Web Intelligence: New Frontiers of Exploration

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***Abstract*— Web Intelligence (WI) deals with the scientific exploration of the new territories of the Web. As a new field of computer science, it combines artificial intelligence and advanced information technology in the context of the Web, and goes beyond each of them. From several perspectives of the Web, we investigate the scope, goals, challenges, and future development of WI. Intelligent web information systems can be designed and implemented to explore the structures of the Web, and data, information, and knowledge on the Web and to provide efficient and effective communication, collaboration, information and resources sharing, and better services. As an example to illustrate the basic ideas, web-based support systems are discussed.**

I. Introduction

In the very short history of the Web, we have witnessed its fast growth speed and huge technological, social impacts [2], [15], [36]. Many web-related theories, technologies, and tools have been proposed and extensively studied. Classical theories and methods have been applied to analyze and study the phenomenon of the Web. The introduction of Web Intelligence (WI), as a new field of computer science, and the establishment of Web Intelligence Consortium (WIC) make a further contribution to the growth of the Web [37], [50].

Web intelligence deals with systematic studies of advanced web related theories, methodologies, technologies, and tools, as well as the design and implementation of Intelligent Web Information Systems (IWIS) [43]. It explores the fundamental roles as well as practical impacts of Artificial Intelligence (AI) and advanced Information Technology (IT) on the next generation of web-empowered products, systems, services, and activities [19], [20], [21], [23], [44], [45], [46], [47], [48], [49], [50], [51]. Web intelligence is the key and the most urgent research field of IT in the era of web and agent intelligence. A practical goal of WI research is the design and implementation of Intelligent Web Information Systems [43].

The Web exposes us to fascinating and uncharted new territories. The Web is a growing organism [28] and is far from being well-developed or "done" [2]. The scientific exploration of the Web, leading by web intelligence, would bring us to new horizons. On the one hand, results, lessons, and experiences from existing disciplines can be applied to the study of the Web. On the other hand, the Web may also introduce new problems and challenges to the established disciplines [43]. The Web provides the necessary infrastructure and a platform for intelligent systems, and new generalizations of intelligent systems raise new requirements and motivate the further growth of the Web. The co-evolution of intelligent systems and the Web will one day bear surprising fruits [42].

The dream of web intelligence is the Wisdom Web [19], [20], [21], [23], [48]. The new generations of the Web will enable us to gain information from data, knowledge from information, wisdom from knowledge, and life from living, as being desired by many people [1], [10], [33]. In realizing this dream, there may be more questions than answers, more problems than solutions, more unknowns and uncertainty. The success of the Web so far inspires us to pursue this dream. We can explore the Web one step at a time, and build the Wisdom Web piece by piece.

In this paper, we present some scattered, and perhaps immature, ideas and issues related to the exploration at the new frontiers of the Web. In Section II, the Web is examined from different perspectives. In Section III, a few observations and issues of web intelligence research are discussed. Finally, in Section IV, Web-based Support Systems (WSS) are used as an example to illustrate the basic ideas and arguments presented in the previous sections.

II. Perspectives of the Web

The Web emerges as both a technical and a social phenomenon [2], and grows into a huge and complex organism [28]. It affects almost every business, everyone's life and has far-reaching social implications. It is difficult to address every perspective, if not impossible. In this section, we cover only the ones pertinent to web intelligence and intelligence web information systems. They are more to do with the intelligence related and technical aspects of the Web.

Many important issues are not covered, but need to be seriously mentioned, such as security, trust, ethic, law, intellectual property, and social responsibility [2].

A. The computer science perspective: infrastructure and intelligent systems

For a computer scientist, some of the main tasks related to the Web are: to study its theoretical foundations, to establish its technical foundations, to build physical infrastructures and to develop software systems that support the Web, and to develop various applications that fully realize the potentials of the Web in many different domains. Research efforts can be broadly summarized into three categories: theoretical studies or the logical view of the Web, implementations or the physical view of the Web, and the application view of the Web.

Some of the major technology developments and their implications for the growth of the Web, as well as web applications, are summarized below [2], [3], [15], [24], [36].

Web of Machines. A prerequisite of the Web is massive connected computer networks, which form its backbone. Computer network and distributed computing had been studied before the explicit introduction of the Web. Computer networks support a number of activities of communication and information sharing, ranging from email, on-line talk, news groups, and many more. The limited functionality, as well as the high cost of computer hardware, makes a web of only machines difficult to use in many domains.

Web of Pages (Websites). Based on the notion of hypertext, the Web brings the computer networks closer the real life. At the early stage of the Web, a web page is basically a document written in terms of a hypertext mark up language (HTML). A web site consists of a set of static web pages stored as files. The links in the web pages create explicit connections between web pages, and thus produce a web of pages. Once implemented on computer networks, it is possible to access information anywhere in the world.

The massive use and growth of the Web are brought by, to a large extent, three types of systems, namely, web browser, web page composer or editor, and web search engines. Web browsers, especially the ones using graphic user interfaces, increase the accessibility of the Web for ordinary people. Web page composers make it a relative easy task to write a web page, and thus help the Web to grow faster. With web searching engines, one can quickly and easily find the required information on the Web.

Web of Dynamic/Adaptive Pages (Websites). With more business moving to the Web and more people using the Web, the static web pages no longer meet all the desired requirements. This leads to the introduction of dynamics, adaptation, interaction and personalization into the Web. Many methods, techniques, tools, and languages have been emerged for the production of dynamic, interactive, and personalized web pages, as well as adaptive websites.

Web of Agents. The application of intelligent agents further increases the power of the Web. Search agents can be used to find useful information. A web site agent can promote the site by helping a visitor. Web agents can communicate and collaborate with other agents to solve a complicated problem, such as automatic purchasing.

The theory of autonomy oriented computing [22] may be used to provide a model of the Web. A web page or site may be viewed as an autonomy entity, this allows more functionality of a page, as well as additional connections and interactions between different pages and sites.

Web of Services. Electronic commerce on the Web need many types of web services. In contrast to the human centered activities, web services allow applications to communicate with applications. This will relieve users from a lot of tedious routine work when conducting business on the Web. If combined with web agents and autonomy oriented computing, the connectivity and power of the Web will be greatly enhanced.

Web of Resources. Machines in computer networks, pages, agents, and services on the Web may all be regarded to as web resources. The Web therefore provides a means for resources sharing through its universal connectivity and scalability. In this aspect, the recently developed Grid theory and technology can be combined into the Web [9].

In summary, similar to the development of any other branch of computer science, the Web went through conceptual formulation, physical implementation, and real world applications. Early generations of the Web deal with well-defined problems, new generations of the Web deal with more complex problem. Systems that support the Web and systems that make use of the Web become more intelligent and complex, as well as diversified.

B. The information science and knowledge management perspectives: data, information, knowledge, wisdom hierarchy

Data, information, knowledge and wisdom hierarchy is a well studied notion in both information science and knowledge management [1], [33]. The hierarchy represents increasing levels of complexity that require increasing levels of understanding. The generations of intelligent information systems are determined by the hierarchy.

The evolution of the Web, a huge intelligent organism, may be described using the data, information, knowledge, and wisdom hierarchy. This can be done by considering both the contents stored on the Web and the functionality of the Web. Thus, we may have a hierarchy consisting of:

Web of Data,
Web of Information,
Web of Knowledge,
Web of Wisdom.

Generations of the Web so far deal with mainly data and information, and knowledge to a certain degree. New generations of the Web need to focus on the knowledge and wisdom levels.

Two important research initiatives need to be reviewed. They are the Semantic Web [4], [32] and the Wisdom Web [19], [20], [21], [23], [48].

According to Berners-Lee *et al.* [4]:

> "The Semantic Web is not a separate Web but an extension of the current one, in which information is given well-defined meaning, better enabling computers and people to work in cooperation."
>
> "The Semantic Web will bring structure to the meaningful content of Web pages, creating an environment where software agents roaming from page to page can readily carry out sophisticated tasks for users."

The Semantic Web has a more specific goal. It deals with the issue of machine understandable meaning of, in contrast to the form of, web documents. One of the immediately benefits of Semantic Web is that it provides support to web agents and web services through machine understandable web documents. This represents an important step, enabling us to move from the Web of data to the Web of information, to the Web of knowledge, and eventually to the Web of wisdom.

According to Liu *et al.* [23]:

> "The next paradigm shift in WWW will lie in the keyword of *wisdom*. The new generation of WWW will enable users to gain new *wisdom* of living, working, playing, and learning, in addition to *information* search and *knowledge* queries."

The Wisdom Web attempts to layout the ultimate dream of the intelligent Web. It focuses more on the knowledge level and intelligent web systems for real world, complex problem solving.

The Wisdom Web covers a wide spectrum of issues. Some of them may not be easily solved in the near future. We need to answer a fundamental question: "Where is the wisdom we have lost in knowledge?" [10]. The broad view given by the Wisdom Web will inspire enthusiastic research on the future generation Web.

C. The social intelligence perspectives: connectivity, social network intelligence

As pointed out by Berners-Lee, "the Web is more a social creation than a technical one" [2]. It provides a means for people to collaborate and interact better. The Web facilitates the formation of emergent intelligence and intelligent social networks [2], [22].

Web-based community and society may be formed either explicitly or implicitly through associations. Explicit associations are given by memberships, such as mail lists, special interest groups, and registered members. Implicit associations can be derived from co-occurrence in web documents or click stream patterns. They may be discovered by using web mining tools. Such associations create the social networks.

The connectivity of the Web leads to the connectivity of people, which is an essential component of a weblike and virtual digital society. It is necessary to analyze the social network intelligence, in order to better support interaction and collaboration.

D. Application perspectives: electronic commerce

The applications of the Web are too many to list. An important point is that applications evolves with the Web. In many cases, new applications give the birth to new methods and tools that enhance the power of the Web.

Electronic commerce is one of the successful applications. Its evolution is shown by the Moore's E-commerce escalator [26]:

Website for corporate information,
Website for product/service information,
Customer support via the Web,
Credit card order processing,
Web access to order information,
Purchase order processing,
Web-based marketplaces.

Clearly, it starts as an information provider with one-way communication, and moves to a service provider with two-way interactive communication.

III. Web Intelligence Exploration

Web intelligence further explores the transformation of knowledge from information, and wisdom from knowledge, in its search of the Wisdom Web [48]. Some of the important issues, although may not be well-conceived yet, are briefly discussed in this section.

A. A new field of science, technology and engineering

The Web, as a new technical and social phenomenon and a growing organism, creates a new field of science that involves a multi-disciplinary study and enquiry for the understanding of the Web and its relationships to us.

The Web may be studied from many perspectives, such as philosophical foundations, theoretical and technical foundations, applications, and social impacts. Some examples are given below:

Webology,
Web Science,
Web Technology,
Web Engineering.
Weblization.

The term, webology, is coined to label the study of the Web as a new field of science [13], [28]. By post-fixing the phrase, science and technology, one clearly states the scope. By post-fixing the phrase, engineering, one emphasizes the design and implementation aspects. Together, they are driving forces for information revolution. The term, weblization, concisely summarizes the development of the Web and web based systems so far. The process of weblization involves building the Web itself and reconstructing existing tools and systems on the web platform.

B. Design philosophy and principles of the Web

The design philosophy and principles set the direction of web growth and its ultimate destiny. It may be difficult to compile a non-controversial and complete list. However, examples include [2]:

Decentralization principle.
Universalist principles,
Minimum constraint principle,
Separation of form and content principle,

The decentralization principle is inherited from the decentralization property of the Internet. The universalist principles cover universal connectivity, universal accessibility, as well as diversity of web contents and users. The minimum constraint principle suggests that the Web should be as unconstraining as possible to realize its universality. The separation principle deal with the presentation of web documents, in order to achieve location, machine, and application independence.

The design principles ensure that the Web has the desirable properties, such as decentralization, adaptability, evolvability, scalability, universal connectivity and accessibility, affordability, anonymity, diversity, and many others. The Web is able to support communication, collaboration, interaction, and intercreation.

C. The laws of the Web

Two sets of laws have been studied, namely, the set of laws governing the Web and the set of empirical laws observable on the Web.

The Web has given new meaning to publishing and library, but not their underlying principles. Noruzi argued that Ranganathan's Five Laws of Library Science is well applicable today as it was more than 70 years ago [27]. Ranganathan's Five Laws of Library Science state [31]:

1. Books are for use.
2. Every reader his or her book.
3. Every book its reader.
4. Save the time of the reader.
5. The Library is a growing organism.

These laws describe a user-oriented, as well as a service-oriented, view of library science. The Web consists of a massive collection of resources. By replacing "book", "reader", and "library" with "web resource", "user", and "web", respectively, Noruzi stated Five Laws of the Web [27]:

1. Web resources are for use.
2. Every user his or her web resource.
3. Every web resource its user.
4. Save the time of the user.
5. The Web is a growing organism.

They concisely represent the underlying philosophy of the Web and web services [27]. They also describe the ideal Web – "of the people, by the people, for the people".

Many researchers studied empirical laws revealed by the Web, either its growth, web page distributions, or user surfing patterns. An example set of such laws is reported by Huberman [16], [17]:

1. Power Law of Distribution.
2. Small World Law.
3. Law of Surfing.
4. Law of Congestion.
5. The Free Ride Law
6. The Law of Downloading.

Website designers, webmasters, and organizations can apply such laws for the design of better website and web resources.

D. The Web revolution: one link at a time

The story of the invention of the Web and the revolution brought by the Web [2] provides a good case study for web intelligence. It poses a challenge: how to derive insights and wisdom from the existing data, information, and knowledge.

Regarding the pre-web uses of hypertext links, Berners-Lee commented [2],

> "The research community had used the links between paper documents for ages: Tables of contents, indexes, bibliographies, and reference sections are hypertext links."

A crucial question is what we can get from this common knowledge and practice. Two types of approaches have been proposed and studied. One focuses on the exploration of the potential implications of such knowledge, which leads to the creation of a field of science known as citation indexing and analysis [11], [12], [13]. The other focuses on the representation, storage, and access of the similar types of data and knowledge using new media as they become available, which leads to the invention of the Web [2].

A basic idea of citation indexing and analysis is to index and study the literature of science based on how scientists cite each other [11], [12]. Although it mainly uses bibliographies, citation indexing and analysis brings more insights into science, publishing, scientific research, and many more fields. Information retrieval systems, based on citation indexing and analysis, have been implemented and used by scientists for many years [12], [34], [39]. The same methods have been applied or rediscovered in many recent studies, such as web search engines, social network analysis, and so on.

A basic idea of the Web is to create a global space in which anything can be linked to anything [2]. The development of the Web emphasizes the implementation of this idea using different type machines and media. The Web attempts to make the existing associations and links, that people had used either explicitly or implicitly, concrete and computer manageable. The similar concepts had been explored in pre-web age [2], [3], [36]. Vnnevar Bush described a photo-electro-mechanical machine called the Memex that can make and follow cross-references among microfilm documents. Ted Nelson introduced the concept of hypertext, so that people can use computers to read, write and publish non-linear texts. Doug Engelbart demonstrated a collaborative work space called NLS which does hypertext browsing editing, email, and so on. Thanks to the timely invention of the Internet for providing global connectivity, the dream of the Web became a reality. The revolution of the Web is brought by grassroots effort that builds the Web link by link.

There are recent research efforts in cross-applications of the two types of approaches. The methods developed for citation indexing and analysis are used and extended to analyze the links and conductivity of the Web [5], [6], [29]. Existing systems for citation indexing and analysis are moved to, and new such systems are impregnated on, the Web [7], [8], [34], [39].

The above brief description, which is almost common knowledge, is repeated here to serve one special purpose. It demonstrates that the great minds of our time bring revolutions by analyzing what everyone has already known or by implementing, alternatively, what everyone has already used. The question is: Can web intelligence help in the future?

E. The more things change, the more they stay the same

Now, we turn our attention to the other side of the same coin by investigating the things that the resolutions do not change.

In spite of the technological changes, achievements of the current Web and associated systems lie in the process of weblization. The weblization of a specific field or an organization does not change its fundamental principles, although it may become more effective and efficient, as well as being

at different level of scale. For example, electronic commence does not change the principles of doing business, but does introduce more dynamics, opportunities, flexibility, and other new properties. Another example is the Five Laws of the Web: the subject matters are changed, but the philosophy remains to be the same. Both paper documents and the Web use links. The physical implementations are different, one on paper and the other on computer, but the logical meanings stay more or less the same. The same analytical tools and methods apply to both.

The property of "unchangeness" makes it possible to apply the same principles again and again, with possible adaptation and adjustment. The philosophy and principles that have been proved to be effective in past can be applied to design and implement intelligent web information systems. Some illustrative examples are listed here:

Separation of logical view and physical view.
Separation of knowledge and inference engine.
Keep It Simple, Stupid!

The first two separation principles are along the same line as the separation of content and form principle. The first one is widely used in the design and implementation of database systems. Its application to the Web implies that one can generate many virtual logical views from the same physical web. The second principle is a fundamental one in expert systems. It is applicable to the design of web inference engines. The last rule, also known as the KISS principle, is universally applicable [30]. It has been applied throughout the design of the Web [2].

In discussing the philosophy of Unix, Raymond summaries it into a list of 17 basic rules [30]. This prompts a more concrete challenge to researchers in web intelligence: Can we design a search and inference engine that will search the literature on the Web and produce a similar list of rule for a given field?

IV. Web-based Support Systems

Web-based support systems (WSS) concerns multidisciplinary investigations which combine computer technologies, the Web, and domain specific studies [38]. Domain specific studies focus on the investigation of activities in a particular field. Computer technologies are used to build systems that support these activities. The Web provides the platform for such systems.

There are two important features of WSS. They can be understood as extensions of existing research in two dimensions. In the application dimension, WSS cover support systems in many different domains. They can be viewed as natural extensions of decision support systems (DSS) [35]. In the technology dimension, WSS use the Web as a new platform for the delivery of support. Along the application dimension, the lessons and experiences from DSS can be easily applied to other domains. Along the technology dimension, the new advances in technology can lead to further innovations in support systems.

The two-dimensional view of WSS provides an easy classification. Schematically, suppose $\mathcal{A}$ is a specific domain, a computerized support system for domain $\mathcal{A}$ can be termed as an $\mathcal{A}$ support system. The use of the Web results in Web-based $\mathcal{A}$ support systems. Based on such a scheme, we can identified many classes of WSS: web-based decision support systems, web-based business support systems, web-based information retrieval support systems, web-based research support systems, and many more [38].

For a better understanding of WSS, we briefly describe Web-based Research Support Systems (WRSS) [40], [41]. Typically, research may be modeled as a process consisting of the phases [14], [18], [25]:

Idea-generating phase.
Problem-definition phase.
Procedure-design/planning phase.
Observation/experimentation phase.
Results-interpretation phase.
Communication phase.

In order to assist a scientist, we need to provide the following support:

Exploring support.
Retrieval support.
Reading support.
Analyzing support.
Writing support.

Existing systems can be extended and integrated on the platform of the Web to provide better research support. New systems can also be added.

The study of web-based support systems is an important area of web intelligence. The implementation of such systems will help us to materialize more potential power of the Web.

V. Conclusion

In this paper, we have made an attempt to contribute to the field known as Web Intelligence (WI). It is not intended to be a complete and systematic study of the field, but rather a record of personal observations, scattered (perhaps immature) ideas, general comments, speculations, and opinions. We hope that a careful study of these not yet well-connected points may lead to a web of knowledge for web intelligence.

From several perspectives, we examined the Web. This enables us to see clearly the current status, the scope, and the future of web intelligence research. Web intelligence exploration of the Web was then commented from a few angles. A couple of challenges were posed. Finally, Web-based Support Systems (WSS) were used to demonstrate the ideas presented, which may further enhance the Web as a tool – "of the people, by the people, for the people".

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