IST Project 2001-33052 WonderWeb:
Ontology Infrastructure for the Semantic Web

D29: Final Report

Ian Horrocks
University of Manchester
Kilburn Building
Oxford Road
Manchester M13 9PL
email: horrocks@cs.man.ac.uk

Report Version:	1.0		
Report Preparation Date:	03/01/2005		
Classification:	Restricted		
Contract Start Date:	1/1/2002	**Duration**:	30 months
Project Co-ordinator:	University of Manchester, Prof Ian Horrocks		
Partners:	Vrije Universiteit Amsterdam		
	ISTC-CNR		
	University of Karslruhe		

Project funded by the European Community under the "Information Society Technology" Programme (1998–2002)

WonderWeb Project

This document forms part of a research project funded by the IST Programme of the Commission of the European Communities as project number IST-2001-33052.

For further information about WonderWeb, please contact the project co-ordinator:

Ian Horrocks
The Victoria University of Manchester
Department of Computer Science
Kilburn Building
Oxford Road
Manchester M13 9PL
Tel: +44 161 275 6154
Fax: +44 161 275 6236
Email: wonderweb-info@lists.man.ac.uk

Project Consortium

Academic Partners

University of Manchester (VUM), Manchester, UK (co-ordinator)
Vrije Universiteit Amsterdam (VUA), Amsterdam, Netherlands
ISTC-CNR (ISTC), Trento, Italy
AIFB University of Karslruhe (AIFB), Karlsruhe, Germany

Industrial Advisory Board

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Hans-Peter Schnurr, ontoprise, Karlsruhe, Germany
Massimo Soroldoni, Nomos Systema, Milan, Italy
Prof. Austin Tate, AKT project, AIAI, Edinburgh, UK
Arthur J. Thomas, Ph.D., BioWisdom, Cambridge, UK
Dr. Luca Toldo, Merck KGaA, Darmstadt, Germany
Dr. Michael Uschold, The Boeing Company, Seattle, WA, USA
Guido Vetere, IBM Rome Tivoli Labs, Rome, Italy
Matthew West, Shell Services International, London, UK
Mario Wolczko, Sun Microsystems, Palo Alto, CA, USA

Contents

Executive summary

The project has now been completed after having received a six month extension (the revised end date of the project being 31st December, 2004). The project proceeded according to plan and met all of its key objectives, including standardisation of the *OWL ontology language*, the development of the *KAON ontology engineering environment*, the development of the *WonderWeb ontology library*, and the development of an *ontology modularisation framework*. Significant results above and beyond the stated objectives of the project have also been achieved, including the development of techniques for the semi-automatic annotation of dynamic Web sites and the investigation of alternative reasoning techniques.

Members of the consortium made key contributions to the development and standardisation of the OWL web ontology language, which is now a fully fledged W3C recommendation (as of 10th February, 2004). WonderWeb consortium members have also been central to ongoing language development efforts, including the already widely adopted SWRL rules language extension to OWL (now a W3C Member Submission) and OWL Query Language, as well as being involved in the new W3C Semantic Web Best Practices and Deployment and RDF Data Access Working Groups.

As far as tools and services are concerned, an important result of the project has been the development of KAON (which has already seen more than 14,000 downloads from SourceForge), and the integration of a wide range of software components (editors, reasoners etc.). A completely new inference engine has also been developed in order to provide improved reasoning services for OWL applications. The result is a powerful and extensible ontology development environment.

Complementing the KAON and tools is the WonderWeb ontology library, a rich collection of foundational ontologies and domain specific extensions. The library includes the DOLCE, OCRE and BFO foundational ontologies, as well as extensions covering areas such as web services, plans, and descriptions and situations. An influential review of the current state of the art in ontology design methodologies has also been produced. Ontologies from the WonderWeb library are already in widespread use outside the project, and alignment with DOLCE has been used, e.g., to reveal conceptual problems in the OWL-S services ontology.

Finally, work on ontology engineering methodologies resulted in the development of ontology versioning facilities comparable to those available in software engineering, and a framework for representing and reasoning about modular ontologies, including automated methods for splitting up large ontologies into modules. The versioning facilities have been implemented in the “OntoView” system, and have also been used in Stanford University’s PROMPT tool (part of the Protégé tool suite).

The project has been highly influential, with results having been widely disseminated via invited talks and tutorials, publications in leading international conferences and journals, open source software, and cooperation with industry, including two highly successful meetings of the Industrial Advisory Board (IAB)—it is indicative of the quality and significance of the work carried out within the project that members of the IAB participated in these activities entirely at their own expense. Also indicative of the importance of the project's output is that it has a life that extends well beyond the project itself: language development and standardisation work is ongoing (in cooperation with DARPA and the W3C); KAON and the OWL API are now open source projects; DOLCE and other components of the ontology library are important resources that have been influential, e.g., in the W3C Semantic Web Best Practices and Deployment Working Group and the development of OWL-S; and the versioning framework forms part of tools such as Protégé.

To quote from a report by TopQuadrant, Inc. (a leading consultancy focused on the emergence of semantic web technologies and solutions):

> "The semantic wave is building steadily and is on a track that will take it from vision to markets valued in the tens of billions of euros by the end of this decade. WonderWeb has played a seminal and influential role in this story."

Project Achievements

Comparison with Original Objectives of WonderWeb

The goal of the project was to develop a methodology and toolkit supporting Web based ontological engineering. All of the key objectives of the project have been achieved, or even exceeded:

- the OWL language is now a W3C recommendation, and as well as being the official standard language for Semantic Web ontologies, it is rapidly becoming a de facto standard for e-Science ontologies, and for ontology development in general;
- work on language extensions includes major contributions to the SWRL rules language proposal, which is now a W3C member submission, and already being widely adopted (e.g., available tools include a syntax validator, a reasoner and a plugin for the popular Protégé editor), to the OWL Query Language, and to SWRL FOL, a recent extension of SWRL to (almost) a full First Order Logic;
- KAON has been completed, along with a range of software components which together provide a complete ontology development environment;
- complementing the KAON is the WonderWeb ontology library, which includes a rich collection of foundational and domain specific ontologies;
- engineering methodologies have been developed to deal with issues such as change management in distributed ontologies, and the modularisation of ontologies;
- the IAB provided useful feedback and testing of the languages, tools, ontologies and methodologies developed in the project;
- results from the project have been published widely and have had a major impact on the development of web based ontology engineering.

In the following sections, the contribution of each workpackage to these achievements will be examined in more detail.

Workpackage 1: Language Architecture

Work on the development of the Ontology Language Layer culminated in the standardisation (by the W3C) of the OWL ontology language, which became a full recommendation on February 10th, 2004.

Members of the consortium, including Sean Bechhofer (VUM), Frank van Harmelen (VUA), Ian Horrocks (VUM) and Raphael Volz (AIFB), were active members of the W3C Web Ontology working group,[1] made crucial contributions to the development of OWL, and edited/authored several key documents including the Overview,[2] Reference[3]

[1] http://www.w3.org/2001/sw/WebOnt/
[2] http://www.w3.org/TR/owl-features/
[3] http://www.w3.org/TR/owl-ref/

and Semantics and Abstract Syntax.[4] Bechhofer was also asked to produce a guide to parsing the OWL RDF/XML syntax, based on his experience developing (as part of the WonderWeb project) an OWL API, and this is now a W3C Working Group Note.[5] In addition to the OWL language specification itself, this work is described in publications such as [9, 11, 2, 1].

Work on language extensions resulted in the development of SWRL (a rules language extension to OWL), OQL (a query language for OWL) and SWRL FOL (a recent extension of SWRL to (almost) a full First Order Logic), with Horrocks (VUM) being a lead author of all three proposals. This work was carried out in cooperation with the DARPA DAML program and the Joint EU/US committee on agent markup languages,[6] of which both van Harmelen and Horrocks are members.

SWRL is now a W3C Members Submission,[7] and will be an important input to a new W3C "Semantic Web Rules" working group that is likely to be established within the next twelve months (a W3C sponsored workshop to discuss will be held in April 2005 in order to discuss the issues surrounding ontologies, rules and W3C standardisation). SWRL FOL has recently been submitted to W3C.[8]

Detailed studies of the relationship between rules and description logics, and possible implementation pathways, have also been carried out. This included studying the possibility of translating a (maximal) fragment of the ontology language into Prolog, and investigating the extent to which the semantics of the ontology can be preserved. Volz (AIFB) has shown, by empirical assessment of available ontologies, that the fragment of the ontology language which can be fully expressed in Prolog is able to capture many realistic ontologies, and that use of rule-based reasoners for implementing reasoning in this fragment is a feasible alternative to native reasoners such as those developed in WP 2.4. The empirical assessment also showed that equality reasoning severely slows down rule-based reasoners, but suggested that the materialisation of entailment's and the incremental maintenance thereof might be a possible means by which to regain acceptable performance. This work (which goes well beyond what was envisaged in the technical annex) is described in deliverable D2 and in publications such as [7, 10, 27, 30, 29, 3].

Another implementation pathway studied in the project involved the reduction of OWL ontologies and SWRL rules to First Order Logic (FOL) axioms, and the use of a FOL automated theorem prover to answer queries against the resulting axiom schema. This work (which again goes beyond what was envisaged in the technical annex) is described in publications such as [24].

Further language extensions that have been studied within the project include extended support for datatypes and predicates (e.g., arithmetic predicates), a more powerful language for describing relationships between properties (e.g., complex role inclusion axioms), and the ability to use data values as database style keys. This work is described in deliverable D3, and has already led to several important publications such as [20, 12, 15, 13, 16].

[4] http://www.w3.org/TR/owl-semantics/
[5] http://www.w3.org/TR/2004/NOTE-owl-parsing-20040121/
[6] http://www.daml.org/committee/
[7] http://www.w3.org/Submission/2004/SUBM-SWRL-20040521/
[8] http://www.daml.org/2004/11/fol/

Workpackage 2: Tools and Services

At the core of this WP was the development of the KAON open-source ontology management infrastructure. It includes a comprehensive tool suite allowing easy ontology creation and management, as well as building ontology-based applications. An important focus of KAON is on integrating traditional technologies for ontology management and application with those used in business applications, such as relational databases. KAON is jointly developed and used in several EU-funded projects, amongst which are Ontologging,[9] Vision,[10] SWWS,[11] Harmonise [12] and VICODI.[13] This maximises the dissemination of the project results and allows for synergies across projects.

The design of KAON is based on existing Application Servers, but we have applied and augmented their underlying concepts for easier use in the Semantic Web, and integrated semantic technology within the server itself in order to improve its flexibility and facilitate its use. KAON's architecture has been extensively revised and improved during the second year of the project, resulting in the "demonstrator" version described in deliverable D7. Deliverable D7 also includes a user's guide and shows how to start the server, work with the management console, deploy and discover components and how to work with client-side surrogates. KAON is open source and is available from SourceForge.[14] Statistics from SourceForge show that KAON has already been downloaded more than 14,000 times.

In parallel with the work on the KAON itself, work continued on the integration of software modules providing a variety of services to applications. These included the Sesame RDF store, the OntoEdit and OilEd editors, the FaCT, Racer and Ontobroker reasoners, and the LiFT client, a tool for extracting lightweight ontologies from legacy resources such as database schemas, UML software specifications and XML schemas (see deliverables D8, D9, D10, D11 and D12). KAON and the available set of software modules provide a powerful ontology development environment that is highly flexible (e.g., provides multiple editors and reasoners), and yet at the same time fully integrated.

A combination of work on the KAON, the OilEd editor and a syntax validator for the OWL ontology language has resulted in the development of the WonderWeb OWL API,[15] which provides programmatic access to data structures representing OWL ontologies. The API is open source (it is also available from SourceForge[16]) and is already seeing widespread adoption by OWL implementors (SourceForge statistics show that it has already been downloaded more than 3,500 times).

Work on KAON and the OWL API has led to several important publications, including [19, 28, 2, 1].

An important strand of the work in this workpackage was the development of the new FaCT++ inference engine to support the OWL ontology language (see deliverables D13

[9] http://www.ontologging.com/
[10] http://wim.fzi.de/vision/
[11] http://swws.semanticweb.org/
[12] http://www.harmonise.org
[13] http://www.vicodi.org/
[14] http://sourceforge.net/
[15] http://owl.man.ac.uk/api.shtml
[16] http://sourceforge.net/projects/owlapi

and D14). Compared to existing DL reasoners, the new engine employs a completely new architecture (it does not use the standard depth first tableau construction) that is better suited to more expressive languages, incorporates many new optimisations, supports integer and string datatypes (as specified in the OWL standard), and is written in C++ in order to combine efficiency with portability. The FaCT++ engine also has a DIG interface,[17] which makes it plug compatible with existing reasoners such as FaCT and Racer.

In addition to the work on the Lift tool that was foreseen in the technical annex, further work led to the development of an integrated scenario for bootstrapping ontologies that includes a means to exploit the bootstrapping process for the semi-automatic annotation of dynamic Web sites, i.e., Web sites where Web pages are generated from a database. This results in the so-called *deep annotation* of the database—either directly by annotation of the logical database schema, or indirectly by annotation of the Web presentation generated from the database contents. From this annotation, the Lift data mapping and/or migration steps can be executed, preparing the data for use in the Semantic Web.

Deep annotation will be important given that dynamic Web pages generated from databases outnumber static Web pages; it may also provide a very intuitive way to create semantic data from a database. This data can then be queried directly or materialised as RDF files. This work is described in deliverable D12, and has already led to several important publications such as [26, 8].

Workpackage 3: Foundational Ontologies

The work in this workpackage consisted of three main strands. The first of these was the review of current state of the art of ontology design methodologies. Particular attention was given to two key problems: the problem of characterising the notion of ontology quality and more specifically the problem of introducing formal frameworks for evaluating and comparing ontologies; and the problem of defining—on the basis of the primitives offered by the foundational ontologies and some additional "application oriented" extensions—ontology design patterns that are useful in specific "clusters" of applications. The result of this work was presented in deliverable D16.

The second strand of work has been the development of the WonderWeb Foundational Ontology Library (WFOL). The final version of the library (described in deliverable D18) includes:

- The first order axiomatic characterisation of three reference modules (called visions): DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering), OCHRE, BFO. These visions have been informally compared to each other on the basis of the major ontological design options discussed in the Ontology Roadmap deliverable (D15).
- Two new extensions of DOLCE: the ontology of "Descriptions and Situations" (D&S), and a minimal ontology of plans (PO).
- An ontology of web services (WSO) based on D&S and PO.

[17] http://dl.kr.org/dig/

- Machine-readable encodings of several library modules, including KIF versions of DOLCE, D&S, PO and OCHRE, and OWL versions of DOLCE, D&S, PO and WSO.

- An example illustrating the importance and complexity of formal "semantic links" ("semantic mappings") between modules: a part of DOLCE has been formally translated into OCHRE.

- A mapping between DOLCE+D&S+PO and the English version of WordNet. This is particularly relevant for two reasons: it provides a bridge between ontologies and natural languages which is particularly useful in applications, and it contributes to the improvement of the ontological structure of lexical resources.

The DOLCE ontology is a rich, carefully axiomatised top-level ontology, which despite its clear cognitive bias (especially appropriate for the semantic web) has been designed in such a way to avoid hidden ontological assumptions, by relying on a rich axiomatisation. Indeed, a peculiarity of the WonderWeb Foundational Ontology Library (with respect to, say, ontology repositories) is that it aims at making rationales and alternatives underlying ontological choices as explicit as possible, in order to form a network of different but systematically related modules that the various Semantic Web applications can commit to, according to their own ontological assumptions. From this perspective, making people (and computers) understand one another (possibly including the reasons for any ontological disagreement) is more important than enforcing interoperability by means of a common, overarching ontology. Positive feedback on DOLCE has already been expressed by distinguished researchers involved in major ontology projects.[18] Versions of DOLCE are now in widespread use in ontology-related projects involving various application domains.

The final strand of work was involvement in standardisation efforts. Members of the consortium have closely monitored discussions on the IEEE-SUO mailing list, where work from the WonderWeb project has been mentioned many times, and are key participants in the W3C "Semantic-Web Best Practices and Deployment" (SWBPD) Working Group;[19] the DOLCE ontology, together with other foundational ontologies, was an important input resource for this Working Group.

As well as deliverables D15–D19, the above work is described in publications such as [5, 4, 6, 17].

Workpackage 4: Ontology Engineering

Like software engineers, ontology engineers need methodological guidelines and tool support if they are to produce high quality and maintainable ontologies. The focus of

[18] Including: Christiane Fellbaum, WordNet, Princeton University; Tony Cohn, University of Leeds; Barry Smith, IFOMIS, University of Leipzig; Chris Welty, IBM Watson Research Center; Bill Andersen, OntologyWorks; Werner Ceusters, Language and Computing; Peter Eklund, WebKB, University of Queensland; Joost Breuker, University of Amsterdam.

[19] http://www.w3.org/2001/sw/BestPractices/

WP4 has been the development of such guidelines (and, to a lesser extent, corresponding tool support), in particular for managing the evolution and modularisation of ontologies.

In order to manage evolution, a versioning framework for ontologies was developed, based on techniques for comparing two ontologies and reporting on the differences between them—the underlying idea was to provide tools that perform a kind of semantic based "diff" on two ontologies. After a detailed study of relevant techniques (see D20), a suitable framework was developed, implemented in the "OntoView" system, and integrated with the KAON server to provide a versioning mechanism for OWL ontologies. Foundational work was also carried out to extend these results to distributed ontologies.

Part of the result is an ontology of changes that can be used to describe the transformation (differences) between two versions of an OWL-lite ontology. The OntoView versioning tool 1) is able to derive such a transformation description by comparing two ontology versions and 2) will be able to use this transformation to calculate the effects of changes.

In cooperation with the Protégé development team at Stanford University, the resulting general methodology for change management [14] has been adapted to the Protégé Knowledge Model and integrated into the Protégé Ontology Editor; in addition, their PROMPT tool has been extended so that it can find and export the differences between two Protégé ontologies using the WonderWeb change ontology. The Protégé group has also independently developed a special plugin for the OntoClean methodology, developed at ISTC-CNR before the beginning of the project and integrated with the general methodology to be presented in Deliverable D26. A similar plugin has also been incorporated in the WebOde tool, developed at the Technical University of Madrid.

As a response to the weaknesses of the modularisation and import mechanisms provided by OWL, a formal framework for representing and reasoning about modular ontologies was developed based on the notion of distributed description logics. It was also shown that the change management framework can be used to check the integrity of distributed modules in the presence of change. The framework was applied in the setting of the case study presented at the first WonderWeb review meeting. This work is described in deliverable D21 and in publications such as [22, 23].

Important additional work was also carried out on the acquisition, representation and use of web service semantics. This work went well beyond what was envisaged in the technical annex; it cut across several workpackages, and addressed new challenges that were identified in the course of the project.

The use of semantic web technology for modelling the functionality of semantic web tools was investigated in a cooperation between VUA and AIFB. The use case presented at the first WonderWeb review meeting was used as a scenario for this investigation. The resulting component ontology was integrated into KAON, where it is used to support the automatic selection of components.

Further investigations (in a cooperation between VUA and ISTC-CNR) concerned the use of the OWL-S services ontology[20] for representing the functionality of semantic web tools. First experiments revealed shortcomings in OWL-S w.r.t. capturing some system features. Beyond that, the conceptual design of OWL-S was analysed by aligning it to

[20] http://www.daml.org/services/owl-s/1.0/

DOLCE, revealing conceptual problems as well. As a result of this work, members of the WonderWeb consortium are now active in the OWL-S standardisation committee.

In another strand of this work, semi automatic methods for extracting service semantics from software design documents and software libraries were investigated. Experiments were carried out on the use of text mining techniques to extract key functionalities from JAVAdoc and on the extraction of service semantics from UML diagrams. Early results have been promising, and this work is still ongoing.

The work on Web Services benefited from strong collaborations between VUA, AIFB and ISTC-CNR, and is described in a number of joint publications such as [6, 21, 18].

Workpackage 5: Assessment, Dissemination and Evaluation

As foreseen in the technical annex, interaction with members of the Industrial Advisory Board (IAB) was an important mechanism for dissemination and evaluation. During the course of the project, two IAB workshops were held, the first in Manchester (11/09/02) and the second in conjunction with the International Semantic Web Conference in Florida, USA (20/10/2003). Attendees included representatives from Boeing, Canon, Cognit, GlaxoSmithKline, France Telecom, Hewlett Packard, IBM, Lucent, Network Inference,Sun, AIAI and W3C; in addition, representatives from DAML and the US Military attended the workshop in Florida.

At each of these workshops, the latest results of the project were presented, IAB members presented up to date information about their own related research activities and there were extended technical discussions and feedback from the IAB. Feedback from the IAB was particularly valuable as several members of the board, including e.g., Boeing, IBM and SUN, are evaluating tools and methodologies developed in the project by using them in internal R&D projects.

Most of the software developed in the project is open source and can be downloaded from the project website and/or SourceForge. SourceForge reports that the KAON has had more than 14,000 downloads and that the OWL API has had over 3,500 downloads.

The ontologies and methodologies developed in WP3 have also been adopted by numerous institutions, research projects and companies, including, e.g., the Dept. of Zoology, University of Oxford, UK; the UN/FAO Agricultural Ontology Service; IBM Watson Research Center, USA; and Nomos SpA, Milano, Italy.

Over 100 papers describing the work carried out in the project have been published in journals and in conference and workshop proceedings. These include papers in the field's leading international conferences and journals, including nine papers in the World Wide Web conference (average acceptance rate ≈15%), twelve papers in the International Semantic Web Conference (average acceptance rate ≈20%), four papers in Elsevier's Journal of Web Semantics, and two papers (plus several shorter items) in IEEE Intelligent Systems. Particularly noteworthy has been the number of joint papers resulting from cooperations between various project partners and members of the IAB, e.g., [18, 6, 2, 21, 7, 25]. A complete list of publications is available from the project web site.

Members of the consortium have given numerous invited talks and tutorials on ontology languages, infrastructure and engineering, e.g., at the 2003 International Semantic

Web Conference (ISWC), at the Semantic Web Summer School, at the 2003 ACM Symposium on Applied Computing, at the 2003 International Joint Conference on Artificial Intelligence (IJCAI), at the 2003 IFIP Conference on E-Commerce, E-Government and E-business, and at Hewlett-Packard Laboratories in Bristol, UK. They are also heavily involved in the organisation of relevant conferences and journals such as ISWC, the Semantic Web track of the World Wide Web conference, the Journal of Web Semantics and the Journal on Data Semantics.

The project web site proved a valuable resource, both within the project and as means of dissemination; project deliverables, publications and software are all available from the site.

Project management and co-ordination

The project ran very smoothly, and exceeded expectations in several respects—being a small consortium, we were able to keep the organisational overhead to a minimum and spend the majority of our time on technical issues. The project ran consistently on or ahead of schedule—all deliverables were produced on time (see Appendix A), and all milestones were achieved.

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On the management side, we should remark that more effort went in to WP 3.2 than originally foreseen. This has, however, produced results considerably exceeding those envisaged in the technical annex.

Contractual Issues

Due to an internal restructuring within the Italian National Research Council (CNR), the name of LADSEB-CNR was changed to ISIB-CNR (Istituto di Ingegneria Biomedica). With effect from January 1st, 2003, the ISIB-CNR research group working on WonderWeb (with two staff members: Nicola Guarino and Claudio Masolo) changed affiliation (while remaining within CNR) to the Institute of Cognitive Sciences and Technologies (ISTC-CNR), directed by Professor Cristiano Castelfranchi.

The director of ISIB-CNR (dr. Ferdinando Grandori) had no objection to the transfer of WonderWeb-related activities and funding to ISTC-CNR, and the change of affiliation did not affect the work carried out within the project.

Project meetings

Project meetings were held in Amsterdam on the 31/1–1/2/02, Karlsruhe on the 21–22/05/02, Manchester on the 9-11/09/02, Amsterdam on the 15-17/01/03, Trento on the 14–15/04/03, Trento again on the 30/6–1/7/03, Karlsruhe on the 29–30/09/03, Manchester on the 14-15/01/04 and Amsterdam on the 1–2/04/04.

Each of these meetings included a meeting of the Project Management Board (Ian Horrocks (VUM), Frank van Harmelen (VUA), Steffen Staab (AIFB) and Nicola Guarino (ISTC-CNR)); these were open meetings, and both minutes and presentation materials are posted on the project web site.[21]

Cooperation and co-ordination

As well as the regular face to face meetings, telephone conferences were used to facilitate close co-ordination between the various work packages. Visits and exchanges also played a key role in cementing cooperations and producing important results. These included a 3 month visit to VUM by Raphael Volz (AIFB), a visit to ISTC-CNR from Peter Mika

[21] http://wonderweb.semanticweb.org/meetings.shtml

(VUA) and a visit to AIFB from Marta Sabou (VUA). Various other technical meetings were also organised around project meetings, conferences and workshops. As already mentioned, these cooperations led to a number of joint publications such as [18, 6, 2, 21, 7].

Industrial Advisory Board

Members of the IAB were kept informed about the progress of the project via the web site and mailing list. The mailing list also enabled more active members of the IAB to participate in technical discussions (see list archive[22]).

As mentioned above, two very successful IAB workshop were held at Manchester and in conjunction with ISWC, and were attended by representatives from Boeing, Canon, Cognit, GlaxoSmithKline, France Telecom, Hewlett Packard, IBM, Lucent, Network Inference,Sun, AIAI and W3C. Several members of the IAB, including e.g., Boeing, IBM and SUN, are evaluating tools and methodologies developed in the project by using them in internal R&D projects.

It is worth pointing out that members of the IAB participated in all of these activities without any financial contribution from the project.

External co-ordination and cooperation

Members of the consortium were active in the IST OntoWeb Network:[23] Nicola Guarino (ISTC-CNR) chaired the Special Interest Group on Content Standards, Ian Horrocks (VUM) and Frank van Harmelen (VUA) chaired the Special Interest Group on Ontology Language Standards, and Andreas Persidis (IAB) and Alain Léger (IAB) chaired the Special Interest Group on Industrial Applications. They are also active the FP6 networks Knowledge Web[24], REWERSE[25] and Semantic Mining.[26] Clustering was further facilitated by members' participation in numerous related projects such as Harmonise, MetoKIS, MONET, Ontologging, SWWS, VICODI and Vision.

Members of the consortium were also very active in international cooperation and standardisation efforts. Both VUM and AIFB are involved in the DARPA DAML program,[27] and several members of the consortium were on the Joint EU/US Committee on Agent Markup Languages,[28] which developed the SWRL rules language and DQL query language proposals. VUA also worked with the Protégé development team at Stanford University, helping them to extend their versioning tools to use the framework developed in WP4. VUM, VUA and AIFB were active in the W3C Web Ontology language standardisation working group,[29] and ISTC-CNR was active in the IEEE SUO Standard

[22]http://lists.man.ac.uk/mailman/listinfo/wonderweb
[23]http://ontoweb.aifb.uni-karlsruhe.de/
[24]http://knowledgeweb.semanticweb.org/
[25]http://www.learninglab.de/deutsch/projekte/rewerse.html
[26]http://www.imt.liu.se/mi/semanticmining/
[27]http://www.daml.org/
[28]http://www.daml.org/committee/
[29]http://www.w3.org/2001/sw/WebOnt/

Upper Ontology (SUO) Working Group.[30] VUM was a founder member of the Description logic Interface Group (DIG),[31] whose objective is to develop a standard interface for description logic reasoners.

Effort and Cost breakdown

Effort in person months and costs are shown in Appendix B and Appendix C respectively.

Exploitation of Results

Exploitation opportunities look promising, with results of the project already being used by members of the IAB such as Boeing, IBM and SUN, as well as by other research groups and projects. Close cooperations were also established with HP Labs in Bristol, UK (see, e.g., [1]), where a 4 day invited visit was made by Sabou (VUA) and a full day tutorial given by Horrocks (VUM). Standard APIs such as DIG and the OWL API are being widely adopted, and SME members of the IAB, such as aidministrator, Network Inference and ontoprise have expressed interest in the commercial exploitation of tools developed in the project.

As mentioned above, the ontologies and methodologies developed in WP3 have been widely adopted. DOLCE and the WFOL have also been successfully used by ISTC-CNR in a number of application projects, especially for the development of so-called core ontologies of application domains, e.g., in the Fishery Ontology Service project with UN-FAO, and in several use cases from the Intelligent Knowledge Fusion EUREKA project.

An evaluation and market report has been produced by TopQuadrant, Inc. (D25), In this report, it is concluded that “WonderWeb products have created much of the infrastructure for the modern semantic web”, that Semantic Web technologies will be a market “valued in the tens of billions of euros by the end of this decade”.

[30] http://ltsc.ieee.org/suo/
[31] http://dl.kr.org/dig/

A Deliverables

Del. No.	Rev.	Title	Type[1]	Class.[2]	Due Date	Issue Date
1	1.0	Ontology Language	R	Pub.	30/09/02	30/09/02
2	1.0	Rule Language	R	Pub.	30/06/03	30/06/03
3	1.0	Language Extensions	R	Pub.	30/06/04	30/06/04
4	1.0	Standardisation Report	R	Int.	30/06/04	28/05/04
5	2.0	OntoServer Architecture	R	Int.	30/06/02	30/06/02
6	1.0	OntoServer Prototype	R/S	Pub.	31/12/02	18/12/02
7	1.0	OntoServer Demonstrator	D	Pub.	31/12/03	15/12/03
8	1.0	Triple Client	D	Pub.	30/06/03	30/06/03
9	1.0	OntoBroker and OntoEdit Adaption	D	Pub.	31/08/03	29/07/03
10	1.0	FaCT and OilEd Clients	D	Pub.	31/08/03	28/08/03
11	1.1	LiFT Prototype	R/S	Int.	31/12/02	20/12/02
12	1.0	LiFT Demonstrator	D	Pub.	30/06/04	29/04/04
13	1.0	Reasoner Prototype	P	Pub.	30/09/03	25/09/03
14	1.0	Reasoner Demonstrator	D	Pub.	30/06/04	30/06/04
15	1.0	Ontology Roadmap	R	Pub.	31/12/02	27/12/02
16	1.0	Ontology Methodologies	R	Pub.	30/04/02	07/05/04
17	2.0	Ontology Library (prelim.)	R/S	Int.	30/06/02	30/06/02
18	1.0	Ontology Library (final)	D	Pub.	31/12/03	31/12/03
19	1.0	Standardisation Report	R	Pub.	30/06/04	31/12/04
20	1.1	Versioning Framework	R	Pub.	31/08/02	26/08/02
21	1.0	Modularisation Mechanisms	R	Pub.	30/06/03	26/06/03
22	1.0	Ontology Refinement	R	Pub.	30/06/04	27/06/04
23	1.0	Assessment Report	R	Int.	30/06/04	14/06/04
24	1.0	International Conference	D	Pub.	31/12/03	19/12/03
25	1.0	Evaluation and Market Report	R	Int.	30/06/04	31/12/04[3]
26	1.0	Project Presentation	O	Pub.	31/03/02	15/03/02
27	1.0	Dissemination and Use plan	R	Int.	30/06/02	30/06/02
28	1.0	Technical Implementation Plan	R	Int.	30/06/04	31/12/04[3]
29	1.0	Final Report	R	Int.	30/06/04	31/12/04[3]

[1] R: Report; P: Prototype; D: Demonstrator

[2] Int.: Internal circulation within project (plus Commission Project Officer and reviewers if requested)
Rest.: Restricted circulation list (specify in footnote) plus Commission SO and reviewers only
IST: Circulation within IST Programme participants
FP5: Circulation within Framework Programme participants
Pub.: Public document

[3] Delivery date postponed due to project extension

B Effort expended

Appendix B

Effort in person months for reporting period 1/1/2002 - 31/12/2002

	VUM				VUA				LADSEB				AIFB				Total			
	Period		Total		Period		Total		Period		Total		Period		Total		Period		Total	
WP/Task	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.
WP1																				
D 1	7.0	4.0	7.0	4.0	1.0	1.5	1.0	1.5					1.0	2.0	1.0	2.0	9.0	7.5	9.0	7.5
D 2	1.0	0.5	1.0	0.5	0.5	0.5	0.5	0.5					0.5	1.5	0.5	1.5	2.0	2.5	2.0	2.5
D 3	1.0	0.0	1.0	0.0	0.5	0.5	0.5	0.5					0.5	1.5	0.5	1.5	2.0	2.0	2.0	2.0
D 4																	0.0	0.0	0.0	0.0
WP2																				
D 5	0.5	0.5	0.5	0.5									2.5	5.5	2.5	5.5	3.0	6.0	3.0	6.0
D 6													3.0	6.0	3.0	6.0	3.0	6.0	3.0	6.0
D 7													0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0
D 8													3.5	4.0	3.5	4.0	3.5	4.0	3.5	4.0
D 9													4.0	0.0	4.0	0.0	4.0	0.0	4.0	0.0
D 10	2.5	1.5	2.5	1.5									0.0	0.0	0.0	0.0	2.5	1.5	2.5	1.5
D 11													3.0	4.5	3.0	4.5	3.0	4.5	3.0	4.5
D 12													0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 13	3.0	1.5	3.0	1.5									0.0	0.0	0.0	0.0	3.0	1.5	3.0	1.5
D 14													0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WP3																				
D 15									6.0	5.0	6.0	5.0					6.0	5.0	6.0	5.0
D 16									0.0	0.0	0.0	0.0					0.0	0.0	0.0	0.0
D 17									6.0	7.0	6.0	7.0					6.0	7.0	6.0	7.0
D 18					1.0	1.0	1.0	1.0	3.0	3.5	3.0	3.5					4.0	4.5	4.0	4.5
D 19									0.0	0.0	0.0	0.0					0.0	0.0	0.0	0.0
WP4																				
D 20					7.0	9.0	7.0	9.0									7.0	9.0	7.0	9.0
D 21					4.5	6.0	4.5	6.0									4.5	6.0	4.5	6.0
D 22					0.0	1.0	0.0	1.0									0.0	1.0	0.0	1.0
WP5																				
D 23	1.0	0.5	1.0	0.5	0.5	0.5	0.5	0.5									1.5	1.0	1.5	1.0
D 24																	0.0	0.0	0.0	0.0
D 25																	0.0	0.0	0.0	0.0
WP6																				
D 26	2.0	2.0	2.0	2.0													2.0	2.0	2.0	2.0
D 27	2.0	2.0	2.0	2.0													2.0	2.0	2.0	2.0
D 28	0.0	0.0	0.0	0.0													0.0	0.0	0.0	0.0
D 29	0.0	0.0	0.0	0.0													0.0	0.0	0.0	0.0
Mgmt	1.5	0.0	1.5	0.0	0.5	0.0	0.5	0.0	0.5	0.0	0.5	0.0	0.5	0.0	0.5	0.0	3.0	0.0	3.0	0.0
Total	21.5	12.5	21.5	12.5	15.5	20.0	15.5	20.0	15.5	15.5	15.5	15.5	18.5	26.0	18.5	26.0	71.0	74.0	71.0	74.0

Appendix B

Effort in person months for reporting period 1/1/2003 - 31/12/2003

	VUM				VUA				ISTC-CNR				AIFB				Total			
	Period		Total		Period		Total		Period		Total		Period		Total		Period		Total	
WP/Task	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.
WP1																				
D 1	0.0	0.0	7.0	4.0	0.0	0.0	1.0	1.5					0.0	0.0	1.0	2.0	0.0	0.0	9.0	7.5
D 2	3.5	3.5	4.5	4.0	1.5	2.5	2.0	3.0					2.0	2.0	2.5	3.5	7.0	8.0	9.0	10.5
D 3	1.5	2.0	2.5	2.0	1.0	1.5	1.5	2.0					0.5	0.5	1.0	2.0	3.0	4.0	5.0	6.0
D 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WP2																				
D 5	0.0	0.0	0.5	0.5									0.0	0.0	2.5	5.5	0.0	0.0	3.0	6.0
D 6	0.0	0.0	0.0	0.0									0.0	0.0	3.0	6.0	0.0	0.0	3.0	6.0
D 7	0.0	0.0	0.0	0.0									6.0	6.0	6.0	7.0	6.0	6.0	6.0	7.0
D 8	0.0	0.0	0.0	0.0									6.0	6.0	9.5	10.0	6.0	6.0	9.5	10.0
D 9	0.0	0.0	0.0	0.0									9.0	9.0	13.0	9.0	9.0	9.0	13.0	9.0
D 10	3.5	3.5	6.0	5.0									0.0	0.0	0.0	0.0	3.5	3.5	6.0	5.0
D 11	0.0	0.0	0.0	0.0									0.0	0.0	3.0	4.5	0.0	0.0	3.0	4.5
D 12	0.0	0.0	0.0	0.0									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 13	6.0	7.0	9.0	8.5									0.0	0.0	0.0	0.0	6.0	7.0	9.0	8.5
D 14	3.0	4.0	3.0	4.0									0.0	0.0	0.0	0.0	3.0	4.0	3.0	4.0
WP3																				
D 15					0.0	0.0	0.0	0.0	0.0	0.0	6.0	5.0					0.0	0.0	6.0	5.0
D 16					0.0	0.0	0.0	0.0	3.5	4.5	3.5	4.5					3.5	4.5	3.5	4.5
D 17					0.0	0.0	0.0	0.0	0.0	0.0	6.0	7.0					0.0	0.0	6.0	7.0
D 18					1.0	1.5	2.0	2.5	9.0	12.5	12.0	16.0					10.0	14.0	14.0	18.5
D 19					0.0	0.0	0.0	0.0	0.0		0.0	0.0					0.0	0.0	0.0	0.0
WP4																				
D 20					0.0	0.0	7.0	9.0	0.0	0.0	0.0	0.0					0.0	0.0	7.0	9.0
D 21					4.5	7.5	9.0	13.5	1.0	1.0	1.0	1.0					5.5	8.5	10.0	14.5
D 22					5.5	9.0	5.5	10.0	1.0	1.0	1.0	1.0					6.5	10.0	6.5	11.0
WP5																				
D 23	1.5	1.5	2.5	2.0	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0.0					1.5	1.5	3.0	2.5
D 24	2.5	2.5	2.5	2.5	1.5	2.5	1.5	2.5	0.0	0.0	0.0	0.0					4.0	5.0	4.0	5.0
D 25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					0.0	0.0	0.0	0.0
WP6																				
D 26	0.0	0.0	2.0	2.0													0.0	0.0	2.0	2.0
D 27	0.0	0.0	2.0	2.0													0.0	0.0	2.0	2.0
D 28	1.0	1.5	1.0	1.5													1.0	1.5	1.0	1.5
D 29	1.0	1.5	1.0	1.5													1.0	1.5	1.0	1.5
Mgmt	2.0	4.5	3.5	4.5	0.5	0.5	1.0	0.5	0.5	0.5	1.0	0.5	0.5	0.5	1.0	0.5	3.5	6.0	6.5	6.0
Total	25.5	31.5	47.0	44.0	15.5	25.0	31.0	45.0	15.0	19.5	30.5	35.0	24.0	24.0	42.5	50.0	80.0	100.0	151.0	174.0

Effort in person months for reporting period 1/1/2004 - 31/12/2004

	VUM				VUA				ISTC-CNR				AIFB				Total			
	Period		Total		Period		Total		Period		Total		Period		Total		Period		Total	
WP/Task	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.
WP1																				
D 1	0.0		7.0	4.0	0.0	0.0	1.0	1.5					0.0	0.0	1.0	2.0	0.0	0.0	9.0	7.5
D 2	0.0		4.5	4.0	0.0	0.0	2.0	3.0					0.0	0.0	2.5	3.5	0.0	0.0	9.0	10.5
D 3	1.0	12.0	3.5	14.0	1.5	1.5	3.0	3.5					1.5	1.5	2.5	3.5	4.0	15.0	9.0	21.0
D 4	1.0	2.0	1.0	2.0	0.0	0.0	0.0	0.0					0.0	0.0	0.0	0.0	1.0	2.0	1.0	2.0
WP2																				
D 5	0.0		0.5	0.5									0.0	0.0	2.5	5.5	0.0	0.0	3.0	6.0
D 6	0.0		0.0	0.0									0.0	0.0	3.0	6.0	0.0	0.0	3.0	6.0
D 7	0.0		0.0	0.0									0.0	0.0	6.0	7.0	0.0	0.0	6.0	7.0
D 8	0.0		0.0	0.0									0.0	0.0	9.5	10.0	0.0	0.0	9.5	10.0
D 9	0.0		0.0	0.0									0.0	0.0	13.0	9.0	0.0	0.0	13.0	9.0
D 10	0.0		6.0	5.0									0.0	0.0	0.0	0.0	0.0	0.0	6.0	5.0
D 11	0.0		0.0	0.0									0.0	0.0	3.0	4.5	0.0	0.0	3.0	4.5
D 12	0.0		0.0	0.0									4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
D 13	0.0		9.0	8.5									0.0	0.0	0.0	0.0	0.0	0.0	9.0	8.5
D 14	6.0	13.0	9.0	17.0									0.0	0.0	0.0	0.0	6.0	13.0	9.0	17.0
WP3																				
D 15					0.0	0.0	0.0	0.0	0.0		6.0	5.0					0.0	0.0	6.0	5.0
D 16					0.5	0.5	0.5	0.5	3.0		6.5	4.5					3.5	0.5	7.0	5.0
D 17					0.0	0.0	0.0	0.0	0.0		6.0	7.0					0.0	0.0	6.0	7.0
D 18					0.0	0.0	2.0	2.5	0.0		12.0	16.0					0.0	0.0	14.0	18.5
D 19					0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0					1.0	1.0	1.0	1.0
WP4																				
D 20					0.0	0.0	7.0	9.0	0.0		0.0	0.0					0.0	0.0	7.0	9.0
D 21					0.0	0.0	9.0	13.5	0.0		1.0	1.0					0.0	0.0	10.0	14.5
D 22					2.5	2.5	8.0	12.5	1.0		2.0	1.0					3.5	2.5	10.0	13.5
WP5																				
D 23	2.0		4.5	2.0	0.5	0.5	1.0	1.0	1.5	1.5	1.5	1.5					4.0	2.0	7.0	4.5
D 24	0.0		2.5	2.5	0.0	0.0	1.5	2.5	0.0		0.0	0.0					0.0	0.0	4.0	5.0
D 25	2.0		2.0	0.0	0.5	0.5	0.5	0.5	1.5	1.5	1.5	1.5					4.0	2.0	4.0	2.0
WP6																				
D 26	0.0		2.0	2.0			0.0	0.0			0.0	0.0			0.0	0.0	0.0	0.0	2.0	2.0
D 27	0.0		2.0	2.0			0.0	0.0			0.0	0.0			0.0	0.0	0.0	0.0	2.0	2.0
D 28	0.5	3.0	1.5	4.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	2.0	4.5	3.0	6.0
D 29	2.0	3.0	3.0	4.5			0.0	0.0			0.0	0.0			0.0	0.0	2.0	3.0	3.0	4.5
Mgmt	1.0	6.5	4.5	11.0	0.5	0.5	1.5	1.0	0.5		1.5	0.5	0.5	0.5	1.5	1.0	2.5	7.5	9.0	13.5
Total	15.5	39.5	62.5	83.5	6.5	6.5	37.5	51.5	9.0	4.5	39.5	39.5	6.5	6.5	49.0	56.5	37.5	57.0	188.5	231.0

C Costs breakdown

Costs for reporting period 1/1/2002 - 31/12/2002

	VUM				VUA				LADSEB				AIFB				Total			
	Period		Total		Period		Total		Period		Total		Period		Total		Period		Total	
Cost category	Est.	Act.	Est.	Act.	Est.	Act.*	Est.	Act.*	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.*	Est.	Act.*
Direct costs																				
1. Personnel	138	61	138	61	68	73	68	73	67	66	67	66	85	95	85	95	358	295	358	295
2. Durable equipment	0	0	0	0	9	7	9	7	12	8	12	8	5	2	5	2	26	17	26	17
3. Subcontracting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4. Travel and subsistence	15	14	15	14	12	10	12	10	9	11	9	11	12	2	12	2	48	37	48	37
5. Consumables	7	3	7	3	1	1	1	1	2	1	2	1	1	1	1	1	11	6	11	6
6. Computing	13	6	13	6	0	0	0	0	0	0	0	0	0	0	0	0	13	6	13	6
7. Protection of knowledge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8. Other specific costs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	173	84	173	84	90	92	90	92	90	86	90	86	103	100	103	100	456	361	456	361
Indirect costs																				
9. Overheads	35	17	35	17	18	18	18	18	54	53	54	53	21	20	21	20	128	108	128	108
Total	**208**	**101**	**208**	**101**	**108**	**110**	**108**	**110**	**144**	**139**	**144**	**139**	**124**	**120**	**124**	**120**	**584**	**469**	**584**	**469**

Costs for reporting period 1/1/2003 - 31/12/2003

	VUM				VUA				LADSEB				AIFB				Total			
	Period		Total		Period		Total		Period		Total		Period		Total		Period		Total	
Cost category	Est.	Act.	Est.	Act.	Est.	Act.*	Est.	Act.*	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.*	Est.	Act.*
Direct costs																				
1. Personnel	147	104	285	165	71	91	139	164	67	81	134	147	115	102	200	197	400	378	758	673
2. Durable equipment	0	0	0	0	0	2	9	9	0	4	12	12	0	2	5	4	0	8	26	25
3. Subcontracting	45	0	45	0	0	0	0	0	0	0	0	0	0	0	0	0	45	0	45	0
4. Travel and subsistence	15	26	30	40	12	16	24	26	9	2	18	13	12	24	24	26	48	68	96	105
5. Consumables	2	3	9	6	1	0	2	1	1	0	3	1	1	0	2	1	5	3	16	9
6. Computing	13	11	26	17	0	0	0	0	0	0	0	0	0	0	0	0	13	11	26	17
7. Protection of knowledge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8. Other specific costs	18	3	18	3	0	2	0	2	0	0	0	0	0	0	0	0	18	5	18	5
Subtotal	240	147	413	231	84	111	174	202	77	87	167	173	128	128	231	228	529	473	985	834
Indirect costs																				
9. Overheads	39	29	74	46	17	22	35	40	54	65	108	118	26	26	47	46	136	142	264	250
Total	**279**	**176**	**487**	**277**	**101**	**133**	**209**	**242**	**131**	**152**	**275**	**291**	**154**	**154**	**278**	**274**	**665**	**615**	**1249**	**1084**

Costs for reporting period 1/1/2004 - 31/12/2004

	VUM				**VUA**				**LADSEB**				**AIFB**				**Total**			
	Period		**Total**		**Period**		**Total**		**Period**		**Total**		**Period**		**Total**		**Period**		**Total**	
Cost category	Est.	Act.	Est.	Act.	Est.	Act.*	Est.	Act.*	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.*	Est.	Act.*
Direct costs																				
1. Personnel	76	150	361	315	46	24	185	188	40	30	174	177	39	43	239	240	201	247	959	920
2. Durable equipment	0	0	0	0	0	0	9	9	0	0	12	12	0	2	5	6	0	2	26	27
3. Subcontracting	45	24	90	24	0	0	0	0	0	0	0	0	0	0	0	0	45	24	90	24
4. Travel and subsistence	11	3	41	43	6	6	30	32	3	1.7	21	14.7	6	18	30	44	26	28.7	122	133.7
5. Consumables	1	2	10	8	1	1	3	2	0	0	3	1	1	2	3	3	3	5	19	14
6. Computing	7	19	33	36	0	0	0	0	0	0	0	0	0	0	0	0	7	19	33	36
7. Protection of knowledge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8. Other specific costs	4	0	22	3	4	4	4	6	8	0	8	0	4	0	4	0	20	4	38	9
Subtotal	144	198	557	429	57	35	231	237	51	31.7	218	204.7	50	65	281	293	302	329.7	1287	1163.7
Indirect costs																				
9. Overheads	20		94	46	11		46	40	32		140	118	10		57	46	73	0	337	250
Total	**164**	**198**	**651**	**475**	**68**	**35**	**277**	**277**	**83**	**31.7**	**358**	**322.7**	**60**	**65**	**338**	**339**	**375**	**329.7**	**1624**	**1413.7**

Selected Publications

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[4] Aldo Gangemi, Nicola Guarino, Claudio Masolo, and Alessandro Oltramari. Sweetening WORDNET with DOLCE. *AI Magazine*, 24(3):13–24, 2003.

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[12] Ian Horrocks and Ulrike Sattler. The effect of adding complex role inclusion axioms in description logics. In *Proc. of the 18th Int. Joint Conf. on Artificial Intelligence (IJCAI 2003)*, pages 343–348. Morgan Kaufmann, Los Altos, 2003.

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[17] P. Mika, D. Oberle, A. Gangemi, and M. Sabou. Foundations for service ontologies: Aligning OWL-S to dolce. In S.I. Feldman, M. Uretsky, M. Najork, and C.E. Wills, editors, *Proc. of the Thirteenth International World Wide Web Conference (WWW 2004)*, pages 563–572. ACM, 2004.

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