service WEB 3.0

Semantic Technologies

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Special Purpose Roadmaps

Lyndon Nixon (STI)

Graham Hench (STI)

Elena Simperl (UIBK)

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Authors (Partner)	Lyndon Nixon (STI), Graham Hench (STI), Elena Simperl (UIBK)			
Resp. Author	Lyndon Nixon		E-mail	lyndon.nixon@sti2.org
	Partner	STI	Phone	+43-1- 236-4002-13

Abstract (for dissemination)	Following the Service Web 3.0 roadmap for Future Internet, we turn to specialized roadmaps focusing on two technological trends which we expect to play a very significant role in the realization of the full potential of Future Internet. In a complementary document, we will outline a roadmap for services in industry; in this document we focus on the expected developments in semantic technologies over the next 15 years.

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Executive Summary

1. Introduction

Following the Service Web 3.0 roadmap for Future Internet, we turn to specialized roadmaps focusing on two technological trends which we expect to play a very significant role in the realization of the full potential of Future Internet. In a complementary document, we will outline a roadmap for services in industry; in this document we focus on the expected developments in semantic technologies over the next 15 years.

Looking back over the past 15 years, few would have predicted the impact of the Internet to our daily lives. Internet technologies have effected a major transformation and spurred innovations in many other technologies and sciences. This transformation has been achieved by tearing apart prior frictions in communication and information exchange. Semantic technologies are on the cusp of becoming mainstream technologies and promise to remove many of the remaining frictions in communication and information exchange.

Wondering about what the impact of semantic technologies in the near and not so far future would be, STI International invited world-leading experts in semantic technologies to a number of roadmapping workshops in 2008 and 2009 to discuss questions such as:

1. Which set of major transformations can we expect from semantic technologies?
2. What is the role of semantic technology in responding to large societal challenges?
3. Which new application areas could emerge from the fusion of semantics with other technologies and sciences?
4. Which technologies come next?

This document summarizes the results of those roadmapping workshops. We hope that this roadmap can become a shared vision of the future and fully enfold its potential to create powerful expectations of emerging technologies and mobilize the resources necessary for their realization.

2. Roadmap Methodology

To gather opinions and form insight into the future of semantic technologies, STI International invited world-leading experts in future Internet technologies as well as semantics to a series of workshops to come up with a vision of the future of Semantic technologies and a technology roadmap towards the year 2024.

The first workshop was held at the "Österreichische Computer Gesellschaft (OCG)" in Vienna, Austria. Its focus was on semantic technologies in the next 5 years, i.e. by 2014.

The second Semantic Technology Roadmap workshop was held at the IHK Haus der Wirtschaft Karlsruhe GmbH, in Karlsruhe, Germany. Its focus was on semantic technologies in 10 years from now, i.e. by 2019. A group of invited experts on semantic technology presented their personal visions.

The third Semantic Technology Roadmap workshop was during the European Semantic Web Conference (ESWC) 2009, in Heraklion, Greece. It opened the discussion to the wider international semantics research and application community under the subtitle “How will semantic technologies be used in 2024? “.

Based on the expert input from these workshops, we are able to present the vision of the semantic technology community for the development of the technology over the next 15 years. To create the roadmap, we followed a staged approach. The three workshops are intended to gather a wide array of input from members of the semantics community (from within STI International), distinguished experts as well as the wider semantics community. All participants were invited to pitch their vision of the future in a 15 minutes presentation with the audience taking note of the most compelling arguments. These notes were then brought together and clustered among application areas and enabling technologies.

Table 1 lists the participants of the first two workshops in Vienna and Karlsruhe, which were invitation-only events.

Table 1: Participating Experts in the Invitation-only Events

1st Workshop (Vienna, Austria – co-located with ESTC'08)	**2nd Workshop (Karlsruhe, Germany – co-located with ISWC'08)**
• Diego Berrueta • Michael Brodie • Fabio Ciravegna • Marko Grobelnik • Dunja Mladenic • Lyndon Nixon • Rudi Studer • Emanuele Della Valle • Vojtech Vatek	• Philip Cimiano • Fabio Ciravegna • David De Roure • Stefan Decker • John Dominque • Aldo Gangiemi • Marc Greaves • Carole Goble • James Hendler • Guus Schreiber • Elena Simperl • Rudi Studer

The third workshop was an open public event co-located with ESWC 2009, with expert presentations from:

- Fabio Ciravegna
- Ioan Toma, Elena Simperl and Graham Hench
- Catherina Burghart, Andreas Abecker and Rudi Studer

3. Semantic Technologies in the Future

In 2006-7, the EU Network of Excellence KnowledgeWeb produced a “Technology Roadmap of the Semantic Web”[1]. Based on interviewing both researchers and practitioners, it found both groups

[1] Roberta Cuel, Alexandre Delteil, Vincent Louis and Carlo Rizzi, “Knowledge Web Technology Roadmap” cf. http://kw.dia.fi.upm.es/O2I/menu/KWTR-whitepaper-43-final.pdf

expected mainstream adoption to be reached in the period 2009-2014. The World Wide Web consortium (W3C) considers semantic technologies to be on the cusp of maturity and widespread uptake (see Figure 1 below).

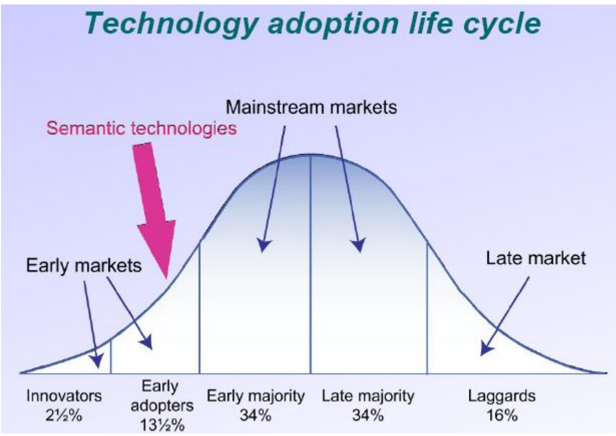

Figure 1: Semantic technologies adoption life cycle (October 2009) [2]

[2] From W3C / Ivan Herman cf. http://www.w3.org/People/Ivan/CorePresentations/Applications/

Gartner has also predicted the mainstream adoption of the Semantic Web, albeit after 2018. Other aspects which can make use of semantic technologies are placed earlier in the timescale for achieving maturity, as seen in the “Priority Matrix for Web and User Interaction Technologies 2008”:

- Less than 2 years: Web 2.0 and Mashup Technologies
- 2 to 5 years: Social Mining and Social Intelligence, Advanced Web Services
- 5 to 10 years: Context Delivery Architecture

benefit	years to mainstream adoption			
	less than 2 years	2 to 5 years	5 to 10 years	more than 10 years
transformational	Enterprise Portals Web 2.0	Cloud/Web Platforms Public Virtual Worlds SOA Social Applications	Cloud Computing Context Delivery Architecture	
high	Mashup Applications Portlets	Composite Applications Service-Oriented Business Applications Social Mining and Social Intelligence Social Software Suites WOA: Enterprise REST and POX	Federated Portals Across Vendor Families Portal Fabric Private Virtual Worlds	Semantic Web
moderate	Basic Web Services Corporate Blogging	Advanced Web Services Federated Portals Within Vendor Families RIA Platforms RIA Rich Client RSS in the Enterprise Second-Generation Portlet Standards (JSR 286 and WSRP v.2) Web Analytics	Enterprise-Class RSS	
low				

As of July 2008

Figure 2: Gartner Priority Matrix for Web and User Interaction Technologies

Further insight can be gained by directly engaging active experts in the field, as already seen by the Knowledge Web roadmapping work carried out in 2006-7. STI International as an association of semantic technology expert organisations is a direct follow-on from the Knowledge Web network of excellence and includes many of the experts who were involved in KnowledgeWeb. The roadmapping activities in 2008-9 which are reported here bring new insights for the future, reflected by the latest progress made in specifying and standardising the technology and the maturing of the tools.

4. Expert visions on semantic technologies

We present here the individual presentations of the experts from the semantic community made at the roadmapping workshops.

The intention at the workshops was not to capture the widest democratic consensus, but to reflect the (potentially diverging) views among the group of visionaries and experts. In fact, we consider “consensus” to be counterproductive for the roadmap, which aims to open new frontiers for the development of semantic technologies.

4.1. In 2014

Diego Berrueta, Researcher, CTIC Foundation
Recognizing that the current Internet still has a lot of problems (spam, trust, precise search, system interoperability) the first steps must be to provide solutions here. Our hot research topics for the next years are: context and profiling, data grounding, knowledge sharing and management, and pervasive sensor networks.

Michael Brodie, Chief Scientist, Verizon Communications
In 5 years from now the world will be even more networked as before and the Internet even more ubiquitous. We will be measuring data and traffic in zettabytes (each representing 250 billion DVDs). We should find niches in emerging technologies where we can bring semantics: such examples are social networks/computing, master data management, business rule management. The Gartner hype curves for different technology trends don't mention semantics at all! The main thing is to find problems where semantic technologies provide an unique advantage and develop real solutions.

Fabio Ciravegna, Professor, University of Sheffield
Semantic technologies will gain traction for large scale distributed organisations. A future trend with high impact will be the "Corporate Semantic Web" (Gartner).

Marko Grobelnik, Researcher, Josef Stefan Institute
The role of semantics can be to reduce and control the complexity of information, so semantic technologies are really a horizontal area technology for anywhere that has to deal with abstractions. We expect semantic research to aid a defragmentation of scientific discipline, that semantics will aid machine understanding of text and become very practical at the "long tail" of lightweight reasoning, sensors will make real time solutions on data streams more important and "cloud computing" will address the scalability of heavyweight reasoning.

Dunja Mladenic, Researcher, Josef Stefan Institute
Semantics in 2014 will address all data modalities, including media types, enterprise networks, personal content and community. Knowledge generation and flow between actors in the networked world will be modelled by semantic technologies, enabling the understanding and prediction of interactions and incorporating knowledge bases and reasoning to produce more observable concrete data from content and interactions. There will be more gadgets, more services, more fun, and ... less privacy.

Lyndon Nixon, Senior Researcher, STI International
Media is no longer tied to a single device, but will be as ubiquitous as the Internet. Added value services will be part of media delivery and media storage will be in the cloud. Semantics will be beginning to enter the mainstream in 5 years, and we will be on the cusp of rich, intelligent added value media services.

Rudi Studer, Professor, University of Karlsruhe / Karlsruhe Institute of Technology
The trends are towards more mobile (PDA) and ubiquitous computing, the emergence of the Internet of Services and even greater information overload. Semantic technologies will become more mature and more pragmatic, with the market mainly lightweight applications, and the main usage being data integration across service providers and contextualised service/information delivery and consumption.

Semantics will be for the masses: emerging as a byproduct of daily work and collaboration. New application areas emerging from the fusion of semantics and other technologies include intelligent assistence in automobiles and augmented reality. Tackling global problems, semantics may help resource-aware and sustainable IT, better information access for the "digitally disadvantaged", and eHealth.

Emanuelle Della Valle, Assistant Professor, Politecnico di Milano
The growth in sensor networks has generated the area of stream databases and processing. With semantic technologies, this will become "stream reasoning". A sample application is Urban Computing (pervasive computing in urban environments), where stream reasoning could address dynamic, real time problems in cities, e.g. changes in environment, accident notification, tracking movement of persons and goods.

Vojtech Svatek, Associated Professor, University of Economics Prague
Semantics will be used in cost/benefit modelling - to help determine in which cases semantic technologies are worth using! For example, some are still sceptical in the database community about semantics in knowledge discovery, but we expect the benefits will soon outweight the costs. There is a need for 'metamorphic' ontologies that can be automatically refactored according to need. Since ontologies will be the backbone of semantic applications, they need to bend along with application use!

4.2. In 2019

Philip Cimiano, Assistant Professor, Technical University of Delft
Entitled “Semantics reaches the masses!”, the key trends were seen as data and application ubiquity, information overload and data redundancy. Semantics will improve search and information delivery, and by 2019 will have achieved measurable criteria in benchmarks, performance and usability. The “shallow web” (Web 2.0 data) will have merged with semantics to allow on-the-fly data processing from low level data (clicks, tags) and personalized/contextualized social information delivery. Metadata creation will be a fully implicit action from daily work and from context, e.g. sensors. In applications, particularly the automative and healthcare sectors may have semantics in critical systems.

Fabio Ciravegna, Professor, University of Sheffield

Virtual Worlds will be in use for social participation, commercial simulation, complex experiments and cultural preservation. Semantics will be embedded into objects in those worlds for interoperability, trading and interaction, and for trust and provenance.

David De Roure, Professor, University of Southampton
Semantics will enable rapid application development over multiple legacy network information systems. For example, semantics make it possible for sensor networks to dynamically discover and integrate with one another and with other data sources, as well as for the rapid development of flexible decision support systems based on data from different networks. This will be based on production quality tools, network “mash-up” tools for non-experts and effective automation.

John Domingue, Professor, Open University and President, STI International
The growth in mobile and ubiquitous Internet devices will necessitate the development of a new network infrastructure for the Internet. Everything will become a service, and be tradable. Semantics are needed to enhance and enable planet scale networks, hence they will be an unavoidable part of the Future Internet.

Aldo Gangiemi, Senior Researcher, ISTC-CNR
Semantics will come to underlie application development, and result in large scale CMS and “knowledge units” which will help online organizations to move from an “image” to an “identity”, and reducing the time for the delivery of personalized web-based applications. Ontology creation will be fully automated and high quality, leading to on-the-fly ubiquitous semantics, situation awareness and anomaly detection. Analogical representation and reasoning will make possible a semiotic web. Maybe semantics can solve some of the worlds problems: energy consumption, environmental sustainability, cultural integration...

Carole Goble, Professor, University of Manchester
Semantics will be part of global, digital health systems, e.g. MyFamily – health information sharing between family members, Energy Balance Wristwatch – a personal device for sensing fat depositing and burning activities, Electronic Health Records – which can be shared under certain conditions to process health trends in a sample of people and make predictions, E-laboratories – where data from experiments and experts can be combined and processed to discover new information.

James Hendler, Professor, Rensselaer Polytechnic Institute
trends are the increased import of “social context”, decreased importance of the machine (life in the cloud), changing concept of trust and privacy, and increased data intensity. Semantics will make possible better profile-based matching, scalable back-end reasoning technology, next generation personal information devices and context-aware end user applications. Agents will be taking care of many information tasks for humans, and avatars will make it out of games (e.g. doctor, librarian)

Guus Schreiber, Professor, Vreie Universitaet Amsterdam
There will be greater context awareness, personal profiles “in the cloud”, XXL datasets and lightweight reasoning. Virtual worlds will be commonplace and we will have knowledge democracy (e.g. semantic wikipedia for niche areas, cooperative semantic annotations, medical information access)

Elena Simperl, Vice Director, Semantic Technology Institute Innsbruck at the University of Innsbruck
“The network is the people” Human intelligence will be channeled and exploited to resolve semantic computing tasks and integrate human with computational intelligence. Semantics will have been simplified w.r.t. language and interface, and ontology lifecycles will be part of the personal information management. A semantic “Web 2.0” will create metadata and ontologies through incentive structures and integration into games, virtual worlds, or office tools.

4.3. In 2024

Following the two roadmapping workshops involving STI experts, the third workshop opened the discussion to the wider semantics research and application community and was co-located at the European Semantic Web Conference (ESWC) 2009 in Heraklion, Crete.

Under the subtitle „How will semantic technologies be used in 2024?“ the workshop asked the question, given how in the last 15 years the World Wide Web has radically changed how our society communicates, connects, does business, shares information and performs tasks, how will computing change in the next 15 years, and what role will semantic technologies play in that?

The discussion was kicked off by the invited expert Prof. Dr. Fabio Ciravegna, of the University of Sheffield and also Service Co-ordinator for the STI International Roadmapping Service. His talk entitled „Six Impossible Things“ laid out a challenging vision of an expansion in computing power, digital storage and Internet-accessing devices in the next 15 years. Selecting certain futurist views on technology in 2024 such as nano-implants, he showed how we need to think big if we are to think about the place of semantics 15 years from now.

Two further presentations solicited by a public call for submissions took place, delving down into two specific technology directions which will grow in significance in the next 15 years:

- *A joint roadmap for semantic technologies and the Internet of Things*, Ioan Toma, Elena Simperl and Graham Hench (STI Innsbruck and STI International): considered the challenges in research that arise when (nearly) everything is on the Internet and consuming and providing data, and the potential of semantic technologies to organize and mediate between the large scales of data which result;
- *Future Challenge: Fast and Reliable Aggregation of Information from Ubiquituous Data Streams*, Catherina Burghart, Andreas Abecker and Rudi Studer (FZI Research Center for Information Technology): followed on from the topic of Internet of Things into the ubiquitous data streams that those things would be generating, and how the information in those streams may be extracted and shared with others in an automated fashion taking privacy and trust issues into account (supported by semantics).

These talks were followed by a group of international experts, including representatives from the United Nations FAO, Malaysia and Australia. In an open discussion with the group, many points were raised, inspired from the presentations:

- the gradual convergence of the digital and real world, and semantics as a means to model complex events;
- the dangers of omnipresent data and the need for (semantic) technology to identify untrusted information, sensor errors, deception etc.;
- the need to fill the gap between knowledge experts and the „farmer in the field“ whose knowledge should be modelled, if semantics are to ever come out of their high tower and down to e.g. agriculture in the developing world.

Finally, an interactive session took place involving the participants sharing their visions for semantics in terms of emerging application areas of semantics over the next 15 years, as well as the semantic and non-semantic technologies whose maturity and mainstream uptake would combine to generate new use cases in those application areas. The session generated some new ideas for application areas and technologies in addition to those identified in the previous workshops:

- Application areas - Augmented Education, Smart Home, Robotics, Agriculture
- Technologies - Knowledge verification, Smart Grids, Recommendation Systems, Knowledge engineering

5. Focus on particular technologies and application areas

The workshop participants have paraded a wide array of visions for future applications of semantic technologies. All applications identified have assumed the omnipresence of basic Internet technologies and the Web. Almost all visions presented (see http://roadmap.sti2.org/index.php/presentations for the individual presentations (partly with videos)) have assumed that core semantic technologies, such as annotation, data mining / knowledge discovery, modelling and reasoning, will interact with other emerging technologies to enable new applications and solve real-world problems.

The following technologies were identified as particularly interesting candidates for a pairing with semantic technologies:

- Social technologies (such as social networks)
- 3D technologies (e.g. virtual worlds)
- Mobile networks
- Sensors and sensor networks (e.g. RFID)
- New media technologies (such as IPTV)

In their interaction with these other technologies, semantic technologies are considered to reach the mainstream in the next years in many application areas:

- in enterprises where they will increase the effectiveness of administration and management (e.g. IT asset management)
- to manage energy more intelligently
- to increase flexibility and effectiveness of production
- to enable new ways of interaction in media, art and entertainment
- to better our health care

to improve urban life, e.g. by optimizing traffic flow and other types of urban computing

The interplay between application areas, semantic technologies and non-semantic technologies, leading to new technological and social developments, is illustrated in Figure 3.

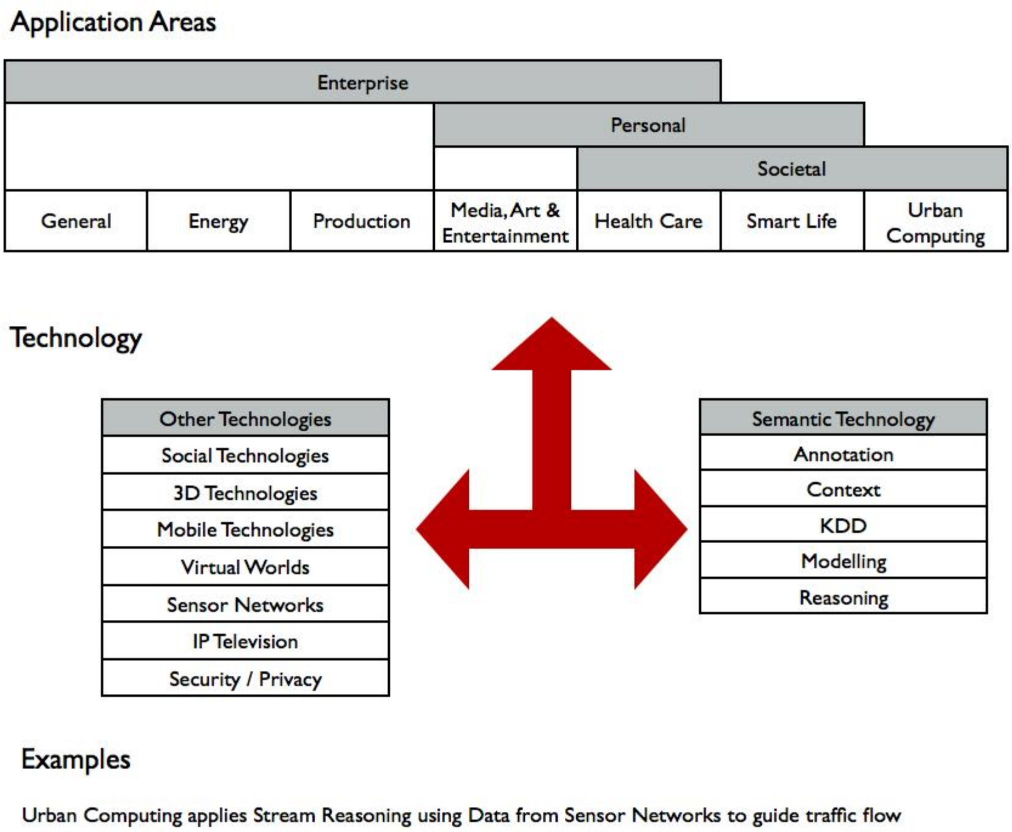

Figure 3: Future mainstream application areas for semantic technologies

In the following, we focus on the state of the art and future visions of experts for these specific semantic and non-semantic technologies and application areas.

Semantic Technology

5.1. Annotation

In the context of the Semantic Web *annotation* is understood as the process of assigning terms from an ontology to a resource (e.g., a text document, Web page, image, graphics, audio or video) or a part of a resource (e.g., a sentence, term, spatial/temporal region of a media item) in order to describe the resource in a machine-understandable way. End-user applications which benefit from the availability of semantic annotations are numerous and range from information and knowledge management to personalization or data integration.

Technology for the creation, management and usage of semantic annotations can be found in various areas. Methods from computational linguistics provide means for named entity recognition, structure analysis, information extraction, semantic tagging or even ontology learning from textual sources, leading to semantic annotations. Foundational technologies to (semi-) automatically annotate non-textual resources have been investigated by the multimedia semantics community, which spans more broadly the areas of computer vision and multimedia analysis. These areas provide means to analyze visual streams of information with the help of low-level feature extraction, object detection or high-level event inferencing. Together with information extraction solutions such means can be used, amongst others, in cross-media document indexing, media indexing or for the annotation of Web-based resources on the swallow as well as on the Deep Web. Most notably, for non-textual resources, annotation is still carried out manually to a large extent, thus being associated to significant costs. Therefore, specialized annotation tools are provided to accompany automated solutions and to overcome limitations of state-of-the-art multimedia understanding technology.

Despite promising advances, approaches that can be generically and efficiently applied to automate annotation across media still remain to be defined. In contrast to textual resources, which are annotated automatically to a large extent, non-textual media semantic annotation heavily relies on human input. Other challenges in this context include solutions for cross-media annotation, as well as the scalability and portability of existing solutions to other domains.

Semantic annotation of texts relies on existing technology for information extraction, named entity recognition or document classification, which can be adapted to the purpose of semantic applications. What has still not happened on a large scale is the automated interconnection of information from different sources or even different media. In an enterprise setting, for instance, information is distributed across a high number of different repositories and has to be consolidated to solve problems. This is not only true for knowledge management but also in other business intelligence scenarios. The support of individual knowledge workers still lacks contextualization, which results in systems that still to some extent suffer from information overload. This is an issue especially when information should be delivered as targeted or as timely as possible.

In the area of legacy data integration, which aims at bootstrapping annotation by exploiting richly structured data sources to make them part of the annotated Web, solutions have been proposed to convert relational databases to RDF or to provide wrapper-based approaches to query databases using SPARQL. Furthermore, tools to semantically enrich office documents like emails, text documents or Excel sheets and to provide rich semantic annotations of these resources become mainstream. Underlying techniques have recently been proposed in relation to research on semantic desktops and in the efforts of the Linked Data community. Again, what is currently missing here is the inclusion of non-textual resources like presentations, images, or audio files on the desktop in a meaningful way.

The area of computer vision provides methods to make visual resources eligible for machines. Recent years have seen considerable advancement in the range of things which are detectable in still and moving images. This includes object detection scaling up to a considerable amount of different objects for some tools, to object tracking in e.g. surveillance videos. All of these approaches try to derive meaning from low-level features (like colour histogram, motion vectors, etc.) automatically. Despite constant advances these tools are still not capable to exploit the full meaning of visual resources as not all meaning is localized in the visual features and needs human interpretation. Two ways are currently followed in current research: The first one is to provide rich human annotations as training data for future automated analysis. The second one relies purely on analysis of raw content, which only performs well for specialized domains and settings in which relevant concepts can be easily recognized. Richer semantics, capturing implicit features and meaning derived from humans can not be extracted in this manner. Present trends put therefore the human more and more into the loop by lowering the entry barrier for his participation. This is done by adopting Web2.0 or game based approaches to engage users in annotation of visual resources. Recent approaches e.g. try to support automatic analysis with tagging or vice versa. What is still missing are approaches that are capable of exploiting more high level features also in visual resources of lower quality and which can be adapted across domains. Scalability of these approaches is still an issue and Web scalability is not to be expected in the near future.

Due to aforementioned issues, multimedia analysis has still to be supported by end users to a great extent. This is why recent years have seen a huge growth in available annotation tools which allow manual or semi-automatic annotation of visual resources. These approaches are either targeted at the support of analysis approaches to provide training data or as a means for users to organize media. These approaches show a varying complexity: While some of allow users to express complex statements about visual resources, others enable the provision of tags. Some approaches apply annotation or tag propagation and offer support based on previously supplied annotations. Most of these approaches are still not mature and only applied in research. While approaches based on (complex) ontologies exist, some of them are not suitable for most end users. At the other side of the spectrum, tagging based approaches are not suitable to capture all semantics in visual resources. What is still needed are tools that allow to capture subjective views of visual resources and combine these views to deliver a consolidated objective view that can represent a view which holds across users. Also scalability is an issue here. While tagging based approaches are proven to ease large-scale uptake, motivating users to provide more meaningful annotations is still an issue.

5.2. Context

Context refers, in its general sense, to “that which surrounds and gives meaning to something else” (Free Online Dictionary of Computing). In semantic technologies, it refers to the need to capture (possibly in a formal manner) the circumstances in which knowledge is being obtained, modeled, changed, used or acted upon, in order to enable a semantic system to make use of that information when interacting with other users, systems or data, i.e. for purposes of personalization, adaptation, filtering, ranking or selection (or, more generally described, to enable “contextualization”).

Capturing context for semantic applications is currently limited to specific aspects which are easier to identify and model, e.g. location expressed in degrees of longitude and latitude. More complex context models for fine grained contextualization in semantic applications are missing. Research considers in particular mobile and pervasive environments where the contextual information can play a particularly significant role for appropriate data and service provision.

Incorporation of semantic approaches to context modeling and contextualization of data and services on the basis of a semantic context model will follow from the convergence of two medium term trends: the incorporation of semantic technologies into computing environments – particularly those where context plays a significant role such as mobile and pervasive -, and the increased use in the meantime of non-semantic approaches to contextualization (e.g. GPS data for location-based services).

5.3. Knowledge Discovery and Data Mining (KDD)

KDD refers to the act of extracting useful knowledge from data making use of analytic, statistical and mining techniques. The persistent and rapid growth of data to be processed in IT systems due to the Internet, increased digitalization of content and processes, and trends such as sensor networks have created an immense need for KDD methodologies. With respect to semantic technology, KDD can aid in extracting useful knowledge for ontology modeling (cf. the next point) as well as ontology population (cf. i) Annotation above).

Current challenges in KDD include the need to handle dynamic data streams (e.g. from sensors), processing in real time, extracting actionable knowledge from text (computational linguistics), and handling data which is not clean, consistent or correct (probabilistic approaches) [1]. Breakthroughs in KDD could contribute significantly to the challenges of ontology creation and instance data creation, particularly when dealing with large scale data (an increasingly relevant issue in both enterprise and Web environments). However, areas such as computational linguistics have not shown much progress since decades, and it is clear that new approaches need to be taken.

To the extent that computational understanding of data may be a question of computational power, a breakthrough may be expectable in the period 2015-2025 if computers achieve capabilities close to those of the human brain (which includes the understanding of natural language) as predicted by futurist Ray Kurzweil [2].

5.4. Lightweight semantics and ontology modelling

Developing ontologies requires domain expertise and the ability to capture this knowledge in a clean conceptual model. Both skills are not likely to be found in one individual therefore ontology building is a collaborative task. As ontologies are community contracts, here is broad consensus that ontologies should be developed collaboratively in order to capture the consensus of the developers. Recently, not only approaches for ontology development in (big or small) teams were proposed: the focus is shifted more and more to a community-driven way of ontology building. This is because the power of a large group of people collaborating (if channeled in the right way) has the potential to produce widely accepted domain models, which will then be accepted by a large user group. Domain models will be rather lightweight ontologies that capture the domain properly but do not contain many axioms or rules. In the past years, it has become clear that lightweight semantics are more feasible and realistic to be produced on a large scale. This does not only apply to ontology engineering but also other areas of semantic content creation, such as ontology matching or semantic annotation. The necessity of the human in loop must be acknowledged as most tasks in semantic content creation require human input to a certain extent.

The creation and maintenance of semantic content by a large community and the involvement of the "normal" user in the process involves special challenges. In the following, we outline some of the research challenges that need to be tackled in the area of modeling and lightweight semantics. 1. Community-driven conceptual modeling 2. Automatic refactoring of semantic models 3. Design patterns in ontology modeling 4. Lightweight mapping 5. Lightweight models 6. Lightweight reasoning 7. Knowledge extraction 8. Interfaces for knowledge capture 9. Ontology visualization 10. Work-integrated lightweight semantics

COMMUNITY-DRIVEN CONCEPTUAL MODELING

Despite bits and pieces have been already done in the direction of community-driven conceptual modeling , a generic methodology is still missing. This challenge especially involves determining the degree of expressivity that is possible and how the collective intelligence of a community can be most efficiently channeled plus motivations for users to contribute. Another aspect is that many current approaches focus on the development but neglect the maintenance of ontologies.

AUTOMATIC REFACTORING OF SEMANTIC MODELS

Models that were designed by a large group are likely to contain modeling errors. Another challenge is to support the users by automatically detecting and repairing such modeling errors. One can identify patterns of common modeling mistakes that allow identifying and solving them. Refactoring of semantic models is different with lightweight semantics as logical inconsistencies are easier to track than, e.g., a wrong subClassOf relationship (flour and egg are no sub-classes of cake).

DESIGN PATTERNS IN ONTOLOGY MODELING

Discovering design patterns in ontology building can complement existing work on ontology engineering methodologies. Many methodologies do not go into much detail about the actual modeling part. Design patterns can be then re-used to ease the task of conceptual modeling.

LIGHTWEIGHT MAPPING

Work in ontology matching focuses on the most relevant set-theoretic),⊥), and disjointness (⊇relations equivalence (=), more general ( ). However, the true⊆often also denoted as equivalence, subsumption (relationship among two concepts lies often somewhere between "same as" and "not related". SKOS takes a first step in the direction of "softer" mapping relations. In order to make meaningful statements about the relation of two ontologies, more detail in mapping is required as well as sufficient automation support.

LIGHTWEIGHT MODELS

Investigating how much expressivity is required and how much is possible (on a large scale) is another challenge. How lightweight can semantics get in order to be still useful? These findings must be captured in underlying models that should build on the foundations provided by OWL, RDF, or SKOS.

LIGHTWEIGHT REASONING

This challenge is closely related to the previous and is taking a look at two areas that seem opposing: reasoning and lightweight semantics. Based on lightweight semantic models, inference and reasoning power must be determined.

KNOWLEDGE EXTRACTION

The awareness of large collections of data that can be used for extracting knowledge has been raised with the advent of Web 2.0. However, Web 2.0 is not the only place where large amounts of data accumulate. The automatic extraction of knowledge (and lightweight semantics) is extremely relevant not only on a Web scale, but even more in closed world environments such as enterprises. Intelligent methods for the automatic extraction of lightweight semantics can be another step in overcoming the knowledge acquisition bottleneck.

INTERFACES FOR KNOWLEDGE CAPTURE

There is a great need for interfaces for knowledge capture that comply with high usability requirements. Semantic wikis and games for semantic content creation are examples for interfaces that capture knowledge and try to address a large community. A related challenge is addressing closed world environments. Moreover, it is likely that there will not be huge tools for ontology building and annotation but many small plug-ins that allow work-integrated creation and maintenance of semantics plus immediate re-use of those semantics (comparable to tags).

ONTOLOGY VISUALIZATION

Ontology visualization is central for understanding conceptual models: so far, mostly graph-based approaches have been investigated. However, for a higher usability and openness to a large community, more sophisticated approaches to ontology visualization are required. Work-integrated lightweight semantics As mentioned previously, the creation of semantics should not be completely de-coupled from (1) work and (2) later re-use. Tagging gives a good example for being both work-integrated and providing immediate benefit.

5.5. Reasoning

Reasoning refers to the means to infer new knowledge from the basis of instance semantic data, ontologies and a formal logic model on which those ontologies are based (i.e. base axioms). Reasoners form a critical part of the semantic application architecture, whenever inference or semantic validation is required (as opposed to simply using RDF as a flexible data model).

Reasoners exist for many different ontology languages/flavours of logic, from RDFS and OWL Lite to theorem provers working in First Order Logic. The “classical” Semantic Web approach uses a decidable subset of First Order Logic called Description Logic. Several reasoners exist for RDFS and OWL(-DL plus/minus some constructs) level reasoning and are achieving maturity as well as scalability up to billions of RDF triples – providing the usual trade-offs between data size, reasoning complexity and completeness/correctness requirements. Open challenges focus on providing flexible reasoning frameworks that can adapt to the needs of differing inference tasks, as well as better handling of inconsistency, fuzziness and approximation in data inference.

While reasoning over finitely large data sets in controlled environments (e.g. on an enterprise network) is mature enough for commercial application today (using tractable logic fragments such as OWL-DL), large scale distributed reasoning tasks (the ultimate example of which being reasoning over the Web) currently face scalability limits which can be gradually overcome by relaxing the inference guarantees of completeness and correctness, as well as permitting greater approximation and fuzziness in the calculation. This is the subject of a major European research effort (LarKC) which is aiming to enable reasoning over 20 billion RDF triples with completeness and 100 billion RDF triples with incompleteness by 2010 [3].

Other Technology

5.6. Social Web

Web 2.0 has already been trumped as a key Emerging Technology by Gartner in 2006[3]. They identify "Collective Intelligence" as reaching mainstream adoption by 2011-2016. This refers to the creation of data and completion of processes by groups of people without central control. Gartner also projects a 42% compound annual growth rate in the Web 2.0 market through 2011[4]. Already, thoughts have been made about where the Web is expected to go from when Web 2.0 has established itself as being the Web per se: then what will be the new "Web 2.0" trend to emerge from that social Web and its collective intelligence? "Web 3.0" was coined by the New York Times in 2006 to refer to the "intelligent Web" which would be that next step, where human-powered intelligence would be complemented by machine-powered intelligence. Nova Spivack considers Web 3.0 the third generation of the Web which would emerge in the next decade (2010-2020)[5]. Whereas Web 2.0 is the 'read-write' web,

[3] http://www.gartner.com/it/page.jsp?id=495475

[4] http://www.networkworld.com/news/2007/092107-gartner-web-20.html?page=2

[5] http://www.kurzweilai.net/meme/frame.html?main=/articles/art0689.html?m%3D3

Web 3.0 is the 'read-write-execute' web in which applications would be executed online and individual websites with their back-end data silos morph into interoperable services sharing their data in the Web 'cloud'. Hence, it will represent the coming to maturity of the "Cloud Computing" vision and emergence of an "Internet of Services".

Semantic technology research has a key role to play in bringing Web 2.0 to its full potential. The current trend acquires its benefits from "intelligence" which emerges from the participation of a sufficient number of people in an activity. In other words, as more people participate, the more chance there is that certain information will be made available or concluded from other information. Both social networks and other data collectors (such as wikis) benefit from scale. They rely on people giving up knowledge because of the perceived added benefit of doing so, whether altruistically (Wikipedia) or rather more egoistically (social networks). Semantics will play an important role in capturing the knowledge of users formally and unambiguously from their web-based activities and enable further machine-based reasoning on that knowledge to infer new knowledge and make use of it. This will provide new added value to Web 2.0 services and potentially give those using semantics a competitive edge (e.g. "Twine"). Both Semantic Wikis for the collaborative capturing of knowledge and Semantic Web Services for its web-wide exchange between sites will play a technological role. Common standards for semantic description of Web social data (building from FOAF and SIOC) will need to be complemented with appropriate tools and methodologies for reasoning from that data (rules may take on a greater role) and emerging open standards for log-in and access to social network sites (OpenID, OpenSocial) may develop into semantic versions with which machines can handle log-in and data exchange without human intervention. Through the evolution to semantic data and services, the Social Web 2.0 could become the Collective Intelligence Web 3.0 in the next 5 years. The major research challenges will be the scalability of knowledge capture and reasoning, as well as the trustworthy automated exchange of knowledge between sites.

5.7. 3D Technology

The third dimension has always been a part of human perception, but in the digital world it has had a shorter existence. Today, on the other hand, computers are capable of rendering highly complex 3D scenes which can even be mistaken for real by the human eye. 3DTV is on the cusp of market introduction. A new IT segment must deal with the capturing of 3D objects, their manipulation and management, in application domains from healthcare to cultural heritage.

Challenges in the 3D technology domain include how to describe 3D objects for their indexing, storage, retrieval and alteration. Semantics provide a means to improve the description, search and re-use of complex 3D digital objects. Awareness of the value and potential use of this technology in the 3D media community is at an early stage [4]. It is being promoted to industry through initiatives like FOCUS K3D (http://www.focusk3d.eu) which has application working groups for the domains of medicine and bioinformatics, gaming and simulation, product modeling and archaeology. A survey on the state of the art in cultural heritage [5] notes that progress is being made on standardized metadata schemes and ontologies, current limitations relate to methodologies and the lack of specialized tools for 3D knowledge management, yet this could be addressed in the short to medium term.

5.8. Mobile Technology

The mobile Internet is expected to take off in the next few years. The iPhone broke a major uptake barrier by finally providing a good Web surfing experience on a mobile device. Google is seeking to establish the mobile Internet based on its Android OS. Mobile network bandwidth and device performance is gradually growing to the point where rich media Web content can be comfortably accessed. Predictions foresee as many connected mobile devices as world human population by 2012. There will be a shift in how the Web will be used with a greater focus on interface and interaction, with more data being collected and used implicitly. An early indicator of this is the use of GPS in mobile devices to implicitly know the user location and tailor data and services accordingly. Mobile Web portals such as those offered by Yahoo! and Google focus on providing location-based services, and as bandwidth and performance increases applications such as Google Maps and Street View will play a big role in mobile Web access. The Web's increasing ubiquity, meaning access to the data and services in that "cloud" anywhere, will empower connectivity in new places and situations, which will generate new types of service. Besides the Internet mobile phone, we can expect Internet TV, the Internet kitchen, Internet-connected automobiles, and even Internet-enabled clothing and accessories to become a part of the consumer market in the next years. This feeds into the vision of Internet of Things and Ambient Intelligence (seen as reaching maturity in 2010-2020)

Mobile Web access necessitates appropriate means to access and view data and interact with services, which can be supported by their semantic description and the semantic description of the user's context. Reasoning is applicable to the selection, adaptation and presentation of Web data. In combination with semantic descriptions of current location - richer than just longitude and latitude - location-based services can become more relevant by "understanding" more about the user's surroundings. If the mobile and ubiquitous Web is to become just as semantic as the Web itself, research is needed on packing more reasoning power into smaller, simpler devices as well as efficiently sharing knowledge across large scale networks of devices.

The amount of data being collected by Internet devices is growing exponentially with the growth of use of such devices. This data, and knowledge about the process in which the data was collected, can be reused both to support better the user him- or herself, but also within large scale data mining to allow Web services to better develop their offer to their users as a whole. This is already being done in Google, Yahoo, Amazon etc. With the increasing movement of everyday activities to the Web, and the Web's mobility with the user in their everyday life, we expect not only more data to be generated online by users but also more data to be generated over context-aware devices (e.g. with RFID, or sensors) relating to offline activities. Data collectors can analyse this data so to provide a more personalised offer to that user (based on preferences, language, past usage...) as well as to personalise offers to users who are seen to be similar.

The challenges of providing personalization and contextualization (e.g. location-based) to application use in a mobile scenario, dynamicism and adaptation to the data/service provision and building the necessary scalability and flexibility into mobile networks have driven the consideration of semantic solutions. Telecommunications operators have been one of the early adopters of the technology, both in research and development and in some cases, actual products (Vodafone live! Portal, http://www.w3.org/2001/sw/sweo/public/UseCases/Vodafone/). They are also a strong area for wider uptake of the semantic technologies, often based around service architectures [6].

5.9. Virtual Worlds

Virtual worlds have been around as an idea since virtual reality in the 1980s; however their breakthrough into the social mainstream may have arguably been initiated by the Web-based computer application Second Life. Started in 2003, there are 16 million registered users as of October 2009.

Virtual worlds are a natural extension of 3D technology into reflecting the perceptive realities of our own world and have also found applicative usage in domains such as medicine, social analysis, education and e-commerce. Making virtual worlds "react" more realistically to actions and activities performed by the actors of that world requires a (semantic) understanding of the objects rendered in the world and the events which (can) occur between them. There is also a trend to more closely couple real and virtual worlds through (real world) sensors which generate data streams to cause the virtual world to reflect the real in near-real time. This leads to a requirement to handle increasing scales of heterogeneous, dirty data for information extraction and actionable inference within the virtual world.

As in the 3D technology field, barriers to use of semantic technologies lie in the need to agree on the vocabularies and schema for description of the worlds (which now goes beyond the form of objects, and encapsulates what can be done with them, how they react to external events etc.), as well as the availability of appropriate tools for the creation and maintenance of semantic virtual worlds. Hence it is likely that semantics will first need to experience wide uptake in 3D technology systems before it also further develops into a technology for virtual worlds in the medium to long term.

Projects such as *Semantic Reality* (http://www.semanticreality.org) provide exciting longer term visions of a virtual world tightly connected to the real world, with trillions of sensors able to ensure a close correlation between both. This requires an even greater research effort, integrating the domains of sensor networks, embedded systems, ambient intelligence, networking, distributed systems, social networking and the Semantic Web. Even within the latter, further work is required on provisioning large scale, open semantic infrastructures, semantically enriched social networks, semantic sensor networks (see the next item), emergent semantics, real time query processing and aspects of integrity, confidentiality, reputation and privacy [7].

5.10. Sensor Networks

The future Internet will increasingly involve machine-generated data rather than user-generated, sourced in Internet-connected sensors, RFID tags and other embedded devices. An enormous amount of (potentially useful and re-usable) data is being generated and processed by applications in the fields of environment, agriculture, health, transportation, surveillance and public security, among others. In the future, this could explode with 50 to 100 thousand billion connected objects ("Internet of Things").

"Semantic Sensor Web" has established itself as a term for the annotation of sensor data with spatial, temporal and thematic semantic metadata. This is a reaction to the need to better extract actionable intelligence from increasing scales of heterogeneous and often dirty data coming from sensor networks. Semantics also facilitate the integration and communication between the networks. Leading projects in the field are already able to demonstrate real prototypes built on top of existing and emerging sensor data standards [8].

The extension of sensor network deployments to use semantic technologies requires (1) appropriate modeling and language support for describing objects, (2) reasoning over data generated by objects, (3) semantic execution environments and architectures that accommodate network requirements and last but not least (4) scalable storing and communication infrastructure [9]. Initial roll-outs of semantic sensor networks can be expected in the short to medium term, extending existing standards and approaches with semantics, while larger scale, critical sensor applications will develop longer term in line with both the technological emergence of the Internet of Things and parallel maturing of semantic technology in terms of scalability, heterogeneity and handling inconsistent or incomplete data.

5.11. IP Television

IP Television refers to the convergence of Internet and Television, which is also happening outside of the television set (e.g. also Web-based TV, Mobile TV). Currently it is focused on new types of services around television such as EPGs, programming on demand and live TV pause. An emerging trend in IPTV is towards Web integration through widgets, which are lightweight self-contained content items that make use of open Web standards (HTML, JavaScript) and the back-channel of the STB to communicate with the Web (typically in an asynchronous manner). Yahoo and Intel, for example, presented their Widget Channel at the CES in January 2009, where Web content such as Yahoo news and weather, or Flickr photos, could be displayed in on-screen widgets on TV. Sony and Samsung will go to market in 2010 with Internet-enabled televisions. A 2009 survey found that there should be a gradual but steady uptake of TV Internet usage with "the mass market inflection point occurring over the next 3-5 years" (http://oregan.net/press_releases.php?article=2009-01-07).

Parallel to this, research into semantic IPTV applications and solutions is being established in academic and industry labs. A key focus for semantics is the formal description of the programming and user interests to provide for a better personalization of the TV experience (EU project NoTube, http://www.notube.tv, 2009-2012) as well as formal description of networks and content to enable a better delivery of complex services (myMedia, http://www.semantic-iptv.de).

A major barrier to uptake by broadcasters and content providers is the lack of support for semantic technology in the legacy broadcast systems. Shifts in the provider-side IT infrastructure to Internet-based (even cloud-based) infrastructures should give the opening for an introduction of semantics into the production systems of the television and media companies. Vocabularies and technologies will need to converge on specific standards to encourage industry acceptance, which should emerge in this next "uptake" period. As Internet-TV reaches the mass market point (possibly by 2014), companies will seek Unique Selling Points for their products and services, which will drive the incorporation of semantic technologies into IPTV infrastructures and packages.

5.12. Security/Privacy

In a study on critical issues in the Future Internet conducted by RAND Europe for the Netherlands Ministry of Economic Affairs [10], *identity*, *privacy* and *trust* were all indicated as being highly important by all experts participating in the study. Identity refers to the ability to refer unambiguously to an actor in the Internet (human or device) and privacy reflects as well the need to be able to maintain and protect one's own identity. The problem is compounded by the rapid increase of number of devices connecting to the Internet as well as their differing roles and purposes.

As noted in [11], semantic technologies have a role to play in solving challenges relating to identity and privacy:

- URIs/URLs are a big success story on how identity could be handled in large, open distributed environments and could be applied in an identity management solution in Future Internet.
- The "Identity Anarchy" which is mainly due to heterogeneity of models, devices, applications and languages could benefit from the mediation and interoperability research done as part of Semantic Web.
- Semantic technologies have/will provide ontological model for various identity related aspects such as policies, profiles, networking, etc

Existing frameworks for privacy, trust and security management do not take semantic technology in consideration. However, models for these frameworks need to be able to represent the actors in a transaction, how they know one another, what they know about one another, other knowledge about them, previous experience etc. The lack of models which are sufficiently descriptive, dynamic, and re-usable across applications and domains will drive the uptake of semantic technology parallel to social trends which will drive the necessity of such solutions, such as the increased use of the Internet for transactions and increased number of actors in a transaction, not all of whom may be or can be knowable. Significant research work [12] has considered trust and trust relationship models using semantics. These are affinable to reasoning and rules, to build security and trust policies that can be checked, modified and evolve in dynamic situations. Further work is needed on application of semantic security and trust models in real world situations, such as in Service Level Agreements (SLA).

Application Areas

5.13. General (Enterprise)

Business use of semantic technologies is considered on the verge of widespread application, seen in both the W3C business use case collections and attendance figures at the main business conferences for semantic technologies (SemTech with >1000 attendees in 2009, European Semantic Technologies Conference with >200 attendees in 2008). Using the Chasm Group's Technology Adoption Life Cycle, the W3C in October 2009 places semantic technologies at the end of the early adopters phase, shortly before mainstream markets (early majority) – see Figure 1 on p.9. We are now at the stage where "Semantic web technology is on the verge of becoming commercially viable for businesses looking to develop their web capabilities" (John Davies, British Telecom), and "there will be significant increases in the real-world application of semantic technology over the next 12 to 18 months" [13]. Given that the interview was at end of 2008, this would place the tipping point for mainstream semantic application usage in enterprises to the end of 2009/beginning of 2010. Looking beyond this to widespread adoption, the Semantic Wave 2008 report from Mills Davis [14] forecasts:

- Public and private sector R&D relating to semantic technologies in the 2008-2010 period will exceed $8 billion.
- Global ICT markets for semantic technology infused products and services will grow from $2.1 B in 2006 to $52.4 B in 2010.
- Enterprise adoption of semantic technologies will increase dramatically. Public and private sector enterprises represent three-fourths of global ICT spending.

It remains to be seen if by the end of 2010, semantics will be so pervasive in industry. It is more likely that early adopters will continue to lead the way in increasingly more critical activities being supported by mature semantics tools and technologies. The reality of wide usage of semantics in business processes will be somewhere between then and a decade later, which is Gartner's more conservative bet.

5.14. Energy

The energy sector is seen as one of the key areas for early adoption of semantic technologies. Chevron's input to the W3C Semantic Web Education and Outreach working group noted several uses of semantics in the oil and gas industry [15]. The industry has some of the aspects which act as key business drivers for semantics: large amounts of heterogeneous data being generated daily from multiple sources from which information value must be extracted; information search and access across the data sources and formats; information needing to be standardized and integrated across systems. Semantics in the energy sector is a trend which will continue, especially as technologies mature and gain acceptance such that they become increasingly applied in the core, critical business processes. In particular, scalability of semantic tools will be a critical technology driver to its breakthrough into mainstream energy IT systems.

5.15. Production

Manufacturing and production chains involve very complex processes and rules [16]. When the manufacturing industry started using IT, there was less attention made to heterogeneity as systems operated more independently and large investments were made in large and complex systems; today's IT systems for manufacturing on the other hand must – if the manufacturer is to remain competitive – find ways to seamlessly integrate different manufacturing subsystems with one another and also with the systems of the other players in the production chain (suppliers, purchasers etc.). Key business drivers for semantics in manufacturing are improved collaboration, reduced integration costs and increased business agility. Key challenges to be overcome are:

- Achieving consensus on meaning across organizations
- Many overlapping standards for manufacturing interoperability lacking explicit and rigid definitions of terms
- Globalization, making it vital that information sharing is done correctly, efficiently and inexpensively
- People, meaning that it is still people who provide the knowledge needed to interpret information and make decisions based on their tacit understanding of it

Here, semantic SOA (Web Services) is the critical technology driver, enabling a semantic interoperability layer to be applied on top of the existing and emerging SOA being introduced into enterprise IT infrastructure. (SOA is seen as already a mainstream technology, and Gartner foresees 80% of mission-critical enterprise IT processes as being SOA-based in 2010)

5.16. Media, Art and Entertainment

The media sector faces new challenges in the scale and complexity of media being produced and shared. Online media in particular needs improved retrieval, adaptation and presentation if content owners are to win market share in a broad and overfilled market. Semantic media involves providing media objects with a semantic description (annotation) and using this to offer better search for media, automated adaptation (personalization, contextualization) and meaningful presentation. Creating the media annotations is the biggest challenge, since full automation of the process is difficult and lacks precision, while manual annotation is time consuming and cannot keep up with the scale of media being produced. A few media organizations have begun to lead the way in using and demonstrating semantics, e.g. the BBC has begun to publish its online content with RDF.

The arts – i.e. cultural heritage – is another sector in which semantics are gaining traction. Museums, for example, have large amounts of metadata about their collections which can not be easily interpreted or re-used due to non-digital, non-semantic and proprietary approaches. Again, some pioneers such as Rijksmuseum in Amsterdam are taking the first steps to digitalize and annotate their collections and explore the new possibilities which are realized.

The media, arts and entertainment sector looks on semantics as a clear future solution for their problems with large scales of heterogeneous non-textual content, and for the emerging challenges in realizing attractive and competitive content offers on a ubiquitous Web with millions of content channels. The cost of creating the semantic data tends to be larger at present than the benefits purchased from its creation, so while the potential benefit from semantics will continue to grow as Web media becomes more ubiquitous (making having a Unique Selling Point ever more critical for a content owner and provider), the actual costs of semantics must still fall through better, more automated content annotation tools and approaches.

The semantic multimedia community will achieve important steps in standardization and maturity of technology and tools in the short to medium term. So a semantic technology breakthrough in the media sector can be expected in the medium to long term.

5.17. Health

eHealth is a leading and exemplary adopter of semantic technologies. It demonstrates an increasing focus on end users, allowing semantics to be applied in real and important problems and to improve healthcare standards to the benefit of society and individuals. The W3C Health Care and Life Sciences group exists to explore the “use of Semantic Web technologies … to improve collaboration, research and development, and innovation adoption”. It has over 60 participants from 40 organizations, including Agfa, AstraZeneca, Cleveland Clinic, Eli Lilly, HL7, Merck and Pfizer. Task forces explore for example the application of semantics in areas such as drug safety and efficacy, adaptable clinical protocols and pathways, and clinical observations interoperability.

As a significant prerequisite for semantic eHealth, the community is particularly active in generating healthcare and life science ontologies. These are already being applied in pharmaceutical and biological research departments. The use of ontologies allows for the exploration and discovery of new knowledge out of large knowledge bases (e.g. results of experiments). While semantic eHealth is a reality now, and indicators exist of actual usage of semantics in pharmaceutical and life science R&D, grander visions of the semantic healthcare community may still require a longer term focus. For example, the semantic HEALTH project which was tasked with a roadmap for “semantic interoperability for better health and safer healthcare”[17] noted that interoperability of Electronic Health Record Systems may take another 20 years to achieve.

5.18. Smart Life

Smart living refers to the ubiquity of the Web and Web-enabled devices in an individual's daily life, so that every personal and social activity may be supported in a meaningful and beneficial manner. It covers intelligent homes as well as smart cars and personal devices (e.g. Internet aware clothing).

Home networks are an emerging trend, slowed in recent times by lack of interoperable standards across all devices and the need to reflect the expectations of consumers (where it has already been seen that a too rapid convergence of functionalities on devices is not taken up by a market where people are used to separate devices for separate purposes). Solutions are emerging through common standards (overseen by the Digital Living Network Alliance) and clearer delineation of devices. Device interoperability and computational awareness of the home environment supports vital "assistive living" scenarios. The business driver for semantics is found in the current state of the art, where various technologies are needed to be integrated in the smart home, each of which provides a fragment of the necessary functionality. A vision for adaptive, personalized and context-aware smart homes needs a future infrastructure which can support the full richness of the smart home vision. Semantics are seen to have a role in defining knowledge about the environment in a re-usable and processable manner (e.g. captured through sensors), integrating services and data between devices and enabling the definition of rules for reactive situations in smart home environments (e.g. analyzing the mood of the person and adjusting the home lighting or background music accordingly). An architecture to enable this "Semantic Smart Home" [18] has been presented. The building blocks exist but the acceptance and uptake by the industry is notably slower than in other sectors which have been previously mentioned. In line with the general trend towards more mainstream uptake of semantics across industry, the Semantic Smart Home may be realized in the mid-term. More complex reasoning cases which foresee dynamic composability of semantic Web services can be seen as having a longer term solution.

Cars are another emerging target for the integration of IT and telecommunications technology to allow for in-car intelligent services, typically related to vehicle location (through GPS) and the surroundings. This field is called *telematics*. European car manufacturers are very active in developing telematic solutions for their automobiles, especially in response to increasing competitiveness in the global market from low-cost car manufacturers. Telematic solutions (e.g. intelligent in-car navigation systems) are already in development and deployment in the automobile industry. Semantics can play a role in integrating data and composing services to deliver functionality to the end user. However, there is a long way foreseen for new technologies which potentially change the driving experience to move out of the research lab and into the roads; even the potential integration of social networks into driving is cautioned as being "a long way off" (Venkatesh Prasad, Ford USA quoted in Telematics Update, Nov 5 2009).

Finally, the introduction of semantic technologies to Internet-aware personal objects lead to the ideas of "smart clothing", "smart glasses" etc. where normal, everyday objects will be enhanced by electronics, Internet accessibility and the ability to provide services to the user (e.g. clothes changing colour or design to adapt to the surrounding situation, glasses overlaying information about objects seen by the wearer). This requires an interdisciplinary approach within the fashion, textile, electronics and IT industries, as well as preparing the general public with respect to acceptance of potentially disruptive ideas.

5.19. Urban Computing

Urban computing refers to the increasingly ubiquity of Internet and devices connected to the Internet in the urban environment leading to smart cities. Current technology lacks the capability to effectively solve urban computing problems as it requires combining a huge amount of static knowledge about the city with larger, real time data being generated by sensors and devices in a heterogeneous and noisy manner. To act upon the data acquired, its combination is insufficient; rather there must be intelligent reasoning to draw in-time inferences.

Current projects provide test solutions in more controlled and controllable environments, but the technological challenge remains to satisfactorily deal with large scale, heterogeneous and “dirty” data. Hence, current research seeks new solutions based on semantics [19], yet mature solutions for true, open urban environments may be expected first in the middle to long term.

Having considered the opinions of different experts in the semantics research field and given an overview of the predictions for semantic technology uptake in individual application and technology areas, we summarize the expert findings of each workshop (focused on the technology by 2014, 2019 and 2024 respectively) and draw conclusions on the key open issues for the next phases of semantic technology research.

6. Future roadmap for semantic technologies

6.1. Semantic Technologies by 2014

In conclusion to the meeting, there was the recognition that the maturity of particular aspects of semantic technology by 2014 did not necessarily mean their immediate uptake and integration in the application areas seen as particularly standing to benefit from them. Rather, the next years would see the maturity and adoption of semantic technology from research labs to early adopters with particular urgent need for semantics (e.g. e-health), and the “widespread deployment” would be mostly across those sectors (research labs, public sector, health, telecommunications) which are already leading in semantic technology application. In these end scenarios, semantics can achieve their final (industrial) maturity and act as convincing showcases to the wider community. In parallel, the application areas listed will develop from being today’s “trends” to being part of the digital mainstream. In doing so, they will reach their natural limits (without semantic technology).

6.2. Semantic Technologies by 2019

The participants found consensus on the gradual "mainstreaming" of semantic technologies as they achieve maturity in key areas such as automated ontology creation, Web scale reasoning and personalized information delivery. The new and increased demands in the Future Internet – the ubiquity of access, overload of information and heterogeneous sources of data – would make semantics even more critical and spur their development and uptake. First application areas would start widespread usage of semantic technology in critical processes, most likely healthcare and automotive. Virtual worlds and sensor networks are seen as two IT trends which will not only become mainstream and widespread, but will find new uses for semantics. The participants have, however, diverged on the exact timing and the market potential of each of these future applications areas.

6.3. Semantic Technologies by 2024

The vision for 2024 which formed during the workshop could be seen as being less utopian about the future than the results for 2014 and 2019, with a recognition of the breakthroughs which may be reached in terms of capturing semantic data about almost everything in the world and making it available everywhere and at every time. Combined with the potential for large scale inference, it may be that too much knowledge can become accessible, and there is an imperative for semantic technology researchers to also consider and tackle the challenges of preserving privacy and trust in a semantic world (where previously unforeseen knowledge becomes inferable from combining heterogeneous and separate data sets).

6.4. Key Open Issues for Research

To reach the vision of each phase of a semantically-enabled world – in 5, in 10 and in 15 years from now – would not be possible without the underlying research which provides the theories and their proofs, the methodologies and tools, and the specifications, standards and technologies based on those. A research agenda for semantic technology needs to anticipate the needs arising from application areas, the trends developing in other technologies and set the right focus on the development in specific semantic technology areas. It needs to predict the gap between present research expectations (based on things as they are) and the required research expectations (based on the visions of experts and the surrounding needs and trends), and fill that gap by specifying what research now needs to be done which is currently not being done / not being done enough.

Present research expectations for semantic technology can be charted thus:

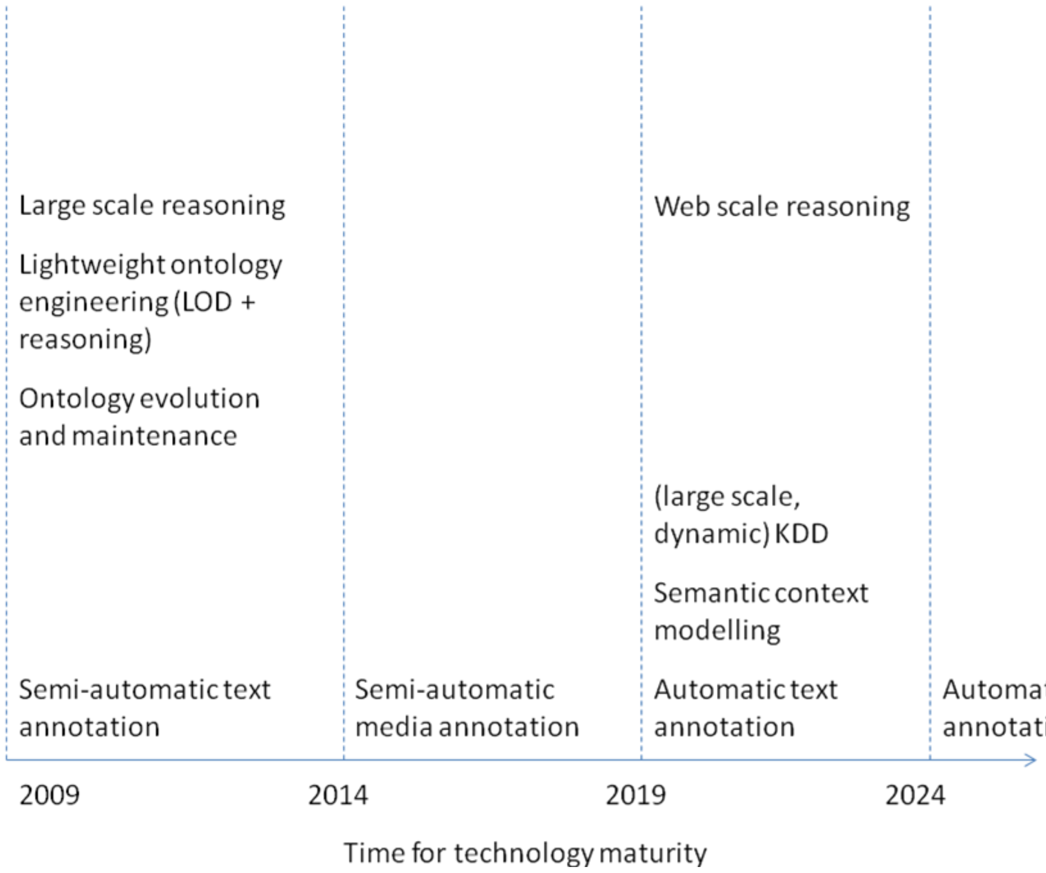

Figure 4: Charting the maturity of semantic technology

It can be seen that core Semantic Web technologies such as ontology development and reasoning are seen as being mature as of 2009, meaning they are already leaving the research lab and building commercial applications which are mature enough for enterprise usage. Over the next 5 years, research will address some critical gaps for industrial uptake – scalability of reasoning, using lightweight ontologies and maintaining and evolving ontologies – and semantic technology will be ready for the mainstream. Some longer term aspects which can be linked to a need for more computing power combined with semantic technology and are medium to long term challenges include reasoning at the scale of the Web, semantic data mining e.g. of real time data streams, semantic context and automated annotation. These will be necessary to first address data outside of controlled walled gardens (e.g. inside an enterprise, to handle specific aspects) and bring semantics effectively to large scale data, whether it is data being generated in specific application domains or the Web. Hence while semantics in the enterprise may, as per the W3C expectation (Figure 1), be moving into mainstream markets over the next decade, the Semantic Web as it was originally thought of as an extension of the existing Web will first emerge (as a network underpinned by rich ontological reasoning) after this period (the next decade on the Web will be marked by the growth of structured data and APIs, in particular Linked Open Data and SPARQL as access mechanism, with some simple reasoning being added e.g. sameAs).

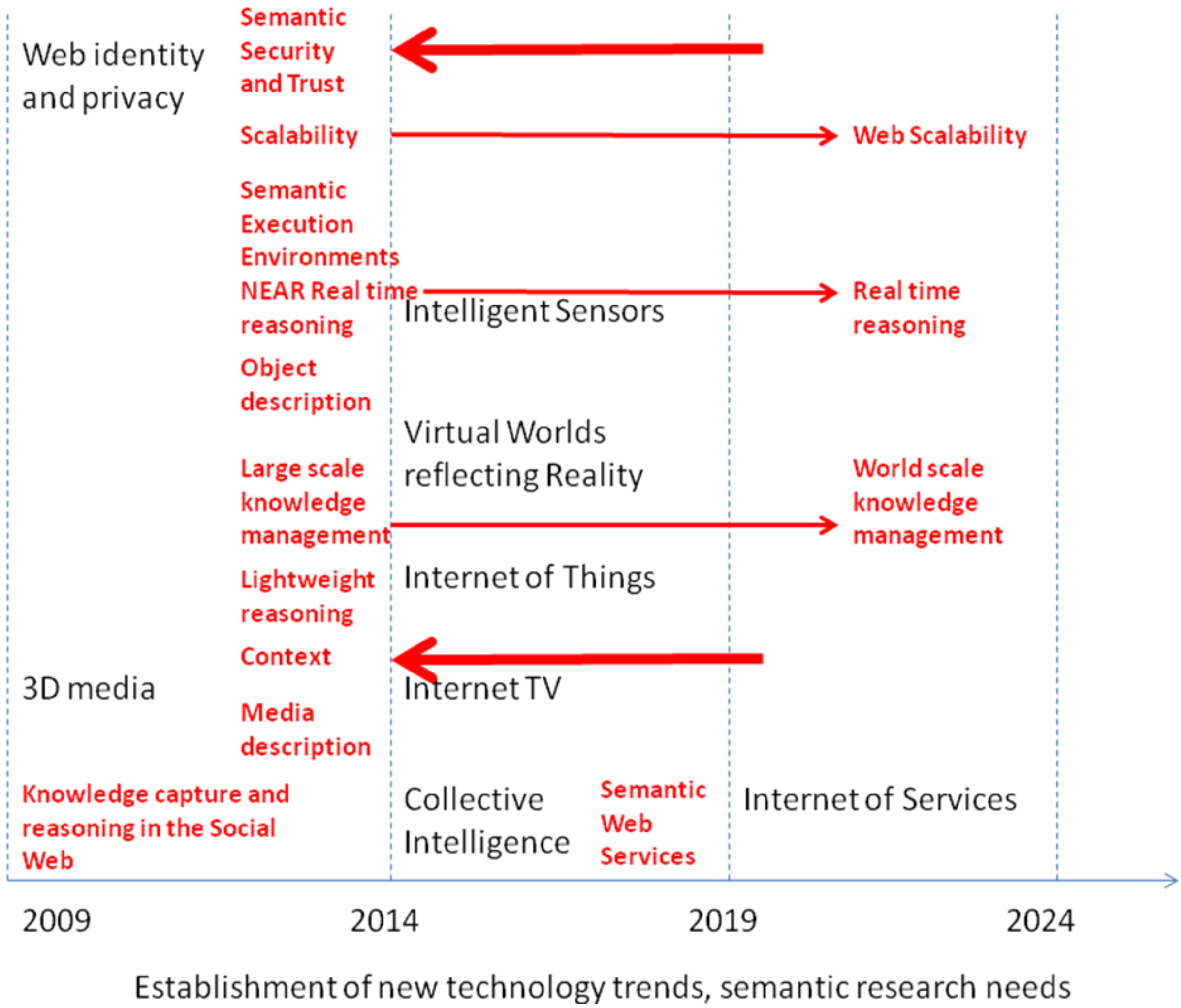

Figure 5: Charting the emergence of new technology trends

The above figure charts the emergence of future technology. Most technologies mentioned here are expected in 5-10 years while 3D media and Web identity is set for mainstream realization in a shorter time period (3DTV will be launched in 2010; OpenID and OAuth are examples of Web-based security and identity which are gaining traction). The lack of longer term technology trends in this figure may be a reflection of the difficulty to anticipate anything beyond "the next wave", however it is interesting to note that this may also represent a natural technological limit without semantics for these different strands of technological development. Longer term trends which could be identified as natural progressions of those given above are arguably unfulfillable on top of the current underlying technology framework (given that this framework is increasingly the Internet, the EU has reacted to this potential technology bottleneck with the Future Internet initiative, http://www.future-internet.eu) and hence unforeseeable without future research. Challenges which can be mentioned include data scale, heterogeneity, dynamics (e.g. from sensor data), network infrastructure, and trust/data provenance.

Alongside the expected emerging technology trends, the smaller text refers to aspects of semantic research which have been identified by the experts as relevant to the full realization of that technology. While future developments may augment some existing trends, such as Web identity/privacy and 3D media, these research challenges are arguably key enablers of the future technologies in the figure, hence they are positioned time-wise *before* the technologies' mainstream emergence. Two alternative consequences to this may be inferred:

- A technology will emerge as foreseen independent of the state of the semantic research at that time, based on other business and technology drivers, and become established without semantics. It will incorporate semantic solutions as research results mature and are ready to be transferred. There is a potential uptake barrier in that once new technologies are applied (with the associated training and investment costs), users may be reticient to move to semantics-based versions afterwards, delaying the mainstreaming of the semantic technology further
- A technology will emerge in parallel to or following the maturing of relevant semantic solutions for issues that the technology faces, and hence will incorporate semantics-based specifications, methodologies, tools and standards into its own specifications, methodologies, tools and standards. This is strongly predicated on the successful communication of the semantic solutions into the community from which the technology is emerging, and an early interlinking of the activities of both communities in order to ensure timely exchange of requirements and solutions.

As seen in current emerging technology fields such as Web identity, or 3D media, semantics do not yet play a role in the initial specifications and systems, even though they offer clear benefits to the technology field. This can be explained in the relative immaturity of the semantic technology in the past 5-10 years as these technologies fields have been born and grew. Presuming the availability in the next decade of mature semantic solutions to key technological challenges, it should be without doubt that the technologies that will emerge by 2014 or 2019 will incorporate semantics in their specifications and systems, but it is not guaranteed without the semantic technology community addressing those areas *now*, through specific communication, collaboration and co-operation in which semantics are used to overcome challenges in those technology areas.

The remaining issue for semantic technology and other technologies is *whether* semantic solutions can be expected in line with the emergence of the technology driven by other business and technological factors. Only Semantic Web Services can emerge in the medium term still in time for the projected mainstreaming of the Internet of Services, the other research areas should be mature in the short term (next 5 years) to be ready to play a role in emerging technologies. Let us consider each emerging technology in turn:

- **Web identity and privacy** will emerge in the next years driven by specifications such as OpenID and OAuth. Semantic enrichments of security and trust models are vital for future dynamic data and service usage situations, and will probably gain traction in commercial infrastructures in 5-10 years as research work is mature and the limitations of non-semantic approaches become clear. In particular, uptake will be driven by the new challenges arising from Web ubiquity (incl. Internet of Things), scale and heterogeneity of data streams (incl. from sensors and virtual worlds), and dependence on the social Web and collective intelligence (where trust and provenance play a vital role). Semantic security and trust will mature by 2019, and face issues of transfer into the already emerged technologies but it will be ready to play a fundamental role in the then emerging Internet of Services. A related requirement here is scalability, which will be less important for early semantic security solutions (applied in the enterprise at smaller scale) but is vital for a Web-wide semantic solution to identity and privacy.

- **Intelligent Sensors** will become omnipresent in the next 5 years, e.g. in urban computing we can expect the use of sensors in city infrastructure to regulate all aspects such as traffic flow, lighting, pollution etc. Current work on semantic sensors can lead to uptake of semantic technology in the emerging technology provided various requirements can be demonstrably met by semantics: scalability, service execution environments, real time reasoning and object (sensor) description. Object description and service execution environments are being addressed well in the research while in the former, industry standardization is missing and in the latter, maturity for critical applications ([20], [21]). Scalability and real time reasoning are still open challenges, where good progress is expected in the next 5 years; however performance at Web scale will probably remain inadequate for 10-15 years yet.
- **Virtual Worlds reflecting reality** will emerge as the digital variant of the real world intelligent sensor networks. Object description for 3D worlds as a research topic requires further focus. The other key requirement is large scale knowledge management, to maintain a semantic view on both the state of the virtual world and of the real world. This will be achievable in the short term for large scale, centralized approaches; world scale and distributed solutions will remain a challenge for 10-15 years' research.
- **Internet of Things** is a natural consequence of Net connectivity across all devices. Large scale knowledge management is a prerequisite for a semantic Internet of Things, however the complexity of the knowledge may be less than in sensor networks and virtual worlds, hence efficient light-weight ontologies and reasoning may be the key enabler. Context will also be needed to ensure rich adaptive services and applications, and there remains the main challenge of how to model context and develop services which can adapt to it, something predicted for the middle to long term of current research.
- **Internet TV** reflects the convergence of audio-visual media and the Internet, and will be semantic as long as media descriptions are standardized – something which is ripe to begin, as research within W3C has been ongoing since 2001 and ontologies such as COMM exist as a basis (http://comm.semanticweb.org).
- **Collective Intelligence** as an extension of Social Web principles to enable the decentralized performance of tasks through the involvement of Web users could make more use of semantic technology, something which has been largely ignored in Web 2.0 circles. Key here is the maturing of combined Social-Semantic Web approaches to knowledge capture and reasoning. Challenges in annotation and ontology development are eased by the involvement of the community and semantic means to do this are emerging from research, while support for non-textual content may be 2-3 years behind. Lightweight ontologies and reasoning will mature also in the period before the emergence of Collective Intelligence, and should be a main driver of Collective Intelligence solutions.

In conclusion, this review has shown that the maturing of key areas of semantic technology in the next 5 years (2009-2014) fit well to positioning the use of that technology in soon emerging technology trends, provided there are the preparations made now to create communication and collaboration channels between the semantics community and those from which the technologies are emerging. A key bottleneck for the next 10-15 years will be the scalability of semantic technology in comparison to the scalability of the surrounding technology infrastructure: Web or world-scale frameworks for sensor networks, Internet of Things or Internet of Services are expected to emerge without semantics earlier than the timepoint where semantic technology may work as well at that scale. This leads to the danger of a split in approaches: semantically-enabled "intelligent" approaches for smaller scale (e.g. in enterprise) deployments while the realization of the trends on the Web proceeds without semantics.

Two research areas for semantic technology which appear to be needed before they are expected to be mature according to current research directions are *semantic security and trust* and *context*. Hence, these areas may be worth a stronger focus in the next 5 years.

In terms of application areas, we make the following observations:

- **Energy** has key business drivers for uptake of semantic technology and will increase uptake as the technology matures, particularly with respect to scalability.
- **Production** shares key business drivers such as data integration, but also faces greater challenges in terms of cross-enterprise communication. Besides the business barriers which occur here (e.g. agreement on common ontologies), it is dependent on semantic technologies which are developing later with respect to industry maturity: rules, trust and semantic SOA. First when these technologies can be demonstrably used to solve real production sector issues, can we expect uptake to start at a measurable level.
- **Media** also has key business advantages from a transition to use of semantic technologies, yet very strong challenges are faced in terms of multimedia annotation. There will be gradual uptake pushed by emerging standards and mature tools, with a wide breakthrough first achieved when almost full automatized annotation becomes possible to handle the even larger scales of media being produced (not necessarily machine-automated, but also human-sourced collaborative annotation may become a solution here)
- **Health** is a fellow early adopter of semantic technology, especially in the research labs. In terms of wider uptake, e.g. in end patient systems, it can be expected that the industry will be quite conservative in end implementation and will wait on the application of semantics in critical systems in other domains such as energy.
- **Smart Life** will be driven by the Internet of Things, while semantic solutions will be dependent on semantic technology expected to mature later, such as context models and efficient processing of actionable knowledge. Full implementations based on semantic services will be long term. Also, the uptake of technology in new areas such as in-car, clothing etc. can be expected to be slow in any case.
- **Urban Computing** will be driven by Sensor Networks, yet the technological challenges it faces are already well known and act as a driver for the use of semantic technology. Given that the application area will develop after the maturing of the semantic technology which can address its challenges, semantic uptake should be rapid, with scalability being the main bottleneck over the first decade.

This results in the following chart, mapping the state of semantic technology in enterprises in general (based on the W3C adoption life cycle) to a time frame (based on our observations) and adding individual uptake growth by sector (with the vertical axis representing the level of uptake in the sector up to reaching the mainstream market).

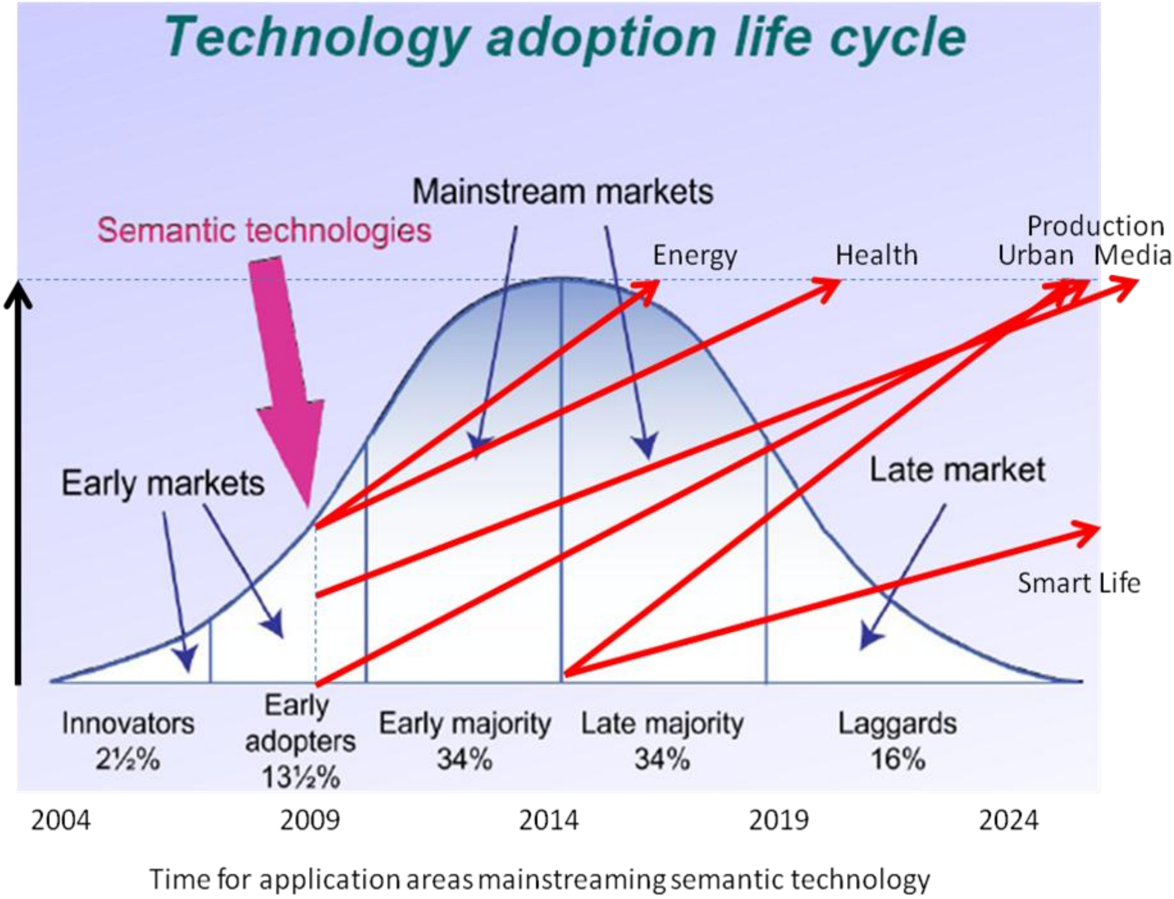

Figure 6: Mainstreaming of semantic technology in industry

Based on continuing maturation of the semantic technologies and a conservative view of enterprise adoption, we place first mainstream breakthroughs of semantics in industry in the period 2016-2021, where research reaches fruition in early adopter sectors such as energy and healthcare.

By 2024, semantic technology could be as ubiquitous as the Web is today, and combined with capabilities of Web scalability, real time reasoning and World scale knowledge management, there are both exciting new possibilities ahead as well as brave new challenges.

7. Conclusion

In this document, we have attempted to chart a possible future of semantics in IT and society. With respect to that, please reflect[6]:

[6] http://download.intel.com/museum/Moores_Law/Articles-Press_Releases/Gordon_Moore_1965_Article.pdf; Bill Buxton, "Sketching user experiences", page

- Moore's law for computational power that doubles every 18 months
- A variant of this law stating that network bandwith doubles every 9 months (twice the rate of Moore's law)
- Many new technologies emerge enabling new applications when combined with existing technologies such as Semantics
- Many new applications emerge from price-decreases of existing technologies
- "... the future is already here. It's just not evenly distributed..." (William Gibson). So don't count on any deus ex machina and don't expect any magic (silver) bullets. It is unlikely that there will be any technology that we don't know about today will have a major impact on things over the next 10 or 20 years.

This document can act as a 'pathfinder' to new research directions in the area and thereby will contribute to, and inform, national and international scientific debate and science policy. It is also just a start, a catalyst for more discussion, so lastly, we hope that you find it useful, inspiring and provocative.

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