Semantic Web Technologies

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1. INTRODUCTION: THE SEMANTIC WEB IN THE NEWS

The Semantic Web initiative of the World-Wide Web Consortium (W3C) has been active for the last few years and has attracted interest and scepticism in equal measure. The initiative was inspired by the vision of its founder, Tim Berners-Lee, of a more flexible, integrated, automatic and self-adapting Web, providing a richer and more interactive experience for users. The W3C has developed a set of standards and tools to support this vision, and after several years of research and development, these are now usable and could make a real impact. However, people are still asking how they can be used in practical situations to solve real problems.

This article discusses the current state of the Semantic Web, and how it may impact on the UK Higher and Further Education sectors over the next few years. It introduces Tim Berners-Lee's initial vision for the Semantic Web, briefly discussing the technology and tools now available to support it, taking a look at the 'layer-cake' diagram of the Semantic Web architecture. The impact of the Semantic Web is likely to be particularly strong in distance learning, libraries and information management, and collaborative research; we shall take a look at each. The UK is particularly strong in these areas, and we present a roundup of the research and development, with an emphasis on the leading UK research teams.

2. SOME DEFINITIONS AND BACKGROUND

The term 'Semantic Web' is one which is widely used, often without much care or understanding of its origins and meaning. However, in general there are three main views of the term which are widely used: the *vision*, the *programme* and the *technology*.

2.1 The Vision

The Semantic Web is inspired by a vision of the current Web which has been in the background since its inception, and which is influenced by earlier work dating back to Vannevar Bush's idea of the 'memex' machine in the 1940s (based on a universal library, complete with a searchable catalogue) [15]. Tim Berners-Lee originally envisioned the WWW as including richer descriptions of documents and links between them [6]. However, in the effort to provide a simple, usable and robust working system, which could be used by everyone 'out-of-the-box', these ideas were put to one side, and the simpler, more human-mediated Web which we know today resulted.

The bigger vision found expression in an article written by Tim Berners-Lee, Jim Hendler and Ora Lassila in Scientific American in May 2001 [8]. In this article they provide a compelling vision of a world where instead of people laboriously trawling through information on the Web and negotiating with each other directly to carry out routine tasks such as scheduling appointments, finding documents and locating services, the Web itself can do the hard work for them. This can be done by providing sufficient context *about* resources on the Web and also providing the tools to use the context so that machines (or 'software agents' – programs working on behalf of people) can find the right things and make decisions. In the words of the article:

> *'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.'*

This is an ambitious long-term aim: nothing less than imbuing the Web itself with *meaning*. That is, providing meaningful ways to describe the *resources* available on the Web and, perhaps more importantly, why there are *links* connecting them together [41]. Thus the notion arises of *semantics* being part of the Web, capturing the reason things are there. 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. In the same article, the Semantic Web is defined as:

> *'...an extension of the current Web in which information is given well-defined meaning, better enabling computers and people to work in cooperation.'*

A simple example used to motivate the Semantic Web is the need to discover documents on the Web, not only from their textual content, as conventional search engines do, but also from a *description*. The problem is exemplified by the frustration in finding articles written by a particular author, rather than those which include the author's name. In response to the query 'Tim Berners-Lee' a search engine will respond with all the papers including that phrase, some of which will be by Tim Berners-Lee, but most of which will cite or refer to him – as this paper does. The Semantic Web can allow each document on the Web to be annotated stating who its author was, when it was created, and what content it has; then only those with the appropriate author will be returned.

To add these descriptions or annotations, it is necessary to state what this additional description, sometimes known as 'metadata', should be, and how it should be interpreted. How this is done is the subject of the programme set out in the next section.

2.2 The Programme

It was not until the Semantic Web Roadmap [7] appeared, setting out a plan for re-engineering the Web to achieve this vision, that the Semantic Web became a programme. The Semantic Web is an initiative of the World-Wide Web Consortium (W3C) [75], the international organisation which sets standards for the technologies which underlie the World-Wide Web.

The W3C was set up when it became clear that there was a danger of the Web breaking apart through the pressure of competing commercial interests, and it is now a major forum providing information infrastructure between people and organisations in the world. Headed by Tim Berners-Lee, the W3C seeks to maintain the interoperability and universality of the Web via the setting of open standards to which Web tools should conform – independent of particular interests. It is funded by member subscription and there are some 400 members world wide. Members include the leading commercial companies in the field as well as many not-for-profit organisations and universities.

The Semantic Web initiative was started as the Web Metadata Working Group in 1998, and subsequently became the Semantic Web Activity [63] which has taken the view that the Semantic Web:

> *'... provides a common framework that allows data to be shared and reused across application, enterprise, and community boundaries. It is a collaborative effort led by W3C with participation from a large number of researchers and industrial partners. It is based on the Resource Description Framework, which integrates a variety of applications using XML for syntax and URIs for naming.'*

Early work produced two influential proposals: the Resource Description Framework Model and Syntax Specification [42], and the Resource Description Framework Schema Specification [11]. However, at that stage activity was on a small scale and there was confusion on its scope and usefulness, so work returned to a more exploratory phase. The DAML programme, a DARPA-sponsored initiative in the US, was set up and proposed several influential approaches to the problems posed by the Semantic Web [20].

Within the last two to three years, work has moved on within W3C with increased vigour. Two major working groups of the W3C, the RDF Core Working Group [59] and the Web Ontology Working Group [76] have produced major sets of recommendations. Exploratory activities within W3C have also been extensive under the Semantic Web Advanced Development programme [64], and the Semantic Web Advanced Development in Europe project [65], sponsored by the European Commission.

The work is continuing within two recently constituted groups. The Semantic Web Best Practices and Deployment Working Group [67] seeks to support and extend the practical application of the Semantic Web within a number of fields, providing sample tools and general descriptive vocabularies in key areas. The RDF Data Access Working Group [60] is developing languages for querying and processing semantic annotations across the Web. Initial work is taking place on the reasoning tools, which will greatly enhance the level of power of Semantic Web agents.

Beyond the W3C, the programme has taken on a life of its own. A large number of researchers are now exploring how to take best advantage of the technology. It has the attraction of combining the distributed nature of the Web with the power of semantic description, logic and reasoning. There are many projects within the UK and sponsored by the European Commission, as well as in the US and the rest of the world. The total investment in the Semantic Web world-wide has been in the tens of millions of pounds.

Also notable within the Semantic Web is how communities of individual developers and users are working together to provide tools and information collaboratively. However, in order to make a major impact on the IT infrastructure, major IT companies will need to take part. Companies such as Hewlett-Packard and British Telecom are investing in research programmes in the area, and with the base recommendations now in place, opportunities are emerging that will allow the initiative to have considerable impact in the next few years.

2.3 The Technologies

The third common use of the term Semantic Web is to identify a set of technologies, tools and standards which form the basic building blocks of a system that could support the vision of a Web imbued with meaning. The Semantic Web has been developing a layered architecture, which is often represented using a diagram first proposed by Tim Berners-Lee, with many variations since. Figure 1 gives a typical representation of this diagram.

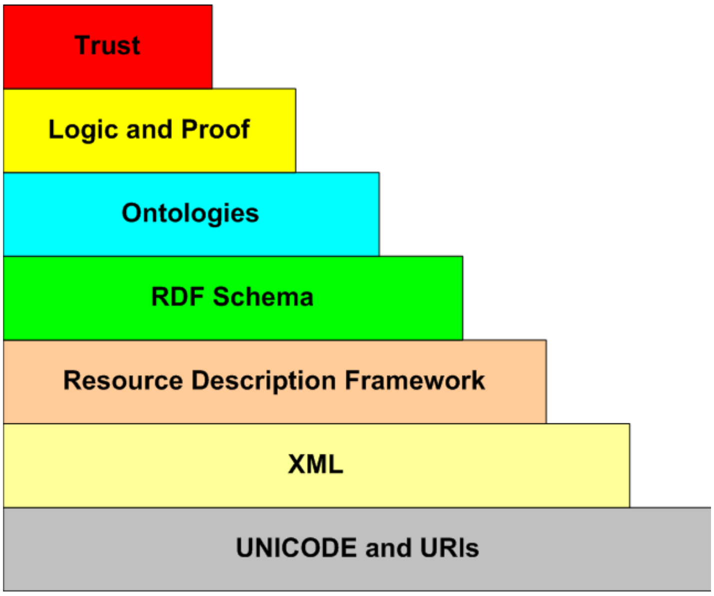

Figure 1: Semantic Web layered architecture

While necessarily a simplification which has to be used with some caution, it nevertheless gives a reasonable conceptualisation of the various components of the Semantic Web. We describe briefly these layers.

- **Unicode and URI**: Unicode, the standard for computer character representation, and URIs, the standard for identifying and locating resources (such as pages on the Web), provide a baseline for representing characters used in most of the languages in the world, and for identifying resources.
- **XML:** XML and its related standards, such as Namespaces, and Schemas, form a common means for structuring data on the Web but without communicating the meaning of the data. These are well established within the Web already.
- **Resource Description Framework:** RDF is the first layer of the Semantic Web proper. RDF is a simple metadata representation framework, using URIs to identify Web-based resources and a

graph model for describing *relationships* between resources. Several syntactic representations are available, including a standard XML format.

- **RDF Schema:** a simple type modelling language for describing classes of resources and properties between them in the basic RDF model. It provides a simple reasoning framework for inferring types of resources.
- **Ontologies:** a richer language for providing more complex constraints on the types of resources and their properties.
- **Logic and Proof:** an (automatic) reasoning system provided on top of the ontology structure to *make new inferences.* Thus, using such a system, a software agent can make deductions as to whether a particular resource satisfies its requirements (and vice versa).
- **Trust:** The final layer of the stack addresses issues of trust that the Semantic Web can support. This component has not progressed far beyond 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.

We do not go into the details of these languages here. For an introduction see particularly the primer and guideline material [48], [71], or one of the books which are appearing, for example [2], [55] .

The Semantic Web initiative has an ambitious programme to bring existing work on knowledge representation and reasoning to bear on the Web. These concepts were traditionally developed within the Artificial Intelligence community, and this has given the impression that the activity is of largely academic interest. A common misconception is that it is an attempt to bring AI to the Web. However, the Semantic Web has a less ambitious and more immediately realisable goal of making the Web *machine processable,* making it in practice more like database and information systems management, but extended to the database of the whole Web. The application and potential of this work is enormous.

The basic layers of the Semantic Web are in place, and the following recommendations were released by the W3C on 10th February 2004, covering the RDF, RDF Schema and Ontology layers.

- RDF/XML Syntax Specification (Revised) [4]
- RDF Vocabulary Description Language 1.0: RDF Schema [12].
- RDF Primer [48]
- Resource Description Framework (RDF): Concepts and Abstract Syntax [38]
- RDF Semantics [31]
- RDF Test Cases [30]
- Web Ontology Language (OWL) Use Cases and Requirements [33]
- OWL Web Ontology Language Reference [21]
- OWL Web Ontology Language Semantics and Abstract Syntax [56]
- OWL Web Ontology Language Overview [45]
- OWL Web Ontology Language Test Cases [16]
- OWL Web Ontology Language Guide [71]

Progress on the rule and reasoning layer of the Semantic Web has been slower, with many proposals varying from simple queries to modal logic theorem provers. This is still an active research area, and we would anticipate that several approaches will emerge that are suitable for different purposes. Recently, there have been initial proposals to provide standardised languages for the querying of RDF data, called SPARQL [58]. There have also been experiments with rule languages, such as RuleML [61] and CWM [18]. These are demonstration applications to illustrate the value of reasoning, but they have not been widely adopted, nor do they approach standardization. This is now beginning with the emergence of a language for rules and reasoning called SWRL [34]. However, there is some way to go until there is greater consensus on the best approaches and required functionality of reasoning tools.

Large numbers of development tools, program libraries and environments have emerged to support the development of the WWW. For a comprehensive list of development tools as well as links to a wealth of other information on the Semantic Web, see Dave Beckett's Resource Guide [5].

Applications of RDF are emerging, including Dublin Core [50], RDF Site Summary [1], Composite Capability/Preferences Profiles [38], and proposals for the Protocol for Internet Content Selection [13] and Protocol for Privacy Preferences Project [44]. These are applications that are ideal for the Semantic Web as they describe properties of Web-based resources. Nevertheless, each individually could be described using some domain-specific method, and possibly in a more succinct manner. The benefit comes when they are merged together – then a 'network effect' can take place, with emergent properties appearing. This is perhaps the key advantage of the approach.

In this report we concentrate on the application projects of interest to the general user in the Higher and Further Education sector. Further, we shall concentrate on tools which use the RDF/RDF Schema layers of the model; using Ontologies is covered in a previous report within the JISC Technology and Standards Watch series [78]. With the emergence of ontologies and, in the future, reasoning tools, we can expect the full vision to be delivered. However, we can achieve a good deal with the tools available now.

3. IMPACT ON HE AND FE

It is difficult to predict where the Semantic Web will affect the Higher and Further Education sector as it is not yet clear where the major impact of the Semantic Web will be in general. However, there are four clear areas where there could be major implications for both teaching and research: in information management; in digital libraries; in support for interaction between virtual communities and collaborations; and in e-learning methods and tools.

3.1 Information Management and Discovery Tools

Perhaps the most widely developed space at the moment within the Semantic Web is in information management, i.e. the organisation and discovery of information. This is the primary motivation behind the Semantic Web's development, but people are taking a variety of approaches to developing tools to extend the current Web into a true Semantic Web. These tools typically take an existing Web component we are familiar with, such as browsers, servers and search engines, and augment them with the power to process the semantic annotations associated with webpages.

Semantic Web Browsers, for example, 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. For example, the Haystack Web-browser from MIT [32]:

> *'aggregates RDF from multiple arbitrary locations and presents it to the user in a human-readable fashion, with point and click semantics that let the user navigate from one piece of Semantic Web data to other, related pieces'*

A user can load RDF annotations from other websites, and also catalogue information from his or her own file-store or e-mail accounts. The structured searches can be made based on this annotation, and links between information can be created and presented based on the connections between resources embodied in the RDF. Figure 2 gives a typical view of Haystack in practice.

The Magpie Semantic Web filter takes an alternative approach, providing a plugin which can be added to a standard Web browser such as Internet Explorer [47]. This uses an ontology representing some area of shared interest, such as academic life. The ontology is then used to 'semantically markup' webpages on the fly, recognizing key terms from the ontology, and then provides a series of 'semantic links' from that page. Thus on recognizing that a term in a webpage describes a project (such as 'Magpie'), it can provide links to such related categories such as what the project is about, who is working on the project, and publications arising from the project.

Semantic Web servers such as Joseki [36] from HP Labs in Bristol provide the other side of the Web architecture, allowing RDF annotations of resources to be published onto the Web. Such tools allow querying and manipulation of RDF across the Web. Whilst a vital part of the Semantic Web infrastructure, such tools currently require a lot of technical knowledge to be used effectively.

The other most widely used tools on the Web, as far as a user's experience is concerned, are search engines, with Google today being the most popular. Semantic Web search engines such as Swoogle

[73] are under development. Swoogle can use ontologies to refine the search, and has harvested the existing ontologies and RDF data available on the Web. As yet there is a long way to go to make such tools intuitive to the general user, but in the future we can reasonably expect powerful extensions to general search engines.

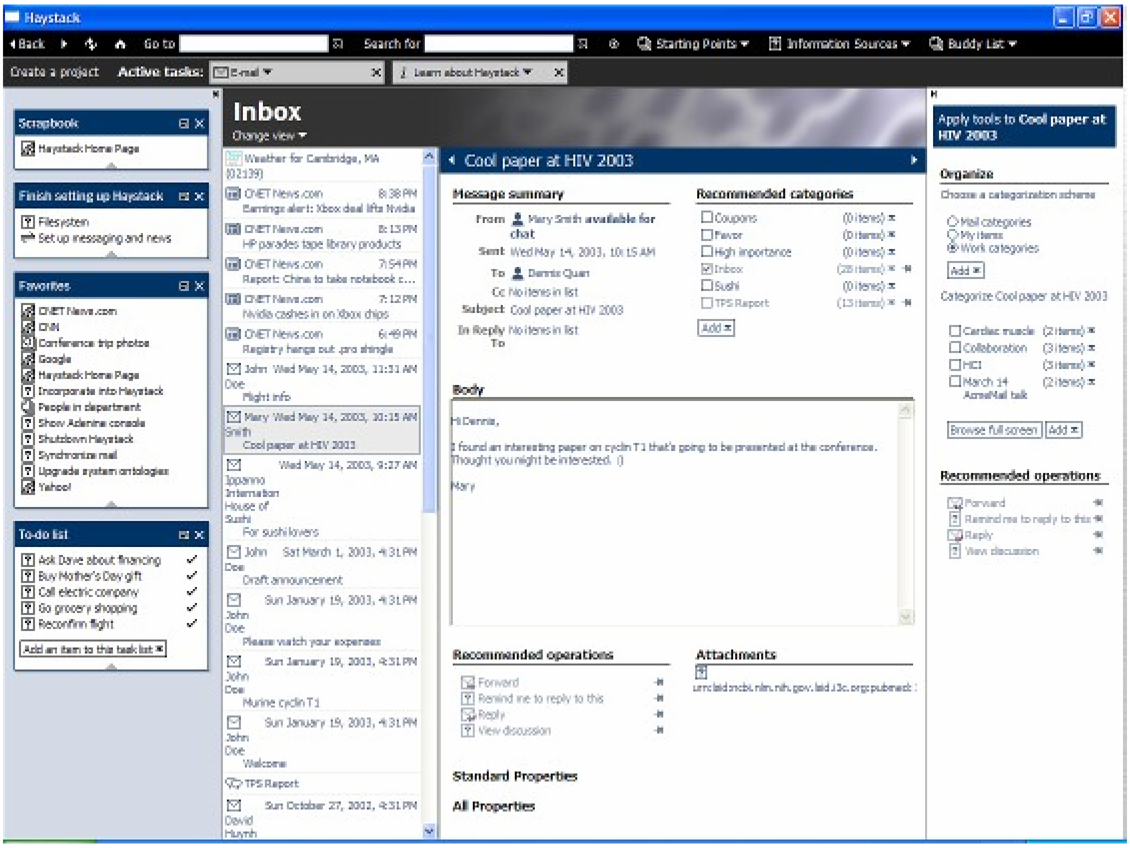

Figure 2: A screenshot of the Haystack Semantic Web Browser

Perhaps a more practical approach at this stage is the provision of 'Semantic Portals', including SEAL [46], Ontoweaver [53] and SWED [68], which have been used to deliver websites such as Knowledge Web [40]. These portals use the organisation provided by annotating webpages using ontologies, to structure and display the information. The relationships embodied within the semantic structures can be used to provide a richer and more precise search method, for example to find projects working in a specific topic area. When information is then discovered and inspected, the portal can present other relevant information via links which are categorized by the relationships between resources.

Taken together, these information management tools provide a prototype of the basic infrastructure which will underlie the Web. They provide the user with an enhanced information management capacity, with the means to organise and structure the chaotic information on the Web. By providing the annotation in a machine readable format, user agent software can access and process that information automatically. Further, they can also annotate information in local file stores, e-mail and intranets, providing an economic means of improving the information infrastructure within organisations. Consequently, it is likely that it is within organisations and collaborations where the annotation can be effectively controlled that the largest initial impact of the Semantic Web will be felt. HE and FE colleges could well be in the forefront of such developments, as they often have a pool of motivated and technologically aware users.

3.2 Semantic Web and Digital Libraries

Libraries are a key component of the information infrastructure which underpins Further and Higher Education. They provide an essential resource for students and researchers for reference and for research. And they are increasingly converting themselves to *Digital Libraries.*

A key aspect for the Digital Library is the provision of *shared catalogues* which can be published and browsed. This requires the use of common metadata to describe the fields of the catalogue (such as author, title, date, publisher), and common *controlled vocabularies* to allow subject identifiers to be assigned to publications.

By publishing controlled vocabularies in one place, which can then be accessed by all users across the Web, library catalogues can use the same Web-accessible vocabularies for cataloguing, marking up items with the most relevant terms for the domain of interest. Then, search engines can use the same vocabularies in their search to ensure that the most relevant items of information are returned.

The Semantic Web opens up the possibility to take such an approach. It offers open standards that can enable vendor-neutral solutions, with a useful flexibility (allowing structured and semi-structured data, formal and informal descriptions, and an open and extensible architecture) and it helps to support decentralized solutions where that is appropriate. Thus RDF can be used as a common interchange format for catalogue metadata and shared vocabulary, which can be used by all libraries and search engines across the Web.

3.2.1 Metadata

Metadata is a key component of the provision of online catalogues that are searchable across the Web. In order to use the Semantic Web to its best effect, metadata needs to be published in RDF formats. There are several initiatives involved with defining metadata standards in the library and publishing community, including:

- **Dublin Core Metadata Initiative** which provides a standard set of machine readable fields and guidelines for their use. This now has a well-established RDF vocabulary [24], [50].
- **MARC**. The well known MARC format from the Library of Congress has an XML representation [49].
- **ONIX**. The ONIX for Books Product Information Message is the international standard for representing and communicating book industry product information in electronic form XML representation [52].
- **PRISM.** The Publishing Requirements for Industry Standard Metadata specification defines an XML metadata vocabulary for magazine, news, catalogue, book, and journal content [57].

Such standards can be used across the Web in that they provide a common metadata vocabulary in XML or RDF which can be used to mark up and share library catalogues on the Web. PRISM and Dublin Core are usable now in the Semantic Web. MARC and ONIX require further work, but could be used as a source to enrich the metadata provided on the Web.

3.2.2 Controlled Vocabulary

Controlled vocabularies such as classifications, taxonomies and thesauri are the other key components for cataloguing and searching by classifying documents by subject. Developing tools and formats for representing and delivering such thesauri on the Semantic Web has been a major initiative of the SWAD-Europe project [66]. This provides a set of standard formats and tools for describing controlled vocabularies and classifications called the Simple Knowledge Organisation System (SKOS). It also provides some sample thesauri which use these formats, and some demonstration software to allow people and programs to browse and select terms from a thesaurus across the Web. This work is now being taken up by the W3C Semantic Web Best Practices and Deployment Working Group in their Thesaurus Taskforce [70].

3.2.3 Other projects

There are many other projects and initiatives which are providing access to libraries across the Web, some of which are using the Semantic Web directly, others behind the scenes. Some important ones include: The Open Archive Initiative [54], which is providing direct access to structured metadata via its metadata harvesting protocol; the Simile Project, which is using the Semantic Web to enhance inter-operability among digital assets, schemata/vocabularies/ontologies, metadata, and services; and DELOS, a European Network of Excellence on Digital Libraries whose website provides many more links to Digital Library projects [22].

3.3 Supporting interaction

A major theme that has emerged during the development of the Semantic Web is the ability to support *interaction between groups of people* across the Web. This has two aspects: support for virtual communities and support for virtual organisations.

3.3.1 Semantic Web in Virtual Communities

Within virtual communities individuals can publish information about themselves, their interests and their work, and allow other like-minded individuals to discover and share that information in order to build a virtual community of people sharing ideas.

The 'Friend of a Friend' or FOAF [29] project provides a simple language that allows people to publish information about themselves, their work and interests, along with their contact details (with due respect to privacy). This is useful, but becomes interesting when people can also publish links to others they know in the community. Taken together, FOAF provides a network of links between people. You can trace the extent and scope of the virtual community of individuals, discovering new potential contacts and adjacent communities of interest. People are taking up this idea to build tools, such as FOAFNaut, which allow you to explore the connections between communities [28]. Thus we have an example of a network effect within the Semantic Web when simple tools and small amounts of information combine to form something of greater value.

Other tools are designed to allow communities to share information and opinion. Web-logs (or blogs) are well-established outside the Semantic Web, allowing people to publish onto the Web and others to comment. By bringing blogs into the Semantic Web, with annotation, they can be included within Semantic Web information harvesting, combination and searching, so they can be shared in a more directed fashion. An example of this is the work on Semantic Blogging from HP Labs in Bristol, where blogs are annotated so that information on bibliographies and reading lists can be shared, searched and discussed [62]. Potentially, this provides an invaluable shared resource of annotated reference materials for a community, such as a group of researchers or students. Similarly, tools such as Annotea use annotation in RDF to provide comments and annotations on webpages, so that comments provided by the community lead to discussion [1]. Similarly, the Web-based news-syndication system RSS (for either Rich Syndication System, or RDF Syndication System), provides a mechanism for publishing, sharing, combining, annotating and searching news lists and discussion groups [3], and some versions of RSS use RDF, including RSS 1.0. As an example, RSS is being used by the Nature Publishing Group to keep scientists and librarians informed of the latest news from their journals, using a combination of Dublin Core and Prism metadata [51].

Community portals provide central points where virtual communities can communicate and share information, find new contacts and comment on each other’s work. Semantic Web technology is being used to construct such portals to provide a richer approach to organising and searching community portals, typically built on top of the Semantic Portal technology above. An example is CSAktiveSpace [17] from the University of Southampton which gathers together information on the active researchers in Computer Science within the UK, categorising their research topics and rating them on output. This tool provides a rich interface allowing the user to explore the Computer Science community within the UK from different angles, including some unusual search interfaces allowing geographical searches, such as finding experts on Neural Networks working in Scotland.

Another approach to community portals is provided by the Semantic Web Environmental Directory (SWED) also from HP Labs in Bristol [68]. This portal brings together information about environmental organisations in the UK, large and small, from the RSPB to local wildlife observation groups, which again can be searched in a structured manner, so that users can rapidly identify the groups which most closely match their requirements. An interesting feature of the design of this system is that rather than being managed centrally, each organisation is responsible for entering and maintaining its own information in a distributed fashion which is then aggregated together. As each organisation has a vested interest in keeping the information up to date, there is a greater chance that the portal will remain current with little effort on the part of the central host. The front page of SWED is given in Figure 3.

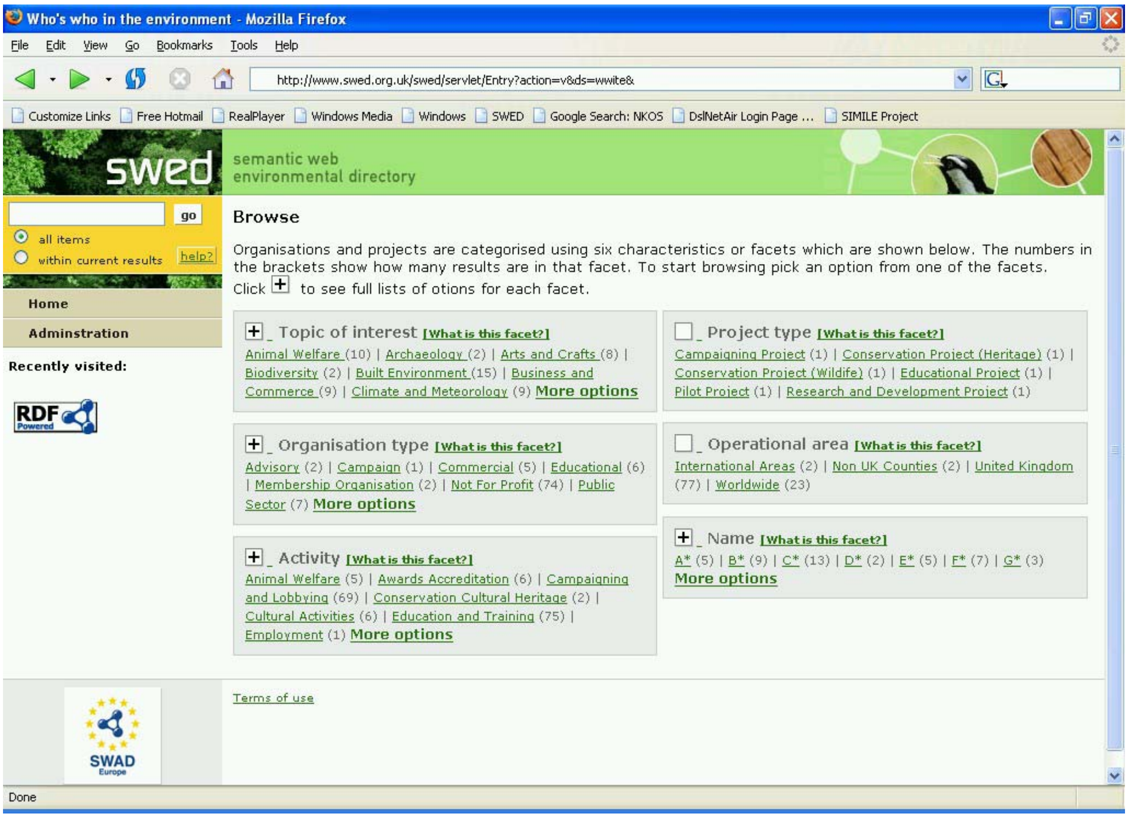

Figure 3: The SWED Environmental Directory

FOAF has been extended to support *Community-based trust networks*, especially the work of Jennifer Golbeck at the University of Maryland [74]. The idea here is to not only let others know who you know, but also how much you trust them. By aggregating each other's opinions of the individuals in the network, the community can identify trustworthy individuals. This becomes akin to the 'reputation-management' system which is provided by online services such as the auction house eBay. Clearly, such an approach is open to abuse of defamation and highly subjective bias (people rating their ex-boy/girl-friends as extremely untrustworthy is not uncommon!), but handled with caution, such a system could be extremely useful to identify community authorities on particular topics.

A key feature that these community-based tools share is that they are *cheap*, *simple* and *open*. Infrastructure to support a community can be quickly assembled with little expense and with a relatively small amount of technical expertise. By aggregating information from different sources, new and unforeseen connections and information can emerge.

The support for communities could be of great value in the HE and FE sectors. Using these tools, accessed through Virtual Learning Environments, communities of students within courses and departments, or across institutions could be supported with or without moderation and direction. This could facilitate sharing of useful information and opinion, such as bibliographies, and discussion through blogs, news-streams and annotation. Similarly, in research activities, these tools can support the research communities in particular fields via their integration into Virtual Research Environments.

3.3.2 Semantic Web in Virtual Organisations

A more rigorous approach is being taken when people and organisations wish to formally collaborate towards common goals across the computer infrastructure. Examples of this in the HE and FE community would include research projects with partners spread across Europe, or in computer-assisted learning, where students and teacher wish to share online teaching and learning resources, and engage in group activity such as a team project.

The term *virtual organisation* has been coined to describe a computer-mediated collaboration which can be formed across organisational boundaries. Standards are emerging within the Web and Grid communities to provide the infrastructure to support virtual organisations, typically using the concept of a *Service Oriented Architecture* where programs and tools offer standard Web-based access to a service to other members of the collaboration. To support this virtual organisation there needs to be ways for members of the collaboration to find the offered services most appropriate to their needs, negotiate their use in the confidence that malicious acts will not take place, and co-ordinate the use of disparate services to provide the desired result.

These standards require the development of common vocabularies and negotiation protocols. The Semantic Web can provide an underlying framework to allow the deployment of service architecture to support virtual organisations. This concept is now sometimes given the description the *Semantic Grid*.

In order for a service to be used it needs to be found. Also, the requirements of the user need to be reconciled with the capabilities of the service. Discovery could use a semantic description, using an RDF statement of the service interface provided. These statements should be a machine processable, extensible description to support whether a service can perform a given task, and what kind of performance the service can provide. Then we could reason to see whether the service descriptions satisfy the user requirements. The DAML-S [19] and the Web Service Modelling Ontology projects [77] are exploring alternative approaches to the problem of providing semantic annotation to services.

An important aspect of virtual organisations is the confidence that malicious use of services is prevented, and again the Semantic Web can support secure access to services. Some initial efforts in the use of Semantic Web representations for basic security applications (for example, authentication, access control, data integrity, and encryption) have begun to bear fruit. For example, Denker et al. [23] have integrated a set of ontologies and security extensions for Web Service profiles. Kagal et al. are also developing Rei, a Semantic Web-based policy language [37]. Furthermore, KAoS services and tools allow for the specification, management, conflict resolution, and enforcement of policies' complex organizational structures [10].

The final step to support virtual organisations is to allow users to combine services together. For example, a researcher may wish to redirect data from a service at one location, to an analysis tool at a second location, with the results of the analysis redirected to a visualisation tool at a third location. These services need to be co-ordinated. Workflow systems within organisations have emerged in the last few years as a way of co-ordinating business, and standards such as BPEL4WS are emerging [9]; these need to be extended and modified to allow the composition of services. The Web Services community is beginning to consider how to extend the semantic annotation to allow the combination of Web Services.

Research, development, and installation of Grid infrastructure is proceeding rapidly in the UK under the National E-Science Programme, and so computer infrastructure supporting virtual collaborations is becoming a reality for many researchers across all disciplines. There is increasing interest in exploring how it might be best exploited to support teaching, with projects such as the European Learning Grid Infrastructure taking a lead [27]. Over the next two to three years the prototype results of this work are likely to appear in the next generation of Virtual Research Environments.

3.4 E-Learning

The Semantic Web clearly has large application to e-learning, supporting both distance and local education. The notion of a 'learning object' as a separable unit of educational material which can be reused and combined with other learning objects has been a central feature of e-learning systems. This concept has been criticised for being too inflexible and not taking into account the particular learning needs of individuals or the requirements of context and emphasis of educators. However, used properly, it is a useful and powerful concept and one which the Semantic Web has much to offer.

Learning objects can be organised into repositories, and shared across peer-to-peer (P2P) networks. The Edutella project [26] is seeking to provide an RDF-based P2P network for sharing learning objects. Individuals can publish learning objects to the network, providing rich metadata that is '*descriptive information about learning resources for the purposes of finding, managing, and using these learning resources more effectively*'. Then the shared repository of learning objects can be searched and objects can be retrieved based on their semantic annotations.

Rich semantic annotation languages for learning objects are appearing. For example, the Educational Modelling Language (EML) [25]; the IMS Global Learning Consortium's proposed set of integrated standards for e-Learning subjects, including a Metadata Specification [35]; and the *Learning Object Metadata* (LOM), a standard defined by the *Learning Technology Standardization Committee* (LTSC) of IEEE [43]. All these are currently defined in XML but are adaptable into RDF for use in the Semantic Web. This will allow a richer interaction with the learning material, with ontology-based brokers for negotiating the requirements of learners to the available learning materials. Again, we are likely to see, in the next two to three years, the introduction of Semantic Web technology into Virtual Learning Environments, firstly at an experimental stage, and then more deeply embedded.

Beyond the search and discovery of learning objects, the development of learning plans and courses can be controlled via workflow languages. Explanatory context and insight into the development of knowledge can be provided by 'knowledge charts', defined by Stutt and Motta [72] as '*pathways through controversies and narratives and other structures such as analogies and expositions of scientific principles*'. Again, RDF and other Semantic Web technologies provide the natural medium for representing and delivering such charts.

4. RESEARCH GROUPS IN THE UK

There are many researchers working in the Semantic Web in the UK both in academia and in industry, with, for example, active research groups in HP Laboratories and BT. British researchers are taking a leading role in all aspects of Semantic Web development. Here, we highlight some of the leading research groups in the UK:

- **ILRT, University of Bristol http://www.ilrt.bristol.ac.uk/.** The Institute of Learning and Research Technology at the University of Bristol has taken a leading role in the W3C's effort to provide the basic infrastructure of the Semantic Web, especially in the RDF, RDF Schema and RDF querying infrastructure. They often collaborate with the HP research laboratories, also based in Bristol, and are heavily involved both in the development of tools to support virtual communities and bringing technologies into education.
- **University of Southampton http://www.ecs.soton.ac.uk/.** The Department of Electronics and Computer Science has a long tradition of high quality research in Hypermedia and Agent technology, especially within its Intelligence, Agents, Multimedia (IAM) Group, which is now developing Semantic Web tools in a wide range of applications, including e-Science and in digital libraries and archiving. Along with the University of Manchester it is one of the major developers of the Semantic Grid.
- **University of Manchester http://www.cs.man.ac.uk/.** The Department of Computer Science has a long tradition of high quality research in Hypermedia and Ontologies technology, especially within its Information Management Group. It has contributed to the OWL work within W3C, especially in the foundational underpinnings of the language. It is using Semantic Web tools in a wide range of applications, including e-Science, and especially in bioinformatics

and medical applications. Along with the University of Southampton it is one of the major developers of the Semantic Grid.

- **Knowledge Media Institute, the Open University http://kmi.open.ac.uk/.** KMI has a prestigious reputation for the development and use of knowledge-based technologies, especially in knowledge management, human-computer interaction and tools to support learning and teaching. It has an active interest in the Semantic Web, using Ontologies to develop portals and browsers and also working to develop Semantic Web Services.

This is just a snapshot of the wide-ranging and exciting research on the Semantic Web which is going on in UK Universities.

5. THE FUTURE OF THE SEMANTIC WEB

We have seen in this paper that there has been significant and enthusiastic effort over the last few years to explore and develop the technology, shared vocabularies and ideas which are turning Tim Berners-Lee's vision into a reality. There is a long way to go until it is a standard part of the Web infrastructure but, nevertheless, there has been startling progress in the last few years, with UK research groups amongst the leaders.

5.1 Barriers to adoption

There are inevitable barriers to the Semantic Web that still need to be addressed. We have mentioned the slow progress on certain features, particularly ontology and reasoning support, due to the development community not coming to a consensus. This does not mean that progress cannot be made immediately using the simpler tools for RDF and RDF Schema available now.

Some of the larger IT companies are hanging back, waiting to spot the opportunity and waiting for the research community to settle on standards. Thus the main impetus is coming from communities themselves – it is an opportunity to profoundly affect the way that the world talks to each other.

There is a good deal of RDF data giving semantic descriptions already on the Web, both from website owners publishing their own annotations as RDF files and from sites such as *rdfdata.org* which provide portals for RDF data. However, before the Semantic Web can become globally usable, there does need to be more, and it needs to be more easily available. There is a distinct overhead to using the Semantic Web in terms of establishing shared vocabularies and ontologies, and in providing the appropriate annotations to resources which make them visible to the Semantic Web. This is a non-trivial task and often users will either not have the time to include this, or the expertise to do it well. A missing component of the Semantic Web is a simple means to support this, similar to the editors and tools for the conventional Web. Undoubtedly the simplicity of the HTML language used within the current Web was a major influence on its success and in order for the Semantic Web to break out from narrow communities to universal use it needs to address the issues of making it easy to use and accessible to all.

Otherwise, the Semantic Web is likely to require particular effort and expertise. This is expensive, and so it may well be confined to particular domains on the Web which see a strong advantage in its use, although over time as the expertise becomes more commonplace it should become cheaper. Also, the 'network effect' can work as both a barrier and an incentive. One of the main advantages of supplying Semantic Web annotation is that is can be shared and can gain advantage to others, so when there is little data to share, then there is little incentive to take the extra expense in sharing; however, once the ball starts to roll, there is an exponential advantage in combining your own data with others'.

These problems may be less of a disadvantage in the HE and FE sectors, which has well-integrated communities with stronger control over their resources. Information science professionals in libraries are available to help with the task of cataloguing and publishing annotations. Thus it is likely that this sector will be in the forefront in the use of this technology.

5.2 Summary of impact areas

We have discussed four areas where the Semantic Web is most likely to make an impact: information management, digital libraries, virtual communities, and e-learning. To summarise:

- **Information Management:** the Semantic Web enhances the capabilities of those tools which form a familiar part of the current Web so that they can become useful information management tools in their own right. The Web is already an information source of choice for many learners and researchers. A more structured and directed approach to managing this information space, both within institutions and across the whole community, can make this information more useful, with less wasted effort, and more capacity to measure the quality of information. By making the annotation machine readable, it becomes accessible to automatic processing, carrying out many routine tasks which consume people's time. A further impact is likely to be in the business of running education, allowing more efficient information flow around institutions.
- **Digital Libraries:** the impact on digital libraries, combined with the Open Access Initiative and the rise of open archiving is likely to be quite profound. Libraries become 'value-added' information annotators and collators rather than the archivists of externally published literature and the holders of the published output of institutions. The Semantic Web, although not a prerequisite or a motivator for this change is nevertheless likely to smooth its development. The tools are in place for sharing classification schemes and to allow the community to develop, deepen and share such schemes. The information infrastructure tools discussed above will have particular impact on the way students and researchers find information, so these tools may typically be provided and adapted by libraries who will tailor them to the needs of their own users. The Semantic Web, like the current Web, has the capacity of being an overwhelming place; libraries are well-placed to make sense of this for the HE and FE community.
- **Building communities and collaborations:** a major impact is likely to occur in the way that academic communities work together. The tools for forming virtual communities and sharing information across that community are simple and lightweight, and, if the development of blogs and the use of RSS is an indication, can enhance the interaction of an interested community by an enormous amount. Providing a richer annotation structure to these can only enhance their usefulness, bringing them into the information infrastructure as well as providing a means of communication to people across the world.

  Support for virtual collaborations is a much larger issue, as it requires tighter control over resources and security. This is largely taking place in the Grid community and efforts to construct a *Semantic Grid* are already well underway, bringing the machine readable annotation to automate the discovery and negotiation of services onto the Grid.
- **E-Learning:** all of the above can influence e-learning. However, we should also consider specifically, support for the presentation and delivery of course materials and for assisting and assessing students. Again, the impact of the Semantic Web is likely to mean that these can be more closely tailored to the needs of the user, with a choice of learning objects mediated through selection mechanisms. The Semantic Web can provide context and co-ordination, with workflow tools providing a supporting infrastructure.

5.3 Timescales

A major question is how long this is going to take. We have already seen a set of inflated expectations and false starts, and this may reasonably result in some caution when assessing the Semantic Web's progress in the future. However, there are reasons to believe that we may see a more serious uptake of this technology.

Firstly, the basic recommendations are very much in place, particularly RDF and RDF Schema, but also OWL. These have now had time to establish themselves, with most problems being ironed out and with a large body of knowledge established on their usage. These can be used right now without waiting for the higher layers of the architecture to become more concrete. Within two to three years we will find that RDF is being used 'behind the scenes' for a variety of tasks which we may not even be aware of, similar to the way XML is now being used. This is likely to be particularly true of 'community building tools' which will just come with RDF included.

Secondly, there is greater interest from user organisations such as libraries, infrastructure funding organisations such as JISC and the research councils, and other user communities. These are beginning to work together in areas such as information science, medicine or genomics to provide the common underlying ontologies for these domains. Agreement on these will take longer, and it is likely that there will be areas of disagreement for a long time – and there will always be a question of revision. However, it seems likely that there will be workable ontologies for some domains within the current round of European projects, say three to four years.

Thirdly, there is now interest from major IT suppliers and a host of smaller companies in providing tools and expertise to build on this infrastructure. Companies such as BT, HP, and Adobe are beginning to use Semantic Web tools seriously and include them in their products. The popular browser Firefox uses RDF internally to represent internal data. Search engine companies such as Google and Yahoo are seriously considering how to best use this technology. Mobile communications companies are renewing interest in using the Semantic Web to enhance the experience of mobile users of the Web. Clearly these are going to take some time to come to market, but it is reasonable to expect further 'early adopter' products to appear within the next two years and then for mainstream usage to be within three years after that.

More sophisticated use of ontologies, particularly combined with reasoning tools, will take some time. The standardisation process has not passed the exploratory stage, and we can reasonably expect it to be some three years before a recommendation appears from the W3C. Then we will expect another two to five years for major applications to appear. The time is not yet ripe to invest heavily in reasoning tools in anything other than an experimental capacity.

As for the different applications areas identified – these are moving at different paces. Tools for semantic information management are developing at a steady pace, with research prototypes currently available, and, I would estimate, the first commercial offerings not far behind, perhaps within the next one to two years, although it may take much longer for them to become universal. Similarly, support for virtual communities is now fairly established and for these types of applications, which are largely community driven in the first place, the tools are likely to be Semantic Web-driven within a relatively short period.

The digital library community is already well organised and experienced in the skills required to best use the Semantic Web, and it is here that 'quick wins' could be gained, leveraging a large amount of material which is already catalogued. The barriers in this area are more likely to be cultural, with a tradition of centralised library services and copyright-protected publications, coupled with a suspicion of the more open and anarchic world of the Web, slowing down adoption. Nevertheless, as recent conferences on Digital Libraries have shown, there is considerable interest in exploring the opportunities offered by the Semantic Web. E-Learning applications are likely to follow the digital library community as there is already an overlap between these communities.

Supporting virtual collaborations and e-learning is still some way off. The work on the Semantic Grid is still in its infancy. The base of Web Service and the Grid is still under development, so providing a richer semantic architecture will be constructed on a moving target, which means that solutions are unlikely to be anything other than experimental for the time being. However, funding organisations such as the European Commission are interested in exploring this area, and we are likely to see solutions emerge out of research and development at the end of the current round of new projects, in say four to five years time. Then it will take two to three more years to become mainstream

5.4 Final word

The Semantic Web has great potential, and with direct application to the HE and FE sector. However, it has been a long time in development and does require an investment of time, expertise and resources. Nevertheless, the time does seem right to start to think how best to use the simpler applications of the technology.

So what should HE or FE institutions consider doing now? Institutional libraries should be considering joining collaborations to explore how Semantic Web can best be exploited and investing in training staff, with a view to providing Semantic Web solutions within the next two to three years. Information science professionals and academics working in particular fields should work together to provide the vocabularies and domain ontologies required to support particular fields. Particular communities and research groups could be looking at exploiting the emerging infrastructure to enhance the interaction of their community.

In the future the Semantic Web may not even be noticeable. The tools of the Semantic Web will be integrated into Virtual Learning Environments and Virtual Research Environments on our desktops, as well as in browsers and search engines. What we will have is a richer experience of IT that is better able to deliver the right information at the right time in the right way, so we can get on with the serious business of research and teaching.

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