Maturity and Applicability Assessment of Semantic Web Technologies

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Abstract: This article analyses the maturity and applicability of Semantic Web (SW) technologies, providing the cross comparison of the key SW technology segments and the key application areas. Based on the analysis of the W3C collection of Case Studies and Use Cases, the benefits of using semantic technologies are identified. As a result of comprehensive survey of SW tools and technologies and extensive study of the SW scientific literature we extrapolate the trends in SW research and development. The overall analysis has shown that SW technologies are finding their ways to real-world applications, and that, rather than being another fashionable research issue, the Semantic Web is becoming our reality.

Keywords: Semantic Web, Semantic Web Technologies, Maturity, Assessment, Adoption, Applications, W3C
Categories: L.1.4, L.0.0, A.1, H.4.0, J.0

1 Introduction

Management of new technology development process includes several steps that range from idea generation and concept development, via market definition and product research and development to manufacturing and market launch and follow-on [Souder, 1994]. Generally speaking, when a new technology is first invented or conceptualized, it is not suitable for immediate application. Instead, in order to support strategic decision on technology, a comprehensive research is conducted that go well beyond the simple reading of a few newspaper or journal articles and sales brochures. Furthermore, new technologies are usually subjected to experimentation, refinement, and increasingly realistic and exhaustive testing. This kind of information gathering, that aims at looking beyond the immediately obvious and analysing the ramifications of a given technology in as wide-ranging and far-sighted a manner as possible is known as technology assessment [Braun, 1998].

Technology assessment is usually based on: different forecasting methods including extrapolation, expert opinion (the Delphi method) and modelling, cost-benefit analysis, cross-impact analysis, and others. Prior to incorporating that technology into a system or subsystem, many of the world's major companies and some governmental agencies are using a measure named Technology Readiness Level. For example, the USA Department of Defence and the National Aeronautics
and Space Administration distinguish nine technology readiness levels. At the lowest "level" of technology maturation the scientific research begins to be translated into applied research and development. At the middle level the prototype system (technology) is tested in real environment, while on the highest level the new technology is integrated into an existing system.

In order to locate the achievements in the Semantic Web field, especially the status of adoption of these technologies by industry, and predict the future development of SW technologies, we studied and analysed many different sources. These range from deliverables from projects financed by European Commission in 6th and 7th Framework programmes (EU FP6+FP7), via scientific papers from prestigious international conferences and journals and Web resources of standardization bodies to Semantic Web technologies and tools from industry top vendors and open source communities. In our view, the most complete analysis of the SW technologies maturity, applicability and adoption is given in the white paper “The Technology Roadmap of the Semantic Web” conducted in 2007 in the framework of the EU FP6 KnowledgeWeb project [Cuel, 07]. Herein, the authors use the Gartner Hype Cycle Curve [Linden, 03] to discuss the development and adoption of the SW technologies and applications both from the researchers’ and the business point of view. They had found out that: „research community considers that developments from the past ten years have resulted in some tools and standards, which are reliable and mature enough to be transferred to industry and successfully integrated into SW applications. The developers’ community however is not yet fully aware of the availability of such tools, which, consequently, has to be promoted further, together with the innovative functionalities they can provide to software applications.”

The paper is organized as follows. Section 2 presents the research framework. Next, Section 3 summarizes the main findings of a survey of semantic tools, while Section 4 presents the results of an analysis of the W3C collection of Case studies and Use cases. At the end, Section 5 discusses the future development of Semantic Web technologies.

2 Research framework

Semantic Web is one of the fastest developing fields within the ICT sector and, as such, under constant examination by scientists and IT professionals. Most academic work, up to now, has focused on the global public gains of adopting SW technologies, and somehow neglected the industry development and migration needs to meet SW challenges. As a result, many organizations hesitate to be early adopters and still view the Semantic Web with some skepticism [Alani, 08]. Therefore, this paper aims at (see Fig. 1):

- reporting about the main findings of a survey of semantic tools from more than 30 different commercial vendors and open source communities; and
- a snapshot of the key application areas of Semantic Web technologies and a summary of the achieved benefits based on the analysis of the W3C collection of Case Studies and Use Cases, as well as
- predictions about the future development of semantic technologies based on the above results and the analysis of the state-of-the art research in EU.
Figure 1: Research Framework

<table>
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<tr>
<th>Technology</th>
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<tr>
<td>RDF, 2004</td>
<td>RDF is a general-purpose language for representing information on the Web. Information is described in terms of objects (&quot;resources&quot;) and relations between them using RDF Schema.</td>
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<td>RDFS, 2004</td>
<td>RDF Schema serves as the meta language or vocabulary to define properties and classes of RDF resources.</td>
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<td>SPARQL, 2008</td>
<td>SPARQL Query Language for RDF is a standard language for querying RDF data.</td>
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<td>OWL, 2004</td>
<td>OWL is a standard Web Ontology Language that facilitates greater machine interpretability of Web content than that supported by XML, RDF, and RDF-S by providing additional vocabulary along with a formal semantics.</td>
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<td>WSDL, 2007</td>
<td>WSDL provides a model and an XML format for describing Web services.</td>
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<td>SAWSDL, 2007</td>
<td>Semantic Annotations for WSDL and XML Schema (SAWSDL) defines how to add semantic annotations to various parts of a WSDL document such as input and output message structures, interfaces and operations, etc.</td>
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<tr>
<td>RDFa, 2008</td>
<td>A collection of attributes and processing rules for extending XHTML to support RDF.</td>
</tr>
<tr>
<td>GRRDL, 2007</td>
<td>A mechanism for Gleaning Resource Descriptions from Dialects of Languages (e.g. microformats).</td>
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One of the crucial dilemmas that has to be clarified when analysing new technologies (in our case Semantic Web technologies) is how to distinguish “Semantic Web” technologies from others. Semantic Web technologies form the basic building blocks of the Semantic Web that is '…an extension of the current Web in which information is given the well-defined meaning, better enabling computers and people to work in cooperation' [Berners-Lee, 01]. Or, we can say that “Semantic Web technologies are technologies that enable explicit, unambiguous and shared definition of domain terms and relations (for humans and machines to interpret), and preferably
a global system for identification and a global system for reuse” [Norheim, 08]. Since
the Semantic Web was conceived, numerous web technologies have been accepted
as standards or recommendations by the W3C’s Semantic Web Activity. In an attempt
to structure and relate these technologies, Berners-Lee, presented several versions of
the Semantic Web architecture where these technologies were layered into a so-called
stack of increasingly expressive languages for meta-data specification. After the
standardization of the RDF and the Ontology layer (see Table 1), main efforts of the
Semantic Web research community in last years were devoted to: standardization
of technologies (WSDL and SAWSDL recommended in 2007) for development
Semantic Web Services and provision of tools that enhance interoperability;
development of rule languages (SWRL, RuleML), rule exchange language (RIF) and
provision of engines (ontology reasoning and rule) that enhance reasoning;
 improvement of OWL and invention of new knowledge representation formalisms
(see Table 2).

<table>
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<tr>
<th>Technology</th>
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<tr>
<td>OWL-S</td>
<td>OWL-S (formerly DAML-S) is ontology of services that enable software agents to discover, invoke, compose, and monitor Web resources.</td>
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<td>OWL 2</td>
<td>OWL 2 extends the W3C OWL Web Ontology Language with a small but useful set of features (EL, QL, RL) that enable effective reasoning.</td>
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<td>WSMO</td>
<td>WSMO provides a conceptual framework and a formal language for semantically describing all relevant aspects of Web services in order to facilitate the automation of discovering, combining and invoking electronic services over the Web.</td>
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<td>WSML</td>
<td>WSML provides a formal syntax and semantics for the Web Service Modeling Ontology WSMO. WSML consists of a number of variants such as: WSML-Core, WSML-DL, WSML-Flight, WSML-Rule and WSML-Full.</td>
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<td>SWRL</td>
<td>SWRL aims to be the standard rule language of the Semantic Web. It is based on a combination of the OWL DL, OWL Lite, RuleML, etc.</td>
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<td>RuleML</td>
<td>RuleML constitutes a modular family of Web sublanguages including derivation rules, queries, and integrity constraints as well as production and reaction rules.</td>
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<tr>
<td>RIF</td>
<td>RIF aims to be the standard rule language of the Semantic Web for rule interchange.</td>
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Table 2: An overview of emerging Semantic Web technologies

3 A survey of Semantic Web tools

SW tools and technologies are named using different keywords: ontology design/management/maintenance tools, data integration and management platforms, RDF triple storage systems, web services, SOA middleware platforms, semantic annotation tools, content indexing and categorization tools, search engines based on NLP, linguistic analysis and text mining, collaboration and other social networking technologies, knowledge visualization/presentation technologies, ontology mediated portals, ontological querying/inference engines, rule-based engines, ontology reasoners, etc. According to our investigation, most of the scientific studies analyze a
single application area of SW technologies such as: semantic annotation [Reeve, 05], ontology platforms and semantic integration [Ahmad, 07], semantic search and retrieval [Mangold, 07; Andrews, 07], ontology learning and reasoning techniques [Gómez-Pérez, 03] or collaborative knowledge construction and social networking [Correndo, 07; Gootzit, 07]. Some studies attempt to provide an overall picture of the ontology methods and techniques [Cali, 05] and discuss the key trends in the Semantic Web field [Cardoso, 07; d’Aquin, 08]. Therefore, we conducted a comprehensive survey of functionalities of the SW tools and technologies provided by more than 30 different commercial vendors and open source communities (see [Vraneš, 08]) taking into consideration all aspects of the ontological engineering (OE) process. Ontological engineering studies the ontology development process, the ontology life cycle, the methods and methodologies for building ontologies, and the tool suites and languages that support them. Common goals in developing ontologies are: sharing common understanding of the structure of information among people or software agents, enabling reuse of domain knowledge, separating the domain knowledge from the operational knowledge, analyzing domain knowledge, etc.

<table>
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<th>Tools / Technologies</th>
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<tr>
<td>Tools that enable design and development of OWL ontologies, RDF/OWL knowledge stores, as well as tools for development semantic services applications</td>
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<td>Technologies that support automatic semantic annotation, information extraction, text mining, other language processing tasks</td>
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<tr>
<td>Ontology-driven information systems and server platforms that enable RDF triple storage, semantic data integration and management, semantic interoperability based on W3C standards (XML, RDF, OWL, SOA, WSDL, BPEL4WS).</td>
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<tr>
<td>Semantic data access and search tools based on W3C standard query languages (Xquery, SPARQL), semantic search engines based on NLP, linguistic analysis and text mining, as well as technologies, including content classification, categorization and clustering; fact and entity extraction; taxonomy creation and management (tagging engines); knowledge presentation, etc.</td>
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<tr>
<td>Portals based on semantic standards (RDF/OWL), semantic wiki technology, as well as solutions that support social networking, data aggregation, dynamic publishing (RSS format) of contents and media</td>
</tr>
<tr>
<td>OWL reasoners, ontology learning tools, rule engines</td>
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Table 3: Semantic technology segments

The results of this survey were used to establish the Web4WeB repository of SW tools (see http://www.web4web.org/portal/Semantic_Web_Tools). The repository is based on Semantic MediaWiki. Each tool is described with semantic properties such as dc:description, dc:type, swrc:name, swrc:homepage, swrc:developedBy. In general, SW tools can be classified in one of the following technology segments.: o - semantic modelling and development, ■ - semantic annotation, ▲ - semantic data management and integration, ♦ - semantic search and retrieval, ☀ - semantic collaboration including portal technologies, ☋ - learning and reasoning. Table 3 gives a short description of these technology segments and identify SW tools and technologies that fit in the concrete segment.
According to our analysis, vendors have made recognizable progress towards the specification and acceptance of semantic standards, but still lack reasoning support that is crucial for the realization of the Semantic Web vision. Investigating the adoption of the SW technologies by enterprises, we have identified the following open issues: scalability and run-time support, interoperability between different knowledge organization schemas, data synchronization between OWL/RDF based knowledge bases and the traditional persistence mechanisms, migration from traditional to semantic-enabled technologies, and others.

4 Analysis of the W3C Collection of Case studies and Use cases

The World Wide Web Consortium (W3C) is the main standardization body in the Semantic Web field that was created in October 1994, to "lead the World Wide Web to its full potential by developing common protocols that promote its evolution and ensure its interoperability." The W3C collection of Semantic Web Case studies and Use cases was established in year 2007, based on an enterprise survey conducted by the SW Education and Outreach Interest Group (SWEO). Use cases include examples of built prototype systems that are not used by business functions. Case studies include descriptions of systems that have been deployed within an organization, and are now being used within a production environment. Currently (retrieved from http://www.w3.org/2001/sw/sweo/public/UseCases/ on March 20, 2009), the database stores 36 entries, where 24 are case studies. Herein, we will use the cross-tabulation to analyse the SW applications using variables such as the enterprise area of activities, the application area of SW technologies, the SW technologies used and the benefits of SW technologies.

Cross tabulation analysis, also known as contingency table analysis is most often used to analyze categorical (nominal measurement scale) data. A cross-tabulation is a two (or more) dimensional table that records the number (frequency) of respondents that have the specific characteristics described in the cells of the table. Cross-tabulation thus provides a wealth of information about the relationship between the variables. Usually, in cross-tabulation analysis a surveyed item responds to one value of the analysed variable. E.g. A SW application refers to “data integration” only. However in our analysis one SW application could tackle many problems, e.g. “data integration” and “search”.

4.1 Relating Company activity area to SW technologies used

The primary objective of this analysis is to assess the applicability of a specific SW technology in a particular business activity. The first row in Table 3 shows how many applications are related to activities such as public, e-government, health, IT, energy, life science, oil & gas, publishing and others. According to this distribution, one third of the organizations are from public sector (12) and six of them are performing e-government activities. Not presented in this table is the information that there is just one SW application in the financial sector, one in the utilities sector (eTourism), and one in education.

The first column in Table 4 shows the number of items (SW applications) that are using one specific technology. This distribution shows that almost all applications are
based on RDF(S), and most of them use in-house vocabularies. However, half of the applications incorporate public vocabularies, and just one tenth of them have implemented SKOS. Analyzing the use of public vocabularies in SW applications, it is obvious that all SW applications in health care incorporate public vocabularies, while the two SW applications in automotive industry and the SW application from finance sector rely on in-house vocabularies. Further on, we could notice that in this set of SW applications, SPARQL is ten times more frequently used than SeRQL. Considering the use of rule languages, we could conclude that they are used in just a small number of applications in public institutions (3), health care (2) and IT (1).

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</table>

Table 4: Relating Activity area to SW technologies used

4.2 Relating Application area of SW to SW technologies used

This analysis (see Table 5) aims at identification of the SW technologies applied in particular application domain such as: data integration (DI), portals, improved search (IS), content discovery (CD), semantic annotation (SA), social networks (SN), natural language interfaces (NL), service integration (SI) and customization (C). The results of the analysis have shown that in almost all SW applications the data integration function is based on RDF(S) ontological models. Less than half applications use OWL models for data integration. It is interesting to notice that SPARQL, which is a standard query language for RDF, is more exploited for data integration i.e. syntactic matching of different knowledge schemas, than for querying and retrieval. The search and content discovery function rely both on public and in-house vocabularies. It is encouraging that, besides the mature SW technologies (RDF and OWL), technologies such as OWL-S and WSMO that are still in the process of standardization are considered to be used for service integration.
4.3 Relating Benefits of SW to SW technologies used

The last analysis reports about the benefits the end user organizations have utilizing SW technologies. The analyzed benefits are as follows: data share and re-use (SR), improved search (IS), incremental modelling (IM), explicit content relation (ER), identifying new relation (IR), personalization (P), open model (OM), rapid response to change (RR), and reduced time to market (TM). From the results presented in Table 6, it is obvious that SW technologies are very suitable for data sharing and reusing, as well as knowledge search. Using faceted navigation technique, knowledge bases could be full-text searched, as well as filtered and sorted using semantic relations. Semantic technologies make the content relationships explicit and hence machine processable. This analysis has shown that semantic technologies could be used for identifying new relationships. The British Telecom Use Case has shown that adoption of the SOA could lead to reduction of time to market.

5 Future development of Semantic Web technologies

Although many Semantic Web related technologies have emerged or have been elaborated in the last few years, yet a lot has to be done until the Berners-Lee’s vision of Semantic Web becomes true. In [Benjamins, 02], the authors identified six main SW challenges (i) the availability of content, (ii) ontology availability, development and evolution, (iii) scalability, (iv) multilingualism, (v) visualization to reduce information overload, and (vi) stability of SW languages. As the ontologies are the backbone of the Semantic Web, first we will discuss the future development of SW technologies from the ontology engineering perspective.
SW methodologies: Ontology building exhibits a structural and logical complexity that is comparable to the production of software artefacts. Unlike the conventional software development, where methodologies have matured, and are usually facilitated by well defined modelling languages (like UML) and computer-aided software engineering tools (like Rational Rose), SW methodologies and tools are in their inception phase. Depending on the type of ontology to be developed, a SW methodology could be classified as a centralized or collaborative approach in the development of ontologies [Jimenez-Ruiz, 06]. In [Cardoso, 07], the author surveys the most frequently used OE methodologies and has found out that (60%) of responders develop ontologies without using any methodology. Our analysis of methodologies used in recently ended and on-going EU FP6+FP7 projects indicated that each project developed / develops its own methodology (see [Vraneš, 09]).

The availability of content: Semantic Web is an extension of the conventional Web, and therefore existing contents should be available on Semantic Web as well. For this purpose, W3C recommended several technologies including GRRDL, RDFa, and microformats. Also SW contents in RDF and OWL could be provided by semantic annotation and ontology learning techniques that involve use of advanced text mining, natural language processing and statistical algorithms. The process of online conversion of the existing unstructured contents on the web into a format understandable by computers is not a trivial and not a generally solvable task. Therefore, ontology learning is still a hot research topic.

When the content stored in RDBMS is exported into RDFS the problem of consistency and synchronization appears, because the RDF store should be updated each time the RDBMS is updated. Therefore, it is a trend lately to use the RDBMS as a SW endpoints and SPARQL+SPARQL/Update for ontology-based read and write access to relational data [Hert, 09].

Ontology availability: One of the most challenging and important tasks of ontology engineering is integration of ontologies with the purpose to build a common

<table>
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<th>Methodology</th>
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Table 6: Relating SW Benefits to SW technologies used
ontology for all Web sources and consumers in a domain. Up to now, a lot of high quality domain ontologies have been produced and made publicly available. Some of them are already adopted in real world applications (see [Doms, 08]). However, the available ontologies often exhibit different conceptualizations of similar or overlapping domains, thus leading to the interoperability problem. The problem could be overcome by detecting of semantic relations between concepts, properties or instances of two ontologies i.e. ontology matching. Due to the increasing number of methods available for schema matching/ontology integration, the Ontology Alignment Evaluation Initiative was started with the aim to compare systems and algorithms on the same basis and to allow anyone to draw conclusions about the best matching strategies. The recent and future trends in ontology matching consider using reasoning languages (e.g. Distributed Description Logics [Meilicke, 09]) to reason about ontology alignments in distributed environments.

**Standardization and stability of languages:** While the W3C is making extensive efforts to define and standardize the upper layers of the W3C SW architecture model that refers to logic, inference, and reasoning, the research communities come out with new SW languages. E.g., a new TRREE rule language is proposed in the framework of the FP6 TripCom project [Momtchev, 08]. Reasoning is a distinctive feature of the Semantic Web. However, various W3C standards related to the Semantic Web are not easy to use by a reasoner, especially due to their heterogeneity. As a result, the available reasoning tools and technologies are mainly delivered by open source communities, while the contemporary SW development frameworks offer integration with reasoning engines such as Pellet, KAON2, or Jess.

**Scalability:** Scalability is one of the key SW issues that relates to large ontology creation and maintenance, semantic metadata extraction of massive and heterogeneous content and inference mechanisms [Sheth, 03]. The scalability issue was identified very early in SW research community and adequately addressed. However, despite of huge number of SW applications today, advanced SW technologies are hardly applicable in real time on web scale. Thus, we come to the problem of adoption of SW technologies in situations where existing Web technologies already proved useful. Therefore, additional investments are needed to mature SW technologies, especially, to optimize the querying and reasoning strategies. One way to do this is to adopt concepts already proven in data base community, e.g. using caching to improve the performance of distributed systems.

### 6 Conclusion

The study presented in this article aims to answer the question “Is Semantic web another fashionable research issue or rather our reality and future?” It analyses the current status and trends in the Semantic Web and discusses the adoption the semantic web technologies by practice.  
The results reported in this article have shown that semantic-based technologies have been increasing their relevance both in the research and business worlds in recent years. W3C, together with universities and IT research organizations, and in cooperation with the major software companies and governmental agencies have already accepted many specifications, guidelines, protocols, software, and tools that are the basis for realization of the Semantic Web vision. Innovative enterprises,
interested in catching new opportunities from the Semantic Web and also developing new business models are involved in research projects and are introducing semantic technologies that facilitate data integration and interoperability, as well as improve search and content discovery. Considering the benefits from introducing SW applications, the analysed early adopters from the W3C collection of Case studies and Use cases prove that SW technologies are useful for sharing and reusing of data, improving search and establishing explicit content relations. To summarise, based upon the overall analysis we have performed, we could conclude that SW technologies are finding their ways to applications, and that rather than being another research project, the Semantic web is becoming our reality.

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