntactic interoperability' is the ability to exchange information, and 'semantic interoperability' is the ability to use the information once it has been received [2]. That is to say, semantic interoperability ensures that these exchanges make sense—that the requester and the provider have a common understanding of the "meanings" of the requested services and data [3]. The semantic heterogeneity of data leads to very serious issues since there are several interpretations of one expression. Let's take the example of the term "tank". In an information system of armored vehicles, the term normally refers to a certain kind of specialized armored vehicle used by army, but in an information system that store zoological equipment, the term 'tank' refers to a kind of container which can hold water. Now suppose that a military basis uses the two information systems and that the two information systems are to interoperate within a base-wide facility management system. In this case, it is not evident how to interpret the expression 'three tanks' [4].

To overcome semantic heterogeneity and to guarantee a consistent shared understanding of the meaning of information, the use of ontologies is crucial [5]. Ontologies are expressed in a logic-based language, so that accurate, consistent, and meaningful distinctions can be made among the classes, instances, properties, attributes, and relations to reveal the implicit and hidden knowledge in order to understand the meaning of the data. Thus, they offer the richest representations of machine-interpretable semantics for systems and databases [6]. They serve as both knowledge representation and as mediation to enable heterogeneous systems interoperability [7]. However, the question that arises is how to match these ontologies in order to provide semantic interoperability of multiple information systems. The key way for integrating heterogeneous knowledge across various ontologies is to make use of upper level ontologies. It provides a common ontological foundation for domain ontologies which describe the most general domain independent categories of reality as: time and space, individuals, objects, events, process, instantiation and so on [8].

Many upper level ontologies have been developed over the years and used in different domains such as emergency management. This field is often challenging, it evolves the correlation of different actors and various pieces of information. Emergency management is the ability of an organization to quickly respond to an incident in order to reduce the negative impacts. It includes coordination of services efforts and strategic directions. In such domain, information interoperability is essential during an emergency to exchange data between the different stakeholders to successfully respond to day-to-day incidents and large-scale events.

This work aims in one hand to investigate the role of upper level ontologies as a mean for enabling the formalization and integration of heterogeneous sources of information in the field of systems interoperability. On the other hand, we work toward defining the knowledge of emergency responders by developing a modular ontology starting with firefighter's module to solve the issue of semantic interoperability during emergencies. Hence, this paper is organized as follows: in the next section, we discuss the four levels of abstraction specifically the upper, mid-level, domain and sub-domain ontologies and we look into the advantages and the possibilities opened by the use of upper level ontologies for semantic interoperability of systems and then we discuss several upper level ontologies. In section 3, we justify our choice for selecting the appropriate upper level ontology. Section 4 goes into the details of how we used BFO (Basic Formal Ontology) and CCO (Common Core Ontology) to develop our ontology. At last, the conclusion and the future work are presented.

2 Background

2.1 Ontologies levels of abstraction

There are three levels of abstraction of ontologies specifically upper, mid-level, domain and sub-domain ontology as illustrate in Figure 1; First, the upper level ontology, as defined in [9], it ‘‘describes very general concepts that are the same across all domains and usually consist of a hierarchy of entities and rules (both theorems and regulations) that attempt to describe those general entities that do not belong to a specific problem domain”. They provide a high-level domain independent conceptual model that describes abstract concepts such as object, process, events and quality. Examples of upper level ontologies include: Basic Formal Ontology (BFO), Descriptive Ontology for Cognitive and Linguistic Engineering (DOLCE), General Formal Ontology (GFO), Suggested Upper Merged Ontology (SUMO), Common Semantic Model (COSMO), Cyc project and so on. Second, middle level ontology presents the bridge between the abstract concepts of upper level ontologies and the rich details of domain ontologies by adding more specific modules like space and time. Domain ontologies or lower ontologies describe concepts of a domain of interest in a very specific way and it may also extend concepts from mid-level ontologies. Ontologies from different domains may be as well integrated by alignment to an upper level ontology. Finally, the lowest level of abstraction is sub-domain ontologies. They describe concepts that depend on a specific task in a particular domain. These concepts often correspond to the roles played by the entities.

Reusing well established ontologies in the development of a domain ontology allows one to take advantage of the semantic richness of the relevant concepts and logic already built into the reused ontology. In this way, ontologies may provide a web of meaning with semantic decomposition of concepts [10].

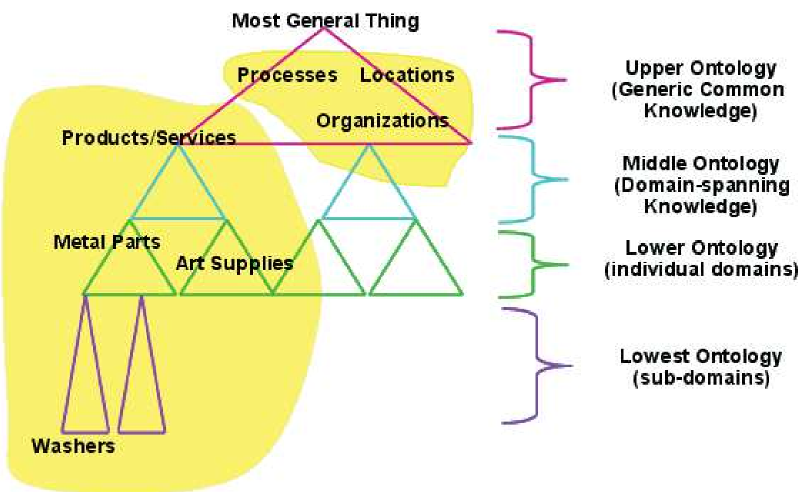

Fig. 1. Ontology’s levels of abstraction [11]

2.2 Upper level ontologies for interoperability of systems

With the increasing amount of data coming from different sources, there is a strong need to determine the meaning of these information to be exchanged precisely enough that a software application can interpret them. So many application of ontologies address the problem of semantic interoperability, in which we have different users using various software tools that need to cooperate by exchanging data with unambiguous, shared meaning. Interoperability could then be achieved by using ontologies that define concepts and their relationships and more over deduce new knowledge from combing existing facts. Then, semantics searches can be performed basing on the meaning of each concept, for example, one could make the difference between horses and cars which both have the same label of "mustang" [10]. Furthermore, the use of upper level ontologies facilitates the alignment between several domain ontologies. In other words, if the ontologies to be mapped are driven from a stander upper level ontology, this will make the mapping task very easy. In addition, upper level ontologies play the same role as libraries in software programming tasks. Once they are used, one could reuse the defined concepts and relationships and so as inherit the inferencing capabilities furnished by them. In this way, developing a domain ontology is an easier task that requires less time than usual. Moreover, the aim is to avoid having several incompatible domain ontologies. The usage of upper level ontologies for integrating information and sharing knowledge among heterogeneous sources has been motivated in various related works [12]. Moreover, they have been used in various domains including situation awareness, pervasive systems [13], biomedical information systems, government and US military system [9] and especially emergency management [14].

Over the years, several upper level ontologies have been already developed and well established, including BFO, SUMO, DOLCE, GFO, Cyc, COSMO.

Cyc project was founded in 1984 by D. Leant as a lead project in the Microelectronics and Computer Technology Corporation (MCC). The aim of Cyc ontology is to enable the usage of knowledge across domains. The ontology includes a wide range of categories. The fundamental distinction of entities in the ontology is between collections and individuals. It is intended to capture concepts such as temporality, mathematics, and relationship types [15].

GFO (General Formal Ontology) project was launched in 1999 in the context of GOL project (General Ontological Language) at the University of Leipzig. It is an upper level ontology presenting a multi-categorial approach that integrates universals, concepts, and symbol structures and their interrelations. it contains several novel ontological modules, in particular, a module for functions and a module for roles. It exposes a three-layered meta-ontological architecture consisting of an abstract top-level, an abstract core level, and a basic level [16].

SUMO (Suggested Upper Merged Ontology) [17] is an upper level ontology developed in 2000 by the Standard Upper Ontology Working Group, an IEEE-sanctioned working group composed of researchers from different fields such as engineering, philosophy, and information science. It proposes definitions for general purpose terms as a foundation that intend to be expanded for more specific domain ontologies. The idea of SUMO was the merging of several existing upper ontologies that did not have licensing restrictions, including John Sowa's upper-level ontology, Russell and Norvig's upper-level ontology, James Allen's temporal axioms, Casati and Varzi's formal theory of holes, Barry Smith's ontology of boundaries, Nicola Guarino's formal mereotopology, and various formal representations of plans and processes. Indeed, SUMO is a mixed upper ontology that contains both elements of realism as well as cognitively specific categories [18].

BFO project was initiated in 2002 under the auspices of the project Forms of Life sponsored by the Volkswagen Foundation. It is designed for use in supporting information retrieval, analysis and integration in scientific and other domains. It doesn't contain specific terms such as physical, chemical or biological terms. BFO is a realist, formal and domain-neutral upper level ontology, it is designed to represent at a very high level of generality the types of entities that exist in the world and the relations that hold between them. It is utilized as a starting point for the categorization of entities and relationships by more than 250 domain ontology [19] [20].

DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering) [21] is the first module of a Foundational Ontology Library for the Semantic Web being developed within the WonderWeb project19 that started in 2002. It is not intended to be a universal or standard upper ontology, but instead, it serves as an ontology of instances. The most fundamental distinction between entities made in DOLCE is related about their behavior in time. On one hand, «*Perdurants*» are entities that unfold in time, on the other hand, «*Endurants* » are entities that are present 'all-at-once' in time.

COSMO (Common Semantic Model) project started in 2006, it arises from the efforts of the COSMO working group (COSMO-WG) and its parent group, the Ontology and Taxonomy Coordinating Working Group (ONTACWG). It is the result of merging some upper level ontologies, COSMO integrates concepts from the Cyc project, SUMO ontologies, DOLCE and BFO [22].

3 Towards the choice of "Basic Formal Ontology" and "Common Core Ontology"

To select the appropriate upper level ontology among several ones, we first looked for a realist upper ontology that represent the world as is and not underlying natural language and human common-sense. This criterion excludes DOLCE, SUMO, COSMO and Cyc in view of the fact that they are more particular and descriptive than realist [23]. Then, to ensure that the upper level ontology can be extended to an emergency management ontology, it should be universal. Universal classes are often characterized as natural classes that abstract or generalize over similar particular things. Person, Location, Process, etc., are examples of universals [24]. So, this disqualifies GFO. Accordingly, in this work, we employed BFO as an upper level ontology. The choice of a BFO-based approach lies in the fact that it focuses on the universals in reality, — we might say that the ontology encapsulates the knowledge of the world that is associated with the general terms used by scientists in the corresponding domain [25]. As a starting point, BFO uses the term «*entity*» as a common representation of anything that exist in the world from the point of view whether of philosophers or scientific researchers. Then, it incorporates two categories of entity «*Continuants*» and «*Occurrents*» in a single framework as a top level distinction between entities. Continuants are entities that persist through time including three axes; objects (Material entity) or and spatial regions (Immaterial entities) as Independent continuant, functions and qualities as Specifically independent continuant and finally, Generically dependent continuant. Occurrents are entities that happen or develop in time such as process.

As a mid-level ontology, we decide that CCO meets most our requirements since it inherits from BFO as an upper level ontology and defines a modular set of extensible classes and relations that can be connected to our domain ontology. The ten mid-level ontologies that compose the common core ontology are: The Information Entity Ontology, the Agent Ontology, the Quality Ontology, the Event Ontology, the Artifact Ontology, the Time Ontology, the Geospatial Ontology, the Units of Measure Ontology, the Currency Unit Ontology, and the Extended Relation Ontology. A simplified explanation of the diverse modules is presented in [26]: "In CCO, Agents (People and Organizations), use Artifacts to perform Actions that occur in both Time and Space, and are differentiated from other Agents and Artifacts via Attributes". The development of CCO started since 2010 in IARPA's Knowledge, Discovery and Dissemination programs. The purpose of this core ontology is to provide a structured base vocabulary that serves as the unified semantics. Once extended, it represents the content of any data sources [27].

4 Firefighters use case

To develop our ontology, we adopted the following four steps [28]; First, we identified the purpose of defining this ontology; Basing on the feedbacks of emergency management experiences, there is a strong need to solve real issues that cause slower decision making in emergency situations such as heterogeneity of data, deficiency of interoperability in emergency management systems and misunderstanding between stakeholders (firefighters, police, army, medical team etc.). To solve these issues, there is an ample need to define the complex knowledge of the different stakeholders so as to come up with a common shared vocabulary.

For all we know, the modular ontology proposed in this paper is the first ontology based on the BFO and CCO that aims to define the emergency responders' knowledge starting with firefighter's module, the rest of the modules will be presented in future works.

In the second step, interviews were conducted with firefighters so as to capture their needs and to identify their technical vocabulary (Commandment hierarchy, means, types of intervention, roles, etc.). In the third step, we used Protégé, an open-source ontology editor, to create our modular ontology.

In order to ensure a better understanding of the created ontology, the architecture of the ontology development is shown in Figure 2. The three levels are layered from top to bottom. As a starting, we integrate the Basic Formal Ontology (BFO) as an upper level ontology. It contains a total of 35 classes including one top class «*entity*» and all classes are connected by means of "is-a" relation. The most general categories in this level are «*Continuant*» and «*Occurrent*» as explained in the previous section.

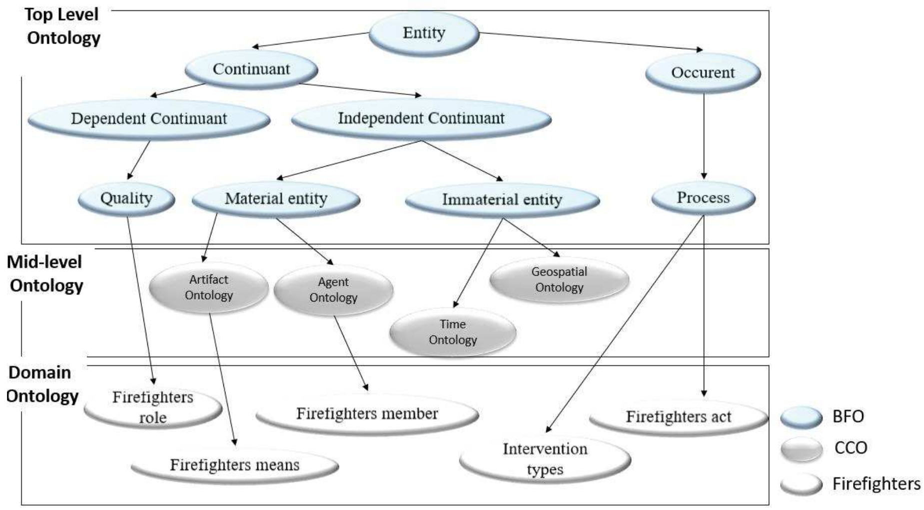

Fig. 2. Architecture of ontology development

Once the upper level ontology is integrated, it is time to incorporate the mid-level ontology which is Common Core Ontology. The ability to reuse modules in a flexible manner is a key feature of modular ontologies. In our work, we reused only four modules that will be extended according to the domain level needs which are (1) Agent Ontology, (2) Artifact Ontology, (3) Time Ontology and (4) Geospatial Ontology [18].

(1) Agent Ontology: The notion of Agent includes both Person as an individual agent and Organization as a group of individuals. In addition, it contains agents' roles and agents' quality.
(2) Artifact Ontology contains concepts representing general types of artifacts like Communication Artifact, Facility, Tool, Vehicle, and Weapon. Furthermore, the ontology enables a user to make assertions about which qualities or functions an artifact is designed to have.
(3) Time Ontology provides the basic vocabulary for describing when events occur.
(4) Geospatial Ontology offers the basic vocabulary for describing the locations of agents and occurrences of events.

In the Firefighters module, as regards to the continuant part, we extended the Agent ontology to cover the different members of firefighter organization. Under Agent quality, we incorporated the firefighter hierarchy of commandment and we attributed a grade for each member. In the class quality of Dependent Continuant, we affected the role of each member. In the Artifact ontology, we classified firefighter different means by specifying their functions. Concerning Occurrent entities, we added the different types of firefighters' interventions and its needs in terms of means and staff. Furthermore, Time ontology and Geospatial ontology will be very helpful in emergency management context, it will determine when and where events occur. To summarize, the ontology we created, once it is complete and all the modules are integrated, can be used to be a common shared vocabulary for emergency management systems.

At the end of this stage, the firefighters' ontology had around 429 classes and 246 relations. The classes are labelled in English and in French. The final step consists on the evaluation of the proposed ontology by domain experts in term of inconsistency, incompleteness and redundancy [29]. Once all the emergency management actors' modules are created, the ontology will be instantiated to test it by means of a concrete use case and it will be used in an Emergency Management System as a common shared vocabulary. Domain expert and users should then evaluate and validate the obtained results.

5 Conclusion and future work

In this paper, we presented how we employed BFO as an upper level ontology and CCO as a mid-level ontology to propose a modular ontology that defines firefighter's knowledge (vocabulary, graphical charter, data representation etc.). The use of upper ontologies improves data quality, reduces development time and especially facilitate large-scale information integration by avoiding ambiguities or inconsistencies to guarantee semantic interoperability of systems. The suitable interoperability among emergency response systems can ensure the speed, efficiency, and appropriateness of emergency management. This work is an important step towards defining and formalizing emergency responder's knowledge.

As a future work, in emergency management situation, there are other stakeholders beyond firefighters, including police, medical team, army, etc. The idea is to formalize their knowledge to come up with a common shared vocabulary that will be used latter in an Emergency Management System to ensure a better coordination and cooperation between these stakeholders so as to guarantee the efficiency and appropriateness of emergency management.

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