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Research challenges and perspectives on Wisdom Web of Things (W2T)

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Abstract The rapid development of the Internet and the Internet of Things accelerates the emergence of the hyper world. It has become a pressing research issue to real-

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ize the organic amalgamation and harmonious symbiosis among humans, computers, and things in the hyper world, which consists of the social world, the physical world, and the information world (cyber world). In this paper, the notion of *Wisdom Web of Things* (W2T) is proposed in order to address this issue. As inspired by the material cycle in the physical world, the W2T focuses on the data cycle, namely "from things to data, information, knowledge, wisdom, services, humans, and then back to things." A W2T data cycle system is designed to implement such a cycle, which is, technologically speaking, a practical way to realize the harmonious symbiosis of humans, computers, and things in the emerging hyper world.

Keywords Wisdom Web of Things · Internet of Things · Data cycle · Active service · Transparent service

1 Introduction

The Internet connects dispersive computers into a global network. On this network, the World Wide Web (Web) provides a global platform for information storage, resource sharing, service publishing, etc. An information world, called the cyber world, comes into being between the social and physical worlds.

In recent years, advanced information technologies accelerate the development of the cyber world [38, 39]. On one hand, various new Internet/Web-based technologies, such as semantic Web [3, 11, 12], grid computing [13, 14], service-oriented computing [51], and cloud computing [2, 17], make the cyber world become not only a research/service platform but also a global communication and cooperation space in which various virtual communities, associations, and organizations have been established. The cyber world is constantly expanding toward a social world. On the other hand, embedded technologies, automated recognition based on Radio Frequency Identification (RFID) technologies, wireless data communication technologies and ubiquitous computing technologies impel the forming of the Internet of Things (IoT) [5, 62]. A large number of sensor nets, embedded appliance nets, and actuator nets (SEA-nets) have been constructed. Transparent computing technologies [55, 71–73, 85] ensure the effective deployment and publishing of resources/services on these heterogeneous nets. Furthermore, these SEA-nets are integrated and connected into the Internet through various gateways. The Web of Things (WoT) [10, 52] is emerging on the IoT to integrate the sensor data coming from various SEA-nets into the Web. The cyber world is also extending toward a physical world.

At present, various Internet/Web and IoT based applications, such as Web 2.0 [47, 48], Web 3.0 [20, 30], smart world [39, 45], smart planet [24], green/eco computing [29, 64], etc., accelerate the amalgamation among the cyber, social, and physical worlds. It can be predicted that the cyber world composed of computers will be gradually syncretized with the social world composed of humans and the physical world composed of things in the near future. A *hyper world* [28, 37] will come into being on the IoT/WoT. It consists of the cyber, social, and physical worlds, and uses data as a bridge to connect humans, computers, and things. Such a data-based hyper world will bring a profound influence in both work and life to the whole human society and every member in it. Multi-domain experts should closely cooperate to cope with the subsequent research challenges and opportunities.

The core research challenge brought by the hyper world is to realize the organic amalgamation and harmonious symbiosis among humans, computers, and things using the Internet/Web based technologies, ubiquitous computing technologies and intelligence technologies, i.e., to make everything in the hyper world more "intelligent" or "smart" by computers or cells with storage and computing capabilities, to provide active, transparent, safe, and reliable services for individuals or communities in the hyper world. Though various theories and technologies have been developed to realize different levels of intelligent services on the Internet/Web and various SEA-nets, they do not fit well in the hyper world that is built on top of the IoT.

This paper proposes the notion of *Wisdom Web of Things* (W2T) that represents a holistic intelligence methodology for realizing the harmonious symbiosis of humans, computers, and things in the hyper world. A W2T data cycle system is also designed to implement such a cycle, namely "from things to data, information, knowledge, wisdom, services, humans, and then back to things." The W2T provides a practical technological way to realize the harmonious symbiosis of humans, computers, and things in the emerging hyper world. The rest of the paper is organized as follows. Section 2 discusses fundamental issues on intelligence in the hyper world. Section 3 proposes the W2T as a holistic intelligence methodology in the hyper world. For realizing the W2T, Sect. 4 describes a W2T data cycle system. Three use cases are introduced in Sect. 5. Finally, Sect. 6 gives concluding remarks.

2 Intelligence in the hyper world

2.1 Web Intelligence (WI) and Brain Informatics (BI)

The Web significantly affects both academic research and daily life, revolutionizing the gathering, storage, processing, presentation, sharing, and utilization of data/information/knowledge. It offers great research opportunities and challenges in many areas, including business, commerce, marketing, finance, publishing, education, and research and development.

Web Intelligence (WI) [67, 74, 77, 81, 83] may be viewed as an enhancement or an extension of Artificial Intelligence (AI) and Information Technology (IT) on a totally new domain – the Web. It focuses on the research and development of new generations of Web-based information processing technologies and advanced applications to push technologies toward manipulating the meaning of data and creating distributed intelligence.

The tangible goals of WI can be refined as the development of Wisdom Web [75, 76], which is involved with the following top 10 problems [34, 35]:

- Goal-directed services (best means/ends),
- Personalization (identity),
- Social & psychological context (sensitivity),
- PSML, i.e., Problem Solver Markup Language (representation),

– Coordination (global behavior),
– Meta-knowledge (planning control),
– Semantics (relationships),
– Association (roles),
– Reproduction (population),
– Self-aggregation (feedback).

Though many efforts [16, 22, 31, 53] have been made to solve these problems, it is difficult to develop the Wisdom Web by using only the existing AI and IT technologies.

Brain Informatics (BI) [79, 80, 82] is an emerging interdisciplinary field to study human information processing mechanism systematically from both macro and micro points of view by cooperatively using experimental, theoretical, cognitive neuroscience, and WI centric advanced information technology. It emphasizes on a systematic approach to an in-depth understanding of human intelligence. On the one hand, WI based portal techniques (e.g., the wisdom Web, data mining, multi-agent, and data/knowledge grids) will provide a new powerful platform [78] for BI; On the other hand, new understandings and discoveries of human intelligence in BI, as well as other domains of brain sciences (e.g., cognitive science and neuroscience) will yield new WI researches and developments. At present, some new human-inspired intelligent techniques and strategies [69, 70] have been developed to offset the disadvantages of existing intelligence technologies, especially logic-based technologies.

2.2 Ubiquitous Intelligence (UI) and Cyber-Individual (CI)

The development of RFID technologies and wireless data communication technologies impels the forming of IoT. The real physical things are called u-things if they are attached, embedded, or blended with computers, networks, and/or some other devices such as sensors, actors, e-tags and so on [38]. The IoT makes it possible to connect u-things dispersed in various SEA-nets and ubiquitous computing applications for realizing a Ubiquitous Intelligence.

Ubiquitous Intelligence (UI) [39, 59], generally speaking, is that intelligent things are everywhere. It means pervasion of smart u-things in the real world, which would evolve toward the smart world filled with all kinds of smart u-things in a harmonious way [38–40]. The construction of smart u-things is a core issue in the UI. So-called smart u-things are the active/reactive/proactive u-things, which are with different levels of intelligence from low to high. Ideally, a smart u-thing should be able to act adaptively and automatically. Its construction is involved with the following 7 challenges [38, 40, 41]:

– Surrounding situations (context),
– Users' needs,
– Things' relations,
– Common knowledge,
– Self awareness,
– Looped decisions,
– Ubiquitous safety (UbiSafe).

Constructing such a smart u-thing is involved with various challenging topics, including the collecting and mining of logs [42], context modeling [21, 26, 27, 58], user modeling [4, 18, 19, 56], etc. However, there are many challenges due to the real world complexity. For realizing the UI, the human essence in the cyber world needs to be re-examined and analyzed. The research of Cyber-Individual (Cyber-I or CI) [63] is emphasized on re-examining and analyzing the human essence and creating cyber individuals in the cyber world. A Cyber-I is a real individual's counterpart in the cyber space. It is a unique and full description of human being in the digital world. On the one hand, ubiquitous computing technologies make it possible to collect individual's information anytime and anywhere. With the increasing power of computers, networks, ubiquitous sensors, and massive storages, it is no longer a dream that everyone on this planet can have a Cyber-I going with and even beyond his/her own whole life. On the other hand, a comprehensive and exact Cyber-I can effectively guide smart u-things to provide active and transparent services for realizing the UI.

2.3 The holistic intelligence in the hyper world

For realizing the harmonious symbiosis of humans, computers, and things, u-things in the hyper world should be intelligent and able to provide active, transparent, safe, and reliable services. This intelligentizing will realize not only individual intelligence but also holistic intelligence, i.e., all of related u-things can intelligently cooperate with each other for each application. Realizing such holistic intelligence will bring new challenges and opportunities for intelligence researches:

– The hyper world is involved with heterogeneous networks, service types, data forms and contents, efficiency/accuracy requirements, etc. Thus, it is impossible to realize holistic intelligence in such a complex environment by only separately using the WI, BI, UI and CI. For WI supported by BI, though the ubiquitous computing oriented data/services have been mentioned at the beginning, its related researches and developments are mainly focused on Web based data/services because of lacking the IoT and WoT, which can provide an effective approach to dynamically and largely gather the real-time sensor data coming from different SEA-nets, and realize active and transparent services anytime and everywhere. For the UI supported by the CI, though recent studies begin to focus on mining a large number of historical data for providing higher quality of services, related researches and developments were mainly oriented to specific applications and data because of lacking effective technologies and strategies to organize, manage, mine and utilize the multi-aspect real-time data and historical data, as well as information and knowledge derived from the data. Thus, the holistic intelligence research in the hyper world will present new research challenges to WI, BI, UI and CI.
– The infrastructure of hyper world consists of the Internet and a number of SEA-nets. It is possible to continuously and dynamically gather both real-time sensor data and historical Web data in the hyper world by the IoT and the WoT. Moreover, grid computing, cloud computing, and transparent computing also make it possible to integrate the powerful storage and computing capabilities on the IoT for effectively storing, managing, mining, and utilizing the gathered data, as well as the

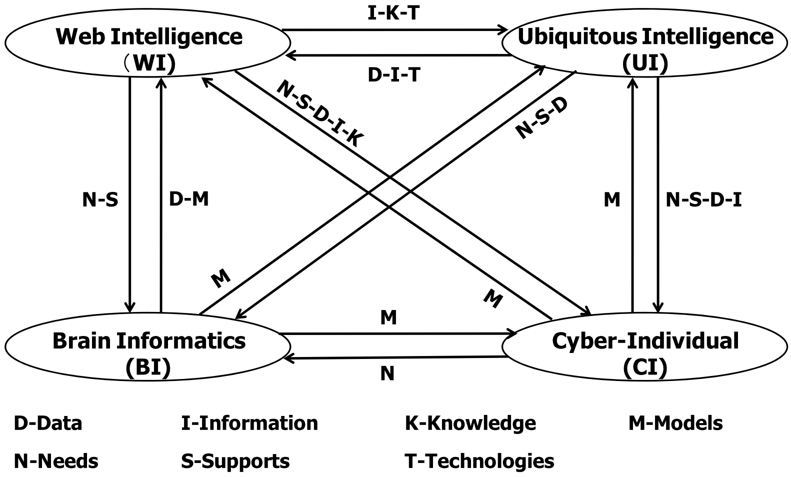

Fig. 1 The holistic intelligence research in the hyper world

information and knowledge derived from data. Based on such an infrastructure, the hyper world will provide significant opportunities to the holistic intelligence research. It will integrate the WI, BI, UI, and CI to develop a new holistic intelligence methodology for realizing the harmonious symbiosis of humans, computers, and things in the hyper world.

In summary, the hyper world makes it possible and necessary to integrate separate intelligence researches into a holistic research. As shown in Fig. 1, in this holistic research, WI, BI, UI, and CI are independent but promote each other. Finally, a holistic intelligence methodology with its associated mechanisms can be developed to realize the harmonious symbiosis of humans, computers, and things in the hyper world.

3 Wisdom Web of Things

The Wisdom Web of Things (W2T) is an extension of the Wisdom Web in the IoT age. The "Wisdom" means that each of things in the WoT can be aware of both itself and others to provide the *right service* for the *right object* at a *right time* and *context*. Thus, the W2T is not a copy of the Web on the IoT. As shown in Table 1, it is different from the existing Web in many aspects, including infrastructure, function, data characteristic, modeling, and so on. Such a W2T is impossible to construct by using only the existing intelligence technologies that are oriented to specific humans, computers, and things.

The nature is based on materials. An effective material cycle ensures the harmonious symbiosis of heterogeneous things in nature. Similarly, the hyper world is based on data. Thus, constructing the W2T for the harmonious symbiosis of humans, computers and things in the hyper world requires a highly effective W2T data cycle:

Table 1 A comparison between the Web and W2T

	World Wide Web	W2T
Infrastructure	Internet	Internet of Things
Function	a sharing platform and communication space	an environment to provide active, transparent, safe and reliable services for the harmonious symbiosis of humans, computers and things in the hyper world
Storing and Computing Medium	different types of computers	all electronic media with the capabilities of storage and computing (including different types of computers, PDAs, mobile telephones, embedded chips, and so on)
Data Characteristic	reliable data sources and relatively stable data streams	various data availabilities, data stream modes, and data gathering strategies
Modeling	data and user preference modeling	not only data and user preference modeling but also space modeling (including environment modeling, thing modeling, context modeling, user behavior modeling, etc.)
Formal Knowledge	domain knowledge for the data and computing integration	both domain knowledge and common sense knowledge for guiding the Web and ubiquitous computing
Awareness Mode	a human centric mode (i.e., users choose the appropriate services based on individuals' judgments about the current Web environments)	a ubiquitous awareness mode (i.e., all of humans, computers and things can be aware of themselves and others dynamically for providing active and transparent services)
Computing Mode	computing on the Internet/Web	computing in everywhere
Service Mode	passive services	both active services and passive services

– Things to Data: Various data of things are collected into a distributed integrated data center through the WoT. These data include the real-time data of things coming from the sensors in SEA-nets and measuring equipments (such as MRI, EEG, CT), the Web accessible historic data of things stored on the Web, and the data of Web produced on the Web.
– Data to Information: After data cleaning, integration, and storage, both sensor data and Web data are analyzed and re-organized to generate multi-aspect and multi-granularity data information by various data mining/organization methods. The obtained data information is also described and stored in the data center.
– Information to Knowledge: The valuable knowledge is extracted from the data information by various modeling. Other related knowledge is also gathered and described using knowledge engineering technologies. All of knowledge is stored in the data center.
– Knowledge to Wisdom: Based on the obtained knowledge, the top 10 problems of Wisdom Web mentioned in Sect. 2.1 and 7 characteristics of smart u-thing mentioned in Sect. 2.2 are studied to develop the key intelligence technologies and strategies.
– Wisdom to Services: An active and transparent service platform is constructed on the integrated data center using the developed intelligence technologies and strate-

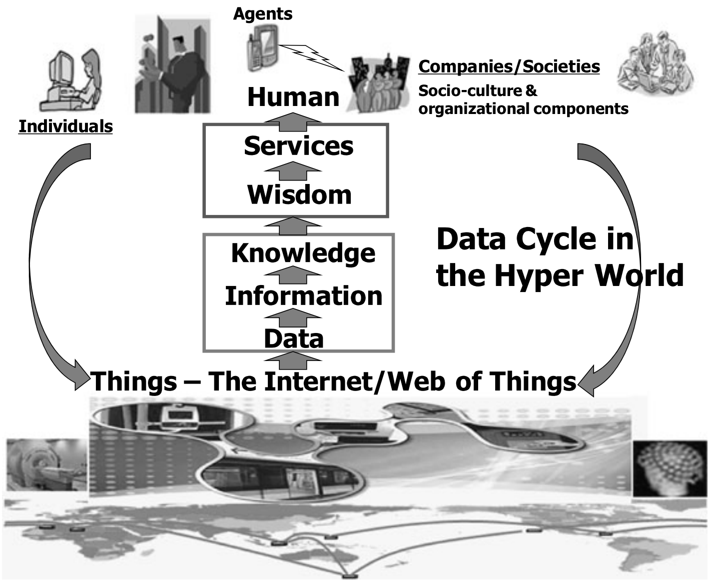

Fig. 2 A data cycle in the hyper world

gies. It can provide active, transparent, safe, and reliable services by synthetically utilizing the data, information, and knowledge in the data center.

- Services to Humans: The service platform provides various active and transparent services to individuals and communities by a variety of sensors and actuators.
- Humans to Things: During the process of receiving services, humans continues to influence the things around him/her and brings the changes of things. Finally, the data reflecting these changes are collected into the integrated data center.

As shown in Fig. 2, a variety of sensors, storage, and computing terminals in the IoT provide a data storage and conversion carrier for implementing the data cycle. The emerging WoT provides a transmission channel of data cycle. Therefore, the core problem of data cycle construction is to develop a highly efficient data cycle system.

4 A W2T data cycle system

4.1 The system framework

Figure 3 illustrates the system framework of W2T data cycle system. It includes two parts, W2T data conversion mechanism and W2T data/service interface. The W2T data conversion mechanism is the main body of cycle system and used to drive the process of data cycle, as shown in the right of Fig. 3. The W2T data/service interface includes two middlewares and is used to connect the cycle system to the WoT, as shown in the center of Fig. 3.

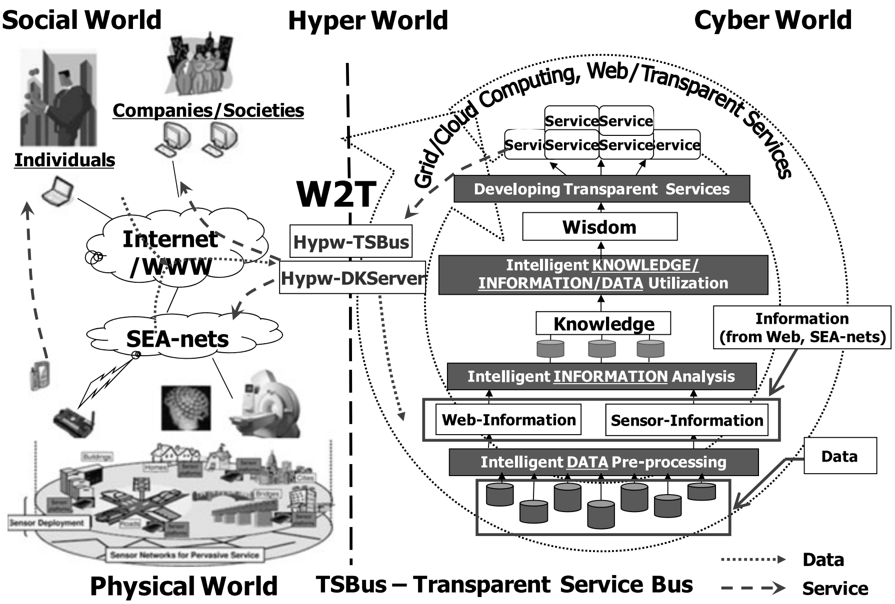

Fig. 3 A W2T data cycle system

4.2 The W2T data conversion mechanism

The W2T data conversion mechanism includes a group of information technologies to transform data forms along the process of the W2T data cycle. As shown in the center of Fig. 4, it includes the following five levels:

- The *data* level of technologies is involved with various data management and preprocessing technologies, including data collection, cleaning, integration, storage, etc., for completing the “Things-Data” sub-process of the data cycle. Because the objective data include sensor data, Web accessible data, and Web data, the data collection is a core issue at this level. It is involved with not only collecting data from the Web and information systems, but also producing data by deploying sensors and embedded chips [23, 54] or designing and implementing cognitive experiments [32, 33, 84]. The data integration is also an important issue because of the differences on data formats, contents, and applications.
- The *information* level of technologies is involved with information extraction, information storage, and information organization for completing the “Data-Information” sub-process of data cycle. Because of the limited data transmission and computing capabilities, it is necessary to perform the off-line information extraction and organization before services are requested. This is especially important to the hyper world which includes mutable data, computing, and network environments. However, the existing technologies cannot meet the requirements of off-line information extraction and organization. Thus, it is necessary to study human information processing and organization mechanisms, such as induction [33], for

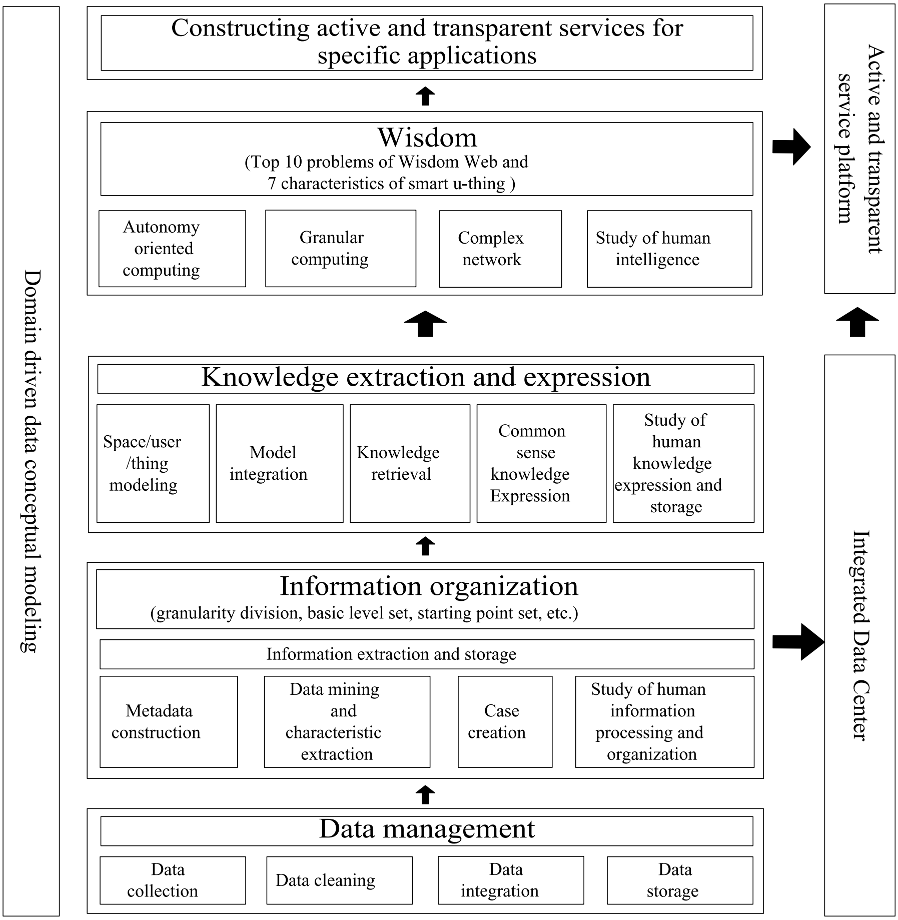

Fig. 4 The W2T data conversion mechanism

developing the new information level of technologies, such as granularity division, basic level setting, and starting point setting [69, 70].

– The *knowledge* level of technologies is involved with knowledge extraction and knowledge expression for completing the "Information-Knowledge" sub-process of data cycle. The core issues include model, common sense, and knowledge retrieval. The studies of human knowledge expression and storage are also implemented to develop the more effective technologies of knowledge expression and storage.
– The *wisdom* level of technologies mainly focuses on the top 10 problems of Wisdom Web and 7 characteristics of smart u-thing for completing the "Knowledge-Wisdom" sub-process of data cycle. The autonomy oriented computing [36], granular computing [66, 68], and complex network [57] are three core theories for realizing "Wisdom" on the WoT which includes enormous data and heterogeneous

networks. The results of human intelligence studies are also used to develop new intelligence technologies and strategies.
– The *service* level of technologies is involved with service construction, service publishing and service integration on the Internet/Web and various SEA-nets for completing the "Service-Human" sub-process of data cycle. They are based on grid computing, cloud computing, and transparent computing, and oriented to various specific applications in the hyper world, such as pervasive elderly/kid care, active and transparent service platform for depression, etc.

These technologies are realized as an integrated data center and an active and transparent service platform, as shown in the right of Fig. 4.

As shown in the left of Fig. 4, the five levels of technologies are integrated by a domain driven data conceptual modeling. Such a data conceptual modeling is not the traditional conceptual schema design of databases/metadata or the ontological modeling of data related domain knowledge. It models the whole process of data cycle by different dimensions and has various specifications on the different levels of conversion mechanism:

– At the data level, it can be specified as the conceptual schema designs of databases and data warehouses.
– At the information level, it can be specified as the conceptual descriptions of metadata, cases and data characteristics.
– At the knowledge level, it can be specified as space/user/thing conceptual modeling, domain/common-sense knowledge modeling, and knowledge structure modeling.
– At the wisdom level, it can be specified as intelligent agent modeling, granular knowledge structure modeling, networks and network behavior modeling, as well as the modeling of human higher-level information processing capabilities.
– At the service level, it can be specified as the applications of the different levels of conceptual models.

4.3 The W2T data and service interface

The W2T data and service interface includes two middlewares, hyper world data/knowledge application server (Hypw-DKServer), and hyper world transparent service bus (Hypw-TSBus). They are used to connect the data cycle system to the WoT for making it "Wisdom".

The Hypw-DKServer is a software middleware for the service publishing on the WoT. It can support centralized or distributed data/model/knowledge publishing and respond to data/model/knowledge requests coming from the Internet and various SEA-nets. Different from the existing Web based application servers, such as Weblogic, Tomcat, Jboss, etc., the Hypw-DKServer is an entirely new WoT based application server, as shown in Table 2.

The Hypw-TSBus is a software middleware for the service integration on the WoT. It can support dynamic service discovery, service evolution, service composition, and security validation for meeting various service requests on the Internet/Web and SEA-nets. Different from the existing Enterprise Service Bus (ESB), such as WebSphere ESB (WESB), BizTalk Server, etc., the Hypw-TSBus is an entirely new WoT based service bus, as shown in Table 3.

Table 2 A comparison between Web application servers and the Hypw-DKServer

	Web Application Servers	Hypw-DKServer
Environment	the Web on the Internet	the WoT on the IoT
Operating System	operating systems in computers (such as Windows, Unix, Linux, etc.)	new-style network operating systems on various networks
Main Function	supporting the establishment, deployment and management of static and dynamic Web applications	supporting the establishment, deployment and management of data/model/knowledge services
Protocol	standard Web protocols (such as HTTP, FTP, SOAP, WSDL, UDDI and so on)	new-style standardized protocols for data/model/knowledge communications, descriptions and publishing
External Interface	database interfaces for main database systems such as Oracle, SQL Server, DB2, and so on	database interfaces for main database systems, and knowledge/model base interfaces for the existing/developed description languages of knowledge/models

Table 3 A comparison between ESB platforms and the Hypw-TSBus

	ESB platforms	Hypw-TSBus
Environment	the Web on the Internet	the WoT on the IoT
Operating System	operating systems in computers	new-style network operating systems on various networks
Main Function	providing a Web oriented infrastructure for the process-description driven service discovery and integration	providing a WoT oriented infrastructure for the purpose-driven dynamic service discovery, evolution and integration
Other function	supporting message routing, message conversion, message expansion, protocol intermediary, security validation, event handling, service scheduling, etc.	supporting message routing, message expansion, security validation, event handling, etc.

5 Case studies of applications

In this section, we present three use cases to demonstrate the usefulness of the proposed W2T methodology.

5.1 A W2T based kid care platform

An interesting survey [50] recently made in Japan reported that 72.5% parents worried about their kids, 82.3% parents felt tired in caring for their kids, and 91.9% parents had not enough well time taking care of their kids. Although the survey data may vary from country to country or from region to region, it shows that caring for kids is not an easy work and it does consume a lot of time/energy for many parents. In fact, parents have been putting a lot of effort to ensure their children's safety. However, unexpected matters sometimes still happen. In other words, it is impossible for parents to keep an eye on their kids and give them prompt help 24 hours a day. Fortunately, with the rapid advancing of ICT and ubiquitous computing, not only kids can enjoy the fruits of developments brought by IT like digital games, real time animations, multimedia contents, but also their parents benefit from the advanced technologies. This section presents the W2T based kid care platform on top of which kid care systems are built. With the support of kid care systems, parents benefit from the supporting systems and can be relieved more or less from their various worries regarding to kid cares, especially to those working couples.

The issue of kid care is important to a family but it is also an ordinary and common activity. It has not been receiving much attention from research communities although there have been some research going on [23, 39, 54]. Using kids as a specific group of humans, it is necessary to have a thorough study. With the rapid advancing of ubiquitous computing [5, 60, 61] and wireless communication technologies, developing kid care systems with ubiquitous sensors and wireless communications become feasible. This research field has received increasing attention. Based on related research results, we will develop a W2T based kid care platform, as shown in Fig. 5, which can be described as follows.

To take care of a kid, the first step is to know the kid. A system has to first record all the kid's activities and get to know the kid by analyzing his/her activities that just like a parent is doing in the process of caring for children. A kid's activities are recorded via SEA-nets in the physical world. The recorded data are classified and stored in life-log, space-log, and thing-log, respectively. For example, Bob comes back from school, he watches TV in the living room from 2:30 p.m. to 3:30 p.m., then studies in the study room from 3:30 p.m. to 5:30 p.m. The recorded data are classified according Bob's identification, physical location Bob has been, and devices

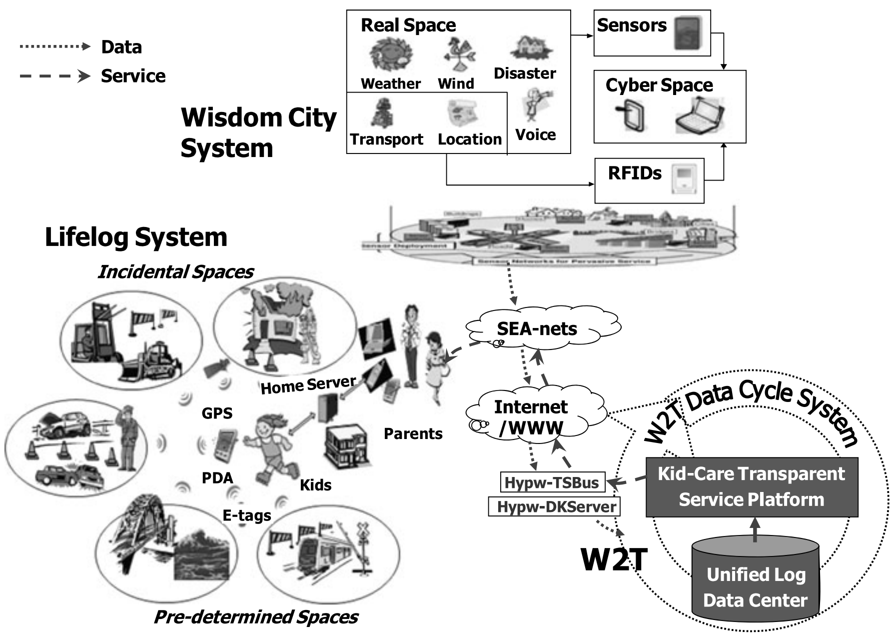

Fig. 5 The W2T based kid care platform

he has been using into life-log (Bob-id), space-log (Bob-id,(living-room (2:30–3:30), study-room (3:30–5:30))), thing-log (Bob-id,TV (2:30–3:30), book (3:40–4:40), pen (4:40–5:10), ...)). The log data are transferred via the Internet/WWW and SEA-nets to the Unified Log Data Center as shown in Fig. 5.

Each unified log database is a well-organized data structure and their relationships, such as the relationships regarding who, where, what, when in a 4-W hierarchical structure are implicitly preserved and accessible in an organized relational structure in the outer layer. To any situation in which a kid is, a node with its branch in the structure corresponding to the situation represents a knowledge set which is derived and composed from the log database. The knowledge set about a kid and for handling a certain situation that the kid is in, can be envisaged as a grape branch; its structure varies from a situation to a situation.

The processes from being aware of a situation or a context to derivation of a knowledge set and from the knowledge set to provision of transparent and active services to the kid are two important cores. The former requires mechanisms to extract, retrieve, and analyze data/information in the log database along the time axis or at a certain time section. The relational data/information is linked in a way that a kid's situation and context that the kid is in are represented either explicitly or implicitly. The relationships may be expressed in a n-dimension relational matrix. To be aware a situation and a context, a knowledge set can be dynamically composed together with history situation-solution experience and new learning. Based on the derived knowledge set, the system provides transparent and active services to the kid. For instance, providing a warning message if the kid is in a dangerous situation, informing his/her parents if the kid has fever, or reminding the kid to study when he/she has been playing game all the time, locking the door if the kid forgot, etc. To sum up, the system supports kid care from all aspects, safety, health, education, security, etc.

From acquisition of raw data via SEA-nets in the physical world to the provision of active services in the cyber world to kids in the social world, it is a complete data cycle. Kids (in the social world), things (in the physical world), and computer systems (in the cyber world) are actually integrated as an entity. Their harmonization and symbiosis are realized by using the W2T including SEA-nets, IoT, WoT, Hypw-DKServer, and Hypw-TSBus to guide a highly effective W2T data cycle.

5.2 A W2T based brain data center

Different from traditional human brain studies, Brain Informatics (BI) emphasizes on a *systematic* approach for the human thinking centric investigation, which is complex and involved with multiple inter-related functions with respect to activated brain areas and their neurobiological processes of spatio-temporal features for a given task. Based on a systematic methodology of experimental design, a series of cognitive experiments are designed to obtain multiple forms of human brain data, which are involved with multiple granularities and aspects of human thinking centric cognitive functions. A systematic analysis methodology is also proposed to analyze these data comparatively and synthetically. For supporting such a systematic BI study, a brain data center needs to be developed to realize not only data storage and publishing oriented data management but also systematic analysis oriented management. This

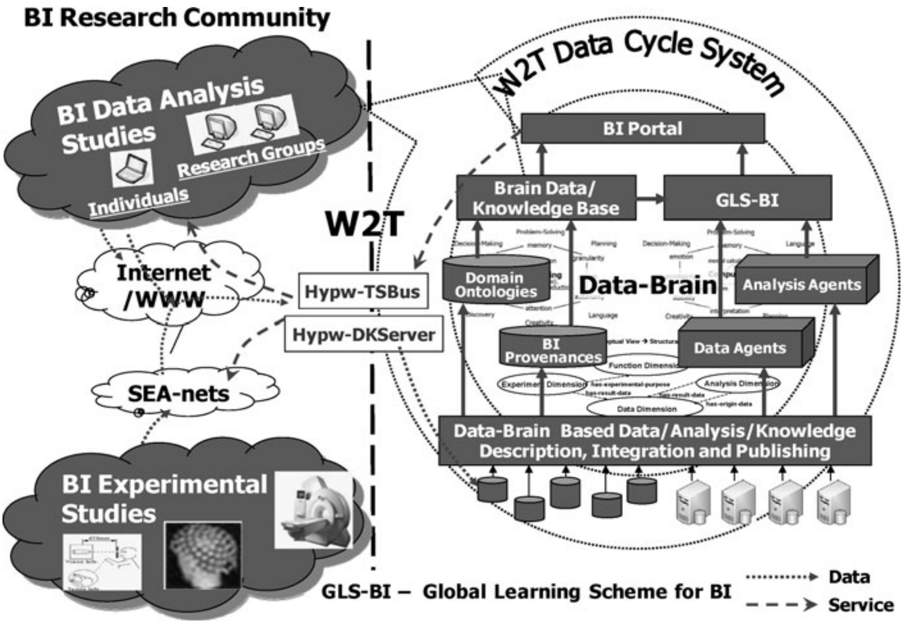

Fig. 6 The W2T based brain data center

section presents the W2T based brain data center which is a global BI research platform for supporting the whole process of BI study. Guiding by this brain data center, various BI experimental studies and BI data analysis studies can be integrated to realize a systematic BI investigation.

The issue of brain database construction is a long-time focus in brain science. Although various brain databases [1, 15, 44, 46] have been constructed to effectively store and share heterogeneous brain data, especially EEG (electroencephalogram) data and fMRI (functional magnetic resonance imaging) data focused by present BI studies, these brain databases mainly focus on data storage and publishing. They cannot effectively support the systematic BI study. Based on all of the fundamental considerations, we will develop a W2T based brain data center, as shown in Fig. 6, which can be briefly described as follows.

BI is a data-centric scientific study whose process can be generalized as a BI data cycle, including data production, data collection, data storage, data management, data description, data mining, information organization, knowledge extraction, knowledge integration, and knowledge utilization. All of BI research activities apply themselves to impel this data cycle. Thus, to support the systematic BI study, the first step is to collect heterogeneous brain data, including not only experiment data obtained by BI experimental studies but also derived data, information, and knowledge obtained by BI data analysis studies. These data, information, and knowledge are transferred via the Internet/WWW and SEA-nets to distributed brain databases as shown in Fig. 6.

A new conceptual data model, named Data-Brain [6, 7], is used to integrate the data, information, and knowledge stored in brain databases. The Data-Brain models the four aspects of systematic BI methodology by four dimensions. Related domain ontologies are also integrated into these dimensions. Based on the Data-Brain, the information and knowledge derived from data are integrated and organized as Data-Brain based BI provenances and sub-dimensions of Data-Brain, respectively. They provide multi-granularity and multi-aspect semantic descriptions of brain data for data understanding and utilization. The Data-Brain, BI provenances, and brain data form a multi-level brain data-knowledge base, which provides data, information, and knowledge services for BI researchers and other research assistant systems, such as the Global Learning Scheme for BI (GLS-BI) [8]. The GLS-BI is a brain data analysis platform which models BI experimental and data analysis studies, as well as available BI data and computing resources. It is implemented as a multi-agent system with various data agents and analysis agents to support multi-aspect brain data analysis by various assistant functions, including dynamical mining process planning, workflows filter and performance, etc. Finally, all of the functions provided by the brain data-knowledge base and the GLS-BI are enclosed as services on the BI portal and published by the Hypw-TSBus and the Hypw-KDServer to provide transparent and active research supporting services during the whole BI research process.

As a BI data cycle system, the W2T based brain data center guides a complete data cycle in the global BI research community, from acquisition of heterogeneous data, information, and knowledge in the physical world to the provision of active services in the cyber world to BI researchers in the social world. By this brain data center, BI researchers (in the social world), brain detecting equipments (in the physical world), and data/computing resources (in the cyber world) are harmonious and symbiosis to impel the BI studies together.

5.3 A W2T based depression data center and diagnosis-recovery platform

Depression, one of the most prevalent disorders, is a huge public-health problem. It is a chronic, recurring, and potentially life-threatening illness that affects up to 20% of the population across the world. An estimated 20% of the general population will suffer depression sometimes in their lifetimes. About 15% of patients with a mood disorder die by their own hand, and at least 66% of all suicides are preceded by depression. Depression is expected to be the second leading cause of disability for people of all ages by 2020 [43, 65]. The increasing of depressed patients will burden the family and society heavily. Even if treatment with medication and/or electroconvulsive therapy (ECT) and psychotherapy are performed, it is still a long-term process which needs the support of information technologies. This section presents the W2T based depression data center and diagnosis-recovery platform on the top of which depression diagnosis-recovery systems are built. These systems can provide various supports for depression prevention, diagnosis, therapy, care, and recovery.

Depressive symptoms are characterized not only by negative thought, mood, and behavior but also by specific changes in bodily functions (for example, crying spells, body aches, low energy, or libido, as well as problems with eating, weight, or sleeping). Neuro-imaging studies [9, 25, 49] also found that the abnormal activity for depressed patients in brain regions including prefrontal, limbic, cinguale, subthalamus, hippocampus, amygdala, as well as globus pallidus. Depression is usually first identified in a primary-care setting, not in a mental health practitioner's office. Moreover,

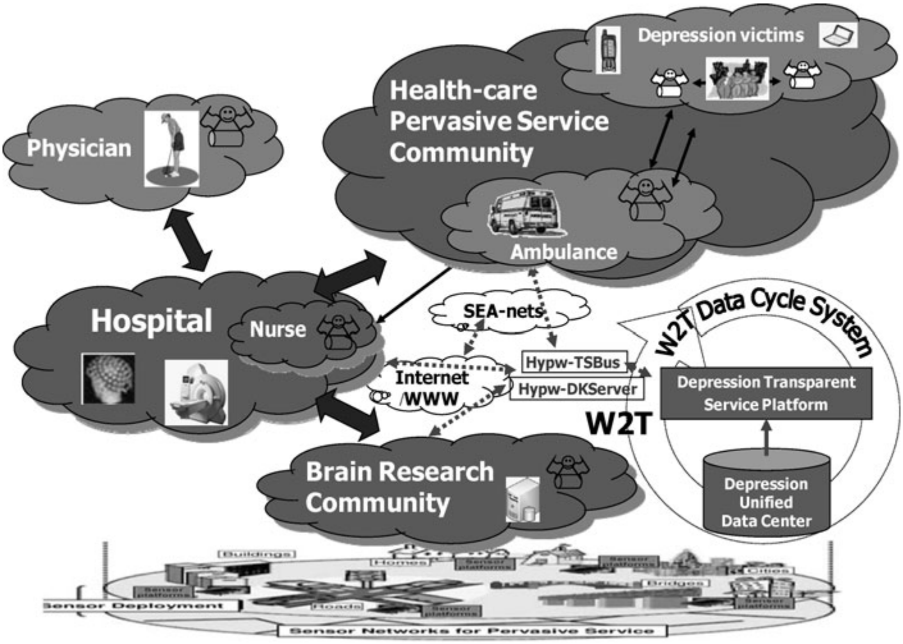

Fig. 7 The W2T based depression data center and diagnosis-recovery platform

it often assumes various disguises, which cause depression to be frequently underdiagnosed.

Although clear research evidences and clinical guidelines have been found, treating depression is still a long-term and hardy process which cannot be completed only depending on hospitals, physicians, and nurses. The depression prevention, diagnosis, therapy, care, and recovery need the support of ubiquitous computing and wireless communication technologies. This research field has received increasing attention. Based on related research results, we will develop a W2T based depression data center and diagnosis-recovery platform, as shown in Fig. 7, which can be briefly described as follows.

Treating depression needs the cooperation among hospitals, brain research institutions, families, and society. The first step is to timely gather multi-aspect data of depressed patients or latent patients, including medical data obtained by hospitals, brain activity data obtained by the brain research community, and other health-related data, such as mood, behavior, physical symptoms, recorded by sensors or people around patients in the health-care pervasive service community. As shown in Fig. 7, these data are transferred via the Internet/WWW and SEA-nets to the Depression Unified Data Center.

Multiple types of databases are included in this data center. Some stored data are with a well-organized data structure and implicit or explicit relationships. Others are multimedia data and stream data with semantic and well-organized metadata. The derived multi-granularity information and knowledge are also organized and stored in this data center.

The processes from gathered data, information, and knowledge to the provision of transparent and active services are diversiform because of different requirements of depression prevention, diagnosis, therapy, care,, and recovery. For monitoring latent patients, their behavior modes are extracted from data to find physical symptoms and to provide active reminding services by SEA-nets. For diagnoses of depressed patients, intelligent data query services are provided to integrate multi-aspect information, including mood, behavior, brain activities, and present/history medical treatments, for assisting diagnoses in hospitals. For treatments of depressed patients, mild patients can join the health-care pervasive service community to obtain transparent and active treatment/care services out of hospitals. Even if unexpected incidents happen on patients, physicians on vacation can give treatment programs and provide treatment services by ambulances. All of these services are integrated in a depression transparent service platform and published by the Hypw-DKServer and the Hypw-TSBus on the top of IoT/WoT, as shown in Fig. 7.

It is a complete data cycle from acquisition of raw data via SEA-nets, brain detecting equipments, physicians, and families in the physical world and social world to the provision of active services in the cyber world to patients in the social world. Depressed patients (in the social world), things (in the physical world), and computer systems (in the cyber world) are integrated into an entity to realize their harmonious and symbiosis by using an effective W2T data cycle.

6 Conclusions

With the development of advanced information technologies, especially IoT related technologies, a hyper world, which integrates the social, physical, and cyber worlds, is emerging. Data will be the vital ingredients of the hyper world. Although the WoT constructed on the IoT, data "run" in the hyper world with multiple formats, including information and knowledge, to tightly connect humans, computers, and things, which are dispersed in the social, physical, and cyber worlds.

The existing intelligence technologies for the Web and ubiquitous computing have focused on the conversion and utilization of data to provide more intelligent services on the Internet/Web or SEA-nets. However, these studies are limited in specific technologies, applications, data, and data conversions. Only using these technologies cannot fully utilize the enormous data and realize holistic intelligence for the harmonious symbiosis of humans, computers, and things in the hyper world.

Integrating the existing studies of intelligent information technologies, this paper proposed the W2T as a holistic intelligence methodology in the hyper world. A W2T data cycle system is designed to drive the cycle, namely "from things to data, information, knowledge, wisdom, services, humans, and then back to things" for realizing the W2T. This is a practically technological way to realize the harmonious symbiosis of humans, computers, and things in the emerging hyper world.

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