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In the Search of Web of Intelligence

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***Abstract*—From the very early days, and due to its unprecedented opportunities and advantageous facilities, the Web has been revolutionizing almost every aspects of human life, technology, etc. As a dynamic phenomenon, the Web itself has experienced several major evolution stages. Such fundamental changes never thought to abolish predecessor technologies and concepts but taking them to a new level of functionality. In fact, these paradigm shifts are necessary and inevitable in order to take advantages of state of the art technologies and approaches. In this regard, social Web, semantic Web and similar nomenclatures aimed to emphasize the key idea that best represents the latest achievements and possibly future directions. Thanks to many years of research and development, the current state (version) of the Web puts forward some outstanding opportunities both to make the most of available resources/capabilities and establish the foundation of the future Web. Specifically, convergence of human intelligence (of Web users), machine intelligence (of Web agents) and intelligence of things (through Web of Things) toward shaping Web of Intelligence (WoI) can be regarded as a breakthrough in the field. The major contribution of this work is proposing a Web-based conceptual model for intelligence harvesting (i.e. Web of Intelligence) through which humans, machines and things could collaborate to solve large scale intelligence-intensive problems in a more efficient and effective way. The rationale behind this idea, its building blocks and related considerations are delineated in this paper. Moreover, a novel application based on the proposed concept, entitled comprehensive intelligent search, is introduced.**

Keywords—Human Intelligence; Web Intelligence; Web of Intelligence; Distributed Computing; Web of Things; Search Engines

I. INTRODUCTION

Undoubtedly, the Web is one of the most important and influential inventions of the computer era. Besides providing numerous benefits and facilities for a very broad range of application domains; it has almost affected every little parts of human life [1-3]. In order to comply with technological advancements and forthcoming requirements, the Web itself has been subject of several evolution stages [4-7]. Nonetheless, such an evolution never thought to be an extinction race but an indispensable improvement process. Taking a closer look at the transition from early Web of documents to (i.e. Web 1.0) to social [8] and semantic [9] versions of the Web represents a progressive enhancement and empowerment of infrastructures, services, applications and even users. Among various notable aspects of the current Web, its fertile ground for harvesting distributed and collective intelligence is somehow less-attentioned in the literature. In fact, any attempt toward convergence of human intelligence of Web users, machine intelligence originated from Web agents and intelligence of connected things that is viable through the Web of Things (WoT) [10] could lead to an unprecedented level of intelligence and computing capabilities. In other words, teaming up humans, machines and things in the context of the Web could result in a breakthrough in the field by shaping the Web of Intelligence. Aimed at elaborating of this idea and inspecting its different aspects, the major contributions of this research study are:

- Uncovering potentiality of the Web for intelligence harvesting
- Proposing a conceptual architecture for organizing Web of Intelligence
- Introducing a novel application, namely comprehensive intelligent search, based on the concept of WoI

To the best of the authors' knowledge, this the first study in which the Web is considered as a synergistic platform for flourishing collective heterogeneous intelligence. Therefore, it is anticipated that the present study could be served as a source of inspiration for future works in the field. The rest of the paper is organized as follows. The background and motivation of the presented work are discussed in section 2. The underlying concepts and building blocks of the WoI are delineated in section 3. Then, the nuts and bolts of the redefined Web of Intelligence as well as an example scenario are introduced in section 4 and 5, respectively.

II. BACKGROUND AND MOTIVATIO

From a webological point of view, the evolution and implications of the Web have been subject of many studies over the years. Specifically, one can find a remarkable number of research papers on studying evolution of the Web [4-7, 11,12] and anticipating its future [13-15]. In this context, the fever of introducing new extension to the Web in the form of coining brand new terms and/or versioning have gained many attentions, such as works done in [16-18].

Nonetheless, perhaps the classification presented in [13] is the most appropriate and reasonable one for the sake of overviewing the Web from the past to the future (Fig.1). On the other side, flourishing the concept of Web of Things [10, 19] takes the Web to a new level of functionality through providing interface to connected ubiquitous things (i.e. Internet of Things (IoT)). Following this blessing integration, introduction of Social Web of Things [20], Web of Things Search Engines [21] and so on have opened new windows on taking benefits of the Web as a powerful and highly flexible

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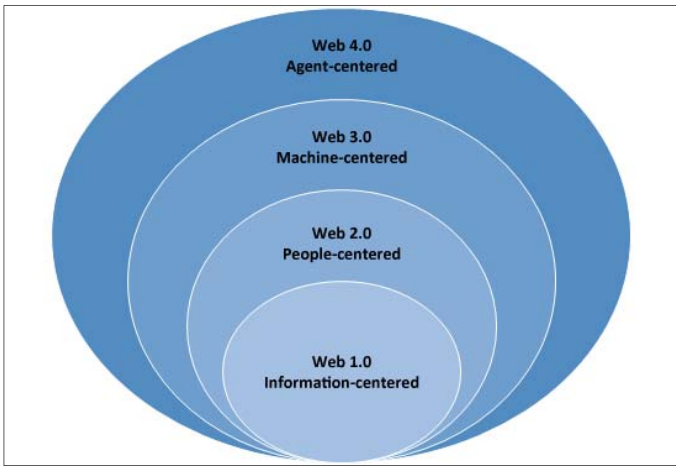

Fig.1. Classification of the Web evolution [13]

platform. From another point of view, the World Wide Web could be considered as a fertile distributed computing platform. Browser-based [22] and volunteer computing [23] concepts are only two examples of how Web users and their resources may be employed to efficiently handle large scale computing tasks and problems [24, 25].

For performing intelligent computing processes of various scales, there are some essential prerequisites including communication infrastructures, computational resources, human (intellectual) intervention as well as high-capacity machine processing capability. However, a decade ago or two having these building blocks to together was a untouchable dream; thanks to the recent advancements the current Web provides an all-in-one platform ready for conducting a broad range of computational projects.

As a matter of fact, high-speed (world-wide) connections, cloud-based computing environments and Web services, powerful personal computers and highly capable smart devices, advanced machine learning algorithms and augmented Artificial Intelligence (AI) that accompanied with humans' intelligence and problem solving ability constructed an unprecedented comprehensive computing paradise. Accordingly, in order to best describe the today's Web - in the light of synergy among humans, machines and things - it could be referred to as Web of Intelligence. With the aim of investigating this reciprocal relationship, its benefits and implication, a conceptual architecture and a novel application area will be presented in this paper.

III. UNDERLYING CONCEPTS

As mentioned earlier, the Web of intelligence can be founded on intelligence of humans, machines and things. Therefore, prior to delve into nuts and bolts of WoI, the building blocks are introduced in this section.

A. Human Intelligence

For years, humans were considered as merely passive Web users or in other words consumers of the Web brought to them. The one-way road of the Web, of course, turned into a two-way highway by introduction of Web 2.0 [4]. Such a paradigm shift, by emphasizing on humans' capability for being information producers – rather than only consumers- as well as facilitating their relationships through social media [8] changed the Web into an active, collaborative and even competitive environment. Flourishing of the user-generated information, content and intelligence in the form of wikis [26] and folksonomies [27], etc. – the phenomena before the Web 2.0 were rarely seen- could be considered as significant effects of involving humans into the intelligence-intensive processes. Besides unprecedented impacts of the Web 2.0, the crowdsourcing concept [28, 29] has been revolutionized humans' role and position as intelligent agents that could outperform machines in some real world application scenarios. Specifically, leveraging humans' intelligence, cognitive and problem solving abilities for dealing with issues in which machines are not as powerful and accurate as them directed much attention toward this new working strategy. In this regard, similar complementary concepts such as human computation [30], crowd computing [31] and so on have been proposed and employed. In order to organize such an endless ocean of people around the Web who could participate in computing and intelligence-intensive workflows, crowdsourcing platforms (such as Mechanical Turk, Crowdflower and TurkPrime [32]) have been established. Aiming at outsourcing different types of tasks to the crowd, such intelligence markets gained a remarkable acceptance both from contributors (workers) and requesters [33, 34]. On the other side, huge participation in social networks and collaborative/competitive platforms, e.g. online games and forums that should be referred to as intelligence farms, made them fertile grounds for discovering hidden, latent intelligence [35,36]. Putting them all together, the Web has become an efficient platform for intelligence harvesting. However, there is a long unpaved way to take full benefits of this land of opportunities. For example, asking those intelligent workers to share their computing and processing resources – in the form of distributed and volunteer computing- can drastically enhance efficiency and performance of the collective Web-based participations.

B. Web Intelligence

The notion of Web intelligence was introduced about two decades ago with the aim of leveraging artificial intelligence and advanced information processing techniques for improving next generation of Web-based services, applications, etc [37, 38]. As a matter of fact, it is thought that AI could be considered as an enabling technology (catalyst) to facilitate creation of new e-products, dissemination of e-services and so on [37]. Over the years, a remarkable number of research studies conducted around the topic in a wide variety of application domains [39-41]. With outstanding achievements in machine learning and related fields, the Web - as an intelligent super agent – has been empowered so that provides users with more accurate and usable services (e.g. recommendation) than ever before [37]. Further, regarding the advancement of semantic technologies [42], intelligent Web agents could bring users with more humanized and natural responses. State of the art Web personalization [37] and semantic search [43] are of practical realization of Web intelligence. Nonetheless, such level of functionality is not the stop point and there are some anticipated goals ahead. Building machines (i.e. intelligent Web agents) with human-level capabilities for more efficient interaction and problem solving – intelligent expert systems and question answering engines, for example – is of such ambitions goals. On the other side, the Web itself has sufficient requirements (e.g. communication infrastructure, distributed computing resources, etc.) to host collective machine intelligence. Although the human-level intelligence may not be viable – at

least in this time- convergence of machines' intelligent power and capabilities is an applicable strategy to take the non-human intelligence to a new level. As the concluding note, the Web intelligence in its ideal state could also be described as collective intelligence of artificial agents that is cultivated, integrated and leveraged in the Web environment.

C. *Intelligence of Things*

Taking the broad definition of the intelligence, not only it does not merely devote to humans and machines (intelligent artificial agents) but seemingly passive entities, including devices, sensors, etc. can possess it in some way. When it comes to billions of connected things around that equipped with some types of (communication, computing and similar) capabilities; being intelligent becomes a determining and game changer feature. The idea of leveraging intelligence of things has been considered in different forms such as ubiquitous intelligence [44]. The major goal in this regard is to take benefits of everywhere present things in order to capture case- and context-specific intelligence ranging from environmental information [45] and insights to location-based [46] and even personal (life-related) [47] knowledge. Regardless of how intelligence are these things and what type of intelligence they may present, taking advantages of intelligence of things can minimize intrinsic distance of physical and virtual worlds and lead to construction of comprehensive intelligence. The fast pace development and prevalence of Internet of Things [48], smart homes [49] and cities [50] emphasize the significant role of intelligence of things in the near future. Further, more the things become powerful and capable, more their impacts become important and non-negligible. As a ground breaking technology to fill the gap between physical world of connected things and cyber space, the Web of Things [10] comes into the scene. It is essentially intended to make virtual representation of real world things accessible through the Web [10]. Thanks to its potentialities, nowadays it is possible to establish connection among various types of intelligence and plan to converge them into a uniform, multifaceted and super capable phenomenon.

IV. WEB OF INTELLIGENCE EXPLAINED

The intended goal of this paper is neither to coin yet another term nor introduce a new extension to the current Web. In fact, although the term Web of Intelligence has been used earlier in the literature for pointing out different concepts, the authors aimed to redefine it so as to draw attention toward taking advantages of numerous invaluable benefits it can put forward. In this regard, WoI – according to the authors' definition- is a perspective for hybrid and comprehensive utilization of knowledge and intelligence originated from physical and cyber spaces – simply the best of the two worlds – to fill several gaps at once:

- Establishing bilateral connection between virtual and physical worlds (e.g. entities and resources)
- Facilitating access to (human-, machine- and things-generated) knowledge and intelligence through the Web as well as sharing and fusioning such information
- Extending applications and functionality of IoT-based cyber-physical systems
- Providing multidimensional, multifaceted and comprehensive insights and intelligence
- Eliminating the border between real and virtual worlds for developing next generation of mash up systems
- Providing engines for synchronized, integrated and inter-related searching of information and physical entities
- Conducting intelligent interdisciplinary computing processes by involving humans' (brain) power and smart things in the form of brand new distributed computing concepts
- Shaping a hybrid market for human-specific abilities (services), computing power and physical awareness and resources in the form of intelligence as a service (IaaS) and computing as a service (CaaS)

In the context of WoI, the participants, namely humans, machines and things, based on their very intrinsic features present type-specific intelligence. Humans, due to their natural wisdom, problem solving abilities and creativity, are in charge of providing genuine and reasoning intelligence to deal with innovation-intensive and (mostly) cognitive issues. Crowdsourcing platforms are the most fertile grounds to cultivate (tame) such intelligence and make them accessible.

On the other side, computational intelligence of machines (e.g. algorithms, Web agents, super computers, etc.) is useful when it comes to deal with processing multidimensional data, large scale and real-time computational processes and similar common scenarios. Despite their intrinsic weakness in some (human-specific) areas, being combined and converged together in the form collective machines intelligence [51] that comes in handy for (super) fast and inclusive analysis based on the standard patterns and algorithms. The Web, by the way, provides adequate resources and facilities for flourishing collective intelligence and collaboration of artificial agents.

As an unprecedented type of intelligence, nowadays, connected things can bring out context-specific intelligence, such as location-based ones. This capability may be considered from two different points of view. Regarding things as passive entities; they – at least- as simple sensors could provide environment awareness, i.e. limited contextual intelligence. On the other hand, those things which are smart devices with some type of computational capabilities can process and analyze information to produce context-aware knowledge.

Following the idea of hybrid intelligence [52] through which synergy of human and machine(s) could lead to higher levels of functionality and performance, it would be possible to put things in the loop in similar collaborative processes (Fig.2). Clearly, any cooperation and intelligence sharing between humans and things or machines and things may result in enhanced multidimensional intelligence. Location-based crowdsourcing within a smart city in which smart things provide some types of feedback to the intelligent crowdworkers and collective machine intelligence-driven distributed computing that fed by sensory information fusion provided by connected things are two real world scenarios of leveraging the things-oriented hybrid intelligence. Putting all these various types of intelligence together in the context of

the Web is a practical step toward organizing comprehensive, multifaceted Web of Intelligence (Fig. 3).

V. EXAMPLE SCENARIO

With the aims of 1) introduction of an exemplary application based on WoI, and 2) exploring its conceptual architecture and workflow, an imaginary (but working) scenario (system) is presented in this section.

The proposed system is the comprehensive intelligent search engine that provides users (Web searchers) with accurate, cyber-physical and human-level results.

As some backgrounds it could be noted that according to the concepts introduced in the previous sections, there are three types of search engines. The traditional search engines which (mostly) grew on the shoulders of machines. In this category, the crawling, query interpretation, answers' matching and evaluation all performed by means of machine intelligence. For the sake of improving accuracy of results – e.g. for complex search terms – the idea of crowd-powered search engines [53, 54] has recently been introduced. The rationale behind developing such search engines is to leverage humans' cognitive and language processing intelligence for interpretation of submitted queries in a human-driven way. However, such a human-involved process sacrifices real-time response generation for obtaining more accurate and related results; it could meet users' satisfaction criterion [55]. When it comes to look for things, sensors or a particular functionality they may present, Web of Things Search Engines (WoTSEs) are the silver bullet [21]. The comprehensive intelligent search is aimed to combine these facilities into a feature-rich search engine by which 1) the query interpretation and relevance evaluation of results take advantages of intelligent humans' participation, 2) a unified and integrated result list from major Web search engines will be populated, and 3) related physical information – including location intelligence and contextual knowledge – will be brought to the user. As an example of how such a system works, a given workflow is presented as follows (Fig. 4).

A user – with inadequate search skills and domain knowledge- who wants to find a solution/advice for his symptom/disease issues a query with some description on what he is looking for. As the first step, the query and supplementary descriptions will be sent to the intelligent crowdworkers. Then, several keywords- to reflect the user's intention- will be nominated by the participants. The "N" most frequent keywords are the potential candidates for the next step, namely leveraging advanced Web search algorithms of major search engines (that also support local search). In this regard, the acquired results (i.e. top "M" results from each search engine) will be post-processed (by removing duplicates, integrating, etc.) and sent back to the crowdworkers for the final evaluation. For the result items that contain address/location or any inter-relation with the physical world, the related information from Web of Things search engines are retrieved.

For example – and in the context of a smart city and/or existing sensory information- the most appropriate path to a medical center/pharmacy with sufficient facilities for caring/consulting the user must be selected. The appropriateness here – according to the perceived condition of the user- may refer to proximity (a nearby place, for example) and quickest (with light traffic) or healthiest (lowest level of pollution that may threaten the user) path(s), etc. Totally, the user (Web searcher) provided by a hybrid search engine results page (SERP) that guarantees to best matches the issued query.

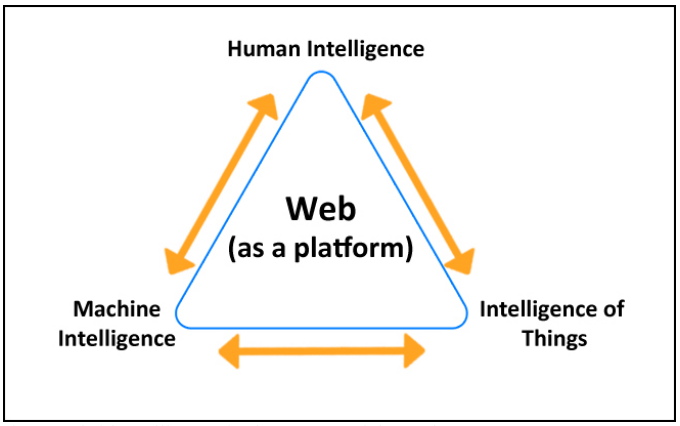

Fig.2. Hybrid Intelligence in the context of the Web

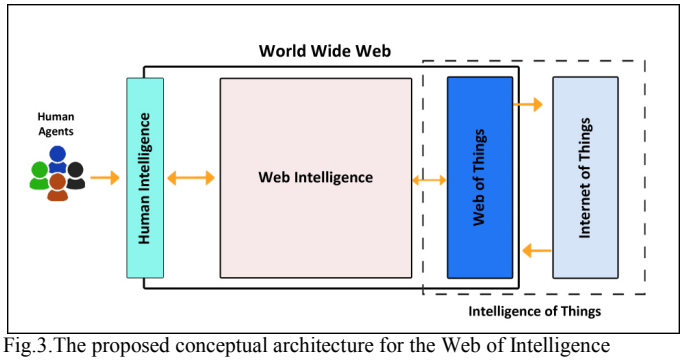

Fig.3.The proposed conceptual architecture for the Web of Intelligence

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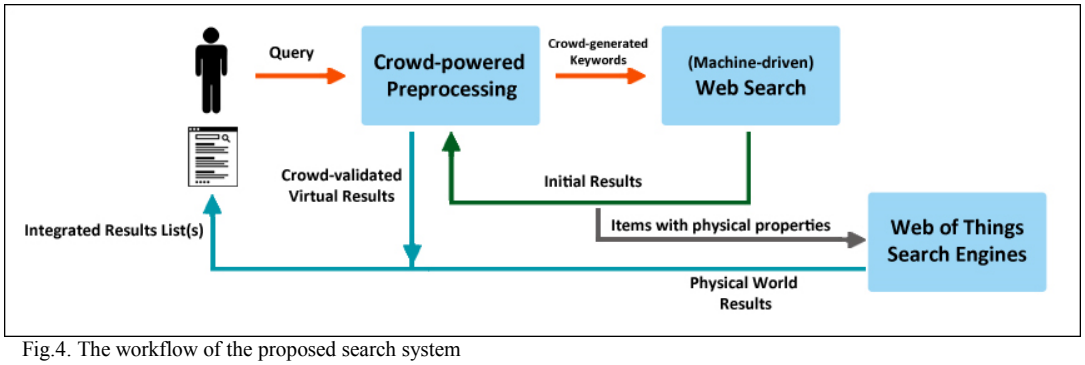

Fig.4. The workflow of the proposed search system

VI. CONCLUSION

In an attempt to look for a practical and inclusive definition for Web of Intelligence, a new perspective is presented and delineated. As a matter of fact, the major goal of this paper is to elaborate on the idea of converging intelligence of humans (i.e. intrinsically intelligent agents), machines (i.e. agents equipped with artificial intelligence) and things (i.e. passive entities capable of presenting some types of contextual intelligence) together with the aim of harvesting comprehensive and multidimensional intelligence in the context of the Web as a platform. In this regard, besides investigating the building blocks and providing a conceptual architecture for the proposed concept, the general workflow of an exemplary system that works based on WoI is explored. The authors believe the idea presented in the paper could shed light on the way of taking advantages of enormous amounts of untamed intelligence out there on the Web.

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