



From the Semantic Web to social machines: A research challenge for AI on the World Wide Web

Jim Hendler^{a,*}, Tim Berners-Lee^b

^a Tetherless World Constellation, RPI, United States

^b Computer Science and AI Laboratory, MIT, United States

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ABSTRACT

The advent of social computing on the Web has led to a new generation of Web applications that are powerful and world-changing. However, we argue that we are just at the beginning of this age of “social machines” and that their continued evolution and growth requires the cooperation of Web and AI researchers. In this paper, we show how the growing Semantic Web provides necessary support for these technologies, outline the challenges we see in bringing the technology to the next level, and propose some starting places for the research.

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Much has been written about the profound impact that the World Wide Web has had on society. Yet it is primarily in the past few years, as more interactive “read/write” technologies (e.g. Wikis, blogs and photo/video sharing) and social networking sites have proliferated, that the truly profound nature of this change is being felt. From the very beginning, however, the Web was designed to create a network of humans changing society empowered using this shared infrastructure. This aspect of the original vision was explained in the book *Weaving the Web* [2]:

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... The stage is set for an evolutionary growth of new social engines. The ability to create new forms of social process would be given to the world at large, and development would be rapid. (pp. 172–175)

In the time since those words were written, we have clearly seen the advent of social machines on the Web. Examples of these include the interaction between the mediawiki technology that underlies Wikipedia and the social system that has evolved to control the content quality of the democratic encyclopedia with, for example, superusers who can lock down wiki pages that are controversial or out of control¹; the Web-application design of LiveJournal, WordPress and others which brings social discourse to the Web in an interactive way, mediated by the technology of “trackbacks” and blog comments which have enabled the creation of the “blogosphere” that now challenges traditional newspaper publishing; and of course, large-scale Web-based social networking sites such as Facebook and mySpace which have provided an important online extension to the social interactions in a community of friends, but are now struggling to superimpose social mechanisms to control predatory behavior and threats to privacy.

* Corresponding author.

E-mail address: hendler@cs.rpi.edu (J. Hendler).

¹ Such as the infamous example of Cobert, “wikiality,” and the elephants page (cf. http://www.news.com/8301-10784_3-6100754-7.html).

Despite these emerging and exciting realizations of the earlier vision, it is our contention that today's interactive applications are very early social machines, and that they are limited by the fact that **they function largely isolated one from another**. This article is based on our conviction that there are forms of social machines that can be significantly more effective than those we have today. Just as human communities interlink in society they must be interlinked on the Web, and there is no single set of social policies or mechanisms that will work across all domains. Thus, new forms of social machines are unlikely to be developed in a single deliberate effort in a single application or site – rather, technology must be developed that allows user communities to construct, share and adapt social machines so that successful models can evolve through trial, use and refinement.

The goal of this paper is to explore some of the research challenges that stand in the way of creating this new generation of interacting social machines that can be used and evolved by online communities of scientists, educators, school children, citizen activists or any other user group. This technology is needed because the magnitude of the problems that our society faces today are such that only the concerted effort of groups of people operating with a joint power much greater than that of the individual can hope to provide solutions. These problems, whether they be major issues such as curing cancer or addressing climate change, or more local like the creation of a community to address a social issue on the south side of Chicago, require people from a number of fields and backgrounds to work together. We believe that a new generation of Web technologies will be needed to address these issues which will allow for:

- Creating tools that allow groups of users to create, share and evolve a new generation of open and interacting social machines,
- Creating the underlying architectural principles to guide the design and efficient engineering of new Web infrastructure components for a new generation of social software, and
- Extending the current Web infrastructure to provide mechanisms that make the social properties of information sharing explicit and that guarantee that the uses of this information conform to the relevant social policy expectations of the users.

Thus, we seek a revolutionarily more powerful platform for the individual, enabled by realizing that the individual is also a member of a community – in fact, of many overlapping communities. In short, in this article we don't try to explain how to build a Web site that can cure a disease, solve world hunger, or mitigate the effects of global climate change. **Rather, we** explore some of the key issues, particularly those of relevance to the AI field, in creating a technology platform that will allow the users who want to attack problems like these, or the simpler problems of every day life, to eventually create, use and share their own social machines. Much as the architecture of the current Web allows a virtually unlimited scaling of the Web of documents, the architecture of the future Web must be designed to allow the virtually unlimited interaction of the Web of people.

1. The Semantic Web as a foundation for social machines

To understand and enable a new generation of social machines, we must start by re-envisioning the way large communities of users interact with the growing masses of information available on the Web. We contend that we must develop models that can allow humans to explore this information at a higher level of abstraction than just tables presented on Web sites: at the level of a global graph of interconnected people and ideas.² For truly evolvable social machines to be created, among the relationships that reside within that graph must be those that express social protocols and policies that define the starting places for the creation and subsequent evolution of those social machines.

To this end, we propose that the starting place for attacking these problems is by the use of Semantic Web technology [3]. This is an innovation that has been progressively developed over the last decade, and is starting to be widely deployed (cf. [10]). These technologies are easily deployed as the base of emerging Web applications because they were designed in a way that is maximally consistent with the best practices of Web architectural principles [11]. In particular, the Semantic Web provides a mechanism that is very useful for formatting data in machine readable form, linking individual data properties to globally accessible schemas, matching local references to entities against various kinds of standard names, and providing a range of inferences over that data in scalable ways.³

Despite the growing success of Semantic Web technologies, especially in Web applications that exploit linked data [7] their truly disruptive potential is just starting to be explored. In particular, this technology represents an important paradigm shift that will be a significant element of the next generations of Web technologies. The Semantic Web represents a new level of abstraction from the underlying network infrastructure, as did the Internet and the Web before it. The Internet allowed programmers to create programs that could communicate without having to concern themselves with the network of cables that the communication had to flow over. The Web allows programmers and users to work with a set of interconnected documents without concerning themselves with details of the computers that store and exchange those documents.

² For more on the idea of a Giant Global Graph see T. Berners-Lee, Giant Global Graph, blog entry – <http://dig.csail.mit.edu/breadcrumbs/node/215>.

³ Some readers may be surprised that we are not spending more time describing and defending Semantic Web technologies or particular approaches thereto. We point out that we have written a great deal on that topic, both individually and together. The interested reader can find those articles through our blogs, Web sites or through any publications search engine. Also, a search of recent news articles on "Semantic Web" is sure to prove enlightening.

The Semantic Web raises this to the next level, allowing programmers and users to make reference to real-world objects – whether people, chemicals, agreements, stars or whatever else – without concerning themselves with the underlying documents in which these things, abstract and concrete, are described.

The basic Semantic Web technologies have been defined and are starting to be more widely deployed with further components of the architecture being the focus of current standardization efforts. However, there has still been very little work in understanding the impact of this new capability: how it truly enables the connections of the Web of people who will use it. **A structural challenge to AI researchers comes from the need to develop mechanisms to enable those connections. Rather than focusing on the challenges of creating large and expressive ontologies by specialized knowledge experts, the large scale social mechanisms we envision require that we must instead figure out how we can maximally break down the task of turning messy human knowledge into a shared information space that is useful to everyone.** The smaller we can make the individual steps of this transformation, the easier it will be to find humans who can be incentivized to perform those steps.

Another challenge to AI is that a crucial aspect of human interaction with information on the Web will be providing people with the ability to represent and reason over social attributes such as trustworthiness, reliability, and tacit expectations about the use of information, as well as privacy, copyright, and other legal rules. While some of this information is available on the Web today, we lack structures for formally representing and computing these qualities. Thus, a whole layer of critically important, socially relevant information and function is missing from today's social machines. Thus, bringing humanity fully into the information loop requires data structures and computational techniques that enable us to treat social expectations and legal rules as first-class objects in the new Web architecture (that is, to create a declarative rule-based infrastructure that is appropriate for the Web).

For rule-based mechanisms to work on the Web, they must be scaled both with respect to performance (so they can reason over large and dynamic data resources) and with respect to distribution. While much is known about how to operate on logic and rule-based dependencies in closed systems, these techniques are of little help in open systems such as the Web. The open and distributed nature of the Web requires that rule sets be linked together, and that policies defined in one domain may need to be used in another, possibly unanticipated, context. **Formal logics that are powerful enough to encode Web policies generally have problems both in tractability (even restrictive subsets may have exponential or undecidable behaviors) and with inconsistency (i.e. from a contradiction it is possible to derive any proposition).** However, in an open system such as the Web, inconsistency is sure to arise from error, disagreement, or malicious behavior. Logics that control contradiction have been explored (cf. <http://plato.stanford.edu/entries/logic-paraconsistent/>) but none has yet been shown to scale well enough to function in a Web environment.

Approaches to solving these problems will need to take a number of forms varying from exploring computational algorithms that control the search during reasoning processes [14,12], and developing new algorithms **that can be scaled using the large computational resources available to Web-application developers (cf. [8]), to developing logics that are designed specifically to allow the specification of contexts and to control inferencing in a distributed, open setting like the World Wide Web [5].**

2. Context mechanisms for the World Wide Web

Developing contextual mechanisms for the Web presents a number of challenges. For rule systems to be really useful on the Web, we must also explore new approaches to the problems of specifying contexts (perhaps based on the long AI history of context logics based on [16]) in the way that current Web ontology languages are based on a long history of AI work in knowledge representation and reasoning. The kinds of social machines we are proposing must have an ability to be able to appropriately apply different policies in different situations, based on their use contexts. Making these use policies explicit is also important. For example, consider medical personnel needing access to an accident victim's medical information in an emergency. In many communities there are no specialized systems for handling medical information outside of the context of a particular hospital or care center. The normal mechanisms for gaining access to these may be prohibitively time-consuming for emergency personnel, but ignoring the information (as is done in many current situations) can often lead to complications and/or loss of life. A context-aware solution could allow the emergency personnel to override controls while being warned "You are breaking the law unless this is being done in a life-threatening situation (and this access will be logged)." While current Web applications use some aspects of context (mobile browsers can use geolocation information to some extent) these uses tend to be fairly simple, built into procedural code, and limited to specific applications. Something more powerful is needed if we are to take Web applications, and social machines, to the next level.

A context mechanism for the Web would be a major step forward for a number of information-related uses. Current datamining and knowledge discovery techniques often require **domain specific knowledge to function properly**, but this knowledge can bias the results. In many systems, however, this knowledge is embedded in procedural code or is implicit in the problem encodings or fitness functions used. Making the different ontological commitments of competing interpretations explicit, and linked together, can permit different views of data to be simultaneously developed and explored. Current work in ontologies developed for the Semantic Web provides a starting place for providing explicit conceptualization, but these techniques must be extended to incorporate techniques that will better allow user communities to identify the biases of different analyses and to explicate and share these varying interpretations. This work would also include interface work in

making it possible to develop and link the vocabularies, tie these to the analyses of data descriptions, and explore how the data would be interpreted based on alternate communities' approaches.

This latter is important as contexts will also be critical in providing social machines with the ability to manage simultaneous, but conflicting, views of data. It is the capability for different scientists to interpret the same data in different ways that provides for the argumentation and testing so crucial to scientific discourse. As an example, consider the current debates over the effects of climate change. The same set of meteorological findings being viewed by most scientists as evidence that human activity is accounting for the major changes is being used by other scientists to claim that alternate factors are responsible and thus different mitigation is needed. Each side makes its case against information systems containing the results of different simulations, datasets, and analyses. Mechanisms that allow different communities such as these to simultaneously have their own interpretations of data resources, and also to understand the interpretations of others, will be a powerful enabler to the social interface of the future Web.

3. Information access and control

Dealing with information access and control for social machines also presents challenges for AI researchers. The development of social machines requires the development of mechanisms that allow users of social machines to more freely share data without having to worry about it being used in inappropriate ways. Well-known access control policy frameworks and traditional cryptographic security research have failed to meet the policy challenges in today's online environments and will be insufficient as foundations for the social machines that we envision for the future. The need and urgency for a new approach is clear. Recent work on formal models for privacy [1] demonstrates that traditional cryptographic approaches to privacy protection fail in many open Web environments. Similar problems with copyright enforcement also hamper the flow of a wide variety of commercial and scholarly information on the Web [19,17]. Continued failure to develop scalable models for handling policy will seriously impede the ability of the Web to become the best medium for the exchange of cultural, scientific and political information, or for it to be used in a trustworthy way by distributed communities of concerned individuals.

The provenance of information is very important in determining what data is trustworthy. On the Web, the availability of vast amounts of information of varying quality, coming from multiple sources, integrated through both automated and human-in-the-loop mechanism, requires that users must become able to understand the sources of the "facts" that they collect, and to determine how the consequences that are derived from the integrated data actually depend on those facts. There is currently considerable work exploring how provenance can be tracked in online systems, especially with respect to the workflows used in eScience systems.⁴ On the Semantic Web, work has shown that systems that construct useful derivations can be built to preserve information about the provenance of their sources and about how the results are constructed from those sources and that such information can also be used to provide coherent explanations of results, citing the sources and the rules by which the source material was combined [15,9].

An approach that has proved useful on the Web, and on which we believe many social machines must come to be based, is that of *information accountability* [20]. To understand the role of accountable systems in the design of social machines, consider the simple example of "robots.txt," the files used to control the access of crawlers on Web sites (<http://www.robotstxt.org/>). A simple standard, that the file will have a particular format and be placed in a particular file on the server, allows a "polite" crawler to avoid pages that it is requested not to crawl. As the Web grew, and crawlers became more common, including those that crawled for email addresses for spammers and other less-desirable uses, the robots.txt mechanism maintained its utility by being coupled with Web-logging facilities, which provided a mechanism to track which crawlers reached what pages. Discovering a crawler on a page it has been requested not to crawl allowed a user (usually a server administrator) to take action, typically denying that crawler's IP address access to the entire site. Thus, the combination of robots.txt with site logging provides a simple accountability mechanism for rewarding crawlers that behave and removing those that do not.

Unfortunately, the accountability mechanisms on the current Web are currently few and far between. Where they do exist, they are often built into a specific Web application, or require complex auditing mechanisms that are not available to the average user. For example, even in the robots.txt example, most users are not allowed to view the logs that would enable them to tell whether their own pages are being accessed appropriately nor are they typically allowed to alter the robots.txt file (and thus control their own page accesses). Again, more is needed. Provenance information can potentially provide a mechanism for accountability in many cases as explanations of rule-based reasoning can be screened to check that the derivations obtained did not violate acceptable rules for gathering and combining evidence. In addition, we must explore designs that allow social machines to provide declarative policies, that speak to social and legal expectations about information usage, and that provide for the identification of information uses that contravene those policies.⁵

For example, recent work on information accountability has already taken a step toward demonstrating the technical viability and social utility of accountability mechanisms as a means of protecting central information policy values such

⁴ For overviews of this area see [18,6].

⁵ In close coordination with this technical research, we must also develop legal and public policy models that support Information Accountability and investigate the social effect of these new approaches to policy compliance. We discuss this in more detail in [20].

as privacy, fair and reliable use of information, and copyright protection. This has been demonstrated via the creation of computer formalisms that can express realistic data-use policies, and implementing policy-rule-based languages and reasoners that can interpret policies and automatically determine whether particular uses of data are policy-compliant [13]. However, work to date has largely been on small-scale prototypes and work in the area still must tackle the problems of scaling. **We also believe there are exciting AI problems related to developing a more formal understanding of the behavior of these systems, to evaluating the social impact of accountable systems and, of course, to make tools for creating such systems available on the Web.**⁶

4. Conclusion

In this article, we look ahead to a time when it will be possible to create and then evolve new kinds of social machines that will provide people, individually and collectively, with the ability to immerse themselves in the accumulated knowledge and the constant interactions of humankind. People's interactions will be not just as passive recipients of information created by others, but also as contributors to this global information space in a way far beyond that of today's Web. In looking to this future, our focus is not primarily in terms of the cyber-infrastructure of high-speed supercomputers and their networked interconnections, but the even more powerful human interactions enabled by these underlying systems. We hope we have demonstrated that exploring this new generation of social machines can take AI researchers and others into the design of new algorithms and interfaces; into new approaches to distributed inference and query; and into developing declarative social machinery, including policy-aware systems of privacy, trust and accountability. Together, these technologies will allow us to further empower the Web of people by developing a next generation of Web technologies and to move from human in the loop to *humanity in the loop*. To this new challenge we believe we must bring to bear not only the best engineering and theoretical perspectives of current computer science, but also to create new and exciting theory and technology as we forge the path toward our goal.

We have outlined some of the critical challenges and potential technology solutions that we and many others⁷ have been exploring. The distance between today's simple social networks and a world in which humans can be empowered to use these promising technologies may seem so great that bridging the gap is almost unimaginable. But we must remember that twenty years ago the notion of an interlinked Web of documents that spanned the world seemed like an unrealizable dream, and a decade ago the Semantic Web vision seemed like science fiction. Looking ahead, we think the coupling of AI, social computing, and the new technologies we've begun to outline will provide us with the ability to create a generation of systems that will empower humanity in new and transformative ways.

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⁶ For one example, see the RespectMyPrivacy project which provides an approach, and simple tools for creating an information-accountability-based approach to establishing privacy on Facebook and other social networking sites – <http://dig.csail.mit.edu/2009/SocialWebPrivacy/>.

⁷ We admit this article has been biased toward what our laboratories, separately and together, have been doing in this direction. We apologize for not citing a great deal of relevant work from which the ideas in this paper arise and for not providing an overview of other relevant work in this area – we hope you will forgive us as we wished to help focus the vision and provide starting points, rather than to provide a comprehensive technical overview. We review a great deal of other literature in [4] and direct the interested reader there for a more complete bibliography.

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