Foundations for the Web of Information and Services

Dieter Fensel
Editor

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A Review of 20 Years of Semantic Web Research

Springer

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Foreword: A History of the Semantic Web

In putting together this volume in honor of Professor Rudi Studer, it was realized that the origins of much of this work were somewhat obscure, and that some history would help people to understand the origins of the papers included in this volume. It was also realized that the number of the key early projects in which Rudi participated would help to make it clear that he was an important player in the founding of this important technology. By dint of being one of the other folks who was around "from the beginning," I was asked if I would write up this brief introduction. In honor of Rudi, I'm happy to accept.

In the Beginning

It is hard to know who first had the idea of creating a language on the World Wide Web that could be used to express the domain knowledge needed to improve Web applications. By the mid 1990s, before most people even knew the Web existed, several research groups were playing with the idea that if web markup (it was all HTML back then) contained some machine readable "hints" to the computer, then we could do a better job of Web tasks like search, query, and faceted browsing. It's important to note that at that time, the potential power of the Web was still being debated, and there were many who were sure it would fail.

However, by 1997 or so, it was clear the Web was going to be around for a while, and there was a burst of energy going on. Various people were publishing algorithms suggesting that different approaches could be used for searching the Web than the traditional AI approaches, and it was around this time that Sergey Brin and Larry Page published their famous "PageRank" paper, which led to the creation of Google and the growth of the modern search engine.[1]

[1] I mention this here as I often hear people saying that the Semantic Web was created to improve search. That is partly true, but it is important to note that search as we knew it back then, pre-Google, was not the same as the current keyword search that powers so much of the modern Web.

At this time, we also see the first "real" refereed publications coming about machine-readable knowledge on the Web. One of these approaches was the SHOE (Simple HTML Ontology Extensions) project which I led at the University of Maryland.[2] Another was the ONTOBROKER project led by Dieter Fensel and Rudi Studer.[3] The slogan for the SHOE project, which continues to be a popular quote in Semantic Web topic, was on shirts we had printed ca. 1998, "*A little semantics goes a long way*." This idea drove the early work in projects like SHOE and Ontobroker, and it is important to note that while these early projects looked at what we now call "web ontology languages," they were driven less by the AI-inspired push for expressive languages, and more by the needs of the emerging Web—what we would now call semantic annotation or tagging.

About that same time, a research effort was growing in Europe that merged two main trends, an effort called XOL (XML Ontology Language) and the work growing out of Ontobroker. The new effort was named OIL (which at various times had slightly different acronyms, but mostly it became known as the Ontology Interchange Language). OIL had significant support from Description Logic (DL) researchers, which is to a large degree why many of the later ontology languages used DL for their logical modeling.

In parallel with this Web representation work, the World Wide Web consortium (W3C) had begun to explore whether some sort of Web markup language could be defined to help bring data to the Web. The Metadata Content Framework[4] working group was drafting a language that was later to be named the Resource Description Format (RDF). I will not recap the history of the split between XML and RDF, it was more political than technical, but suffice to say it added some confusion to the industrial story.[5]

Increasing Research Interest

In 1999, I began a three year position as a funding agent for the US' Defense Advanced Research Projects Agency and convinced them to invest in this emerging technology area. My primary argument was that this could be used to help solve a lot of the DoD's (and, of course, everyone else's) data integration problems. To help sell the US government on funding this research area, the techniques pioneered in ONTOBROKER and SHOE were used to build some demos showing the potential for these new languages.

Based on these demos, a project called the DARPA Agent Markup Language (DAML) was launched. MIT's Semantic Web Advanced Development, led by Tim

[2] http://www.cs.umd.edu/projects/plus/SHOE/.

[3] http://ontobroker.semanticweb.org/.

[4] http://www.w3.org/TR/NOTE-MCF-XML-970624/.

[5] The 2002 paper "XML and the Semantic Web" addresses some of this background http://www.ulitzer.com/?q=node/40496.

Berners-Lee, was funded under this program, with a proposal to base the emerging language in the emerging Resource Description Framework language. RDF, like SHOE, used Universal Resource Indicators (URIs) to name concepts, an important aspect of "webizing" the representation languages for the Web. Along the way, the community (both research and industrial) came to accept Tim's name for this work: The Semantic Web.

In actuality, it is worth noting that the Semantic Web was a realization of part of Tim's original conception of the Web. In fact, in a 1994 talk he said:

Documents on the web describe real objects and imaginary concepts, and give particular relationships between them. . . . For example, a document might describe a person. The title document to a house describes a house and also the ownership relation with a person. . . . This means that machines, as well as people operating on the web of information, can do real things. For example, a program could search for a house and negotiate transfer of ownership of the house to a new owner. The land registry guarantees that the title actually represents reality.

As this work grew, it was decided that an effort was needed to bring together the key players in this emerging area. The outcome of this was a Dagstuhl Workshop entitled "Semantics for the Web" which was held in March of 2000.[6] It was chaired by Dieter Fensel, Wolfgang Wahlster, Henry Lieberman and me. One of the first people we invited was Rudi, as we knew his group was beginning to do exciting work in this area. The workshop was quite successful, leading to an increasing realization that this new technology had significant potential.[7]

Also in 2000, I held a meeting with Hans-Georg Stork, then working for the European Commission funding AI research. We met to discuss the possibility of an international effort to bring forth a standard language, rather than to have competing US (DAML) and European (OIL) efforts. Based on these discussions, and the approval of our respective organizations, a group called the "Ad hoc US/EU Working Group on Agent Markup Languages" was formed. (Rudi was an active member of this group.) Despite its unwieldy name, the group met on a regular basis and created a language that integrated the best features of the DAML language emerging from the DARPA program and the OIL language coming from the EU researchers. The resulting language, which was called DAML + OIL, became a *de facto* standard used in research efforts on both sides of the Atlantic.

Another important event in showing the academic respectability of the emerging field was the publication of the first Semantic Web thesis. Jeff Heflin, a student in the SHOE group at Maryland started playing extended the annotation language to include a rule-based reasoner, a Web scraper for extracting SHOE from non-annotated Web sites, a visual query by example system and a bunch of other things. His thesis[8] included the first formal description of the Semantic Web—defined in terms of multiple ontologies linked together.

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[6] http://www.dagstuhl.de/en/program/calendar/semhp/?semnr=00121.

[7] Many of the papers from this workshop appeared in the MIT Press Book *Spinning the Semantic Web*, edited by the four workshop organizers.

[8] Available online at http://www.cse.lehigh.edu/~heflin/pubs/heflin-thesis.pdf.

Not long after, several European theses on the use of semantics on the Web were completed (and of course one of the leading universities in this was the University of Karlsruhe under Rudi). These theses expanded the work well beyond Jeff's start, adding technologies such as text-mining, ontology development and learning, automated reasoning, and many others.

The growing community, funded by DARPA in the US and the Information Society Technologies (IST) Program[9] in the EU, realized it needed to come together more formally, and in 2001 formed a symposium held in San Francisco in 2000, that evolved the following year into the International Semantic Web Conference (ISWC) which has been held every year since. ISWC is run by an international organization called the "Semantic Web Science Association[10]" and at the first meeting of this organization, Rudi was elected the President of SWSA, a role he filled until 2008 when, at the end of his second three-year term, he moved on to the Past President role.

Starting in 2001, a great deal of research went into developing ontologies on the Web, funded to a large degree by IST funding to researchers coming out of the AI community. While RDF development continued, and the redesigned RDF and RDF Schema became recommendations in 2004, there was a more visible effort going on in the world of ontology languages. Based on the DAML + OIL work, the World Wide Web Consortium created the "Web Ontology Working Group" (often referred to as WOW-G), which created the Web ontology language OWL. (OWL also became a W3C recommendation in 2004.) OWL remains the primary language being used in current AI-based Semantic Web work, its reference manuals have been translated into a number of languages, and there are a number of books available on OWL use. Rudi's research groups, of course, were major players in the IST framework projects, in the design of OWL, and in a number of other important aspects of the emerging Web ontology world.

In short, no matter where one looked during the formative days of the Semantic Web, Rudi and/or members of a research group he ran were always present.

Forward to the Present

Since the goal of this foreword was primarily to discuss the earlier history of the Semantic Web, I won't spend a lot of time on the intervening years from then to now. I do however want to talk about one aspect of the Semantic Web community that has emerged in the years since.

As mentioned previously, much of the work in the early Semantic Web research community was funded in the AI space for work in ontologies. However, around 2006, as the weaknesses in pure social tagging became more and more evident, and

[9] This was later renamed the Information and Communication Technologies area, which funded the large Framework 6 and Framework 7 EU projects.

[10] http://www.iswsa.org/.

as the Semantic Web query language, SPARQL,[11] joined the W3C's growing stack of Semantic Web recommendation and reports, Web application developers became more and more interested in the Semantic Web languages, but primarily the use of RDF as part of the Web architecture (perhaps enhanced with a few terms from RDFS and OWL, but primarily using very little OWL). This community, which is sometimes called the "linked data" community, because it takes much of its inspiration from the earlier "Web of Data" aspects of the Semantic Web, focuses much more on the scaling and Web application use of semantic technologies, and much less on the expressive ontologies of the research community.

At this point in 2010, both communities are healthy, although the linked-data community is showing up far more in applied work, as it makes use of the more mature parts of the Semantic Web technology stack and as it fits nicely with some of the business needs of the modern Web community. In recent days, there have been announcements of the use of RDF-based technologies by Facebook and Twitter, Semantic Search is being actively pursued at Google, Microsoft Live Labs and other large Web companies. A number of small "Web 3.0" companies have emerged, and many of these use some simple ontologies, and a lot of data, to try to gain an advantage over their competitors. Countries around the world are starting to explore the exporting of data to the linked data world, led by efforts in the UK (http://data.gov.uk) and the US (http://data.gov).

This primarily non-academic use of Semantics has not been largely powered by expressive ontologies, but rather by simpler data structures and very simple vocabularies. As I write this, Facebook's "Open Graph Protocol" (OGP)[12] is emerging as a widely used technology on the Web. The "ontology" (if one could call it that) of the OGP is very simple, consisting of a few main properties such as title, type, image and URL. So, for example, the open government data project at RPI (http://logd.tw.rpi.edu) has a like button on it. The embedded RDFa reads:

```
<html xmlns:og="http://opengraphprotocol.org/schema/">
<head>
  <meta property="og:title" content="RPI Data-Gov project"/>
  <meta property="og:site_name" content="Data-gov: Linking Open
Government Data"/>
  <meta property="og:type" content="University Web Site">
...
<head>
```

This enables any user to click on the Web page and say (on their Facebook page) that they like this Web site. This may not seem very much like AI (it's not), nor very much in the way of linked data (the type field is just a string), but these little bits of RDFa are starting to show up on thousands of Web sites, and it is not too unlikely that OGP will soon be the most used ontology in history, given the power of Facebook in the Web world. There is also growing interest in mechanisms for

[11] http://www.w3.org/TR/rdf-sparql-query/.

[12] See http://developers.facebook.com/docs/opengraph for more details.

having the type fields contain reference to online vocabularies (such as SKOS files) increasing the interest in these other, simple, Semantic Web products.

It probably will come as no surprise to the readers of this book that within the Semantic Web research world, there is some tension between those who believe that expressive KR is the future of the technology, and those who feel that studying scaling, data integration and the appropriate use of language and semantic data technologies are the way to go. Most research groups are heavily involved in one or the other of these, and it is clear that in many places, bringing together the linked-data and Semantic Web worlds will be a considerable effort.

I was thus extremely pleased on a recent visit to "Semantic Karlsruhe," where there are several research groups and many projects led by Rudi, to discover that not only were there a number of researchers working in each of these areas, but that they knew and respected each others' work. New ideas in the combination of these technologies and in finding "middle ground" for exploring with new Semantic Web projects is clearly something we see happening there, a promising sign for the future of both sides of the Semantic Web community.

What Comes Next?

As the Semantic Web is starting to flourish in the applied research community and to transition from our laboratories to the "real world" of the Web, there is clearly a lot of discussion as to the future of the research enterprise in semantics. As this was not what I was asked to write about, I'll hold my opinions on this for some later, more contentious, article. However, there is one opinion I hold that I have not heard anyone dispute—I believe that, as he has been since the beginning of the Semantic Web work, Rudi will be a leading researcher in whatever the future brings.

Troy, USA Jim Hendler
August, 2010

Preface

I met Rudi more than 20 years ago, while I was searching for a place to do a PhD on Artificial Intelligence. Originally, I was more interested in Machine Learning but with his great spirit of non-directional leadership, Rudi slowly moved me in the direction of knowledge acquisition and knowledge engineering. What surprised me most about these areas was that they looked more like applied sociology than computer science, and only the recent web science adventure surprised me even more. Anyway, I followed his advice-for many years trying to discover what the "formal semantics" of these areas really were. After earning my PhD with Rudi and my interesting research period in Amsterdam, I really gained some insight and got excited about it. I focused on heuristic problem solvers and tried to answer the questions of why and when they are better than global problem solvers. In the end, all our life is about compromising results by restricting effort. This culminated in an exciting Habilitation that, aside from myself, very few people in the world have ever understood.[1]

Then Rudi shocked me once again. Basically, he told me that I should either focus on something simpler, or I should forget the idea of ever getting a Professorship. I did not like his message but I felt he was right. Reality was simply not ready for my genius. He proposed that I work on Ontologies. Frankly, I hated this suggestion as I regarded Ontologies as quite a boring area of Science and Engineering. First, they are only about data structure, where very few dynamic events happen. Second, most Ontologists have missed the last five hundred years of philosophical development that introduced the notion of an observer and his perspective on any world view. Even conservative physicians had to adopt this point of view nearly one hundred years ago. It was naive of me to assume to know THE model of reality, and to be surprised that others do not share this point of view. That is really not appropriate to the state of philosophy after Descartes and others. Anyway, I had been infected with a virus in Amsterdam that generated an interesting potential of using Ontologies as flexible data schemas. It was the ***Web***. Academics from the hypertext area found

[1] My colleague Enrico Motta from Open University managed to implement some pieces of this grand vision.

the Web primitive, academics from the database area found it even illegal, but I got caught by it. So in Karlsruhe in 1996, we began to work on extending HTML by means of adding semantics to textual and graphical information on the Web. Happily, we found similar work published by Jim Hendler's group and throgh Tim Berners-Lee's work, and then later the RDF work of W3C. This period of time significantly changed my life and I would like to thank Rudi for the great support he gave me for nearly a decade and for the great cooperation we have had since then. Therefore, it is my duty and pleasure to edit this "Festschrift" that has collected contributions from his colleagues and academic offspring.

The book starts with a preface by Jim Hendler that you have already read if you are reading this book in linear order. He provides a historical view on the development of semantic web research and we would like to mention again his early work on SHOE that was a great encouragement for our work.

We then collected six contributions from Rudi's peers (and actually, one 'super peer' is included). The core usage of semantic technology is to provide scalable means to achieve interoperability in large, distributed, heterogeneous, and dynamic environments. The article by Haslhofer and Neuhold[2] puts Rudi's work in context by providing a retrospective on semantics and interoperability research as applied in computer science. His colleagues Oberweis, Schmeck, Seese, Stucky, and Tai from the Institute AIFB, relate Rudi's work to other areas of applied computer science such as Logic, Complexity Management, Efficient Algorithms, Organic Computing, and Business Process Management. There has always been a close link between semantic technology and database technology on the one hand, and knowledge technology on the other. One could even argue that there is a complexity chain of data, information, and knowledge where semantics is mostly busy with the intermediate item, i.e., information. The article contributed by Lockemann, a colleague from the University of Karlsruhe, provides an excellent analysis of the communalities and differences between database and Ontology technology in terms of efficiency and effectiveness. Personally, I think this article already makes this book a good buy! Van Harmelen and Ten Teije from the VU Amsterdam and Wache from the University of Applied Science in Switzerland take a look from the opposite angle, considering semantics from the knowledge technology perspective. Their work on knowledge-based web service selection discusses a pathway for reunifying heuristic problem solving with semantic web technology. The application of semantic technologies for knowledge management issues is discussed in the article by Davies, British Telecom, Warren, Eurescom, and Sure,[3] GESIS and the University of Koblenz-Landau. Using semantics for knowledge management also indicates that the borderline between semantic and knowledge technology is at least as fuzzy as the borderline between database and semantic technology. Finally, Horrocks, from the University of Oxford, takes a technical view on the core of semantic technology, focussing on tools to work and reason with Ontologies.

[2] Obviously, it is the role of Erich Neuhold to put the work of Rudi in context!

[3] Each classification system has to deal with exceptions. York Sure is actually an academic offspring of Rudi.

These articles are followed by eleven contributions provided by Rudi's Academic offspring. Four articles are about the *Web of data, information and knowledge*, focusing on knowledge mining, knowledge networks, and knowledge diversity. The following four articles go beyond the static web of data and discuss the role semantic technology can play in the *Web of software and services* by modeling software, services, cloud computing, and event-driven architectures. Finally, applications of semantic technology are discussed for knowledge management scenarios.

I wish Rudi many more years of productivity and I am looking forward to cooperating with him in as many projects in the future as we have in the past.

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Innsbruck, Austria Dieter Fensel
November, 2010

Sponsor Information

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Application research in the fields of information technology, engineering and economics with reliable knowledge and technology transfer is the core business and expertise of FZI Forschungszentrum Informatik. As a non-profit institution, established 25 years ago by the State of Baden-Württemberg and the University of Karlsruhe (now Karlsruhe Institute of Technology) we deliver the results of scientific research directly to you. As an independent research institution, FZI works for companies and public institutions regardless of company size: from small business to large corporations, from local public administrations to the European Union.

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The Karlsruhe Institute of Technology (KIT) is the merger of the former Universität Karlsruhe (TH) and the former Forschungszentrum Karlsruhe. With about 8000 employees and an annual budget of 700 million Euros, KIT is the largest technical research institution within Germany. The Institute AIFB (Applied Informatics and Formal Description Methods) at KIT is one of the world-leading institutions in Semantic Web technology. Approximately 20 researchers of the knowledge management research group are establishing theoretical results and scalable implementations for the field, closely collaborating with the sister institute KSRI (Karlsruhe Service Research Institute), the start-up companies ontoprise and fluid Operations, and the Knowledge Management group at the FZI Research Center for Information Technologies.

ontoprise GmbH

ontoprise GmbH is a leading provider of products, solutions and services in the area of semantic technologies. These make it possible to: Describe the meaning of information to be machine-readable, structure knowledge, record complex interrelationships and to integrate distributed information. Thereby, employees involved in knowledge-intensive processes are optimally supplied with the right information. Additionally, companies are empowered in making the right conclusions from existing information.

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The Semantic Technology Institute (STI) Innsbruck (http://www.sti-innsbruck.at), formerly known as DERI Innsbruck, was founded in 2002 and has developed into a challenging and dynamic research institute. Through STI International, we collaborate with a network of international institutes and global industrial partners

in Asia, Europe and the USA. Our major objective is to establish Semantic technologies as a core pillar of modern Computer Science, thereby providing interoperability and scalability for the web of data and services.

STI International

STI International is a global network carrying out research, education, innovation and commercialization activities on semantic technologies facilitating their deployment within industry and society at large. STI International is organized as a collaborative association of interested scientific, industrial and governmental parties that share a common vision. It sets up its own research infrastructure and implements public and internal services that support the individual partner organizations in their research collaboration, standardization, dissemination and exploitation activities

WeST

The institute "WeST—Web Science and Technologies" works on issues related to the usage and the technologies of the World Wide Web. Researchers consider the technical aspects of the Web being a globally networked information system and information services as well as the personal and social aspects of Web usage. They aim at understanding the structure and evolution of the Web, for making the Web even more useful and for ensuring its future prosperity and usefulness. Germane to these aspects are the novel technologies of the Semantic Web, Web Retrieval, Multimedia Web, Interactive Web and the Software Web.

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