

SEMANTIC INTEROPERABILITY OF E-SERVICES IN COLLABORATIVE NETWORKED ORGANIZATIONS

Nikos Papageorgiou, Yiannis Verginadis

*Institute of Communications and Computer Systems, National Technical University of Athens
9 Iroon Polytechniou Str., Athens, Greece*

Dimitris Apostolou

Informatics Department, University of Piraeus, Karaoli & Dimitriou Str., Piraeus, Athens, Greece

Gregoris Mentzas

*Institute of Communications and Computer Systems, National Technical University of Athens
9 Iroon Polytechniou Str., Athens, Greece*

Keywords: Top level ontology, Virtual organization, Networked Collaboration.

Abstract: Semantic interoperability is a crucial issue in enterprises when they participate in Virtual Organizations (VOs). Addressing semantic heterogeneities, detected in VOs, aims to ensure that the meaning of information exchanged is interpreted in the same way by all communicating parties and their systems. In this paper we examine how ontologies can be employed by a system of e-services for delivering interoperability to enterprises, independent of particular IT deployments. In order to support interoperability service utilities in VOs, this paper presents a top-level ontology for collaborative networked organizations (code named OCEAN). The OCEAN ontology is designed as a lightweight top-level ontology that provides a common terminological reference for e-services supporting VO collaborations. We demonstrate how the usage of OCEAN enables e-service interoperability in knowledge-intensive collaborations presenting concrete examples from the pharmaceutical industry.

1 INTRODUCTION

Enterprises wishing to take part in collaborative networks participate in formations often referred to as Virtual Organizations (VOs) (Davidow et al., 1992), (Mowshowitz, 1997). A VO is a short-term association with a specific goal of acquiring and fulfilling a collaboration opportunity. A key underpinning of VOs is the logical separation of VO members' requirements (e.g., requests for information, advice, or transactions) from satisfiers (e.g., information services, collaboration services, or transactional services) (Mowshowitz, 1997). Having such a capability allows management to continually examine service requirements, scan for matching service offerings and switch the assignment of satisfiers to requirements so as to optimize performance on the basis of explicit criteria such as

reducing service delivery costs or improving service quality. Since each VO member undertakes particular sub-processes in the joint effort, information and services for enabling knowledge-based collaboration should be available in an interoperable way. Towards this end, adequate semantic interoperability has to be established by means of a common frame of reference or at least a common terminology (Chituc et al., 2008).

Advances in Semantic Web (Berners-Lee, 2007) technologies, which enable machines to process and reason about resources in support of businesses interactions, have paved the way for ontology-based platforms enabling semantic interoperability between heterogeneous information systems. In this paper we examine how ontologies can be employed by a system of e-services for delivering interoperability to enterprises,

independent of particular IT deployments.

The main contributions of the paper are the following. First, the paper proposes an ontology representing VO objects, processes, roles and relationships as a formal framework for enabling resolution of semantic heterogeneities. Second, the paper presents the methodology that we have used for customizing the ontology for the particular needs of VOs and for achieving consensus of the shared conceptualization of a VO among participants. Third, concrete examples from the pharmaceutical industry are used to demonstrate the applicability and benefits of the proposed ontology and architecture in supporting VO collaboration.

The remaining of the paper is organized as follows: In section 2 we discuss the emerging need for supporting semantic interoperability in VOs, while in section 3 the methodology used for the development of the OCEAN ontology are presented. In section 4 we present the main concepts of this ontology. Finally, our paper concludes with the application of our work in the pharmaceutical industry in section 5 and with a discussion on the research implications and conclusions in section 6.

2 SEMANTIC INTEROPERABILITY IN VIRTUAL ORGANIZATIONS

2.1 Interoperability and Ontologies

In the context of networked enterprises (i.e. enterprises that participate in a VO), interoperability refers to the ability of interactions (exchange of information and e-services) between enterprise systems. The Enterprise Interoperability Research Roadmap – EIRR argues that interoperability of enterprises in future business ecosystems will be a utility-like capability that enterprises can invoke on the fly in support of their business activities. The European Commission uses the term Interoperability Service Utility (ISU) to denote a basic “infrastructure” that supports information exchange between diverse knowledge sources, software applications, and Web Services.

Current interoperability solutions are often oriented toward integration of data required for executing a common business goal, often specified in terms of a contract. Protocols and standards such as ebXML(2009), Electronic Data Interchange (EDI, 2009), and RosetaNet (2009) have been enablers for the progress made in the ability to integrate

heterogeneous information and data.

But, semantic interoperability aims to achieve a more ambitious goal, that is to assure that the meaning of the information exchanged (e.g., business documents, messages) is interpreted in the same way by the communicating systems (Chituc et al., 2008). For addressing semantic heterogeneity it is essential that the semantic definitions of the knowledge objects, processes, roles and relationships within VOs are defined based on a mathematically rigorous ontological foundation (Lin et al., 2007). Moreover, as VO members might come from different fields or have different professional backgrounds, it is necessary to introduce a mechanism to share common understanding of knowledge, and to agree on a controlled vocabulary. An ontology provides a representation of knowledge, which can be used in order to facilitate the comprehension of concepts and relationships in a given domain, the communication between VO members by making the domain assumptions explicit and the resolution of semantic heterogeneities between VO systems.

2.2 Existing Approaches

Among the wide spectrum of approaches which differ in the amount of information and specificity, four categories of approaches can be distinguished for developing ontologies i.e., top level, domain, task and application level ontologies (Huang et al., 2007), (Rajpathak et al., 2006), (Andersson, 2006). Top level ontologies are used to represent the building blocks for a particular domain and basically constitute the first step toward knowledge representation for a domain. Basically, this kind of ontology is limited to concepts that are meta, generic, abstract and philosophical, and therefore are general enough to address (at a high level) a broad range of domain areas. In the last decade, many projects aimed at creating top level ontologies for different purposes: word net (Fellbaum,1998), SUMO (Niles et al., 2001), DOLCE (Gangemi et al., 2002), AIAI Enterprise Ontology (Uschold et al., 1998), PROTON (Kiryakov, 2006), ECOLEAD (Plisson et al., 2007) and the Business Management Ontology (BMO), TOVE ontologies for enterprise modeling (TOVE), and the DIP Business Data Ontology (DIP) and ontologies for enterprise interoperability (Ruokolainen et al., 2007), (Castano et al., 2006).

Among these most relevant to our work is the ECOLEAD ontology which proposes an ontology for Virtual Breeding Environments, which are long-

term associations of enterprises that have the potential and the will to form a VO. The OCEAN ontology builds upon and extends the ECOLEAD ontology to cover the creation, operation and termination phases of VOs. In particular, we focus on knowledge-oriented collaboration within VOs and subsequently OCEAN aims to enable interoperability of systems providing e-services for enabling knowledge-based collaboration.

3 METHODOLOGY

Among the various ontology development methods that have been proposed (Cristani et al., 2005), we opted for a collaborative method because it addresses the objective of achieving a shared representation of domain knowledge. Following the ontology development framework proposed in (Holsapple et al., 2002), we aimed to support domain experts to reach consensus through iterative evaluations and improvements of an initial ontology.

Before starting designing the initial ontology, we did an extensive literature review and discussed with domain experts about the scope of the top-level ontology. Domain experts were carefully selected in order to complement each other and represent diverse viewpoints resulting to a group of five academics and five practitioners with extensive experience in VOs.

To design the initial ontology we used the ECOLEAD top-level ontology as a starting point for our work. We then utilized ontology learning tools to analyze a corpus of 79 papers from the related literature with the aim to identify important terms and relationships between terms. This process has been leveraged with Text2Onto (Cimiano et al., 2005), an ontology learning tool. We then identified the terms of the ontology and derived class definitions and class hierarchy. We followed the top-down approach and took into account suggestions for class hierarchies provided by Text2Onto. Next, we determined the properties of classes; suggestions for object properties from Text2Onto were again taken into account. Finally, we determined the restrictions of the data type and the object properties. Having the initial ontology at hand, we worked with experts to evolve the initial version by asking them to evaluate it and finally reach consensus and agree upon the final version. To reach consensus between experts that were not co-located and did not collaborate synchronously, we followed an adaptation of the Delphi method (Fitch et al., 2001), a technique which involves multiple iterative rounds

of anonymous responses to a questionnaire until either the opinions converge or until no further substantial change in the opinions can be elicited. In each round, participants were asked to rank using a 5-point Likert scale each concept, and each taxonomic and non-taxonomic relation of concepts for relevancy to the project and for ambiguity. Moreover, for each concept synonyms were collected in order to broaden the vocabulary of the domain. Finally, participants could enter new concepts and relations in each round which were then fed again into the evaluation process. The facilitator provided details about particular items for which no consensus was reached and participants rated them again. The iterative process continued until all participants agreed on all items.

4 THE OCEAN ONTOLOGY

The Ocean ontology aims to represent a conceptual schema of the domain of VOs typically referred to as terminology box or TBox. The domain of VOs includes concepts such as collaborative network organization, virtual breeding environment and business opportunity that model the external environment in which VOs are being bred; such concepts are modeled in the ECOLEAD ontology. OCEAN mainly focuses on knowledge-oriented collaborations apposite for VOs. Nevertheless, to fully cover the domain of VOs, we have used the part of the ECOLEAD ontology which covers extensively the VO breeding environment and built upon it towards a unified model that captures the general aspects of collaborative network organizations and at the same time present details about knowledge-oriented collaborations that are important during the creation, operation and termination phases of VOs.

For developing the OCEAN ontology we have used Protégé (Protégé) and for validating it we have used the OWL-DL reasoner Pellet (Pellet). Pellet provides reasoning services and performs consistency checking and computation of inferred hierarchies, equivalent classes and inferred individual types (Sirin et al., 2007). Due to spatial restrictions we can not depict the whole (53 terms and 77 relationships were identified and modeled) of OCEAN; instead we depict the critical concepts, only. The OWL-DL representation of the complete OCEAN top level ontology is available online at: <http://www.imu.iccs.gr/ontologies/ocean/>. We have categorized the critical OCEAN concepts into: Breeding Environment related OCEAN concepts and

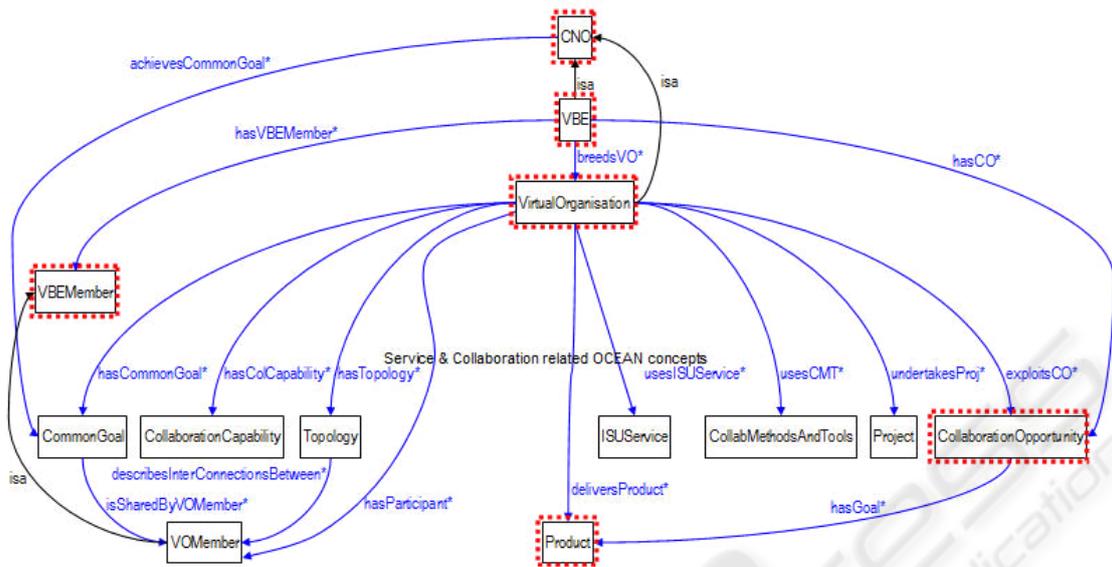


Figure 1: Breeding Environment related OCEAN concepts.

Service & Collaboration related OCEAN concepts (refer to knowledge-enabled collaboration services).

4.1 Breeding Environment Related OCEAN Concepts

We have organised the presentation of OCEAN by putting first concepts and relationships that describe the VO’s breeding environment, as a necessary artifact to describe the full picture of the domain (figure 1). The highlighted concepts were taken from the ECOLEAD ontology, while the remaining concepts and relationships appear as extensions. Some of the breeding environment related OCEAN concepts and relationships are:

A virtual organization is a short-term association (of organizations) with a specific goal of acquiring and fulfilling a collaboration opportunity. A VOMember represents an entity collaborating with other entities in the VO (Plisson et al., 2007). In simpler words VOMembers are the organizations which participate in a VO. A virtual organization is bred in a VBE, an association of organizations and their related supporting institutions, which have both the potential and the will to cooperate with each other through the establishment of a base long-term cooperation agreement and interoperable infrastructure (Camarinha-Matos et al., 2005). VO’s aim is to deliver Products (anything an organization may produce: goods or services), has a CommonGoal, undertakes a Project, uses CollaborativeMethodsAndTools and exploits a

CollaborationOpportunity. With the term CollaborativeMethodsAndTools we define all the synchronous or asynchronous tools and methods that are going to be developed in terms of a system to support and enhance collaboration within a VO.

Every VOMember has (or should have) CollaborationCapability which declares the capability that is relevant to the participation of an enterprise in collaboration with partner enterprises. It includes both HR capabilities of personnel involved in management and operation of collaborative activities, and interoperability of software systems. The concept of CollaborationCapability concerns mainly the pre-creation phase of a VO (i.e. identification phase for (Plisson et al., 2007)) as it focuses on the knowledge about the capability of future VO partners to collaborate. A critical factor, that is often disregarded in efforts that describe and support VOs, is the fact that two potential partners may be unable to collaborate, although they appear to have all the necessary assets for participating in a specific VO (e.g. two partners that had unsuccessful collaborations in previous VOs, partners that have been engaged in lawsuits against each other etc.). Within the system that will use the OCEAN top level ontology, a VO may use an ISUService (described in the next section).

The structure of a VO is described with the term topology which stands for the arrangement of the participants inside the VO (e.g. Star Alliance: A grouping of independent organizations, with a core organization taking the lead). By declaring that a VO

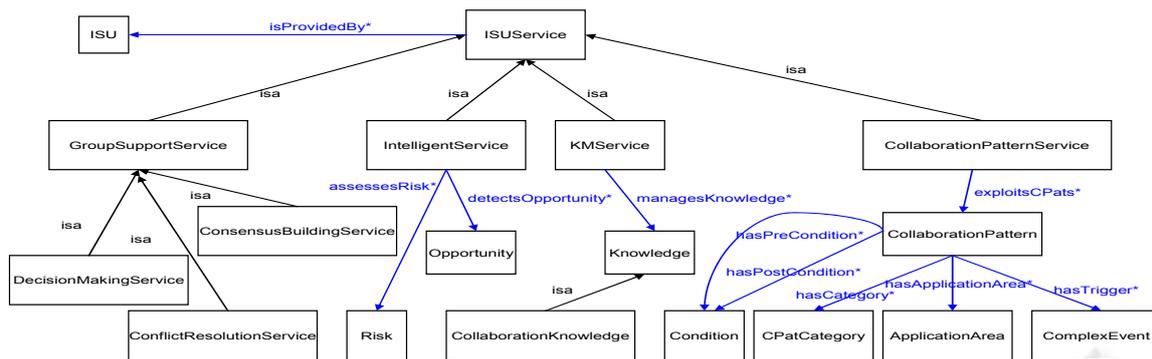


Figure 2: Service & Collaboration related OCEAN concepts.

is a kind of CNO we express that a VO is a collaborative network of organizations.

4.2 Service & Collaboration Related OCEAN Concepts

In this section we present the top-level ontology concepts that refer to collaborations and services (figure 2) that are to be provided by the ISU. The Interoperability Service Utility (ISU) is the enabling system of services for delivering basic interoperability to enterprises, independent of particular IT deployment. It may also denote an enterprise providing such services. A service is a provider-client interaction that creates and captures value (IBM). An ISU service is technical, commoditized functionality, delivered as services provided by an ISU to support the collaboration between enterprises. A non-exhaustive list of ISU services is presented below. Lower-level domain ontologies further specify each one of the ISU services.

DecisionMaking, ConsensusBuilding, ConflictResolution services and other Group Support Services. For example, reach decision on production plans, budget expenditure, etc.

KnowledgeManagementServices helping a company that wants to enter the VO, to efficiently build up and manage a knowledge base of collaboration-oriented internal knowledge, together with knowledge sharing and exchange services which guarantee adequate treatment of confidentiality concerns.

Specific IntelligentServices such as OpportunityDetection (e.g., detection of opportunity to develop a new product) and RiskAssessment (e.g., risk of failure of the new product, risk of conflict between partners).

CollaborationPatternServices as a means to use and reuse proven, useful, experience-based ways of

doing and organizing communication and collaboration activities in specific knowledge-oriented collaborative tasks. A Collaboration Pattern has Pre-Conditions, Post-Conditions, category (CPatCategory), Application Area, and Triggers that are comprised of Complex Events.

5 APPLICATION OF THE OCEAN ONTOLOGY

In this section, we present the application of the OCEAN ontology and architecture for network enterprise collaboration in the pharmaceutical industry. The pharmaceutical industry is considered a typical example of knowledge-intensive sector where the problem of dealing with heterogeneous and vast number of information appears to be insurmountable.

According to Investigational New Drug Application Process (IND), the process of developing a new dermatological drug involves several different stages starting from pre-clinic studies (testing the drug in the lab, use it on guinea pigs etc.) and continuing with the four phases imposed by Foods and Drug Administration (FDA) and the European Medicines Agency (EMA). During these phases a formal proposal is introduced to the FDA or EMA with all the details of the new drug. Upon approval, phase one starts with the testing on a group of healthy people in order to decide on the drug toxicity, liver and spleen reaction, the best dose amount, the best way to administer the new drug (oral, patch, intravenous, intradermal). The next two phases involve the testing on a group of sick people in order to decide on the new dermatological drug effectiveness. Phase two involves 100-300 sick people while phase three involves the testing on an extensive group with ethnographic differences that takes place in different

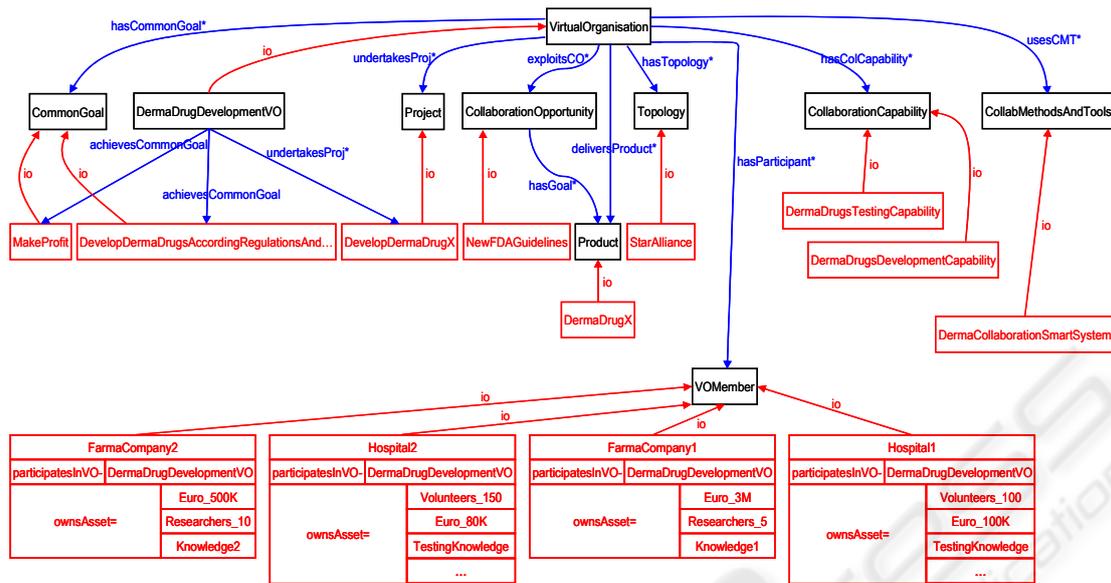


Figure 3: Breeding Environment related OCEAN concepts – Instantiated.

hospitals. Since only a 5% of new drugs are approved to be circulated in the public, not many efforts continue with Phase four where the approved drugs continue to be tested for side effects for many years after their first circulation.

In our case, we consider that the new dermatological drug has reached the critical phase three where the testing must proceed in different hospitals. According to the ICH (International Conference on Harmonization of Technical Requirements for Registration of Pharmaceuticals for Human Use) (ICH) that was held in Helsinki four decades ago, there was an agreement upon a set of good clinical practices. Of course these best practices may be altered by the ethics committees of each country involved that may decide on the details of the drug testing (e.g. people with age less than fourteen should not be tested) or by the release of a new regulation from the FDA or EMEA. Such a change on the clinical practices can be considered as a new opportunity in terms of a VO.

As shown in figure 3, the OCEAN ontology has been instantiated in order to describe our domain. The VO follows a certain topology: Star Alliance. This specific topology for structuring a VO involves the grouping of independent organizations, with a core organization taking the lead management role.

The VO comprises two pharmaceutical companies with expertise in dermatological drug development and two hospitals with their own assets (testing knowledge, doctors supervising and volunteers). The common goal for this VO has been agreed to be the development of dermatological

drugs according to the regulations and ethics taking into account the profit maximization. The VO has been bred by a drug development virtual breeding environment (VBE) that combines pharmaceutical companies that are capable of developing any new drug and hospitals for the testing processes.

5.1 Enabling shared Understanding

The ability of OCEAN to provide a common terminological reference and a shared understanding for human participating in VOs, is demonstrated by the following set of questions for which we were able to get answers from our instantiated ontology. We have used the SPARQL language for assessing the expressiveness capability of OCEAN. SPARQL is a query language for the Semantic Web that can be used to query an RDF Schema or OWL model in order to filter out individuals with specific characteristics (SPARQL).

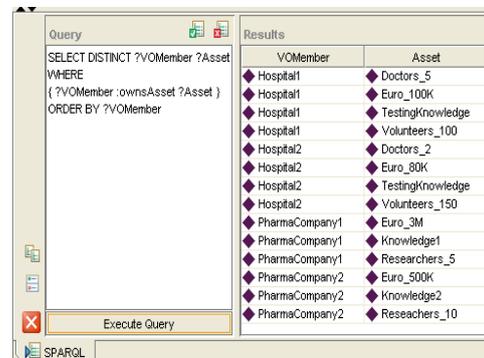


Figure 4: Retrieval of VO members' assets.

One such question could be: Which are the assets of each VO member? In figure 4, it is shown how we can make such a question using SPARQL. Regarding our application, we get as an answer the group of assets per VO members (Hospital 1, Hospital 2, Pharma Company 1 & 2).

In table 3 the reader can find more questions that can be answered using SPARQL queries through the instantiated OCEAN top level ontology.

Table 3: SPARQL Queries.

QUERY	SPARQL QUERY
In which VOs have a specific pharmaceutical company participated in the past?	<pre>SELECT ?VO WHERE { :PharmaCompany1 :participatesInVO ?VO . }</pre>
Which are the projects that the DermaDrugDevelopmentVO has undertaken so far?	<pre>SELECT ?Proj WHERE { :DermaDrugDevelopmentVO :undertakesProj ?Proj . }</pre>
What are the possible moderator services depending on common goals for the DermaDrugDevelopmentVO?	<pre>SELECT DISTINCT ?ModSrv ?CGoal WHERE { :DermaDrugDevelopmentVO :hasCommonGoal ?CGoal . :DermaDrugDevelopmentVO :usesModeratorService ?ModSrv }</pre>

Unlike databases, ontologies built in OWL such as OCEAN has a so-called open-world semantics in which missing information is treated as unknown rather than as false and OWL axioms behave like inference rules rather than as database constraints. For example, if we have asserted that BiotechOne is a VO Member and that it Participates In (which is the inverse property of hasParticipant) BioAlliance, then, because only Virtual Organizations have VO Members as participants, this leads to the implication that BioAlliance is a Virtual Organization. If we were to query the ontology for instances of Virtual Organization, then BioAlliance would be part of the answer. We can also ask if any Collaborative Network Organization that has VO Members as Participants is necessarily of Virtual Organization. Query answering in OWL is analogous to theorem proving; therefore the OCEAN top level ontology plays itself an important role and is actively considered at query time. Considering both the schema and the data represented in OCEAN can be very powerful, making it possible to answer conceptual and extensional, queries as well as to deal with incomplete information.

6 CONCLUSIONS

In this paper we presented OCEAN, a top-level ontology for collaborative networked organizations. The OCEAN ontology covers the creation, operation and termination phases of VOs and is designed as a lightweight top-level ontology that provides a common terminological reference for VO concepts and relations. We validated the OCEAN ontology as an expressive tool for describing such VOs using SPARQL queries.

We believe that the OCEAN ontology formalizes and enables network enterprise collaboration as it models formally the main factors that affect/enable the network enterprise collaboration orchestrated by an entire system. It targets specifically the relationships between “high level pieces” of domain knowledge, explaining how they contribute altogether to the network enterprise collaboration. This top level ontology also enables better communication by defining a common-agreed vocabulary that: ensures shared meaning and understanding regarding project goals; facilitates knowledge acquisition in situations where teams have to work together because the ontology becomes a common, agreed-upon understanding of the terms, which can be understood by team members with different background knowledge (Valente et al., 1996). Ultimately, the OCEAN ontology supports semantic interoperability between software components by formalizing the used vocabulary explicitly in a machine-readable form. This is possible due to the openness of the OCEAN top level ontology which will act as “glue” between other domain ontologies that describe specifics of any VO, VO member, knowledge related functionalities and assets. Although, we briefly described here the application of the OCEAN ontology in the pharmaceutical sector, we intend to also use it in the manufacturing industry, in terms of the SYNERGY ICT project for considering its applicability and address possible limitations with appropriate extensions of the top-level ontology.

ACKNOWLEDGEMENTS

This work has been partially funded by the European Commission under project SYNERGY ICT No 63631. The authors would like to thank the project team for comments and suggestions.

REFERENCES

- B. Andersson, M. Bergholtz, A. Edirisuriya, T. Ilayperuma, P. Johannesson, B. Grégoire, M. Schmitt, E. Dubois, S. Abels, A. Hahn, J. Gordijn, H. Weigand, B. Wangler, Towards a Reference Ontology for Business Models, in: *Proceedings of the 25th International Conference on Conceptual Modeling (ER2006)*, Tucson, Arizona, USA, 2006.
- T. Berneers-Lee, Welcome to the Semantic Web, *The Economist*, 21 (2007) 146. *Business Management Ontology*, available online at: http://www.bpiresearch.com/Resources/RE_OSSOnt/re_ossont.htm
- L. M. Camarinha-Matos, H. Afsarmanesh, Collaborative networks: A new scientific discipline, *Journal of Intelligent Manufacturing* 16(2005) 439–452.
- S. Castano, A. Ferrara, S. Montanelli. Ontology-based Interoperability Services for Semantic Collaboration in Open Networked Systems. *Springer, Interoperability of Enterprise Software and Applications*, ISBN: 978-1-84628-151-8, 2006
- C. M. Chituc, C. Toscano, A. Azevedo, Interoperability in Collaborative Networks: Independent and industry-specific initiatives – The case of the footwear industry, *Computers in Industry* 59 (2008) 741–757.
- P. Cimiano, J. Völker, Text2Onto A Framework for Ontology Learning and Data-driven Change Discovery in: *Proceedings of the 10th International Conference on Applications of Natural Language to Information Systems*, 2005.
- M. Cristani, R. Cuel, A survey on ontology creation methodologies, *International Journal on Semantic Web & Information Systems* 1 (2) (2005) 49–69.
- W. H. Davidow, M. S. Malone, *The Virtual Corporation*, Harper-Collins (Eds.), New York, 1992.
- DIP Business Data Ontology, available online at: <http://dip.semanticweb.org>
- ebXML, available online at: <http://www.ebxml.org>
- EDI, UN/EDIFACT, available online at: <http://www.uncece.org/trade/untid>
- European Medicines Agency (EMA), available online at: <http://www.emea.europa.eu/>
- C. Fellbaum, *WordNet*, An Electronic Lexical Database, MIT Press, Cambridge, MA, 1998.
- K. Fitch, S. J. Bernstein, M. S. Aguilar, B. Burnand, J. R. LaCalle, P. Lazaro, M. van het Loo, J. McDonnell, J. Vader, J. P. Kahan, *The RAND/UCLA Appropriateness Method User's Manual*, 2001.
- Foods and Drug Administration (FDA), available online at: <http://www.fda.gov/>
- A. Gangemi, N. Guarino, C. Masolo, A. Oltramari, L. Schneider, Sweetening Ontologies with DOLCE, in: A. Gomez-Perez and V. R. Benjamins (Eds.) *Knowledge Engineering and Knowledge*
- C. W. Holsapple, K. D. Joshi, Collaborative Approach in Ontology Design, in: *Proceedings of the Communications of the ACM* 45 (2002).
- N. Huang, S. Diao, Ontology based enterprise knowledge integration, *Robotics and Computer Integrated Manufacturing*, 2007.
- IBM Services Sciences, Management and Engineering, available online at: <http://www.research.ibm.com/ssme/>
- ICH, International Conference on Harmonisation of Technical Requirements for Registration of Pharmaceuticals for Human Use, available online at: <http://www.ich.org>
- Investigational New Drug Application Process (IND), available online at: http://www.fda.gov/cder/Regulatory/applications/ind_page_1.htm
- A. Kiryakov, Ontologies for Knowledge Management, in: Davies, J., Studer, R., Warren, P. (Eds) *Semantic Web Technologies: Trends and Research in Ontology-based Systems*, Wiley, 2006.
- H. K. Lin, J. A. Harding, A manufacturing system engineering ontology model on the Semantic web for inter-enterprise collaboration, *Computers in Industry* 58 (2007) 428–437.
- A. Mowshowitz, Virtual Organization, in: *Proceedings of Communications of the ACM* 40 (1997) 30–37.
- I. Niles, A. Pease, Towards a standard upper ontology, in: *Proceedings of the International Conference on Formal ontology in information Systems (FOIS '01, ACM)*, 2-9, USA, 2001.
- PELLET, OWL-DL ontology reasoner, available online at: <http://clarkparsia.com/pellet/>
- J. Plisson, P. Ljubic, I. Mozetic, N. Lavrac, An ontology for virtual organisation breeding environments, *IEEE Transactions on Systems, Man, and Cybernetics – Part C: Applications and Reviews*, 37(6): 1327-1341, 2007.
- Protégé, Ontology Development Platform, available online at: <http://protege.stanford.edu/>
- D. Rajpathak, M. Zdenek, R. Roy, A Generic Library of Problem Solving Methods for Scheduling Applications, *IEEE Transactions on Knowledge Data Engineering* 18(6): 815-828, 2006.
- RosetaNet, available online at: <http://www.rosettanet.org>
- T. Ruokolainen, Y. Naudet, T. Latour. An Ontology of Interoperability in Inter-Enterprise Communities. *Springer, Enterprise Interoperability II*, ISBN: 978-1-84628-857-9, 2007
- E. Sirin, B. Parsia, B. C. Grau, A. Kalyanpur, Y. Katz. Pellet: A practical OWL-DL reasoner in: *Proceedings of the Web Semantics: Science, Services and Agents on the World Wide Web* 5(2): 51-53, 2007.
- SPARQL, ontology query language, available online at: <http://www.w3.org/TR/rdf-sparql-query/>
- TOVE ontologies, available online at: <http://www.eil.utoronto.ca/tove/ontoTOC.html>
- M. Uschold, M. King, S. Moralee, Y. Zorgios, Y. The enterprise ontology, *Knowledge Engineering Review* 13, 1998.
- Y. Verginadis, D. Apostolou, N. Papageorgiou, G. Mentzas. An Architecture for Collaboration Patterns in Agile Event-Driven Environments. *Fourth IEEE Workshop on Agile Cooperative Process-Aware Information Systems (ProGility 2009)*, June 29 - July 1, 2009, Groningen
- A. Valente, J.A.P.J Breuker. Towards principled core ontologies. SRDG Publications, University of Calgary, 1996, available online at: <http://dare.uva.nl/record/15931>