THE SEMANTIC WEB

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Introduction

Originally, the Web was introduced as a distributed system to publish and access documents across the Internet. The main way to use the Web has been browsing: a user retrieves, evaluates, and optionally reads documents with a Web browser (Törmä *et al.*, 2008: 2). Nowadays, the main value of the Web is that it enables human communication, e-commerce, and opportunities to share knowledge (www.w3.org). However, one of the major disadvantages of the current Web is that most information on the Web is designed for human consumption, and that machines can't understand this information (Berners-Lee, 1998; Berners-Lee *et al.*, 2001). That is why the future of the Internet is frequently envisioned as the Semantic Web, which overcomes this problem. In the words of Berners-Lee *et al.* (2001): "to date, the Web has developed most rapidly as a medium of documents for people rather than for data and information that can be processed automatically. The Semantic Web aims to make up for this".

This paper describes the Semantic Web. It will try to answer the following questions:

- What is the Semantic Web, and how is it different from the current Web?
- How can the Semantic Web be built?
- When will the Semantic Web be a reality?

Theoretical framework

The inventor of the World Wide Web, Tim Berners-Lee (1998) coined the term 'Semantic Web'. In a subsequent paper, he explains that "the Semantic Web will bring structure to the meaningful content of Web pages, creating an environment where software agents roaming from page to page can readily carry out sophisticated tasks for users" (Berners-Lee *et al.*, 2001). The ultimate goal of the Semantic Web is "to transform the Web into a medium through which data can be shared, understood, and processed by automated tools" (Medjahed *et al.*, 2003: 333), thus integrating data on the Web and creating a Web of Data (Herman, 2011: 201). The Semantic Web is being developed by the World Wide Web Consortium (W3C) in collaboration with many researchers and industry partners (Sadeh & Walker, 2003: 12).

The Semantic Web will be very similar to today's Web, except that documents will contain Semantic information that is readable by other computers. This Semantic information contains the meaning of the content in a language that is understood by computers (Finin *et al.*, 2005) and would support users in their tasks (Berendt *et al.*, 2002). Thus the Semantic Web aims at improving the current state of the Web (Antoniou & van Harmelen, 2008: 21). Berners-Lee *et al.* (2001) state that "the Semantic Web is not a separate Web but an extension of the current one, in which information is given well-defined meaning, better enabling computers and people to work in cooperation". They further state that the Semantic Web will be very decentralized, just like the current Web. The Semantic Web will lead to a "richer experience of IT that is able to deliver the right information at the right time in the right way" (Matthews, 2005: 16). Hendler (2001: 31) envisions the Semantic Web as a "complex Web of semantics ruled by the same sort of anarchy that rules the rest of the Web".

Literally, the term 'Semantics' means: "the meaning of a word, phrase, sentence, or text" (oxforddictionaries.com). This is exactly what the Semantic Web is about: imbue the Web with meaning. In other words, "knowledge representation meets the Web" (Törmä *et al.*, 2008: 24).

Information varies along many axes, and one of them is the difference between information produced for humans and information produced for machines (Berners-Lee *et al.*, 2001). On the Semantic Web, computers will be able to understand Semantic documents and data. Thus, the defining feature of the Semantic Web is *machine usable Web content* (Uschold, 2003). The Semantic Web must enable everyone – even people with no technical backgrounds – to create machine-readable Web content. The ideal situation would be when users don't even need to know that Web Semantics exist (Hendler, 2001: 31). In the future, the Semantic Web may not even be noticeable (Matthews, 2005: 16).

Berners-Lee *et al.* (2001) say that the Semantic Web will "unleash a revolution of new possibilities". They continue: "the real power of the Semantic Web will be realized when people create many programs that collect Web content from diverse sources, process the information and exchange the results with other programs. The effectiveness of such software agents will increase exponentially as more machine-readable Web content and automated services (including other agents) become available. The Semantic Web promotes this synergy: even agents that were not expressly designed to work together can transfer data among themselves when the data come with semantics". The authors give an example: "such an agent coming to the clinic's Web page will know not just that the page has keywords such as 'treatment, medicine, physical, therapy' (as might be encoded today) but also that Dr. Hartman works at this clinic on Mondays, Wednesdays and Fridays and that the script takes a date range in yyyy-mm-dd format and returns appointment times. And it will 'know' all this without needing artificial intelligence" (Berners-Lee *et al.*, 2001).

Ohler (2008: 9) says that the Semantic Web is "historically unique in that for the first time society can see a foundational shift in technology well in advance of its arrival". However, different people have different expectations of the Semantic Web. Marshall & Shipman (2003) say that in general, there are 3 perspectives on the Semantic Web:

- The Semantic Web as "a universal library, to be readily accessed and used by humans in a variety of information use contexts";
- The Semantic Web as "the backdrop for the work of computational agents completing sophisticated activities on behalf of their human counterparts";
- The Semantic Web as "a method for federating particular knowledge bases and databases to perform anticipated tasks for humans and their agents".

Semantic Web services

A Web service is defined as "a set of related functionalities that can be programmatically accessed through the Web", like stock trading, credit check and electronic tax filing (Medjahed *et al.*, 2003: 333). In other words: "Web services are software systems designed to support interoperable machine-to-machine interaction over a network" (Törmä *et al.*, 2008: 15).

The Web services enabled by the Semantic Web (SWWS or Semantic Web enabled Web services) will transform the Web from a "static collection of information into a distributed device of computation on the basis of Semantic Web technology making content within the World Wide Web machine-processable and machine-interpretable" (Bussler *et al.*, 2002: 24). The goal of Semantic Web services is to "enable dynamic, execution-time discovery, composition and invocation of Web services that would allow automated ad hoc interaction between Web-based applications" (Törmä *et al.*, 2008: 1).

Thus, SWWS will make more possible. Bussler *et al.* (2002: 24) also states what SWWS can do for business: SWWS "will allow the automatic discovery, selection and execution of inter-organization business logic, making areas like dynamic supply chain composition a reality".

Berendt *et al.* (2002) argues that web mining, defined as "the application of data mining techniques to the content, structure and usage of Web resources", can help building the Semantic Web. In addition, the Semantic Web can help improve Web mining results by exploiting the new semantic structures in the web.

Search engines on the Semantic Web

One of the objectives of the Semantic Web is to improve the ability of people and software agents to find information, documents and answers to queries on the Web (Finin *et al.*, 2005). The Semantic Web will cause search engines to change. Most current search engines read HTML content and text, and can't read Semantic information within documents. As a result, search engines sometimes fail to deliver the desired answer if a difficult search query is entered. In his recent article, Berners-Lee (2010) gives the example of a group of researchers at the University of Amsterdam asking the question "what proteins are involved in signal transduction and are related to pyramidal neurons? When put into Google, the question got 233,000 hits—and not one single answer". This makes search engines less precise than they could be if they incorporated Semantic information in their search results. Thus, when computers understand information, search engines will be able to deliver much better search results (Slaghuis, 2009; Shah *et al.*, 2002; Finin *et al.*, 2005). This does not mean that search engines should disregard text; instead, they should combine text and Semantic markup in their search results, which will significantly improve retrieval performance (Shah *et al.*, 2002). Finin *et al.* (2005) adds that Semantic Web documents have to be compatible with Web based indexing and retrieval technology. Several scholars tried to build a Semantic Web search engine, resulting in the prototype Swoogle, available at http://swoogle.umbc.edu/. It is a first attempt to build a search engine that works well with documents encoded in the Semantic Web languages RDF and OWL (Ding *et al.*, 2004). Another Semantic Web search engine is www.sindice.com, which has won the Yahoo Semantic Search 2011 competition (sindice.com; semsearch.yahoo.com).

Fallacies about the Semantic Web

Antoniou & van Harmelen (2008: 247-248) state that there are 4 common fallacies about the Semantic Web; things that people think, but which in fact aren't true. These 4 fallacies are:

- The Semantic Web tries to enforce meaning from the top;
- The Semantic Web requires everybody to subscribe to a single predefined meaning for the terms they use;
- The Semantic Web requires users to understand the complicated details of formalized knowledge representation;
- The Semantic Web requires the manual markup of all existing Web pages, an impossible task.

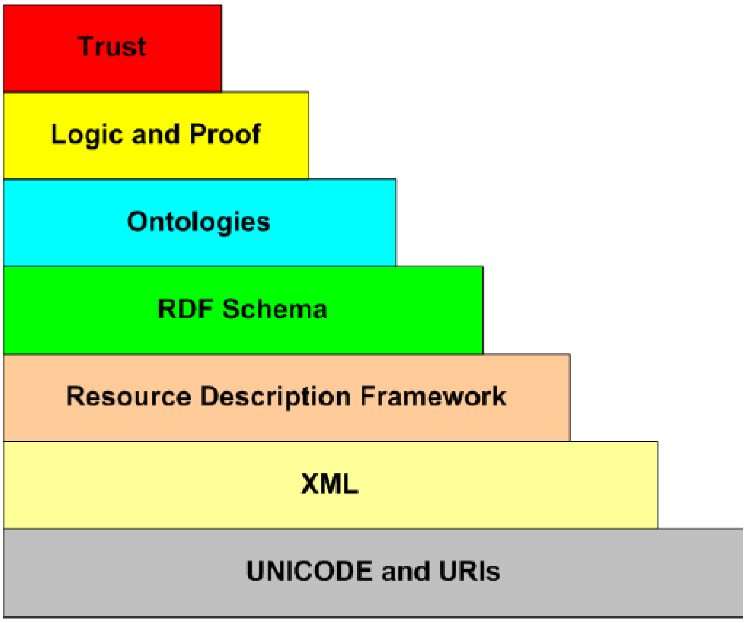
Antoniou & van Harmelen (2008: 247-248) argue that these 4 fallacies aren't true.

Architecture

The Semantic Web contains Web pages enriched with Semantic metadata that is understood by other computers. This Semantic metadata has to be written in a common language that can be understood by all computers. Such languages are called ontologies (Bozak *et al.*, 2002), and are supported by a variety of other technologies.

Two important technologies for developing the Semantic Web already exist: eXtensible Markup Language (XML) and the Resource Description Framework (RDF; Berners-Lee *et al.*, 2001; Stojanovic *et al.*, 2002: 1101). These two technologies form the core of the architecture of the Semantic Web. In fact, the development of the architecture Semantic Web proceeds in layers (Antoniou & van Harmelen, 2008: 21). See figure 1.

Figure 1: the layered architecture of the Semantic Web (Matthews, 2005: 4)



Matthews (2005: 4-5) further explains this:

- Unicode is the standard for computer character representation, and URIs are the standard for identifying and locating resources (such as pages on the Web);
- XML is a common means for structuring data on the Web but without communicating the meaning of data. It is well established on the Web already;
- RDF is a simple metadata representation framework. It is the first layer of the Semantic Web.
- RDF Schema is a simple type of modeling language for describing classes of resources and properties between them in the basic RDF model;
- Ontologies are a richer language for providing more complex constraints on the types of resources and their properties;
- Logic and proof are automatic reasoning systems that make new inferences. Thus, using such a system, a software agent can make deductions as to whether a particular resource satisfies its requirements. In other words: it enables intelligent reasoning;
- Trust represents a vision of allowing people to ask questions of the trustworthiness of the information on the Web, in order to provide an assurance of its quality.

The Semantic Web is basically an XML application, and all Semantic Web languages are build on top of XML (Fensel, 2000). Thus, XML is an important first step towards building a Semantic Web (Fensel *et al.*, 2001: 38).

In the first years of the Web, it grew mainly around HTML. This helped spur the Web's rapid growth, but its simplicity obstructed the development of more advanced Web applications. This led to XML (Fensel *et al.*, 2001: 38). Originally, XML was designed for the representation of structured documents (Törmä *et al.*, 2008: 25). In the words of Berners-Lee *et al.* (2001): "XML lets everyone create their own tags – hidden labels such as or that annotate Web pages or sections of text on a page. Scripts, or programs, can make use of these tags in sophisticated ways, but the script writer has to know what the page writer uses each tag for. In short, XML allows users to add arbitrary structure to their documents". However, XML contains no machine-processable Semantic meaning: it tells computers nothing about what XML structures mean (Törmä *et al.*, 2008: 25; Berners-Lee *et al.*, 2001). Thus, the "Semantics of XML documents is not accessible to machines, only to people" (Antoniou & van Harmelen, 2008: 59).

That is where RDF comes in. RDF is built on top of XML and provides a foundation for representing and processing metadata (Antoniou & van Harmelen, 2008: 109). RDF defines a "syntactical convention and a simple data model for representing machine-processable data semantics" (Fensel *et al.*, 2001: 38). RDF is a standard for metadata on the Web and is developed by the World Wide Web Consortium (W3C; Fensel, 2000). RDF expresses meaning encoded in sets of triples: object, property and value (Fensel *et al.*, 2001: 38). These triples can be written using XML tags (Berners-Lee *et al.*, 2001). Thus, RDF specifies interrelationships between objects. For example, Slaghuis (2009) gives the simple example of how the relationship 'Jan-Peter Balkenende is Minister of the Netherlands' is expressed in RDF:

"<rdf:Description rdf: about=#Jan Peter Balkenende">

<isMinisterOf rdf:resource="#The Netherlands "/>

</rdf:Description>"

RDF Schema (also called RDF-S) is built on top of RDF and can be used to specify vocabularies (classes and properties) to use in RDF descriptions (Törmä *et al.*, 2008: 26). Although RDF-S extends RDF, it is quite a primitive modeling language because many desirable modeling primitives are missing. This means another layer on top of the RDF/RDF-S layer is needed (Antoniou & van Harmelen, 2008: 109).

That is the ontology layer. It is built on all the underlying layers. Data "has structure and ontologies describe the Semantics of the data" (Doan *et al.*, 2003: 303). Bozak *et al.* (2002: 304) say that ontologies are "repositories of common vocabulary and modeling constructs for content descriptions". An ontology "formally defines the relations among terms. The most typical kind of ontology for the Web has a taxonomy and a set of inference rules. A taxonomy defines classes of objects and relations among them" (Berners-Lee *et al.*, 2001). Thus, an ontology describes the structure of data and the interrelationships between classes and subclasses. Hendler & Golbeck (2008: 5) give an example: "a search for information about 'dogs' won't find a picture of Pi unless you know that Pi is a dog". Uschold (2003) says that "the challenge of developing the Semantic Web is how to put this knowledge into the machine". This task – automatically finding meaning in words – is even more complicated for computers due to ambiguity and polysemy, which means that single words can have many different meanings (Hendler & Golbeck, 2008: 5).

Literally, the Oxford Dictionary defines ontology as ''the branch of metaphysics dealing with the nature of being" (oxforddictionaries.com). In the context of the Semantic Web, Fensel *et al.* (2001: 39) define an ontology as "a formal, explicit specification of a shared conceptualization". They add that in this context:

- Conceptualization refers to "an abstract model of some phenomenon in the world that identifies that phenomenon's relevant concepts";
- Explicit means that "the type of concepts used and the constrains on their use are explicitly defined";
- Formal means that "the ontology should be machine understandable";
- Shared "reflects the notion that an ontology captures consensual knowledge – that is, it is not restricted to some individual but is accepted by a group".

Ontologies are crucial to fulfill the Semantic Web vision (Gangemi & Mika, 2003; Bussler *et al.*, 2002: 24), and ontologies promise "a shared and common understanding that reaches across people and application systems" (Fensel *et al.*, 2001: 38). Ontologies give XML documents the Semantics required by automatic reasoning (Törmä *et al.*, 2008: 3).

Fensel *et al.* (2001: 39) states that an ontology language must meet 3 requirements:

- "It must be highly intuitive to the human user. Given the success of the frame-based and object-oriented modeling paradigm, an ontology should have a frame-like look and feel;
- It must have a well-defined formal semantics with established reasoning properties to ensure completeness, correctness and efficiency;
- It must have a proper link with existing Web languages such as XML and RDF to ensure interoperability".

There are several ontology languages, such as DAML-S (DARPA Agent Markup Language for Services; Paolucci & Sycara, 2003), Wordnet, CYC, OIL (Fensel *et al.*, 2001). DAML-S and OIL merged and together they became the Web Ontology Language (OWL). Shadbolt *et al.* (2006: 99) say that a frequent concern of some people about the Semantic Web is the cost of ontology development and maintenance, but Shadbolt *et al.* (2006) argue that the costs – no matter how large – will be easy to recoup.

Currently, OWL is the proposed standard for Web ontologies, and it is endorsed by the World Wide Web Consortium (Antoniou & van Harmelen, 2008: 152; w3.org). It is actually "the language with the strongest impact on the Semantic Web" (Cardoso, 2007: 85-86). Törmä *et al.* (2008: 27) explains that OWL "extends RDF and RDF Schema with additional representational constructs that, for example, allow to say that two classes are disjoint, that number of values of certain property are limited, and so on". However, these authors also explain that there is a tension that "RDF and RDF Schema are targeted to representation of meta-information, while OWL is based on first-order language (Törmä *et al.*, 2008: 30). OWL provides the Semantics that can be understood by different Web agents and applications (Wu *et al.*, 2006: 417).

The application of ontologies is said to especially have a big impact in the areas of knowledge management, e-commerce and electronic business (Fensel *et al.*, 2001: 39). Berners-Lee *et al.* (2001) further explains how ontologies can enhance the Web experience for consumers: “they can be used in a simple fashion to improve the accuracy of Web searches – the search program can look for only those pages that refer to a precise concept instead of all the ones using ambiguous keywords. More advanced applications will use ontologies to relate the information on a page to the associated knowledge structures and inference rules”.

All the above mentioned standards are crucial to the Semantic Web. Shadbolt *et al.* (2006: 99) state that “the Semantic Web can’t exist without carefully developed and agreed standards, just as the existing Web couldn’t have existed without HTTP, HTML and XML”. The Semantic Web is a “collection of standard technologies to realize a Web of Data” (W3C, 2008: 56).

Berners-Lee *et al.* (2001) say that an important part of the functioning of agents in the Semantic Web will be the exchange of ‘proofs’ written in the unifying language of the Semantic Web. For example, a search agent that has found information will automatically exchange proof to see if this is the information that was needed. Another important part of the Semantic Web is trust. Trust can be achieved by using digital signatures, which are “encrypted blocks of data that computers and agents can use to verify that the attached information has been provided by a specific trusted source” (Berners-Lee *et al.*, 2001). Because proofs and trust are so important, they are part of the architecture of the Semantic Web in figure 1.

The Semantic Web is not only about links between web pages, but it extends the current Web by describing the “relationships between things (like A is a part of B and Y is a member of Z) and the properties of things (like size, weight, age, and price). If HTML and the Web made all the online documents look like one huge book, RDF, schema, and inference languages will make all the data in the world look like one huge database" (w3schools.com).

Berners-Lee *et al.* (2001) explains that the current task of the Semantic Web community is “adding logic to the Web – the means to use rules to make inferences, choose courses of action and answer questions. […] A mixture of mathematical and engineering decisions complicate this task. The logic must be powerful enough to describe complex properties of objects but not so powerful that agents can be tricked by being asked to consider a paradox”. Matthews (2005: 2) adds that “once the Web has a mechanism for defining Semantics about resources and links, then the possibility arises for automatic processing of the Web by software agents, rather than mediation by people”.

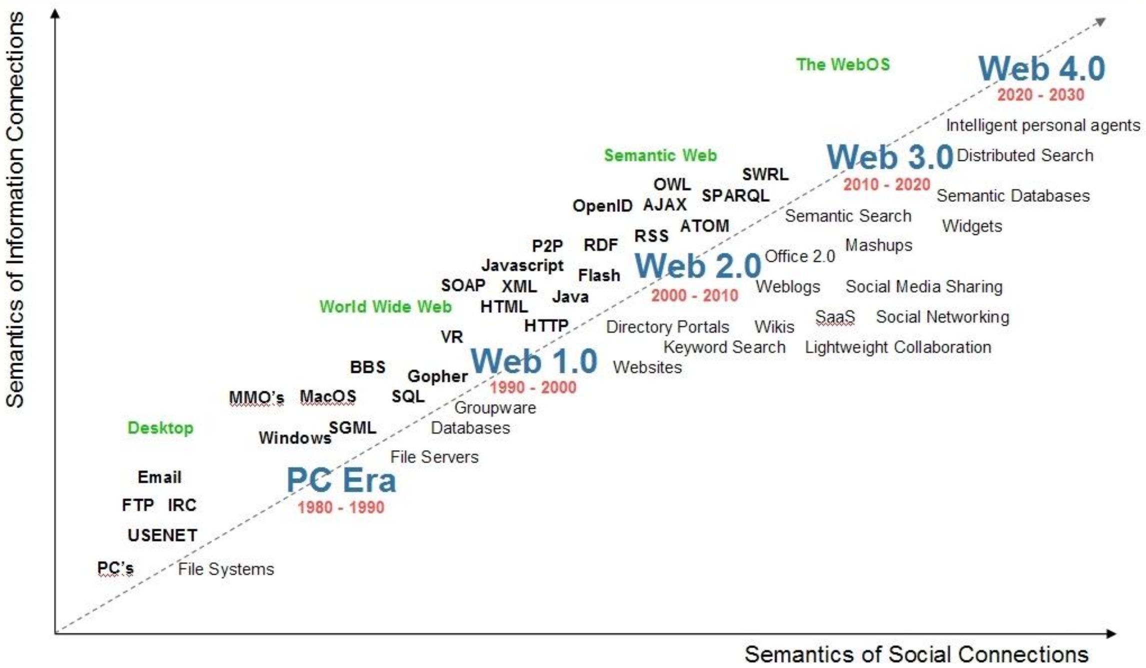
Future

In the future, Semantic Web browsers “extend the notion of the Web browser into the Semantic Web by allowing the RDF annotations of resources to be read and presented in a structured manner” (Matthews, 2005: 6). Berners-Lee *et al.* (2001) state that “the first steps in weaving the Semantic Web into the structure of the existing Web are already under way. In the near future, these developments will usher in significant new functionality as machines become much better able to process and ‘understand’ the data that they merely display at present”. The future web is envisioned by Shah *et al.* (2002) as pages containing both text and semantic markup. However, the Semantic Web suffers from a chicken-and-egg problem, just as many other new technologies. Hendler (2001: 31) explains: webmasters will not mark up their Web pages with Semantic content unless they perceive value in doing so, and tools to demonstrate this value will not be developed unless Web resources contain Semantic content. However, this conversion to Semantic content doesn't have to be done manually. As Antoniou & van Harmelen (2008: 248) explain: "Semantic Web applications rely on large-scale automation for the extraction of such Semantic markup from the sources themselves", thus it is unnecessary to convert all Web pages manually to a Semantic Web markup. But still, the current Web has to be imbued with Semantic content in order to become the Semantic Web. In a recent article the Web's founder, Tim Berners-Lee (2010), says that the Internet "is by no means finished". For example, there are currently no real-world working applications of Semantic Web services (Törmä *et al.*, 2008: 50).

In a survey, Anderson & Rainie (2010) found that technology experts "believe online information will continue to be organized and made accessible in smarter and more useful ways in coming years, but there is stark dispute about whether the improvements will match the visionary ideals of those who are working to build the Semantic Web" (Anderson & Rainie, 2010). One of these visionary ideals is for example that Berners-Lee *et al.* (2001) say that "if properly designed, the Semantic Web can assist the evolution of human knowledge as a whole". Currently, one barrier to widespread adoption of the Semantic Web is the slow progress on certain features, and particularly ontology and reasoning support, due to the development community not coming to a consensus (Matthews, 2005: 13).

Ohler (2008: 9) argues that the Semantic Web is inevitable. The foundation is already there; the underlying technologies already exist. Cardoso (2007: 88) says that the Semantic Web is slowly becoming mainstream. For example, investments are made to develop Semantic desktop and Semantic-based standards. Matthews (2005: 13) observe that many big IT companies are still hanging back, waiting to spot the opportunity. They are waiting for the research community to settle on Semantic standards, before they jump in. Cardoso (2007: 84) is being quite optimistic when he says that mainstream adoption of the Semantic Web is 5 to 10 years away. The Semantic Web is part of web 3.0. The graph in figure 2 is a good summary of the history and the future of the Web.

Figure 2: development of past and future Web technologies (figure from novaspivack.com)



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