Ontological Modeling[♣]

© Leonid Kalinichenko[1], Michele Missikoff[2], Federica Schiappelli[2], Nikolay Skvortsov[1]

[1]Institute for Problems of Informatics, Russian Academy of Sciences
{leonidk,scvora}@synth.ipi.ac.ru
[2]Institute of Systems Analysis and Computer Science (IASI), CNR
missikoff@iasi.cnr.it, fed_schi@iasi.rm.cnr.it

Abstract

This survey is aimed at analyzing some among the most relevant ontological modeling approaches. The semantic role of ontologies is emphasized. Classification of ontological models and languages focusing on their basic features is presented. Examples of applications of ontologies in different areas are also provided.

1 Introduction

The intention of ontology is the study of the categories of things that exist or may exist in some domain [sowa]. One of the definitions of ontology sees an ontology as a vocabulary of interrelated terms which impose a structure of the domain and constrain the possible interpretation of terms [uscho3]. Informally, an ontology can be specified as a collection of terms (concepts) and their definitions stated in a natural language. Formal ontologies can be specified by axioms and formulae stated in a formal language. Axiomatized ontology can be seen as an axiomatic domain theory. Generally an ontology can be defined as a linguistic artifact that defines a shared vocabulary of basic concepts for discourse about a piece of reality (subject domain) and specifies what precisely those concepts mean. As such, ontologies provide the basis for semantic modeling of subject domain, information integration, and communication in the domain.

Semantic interoperability for interconnecting information systems of different parties, compositional development of information systems, management of ubiquitous computing/smart spaces environments and context aware systems, knowledge-intensive information systems are just few examples of areas heavily dependent on the progress in ontological modeling. Specifically intensive are current developments for the Semantic Web that is planned to provide more automated services based on machine-processable semantics of data [berne]. Ontologies as shared and common domain theories, are a key asset in enabling content-based access, interoperability, and communication across the Web, providing it with a qualitatively new level of service. Convergence of Digital Libraries and Semantic Web technologies can be expected to provide more semantics in accessing heterogeneous information collections.

Ontologies became very broad and intensive area of research and development that deserve specific analysis. This paper is a brief survey in the technology of ontologies. Mostly the paper is focused on approaches for ontological modeling distinguished as verbal models, logic-based models, structural (object) based models and hybrid models. The paper provides an analysis of the respective modeling facilities. Projects focusing on the construction of ontologies as practical applications are briefly discussed. Due to the semantic and platform heterogeneity of ontological modeling facilities, ontological integration becomes a hard issue that is considered. Finally, the paper contributes to an analysis of the difference between conceptual data modeling and ontology engineering.

2 Classes of models for ontology construction and reasoning

Ontological modeling in information technologies has undergone considerable evolution. Models and languages used for ontology construction and reasoning can be classified as follows.

2.1 Verbal models

Informal linguistic models are often used for specification of ontologies [briuk2, mille1, defin]. In such models ontological concepts are defined by verbal definitions like in an explanatory dictionary. Some kinds of basic relationships may be established between concepts. A glossary of terms in some subject domain, a thesaurus with its concepts and relationships defining natural language terms may be considered as ontologies. Information retrieval methods are applied to establish relationships between verbally defined concepts as well as to search concepts relevant to a query.

2.2 Logic-based models

In contrast to verbal models, logic-based ontologies are defined formally and have an ability of formal reasoning. One of the first logic-based ontological models was Ontolingua [grube2]. Predicative expressions in Ontolingua are represented in the KIF language [genes], which is based on the first order logic. KIF is highly expressive and due to that it is not tractable for automatic inference. Development of ontologies in this model is regulated by special technique for adding of unambiguous specifications [fikes1]. Ontolingua has been intended as an intermediate language for heterogeneous ontologies interchange.

Ontological model OKBC [chaud] uses a frame model as its basis. The Open Knowledge Base Connectivity (OKBC) API is considered as a key enabler in the distributed ontology repository architecture. The OKBC model serves as an interlingua for ontology that is being communicated using OKBC.

XOL has been developed with the purpose to satisfy the need for a language with the semantics of object-oriented knowledge representation systems, but with an XML syntax. The ontology definitions that XOL is designed to encode include both schema information (meta-data), such as class definitions from object databases, as well as non-schema information (ground facts), such as object definitions from object databases. XOL is similar to other past ontology-exchange languages; in particular, it uses the model of OKBC.

Another class of formal ontological models of today is based on various kinds of description logics [donin]. This is a family of logic-based knowledge representation formalisms well-suited for the representation of and reasoning about terminological knowledge and ontologies. They are mainly characterised by a set of constructors that allow to build complex concepts and roles from atomic ones.

These models become tractable with respect to such tasks as checking of subsumption between concepts and satisfiability of concept definitions as well as of sets of interconnected concepts [donin]. Examples of reasoning systems used often for ontological modeling are KL-ONE, LOOM, CLASSIC, FaCT. Typical reasoning services provided are classification, consistency and instance checking.

The notion of interpretation is introduced to consider description logic concepts as sets of objects. Checking of satisfiability consists in a proof stating that at least one interpretation exists according to which the concept corresponds to a non-empty set. Subsumption between concepts means that for any interpretation a set interpreting one concept is a subset of a set interpreting the other. Proof of subsumption is reduced to that of satisfiability.

OIL [horro1, horro3] is the first ontology representation language in W3C standards that is properly grounded. It is an evolution of existing proposals such as OKBC, XOL, RDF. And it is the first web-based representation language intended for ontology definition with the formal semantics and reasoning services provided by a description logic.

The most noticeable development of logic-based ontological models takes place in frame of the Semantic Web development. DAML+OIL [mcgui] is well known model that uses description logic SHIQ [horro2] possessing reasonably good expressive power. It is the result of the fusion of the DAML and the OIL languages; it is also built on earlier W3C standards such as RDF and RDF Schema and extends them with richer modeling primitives. This model is planned as a basis for the Web Ontology Language (OWL).

OWL [owl] extends RDF and RDF Schema by providing additional vocabulary along with a formal semantics. It has its foundations into the DAML+OIL and it also provides built-in ontology mapping support. OWL has three dialects: OWL Lite, OWL DL, and OWL Full. These styles of ontology representation differ in their complexity and may be used for different application depending on required inference simplicity or formality of descriptions.

A comparison of logic-based languages for ontology representation is given in Table 1.

2.3 Structural (object) models

Several approaches are known to apply structural (object) data models to define ontologies. An approach for extensible ontological model construction in a mediation environment intended for heterogeneous information sources integration in various subject domains has been presented in [kalin]. A mediator ontological language (MOL) may depend on a subject domain and is to be defined at the mediator consolidation phase. On the other hand, for different information sources different ontological models (languages) can be used to define their own ontologies. Reversible mapping of the source ontological models into MOL is needed for information sources registration at the mediator. An approach for such reversible mapping has been developed for a class of the Web information sources assuming that such sources apply the DAML+OIL ontological model. A subset of the hybrid object-oriented and semi-structured canonical mediator data model is used for the core of MOL. Construction of a reversible mapping of DAML+OIL into an extension of the core of MOL has been presented. Such mapping is a necessary pre-requisite for contextualizing and registration of information sources at the mediator. The mapping shows how extensible MOL can be constructed. The approach proposed is oriented on such digital libraries where retrieval is focused on information content, rather than on information entities.

Element	LOOM	CLASSIC	XOL	OIL	DAML+OIL	OWL	OKBC	Ontolingua
Concepts								
Concept definition	✓	✓	✓	✓	✓	✓	✓	✓
Concept name	✓	✓	✓	✓	✓	✓	✓	✓
Concept docs	✓		✓	✓	✓	✓	✓	✓
Slots								
Attribute definition	✓	✓	✓	✓	✓	✓	✓	✓
Attribute name	✓	✓	✓	✓	✓	✓	✓	✓
Attribute docs	✓		✓	✓	✓	✓	✓	✓
Basic types	✓	✓	✓	✓	✓	✓	✓	✓
Collection types			✓		✓			
Relation definition	✓	✓	✓	✓	✓	✓	✓	✓
Concept Axioms								
Conjunction	✓	✓		✓	✓	✓		✓
Disjunction	✓			✓	✓	✓		✓
Negation	✓			✓	✓	✓		✓
Disjoint	✓	✓	✓	✓		✓		✓
Covering				✓				✓
Equality	✓	✓		✓	✓	✓		✓
Slot Axioms								
Constraint	✓	✓	✓	✓	✓	✓	✓	✓
Requirement	✓	✓		✓	✓	✓	✓	✓
Enumeration	✓	✓		✓	✓	✓	✓	✓
Cardinality	✓	✓	✓	✓	✓	✓	✓	✓
Min/max value	✓	✓	✓	✓	✓	✓	✓	✓
Similarity degree	✓	✓	✓	✓	✓	✓	✓	✓
Inverse	✓			✓	✓	✓	✓	✓
Transitive				✓	✓	✓		
Unique					✓	✓	✓	✓
Domain	✓	✓	✓	✓	✓	✓	✓	✓
Range	✓	✓	✓	✓	✓	✓	✓	✓
Semantic Relations								
Similarity								
Synonymy	✓	✓		✓	✓	✓		✓
Is a	✓	✓	✓	✓	✓	✓	✓	✓
Part								
Instances								
Instance name	✓	✓	✓		✓	✓	✓	✓
Concept instance	✓	✓	✓	✓	✓	✓	✓	✓
Relation Instance	✓	✓	✓	✓	✓	✓	✓	✓
Equivalence	✓	✓			✓	✓	✓	✓

Table 1 Comparison of constituents of logic-based ontology representation languages

Another example of structural model is OMG initiative to represent Semantic Web ontologies in UML. The OMG Request for Proposals [ontol] solicits normative specifications for:

- A standard MOF2 compliant metamodel for Ontology Definition (ODM),
- A UML2 Profile to support reuse of UML notation for ontology definition [dutra],
- A mapping from the Ontology Definition Metamodel to the profile, and
- A language mapping for the ODM to the W3C Web Ontology Language for Description Logics, OWL DL.

ODM is expected to be as rich a language as UML and although there is considerable semantic overlap between the languages neither is a subset of the other. RFP seeks two-way and bounded mapping between an instance of the ODM metamodel and an instance of the UML2 metamodel. Bounded means that repeated applications of the two-way mapping does not result in continually larger user models. This is in order that development of ontologies can be supported in and exchanged between both UML and ontology language domains. Proposals are expected to provide a language mapping for the ODM into OWL DL.

Proposals may support mapping multiple ontologies into a single UML model. Proposals may provide a mapping for DAML+OIL, or other ontology languages, with the same characteristics as that described for OWL. Initial submissions are expected in September 2003.

2.4 Hybrid models

To enrich an expressive power of the ontological model there might be a need to use facilities of verbal, logic-based or structural models in one and the same ontology. For instance, ontologies in the SYNTHESIS project use a hybrid model [skvor]. SYNTHESIS project is aimed on component-based development of information systems [briuk1]. It uses a unified extendable object-oriented model for component specifications. Ontologies use this model too. The ontological model has verbal facilities making possible to define ontological or glossary concepts, classifier categories, multilingual definitions. At the same time ontological concepts are defined as object types. Choosing of ontology modeling style [kalin] allows to use different reasoning scenarios, following the principle that complexity is not a property of a model but a property of a task. Ontological concepts in SYNTHESIS may be compared on two levels: linguistic methods establish weak similarity of concepts, formal methods consider concepts as types, check consistency and establish their tight similarity.

Project SymOntos [formi] (and its successor SymOntoX [miss]) addresses issues of enterprise ontology management systems. It is based on the OPAL (Object, Process, Actor Language) model that allows concepts to be defined according to a frame-oriented approach. Actor, Object and Process are concept categories of the model providing for defining active and passive concept instances. The OPAL Model combines features of the verbal and structural ontological models.

3 Unifying philosophy

Ontology sometimes is defined as an explicit specification of conceptualization [grube1]. Conceptualization means an abstract view of a domain. Statements on objects of real world may be expressed by ontological concepts very differently by different authors. Thus ontologies inseparably are linked to the notion of ontological commitment. It means that any manipulation applying given ontology must be performed by an agent (human or machine) in accordance with the defined semantics of ontological concepts [grube1].

Looking on an ontology at a more philosophical angle [guari1], conceptualization is virtually an ontology as it is understood in philosophy (for instance Aristotle ontology). Ontology as a specification of conceptualization is defined by logical theory, axioms of which constrain predicate interpretations. Nikola Guarino uses notions of domain space and conceptual relationships. Bringing the notion of conceptual relationship different from mathematical relationship it is emphasized that relationships in ontology are intensional, they do not say about fact but about properties of concepts from the domain space. It is claimed that only taking into account this condition it is possible to define ontology as specification of conceptualization. It is advisable to group ontological definitions to generate a top-level ontology containing only very common categories (such as time, place, object, event, activity and so on) and ontologies of subject domains inherit their concepts from concepts of the top-level ontology [guari1].

4 Ontology based semantic management

In real projects there might be various intentions for introducing ontologies. Here some of them will be considered.

Construction of an ontology generally consists of the following steps [uscho2]. The basic concepts and their relationships for the chosen subject domain are detected, precise and unambiguous definitions are constructed for them. Concepts and relationships are discovered which are related to basic ones and they are added into the ontology too. Concepts are grouped by thematic classes and expressed in an ontological language.

Several projects are known that create ontologies to define a given subject domain and share this knowledge among users for more coordinated interaction in the domain. TOVE [fox] and Enterprise [uscho1] create ontologies for commerce and production organization, CIDOC [defin] develops an ontology for museums and cultural heritage, PhysSys [borst] creates an ontology in the area of physical systems.

The project SYNTHESIS uses ontologies for semantic interrelating of object-oriented specifications for compositional development of information systems reusing heterogeneous sources as well as for registration

of heterogeneous information collections in a mediator, integrating heterogeneous information collections. Projects OntoSeek and Plinus use ontologies for information retrieval. There are many projects where ontologies help to detect similarities and redundancies in natural language information [evere].

Ontologies are used for context definition in a subject domain. Determination of exact difference between contexts helps to solve a problem of viewing onto an information resource from another context or changing of resource moving from one context to another [farqu]. Using of shared ontologies, establishing correspondence of data to ontological definitions, enhancing ontologies for new tasks allow to achieve correct interoperation between different information systems [fikes2, sure].

The idea of intelligent agents is based on the ontological specifications. For semantic interoperability any communication of such agents, all queries that agents formulate are expressed in terms of the ontology understandable to agents.

The Web needs ontologies for relating Web-information to concepts of ontologies. The project SHOE [luke] proposes to support HTML-pages by additional tags, which relate the information to ontological definitions. Semantic Web consolidating a set of work-groups and projects [ercim, kim, bussl] focuses on bringing semantics into XML technologies.

5 Ontology integration approaches and open issues

The task of merging and reconciliation of ontologies is often required. This task is non-trivial and mostly semi-automatic because on a current level of modeling only a human can finally decide if the semantics of two ontological concepts are the same. Just few examples of ontology integration. The SENSUS project integrated several terminological sources [knigh]. This work was based on detecting closeness of verbal definitions of concepts and placing concepts in the hierarchy analyzing relationships existing in the WordNet [mille1]. Another project ONION [gange1] addressed merging more structurally complicated ontologies. The first step consisted in finding correspondences in concept specifications by classification information, then parts specifying top-level ontology were integrated, and after that every class of concepts in the remaining ontologies was integrated and reconciled. Project OntoClean [guari2] check ontologies using semantic properties of concepts. This methodology may be used for cleaning of integrated ontologies.

In the SYNTHESIS project ontology integration is the process based on verbal and type specifications of ontological concepts [skvor]. Preliminary interrelation of ontologies is detected by linguistic methods including name analysis, verbal definition analysis, linguistic semantic relationship analysis. This process is called weak integration. After that tight integration process may begin, which considers formal specifications of concepts. It uses reasoning similar to that of subsumption algorithms in description logic.

Many issues in the area of ontology integration, evolving of ontologies [klein] continue to be open. A "good" way for ontology integration is still a direction of intensive investigations. Main issue here is a deep semantic analysis. Applying existing facilities there is no way to integrate ontologies created by different working groups automatically. Semantic distinctions in similar concepts may be clarified sometimes only in discussions, applying ontologies to one and the same domain and understanding which real world objects can or cannot correspond to given concepts. For example the DELOS working group for harmonization of the CIDOC ontology with the ABC ontology has detected many differences in understanding concepts that looked similarly on the first glance [build].

6 Data modeling versus Ontology engineering

Due to the fact that modeling facilities for (conceptual) data schemas and ontologies are similar, it might be not clear what artifact has actually been defined. Convincing arguments in favor of one or another kind of a definition look as follows.

The semantics of data schema usually constitute an informal agreement between the developers and the users of a database. Ontologies represent knowledge that formally specifies agreed logical theories for an application domain. Therefore, unlike task-specific and implementation-oriented data schemas, ontologies should be as much generic and task-independent as possible [meers, calva].

7 Concluding discussion

Ontological engineering becomes an important enabling technology for semantic discovery, interoperability and integration of heterogeneous sources. This technology becomes basic ingredient of the Semantic Web. DAML-S [damls] is a good example showing how ontologies will revolutionize the Web. The Semantic Web would allow agents to do the work of searching for and organizing services required by humans or organizations. DAML-S is a Web service ontology intended to facilitate the semantic Web by describing the properties and capabilities of Web-available services in an unambiguous, computer-interpretable form. It is remarkable that reasoning in DAML-S is based on formal provers making possible to identify required services in registries. This is a rare (but promising) example showing how formal logic facilities become part of widely used industrial technologies.

References

[berne] Tim Berners-Lee, James Hendler and Ora Lassila . The Semantic Web. A new form of Web content that is meaningful to computers will unleash a revolution of new possibilities. Scientific American, May 17, 2001

[borst] P. Borst, H. Akkermans, J. Top. Engineering Ontologies. International Journal of Human

Computer Studies special issue Using Explicit Ontologies in KBS Development 46(2/3), 365–406, 1997

[briuk1] D. Briukhov, L. Kalinichenko. Component-Based Information Systems Development Tool Supporting the SYNTHESIS Design Method. Proceedings of the East European Symposium on Advances in Databases and Information Systems, Poland, Springer, LNCS No.1475, 1998

[briuk2] D. O. Briukhov, S. S. Shumilov. Ontology Specification and Integration Facilities in a Semantic Interoperation Framework. Proc. of the International Workshop ADBIS'95, Moscow, 1995

[build] Building Core Ontologies. White Paper of the DELOS Working Group on Ontology Harmonization. April 2003

[bussl] C. Bussler, D. Fensel, A. Maedche. A Conceptual Architecture for Semantic Web Enabled Web Services. ACM SIGMOD Record, vol. 31, N 4, 2002

[calva] D. Calvanese, M. Lenzerini, D. Nardi. Description Logics for Conceptual Data Modeling. In J. Chomicki and G. Saake, editors, Logics for Databases and Information Systems, pp. 229-263, Kluwer, 1998

[chaud] V. Chaudhri, A. Farquhar, R. Fikes, P. Karp, J. Rice. OKBC: A Programmatic Foundation for Knowledge Base Interoperability. AAAI'98, 1998

[damls] DAML-S: Semantic Markup for Web Services. The DAML Services Coalition. http://www.daml.org/services/daml-s/0.9/daml-s.pdf

[defin] Definition of the CIDOC object-oriented Conceptual Reference Model. Version 3.0. Editors N. Crofts, I. Dionissiadou, M. Doerr, M. Stiff. ICOM/CIDOC CRM Special Interest Group, February 2001

[donin] F. Donini, M. Lenzerini, D. Nardi, W. Nutt. The Complexity of Concept Languages. Information and Computation, 134:1-58, 1997

[dutra] M. Dutra, E. Kendall. An Introduction and UML Profile for the Web Ontology Language. Sandpiper Software, Inc. Presented at Object Management Group's Third Workshop on UML for Enterprise Applications: Model Driven Solutions for the Enterprise, October 21-24, 2002, Burlingame, CA.

[ercim] ERCIM NEWS No 51 Special Theme: Semantic Web. http://www.ercim.org/publication/Ercim_News/

[evere] J. Everett, D. Bobrow, R. Stolle, R. Crouch, V. de Paiva, C. Condoravdi, M. van den Berg, L. Polanyi. Making Ontologies Work for Resolving Redundancies across Documents. Communications of the ACM, 45(2): 55-60. 2002

[farqu] A. Farquhar, A. Dappert, R. Fikes, W. Pratt. Integrating Information Sources. AAAI-95

Spring Symposium on Information Gathering from Heterogeneous, Distributed Environments, 1995

[fikes1] R. Fikes, A. Farquhar. Distributed repositories of highly expressive reusable ontologies. IEEE Intelligent Systems, 14(2):73--79, March 1999

[fikes2] R. Fikes, and W. Pratt, J. Rice. Collaborative Ontology Construction for Information Integration. Technical report. Stanford University, 1995.

[fikes3] R. Fikes, A. Farquhar, J. Rice. Tools for assembling modular ontologies in Ontolingua. Knowledge Systems Laboratory, April, 1997

[formi] A. Formica, M. Missikoff. Concept Similarity in SymOntos: an Enterprise Ontology Management Tool. Computer Journal, Vol. 45, n. 4, 2002

[fox] M. Fox, M. Barbuceanu M. Gruninger, J. Lin. An Organisation Ontology for Enterprise Modeling. In Simulating Organizations: Computational Models of Institutions and Groups, M. Prietula, K. Carley, L. Gasser (Eds), Menlo Park CA: AAAI/MIT Press, pp. 131-152, 1998

[gange1] A. Gangemi, D. Pisanelli, G. Steve. Ontology Integration: Experiences with Medical Terminologies. in N. Guarino, ed., Formal Ontology in Information Systems, IOS Press, pp. 163–178, 1998

[gange2] A. Gangemi, N. Guarino, C. Masolo, A. Oltramari, L. Schneider. Sweetening Ontologies with DOLCE. Proceedings of EKAW, 2002

[genes] M. Genesereth, R. Fikes. Knowledge interchange format, version 3.0, reference manual. Technical report, Logic-92-1, Computer Science Dept., Stanford University, 1992

[grube1] T. Gruber. Towards Principles for the Design of Ontologies for Knowledge Sharing. International Journal of Human Computer Studies 43(5/6), pages 907–928, 1995

[grube2] T. Gruber. Ontolingua: a Mechanism to Support Portable Ontologies. Knowledge Systems Laboratory of Stanford University, Jun 1992

[guari1] N. Guarino. Formal Ontology and Information Systems. In N. Guarino (ed.), Formal Ontology in Information Systems. Proc. of the 1st International Conference, Trento, Italy, 6-8 June 1998. IOS Press

[guari2] N. Guarino, C. Welty. Evaluating ontological decisions with OntoClean. Communiations of the ACM, 45 (2), pp. 61-65, 2002

[horro1] I. Horrocks, D. Fensel, J. Broekstar, S. Decker, M. Erdmann, C. Goble, F. van Harmelen, M. Klein, S. Staab, R. Studer, and E. Motta. The ontology inference layer OIL. Technical report.http://www.ontoknowledge.org/oil/TR/oil.long.html

[horro2] I. Horrocks and U. Sattler and S. Tobies. Practical Reasoning for Very Expressive Description Logics. Logic Journal of the IGPL, Volume 8, Issue 3, May 2000

[horro3] I. Horrocks A Denotational Semantics for Standard OIL and Instance OIL. http://www.ontoknowledge.org/oil/downl/semantics.pdf

[kalin] L. A. Kalinichenko, N. A. Skvortsov. Extensible Ontological Modeling Framework for Subject Mediation Proceedings of RCDL'2002 Conference, Dubna, 2002

[kim] H. Kim. Predicting How Ontologies for the Semantic Web Will Evolve. Communications of the ACM, Vol. 45, No. 2, pp. 48-54, 2002

[klein] M. Klein. Supporting evolving ontologies on the Internet. EDBT'2002, Prague

[knigh] K. Knight. and S. Luk. Building a Large Knowledge Base for Machine Translation. Proceedings of the American Association of Artificial Intelligence Conference (AAAI-94). Seattle, WA. 1994

[luke] S. Luke, J. Helfin, J. Hendler. Applying Ontology to the Web: A Case Study. http://www.cs.umd.edu/projects/plus/SHOE/pubs/iwann99.pdf

[mcgui] D. McGuinness, R. Fikes, J. Hendler, L. Stein. IEEE Intelligent Systems: DAML+OIL: An Ontology Language for the Semantic Web. IEEE Distributed Systems Online 3(11), 2002

[meers] R. Meersman, M. Jarrar. Data modeling versus Ontology engineering ACM SIGMOD Record, vol. 31, N 4, 2002

[mille1] G. Miller. WordNet: An on-line lexical database. International Journal of Lexicography, 3(4). (special Issue). 1990.

[miss] M. Missikoff, F. Taglino. "Business and Enterprise Ontology Management with SymOntoX", in *Proceedings of the International Semantic Web Conference (ISWC-2002)*, Sardinia, June 2002, Springer Verlag.

[ontol] Ontology Definition Metamodel Request For Proposal. OMG Document: ad/2003-03-40, March 31, 2003

[owl] OWL Web Ontology Language Guide. W3C. http://www.w3.org/TR/owl-guide/

[sowa] Sowa, J. F. Knowledge Representation: Logical, Philosophical, and Computational Foundations, Brooks/Cole, Thomson Learning, 2000

[skvor] N. A. Skvortsov, L. A. Kalinichenko. An Approach to Ontological Modeling and Establishing Intercontext Correlation in the Semistructured Environment. RCDL'2000, Sep. 26-28, 2000, Protvino

[sure] Y. Sure, S. Staab, R. Studer. Methodology for Development and Employment of Ontology based Knowledge Management Applications. ACM SIGMOD Record, vol. 31, N 4, 2002

[uscho1] M. Uschold, M. King, S. Moralee and Y. Zorgios. The Enterprise Ontology. AIAI, 1995

[uscho2] M. Uschold, M. King. Towards a Methodology for Building Ontologies. Workshop on Basic Ontological Issues in Knowledge Sharing, held in conjunction with IJCAI-95, Montreal, August 20-25, 1995

[uscho3] Uschold, M.: Knowledge Level Modelling: Concepts and Terminology. The Knowledge Engineering Review, vol. 13, N 1, 1998