WaaS: Wisdom as a Service

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Recent advances in cloud computing, the Internet of Things, the Web of Things, Big Data, and other research fields have created the chance to develop an open architecture with intelligent sharing and services.

A huge number of sensors, embedded appliances, and actuators have been deployed in almost every part of every major city. The Internet, the mobile Internet (MI), the Internet of Things (IoT), and the Web of Things (WoT) connect humans, computers, and other devices to form an immense network by which various information technologies (IT) and their applications permeate into every aspect of our daily lives. These continuously extending IT applications have resulted in a hyper-world consisting of the social, cyber, and physical worlds and using data as a bridge.[1,2]

In the hyper-world, the most important changes and characteristics include the following:

- *The human-computer relationship*. In the past, we lived separately from the cyber world and accessed computers and networks only when we needed IT services. The hyper-world changes this kind of loose coupling between humans and computers. Owing to the fusion of the social, cyber, and physical worlds, today we live within a huge network of numerous computing devices, storage devices, and u-Things, where real physical objects are attached, embedded, or blended with computers, networks, or some other devices such as sensors. Adapting and utilizing this

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kind of new human-computer relationship is an urgent task for the development of IT applications.
- *Big Data*. The extension of the Internet, IoT, and MI greatly accelerates the production of data. IDC (a technology research firm) estimates that data has been constantly growing at a 50 percent increase each year, more than doubling every two years. Big Data is an important characteristic of the hyper-world, so how to effectively manage, mine, and utilize it to improve the ability and quality of IT applications is an urgent task.[3,4]

These changes have led to the appearance of many new phenomena and research issues. For example, in China, there's a phenomenon called Human Flesh Search Engine (HFSE), in which a large number of Web users voluntarily gather together to collaborate and conduct truth-finding tasks, mostly without monetary reward. The organizational structure and incentives that motivate people to contribute shed light on the intrinsic understanding of voluntary, large-scale crowdsourcing and how collective intelligence is fulfilled with the help of the Internet.[5] The hyper-world is bringing profound influences in both work and life to society. How to realize the organic amalgamation and harmonious symbiosis among humans, computers, and things in the hyper-world is becoming a significant scientific and social issue.

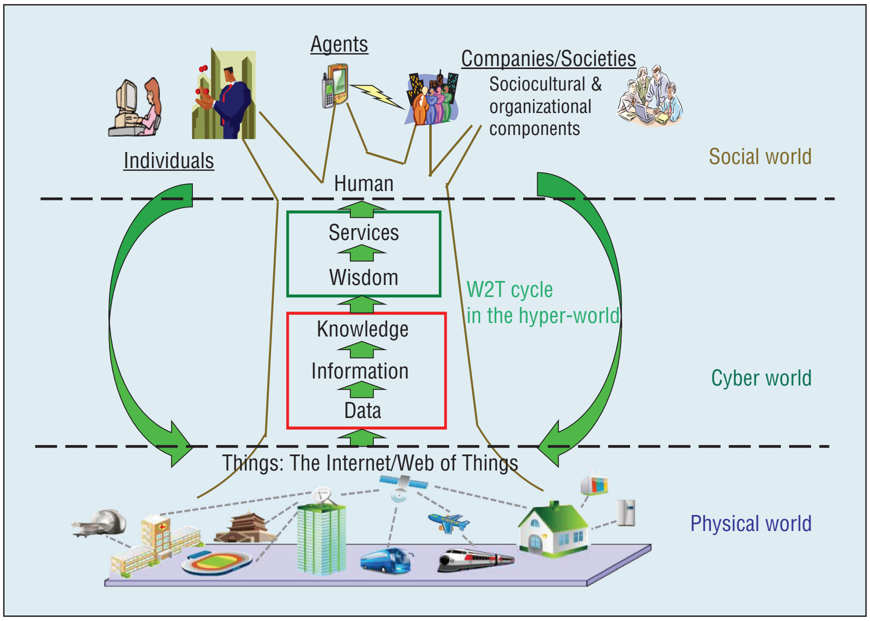

Figure 1. The Wisdom Web of Things (W2T) cycle in the hyper-world. Essentially, it loops from things to data, information, knowledge, wisdom, services, humans, and then back to things.

From Wisdom Web to Wisdom Web of Things

Web intelligence (WI) may be viewed as an enhancement or extension of artificial intelligence (AI) and IT on the Web.[6] One of its goals can be defined as the development of a wisdom Web.[7,8]

In the hyper-world age, this goal can be extended to the development of the Wisdom Web of Things (W2T), where the "wisdom" means that each of the "things" in IoT and WoT is aware of both itself and others to provide the right service for the right object at the right time and context.[2] The W2T core concept is a processing cycle, namely, "from things to data, information, knowledge, wisdom, services, humans, and then back to things" (the W2T cycle, for short), as shown in Figure 1. Similar to the real-world material cycle that ensures the harmonious symbiosis of animal, plant, and microbes, the W2T cycle realizes the harmonious symbiosis of humans, computers, and things in the hyper-world.

Constructing the W2T cycle relies on the large-scale converging of intelligent IT applications. Cloud computing provides an open and service-oriented architecture for meeting such a challenge.[9] It's a new trend in the IT industry with the potential to realize a pay-as-you-go model. Based on cloud computing, all IT applications can be deployed on a uniform platform and organized flexibly for varied applications. The enormous storage and computing resources needed by Big Data can also be obtained by each IT application to improve its ability and quality.

However, cloud computing primarily focuses on the system resource architecture of IT applications—that is, infrastructures, platforms, and software (developing and scheduling abilities). For the large scale converging of intelligent IT applications, it's necessary to develop an open and interoperable intelligence service architecture for the contents of IT applications—the data, information, knowledge, and wisdom (DIKW). The hyper-world with its W2T cycle will serve this purpose.

From Data to Wisdom

Where is the life we have lost in living?
Where is the wisdom we have lost in knowledge?
Where is the knowledge we have lost in information?

—T.S. Eliot, "The Rock," 1934

The first step in developing a content architecture of IT applications is

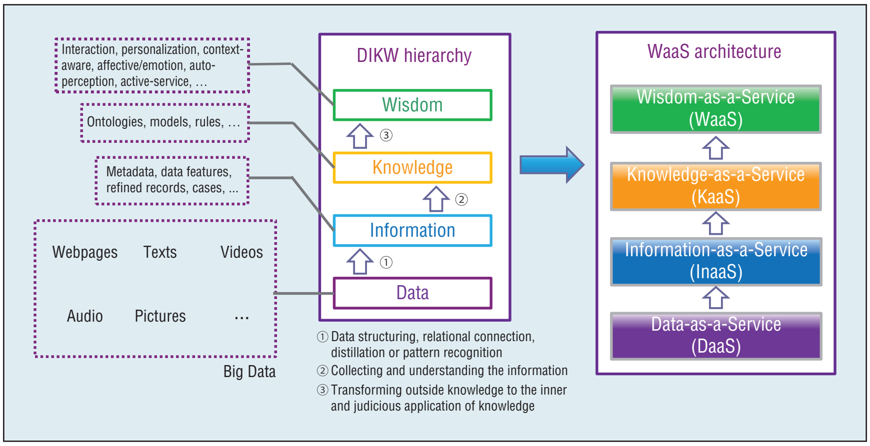

Figure 2. From the data, information, knowledge, and wisdom (DIKW) hierarchy to wisdom as a service (WaaS).

to investigate the relationships among contents. As suggested in T.S. Eliot's poetic lines, a common understanding of the DIKW hierarchy[10] would include the following four levels:

- *Data* is the uninterpreted raw quantities, characters, or symbols collected, stored, and transmitted.
- *Information* is a collection of interpreted, structured, or organized data that's meaningful and useful for certain applications.
- *Knowledge* is acquaintance or familiarity about facts, truths, or principles gained through study or investigation.
- *Wisdom* is sagacity, discernment, or insight to know what's true or right for making correct judgments, decisions, and actions.

Each level in this hierarchy can affect the other and be changed into another: information can be obtained from data by data structuring, relational connection, distillation, or pattern recognition; knowledge can be refined by collecting and understanding the information; and wisdom can be realized by transforming outside knowledge to the inner and judicious application of knowledge. Such creation, organization, and transformation are the essence of the DIKW hierarchy and a core research issue of intelligent IT technologies. Because of the fusion of humans, computers, and things in the hyper-world, developing human-level intelligence becomes a tangible goal of DIKW-related research. Realizing it will depend on a holistic intelligence research.[2]

Wisdom as a Service Architecture

Based on the DIKW hierarchy, we propose a wisdom as a service (WaaS) architecture of IT applications as shown in Figure 2. We have two senses of WaaS. In a wide sense, we use WaaS to denote a new content architecture of IT applications which includes four service layers; in a narrow sense, we use WaaS to denote the highest service layer provided by the WaaS architecture. More specifically, the four service layers in the Waas architecture can be described as follows:

- *Data as a service* (DaaS) provides services based on both current and future raw data. Providing current data is part of the data-sharing service realized in all scientific databases. To realize data sharing, the data collection service integrates dispersive data into a unified database. Providing future data is part of the service that obtains data according to user demand.
- *Information as a service* (InaaS) provides services by using both current and future information. Providing current information is part of the activity of getting information from diversified resources, information retrieval being the most typical. Providing future information means extracting information from data per user demand. Related services include data mining services and data curation services.[3]
- *Knowledge as a service* (KaaS) provides services with respect to existing and will-be-refined explicit knowledge, such as formal ontologies, user models, and so on. Providing existing knowledge is part of what knowledge query services do; providing will-be-refined knowledge means to construct new knowledge bases according to user demand. Related work concerns knowledge retrieval,[11] the development and management of knowledge bases.
- *Wisdom as a service* (Waas) provides various intelligent IT applications, including software and u-Things, as "wisdom" services. Intelligent technologies are core to WaaS and involve personalization, context awareness, affective/emotion, interaction, autoperception, active services, and so on. By using these intelligent technologies on data, information, and knowledge, those software and u-Things can make correct judgments, decisions, and actions to provide the right service for the right object at a right time and context.

WaaS Standard and Service Platform

Figure 3 gives the WaaS standard and service platform architecture, with four components according to the four service layers. Each component includes a software platform and a standard system for realizing all the services in the corresponding service layer. The software platform

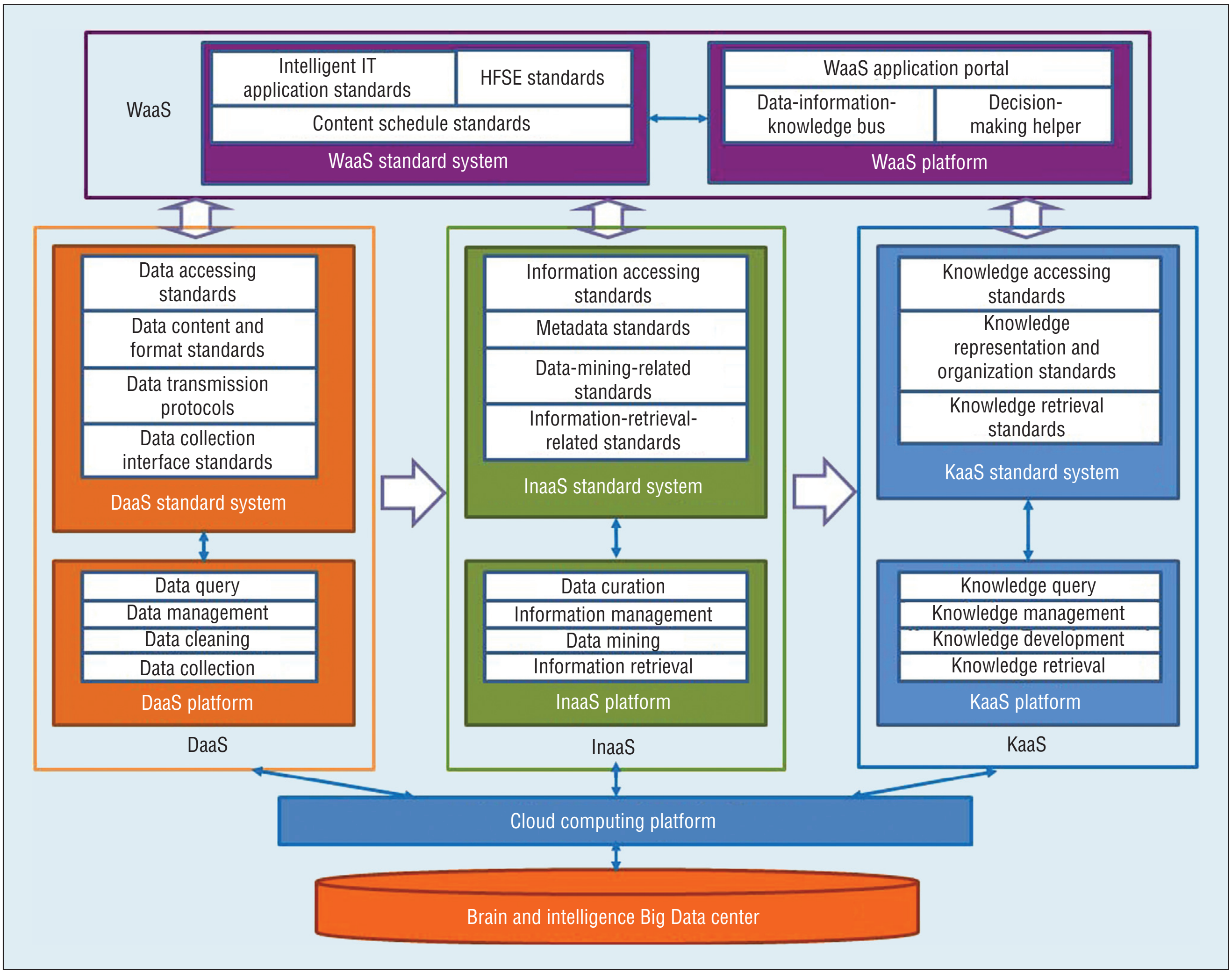

Figure 3. WaaS standard and service platform architecture. A group software platform and standard systems for realizing different layers of services in the WaaS architecture.

is an open portal on which different service modules can be deployed, and the standard system is a group of standards and specifications that describe the requirements and methods for developing and using service modules on the software platform. All the software platforms and standard systems can be described as follows:

- The DaaS platform includes the data collection, cleaning, management, and query modules to support the three types of DaaS services. The core is the data collection module, consisting of many data collection interfaces for "reading" data from the Web, information systems, deploying sensors, embedded chips, experimental devices, and so on.
- The DaaS standard system consists of four types of standards, namely, data collection interface standards, data transmission protocols, data content and format standards, and data accessing standards. These standards or protocols are based on applications and can be classified into different types according to different data sources, application environments, and application purposes. For example, different data transmission protocols should be designed and used in the Internet and MI.
- The InaaS platform includes the information retrieval, data mining, information management, and data curation modules to support the four types of InaaS services. Data curation focuses on information organization, including metadata construction and case creation. Because the hyperworld includes mutable data, computing, and network environments, it's necessary to perform the offline information extraction and organization before services are requested.
- The InaaS standard system consists of four types of standards, namely, information retrieval-related, data mining-related, metadata, and

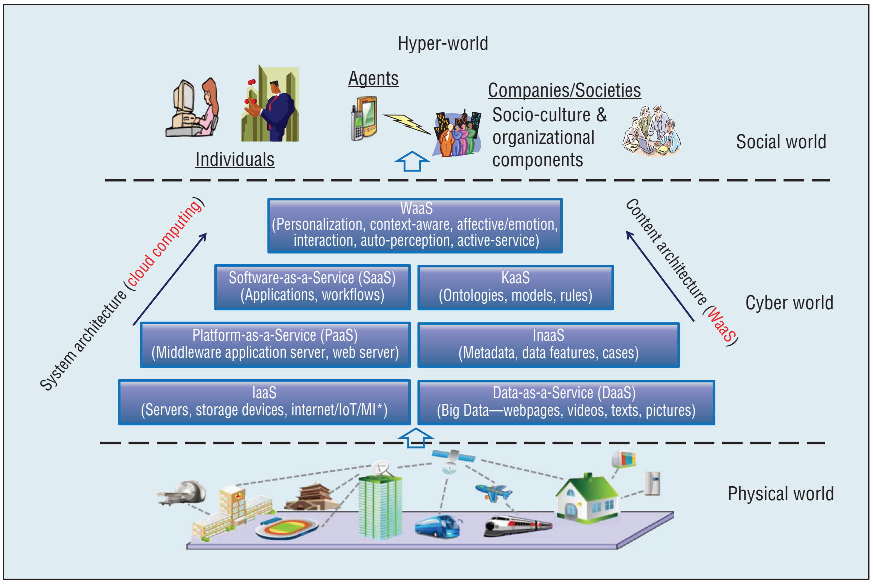

Figure 4. An open and interoperable architecture of IT applications for Wisdom Web of Things (W2T). It binds WaaS and cloud computing to meet six core demands of intelligent IT applications, including infrastructures, platforms, software, data, information, and knowledge, in a unified, pay-as-you-go manner.

information accessing standards. Information retrieval-related standards mainly focus on application service definition and protocol specification, whereas data mining-related standards are involved with mining languages, result representation languages, mining system architectures, and so on. Metadata standards are classified and defined according to application domains. Information accessing standards are used to define accessing interfaces and transmission protocols of InaaS service modules on the InaaS platform.

- The KaaS platform includes the knowledge retrieval, development, management, and query modules for various KaaS services. The knowledge retrieval module is developed based on WI-specific technology that extracts knowledge from enormous information sources. The knowledge development module provides various tools for the development of ontologies, models, and other types of formal knowledge. The knowledge management module and knowledge query module are used to manage formal knowledge and provide knowledge sharing services, respectively.
- The KaaS standard system consists of knowledge retrieval-related standards, knowledge representation and organization standards, and knowledge accessing standards. The knowledge retrieval-related standards are mainly used to define application services and protocols. The knowledge representation and organization standards focus on knowledge representation languages, such as the cyber-individual (Cyber-I) representation language.[12] Knowledge accessing standards mainly involve knowledge query languages, accessing interfaces, system architectures, transmission protocols, and so on.
- The WaaS platform includes the data-information-knowledge bus, decision-making helper, and WaaS application portal. The data-information-knowledge bus is a special enterprise service bus (ESB) for discovery and integration of DaaS, InaaS, and KaaS services. The decision-making helper is used to assist judgments and decisions. Based on them, various intelligent IT applications can be deployed on the WaaS application portal to make correct actions—namely, to provide intelligent services. Furthermore, HFSE can also be regarded as a kind of special intelligent applications.
- The WaaS standard system consists of content (data, information, and knowledge) schedule standards, intelligent IT application standards, and HFSE standards. They concern content schedule languages, application interfaces, application wrappings, application communications, and HFSE-related technical standards and laws.

All software platforms are open. Based on the standards and protocols in the four standard systems, any third party can develop and plug in their service modules on these platforms, which are also interoperable. Because they adopt the same standards and protocols, different service modules on platforms can effectively communicate and cooperate with each other to provide the various services in the DIKW hierarchy. Furthermore, other systems and platforms can also cooperate with these service modules based on the above standards and protocols. This openness and interoperability make it possible to converge all technologies and resources into a unifying framework for realizing a W2T cycle.

Binding WaaS with Cloud Computing

The development of intelligent IT applications needs to meet both system- and content-level demands. Typically, system-level demands are related to infrastructures (network, storage, and computing resources), running platforms, and software (developing

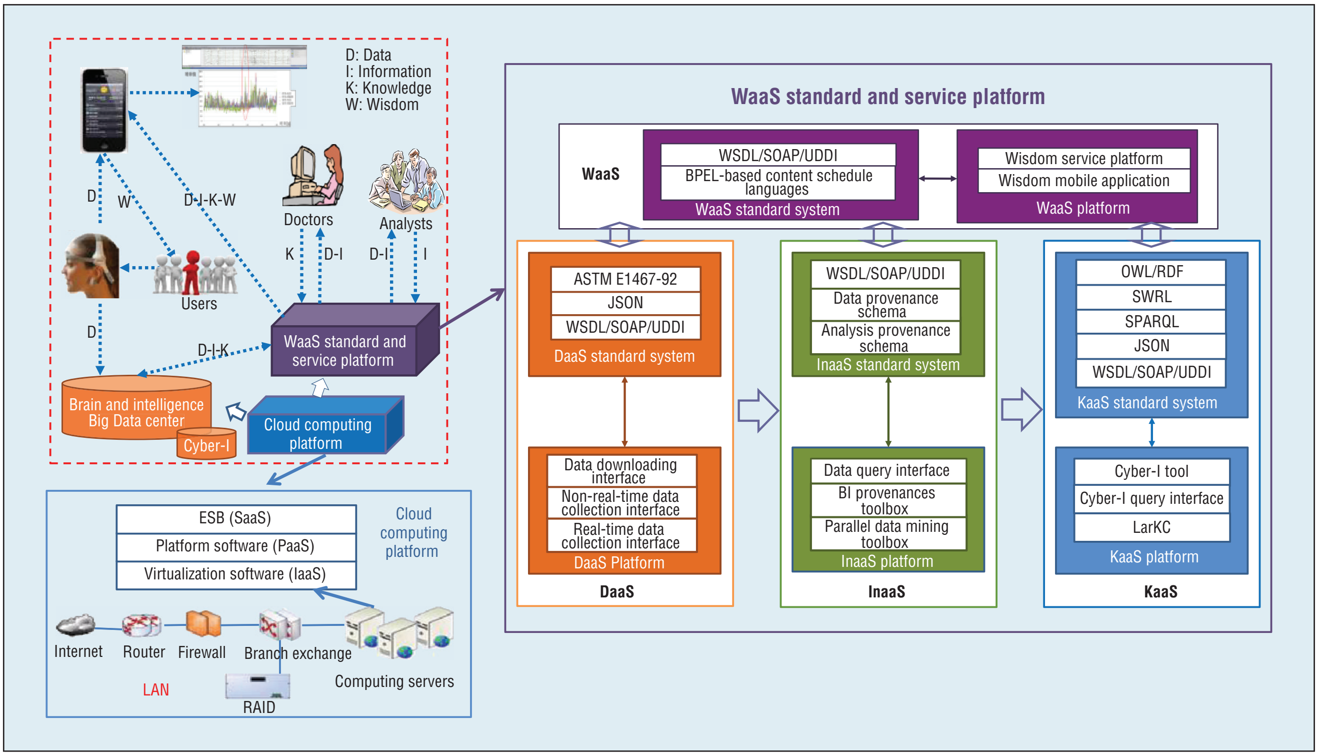

Figure 5. Technological framework of the portable brain and mental health-monitoring system. Various system- and content-level demands in developing this intelligent IT application are met by realizing the architecture that binds WaaS with cloud computing.

and scheduling abilities), whereas content-level demands are related to Big Data and its processing.

Figure 4 shows an open and interoperable architecture of IT applications that binds WaaS and cloud computing. It meets two types of demands in a unified, pay-as-you-go manner: cloud computing provides an open IT architecture for sharing system resources, including infrastructures, platforms, and software, by means of IaaS, PaaS, and SaaS. Paralleling the cloud model, WaaS is about sharing content resources and processing utilities. Through these "as a service" layers, six factors—infrastructures, platforms, software, data, information, and knowledge—will converge into an open and interoperable uniform platform, on which all factors can be effectively utilized by various intelligent technologies to form an intelligent service layer—specifically, the WaaS layer.

Case Study

Based on the architecture that binds WaaS with cloud computing, we developed a prototype of a portable brain and mental health-monitoring system (brain-monitoring system, for short) to support the monitoring of brain and mental disorders, a huge public health concern. As Figure 5 shows, various system- and content-level demands in developing this intelligent IT application can be met by integrating cloud computing and WaaS.

We adopted cloud computing (including IaaS, PaaS, SaaS) to meet the system-level demands of the brain-monitoring setup based on the "anything as a service" paradigm. As a cross-platform, data-intensive intelligent system, it needs credible infrastructures, an open running platform, and an extensible developing and scheduling mode. We constructed a private cloud to meet these demands. As Figure 5 shows, various servers, a redundant array of independent disks, mobile phones, local area networks, the Internet, and MI form a powerful infrastructure on which virtualization software is stepped up to dynamically provide needed infrastructure resources as services for the brain-monitoring system based on the IaaS mode. Open platform software provide the needed running PaaS mode, and we adopted Web service technologies to develop all the functional components and software systems as services on the ESB based on the SaaS mode.

We used the WaaS architecture (DaaS, InaaS, KaaS, WaaS) to meet the content-level demands of the brain-monitoring system based on the "anything as a service" paradigm. To provide smart monitoring services, the brain-monitoring system needs high-quality monitoring data, efficient data processing capabilities and

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methods, accurate diagnosis models, and personalized and wisdom service modules. All these demands are met by a WaaS standard and service platform that includes the four suplatforms shown in Figure 5:

- The DaaS platform is for data-level demands. By using data collection interfaces and the data downloading interface, as well as corresponding portable EEG (electroencephalogram) equipment and mobile phones, global research groups and individuals can provide data production and sharing services to collect high-quality monitoring data.
- The InaaS platform is for information-level demands. Global analysts can use the parallel data mining toolbox and the brain informatics (BI) provenances toolbox[13] to realize various data mining and curation services, which provide efficient data processing capabilities and methods to extract peculiar indexes from patients' EEG data and integrate obtained indexes and other related information into BI provenances.
- The KaaS platform is for knowledge-level demands. Based on the LarKC (Large Knowledge Collider),[14] the Cyber-I tool and the Cyber-I query interface make it possible to realize knowledge extraction and query (sharing) services, which provide individualized diagnosis models (a kind of special Cyber-I) based on peculiar indexes and other information in BI provenances.
- The WaaS platform is for wisdom-level demands. Personalized and wisdom service modules are deployed on the wisdom service platform and the wisdom mobile application to provide various remote and local smart monitoring functions. These functions are realized based on intelligent technologies and DaaS, InaaS, and KaaS services, which are called by the data-information-knowledge bus.

As Figure 5 shows, each subplatform is based on the corresponding standard system. For example, developing the DaaS platform is based on the DaaS standard system, which includes Web services-related standards (Web Service Definition Language, WSDL; Simple Object Access Protocol, SOAP; and Universal Description, Discovery, and Integration, UDDI), a data content and format standard (ASTM E1467-92), and a data interchange standard (JavaScript Object Notation, JSON).

WaaS is a multidisciplinary, interdisciplinary research field for open intelligence service architectures and presents new challenges and issues from both scientific and technological perspectives.

From the scientific perspective, WaaS focuses on the DIKW organization and transformation, whose core is human BI. As one of the most important scientific issues in the 21st century, the study of human BI involves many challenges:

- How do we investigate human BI via research on holistic intelligence?
- How do we collect, manage, and mine BI Big Data to gain a systematic investigation and understanding of human intelligence?

BI provides a systematic methodology for dealing with these challenges, but many problems must be addressed,[15] such as how to develop BI-inspired IT for realizing DIKW organization and transformation. An important part of this is the Cyber-I, a comprehensive digital description of individual humans as a counterpart in the cyber world that brings its own scientific challenges and issues.[13]

From a technological perspective, WaaS is an interoperable content architecture of IT applications for supporting large-scale sharing and cooperation in the DIKW hierarchy. WaaS applications include various kinds of software and u-Things and will be involved in a sustainable development process, so it's important to make the WaaS standard and service platform open, flexible, and friendly so that third parties can develop and plug in to WaaS applications.

A conflict often exists between a system's openness and security. The technological architecture of security and privacy protection should be fit for different application environments, including the Internet, IoT, and MI. We're keeping these issues and challenges in mind for future work.

Acknowledgments

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