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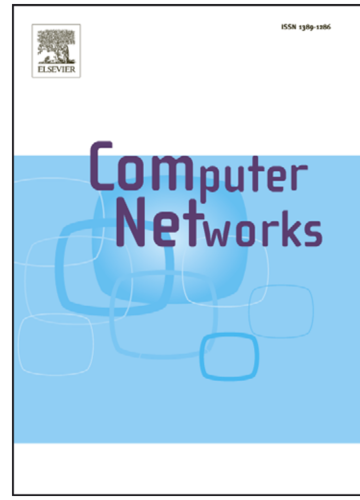

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Web Evolution and Web Science

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This paper examines the evolution of the World Wide Web as a network of networks and discusses the emergence of Web Science as an interdisciplinary area that can provide us with insights on how the Web developed, and how it has affected and is affected by society. Through its different stages of evolution, the Web has gradually changed from a technological network of documents to a network where documents, data, people and organisations are interlinked in various and often unexpected ways. It has developed from a technological artefact separate from people to an integral part of human activity that is having an increasingly significant impact on the world. This paper outlines the lessons from this retrospective examination of the evolution of the Web, presents the main outcomes of Web Science activities and discusses directions along which future developments could be anticipated.

Preamble

The proceedings of the first World Wide Web conference, which was held in Geneva in May 1994, were published in the Elsevier journal of Computer Networks and ISDN Systems – the predecessor of the Computer Networks Journal - in November 1994. By this time the Web was already emerging as the globally ubiquitous hypertext system and the killer application for the Internet but it's true network effects were still little understood. The early search engines such as Alta Vista and Yahoo were beginning to emerge but they were primitive compared to what we expect today. Brinn and Page reported the work that led to the development of Google at the WWW conference in Brisbane in April 1998. It is these papers that this special issue is celebrating. The emergence of Google over the next two years together with developments in communications technology such as broadband and WIFI fuelled the growth of both the Web and the Internet. Google and the Web are completely synergistic – Google's success depends on the hyperlinks of the Web and the Web would be impossible to navigate without a search engine such as Google. But we needed to build the Web in order to understand that. Technologists don't create systems such as the Web – people do by producing the content that determines the growth of the system. But as the system evolves we need new technologies to help us make sense of it. This is the fundamental concept that underpins Web Science and which we explore in this paper.

The Web as an evolving network of networks

One can discern different stages in Web evolution. The Web as it emerged in the early 90s (Berners-Lee, Cailliau, Luotonen, Nielsen, & Secret, 1994) provided ways to publish and access documents online; the first Web standards were concerned with how documents could be rendered by a browser or how those documents could be transferred over the Internet to be read by users. The Hypertext Transfer Protocol (HTTP) and the Hypertext Mark-up Language (HTML) are considered to have contributed significantly to the success of the Web.

The success of other communication services have been characterised by direct network effects; i.e. the value of the communication service (such as telephony) increased as the number of the users increased, and vice-versa. The value of the Web in allowing users to publish instantly information about themselves or their organisation online, led to its unprecedented growth leveraging direct network effects in a similar way; as the number of users publishing documents on the Web increased, the value of the Web increased, which, in turn, led to an even higher number of users. Still, at that stage, the notion of the Web as a network was not understood in the same way by everyone.

The Web of documents

To some the Web was a technological network of servers accessible over the Internet; an overlay network, where the nodes were the servers and the edges were the network connections that allowed the retrieval or posting of documents. To others, the Web was a realisation of a stripped-down hypertext system on the Internet, where the nodes were documents and the edges were the hyperlinks from one document to another (Hall, 2011). However, for the general user, the Web was experienced as single system that could be accessed using a personal computer, and which was primarily a source of information and news initially, and, later, a place to make purchases. At that stage, the Web appeared to be a technological artefact that was introduced to people's lives; its use required very basic computer literacy but its evolution was something in which most users had no part. An essential instrument that enabled users to access this artefact was the search engine, which ensured that this plethora of information, products and services was readily discoverable by the user. That first period of the Web is often referred to as the Web of documents, Web 1.0, or the read-only Web.

However, from the end of the 1990s emerged the vision of a Semantic Web (Berners-Lee, 1999; Berners-Lee, Hendler, & Lassila, n.d.) where knowledge representation and reasoning could be leveraged to add 'meaning' to Web resources on the one hand, and allow agents to perform complex tasks for users on the other hand. The Semantic Web vision was ambitious not only for its global scale but also for its dependency on increased user engagement who would need to be involved in the process of adding 'meaning' to Web content (via annotations) or interpreting it.

The Web of people

The picture started to change dramatically in the early 2000s, when the users started to be a more significant part of the Web evolution. The success of e-commerce, the value of the Web for information discovery and the emergence of business models that could sustain online services led to a very large number of users. The range of network effects that the Web could enable expanded to include ecosystems and indirect network effects. For example, around the very large number of users of e-commerce services it became possible to support a marketplace with additional sellers. At the same time, users could benefit from statistics on most popular items and, at a later stage, online reviews of the items that were on sale. Users provided marketplace sellers with additional value and vice-versa.

Apart from e-commerce the increased number of Web users enabled services that could leverage the crowd as information providers and provide additional value based on collective intelligence applications (O'Reilly & Battelle, 2009). It was the number of users that enabled the emergence of Wikipedia as a global repository of knowledge. Technological innovation enabled users not only to contribute content on the Web (e.g., with blogs) but also to engage in collectively organising and structuring information (e.g., with wikis). Technological advances in broadband and in server technologies enabled the contribution of video content by users, leading to the emergence of services like YouTube. In this new environment it was not only the number of users that increased dramatically but also the volume of contributed content and structured information which also grew in an unprecedented manner. The openness of Web standards enabled a new generation of services based on the combination of resources from different websites, such as mashups; these services demonstrated the value of publishing data on the Web in formats that are easy to combine with other data sources.

At the same time, the critical role of search engines was significantly enhanced by that of recommender systems (Adomavicius & Tuzhilin, 2005), including those based on collaborative filtering. The ability to distinguish the activity of individuals on e-commerce services and online repositories made it possible for recommender systems to propose relevant resources to users. With recommenders, online service providers were able to exploit the 'long tail' of their market, i.e. being able to recommend and sell a large number of products for which there was little demand. At the same time, users had more powerful means for information or product discovery on services such as YouTube or Amazon.

New business models introduced 'freemium' services allowing service providers to charge for premium offerings which were supported by a large number of non-paying users (Shuen, 2008); for example, the large number of users of Flickr made possible the offering of a premium service to professional photographers for disseminating their work. Technological and business model innovation made these new services sustainable and transformed the Web from an artefact that was separate from users to one in which users were active contributors and actors in its evolution. At that stage, the Web could be perceived as a network where nodes were online resources or users; the edges in that network could represent contribution of resources by users, similarity among users or links between resources. Resources were not just static content (such as static HTML pages) on the server side but also dynamic content that could be hosted on the client side. That second period of Web evolution is referred to as the Web 2.0 or the read-write Web.

The Web of data and social networks

In the following years the fact that relationships between users were mainly established by recommenders instead of being explicitly stated by users changed, bringing an enormous impact on the Web. In retrospect, it may seem inevitable that, as users became actors of the Web, they would favour ways that would enable them to bring more of their personal and professional life on the Web. Online social networks and services that allowed users to express their interests, establish their online identity, identify their friends and colleagues, and leverage their real-life relationships to discover online resources and establish new relationships transformed the Web to an artefact that goes beyond a read-only or a read-write medium; it established the Web as an integral part of one's life that pervaded society and many sectors of human activity including business and citizenry. The emergence of online social networks is one of the two characteristics of this new Web era.

One could argue that, if it was the availability of residential Internet connectivity that supported the growth of Web 1.0, and if it was the availability of broadband that enabled the emergence of Web 2.0, it was the post-PC era with cloud computing and smart mobile devices that enabled the transition to this new stage of evolution, where the Web permeates through so many aspects of human activity.

Apart from social networks, one can discern another element of the transition to this new Web era; that of the increased level of digital literacy among people. One can at this stage distinguish between people who grew up using the Web, the 'digital natives' (Prensky, 2001) on the one hand, and 'digital immigrants' with increased digital literacy, potentially honed by higher involvement in the Web activity, on the other hand. The differences between natives and immigrants are a topic of debate (Bennett, Maton, & Kervin, 2008) but one could argue that, overall, there has been an increase in Web literacy levels, based on the high number of users and intensity of use.

In this era, the level of digital literacy among people is growing beyond the ability to contribute or collectively compose online content such text or video, to the ability to publish data in the form of spread sheets or Linked Data, and the ability to develop applications that make use of those data. The value of enabling contribution and access to data is increasingly important for transparency in the government sector, for supporting open supply chains in the business sector or for fostering innovation in the transport and health sectors. The same power of the crowd that enabled new value models based on content is now involved in creative processes based on data. In addition, new ecosystems in this stage of the Web evolution do not evolve around businesses but also around individuals, social networks and crowd-sourcing. If Web portals allowed the crowd-sourcing of digital content that was to be processed and consumed by people, in this new era, data portals enable the crowd-sourcing of data that can be processed by software as well as people. Crowd-sourcing goes even beyond the collection of data, to the development of advanced applications based on collected data.

The availability of standards has been a critical factor to enable this transition to a Web of data. Standards such as RDF and technologies that allow the extraction of structured data from collectively composed content (e.g. structured data in DBpedia, which are obtained from collectively composed content on Wikipedia) ensured the availability of a significant volume of data in interoperable formats. Semantic Web technologies provide the base for intelligent applications that make use of those data. Innovation based on the Web of data can lead further along the roadmap of the Semantic Web vision but in a bottom-up way (Shadbolt, Hall, & Berners-Lee, 2006).

This stage of Web evolution has been labelled as Web 3.0 but this term seems to emphasise mainly the Web of data aspect of Web evolution, excluding the aspects related to online social networks. Digital literacy and the crowd-sourcing models, which have been the powerhouse of the Web of data, are inextricable from the emergence of online social networks; much of the data in the Web of data come from social networks and this is likely to increase given the unparalleled growth of online social networks and of social media. In addition, public engagement mechanisms and campaigns that enable data-based innovation are inseparable from online social networks.

In today's Web, the role of search engines and recommender systems has been significantly enhanced by online social networks, which have provided complementary or, for some people, alternative ways of information dissemination and discovery. People are increasingly relying on online social networks to engage with others; by following their Twitter stream, or their Facebook and LinkedIn news feeds. Interaction with online social networks transforms those networks themselves by inventing new communication modalities such as the 'like' action on Facebook or the 'hash tag' on twitter. In addition, it further establishes the Web itself as part of world developments on a global scale; the role of the Web in the Arab spring is an example of this process.

These developments have also affected how one can perceive the Web as a network. It is a network of networks in that it brings together many different types of networks, not only technological and resource networks but also organisational, social and data networks. In addition, one could consider overlays of homophilous networks of people (i.e. people who share the same interests) or even networks of influence. In these networks the nodes are not only people, resources or servers but also data, concepts, interests, news items or policies.

However, understanding the Web goes well beyond its study as a network. The engagement of individuals or organisations with the Web and the impact of the emergent communication modalities on interacting, collaborating and learning, require a scope of research that is much broader and goes across disciplines. This study across disciplines needs to go beyond multidisciplinarity, which seeks the synthesis of the viewpoint of each discipline independently, to interdisciplinarity, which seeks new research methodologies involving more than one discipline. Web Science is an interdisciplinary area which focuses on understanding the Web and its impact in a holistic way and on taking care of the Web through the following stages of its evolution.

An account of the evolution of the Web would not be complete without reference to the role of standards. The publication of just the necessary number of open standards has been instrumental in the growth of the Web. Standardisation processes have aimed not only to assist the development of the Web but also to ensure its sustainability and openness; for example, through open licences, such as Creative Commons, enabling knowledge sharing and reuse. Perhaps it is this parsimonious and open approach to standardisation that enabled the initial growth of the Web as the Web of documents, transformed it to the Web of people and has now developed it to the Web of data and social networks.

The evolution of the Web has been a journey that has taught us important lessons:

- Lesson One: Big is beautiful. Providing networks in which resources, infrastructure, people and ideas can be linked has shown to be a powerful way to foster innovation.
- Lesson Two: Good enough works. It is important to let the development of the Web rely on bottom-up mechanisms, even if there is a significant margin of error in the beginning. The scale on which people engage with the Web can help improve the quality of its offerings over time.
- Lesson Three: Openness rules. Adopting free, open and universal standards can ensure that the Web will continue to grow in a way that is sustainable and beneficial to society.

A science for the Web

The interdisciplinary area of Web Science was born in 2006 (Berners-Lee et al., 2006a; Berners-Lee, Hall, Hendler, Shadbolt, & Weitzner, 2006b). During that time it was becoming clear that there was a lack of uptake of the Semantic Web vision, according to which the enrichment of Web-based resources with knowledge representation and reasoning capabilities would enable a new wave of innovation on the Web with intelligent services that would benefit people's lives. This lack of uptake required a retrospective examination of the evolution of the Web and the shift of focus to bottom-up approaches that involved (i) the sharing of data before agreeing on how or whether they should be annotated, and (ii) understanding how the engagement of individuals related to shaping the Web and to driving Web innovation. This retrospective examination is what made it even clearer that the Web is more than an application of the Internet and that an interdisciplinary study of the Web was necessary. In this perspective, the Web could be seen not as a technological artefact but as a phenomenon, an experiment that reached far beyond the technological domain.

This science for the Web was born out of the realisation that the Web is changing society and, in turn, that society has changed the Web. It is the realisation that human behaviour and technological evolution have been shaping the Web in a synergistic manner and that, to fully understand the relationship between the two, an interdisciplinary perspective was necessary (Hendler, Shadbolt, Hall, Berners-Lee, & Weitzner, 2008; Shadbolt & Berners-Lee, 2008), involving computer science, social science, law, psychology, economics, humanities and other disciplines. Although the name ‘Web Science’ may not appear to capture the aspect of human behaviour at first, considering the evolution of the Web and the role of society in shaping it can give it a broader, more inclusive context.

The nature of the Web poses new challenges that cannot be efficiently tackled by individual disciplines or established practices. Practice often comes first in Web Science. For example, no search engine or social network could be well studied before people start to use the Web on a large, global scale; at the same time, the combination of quantitative and qualitative research methods is essential to fully explore their impact. The examination of potential underpinning laws that shape the development of the Web and its impact seems to follow practice.

Web Science grows up

The establishment of the Web Science Research Initiative (WSRI) in 2006 followed by the formation of the Web Science Trust (WST) and the Web Science Trust network (WSTNet) in 2010 brought together a number of labs that were already engaging in Web research from these different perspectives. It put up a banner that aimed to bring together researchers in order to discuss, negotiate and establish interdisciplinary approaches to the study of the Web in this light. The aim of this initiative was to accelerate research that was already in progress and to discuss ways in which this research could be enhanced with additional perspectives and with the training of Web Scientists; during the first five years of its life, Web Science saw the development of curricula and doctoral training centres.

There has been an annual Web Science conference since 2009 and in 2011 it became an ACM conference. The Web Science Track in the World Wide Web Conference in 2012 further established the significance of Web Science as the study of the Web in a way that is distinct but still relevant to the evolution of its standards and technological infrastructure. Significant Web Science research activity is under way and its output is reported in a number of conferences across disciplines along with the Web Science conference. Much of this research activity focuses on the opportunities and the challenges that are emerging in the Web of Data and Social Networks. It often addresses the tensions that arise in this phase of Web evolution, e.g. the tension between publishing open data or participating in social networks and privacy. Similar ‘tensions’ or ‘tussles’ have been discussed about the Internet (D. D. Clark, Wroclawski, Sollins, & Braden, 2002).

On the one hand, Web Science research has established that that the social Web and social semantics can provide for more precise information discovery on the Web than deployed Semantic Web search engines and other information retrieval systems(Halpin, Clark, & Wheeler, 2010). Within social networks we can study online communities better and understand the value that individual users bring (Karnstedt, Rowe, Chan, Alani, & Hayes, 2011). There are new ways to measure expertise based on interactions in online communities (Yeung, Noll, Meinel, Gibbins, & Shadbolt, 2011), while the application of semantic technologies to social media is understood to be instrumental to the longstanding vision of social machines (Passant, Samwald, Breslin, & Decker, 2009). It has been shown that, in the Web of data, analysis of Web usage patterns by machine agents, in addition to human agents, can establish correlations between real-world events and Web activity (Möller, Hausenblas, Cyganiak, & Handschuh, 2010).

On the other hand, research suggests that small technological advancements such as real-time search results in search engines can give disproportionate exposure to fabricated content and unverified events (Mustafaraj & Metaxas, 2010). Qualitative research suggests that the Web can be used to fight civil 'infowars' in revolts related to the Arab spring (Amine et al., 2012). In the social Web, network analysis can compromise the privacy of citizens, necessitating policies of incentives and responsibilities to safeguard privacy (O'Hara & Shadbolt, 2010) without compromising requirements for transparency. In addition, the discussion on the balance between openness and control in a networked society is challenging given the increased distribution of resources and it far from over (Powell, 2009).

Web Science research has so far established that interdisciplinary approaches to studying the Web as a socio-technical phenomenon can bear significant benefits for individuals, business, government and society. We have just started to understand some of the workings of the Web as a socio-technical phenomenon, but, at the same time, we are exposed to the complexity of the issues that are not yet understood and require challenging, further research. Beyond interdisciplinary research methods, it has been advocated that a new philosophy for the Web is needed; in (Halpin et al., 2010) it is argued that this philosophy needs to go beyond the discussion on cognition and the extended mind hypothesis (A. Clark & Chalmers, 1998) to consider the social Web and the workings of the infrastructure that enables collective intelligence.

In order to address these significant challenges, it is now time to go further, beyond community building, in order to better foster interdisciplinary research on the Web. It is essential to bring together, harmonise and extend the research infrastructures that Web scientists use. It is essential to further share methodologies and tools for Web Science. The Web Observatory project is aiming to support developments in that direction.

Towards a Web Observatory

Perceiving the Web as an evolving network of networks in this wider scope necessitates the collection of data on those networks. Online social network data is one domain that concerns data collection. This is complemented with data on how the Web develops as a technological network and on how the networks of people that engage in social machines emerge and shape its evolution. Apart from data, bringing together qualitative and quantitative methodologies and tools can better foster the research of the Web as a network of networks.

However, there is more to data about the Web; the Web is increasingly becoming an archive of human activity. Developments in the world are continuously reported on resources available on the Web as blogs, news reports, stock exchange data, geo-tagged and time-stamped resources. The Web is not only a shaper but also a reflection of human activity.

Web Science is aiming at leveraging both the network-related data about the Web and Web archives to study its evolution and impact. The nascent Web Observatory (http://thewebobservatory.org) project under the auspices of WSTnet (http://webscience.org/WSTNet.html) will facilitate the ways in which those data resources could be harmonised and become available for the study of the Web on a global collaborative basis. Other Web Science activities are focusing on the development of interdisciplinary research methods for the study of those data collected and inter-linked as part of the Web Observatory activity. The ambition behind the Web Observatory is to empower Web Scientists to enrich and expand their research by providing a harmonized collection of new and existing data sources and analytic tools; in this sense it will provide a harmonised collection of Web Observatories. A W3C community group on the Web Observatory idea (http://www.w3.org/community/webobservatory) will foster discussion on standardisation that could assist this endeavour. Both applied and core research will be fostered by the Web Observatory project, where understanding about the Web is expected to lead to new insights on its influence on business, policy and society.

Web Science and social machines

The engagement of individuals as Web actors instead of Web users and the role of the Web as a reflection and also an instrument for change in the world requires the study of the Web in a scope that goes beyond the analysis of engagement in the Web processes to being able to make predictions about its impact and its development in the future.

One can consider the Web as the enabler of social machines, as envisaged by Tim Berners-Lee back in the late 90s, when he postulated that "Real life is and must be full of all kinds of social constraint – the very processes from which society arises. Computers can help if we use them to create abstract social machines on the Web: processes in which the people do the creative work and the machine does the administration" (Berners-Lee, 1999). Examples of social machines include collaborative knowledge building environments like Wikipedia, online social networks like Twitter, or crowd-sourced data collection and data refinement environments like Galaxy Zoo (http://www.galaxyzoo.org); in all of these cases, the combination of Web-based computational resources with models of social interaction has had a transformative effect on knowledge building and sharing. Further, the Web itself is a social machine, where the multitude of content, applications, services, data and social networks are the outcome of a process that involves people and technology, and, at the same time, enables further processes that have impacted human activity in so many different ways as discussed in the first part of this paper.

Social machines that support complex processes involving individuals, organisations, government, data, software, and services have been seen to emerge, a prominent example being the open government data portals that are under development in a number of countries. These portals leverage crowd-sourcing among individuals or organisations for data collection, data refinement and application development. Essentially, they can combine computationally intensive data-centric processes with social interaction intensive processes to generate new value and impact

In this light, we can define Web Science as the theory and practice of social machines. However, it is only through the development of a global, collaborative enterprise such as the Web Observatory that the longitudinal studies which are necessary to undertake this type of research will ultimately be possible. It will enable social scientists to access the largest possible volume of quantitative and qualitative research data, methods and tools for Web Science research; they will be able to collaborate with colleagues of the same or other disciplines on the solid basis of shared standards and protocols that this infrastructure will provide. Computer scientists will be able to research how emergent affordances of software and applications on the Web are influencing business and society by building on existing analytic tools, visualisation frameworks and research methodologies. Web Scientists will have at their disposal an invaluable resource that will help them trace the development of previous studies and build on them. Ultimately, the impact of the Web Observatory could extend well beyond Web Science through the disciplines involved in this interdisciplinary area.

The road ahead

Six years after the emergence of Web Science we have a better understanding of its research scope and an outline of how it could be fostered and supported by the development of new research methodologies and infrastructures such as the Web Observatory. The Web Science community is in synergy with Network Science and the emergent interdisciplinary area of Internet Science with which experience, practices and research methodologies could be shared. This stage seems to be the beginning of a new era of Web evolution where developments occur at an increasingly faster pace and the sensitivity of the Web to policies or standards could be more critical.

As the Web evolves, data analytics on a large, global scale will be more significant. The ways in which social machines can be initiated, the range of problems that they are able to solve, their affordances and their limitations will point to new directions of research. New value propositions based on open data and social machine innovation will lead to promising applied research. Novel communication modalities such as those that emerged in social networks will empower people to shape the Web in new, potentially unexpected ways. The evolution of digital literacy could pave the way for new ways of engaging with the Web or via the Web; these new ways of engagement could transform further the way in which individuals, consumers or citizens interact and shape not just the Web but the world in general. Recent discussions on whether the Web is a human right or not indicate its crucial role in that respect.

Web Science itself will evolve as can be seen already in the plethora of research projects and curricula that have already emerged. But twenty years on from the birth of the Web we are only now beginning to develop the tools and methodologies to help us understand the amazingly complex socio-technical system of systems that it has given rise to. Looking forward, in order to protect what we have created and ensure it as a force for good in our increasingly interconnected world, it is imperative that we develop methodologies to observe and analyse it's evolution in order to understand how better to build the Web of the future.

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TITLE
Web Evolution and Web Science

ABSTRACT
This paper examines the evolution of the World Wide Web as a network of networks and discusses the emergence of Web Science as an interdisciplinary area that can provide us with insights on how the Web developed, and how it has affected and is affected by society. Through its different stages of evolution, the Web has gradually changed from a technological network of documents to a network where documents, data, people and organisations are interlinked in various and often unexpected ways. It has developed from a technological artefact separate from people to an integral part of human activity that is having an increasingly significant impact on the world. This paper outlines the lessons from this retrospective examination of the evolution of the Web, presents the main outcomes of Web Science activities and discusses directions along which future developments could be anticipated.

KEYWORDS
Web Science, Web evolution, Web Observatories, Social Machines