Application of ontologies in the enterprise – overview and critical analysis

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Abstract. For many years, it was claimed that semantics should provide foundation of knowledge management in the enterprise. Today, it is easy to realize that this this vision did not materialize. The aim of this work is to critically analyse the state of the art of use of semantic technologies in the enterprise and an attempt at diagnosing key problem(s).

Keywords: Semantics, Ontologies, Enterprise, Overview

1 Introduction

Over time, companies gathered large amount of digitized data, and accessed it using dedicated applications. Often, data was processed by separate units within a company, resulting in data silos. For instance, the HR department processed data independently from the finance department, even though collected data, and used terminologies, overlapped. Upon reflection, it became clear that to deliver actionable knowledge, from *all* available data, cross-institutional analytics is needed [1, 2]. However, for a variety of reasons (e.g. history of IT system development, including "authorship" of applications), data owned by different "entities" may have been represented differently, in terms of syntax and/or semantics. Moreover, large number of mergers and acquisitions, involving companies of all sizes, took (and take) place [3]. They result(ed) in the need to support data processing in newly formed conglomerates. Here, some companies selected one system and "scratched" the others, while combining data was also tried [4, 5].

Separately, note that data needs to be exchanged between enterprises (including data generated in the Internet of Things) [6]. Therefore, data interoperability, without loosing flexibility, has to be addressed. Moreover, as the number of data sources increases, so does (1) data heterogeneity increase, (2) unstructured data is collected, and (3) all data needs to be jointly analysed to capture actionable knowledge. Obviously, this requires flexible and adaptable data models.

In this context, let us consider ontologies, understood as a formal way of representing knowledge [7]. Here, an ontology consists of a vocabulary, defining the meaning of terms, and a set of axioms that constrain the interpretation and well-formed use of terms [8]. Ontologies allow representation of entities, their properties, and relations. Moreover, they allow deduction of “implicit knowledge”. This is achieved by application of reasoning (and reasoners [9]).

Hence, let us assume that: (1) enterprises have to deal with data silos; (2) ontologies and semantic technologies may provide foundation for (knowledge management) applications, which can overcome data heterogeneity. Here, the main questions are: (i) what resources can be used today to bring semantics to the enterprise? and (ii) what technologies are actually available?

To assess this, first, we consider accessibility of business-related ontologies. Second, we report on application of semantic technologies to data workflow management. Finally, we overview work concerning semantic interoperability.

1.1 Problem formulation

Enterprise data is characterized by heterogeneity and complexity. Therefore, one of key challenges arises from differences between individual data models. For instance products and features might differ across geographies, to accommodate regional consumer preferences; while packaging might vary across business units, based on legal requirements, or regional preferences. Note that relational modelling has restrictions, e.g.: schema complexity, no standards for common concepts, need to model “everything” up-front, inability to handle complex queries across heterogeneous data. Here, committing to an ontology forces organizations to understand and document its domain(s), while enterprise ontologies can become part of Master Data Management and serve as a reference models [10].

Authors of [11, 12] outline the applicability of semantics in Master Data Management. In [13], benefits of ontologies for enterprise applications are discussed. However, development of enterprise ontologies is time consuming and complex. To address data heterogeneity, it is possible to apply semantic interoperability [14]. However, here, one needs to define comprehensive translation rules [15].

Note also that business workflows are a part of the enterprise [16], but processes in different entities may have different formal representations. Therefore, it may be semantics that can accommodate differences in data specification.

Besides theoretical applicability of semantic technologies to the enterprise data, actual ontologies are needed. The good practise is to try to reuse, if possible, existing ontologies [17]. Here, let us stress that developing ontologies from scratch is a cumbersome task that requires an advanced knowledge on semantics. However, number of available “ontology engineers” remains very small.

In this context, we have decided to overview state-of-the-art of existing ontologies (ready to be applied in the business domain) and proven ontology uses.

2 Ontologies for business use – critical overview

First, let us note that, the core enabler to model different aspects of business, is a precisely defined method for semantic enterprise modelling, which involves abstract representation, definition of the structure, processes, information and resources of a business, government body, or an organization [18]. This needs knowledge about the enterprise, and/or previous reference models, and may include domain ontologies. Semantic modelling requires the right level of abstraction [19]. Proposed model should be flexible to include and/or remove concepts/instances and/or represent their changes. Hence, in what follows, the key ontologies and initiatives in this area (dating back to 1990s) are presented.

2.1 Business model ontologies

Toronto Virtual Enterprise (*TOVE* [20]) project started in early 1990s, and aimed at developing a comprehensive ontological framework for enterprise integration. A website exists, while ontologies are found in publications (sources are not available). Developed ontologies captured activities, resources, organizations, products and requirements, compliance to the ISO 9000 standards, and costs, and were implemented in Prolog. However, *TOVE* is no longer active.

Enterprise Ontology (*EO*; [21]) was developed around 1998. It is an integrated system of ontologies capturing: activities, processes, organization, strategy, and marketing. *EO* sources are available, with the last version from 2003.

Business Model Ontology (*BMO*; [22]) was developed around 2004. The *BMO* model consists of: product, infrastructure management, customer interface and financial aspects, made of nine building blocks, including: value proposition as an organization objects for an actor, value configuration as a necessary action, and resources for value creation, consumer, distribution channel, relationship mechanism, capability, partnership, cost structure and revenue stream. No ontology sources could be found, and there are no mention of real-life applications. However, it is used by the *BMC*, described below.

Interestingly, in [23], authors proposed merging the three aforementioned ontologies, to create a Unified Business Model Vocabulary. However, no activity in this direction followed.

BMO served as a basis for *Business Model Canvas* (*BMC*; Ph.D. Thesis [24]) – a template for developing business models and documenting existing ones. The *BMC* is a textual technique, designed to illustrate a high-level view of a company and its collaborators, and to capture creation of value. Moreover, *BMC* tools allow model mapping. However, *BMC* did not advance past the dissertation.

Resource Event Agent (*REA*; [25]) model is a domain specific ontology, for accounting and business management. It was developed in 1982. Around 2000, it was extended into a full-grown business ontology, while in 2008 it was re-engineered (in the dissertation [26]) into an OWL representation. It is focused on economic agents, events, resources, and their relations. *REA* was extended with economic contracts and policy infrastructure. There is no source of *REA* ontology, and the last news about it (on its WWW site) is from 2014.

The *Business Object Reference Ontology* (*BORO* [3]) provides a core ontology, and supporting tools, i.e. BORO-UML modelling tool, data loading tools, etc. It was designed for information systems re-engineering, or to mine semantics from

[3] BORO Solutions `http://www.borosolutions.net`

the existing systems, and to support semantic interoperability. Development was completed in 2005, and there are no traces of its use in modern enterprises.

The *Unified Foundational Ontology* (*UFO*; [27]) was to provide ontological foundations for various domains. *UFO* upper ontology consists of ontologies of: UFO-A – objects, UFO-B – events, and UFO-C – entities. UFO-C specializes the other two. The *UFO* website provides documentation of all ontology classes. Interestingly, *UFO* is a foundation ontology for *OntoUML* [4], a conceptual extension of UML. Publications from 2010-15 illustrate attempts at using *OntoUML* in the industry. However, no publications past 2015 have been found.

Unified Enterprise Modelling Language (*UEML*; [28]) was proposed to support integrated use of heterogeneous enterprise models. The *UEML* includes the Unified Enterprise Modelling Ontology (UEMO), expressed in OWL, which captures definitions from variety of enterprise modelling languages. Core publications, related to UEML/UEMO, are dated from around 2010, with no follow-up.

e3value is a business model ontology [29]. Here, the developed models link multiple organizations, and include: actors, value activities, and transfer of resources through services. Overall, a large vocabulary, for modelling value-oriented models, is provided. The *e3value* ontology is still available, and includes documentation, toolset and publications. However, the last update is from 2006.

Finally, creation of an ontology, based on unification of *REA*, *BMO* and *e3value*, is suggested in [30]. However, also this work does not continue.

2.2 Domain-specific ontologies

Let us now consider ontologies addressing specific business domains, knowledge subfields, or tasks. In a semantic system, they should be combined with enterprise ontologies. However, since no general enterprise ontology was widely adopted, they started to be considered and applied in their targeted use cases.

Services and contracts *GoodRelations Ontology* (*GR*; [31]) was developed in 2001, capturing business-related goods and services, e.g. products, offers, prices, terms and conditions. In 2012 it was integrated into *Schema.org* [32] and became supported by Google, Yahoo, Bing, and Yandex [31]. It is available as OWL2, and can be used in all RDF syntaxes, Microdata, etc.

The *Public Contracts Ontology* (*PCO*; [33]) delivers structured data to model public procurement. The *PCO* builds on, among others, *Payments Ontology* for spending description (see, Section 2.2), and *GR* to describe business entities. *PCO* is an OWL ontology. Its last version was published in 2017.

The Agreements Ontology (*AGR-O*; [34]) was developed in 2016. It can be used to model agreements and includes licenses, laws, contracts, etc. It is publicly available (last version from 2018) and well-documented. However, no application examples were found.

Finally, *The Public Procurement Ontology* (*PPROC*; [35]) defines terms related to procurement and contracts. In addition to core terms, e.g. contracts,

[4] OntoUML `https://ontouml.org/`

tenders, deadlines, objectives, etc., it captures the procurement process, from contract publication to termination. It connects other ontologies, e.g.: *Public Contracts Ontology* [33], *W3C Organization Ontology* [36], *Schema.org* [37], *Simple Knowledge Organization System* (SKOS; [38]), *GoodRelations Ontology* [31], and *Dublin Core Metadata Terms* [39]. The Available version is from 2014.

Invoices, payments and product *Payments Ontology* [40] has been developed as a general vocabulary for a representation of a financial flow within an organization and between organizations. Its main modules are: payer, organizational unit, supplier, date of payment. Ontology source cannot be located.

A *Purchase-To-Pay-Ontology* (*P2P-O*; [41]) enables organizations to create semantic invoices following linked data principles. It captures commercial invoice, contract, formal organization, order, payment process, and more. It is compatible with the core invoice model of EN 16931-1:2017 [42] standard. Ontology sources are available in OWL. Papers on *P2P-O* are from 2021 [43]. Hence, it is a bit too early to predict if it will become popular.

The *Product Types Ontology* (*PTO*; [44]) extends *Schema.org* and *GR* ontologies, and provides definitions for types of products/services. Specifically, high-precision identifiers for product types are based on Wikipedia entries. *PTO* classes are represented in OWL DL/OWL2 DL.

The *Financial Industry Business Ontology* (*FIBO*; see, Section 2.4) is a large initiative, delivering a set of enterprise-related ontologies. One of them, named *Payments and Schedules Ontology* [45], contains payment-related concepts. It defines basic concepts such as payment, payer, and payment schedule, extending the scheduling concepts from the dates and times module. It is represented with OWL2, available after registration, and well-documented. This ontology seems to be the most mature and popular, out of discussed financial ontologies.

Transactions *Open-edi Business Transaction Ontology* (*OeBTO*; [47]), developed in 2007, extends *REA* ontology, specifying concepts and relationships from business collaborations. Those concepts are representing a legally enforceable agreement. However, sources of *OeBTO* cannot be located.

2.3 Semantic workflow and process management

The best known method for a formalization of business processes is the Business Process Model and Notation (BPMN, [48]). Its most recent version is from 2014. The core concepts of BPMN are: event, activity and gateway, flow, and data object. Around 2014, a BPMN ontology [49], which formalizes, in OWL 2 DL, structural components of BPMN, was proposed. Unfortunately, the actual ontology resources could not have been located.

Another approach to provide semantic representation for business processes is a BPMN-based ontology (*BBO*; [50–52]). *BBO* is claimed to be designed for Industry 4.0. The core element of *BBO* is a formalization of Chapter 10 of BPMN 2.0 specification. The last version is from 2019, with no signs of applications.

In [53], a Process Mining Ontology and an Events Ontology were proposed. However, their source files could not be found.

Finally, there exist publications ([54–58]) that describe ontologies representing business processes. However, sources of these ontologies cannot be found, and work seems to be a purely academic effort, with no real-life applications.

2.4 Promotion of business use of semantics

Proposing ontologies and semantic solutions is important. However, without promotion and justification, it may be not enough. Here, we briefly summarize most important actions undertaken to popularize semantics in business.

Financial Industry Business Ontology (*FIBO*; [59]) defines entities related to financial business applications, among them OWL ontologies, vocabularies and data dictionaries. *FIBO* is hosted and sponsored by the Enterprise Data Management Council (EDMC) and standardized by the Object Management Group. The EDMC is working in collaboration with many companies to offer open, easy access to *FIBO* content, and to promote its usage. *FIBO* is a broad set of ontologies, organized in a hierarchical structure, following division into domains, subdomains, modules and individual ontologies. Domains cover: business entities, business process, corporate actions and events, derivatives, financial business and commerce, foundations, indices and indicators, loans, market data and securities. FIBO is accessible online through its repository [60].

National Center for Ontological Research (*NCOR* [5]) was established in 2005 and aims at promoting ontology-related research activities. NCOR provides quick start for ontologies for business [61], including training and technology guidelines. However, it does not point to existing solutions that can be explored.

Finally, *Global University Alliance* (*GUA* [6]) was founded in 2004, and provides a collaborative platform for academic research, analysis and development including a *Business Ontology* [62]. It is an extensive ontology with terms organized in a top-level domain, and multiple intersecting subdomains (e.g., business competency, business process, infrastructure). According to the website, various enterprise and industry standards have been developed based on the Business Ontology [63, 64]. However, no publications older than 2016 could have been located, and the ontology sources are not available.

2.5 Summary of findings concerning ontologies for enterprise modelling

In summary, a number of attempts to develop an *ontology of business*, conceptualized from different angles, have been recorded. Majority of them have been tried in the 2005-15. However, almost none of them seem to remain active. Moreover, most of them have not been deployed/tried in real-life. Note that, these ontologies had ambitions to be become general enterprise ontologies, and model

[5] `https://ubwp.buffalo.edu/ncor/`
[6] Global University Alliance `https://www.globaluniversityalliance.org/`

"as much as possible". Hence, it can be stipulated that, in general, this may be one of important reasons for their lack of success.

It can be observed that domain-specific ontologies have proven to be slightly more successful. They are more often (re)used and adopted. The reason may be that it is easier to model (and agree on) a narrow fragment of knowledge, than on a complete domain model. Moreover, such ontologies are easier to understand.

Even though there exist ontologies representing business processes, those were mostly academic efforts, focused on the design of the ontology itself, with no real-world justification for their existence. There is no trace (even anecdotal) of adoption/exploitation of these ontologies by actual businesses.

The initiatives to promote semantic technologies in business have been visible and have resulted in specific products. However, there are no proofs of adaptation of such products to address problems in real-life deployment(s).

3 Semantic interoperability in enterprises

So far we have found that (1) big ontologies "do not work", (2) domain-specific ontologies generate more interest and stay alive "longer" (though only a few are still in use). Finally, (3) there are no standards among both large and small ontologies. Hence, semantic interoperability becomes a crucial challenge.

While adaptation of enterprise ontologies was not particularly successful, numerous ontologies are used in business in task-specific applications [65, 66]. Moreover, besides formal ontologies, other data models, with different levels of expressivity are used, e.g. taxonomies, thesauri. Nevertheless, let us now assume that the problem of semantic knowledge representation has been sucesfully addressed [67]. However, since there are no standard ontologies, it *cannot* be assumed that organizations will use the same semantic models. This brings the question: how data can be exchanged between organizations? Moreover, how can it be interconnected and analyzed across systems/silos?

One of possible approaches is ontology modularization. It means that separate sub-ontologies are linked together with defined relationships. Here, the following structure is considered: top-level ontologies – cover general concepts, domain or task ontologies – provide needed specialization. For example, *BORO* and *UFO* could be the top-level ontologies, while *TOVE* and *BMO* could be used as domain ontologies, while *Payments Ontology* can be used as an application ontology. The crucial task is to propose an appropriate ontology mapping, to relate the vocabulary of two (or more) ontologies.

Semantic interoperability is particularly applicable in business domain, where joining data from different sources, for common analysis, may be of strategic importance. In [68] authors noticed continuous problems with interoperability, and proposed an ontology-based framework to support enterprises. The idea is to apply ontologies on different layers of data processing. This is a straightforward approach However, "bringing data to ontologies", is a very cumbersome task.

Two alternative approaches applied to deliver interoperability are: (a) semantic translation (often of streaming data), and (b) semantic query rewriting.

In both approaches, it is not required to modify data representation. What is needed is semantic-based in-between mechanism that facilitates communication.

For the first approach, let us note that semantic interoperability was addressed in several Horizon 2020 projects [69]. Here, in the INTER-IoT project, an Inter Platform Semantic Mediatior (*IPSM*; [15, 70, 71]), for streaming semantic translations, has been designed and implemented. *IPSM* semantically translates incoming messages, according to rules defined using an alignment format. An alignment is where the mappings between data models of source and target messages are defined.

For the second approach, a commercial solution exists. it was proposed by Eccenca [7]. This approach follows the query rewriting method. Here, the knowledge graph based platform is used for managing rules, constraints, capabilities, configurations and data in a single application. Eccenca offers also Silk [8], an open source framework for integrating heterogeneous data sources. Proposed use cases include: generating links between data lakes, setting RDF links between data sources, applying data transformations to structured data sources.

In summary, semantic interoperability can deliver results without need to modify existing data models, while annotating them semantically, when necessary. The proposed approaches work both for streaming data translation and combining static repositories. Moreover, typically, they do not require to model the enterprise as a whole, but focus on specific fragments of data models, crucial for the exchange/combination of information.

4 Concluding remarks

Even though ontologies can bring a number of benefits, there are very few real-world, production-scale, ontology-based systems, exploiting their expressivity, possibility of reasoning, and adaptability. Moreover, while many ontologies have been developed, few have been "standardized". Furthermore, even standardized ontologies are not adopted. Let us outline some reasons of this situation.

Authors of [72] claim that one of roadblocks is lack of understanding how to model knowledge, resulting in multiple interpretations. Here, problems arise also from insufficient specifications or lack of comments. Naturally, the larger the scope of the ontology, the more visible is the problem. Consequently, numerous, possibly conflicting, definitions materialize. Moreover, since it is hard to reuse ontologies, new (duplicated) ones, are created, introducing "chaos" to their domains. Even though there are repositories that try to organize available ontologies, the problem lies also in the quality of ontologies stored there.

Complexity of modelling is related also to limitations of existing tools. Open source tools, have been tried in academic examples; not in real-world applications. Moreover, updates to many of them have been discontinued.

These facts contribute to the lack of semantics-based business solutions. However, the situation is likely to change. First, there is a tendency to use semantics

[7] Eccenca Corporate Memory `https://eccenca.com`

[8] `http://silkframework.org/`

as a part of proprietary solutions, and not global shared standards. This brings flexibility in a closed world environment, which characterizes many businesses, and allows gathering experience in use of semantics. Second, more focus is put on providing interoperability based on semantic technologies, rather than replacing existing models and standards with ontology-based ones. Finally, European Commission is mentioning semantics and ontologies in more and more project calls. Having this in mind, it can be claimed that semantics in business still has bright future to be realized.

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