The Industrial Ontologies Foundry (IOF) perspectives

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Abstract
In recent years there has been a number of promising technical and institutional developments regarding use of ontologies in industry. At the same time, however, most industrial ontology development work remains within the realm of academic research and is without significant uptake in commercial applications. In biomedicine, by contrast, ontologies have made significant inroads as valuable tools for achieving interoperability between data systems whose contents derive from widely heterogeneous sources. In this position paper, we present a set of principles learned from the successful Open Biomedical Ontologies (OBO) Foundry initiative to guide the design and development of the Industrial Ontologies Foundry (IOF), which is a counterpart to the OBO Foundry initiative for the manufacturing industry. We also illustrate the potential utility of these principles by sketching the conceptual design of a framework for sustainable IOF development.

Keywords 1
Ontology; industrial engineering; semantic interoperability; collaborative manufacturing; production engineering.

1. Introduction

Ontology has been touted as a solution to interoperability and a formal knowledge representation in an evolving collaborative industrial domain. However, even where ontologies are used in industry, they are often embedded as components in larger proprietary systems such that their existence remains unknown to the wider world. Moreover, such ontologies have been in almost all cases developed without any heed to issues of ontology reuse and to the lessons learned in earlier ontology initiatives [1]. Experiences in other fields such as bioinformatics or defense and intelligence, however, show that the most significant benefits of the ontology technology are derived from aggressive reuse of the same ontology content in multiple independent initiatives. The re-use of these developed ontologies from previous projects is not presently on the horizon, as most of the available ontologies we have discussed here are not interoperable, and classes across the ontologies are frequently redundant or used in multiple different ways. And yet, despite numerous benefits of ontologies, industrial companies have remained hesitant in using ontologies. Reconciling ontological researches between the industrial and academic domains is of utmost importance. Therefore, the focus of this work is on defining a framework for

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creating the IOF so that it may help in bridging the gulf that separates industry and academic ontology researches. In what follows, we outline a strategy to address this problem by drawing on the successful Open Biomedical Ontologies (OBO) Foundry initiative to guide the design and development of a foundry for industry: the Industrial Ontologies Foundry (IOF). We hypothesize that this strategy will lead, in an incremental fashion, to a comprehensive suite of interoperable software tools that will provide support for consistent data access and reasoning across the product life cycle.

2. Overview on ontologies and applications in industry

Ontology is a controlled vocabulary providing a consensus-based common set of terms for describing the types of entities in a given domain and the relations between them. It provides a common standardization platform, enabling information processing and exchange of data among both machines and humans.

High-quality domain ontologies are essential for their successful adoption in any domain. However, the field of ontology is nascent and therefore unstable. In practice, many new ontologists begin thinking as software developers who are accustomed to viewing things in terms of information and concepts, and not of things themselves and their natures. We argue that this orientation needs to change as we have also observed that such improper orientation has led to problems in many ontology development projects and has often led to a poor reputation for the ontology itself. Let us acknowledge that creating a new ontology and integrating existing ontologies are both time intensive tasks, and neither has well-documented and effective solutions [2]. Manually identifying relevant types of entities is always laborious and can be exasperating [3]. Extension or integration of existing ontologies is also quite difficult and costly [4]. Additionally, ontologies created by extending or integrating ontologies are often very weak [5]. There exist techniques and methodologies for automatic and semi-automatic ontology construction [6, 7]. However, these automated and semi-automated approaches are limited in scope. Most of the times, users are not fully satisfied with the results of the automated ontology learning techniques [8]. Manual work to validate and adapt the generated ontology is always needed. Another possible solution to facilitate ontology construction, is to reuse and integrate existing ontologies.

In manufacturing and industrial research, many collaborative projects involving industry and academia have been launched to provide ontology-based solutions to the problem of semantic interoperability across different industrial subfields. In a survey, we provide a table[2] which documents some of these projects, which involve both academy and industrial stakeholders. However, few industrial enterprises are adopting ontologies in their work environment, and most of the projects listed in the table are still at the level of research and have not been adopted as real-world solutions. Examples of collaborative efforts among industry and academia include OntoSTEP (based on ISO 10303), the Process Specification Language ontology (based on ISO 18629), and the Gas and Oil ontology (based on ISO 15926), and ONTO-PDM (based on ISO 10303 and IEC 62264). Relevant ontology content has been assembled also within the scope of Reference Architecture Model for Industry 4.0 (RAMI 4.0) project, including the Standards Ontology (STO)[3] and the RAMI Vocabulary Ontology.[4] In none of these cases, however, there is no industrial reuse of the mentioned ontologies on the horizon. They are in almost all cases not interoperable with each other; the same terms are frequently used in different ontologies in different ways or different terms are used in the same way. Taking the example of the class product: this class is presented differently in different ontologies because they adopt different perspectives or conceptualizations (deriving from design, manufacturing, maintenance, sales, and so forth). Yet all of them are referring to more or less one and the same thing in reality. In PSL, a product is defined as: *An object that satisfies a design specification*. In the PRONTO Product ontology [9] it is defined as: *An abstraction representing individual items having physical existence*. In the Event Ontology as: *Everything produced by an event*. In schema.org as: *Any offered product or service* (with

2 https://industrialontologies.org

3 https://github.com/i40-Tools/StandardOntology

4 http://i40.semantic-interoperability.org/rami/Documentation/index.html

examples: a pair of shoes; a concert ticket; the rental of a car; a haircut; or an episode of a TV show streamed online). And in Onto-PDM as equivalent to *MaterialDefinitionType* in IEC:62264.

3. Toward reusing and sharing of ontologies in industry

The goal is to create a suite of principles-based ontologies conforming to a hub-and-spokes model. The hub will contain a small number of reference ontologies that are non-redundant in the sense that they assert no terms in common. Connected to the hub in increasingly widening circles will be a much larger and constantly expanding number of application ontologies, all of which draw on the application ontologies closer to the hub, and ultimately on the reference ontologies at the center, in defining their terms. All the ontologies in the resulting suite will be interoperable, in a precisely defined sense, in virtue of their adherence to the common set of principles. The suite would then constitute The Industrial Ontologies Foundry (IOF)[5], a foundry for industry constructed along the lines of the OBO (Open Biomedical Ontologies) Foundry. The idea is that multiple parties agree to use one another's ontologies, to share a common set of principles, and to share the work of revising both ontologies and principles as these are tested in use with ever-expanding bodies of data, thus ensuring that the result achieves the required degree of interoperability. These benefits can be gained, however, only if the ontologies are developed in such a way as to form an open suite of ontology modules that have been developed in tandem in a way that ensures interoperation

3.1. The proposal of the Industrial Ontologies Foundry (IOF)

The IOF will provide a framework to focus collaboration efforts on developing, standardizing, sharing, maintaining, updating, and documenting industrial ontologies. The main aim of this foundry is to meet the needs of industrial stakeholders by providing a reliable turnkey solution and giving them best practices to integrate ontologies in their businesses.

In other words, such a solution will provide:

- Fully open source stable ontologies.
- Clear and well-documented ontologies.
- Scenarios in which industries will find it advantageous to reuse ontologies, terminologies, and coding systems that have been tried and tested.
- Prospective standardizations built with a coherent top-level ontology and with content contributed and monitored by domain specialists.

Each ontology in the foundry will be managed by a working group that will ensure the collaborative development and the integration of the ontology according to foundry principles. The working group will also edit the documentation about the ontology and define use cases and scenarios of its use. The working group will handle the update and the maintenance of the ontology. As we have mentioned, the objective of the foundry is to have one standard ontology for each domain, so any suggestion to modify or update the ontology must be communicated with the working group that discusses the utility of this update. The working group will be composed of domain experts and users of the adopted top-level ontology. The technical board will involve both senior ontologists and senior domain experts. The role of these boards is to apply the peer review process of the foundry to check the ontologies edited by the working groups according to the IOF principles. Working groups will be created according to a specific process application.

[5] https://www.industrialontologies.org

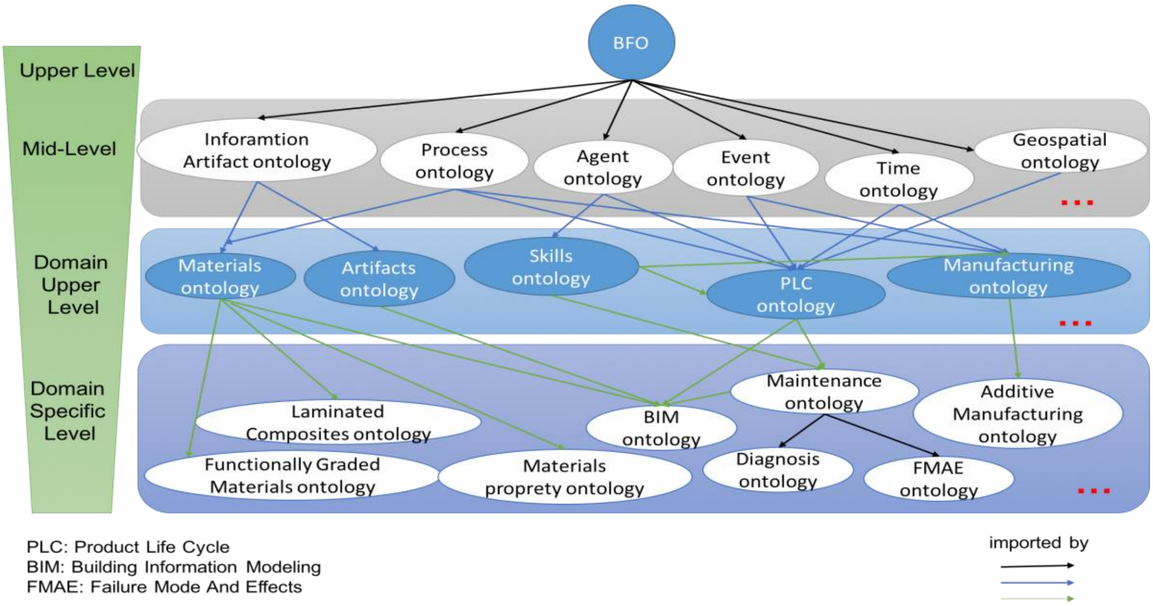

Figure 1: Classification of the proposed IOF core ontologies

The IOF ontologies may be organized according to four levels designated 'Upper level,' 'mid-level,' 'domain-upper level,' and 'domain-specific level' (see Figure 1). The aim of this separation is to ensure greater interoperability and reuse while allowing for the development of domain ontologies. As showed in [10], using such a suite of ontologies, professionals in industry can develop their customized application ontologies. These ontologies can be connected to and may reuse, one another. An 'upper ontology' or 'top-level ontology' is defined as a high-level, domain-independent ontology, providing a framework by which more domain specific ontologies may be derived [11]. These are also sometimes called 'foundational ontologies,' and can be compared to the meta-model of a conceptual schema [12]. A mid-level ontology provides more concrete representations of abstract entities defined in the upper-level ontology. It serves as a bridge between abstract entities defined in the upper-level ontology and the domain ontology [12]. A domain upper level ontology specifies classes particular to a domain of interest and represents those concepts and their relationships from a domain-specific perspective [12]. There may be two layers of domain ontology maintained by IOF as shown in Figure 1. The specialization of a domain ontology (domain specific level) is called an 'application' or 'local ontology', see Figure 2. This type of ontology represents a domain according to a single viewpoint of a user or a developer [13].

Basic Formal Ontology (BFO) [14] is the selected candidate upper-level ontology for the Industrial Ontologies Foundry. BFO is a small ontology, containing about 35 terms, whose role is primarily to work behind the scenes, imposing a perspective on the classes that extend from them. Instead, it is in the low-level ontologies that we will find those terms that predominate in practical uses of the ontology [15]. BFO is now approved as an ISO standard (ISO 21838-2).

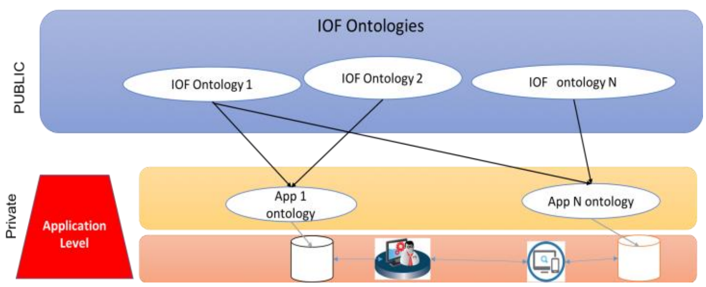

Figure 2: Application interoperability gained through reuse of IOF ontologies

From an operational point of view, as shown in figure 2, industrial users can adopt IOF ontologies to build their own network of ontologies by important terms (with definitions) from different ontologies in the Foundry. In some cases, they will import entire modules from the IOF registry, and then connect them to obtain an application ontology for their own business case. The IOF will then promote the interoperability of the modules in this network.

3.2. The IOF roadmap

To manage the scope and expectations, the IOF community kicked-off its effort with a proof-of-concept (POC) project [16]. This project was intended to test the feasibility of IOF goals. Therefore, the objectives of the POC included not only producing a small initial ontology, but also testing the organizational structure (described above) and producing and testing drafts principles and guidelines. To set the scope, the POC started by asking for most interested manufacturing-related terms from the community. After collecting all the submissions, 20 terms were identified based on the frequencies of matches across the submissions. Each term has a (synonym) set of closely matched terms; therefore, the output of this step is called the top-20 set. According to the objectives of POC, five Working Groups have been created. The Top-down WG, is responsible for providing consistent terms and definitions of high-level entities used across other WGs. Top-down WG started formalizing top-20 set polling from the first step of POC project. The Supply Chain (SC) WG is motivated by use cases such as supplier discovery (i.e., supplier capability matching with manufacturing requirements), supply material traceability. The Maintenance WG is motivated by a few use cases including the maintenance strategy assurance, asset operator failure mode and effects analysis (FMEA), and predictive maintenance [17]. The Process Planning and Production Scheduling (PPS) WG is motivated by use cases including process planning, manufacturability analysis, shopfloor design, and production scheduling. The Product Service System (PSS) working group (WG) aims to create a basis ontology for enhancing engineering of PSS in manufacturing, by modelling all the aspects that affect, or could affect a PSS. In addition to the weekly online meetings, the WGs use a set of team collaboration tools to share models, discuss terms and definitions. A technical principles document[6] has also been developed to guide the design compliance across WGs.

4. Conclusion

This work has proposed the IOF as a strategy for coordinating the development of ontologies, addressing interoperability in the industrial domain, and overcoming the reticence to rely on ontologies as reliable, turnkey solutions. This reticence is due to the problems that persist in ontology engineering such as building methodologies, reusability, integration, as well as costs and dependability. Present research is clear in concluding that existing ontologies suffer from a lack of interoperability. In almost all cases, these ontologies are developed independently, with no reuse of ontology work from the outside and no attempt to profit from lessons learned in earlier initiatives. Hence, they cannot be exploited as a reference in an industrial large scale. In this paper, we have presented a strategy to provide an open ontology framework, called the Industrial Ontologies Foundry (IOF), involving a suite of principles-based ontologies, which broadly represent a hub-and-spokes model. The proposed IOF will provide industrial stakeholders a reliable turnkey solution and give them the best practices to integrate ontologies in their businesses.

5. References

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