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Semantic web and decision support systems

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Semantic Web technologies are intertwined with decision-making processes. In this paper the general objectives of the semantic web tools are reviewed and characterised, as well as the categories of decision support tools, in order to establish an intersection of utility and use. We also elaborate on actual and foreseen possibilities for a deeper integration, considering the actual implementation, opportunities and constraints within the context of decision-making. We conclude that a broader or generalised Semantic Web integration in the decision support community is still a work in progress and much remains to be done.

Keywords: semantic web; decision-making; group decision support; web evolution

1. Introduction

Web 1.0 is known as an early stage of the conceptual evolution of the World Wide Web, where users simply acted as mere publishers and consumers of content, as web page information was closed to external editing. Rather than a specific technology update or specification, the Web 2.0 core was a transformation in the way web pages were made and used. The term 'Web 2.0' is used to describe applications that take advantage of the network nature of the Web, encourage the participation of community members, are inherently social and opened, aiming at enhancing information sharing as well as fostering collaboration (Abramowicz, Fensel, & Frank, 2010). The popularity of the term Web 2.0, that echoed the common people, called for a set of technology that puts users at the centre of the applications (O'Reilly, 2005, 2006). There is a clear change in how technology is used: the application is what users make of it, and so, the more users you have, the better the application becomes. It involves a major conceptual shift in how information is created, validated, managed, shared and consumed. Essentially, Web 2.0 applications add a multitude of users who are responsible for all of these information management activities. The term Web 2.0 classifies applications such as Wikipedia, Facebook, YouTube, weblogs, microblogging, social bookmarking services, etc., which are also termed 'social software' (Lai & Turban, 2008; Richter, Riemer, & Brocke, 2011). Although social software and decision-making are clearly related in terms of their objectives (enhanced collaboration, information sharing and knowledge acquisition, according to Power & Phillips-Wren, 2011), they present major differences from an organisational perspective. Traditional group decision-making

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presents a 'top-down' approach, usually designed to deliberately guide the interactions of groups in decision-making processes, while in social software, users, on the public internet, generate the content and define both the rules and the reasons for usage (Boyd, 2006) – and thus the social software approach is essentially 'bottom up'. This approach brings new possibilities in involving a massive collectiveness (of, for example, potential and actual consumers, voters, subscribers, fans, etc.) into decision processes (like product development, policy definition, content selection, hiring a coach, etc.), especially during its early stages – intelligence and design phases, as defined by Simon (1977). As traditional group decision-making tools do not encompass this situation, it creates a gap between traditional decision support systems, which usually cover the sequential support of all decision-making tasks, and using Web 2.0 tools for decision-making. As Web 2.0 is based on different tools (Nagle & Pope, 2013), depending on the problem in hand, organising and integrating the generated information might constitute a major problem. In this paper, we argue that such a problem can be mitigated by intersecting Web 2.0 and semantic web technologies.

The term 'semantic web' (Berners-Lee, Hendler, & Lassila, 2001) is considered by many an evolution of Web 2.0 – hence the term 'Web 3.0' (Lassila & Hendler, 2007), though there are many detractors of this expression – means a set of technologies that includes ontologies, software agents and rules of logic. These technologies can greatly improve the ability to connect and automatically organise the content of information spread across multiple pages or sites (Kousetti, Millard, & Howard, 2008), created within the intelligence phase, and to structure and represent such information, thus aiding the design and choice phases of decision processes (Simon, 1977).

We will make a brief initial review of the general objectives and technologies proposed with the implementation of the semantic web, to later evidence how to combine its actual implementation to enhance opportunities and tackle perceived constraints within the context of decision-making.

2. Semantic Web technology

While Web 2.0 focuses on humans, mostly by providing efficient platforms for information sharing, the semantic web focuses on machines, by providing machine-processable information (Abramowicz et al., 2010), especially through semantic languages and tools for ontologies and metadata management (Padula, Reggiori, & Capetti, 2009).

This section provides a brief review of the main technical aspects of the semantic web, for later review and integration with the decision-making process and its tools.

2.1 A vision for the future

The semantic web (according to Berners-Lee et al., 2001) will enable machines to comprehend semantic documents and data, not human speech and writings. Moreover, the semantic web, in naming every concept simply by a uniform resource identifier (URI), should express, seamlessly, new concepts that people invent. This unifying logical language should enable these concepts to be progressively linked into a universal web, thus opening up the knowledge and workings of humankind to meaningful analysis by software agents. Therefore, the challenge is to provide a language that expresses both data and rules for reasoning about the data and that allows rules from any existing knowledge-representation system to be exported onto the Web.

2.1.1 XML

The base of Web 3.0 for exposing data to applications is the Extensible Markup Language (XML), which lets everyone create their own tags – hidden labels that annotate web pages or sections of text on a page. Scripts, or programs, can make use of these tags in sophisticated ways, but the script writer has to know the reason for which the page writer uses each tag. In short, XML allows users to add arbitrary structure to their documents, but says nothing about what the structures mean (Berners-Lee et al., 2001).

2.1.2 RDF

Meaning is expressed by Resource Description Framework (RDF), which encodes it in sets of triples that use URIs to name the relationship between things as well as the two ends of the link, each triple being rather like the subject, verb and object of a simple sentence (Berners-Lee et al., 2001). This simple model allows structured and semi-structured data to be mixed, exposed and shared across different applications. The resulting linking structure forms a directed, labelled graph, where the edges represent the named link between two resources, represented by the graph nodes. This graph view is the easiest possible mental model for RDF, and is often used in easy-to-understand visual explanations.

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2.1.3 Queries

With SPARQL (a recursive acronym for SPARQL Protocol and RDF Query Language), a query language for RDF data, applications can access native graph-based RDF stores and extract data from traditional databases (Hendler, 2009). Technically, SPARQL queries are based on triple patterns. These triple patterns are similar to RDF triples, except that one or more of the constituent resource references are variables. A SPARQL engine would return the resources for all triples that match these patterns.

The semantic web is a 'web of data' – of dates and titles and part numbers and any other data one might conceive of. To make it a reality, a huge amount of Web-available data, in a standard format, reachable and manageable by semantic web tools, is needed. SPARQL is intended to integrate disparate databases (domain-limited or specific databases – relational, XML, HTML, etc.) so that one query spans (seamlessly and on the fly) through several data sets to deliver targeted results (Lassila & Hendler, 2007). This collection of interrelated data sets on the Web can also be referred to as linked data.

2.1.4 Ontologies

On the semantic web, vocabularies or ontologies define the concepts and relationships (also referred to as 'terms') used to describe and classify terms that can be used in a particular application, characterise possible relationships and define possible constraints on using those terms. The most typical kind of ontology for the Web has a taxonomy and a set of inference rules. The taxonomy defines classes of objects and relations among them (Berners-Lee et al., 2001). Web Ontology Language (OWL) is a language that can play a main role in the applications of Web 3.0. OWL and RDF are much the same thing, but OWL is a stronger language with greater machine interpretability than RDF. OWL is built on the top of RDF but comes with a larger vocabulary and stronger syntax than RDF does (Pattal, Yuan, & Jianqiu, 2009), being the basis for implementing inference techniques on the semantic web.

Inference rules in ontologies can be characterised by discovering new relationships among terms. This means that automatic procedures can generate new relationships based on the data and based on some additional information in the form of ontologies. Although the computer doesn't truly 'understand' any of these relationships, it can manipulate the terms much more effectively in ways that are useful and meaningful to the human user (Berners-Lee et al., 2001). Inference is also intended to improve data integration and handling possible data inconsistencies on the Web, by seamlessly analysing data content.

2.2 The actual Semantic Web

In spite of the earlier vision for a future with Web 3.0 (Berners-Lee et al., 2001), the problem is that a complete re-annotation of the Web is a massive undertaking. As an alternative, many researchers take a very different approach to the semantic web. Rather than calling for an overhaul of Web formats, and the massive effort of using semantic web tools (not to be expected), which would involve hundreds of thousands of independent sites, they are building software agents that can better understand web pages, as they exist today. Instead of waiting for additional information and for more 'machine-understandable' web pages, the alternative is developing improved software agents for information retrieval and natural language processing.

2.2.1 NLP and IE

Naturallanguage processing/programming (NLP) is a field of computer science, artificial intelligence (AI) and linguistics that regards the interactions between computers and human (natural) languages. NLP is a theoretically motivated range of computational techniques for analysing and representing naturally occurring texts at one or more levels of linguistic analysis for the purpose of achieving human-like language processing for a range of tasks or applications (Acharya & Parija, 2010). NLP is also an ontology-assisted way of programming in terms of natural language sentences.

NLP and information extraction (IE) seek to deduce rules or a domain model out of texts. Such efforts include a strong machine-learning component, in addition to the NLP component. The knowledge base they hope to extract is frequently designed to drive an expert system, or case-based *reasoner* or knowledge-driven decision support systems (Cowie & Lehnert, 1996).

Information extraction (IE) is a more limited task than 'full text understanding', as full text understanding represents all of the information in a text. In contrast, IE delimits, in advance, the semantic range of the output. It identifies specific pieces of information (data) in an unstructured or semi-structured textual document (e.g. a web page) and transforms unstructured information in a corpus of documents or web pages into a structured database (Acharya & Parija, 2010).

2.2.2 Agents

In AI, an intelligent agent (IA) is an autonomous entity, which observes through sensors, acts upon an environment using actuators and directs its activity towards achieving rational goals (Russell & Norvig, 2010). Intelligent agents may also learn or use knowledge to achieve their goals, ranging from very simple or very complex (a thermostat is an intelligent agent if it has a rational goal, as is a human being, as is a community of human beings working together towards a goal, as described in Franklin & Graesser, 1996). IAs in AI are closely related to agents in economics, and versions of the intelligent agent paradigm are studied in cognitive science, ethics and the philosophy of practical reason, as well as in many interdisciplinary socio-cognitive modelling and computer social simulations. Semantics enable agents to locate others (or automated Web-based services) that will perform a required function, and to describe precisely what function they carry out and what input data are needed. The real power of the semantic web will be realised when people create many programs that collect Web content from diverse sources, process the information and exchange the results with other programs (Berners-Lee et al., 2001). Nevertheless, the effectiveness of such software agents can only achieve its full potential when more 'machine-readable' Web content and automated services (including other agents) become available.

3. Decision-making and Semantic Web

The semantic web shares many goals with decision support systems (DSS), namely by being able to precisely interpret information, in order to deliver relevant, reliable and accurate information to a user, but also by presenting an enhanced ability to connect and automatically organise the content of information spread across multiple pages or
AQ3 sites (Kousetti et al., 2008). This ability has implications for decision-making support, namely fulfilled and unfulfilled promises derived from the earlier vision of the semantic web and research opportunities. We will address them in the following sub-sections.

3.1 Intersecting DSS and Web technologies

We can accept the categories of decision support tools (as established in Arnott & Pervan, 2005, 2008), based on their main objectives:

(1) *Personal decision support systems* (PDSS): usually small-scale systems that are developed for one manager, or a small number of independent managers, to support a decision task;
(2) *Group support systems* (GSS): the use of a combination of communication and decision support technologies to facilitate the effective working of groups;
(3) *Negotiation support systems* (NSS): decision support tools where the primary focus of the group work is the negotiation between opposing parties;
(4) *Intelligent decision support systems* (IDSS): the application of AI techniques to decision support;
(5) *Knowledge management-based decision support systems* (KMDSS): systems that support decision-making in aiding knowledge storage, retrieval, transfer and application, by means of supporting individual and organisational memory and inter-group knowledge access;
(6) *Data warehousing* (DW): systems that provide the large-scale data infrastructure for decision support;
(7) *Enterprise reporting and analysis systems* (ER): enterprise-focused decision support technologies, including executive information systems (EIS), business intelligence (BI) and, more recently, corporate performance management systems (CPM).

The semantic web data can be used in several ways to process and share information (Blomqvist, 2013), namely, in a DSS context:

(1) *Information integration* (several data sources, different formats, external data sources, high change rate, exchangeable data sources);
(2) *Information filtering and selection* (several large data sources, different tasks and roles of users, abstraction);
(3) *Information extension, exploration, and explanation* (data may be missing in internal sources, user explanations, browsing relations between data, drill-down of information);
(4) *Information interpretation, event detection and prediction* (large data sources, high change rate of data, abstraction and aggregation, situation detection, 'real-time' data, data analysis);
(5) *Information tracking and post-event analysis* (large data sources, abstraction and aggregation, situation detection, post-session evaluation and session follow-up, provenance);
(6) *Models and model evolution* (different changing data formats, external data sources, changing user tasks and views, model-based analysis, relations amongst information, browsing and linking);
(7) *Sharing decisions* (trust, provenance, accountability, user created data, interaction between users, delegation).

The feature categories span across the different DSS and semantic web tools (presented in section 2), even though they are not always present or do not always bear the same importance. We can match the utility of each semantic web tool to information processing and sharing against each decision support tool category; the intersection of tools and feature categories is depicted in Table 1. For instance, RDF can be very useful in GSS for (1) information integration, (3) information extension, exploration and explanation and (7) sharing decisions.

DSS can be viewed from several different perspectives (Arnott & Pervan, 2005; Power, Sharda, & Kulkarni, 2007; Turban, Aronson, & Liang, 2005), namely:

AQ17 Table 1. Intersection of the semantic web and decision support.

		Decision support tools						
		PDSS	*NSS*	*GSS*	*IDSS*	*DW*	*KMDSS*	*ER*
Semantic Web	*RDF*	1, 3, 7	1, 3, 7	1, 3, 7	1, 3, 7	1, 3	1, 3, 7	1, 3
	XML	1, 3, 7	1, 3, 7	1, 3, 7	1, 3, 7	1, 3	1, 3, 7	1, 3
	Ontologies	3, 5, 6	3, 5, 6	3, 5, 6	3, 5, 6	3, 5, 6	3, 5, 6	3, 5, 6
	Inf. rules	4	4		4		4	4
	Query	2, 3	2, 3	2, 3	2, 3	2, 3	2, 3	2, 3
	NLP		2	2	2, 4	2, 4	2, 4	2, 4
	Agents		2, 3, 4, 7	2, 3, 4, 7	2, 3, 4, 7	2, 3, 4	2, 3, 4	2, 3, 4

(1) Model-driven
(2) Communication-driven
(3) Knowledge-driven
(4) Data-driven.

We can trace those perspectives to Web evolution, according to their intrinsic purposes, as represented in Table 2. It is easy to realise that PDSS are much more related to producing content than disseminating such content, while NSS and GSS naturally involve a multitude of users (even though bearing different objectives). Knowledge-driven and data-driven DSS can benefit the most from semantic web features, as it provides enhanced content relationships with the possibility for greater retrieval accuracy.

The evolution of web technologies creates new possibilities for group decision support, bringing the possibility to access the potential of the 'wisdom of the crowds' (the term is defined by Surowiecky, 2004), although using different tools, a situation that might hinder their integration. The next subsection expresses how semantic web technologies can overcome this problem.

3.2 Group Decision Support

Regarding the creation of information, and contrarily to the traditional group decision-making 'top-down' approach, usually involving small groups, Web 2.0 stands for a 'bottom-up' approach where information is produced by mass collaboration of people (though it does not mean that mass collaboration will substitute for the decision-making of small groups) that create, update and share knowledge on a regular basis (Gehrke & Wolf, 2010), which constitutes a very distinct approach not only from PDSS, but also from traditional GSS, in terms of argumentation process, sequential support of activities and people involved.

Though this 'bottom-up' approach can be very useful for generating information, it is usually done by using distinct tools, like blogs, wikis, discussion groups, etc. (for a more detailed view on the subject see, for instance, Turban, Liang, & Wu, 2011), rather than using a single GDSS that usually supports all group decision-making tasks, thus making information more difficult to integrate. This gap can be filled using semantic web techniques like ontologies, software agents and social classification of information

AQ18 Table 2. Web stages and their adequacy regarding decision-making tools.

		Web		
Power et al., 2007	Arnott & Pervan, 2005, 2008	1.0	2.0	3.0
Model-driven	PDSS	+++	+	+
	NSS	++	+++	++
Communications-driven	GSS	++	+++	++
Knowledge-driven	IDSS	++	+	+++
	KMDSS	++	++	+++
Data-driven	DW	++	+	+++
	ER	++	+	+++

+++ *Excellent fit.*
++ *Adequate fit.*
+ *Poor fit.*

relevance (through registered classifications performed by past information users, according to their perceived relevance). These techniques provide a larger spectrum of possibilities in searching and recovering relevant information (Antunes & Costa, 2012). Compared to ontologies, 'folksonomies' offer greater flexibility and adaptability in organising information, and users do not need to agree on a detailed tag hierarchy and taxonomy, though it implies that each user can create a separate set of tags that would then need to be disambiguated, using specific ontologies to be created or a combination with existing ontologies. Folksonomies may also suffer from ambiguity regarding the meaning of the tags and lack of semantics, for example, synonyms. Moreover, a coherent categorisation scheme when using folksonomies can become difficult to achieve, because their contributors do not operate under a centralised controlling vocabulary, though empirical work shows the emergence of stable collective consensus around the categorisation of information driven by 'tagging' behaviours (Robu, Halpin, & Shepherd, 2009).

Based on the above-mentioned, we have, on one hand, tagging tools that require specific computer skills with low ease of use and, on the other hand, users who do not willingly spend time on this extra work just because it might bring them future unspecified benefits or, more altruistically, improve the development of the semantic web, thus contributing to a feeling of uselessness of the process. Therefore, and according to the Technology Acceptance Model and its extensions (Venkatesh & Davis, 2000), in spite of the fact that people seamlessly create and disseminate information through social media, the intention to individually add any further annotations to content seems compromised (at least until they have better tools to do so). According to this situation, the use of software agents and NLP seems appropriate to perform an automatic processing of the dynamic and massive amount of information encompassed in social media, at least until technology takes full advantage of folksonomies.

Another issue largely different from traditional GDSS is decision-making trust (i.e. that the people involved in the decision are fit or adequate to the process). When in the presence of social-networked decision-making, the notion of decision-making trust must be made explicit (Rodriguez et al., 2007), as friendship, per se (seldom the reason for linking users), does not identify people as good decision-makers. The familiarity with the technological features and communication tools of social media, or satisfaction with past interactions with other community members, are much more important antecedents for online trust than mere acquaintance or friendship (Grabner-Kräuter, 2009). Nevertheless, semantic web reasoners, agents, and other automated systems can enhance trust judgments, by enabling the detection of related statements, and whether they are contradictory (Gil & Artz, 2007), thus enhancing the trustworthiness of web content by analysing their semantic relationship (Gao, 2010) and also to structure web content in order to extract or perceive the implicit argumentation liaisons.

3.3 Decision process

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Rather than representing a completely different approach, the concepts of semantic web complement Web 1.0 and Web 2.0 decision-making quite well. Complementary to Web 1.0, the use of formats such as RDF and OWL and the incorporation of linked data in DSS applications are intended to access, extract and integrate data from existing data sources, which is like data warehousing approaches to database integration but with new formats.

The unstructured nature of decision-making is very well suited for the ad hoc nature of social networking based on different tools (Nagle & Pope, 2013), depending on the problem at hand, with users organising information according to the problem itself, rather than a preformatted way of collaboration that might not be appropriate for every single case. This situation fits rather well the early stages of the decision-making process (as defined by Simon, 1977), and semantic web technologies are, therefore, intertwined with it. In the following sub-sections, we will elaborate on actual and foreseen possibilities for a deeper integration.

3.3.1 Intelligence

During the intelligence phase, problem finding, analysis and definition occur and divergence is supported through the generation of alternatives. As a group evaluates the alternatives, the convergence process evolves.

Input data in the decision-making model is changing (from personal to mass collaboration and integration of external data), although the semantic web is not a decision-modelling technology to improve decision per se, but perhaps more a possibility of integrating data (Necula, 2011). Therefore, improving the search, enhancing knowledge sharing and integrating the available, though heterogeneous, databases and semantic interoperability, will reveal implicit information that usually would remain undiscovered, thereby resulting in suboptimal decisions (Necula, 2012).

In the specific case of social media, the ontologies derived from folksonomies can give a machine-processable form to the social web's collective intelligence, enabling Web 2.0 search engines to deliver more advanced information retrieval options with better results. NLP and semantic web technologies could then be exploited to the advantage of DSS, namely by applying IE to populate semantic web data sets and to perform the automatic detection of arguments within group discourse (and from external data), for later analysis by a DSS. By interconnecting users' contributions, this process would enrich and produce a much more accurate information to be used in the intelligence phase. Nevertheless, the creation of folksonomies lacks tools that can make this a seamless work (or at least very simplified or intuitive), making it a time-consuming task.

3.3.2 Design

During the design phase, possible solutions to the problem are generated, usually followed by the merging of related ideas and the elimination of redundant or irrelevant ones, through a structuring process that might include the elicitation of criteria and their relative importance, as well as the indication of a value system.

One of the ways to support the design phase is based on a group of people debating (which can also be associated to the intelligence phase) and structuring their ideas in a virtual environment. The more structured versions of a group discourse allow a better understanding of the expressed points of view, as well as the logical sequence of the discussion itself, particularly when the deliberative support is provided to a large group or the discussion is active during a long period. Indeed, the incorporation of new people into an already-started decision meeting can be very difficult if previous discourse is not presented in a structured way.

The structured discourse can range from threaded plain text to a more structured presentation, usually sustained by argumentation theory. However, social media does not favour this latter type of structure, or the generation of tags that can explicitly define used concepts, applied values or any types of quantitative or qualitative parameters. Accordingly, the use of XML/RDF to structure the produced meeting content could alleviate this problem. Nevertheless, the generation of tagged content, which would be of enhanced utility in decision-making, requires computer skills that cannot be expected from all participants in all decision meetings. As in the intelligence phase, the lack of tools that can make this a seamless work prevents the automatic (or at least very simplified or intuitive) creation of the structured content, and makes it a time-consuming task.

Therefore (and according to Schneider, Groza, & Passant, 2013), there is a need for ontologies that are suitable for representing *informal* social web arguments and ontologies that map between the social world and the argumentative world. Nevertheless, social media are understood as failing the criterion of 'argumentative discussions' as general Web 2.0 tools, since their argumentation support is considered to be peripheral (Schneider et al., 2013), as web discourse has different characteristics than discourse AQ5 that occurs in person. In the first place, it requires new language forms to express emerging concepts (Bodomo, 2010). Second, it is a kind of discourse that privileges an informal language, as opposed to a more formal and structured language. A literature review shows a perceived difficulty in structuring social network data (Shum, Cannavacciuolo, De Liddo, Iandoli, & Quinto, 2011). The writing style commonly used in these platforms has a pattern out of the ordinary that sometimes makes it incomprehensible to those who are not part of the conversation and/or that culture or context, thus making it very hard to make it 'machine-understandable'. This is because social actors often make mistakes in spelling and/or grammar, use abbreviations (e.g. ASAP = as soon as possible), symbols (e.g. :(= sad) 'stretch' words (e.g. 'nooooo'), or include links, images, audio and video (Bodomo, 2010; Georgalou, 2010). Moreover, normally dialogue does not contain many used words, since users tend to mix symbols (e.g. smileys). There are also dialogues that do not even contain text (only links and/or tags).

Another problem (described in Muysken, 2000) is the fact that a dialogue can be written in more than one language (code-mixing, which refers to all cases where lexical items and grammatical features from two languages appear in a sentence). As users can also omit much of speech, the discourse can become a written summary of what is meant, which might hinder the contextualisation of words and associated concepts. This means that these data are possibly tangled, incomplete and sometimes error-prone. In this case, semantics lie hidden in speech content created by the interveners. Even harder to grasp are the artifices of language such as rhetoric and wordplay (that turn out to be discursive strategies), and the origin, destination, intentions and reception of speech, which help to define how these interactions and respective arguments do come out. Herein lies the challenge to achieving its capture in order to be used by 'machines'. One way of doing this is by using formal models that capture arguments and convert implicit knowledge (concealed in discussions) to explicit knowledge (Nonaka & Takeuchi, 1995).

In spite of the earlier considerations, and knowing that RDF triples consist of text encompassing relations between described entities, we can argue that semantic web tools will be able to transform the representation of a simple (unstructured) text into a representation that follows or is supported by one or more argumentation models. Such a process would follow:

(1) The establishment/extraction of a taxonomy of elements contained in the text/speech;
(2) The development of a specific ontology or the use of existing ontologies to relate the elements included in the taxonomy;
(3) The development of ontologies according to the intended argumentation models;
(4) A combination of step 2 and step 3.

The revelation of implicit attributes or argumentative properties can be achieved by IE/NLP techniques that could also build and associate different ontologies containing rules of the argumentative association derived from semantic terms (e.g. terms such as 'in support of', 'against', 'in favour of', etc.). Future social semantic web prototype tools for sense-making and argument-mapping could be tested for argumentation on some common debate topic in order to find a large audience of potential evaluators. It would also provide meaningful ways to discover new debate topics, and potentially record and share the outcome of these debates, making them potentially more savvy about argumentation schemes and similar abstractions (Schneider et al., 2013).

These processes combine the ease of use of social media for presenting, discussing and narrowing ideas (intelligence and design phases), while using AI tools (IE/NLP in particular) to structure the produced content (even though manual/human intervention is expected to some extent) and, thus, leading to the choice phase. This would be done by enabling a richer and more structured visualisation of the speech (for which visualisation analytics and tools are complementary to semantic web tools), namely by presenting the information according to different models of argumentation.

3.3.3 Choice

Choice involves divergent evaluation of the previous set of ideas and convergent selection, possibly following an iterative process.

Many DSS applications use ontologies and rules as a means for making the DSS 'intelligent' in some data analytics sense, in continuation of the expert systems tradition, though adopting the emerging semantic web standards for knowledge representation (Blomqvist, 2013). The use of an ontology of ontologies (according to Gaševic, Djuric, & Devedžic, 2009) can facilitate collaboration by providing a unifying multiple-criteria decision analysis/aiding (MCDA) decision knowledge skeleton that can be used as a common and shared reference for a collaborative process. In addition, the deployment of service-oriented architectures (SOA), enhanced by semantic web technologies for sharing and accessing data, can apply semantic web technologies in peer-to-peer networks, for facilitating offers in negotiation scenarios (Du, 2009).

3.3.4 Implementation and evaluation

Semantic web tools, namely ontologies, could also be applied to provide a follow-up on decisions after they are taken. This could become an excellent source for decision reconstruction and evaluation of the implemented choice (Antunes & Costa, 2013). Unfortunately, the pervasiveness of ontologies in the Web is not yet a reality, as their creation involves a 'top-down process', which constantly requires disciplinary experts checking the evolution of the ontologies (Padula et al., 2009).

4. Final remarks

Long gone is the idea that DSS were proprietary based and that a single package of software would suffice in supporting all the activities of personal and group decision-making. The pervasiveness of web technologies, especially regarding Web 2.0, made them globally available to be exploited in the major activities in the decision-making process (Turban et al., 2011), though not without a cost. In spite of the fact that the decision-making process still bears its original objectives (as proposed by Simon, 1977), the diversity of tools, formats and types of applications to support them enhance the decision agents' new opportunities for timely and better decisions more than ever before – at least theoretically.

What we conclude in this paper is that there is a gap between foretold promises in using social web tools to the benefit of decision agents and its actual possibilities, as integrating such tools and information poses many problems, especially as regards group support. To do so, we have argued that semantic web technologies need to be intertwined with the above-mentioned tools, especially for information integration and representation during the earlier phases of the decision process, and especially in the design phase, in which increasing amounts of produced information need to be processed properly and in a timely fashion. In Table 3, we present major opportunities and constraints for using semantic web over existing Web 2.0 solutions when used throughout the decision-making process.

We also conclude that the greatest obstacle to actual arrival of the semantic web into decision support mostly relies on the technologies that have to come together in order to make it seamless. Some argue that it is unrealistic to expect busy people and businesses to create enough metadata to make the semantic web work. The simple tagging used in Web 2.0 applications lets users spontaneously invent their own descriptions, which may or may not relate to anything else. However, the solution to this problem may simply rely on better tools for creating metadata, like the blogging and social-networking sites that have made building personal websites easy.

The first step towards a real semantic web-based decision-making environment is making data accessible through queries, with no AI involved. Although Web 2.0 tools provide fundamental technological support to tacit knowledge, Web 3.0 evolution will concern technological tools supporting explicit knowledge (as they are defined in

Table 3. Semantic web and the decision-making process.

	Decision process			
	Intelligence	*Design*	*Choice*	*Implementation and evaluation*
Opportunities	Data integration and interoperability	Enhanced structuring and argument representation of collaborative discourse	Collaborative MCDAFacilitating offers in negotiation scenarios	Follow-up on decisions
Constraints	Requires specialised computer skillsNeeds seamless tools	Requires specialised computer skillsPerception of utilityNeeds seamless tools	Requires specialised knowledge	Ontologies are not web-pervasiveRequires specialised knowledge

MCDA: multiple-criteria decision analysis/aiding.

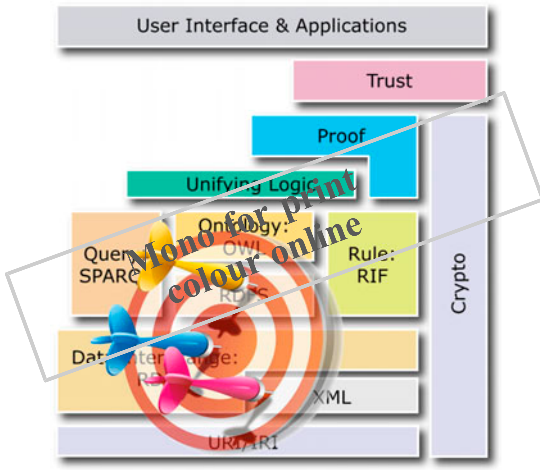

Figure 1. Targeted semantic web layer cake, regarding decision-making (source: adapted with AQ16 permission from http://www.w3.org).

Nonaka & Takeuchi, 1995), where semantic interoperability, interoperable intelligent agents, ontology mapping and their progressive development appear to be overlapping areas requiring strong innovation (Padula et al., 2009).

The second step towards semantic web-based decision-making seems to be ontology mapping, as the number of publicly available ontologies increases steadily and as the semantic web grows (even though some argue its rhythm is not fast enough). The ontology-mapping process defines semantic bridges (and their interrelations) between a source and a target ontology, in order to exchange information between them.

If we combine the whole of the semantic web layer cake with the actual implementation in the decision-making context, we can see that it clearly marks a lesser target (Figure 1). It is easy to understand that a broader or generalised semantic web integration in the decision support community is still a work in progress, and much remains to be done.

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