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From Internet to Smart World

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ABSTRACT The development of informationization and intelligentization prompts Internet developing toward a new era. A deep fusion among cyber space, physical space, social space, and thinking space brings a quaternionic cyber-physical-social-thinking hyperspace, based on which an embryo of smart world is being established through heterogeneous spaces. The smart world is expected to be an attractive perspective involving ubiquitous sensing, computing, and communication to achieve comprehensive interconnections of physical perception, cyber interaction, social correlation, and cognitive thinking. In this paper, evolution of the smart world is briefly introduced, and physical-based coordination, social-inspired interactivity, brain-abstracted cooperativity, and cyber-enabled homogeneity are, respectively, discussed as the main characteristics of the smart world.

INDEX TERMS Smart world, Internet of Things, cyber-physical-social system, hyperspace.

I. INTRODUCTION

The development of informationization and intelligentization has brought a global digital revolution in recent decades, several research areas (e.g., Internet of Things (IoT), social computing, and brain informatics) emerge to launch significative influences for academia and industry. The IoT as a representative system paradigm aims to realize interactions among ubiquitous things through heterogeneous spaces, and is characterized by comprehensive sensing, reliable transmission, and intelligent processing to achieve pervasive interconnections, intelligence, and efficiency [1], [2]. Social computing highlights socialized intelligence by capturing social dynamics, appointing social agents, and managing social knowledge to develop beyond personal computing, facilitating collaboration and social interactions. Brain informatics is based on web intelligence centric information technologies to enhance human brain data, information, and knowledge interactions. It brings an inevitable reconfigurable combination of emerging technologies to prompt Internet developing into a new era, called smart world, in which the ubiquitous things establish dynamical and seamless interconnections in the cyber-physical-social-thinking hyperspace [3].

The smart world originates with an appearance of computer networks, and Internet subsequently emerges to address cyber entities' interconnections in the cyber space. Considering wireless networking and mobile communications being involved into the Internet, physical objects establish interactions with the cyber entities via standard communication protocols. Accordingly, cyber-physical system appears as an integration of ubiquitous processing, networking, and computing, and realizes that the physical objects are mapped into the cyber space as the cyber entities for more convenient interactions. Thereafter, social attributes (e.g., ownerships, and affiliation relationships) are highlighted to address the human oriented interconnections to establish the cyber-physical-social system.

If social attributes are regarded as a person's external elements, thinking related issues (e.g., emotion, self-awareness, and subconsciousness) will be a person's internal elements. Considering a person's both external and internal elements, the cyber-physical-social space is required to evolve towards a wiser ecosystem with thinking participation. Human cognitive capacities (e.g. logic reasoning, and attention distribution) and society principles are involved for designing a harmonious ecosystem [4], and cyber-physical-social-thinking (CPST) hyperspace is established by merging the thinking space into the cyber-physical-social space. Human cognition along with interactions of data, information, knowledge and intelligence are through the CPST hyperspace.

An embryo of the smart world is associated with a concept of hyperworld, which originally refers to real-digital direct mappings between physical space and cyber space involving hyper-connected multi-worlds [5]. The hyperworld resembles a preliminary cyber-physical-social system, in which the social attributes address complicated interconnections through the cyber-physical-social space. Thereafter, the smart world focuses on ubiquitous intelligence of things being attached, embedded or blended with sensors, actuators, middlewares, interfaces, and other network components in practical applications [6]. It covers dynamic contexts of complex physical, human, social environments and the associated cyber space. A digital copy or counterpart of a real individual (i.e., Real-I) is defined as a cyber individual (i.e., Cyber-I), and comprehensive mapping relationships are established between a Real-I and the corresponding one or multiple Cyber-Is [7]. Along with distributed computing developing towards cloud based web computing, mobile communication based mobile computing, and contexts based social computing, the smart world becomes a cyber space driven hyperspace to address the holographic data, information, knowledge, and wisdom oriented physical perception, cyber interaction, social correlation, and cognitive thinking.

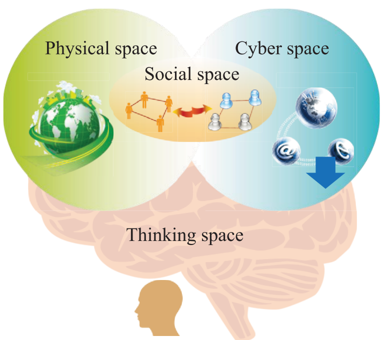

FIGURE 1. The cyber-physical-social-thinking hyperspace.

II. THE CYBER-PHYSICAL-SOCIAL-THINKING HYPERSPACE

Fig. 1 illustrates CPST hyperspace model involving quaternionic cyber-physical-social-thinking dimensions.

- Physical space refers to natural and human-made systems operated in applications, in which physical objects are perceived and controlled by ubiquitous sensors and actuators to establish interactions via information, communication and networking technologies (e.g., remote collaboration, real-time localization, and autonomy maintenance). The physical space mainly addresses the issues such as network infrastructures, heterogeneous interfaces, and interactive environments, in which semantic sensors, cooperative actuators, context-aware networks along with energy consumption, electromagnetic spectrum compatibility, and space-time consistency should be considered to achieve seamless mapping between physical space and cyber space.
- Cyber space is characterized by the discrete, logical, and switched computation, communication, and control. It refers to the generalized information resources, including digital abstractions to achieve interconnections among the cyber entities. The cyber infrastructures are required to support uniform standards and protocols, and to transform the cyber space into an intelligent information ecosystem. The holographic data management, on-demand resource management, and spontaneous service management are required to support cyber interactions.
- Social space is an integration of social attributes and social intra-/inter- relationships owned by human beings and other physical objects/cyber entities. The social space is formally described in semantic representations to address issues such as ownership control management, affiliation relationship modeling, trustworthiness evaluation, and human behavior formalization. Human learning principles (e.g., cognitive psychology, and decision neuroscience) and social rules are introduced to enhance human-nature coexistence.
- Thinking space focuses on cognition issues of human beings and other things, which are reflections of human brains' activities and things' observations on objective existences in the hyperspace. The thinking space mainly addresses the processes of analysis, synthesis, judgment, and reasoning based on representations and abstract conceptions. A concept of Internet of Thinking (IoTk) was first presented on an open forum "Top 10 Questions in Intelligent Informatics/Computing" in World Intelligence Congress for Turing Year [8]. The IoTk is expected that human, nature, and society are collaborative beyond space-time constraints, and human subjective initiative may break cyber-physical-social limitations.

The CPST hyperspace emphasizes convergence to facilitate integration, interconnection, and interaction in the heterogeneous environments. Seamless data, information, knowledge, and wisdom exchanging measurement for the geographically dispersed individuals is anticipated to enhance human thoughts to realize an aggregated functionality. The quaternionic hyperspace convergence is significative for the self-organization of cognitive thinking, and it is an attractive perspective of "thinking being accessed, transferred, discovered, and shared" like other cyber, physical and social resources.

III. MAIN CHARACTERISTICS AND CHALLENGES OF THE SMART WORLD

The smart world is established based on the cyber-physical-social-thinking hyperspace, and there are four main characteristics including physical-based coordination, social-inspired interactivity, brain-abstracted cooperativity, and cyber-enabled homogeneity, as shown in Fig. 2.

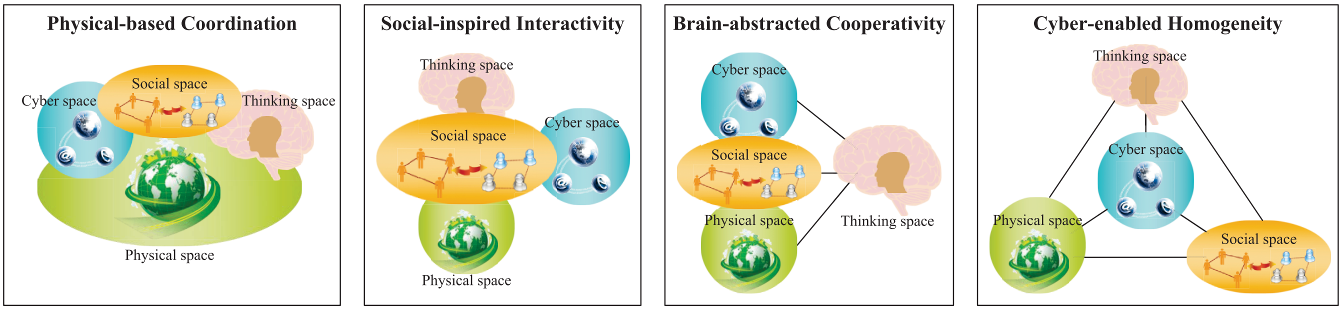

FIGURE 2. The main characteristics of the smart world.

A. PHYSICAL-BASED COORDINATION

Physical-based coordination means that the physical objects establish mutual assistance relationships involving critical infrastructures, heterogeneous interfaces, and interactive environments. During the physical objects' coordination, there are several challenging issues. How to deal with an ultimate limit of Moore's Law? How to guarantee the time-space consistent between physical objects and the corresponding cyber entities under the heterogeneous sensing, communication, and storage environments? How to realize exascale computing by breaking through the bottlenecks including memory, communication, reliability, and energy? The physical-based coordination includes the following main aspects.

- *ID-objects and nID-objects coordination*: The identifier based objects (i.e., ID-objects) and non-identifiers based objects (i.e., nID-objects) establish cooperative relationships [9]. The non-identifiers mainly refer to spatiotemporal, biometric and physicochemical attributes, which are used for object recognition based on temporal and spatial uniqueness, physiological attributes (e.g., fingerprint, hand geometry, iris, and palm vein), behavioral attributes (e.g., typing rhythm, and gait), and other nonunique attributes (e.g., frequency spectrum, and electromagnetic scattering). Note that the nID-objects as necessary supplements for ID-objects have no available identifiers for direct identification, authentication, and addressing.
- *Sensors and actuators coordination*: The wireless sensor-actuator networks are typical forms of sensors and actuators coordination with motivations of automation covering broad domains with real-time requirements. The sensors act as detectors and converters to capture physical data for perception, and semantic sensors should be designed to provide semantic-integration context awareness for supporting meta-service based adaptability and scalability. The actuators convert the received physical data into action commands to realize enhanced efficiency in self-adaptive modes, and collaborative actuators should be organized in interconnected ecosystems to achieve aggregated functionality.
- *Networks and contexts coordination*: Networks and contexts coordination propels context-aware networks, referring to network architectures, protocols, services, communications and applications. Information centric network emerges as a context-aware paradigm [10], which applies content identifiers for enabling context-based operations through information centric channel access, adaptive routing, packet switching and resolution functions. Network middlewares facilitate context-aware services such as social services, migratory services, location services, and multimedia services in heterogeneous networks.

B. SOCIAL-INSPIRED INTERACTIVITY

Social-inspired interactivity addresses the human beings oriented applications in both physical and cyber spaces, in which a person is a comprehensive peer with other networked persons for unrestricted interaction and resource sharing. During the data driven interconnections, Real-Is and Cyber-Is are assigned with the capabilities of accessing transparency, dynamic participation, and accountability.

- *Interactivity between a Real-I and a Cyber-I*: Cyber-I is a digital copy or counterpart of a Real-I with social attribute considerations, and aims to achieve the perfect copy of an individual's internal behaviors. It is a comprehensive digital organism to describe the mapping between a Real-I in the physical space and the corresponding Cyber-Is in the cyber space. Interactivity between a Real-I and a Cyber-I is established, and the Real-I owns inherent and acquired relationships with other Real-Is or Cyber-Is. The Cyber-I is regarded as another self in the cyber space, and adopts data aggregations to address individual modeling in individual-aware applications. The main interactive relationships include the following aspects [7]: 1) enabling a Real-I to own one or more Cyber-Is with symbiotic relationships in the cyber space; 2) enabling comprehensive human modeling involving individual thinking cognition; 3) enabling customized services (e.g., individual-aware service recommendations) and other ubiquitous applications (e.g., service discovery).

- *Interactivity among multiple Cyber-Is*: Social attributes reflect direct/indirect correlations so that socialized relationships exist among multiple Cyber-Is such as collaboration, ownership, communal sharing, equality matching, and authority ranking. A social network game is an online community covering the main components of multi-identifier, status control, assets management, relationship management, resource management, and trustworthiness management. Interactivity among multiple Cyber-Is are organized in autonomous modes to improve social intelligence, and socialized services become noteworthy for the Cyber-Is with social awareness (e.g., social relationships and interactions) considerations. From the perspective of social networking services, the Cyber-Is' interactivity can be analyzed for identifying local and global social patterns, determining influential entities, and monitoring social relationship topology dynamics.

C. BRAIN-ABSTRACTED COOPERATIVITY

Brain-abstracted cooperativity is a reflect of the IoTk, in which cognitive thinking is regarded as the control of associating including the process of analysis, synthesis, judgment, and reasoning based on representations and abstract conceptions. Cognitive thinking aims to perceive, interpret, represent and model the surrounding environments and contexts for decision-making and forecasting, and refers to thinking activities to establish direct mappings of cyber-thinking spaces [3]. Human physiological and mental characteristics (e.g., conditioned reflex, attention allocation, and emotional control) are applied for designing more spiritual interactive mechanisms.

Emerging sensing technologies are applied for brain electrical signal identification, brain information acquisition, human consciousness extraction, and human behavior tendency prediction. Comprehensive human brain data collection realizes to copy and refine cognitive thinking data to support intelligent interactions. Meanwhile, cognitive thinking data collection is achieve for inter-mapping through cyber-physical-social spaces, in which human body sensors are popular for detecting human brain wave and other parameters. Heterogeneous human body area network communications are established for interconnections among multiple individuals. Brain-abstracted cooperativity services are provided to achieve synergetic thinking, and thinking coordination activities are launched to facilitate an optimum interaction in the distributed environments. Brain-abstracted cooperativity promotes creative behaviors, activities, and events for human society to achieve aggregated intelligent services.

Meanwhile, Cyber-Is and other things also have brains to achieve ubiquitous intelligence, which brings several ethical issues. For instance, how to realize harmonious interactions between Real-Is' real brain and Cyber-Is' virtual brains? How to perform communication among a Real-I's multiple Cyber-Is' brains? How to establish consistent interactions between a person's brain and a thing's brain? Will be a cyber brain more smarter than a real brain? Will does a thing's brain control a person's brain?

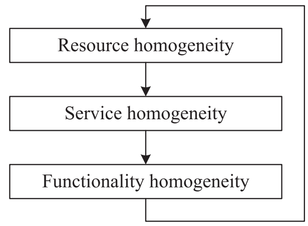

FIGURE 3. The main aspects of cyber-enabled homogeneity.

D. CYBER-ENABLED HOMOGENEITY

Cyber-enabled homogeneity refers to ubiquitous things with different features developing towards an unity of the same nature driven in the cyber space. Almost all cyber entities are formalized by specific rules, models, and semantics. Existing approaches such as object oriented modeling, resource description framework (RDF), web ontology language (OWL), and physical markup language (PML) with particular applicability have emerged as dominant perspectives, and there is less unified cyber entity oriented modeling framework for universal applications. During a physical object mapping into the cyber space as one or multiple cyber entities, the physical object's behaviors, tendencies, and events should be associated with the corresponding cyber entities in dynamic representations. Fig. 3 shows the main aspects of cyber-enabled homogeneity.

- *Resource homogeneity*: Resources refer to heterogeneous elements of limited availability, and can be accessed to support practical applications as essential components during network connections and data interactions. Physical objects and other components are involved in the cyber space to ensure interactive resource cross-sharing and cross-utilization. Network infrastructures, communication channels, computing capabilities, memory storage, and frequency spectrum are typical resources, for which on-demand strategies should be more generalized with negligible differences in the smart world. For instance, frequency spectrum resources are almost fully exploited and utilized, which may be addressed by aggregate programming based on computing and communication resources; Dynamic spectrum allocation may be efficiently addressed according to the similar algorithms as existing energy allocation.
- *Service homogeneity*: The service explosion is an outcome of cloud computing, in which anything as a service (XaaS) covers almost all forms of available resources. Such heterogeneous resources are essentially the same, and service management confronts resources related issues including semantic resource description, on-demand resource allocation, spontaneous resource discovery, and cooperative resource sharing. Web services apply simple object access protocol (SOAP),

Web services description language (WSDL), universal description discovery and integration (UDDI) to support dynamic service provisioning, and configuration of cloud service infrastructures approaches homogeneous to deal with heterogeneous and dynamic requirements. Due to cloud data centers located in different geographical locations, cloud services become homogeneous in user-centric web environments. Complex distributed services should be suitably encapsulated, modulated, and invoked via building-block APIs.

- *Functionality homogeneity*: Though the things' functions become more refined, core functions become more generalized. For instance, wearable devices have the functions including sensing an individual's data (e.g., human body signs, and tracking) based on short-range wireless communication technologies (e.g., Bluetooth, WiFi, and near field communication (NFC)), data analysis is performed for intelligent support and social interaction. Similarly, advanced metering infrastructure (AMI) is an intelligent device to automatically measure, collect, store, and analyze power information for supply-demand balance. In a sense, wearable devices and AMI can be regarded as functionality homogeneous due to the common data acquisition, information processing, knowledge extraction, intelligent computing, and remote cloud storage.

Considering increasing data center sizes restrict the sustainable growth of the remote and geographically distributed cloud services and network operators along with explosive expansion of connections. Network architectures, topologies, and routing protocols have been designed to enhance network capacity and efficiency, and software defined networks (SDN) emerge to manage network services through abstraction of lower-level functionality. The SDN differ from network virtualization (NV) and network functions virtualization (NFV), which create virtual tunnels and functions to physical networks. While, the SDN essentially change physical networks to promote cyber-enabled homogeneity, and bring the homogeneity of hardware components due to a centralized control plane separated from the traffic forwarding or switching plane.

IV. CONCLUSION

In this work, a quaternionic cyber-physical-social-thinking hyperspace has been identified, and an embryo of smart world is presented based on the heterogeneous spaces. The smart world is described according to the main characteristics including physical-based coordination, social-inspired interactivity, brain-abstracted cooperativity, and cyber-enabled homogeneity, in which the challenging issues are accordingly discussed in the field of smart world. It indicates that the smart world will be an attractive perspective to achieve a perfect convergence of cyber-physical-social-thinking hyperspace, and launches comprehensive interactions of data, information, knowledge and intelligence.

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