Cybermatics: A Holistic Field for Systematic Study of Cyber-enabled New Worlds

Jianhua Ma, *Member, IEEE*, Huansheng Ning, *Senior Member, IEEE*, Runhe Huang, *Member, IEEE*, Hong Liu, *Member,* Laurence T. Yang, *Senior Member, IEEE*, Jinjun Chen, *Senior Member, IEEE*, and Geyong Min, *Member, IEEE*

Abstract—**Following the two trends of computerization and informatization, another emerging trend is cyberization in which numerous and various cyber entities in cyberspace will exist in cyber-enabled worlds including the above cyber world and cyber-conjugated physical, social and mental worlds. Computer science and information science as holistic fields, have played important roles in the respective computerization and informatization. Similar to them, it is necessary to have a corresponding field in the cyberization. Cybermatics is proposed as such a holistic field for systematic study of cyber entities in cyberspace and cyber world, and their properties, functions and conjugations with entities in conventional spaces/worlds. This article sets out to explain the necessity, rationality, and significance of the proposed cybermatics, what it is and it encompasses, and how it is related to other fields and areas.**

Index Terms—**Cyber, cybermatics, cyberization, cyberspace, cyber entity, cyber world, cyber-enabled, cyber-conjugated, cyber-physical, cyber-social, cyber-mental, science, computer, data, information, network, communication, ubiquitous, system.**

I. INTRODUCTION

Computation and communication are two basic capabilities of human beings. Over the course of the previous two centuries, these two capabilities have been extended to machines, typically computers and communication devices. Over the last two decades, both these capabilities have been further extended to ordinary things that are part of everyday life such as consumer goods, vehicles, mechanical systems, houses, clothes, furniture, farms, organizations, cities and so on, as first envisioned and called ubiquitous computing by Mark Weiser around 1990 [1], and later named as pervasive computing by IBM in 1999 [2].

In addition to the computation and communication capabilities, these machines, devices and ordinary things are also all able to be interconnected by networks, especially the Internet and Web. In other words, these non-human things are also feasibly capable of sense, information processing, interaction, cognition, and even thinking and taking autonomic actions. As a result, we are stepping into a completely new world environment with pervasive computation, communication, interaction, sensation, information and intelligence embedded in numerous ordinary things, including plants and even the human body as well as the brain, towards a hyper world [3] with hyper-connections [4] we first envisioned in 1995, and a smart world [5] with smart u-things [6] and ubiquitous intelligence [7] as we depicted in 2005. The new world environment covers so many things and various aspects, and also brings a revolutionary change on almost all parts, even on human life and society worldwide.

In actual fact, all profound change brought about by the new world environment will be due to the ubiquitous emergence of digital things, namely, the digital space called cyberspace and digital entities called cyber entities. These two constitute a digital world called cyber world that can be made to closely correlate to and further reshape various ordinary things/entities in the conventional physical, social and mental spaces/worlds with necessary ubiquitous safe guarantee [8]. Following the present two revaluations of computerization and informatization, the next revolution will be cyberization in which numerous cyber entities will be synthesized or generated by computers, and almost all real things/entities in physical, social and mental worlds may also be cyberized to possess corresponding cyber entities as their mappings, counterparts [9] or components [10] existing in the cyber world with digital explosions and digital clones [11].

Actually, such the cyberization has begun from some aspects with dispersive studies such as embedded computing, Internet of Things (IoT), cyber-physical system (CPS), social networks/computing, wearable system [12], smart object [13], smart environment [14], smart city [15], smart agriculture [16], Internet economy [17], cyber security [18], cyber physics [19], cyber psychology [20], and cyber individual (Cyber-I) [10]. Computing cloud [21] can be regarded as a special and huge cyber entity, a common resource infrastructure of computation

J. Ma is with the Faculty of Computer and Information Sciences, Hosei University, Tokyo 184-8584, Japan (e-mail: jianhua@hosei.ac.jp).

H. Ning is with the Faculty of School of Computer and Communication Engineering, University of Science and Technology Beijing(USTB), China (e-mail: ninghuansheng@ustb.edu.cn).

R. Huang is with the Faculty of Computer and Information Sciences, Hosei University, Tokyo 184-8584, Japan (e-mail: rhuan@hosei.ac.jp).

H. Liu is with the Research Institute, Run Technologies Co., Ltd. Beijing, China (e-mail: liuhongler@ieee.org).

T. L. Yang is with the Department of Computer Science, St. Francis Xavier University, Antigonish, Canada (e-mail: ltyang@stfx.ca).

J. Chen is with Faculty of Engineering and IT, University of Technology Sydney, Australia (Jinjun.Chen@uts.edu.au).

G. Min is with College of Engineering, Mathematics and Physical Sciences, University of Exeter, Exeter, EX4 4QF, U.K. (e-mail: g.min@exeter.ac.uk).

and storage to support the above dispersive systems and the cyberization in general. Big data [22] is a one of common features in the above cyberized systems and its technologies will play a very important role as one of general foundations in the process of the cyberization.

The ongoing cyberization will result in not only continuous evolution and formation of the digitized cyber world, but also emergence and development of cyber-conjugated physical, social and mental worlds. That is to say, it is now at the transitional process from the conventional worlds to cyber-enabled worlds including the cyber world and the cyber-conjugated worlds, namely cyber-physical, cyber-social, cyber-mental, and other cyber-combined worlds. These cyber-enabled worlds are completely new in the human history and fully unknown yet to our human beings.

Like computer science [23] and information science [24] (or informatics [25]) that, as respective holistic fields of computation and information, have played fundamental roles in the computerization and the informatization, we believe that it is also necessary to set up a corresponding holistic field for the cyberization. Therefore, we name the field specifically for systematic study of the cyber-enabled new worlds as *Cybermatics* including cyber science, physics, sociology, psychology, medicine, life, engineering, technology and so on. The cybermatics can be regarded as a higher and more comprehensive field for all cyber-related researchers to share common research topics and further coordinately work on common key problems in the novel cyber world and the cyber-conjugated new worlds. It is expected that systematic knowledge about the cyber-enabled worlds, with joint efforts from all cyber-related scientists and researchers, can be finally built so as to deeply understand basic properties of the new worlds, explain their phenomena scientifically, predict their directions precisely, and develop and use their technologies more effectively.

Based on the above vision, we organized the cybermatics congress in 2013 [26], edited a special focus on cybermatics in Science China Journal in 2014 [27], and wrote a paper to address the basic features and issues in cybermatic study [28]. This article sets out to further explain the proposed field of cybermatics, why it is necessary and significant, what it is and what it encompasses, how it is so named and related to other fields.

In what follows, we first give detailed explanations about the trends from computerization, informatization to cyberization in the next section, then examine implications of cyberspace and cyber world that lead to cyber-enabled worlds containing various cyber entities in Section III, describe concept and possible coverage of cybermatic in Section IV, discuss relations between cybermtics and other fields in Section V, and finally show our perspective on cybermatics in the last section.

II. THE TRENDS FROM COMPUTERIZATION, INFORMATIZATION TO CYBERIZATION

If counted from the ENIAC, an electronic computer in modern sense made in 1945, the computer history has been seventy years. In the present, computers have become so popular in our daily life, working, learning, and entertainment. They are used not only for computations but also as ways to process information so that computation-information integrated systems or devices, e.g., smartphones have brought revolutionary change to our lives and the world. All the change is due to two fundamental trends, computerization and informatization. The change is still going on, probably more profound, since another trend, cyberization, has emerged. In the following we further explain how these trends have come.

Weiser and Brown summarized the modern computing history in three phases/eras/waves/trends: the mainframe (MC), the personal computer (PC) and the ubiquitous computer (UC), which corresponds to the three relationships between computers and humans: one-to-many, one-to-one and many-to-one [29]. They described the typical usages and roles of computers in each of the three eras or trends, and further proposed that the so called calm technology would be a fundamental challenge in the UC era. Moreover, we think it is also very important and necessary to figure out the most essential characteristics in each of three eras/trends so as to know what have been happening for the seventy years of computing history. In Fig. 1, we try to summarize these essential characteristics in terms of computational element, existing form, main purpose, processing content, central goal, basic goal, and corresponding field of study corresponding to each of the MC, PC and UC eras/trends.

Mark Weiser's Three Relations in Three Computing Eras	The Place of computer technology in our lives...		
	m-to-1 MC	*1-to-1* PC	*1-to-m* UC
Comp Element	Mainframes	Personal Computers	Things + Clouds
Existing Form	Large/Stationary	Small/Portable	Invisible/Ubiquitous
Main Purpose	Computation	Information	Cyberization
Proc. Content	Numbers/Data	Media/Stream Data	Context/Big Data
Central Goal	Fast/Precise	Rich/On-demand	Aware/Automatic
Basic Behavior	Passive	Interactive	Active
Field of Study	Computer Science	Information Science (Informatics)	Cyber Science - Cybermatics -

Fig. 1. The three computing eras/trends and their characteristics.

In the MC era, many persons, mainly experts, share uses of one computer, which is large, stationary, and mainly for computation to process numbers or pure data [30]. In the PC era, an ordinary person can use a small computer, which can be put on the desk or portable like a notebook/tablet, and is purposed beyond only computation and often for information interaction to process media especially streamed audio/video data [31]. In the UC era, each person is possibly surrounded by many computers, which are further smaller and even invisible since they may be embedded/integrated/blended into ordinary things, and act as these things' cyberization parts that are able to compute with support of the clouds. A computer's behavior should be passive in the MC era for fast and precise computations with strictly following instructions specified in programs, interactive in the PC era for rich and on-demand

multimedia information, and active in the UC era for context-aware and automatic services because it is impossible for a person to interact with so many computable things surrounding him/her and generating so much data, i.e., big data, in various forms.

The computerization has begun since the MC era, and the informatizaion has started from the PC era. The two are still going on to achieve higher and higher performance in making computation and processing information. Now the cyberization has been emerging in the UC era. As different from the computerization and the infomratization in which many computational and informational elements are made available and applicable as systems, machines and devices in our actual worlds, the cyberization is to synthesize or generate pure digital cyber things and further conjugate with, i.e., integrate, embed or blend computational and informational elements into ordinary things to extend and enhance them while still keeping their original function purposes in their daily uses.

Computer science as a holistic field of study to computers, computations and their applications was born in the MC era. Information science, or informatics, was born in the PC era, which is a broader field based on but beyond computer science with further combining information acquisition and processing theories as well as technologies. From the above review of computing history, it is quite obvious that another holistic field should come into being in the UC era. It looks rational to call it cybermatics corresponding to the cyberization purpose in the UC era/trend in parallel with the respective fields of computer science and information science or informatics in the MC and PC eras/trends.

III. CYBERSPACE, CYBER WORLD, CYBER-ENABLED WORLDS AND CYBER ENTITIES

Before fully describing general concepts, characteristics and coverages of cybermatics in the next section, it is necessary to first examine the implications of cyberspace and cyber world, and further discuss what our worlds will be and how the things in these worlds will become during such the cyberization in this section.

A. Cyberspace

Inspired partially by Wiener's book about 'Cybernetics' in 1948 [32], the term "cyberspace" was first used by Danish artist S. Ussing and architect C. Hoff who made "Astelier Cyberspace" in the Copenhagen visual arts in 1969 [33]. Their artistic work was a 'sensory space' – a physical room that could sense and adapt to human and other influences in this room. Later, this term first appeared in W. Gibson's cyberpunk science fiction [34], short story 'Burning Chrome' [35], and novel 'Neruomancer' [36] in 1980s. He described cyberspace as "a graphic representation of every computer in the human system." The term "cyberspace" started to become popular and was generally meant as global digital networks and connections due to the spread of the Internet and the Web in 1990s [37].

Although the cyberspace has become a buzzword from 2000 and several tens of definitions about it have been given, there is no official definition yet. Recently, M. Mayer, et al, defined

that "Cyberspace is a global and dynamic domain (subject to constant change) characterized by the combined use of electrons and electromagnetic spectrum, whose purpose is to create, store, modify, exchange, share and extract, use, eliminate information and disrupt physical resources." [38].

No matter what definitions are, cyberspace should possess two basic abilities: data storage and flow among computers or computational elements that are interconnected locally and globally by networks as well as a network of networks. When associated with some specific meanings, data can be regarded as information. So, cyberspace can also be regarded as a global infrastructure or a gigantic system in which information can be stored and flowed.

B. Cyber World and Cyber-enabled Worlds

The term "cyberworld" first appeared in a film "CyberWorld 3D" in 2000 [39]. So far there are not many definitions on cyberworld yet though it has been used often for various purposes such as a company's name [40] and a course's title [41]. T. L. Kunii defined "cyberworlds as worlds on cyberspace as computational spaces either intentionally or spontaneously, with or without design" [42] in 2004. J. Ma, the first author of this paper, defined that "A cyber world is a digitized world created on cyberspaces inside computers interconnected by networks including the Internet" [5] in 2005. When realizing the great potential and importance, Kunii, Ohmori, Ma and others organized the first international Symposium on Cyber Worlds [43] at Tokyo in 2002, which became an annual international conference [44] from 2003.

As similar to the physical space in which there exist various and numerous real things, the cyberspace can also be an independent 'place' for the existence of digital things that are made of the digital substances, data and information. We can simply define that cyber world is one including cyberspace and all digital things in the cyberspace. The cyber world will be further expended along with enhancement of the cyberspace and increase of the digital things.

The cyber world is a completely new one to our human being in addition to conventional physical, social and mental worlds as drawn in Fig. 2. A digital thing can be synthesized purely by computers, or integrated/embedded/blended into an ordinary thing in the physical, social or mental spaces/worlds, as we previously described about the trend of ubiquitous computing (UC). As a result, the cyber world not only emerges as a novel world but also interconnect physical, social and mental worlds to form cyber-connected worlds.
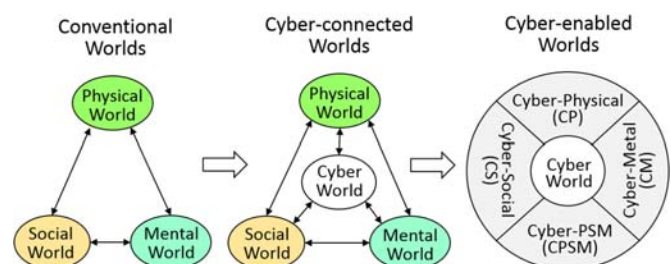

Fig. 2. The conventional worlds and the cyber-enabled worlds.

Besides cyber connections, the cyber world can be further conjugated with the three conventional worlds to form cyber-conjugated worlds including various cyber-physical (CP), cyber-social (CS) and cyber-mental (CM) things/systems as well as other possible cyber-conjugated combinations generally denoted as CPSM shown in the right of Fig. 2. In fact, the artistic work "Astelier Cyberspace" made by Ussing and Hoff in 1969 could be seen as a cyber-physical conjugated 'sensory space' that could respond and adapt to human and others. The basic feature of the 'sensory space' is almost the same as current study of smart space [45] such as smart room [46] and smart office [47]. So, what Ussing and Hoff wanted to express through the "Astelier Cyberspace" was not a gigantic global system for data storage and flow in terms of the current understanding about cyberspace, but actually a conjugation of cyber technologies and real spaces, which is partially similar to our cyber-conjugated worlds. There are already many other studies about such conjugations like cyber-physical system [48], cyber-social system [49], and cyber-mental brain [50].

It is pretty sure that there will be more and closer conjugations of the cyber world and the conventional worlds. That is, one of our world's evolutionary trends is the cyberization to form cyber-enabled new worlds including the emerging cyber world and cyber-conjugated worlds so that the conventional worlds to our human beings will be changed revolutionarily and reshaped greatly.

C. Cyber Entity in Cyber-enabled Worlds

Cyber world is man-made but truly exists in parallel with the physical, social and mental worlds that human beings inhabit. In the cyberization process, more and more digital things will be added to the cyber world. To be relatively more assortive with the terms of cyberspace, cyberization and cyber world, the digital things able to be in cyberspace can be also known as cyber entities. We may generally define that a cyber entity can be anything that exists digitally in cyberspace, either purely synthesized by a computer, or closely correlated to and further conjugated with a real entity in physical, social and mental spaces, as conceptually shown in Fig. 3.
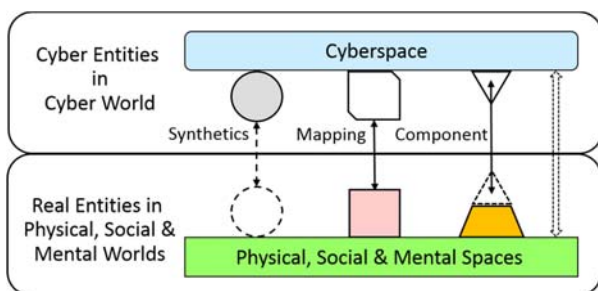

Fig. 3. Entities and their relations in cyber, physical, social and mental worlds.

For a synthetic cyber entity such as the circle with solid line in Fig. 3, it may or may not have a counterpart in any of three conventional worlds, and thus the circle in conventional worlds is drawn in a dotted line. A real entity, e.g., the filled square in conventional worlds may be mapped to a cyber entity in cyber world. Because the mapped cyber entity usually possesses only partial attributes and features of the real entity, it is drawn in an unfilled and incomplete square in the cyber space in the figure. A real entity may contain a digital component, e.g., the triangle in the figure, whose hardware may be together with the entity but its data and software will be as its cyber entity resided in cyber world. The cyberspace can be also seen as a special or super cyber entity that exist in parallel or may have some relations with the conventional physical, social and mental spaces.

There exist many different kinds/forms of cyber entities, many of which directly correlate to or are even closely conjugated with entities in the conventional worlds. It is because of this correlation and conjugation that real entities have a cyber existence, are able to be interconnected via cyberspace, and behave rather differently than they do in the original physical, social and mental spaces/worlds.

To further expand on the implications of this, the following are typical features for various forms of cyber entities.

- A cyber entity may have no direct correlation with an entity in the physical world, such as a virtual 3D graphic object purely synthesized by a computer, or it may directly correspond to a physical entity, such as a digital representation of a real object or a person.
- A cyber entity may be as simple as a brief webpage introduction about a product, or may be as complex as a digitally visualized spacecraft comprising myriad parts and functions.
- A cyber entity may be without life features such as a profile about a person, or can to some extent exhibit life-like features as a digital artificial plant/animal would.
- A cyber entity may possess no intelligence at all like an RFID code stamped on a retail item, or may show high intelligence such as IBM's Watson [51], an intelligent computer system capable of answering questions posed in natural language.
- A cyber entity can be as concrete as an e-book designed merely to be browsed, or as abstract as a knowledge base for automatic intelligent computing.
- A cyber entity may be a part of a larger cyber entity, such as an agent in a software system, or a digital part integrated with a physical/social entity to form a cyber-physical or cyber-social system.

In summary, there are and can be many different forms of cyber entities that exist in the cyber world, and many of them can also be conjugated with entities in physical, social and mental worlds. It is the existence and conjugation of such cyber entities, which is emerging rapidly in the novel cyber world, and which is changing the conventional worlds drastically to build new cyber-physical, cyber-social, cyber-mental and other possible cyber-combined worlds.

IV. CYBERMATICS – CONCEPT AND COVERAGE

The universe is everything that exists within time and space. Science is the systematic study of the universe to build and organize knowledge to explain and predict the universe [52]. It

is divided into branches such as formal science, physical science, life science, social science and earth/space science, which are further divided into more concrete disciplines such as physics, genetics, economics, and so on. To study phenomena or apply scientific knowledge in engineering, multiple disciplines are involved together to form interdisciplinary or transdisciplinary fields, for instance, biophysics and robotics.

The universe now contains special things/members, i.e., digital cyberspace and cyber entities that are entirely and radically new within the realm of human experience, due to the progress of computer and information sciences as well as advances in network, material and other technologies. Besides purely synthesized cyber entities, many things/entities in the physical, social and/or mental spaces can also be mapped to cyberspace with corresponding cyber representations, or contain a cyber functional part. Following the trends of computerization and informatization, we are in the process of ceyberization, which will bring us to the cyber-enabled worlds including the cyber world and cyber-conjugated worlds.

It is thus very natural and necessary to have a new field, as we have called cybermatics, corresponding to the cyberization towards the cyber-enabled new worlds. In the following of this section, the concept of cybermatics and its linguistic origin are first given, and then the possible coverage and important areas of cybermatics are described.

A. Concept and Implications of Cybermatics

Cybermatics is a holistic field to systematically study cyber entities in cyberspace, their properties and functions as well as their relations and conjugations with entities in physical, social and mental spaces. That is, it is the interdisciplinary and comprehensive research and practice of the existence, attribute, identification, structure, model, representation, relation, interconnection, interaction, intelligence and evolution of cyber entities. The cybermatic study is to build and organize the body of knowledge about cyber entities as well as their practical technologies and applications.

The word "entity" is rooted from Latin, *ens*, or being, or existing [53], and an "entity is something that exist in itself, actually or potentially, concretely or abstractly, physically or not" [54]. Cyber entities are a new kind of entities existing digital in cyber world and being made of computable data and information. They may or may not have direct correlation to real entities in the physical, social and mental worlds. There are many forms of cyber entities with different features as we have discussed in the last section.

Cyber- is derived from "cybernetic", which comes from the Greek word κυβερνητικός meaning skilled in steering or governing [55]. It is now often used as a IT related prefix, and may cover, or be related to other prefixes such as *e-*, *i-*, *u-*, *info-*, *net-*, etc. It is also used for neologisms such as cyberpunk, cyberlaw, cybercrime, cyberwarfare, cyberculture, etc. The popularity of *cyber-* prefixed new words (as well as *e-*, *i-*, *u-* ones) also partially indicates the potential of cyber related things, and the coming of a new digital cyber world, in which there will be numerous cyber entities that are possibly correlated to or conjugated with entities in the physical, social

and mental worlds.

The suffix *-matic* comes from *matos* in Greek that means "willing to (perform)" [56]. The suffix *-ic* comes from *-ikos* in Greek, meaning "behaving like" or "having the characteristics of". The suffix *-ics* can be used to form a noun to name a field of study, for instance, mathematics, automatics, kinematics, systematics, and so forth.

The term "*cybermatic*" can be regarded as "*cyber + matos + ikos*", which may mean a thing willing/able to be, behaving like or having cyber characteristics. From the linguistics sense, "cybermatics" can be understood as a field to study cybermatic things, i.e., various cyber entities existing in cyber-enabled worlds as a distinct phenomenon.

Note that the term 'cybermatics' is spelt very similarly to the term 'cybernetics' that is "a trans-disciplinary approach for exploring regulatory systems, their structures, constraints, and possibilities" [57], and which has different focus and scope from cybermatics, although both of their respective spellings and pronunciations are very similar. Their comparisons are discussed after the next subsection. The cybermatic study is very broad and with extreme wide coverage that is described in the next subsection.

B. General Coverage of Cybermatics

Cybermatics is oriented mainly to the cyber entity (CE) that exist in cyber world and may be correlated to an entity in cyber-conjugated worlds. So, cybermaitics falls into two basic research categories, the cyber world category and the cyber-conjugated category, respectively, as shown in Fig. 4.
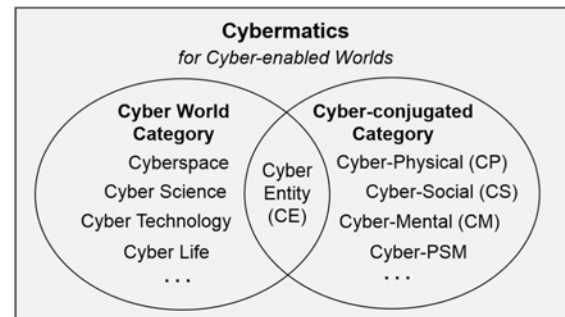

Fig. 4. The general categories of cybermatics for cyber-enabled worlds.

The cyber world category addresses the fundamental properties and functions of cyber entities in cyberspace, which of itself can also be regarded as a special cyber entity. Hence, cyberspace should be covered in this category and studied as a new but different space from the existing spaces with conventional temporal-spatial characteristics. Cyber science is a scientific study of cyber entities (CEs) to build systematic knowledge about them, while cyber technology is to apply the knowledge into design, development, implementation and application of cyber entities. Although the life feature is not a necessary attribute, the cyber life will be definitely an exciting area in cybermatic study. Actually, this category covers many research areas including but not limited to the following.

- Existence feature, form and identification of CEs

- Structure, model and representation of CEs
- Interconnection and interaction between CEs
- Intelligence of CE, cloud, Web and Internet
- Virtual reality, avatar and collaborative CEs
- Data science, Web science and Internet/network science
- Cyber life, evolution, cooperation and security

The cyber-conjugated category is to scientifically study these cyber entities that are conjugated with entities in the physical, social and mental worlds as well as other possible integrations. So, this category can be further divided into four sub-categories of study, cyber-physical (CP), cyber-social (CS), cyber-mental (CM), and cyber-physical-social-mental (CPSM) conjugations, which are explained one by one in the following.

1) Cyber-Physical Conjugation (CPC)

CPC is primarily concerned with how physical entities are conjugated with cyber entities. The conjugation may be direct or indirect, tight or loose, simple or complex, static or dynamic, permanent or temporary, etc. It is aimed at the scientific study and practical approaches to the cyber-physical conjugations. The CPC areas include the following ones.

- Generic forms, properties and models of CP conjugation
- Cyber mapping & representation of physical entities in IoT
- CP entities, systems and augmented/mixed reality
- Smart CP entities, e.g., smart object, vehicle, home, etc.
- Interconnection, interaction and intelligence of CP entities
- Autonomy, control, trust and safety of CP entities
- Life, green and ecological characteristics of CP entities

2) Cyber-Social Conjugation (CSC)

CSC is primarily concerned with how social entities including human social organizations and economic activities are conjugated with cyber entities. A cyber-social conjugation may be a mapping of a social entity with a digital entity in cyberspace, such as a person's identity in a cyber community or a product introduction on the Web. The conjugation may also be through cyber entities such as social networks (SNS) to connect human entities or e-business platforms to support economic activities. The CSC addresses the scientific study and practice of such CS conjugation, its properties as well as the discovery of new phenomena in social behavior in CS entities and activities. The CPC covers the following areas.

- Cyber identities and representations of social entities
- Connective properties of social entities via social networks
- Behavior analysis and modeling of social entities
- Structure and complexity of CS entities and networks
- Crowd sensing, sourcing and intelligence
- Cyber/Internet-based governance, business and economy
- Cyber rights, fairness, privacy and law

3) Cyber-Mental Conjugation (CMC)

CMC encompasses two forms of conjugation. One is the use of cyber entities and cybermatic technologies to study mental activities including cognition, thinking and psychology. The other is for the design of cognitive, thinking and affective cyber-mental (CM) entities that may understand, serve and even collaborate with humans. The CPC areas include the following ones.

- Cyber-based brain science and neuroscience
- Digital brain theory, technologies and engineering
- Internet of knowledge, thinking, emotion and creation
- Hybrid intelligence of humans and intelligent cyber entities
- Activity/behavior/mind recognition and synthesis
- Cyber psychology and affective cyber entities
- Human modeling, digital clone and personalized services

4) Cyber-Physical-Social-Mental Conjugation (CPSMC)

CPSMC addresses the conjugation and integration of more than two types of entities in the four basic spaces/worlds. The possible integrations are cyber-physical-social (CPS), cyber-physical-mental (CPM), cyber-social-mental (CSM) and cyber-physical-social-mental (CPSM). The rationale behind the study of such cyber-based integrations is the fact that many organizations and activities involving physical, social and mental entities can be digitally hyper-connected through cyberspace and cyber entities. CPSMC is the comprehensive study and practice of various multiple integrations towards a cyber-physical-social-mental syncretic hyper world. CPSMC may cover the following areas.

- Relation of cyberspace with physical/social/mental spaces
- Hyper connection of cyber, physical, social, mental entities
- Structure/organization of CPS, CPM, CSM, CPSM system
- Data-Information-Knowledge-Wisdom in CPSM systems
- Smart city, agriculture, organization, factory, etc.
- Cyber-physical-social-mental dynamics and ecology
- Cybermatic philosophy and methodology

From the above it can be seen that cybermatics is with a very broad coverage. This is because cybermatics is for the new cyber world and its conjugations with physical, social and mental worlds, in which there are so many unknown phenomena and challenging problems in various aspects. We have only provided one approach to categorize cybermatic research and list related research areas. This is our first attempt to systematically classify and organize cyber-related studies so that cybermatics can be actually regarded as a holistic field of study for the cyber-enabled worlds. Besides, the cybermtaic research areas given in each of the categories and sub-categories are not exhausted since the cybermatics field is too broad to list all of them and to predict what new areas will emerge in the future. It is sure that other category approaches may arise and additional cybermatic areas will appear in the following years.

V. Relations between Cybermatics and Other Fields

From the cybermatic categories and areas given in the last section, it is obvious that many items are not new, already have existed for certain years or emerged in recent years. It is true that the many cybermatic areas are closely related to or rooted in many other fields or areas of study. Cybermatics is not to replace these existing fields and areas, but to conform all dispersive cyber-related studies, inspire further new studies and organize them organically to form a holistic field so as to build systematic knowledge about cyber-related new phenomena and facts as well as their applications. This is because our worlds are changing abruptly due to the emerging cyberspace and

cyber world as well as their deep conjugations with the physical, social and mental worlds due to knowledge accumulations and fast progresses of many fields and areas of study. In the following, we discuss possible relations of cybermatics with computer and information sciences, other typical fields and some emerging research area, respectively.

A. Relations with Computer and Information Sciences

As we have examined the seventy years' computing history, computer science has emerged from the MC era/trend, information science or informatics has emerged from the PC era/trend, and cybermatics is highly possibly emerging in the current UC era/trend. However it cannot be said that one is super among the three. For information science, its scope looks broader but information processing relies largely on effective data computation, which is the main subject of computer science. Sometimes it is very hard and even impossible to clearly mark their exact differences due to great overlaps and associations between their research areas. This is almost the same for cybermatics, there are definitely many overlaps and close relations with computer and information sciences.

However, the most remarkable difference between the three is the research object on which each of them is focused. Computer science focused more on data, information science is mainly around information, and cybermatcis is concerned primarily with cyber entity. Data is made of binary digits, and information is made of data, while a cyber entity is not only made of data and information, but also able to be conjugated with a real entity to change the real entity's behavior. One may argue that the term 'entity' has been used in some areas of computer and information sciences. Indeed, we can find many studies using 'entity', such as DBMS [58], VHDL [59], ER Model [60], and basic information entity modeling [61]. However, they use the 'entity' as an abreaction of a dataset or an informational unit. Cybermatics is regarded a cyber entity not only as a digital one existing in cyber world but also as a possible organic part of a real entity so that the two entities are integrated into a completely new one existing in both the cyber and real worlds.

B. Relations with Other Typical Fields of Study

Cybermatics is based on the vision that cyberspace and cyber world will not only hyper-connect but also further conjugate with the conventional physical, social and mental worlds, which have been extensively researched in various fields of study. So, cybermatics is naturally with relations to many other fields or disciplines. Among them, the cybernetics is the most related to the proposed cybermatics.

The term cybernetics was first coined by the French physicist Andre-Marie Ampere to denote the sciences of government in his classification system of human knowledge in 1834 [62]. The American physicist and mathematician Nobert Wiener borrowed the term in his book "Cybernetics" and defined it as the study of control and communication in the animal and machine in 1948 [32]. Now days there are many definitions about cybernetics since it has been interweaved with many other fields/disciplines that study such systems containing closed signaling loops for feedback controls [57]. A cyber entity or a collection of cyber entities, especially cyber-physical, cyber social and cyber-mental or other cyber-integrated entity, may also form a system with a feedback control. Hence, the knowledge of cybernetics will be surely useful to study the cyber entities and properties from the viewpoint of system feedback control and on the new dimensional cyberspace. In addition, cybermatics is concerned more with the basic properties of cyber entities and all their possible relations beyond looped behaviors in cybernetics.

In principle, the whole world can be regarded as a gigantic system consisting of many various systems. What's new in cybermatics is the emergence of the cyberspace as well as cyber and cyber-integrated entities. To some sense, cybermatics can be studied as a special branch of system science [63] taking this cyber existence/attribute into consideration. Network science [64] is the study of network representations of physical, biological, and social phenomena, and will be one of foundations of cybermatic study since the hyper-connection between cyber entities via cyberspace is one of their essential characteristics. Due to the penetration and integration of cyber entities into various aspects in the world, cybermatics will also be related to other fields/disciplines, such as sociology, psychology, ecology, life science and so on.

C. Relations with Some Emerging Research Areas

In recent years some new cyber-related areas have emerged, such as IoT, cyber physical system, smart object, smart city, social networking/computing, green computing [65], crowd souring [66], hybrid intelligence [67], digital brain [68], digital clone [69], Web science [70], Internet science [71], cyber ecology [72], cyber warfare/defense [73], and cyber privacy [74]. The appearance of these new areas partially implies the coming of cyberization as well as the cyber world and its conjugation with the physical, social and mental worlds. However, these emerging areas focus only on certain/partial aspects of cyber entities in cyber-enabled worlds, and their studies are carried out separately to a greater or lesser extent. Therefore, cybermatics is aimed to offer a broader and holistic field to aggregate these emerging areas in a united cybermatic framework on which all cyber-related researchers can share their insights, identify common problems and find new directions for more comprehensive and systematic study of cyber and cyber-integrated entities on the new horizon of the cyberspace and cyber-enabled worlds.

VI. REMARKS

Due to the breakneck progress of computer, communication and information technologies, from one year to the next we experience new and exciting development in ICT devices and services. The penetration of ICT technologies and their use in ordinary goods, the home, the urban environments, and almost everywhere in the world even inside our body or brain alerts us to widespread and inescapable change. It is certain that the pace of such change and its impact will intensify. Though exciting, it is hard to know what our world will become and predict how our world will evolve long term.

A major part of this new experience and change will be due to the emergence of the new cyber world made by cyberspace as well as various cyber entities that can be further conjugated with numerous entities in the physical, social and mental worlds. Following the computerization and informatizaion, the cyberization has begun, and being brought us to cyber-enabled worlds. In the same fashion that science has built systematic knowledge for understanding, predicting and shaping worlds, it is believed that the cybermatics will play a significant role forming systematic cyber-related knowledge for the better creation of the new cyber world, and the further understanding, predication and reformation of the present worlds.

In this paper, we try to first figure out the most fundamental emerging trend, i.e., cyberization, from examining the seventy years' computing history according to Mark Weiser' three relationships between computers and humans, and then find out cybermatics naturally being a field of study for the cyberization from analyzing the corresponding relations between computer science and computerization as well as between information science and infomatization. To make the proposed cybermatics more rational from cyber-related terms, we check the originations and meanings of cyber, cyberspace, cyber world and cybernetics, and further identify the cyber-related thing, named cyber entity that should be the core research object in cybermatics. A cyber entity can be synthesized purely by a computer or conjugated with an entity in the physical, social and mental worlds, and thus cybermatic research can be divided into the two basic categories, one for cyber world and the other for cyber-conjugated worlds. We further give representative areas in each of the two categories and discuss the relations between cybermatics and other well established fields and recently emerging research areas.

However, there are lots of work left to further make the proposed cybermatics more exact and more complete. It is necessary to identity the most basic characteristics of the so called cyberization as well as cyber world and cyber-enabled worlds. Since the cyber entity looks the core in cybermatic research, its exact concept and attributes should be well studied and provided. It is also necessary to study what a cyber-conjugated entity does really mean, and how the cyber-physical, cyber-social and cyber-mental conjugations are actually conducted. The refinements of the organization of cybermatic research areas are necessarily further carried out, and more detailed relations between cybermatics and other fields/areas are also needed to be drawn. Although it is believed that the cybermatics is indeed necessary and significant, it is impossible for only we authors of this paper to fully clarify the whole cybermatics for the huge and unknown new world environment. What we have presented in this paper is just a beginning to primarily introduce the cybermatics. Hopefully, many others may also think about it so that all of us can work together to jointly establish the holistic field for systematic study of the coming cyber-enabled new worlds.

REFERENCES

[1] M. Weiser, "The computer for the twenty-first century," Scientific American, pp. 94–100, September 1991.

[2] D. Saha and A. Mukherjee, "Pervasive computing: A paradigm for the 21st century," IEEE Computer, pp. 25–31, March 2003.

[3] T. L. Kunii, J. Ma and R. Huang, "Hyperworld modeling", in Proceedings of the International Conference on Visual Information Systems, pp1-8, Australia, 1996.

[4] J. Ma and R. Huang, "Improving human interaction with a hyperworld", in Proceedings of DMS'96, pp46-50, Hong Kong, 1996.

[5] J. Ma, L. T. Yang, B. O. Apduhan, R. Huang, L. Barolli, M. Takizawa, "Towards a smart world and ubiquitous intelligence: A walkthrough from smart things to smart hyperspaces and UbicKids", International Journal of Pervasive Comp. and Comm., 1(1), pp.53-68, March 2005.

[6] J. Ma, "Smart u-things – challenging real world complexity," IPSJ DSP Symposium Series, pp. 146–150, 2005.

[7] J. Ma, "Ubiquitous Intelligence – The intelligence revolution", ID People Magazine, Published by On Publishing SA, April 2005.

[8] J. Ma, Q. Zhao, V. Chaudhary, J. Cheng, L. T. Yang, R. Huang, and Q. Jin, "Ubisafe computing: Vision and challenges (I)", in the *Lecture Note in Computers Science on Autonomic and Trusted Computing (ATC-06)*, vol. LNCS 4158, Springer, 2006.

[9] J. Wen, K. Ming, F. Wang, B. Huang, J. Ma, "Cyber-I: Vision of the individual's counterpart on cyberspace", IEEE CS Proc. of the 8th IEEE Int'l Conf. on Dependable Autonomic and Secure Computing (DASC'09), pp.295-301, December 2009.

[10] J. Ma, J. Wen, R. Huang, B. Huang, "Cyber-individual meets brain informatics", IEEE Intelligent Systems, Vol.26, No.5, pp.30-37, 2011.

[11] J. Ma and R. Huang, "Digital explosions and digital clones", in Proceedings of the International IEEE Conference on Internet of People, Beijing, 2015.

[12] J. Ma and R. Huang, "Wear-I: A new computing paradigm in wearable computing", in Proceedings of the International IEEE Conference on Ubiquitous Computing and Communications, Liverpool, 2015.

[13] G. Kortuem, et al., "Smart objects as building blocks for the internet of things," Internet Computing, IEEE, vol. 14, no. 1, pp. 44-51, 2010.

[14] D. J. Cook and S. K. Das, *Smart Environments: Technologies, Protocols and Applications*, Wiley-Interscience, 2005.

[15] M. Miller, *The internet of things: How smart TVs, smart cars, smart homes, and smart cities are changing the world*, Que Publishing Incorporation, 2015.

[16] B. M. Campbell, et al, "Sustainable intensification: What is its role in climate smart agriculture?" *Current Opinion in Environmental Sustainability*, Elsvier, Vol. 8, pp. 39–43, October 2014.

[17] OECD (2013), "Ensuring the global participation in the Internet economy for development", No. 227, OECD Publishing. [Online]. Available: http://dx.doi.org/10.1787/5k437p2rp4bq-en

[18] J. Mehan, *CyberWar, CyberTerror, CyberCrime and CyberActivism*, IT Governance Publishing, ISBN13: 9781849285711, 2014.

[19] P. J. Casey, *Physics and Cyber-Enabled Manufacturing Process Control*, PN, 2008.

[20] Gi. Riva and C. Galimberti, *Towards CyberPsychology - Mind, Cognition and Society in the Internet Age*, IOS Press, 2001.

[21] E. Simmon, et al., "A vision of cyber-physical cloud computing for smart networked systems," NIST, Aug, 2013.

[22] A. J. Jara, D. Genoud, Y. Bocchi, "Big data for cyber physical systems: An analysis of challenges", Proc. Eighth International Conference on Solutions and Opportunities, Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), IEEE, pp. 376-380, 2014.

[23] Computer Science, from Wikipedia, the free encyclopedia. [Online]. Available: https://en.wikipedia.org/wiki/Computer_science

[24] Information Science, from Wikipedia, the free encyclopedia. [Online]. Available: https://en.wikipedia.org/wiki/Information_science

[25] Infomatics, from Wikipedia, the free encyclopedia. [Online]. Available: https://en.wikipedia.org/wiki/Informatics

[26] Beihong University (2013, Aug.), *The 2013 World Cybermatics Congress,* [Online]. Available: http://www.china-iot.net/

[27] H. Ning, J. Ma, L. T. Yang, W. Lv, X. Wu, V. C. M. Leung, and V. Piuri, "Editor's note - Special Focus on Advanced Science and Technology for Future Cybermatics," in *Science China, Information Sciences*, Vol. 57, No. 3, March 2014.

[28] H. Ning, H. Liu, J. Ma, L. T. Yang, and R. Huang, (2015, Aug.) "Cybermatics: Cyber–physical–social–thinking hyperspace based science and technology", *Future Generation Computer Systems*, Elsvier, (in press). [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0167739X15002356

[29] M. Weiser and J. S. Brown, "The coming age of calm technology". In: P. J. Denning and R. M. Metcalfe, editors, *Beyond Calculation: The Next Fifty Years of Computing*. Copernicus, Springer-Verlag, 1997.

[30] J. Nathan Kutz, *Data-Driven Modeling & Scientific Computation: Methods for Complex Systems & Big Data*, Oxford Univ. Press, 2013.

[31] C. Stewart and A. Kowaltzke, *Media: New Ways and Meanings*, Jacaranda, Milton, Queensland, Australia, 1997.

[32] N. Wiener, *Cybernetics, or Control and Communication in the Animal and the Machine*, Cambridge, MIT Press. 1948.

[33] J. Lillemose and M. Kryger (2015, Aug.), "The (Re)invention of Cyberspace," Kunstkritikk, [Online]. Available: http://www.kunstkritikk.com/kommentar/the-reinvention-of-cyberspace/

[34] W. Gibson (1980s), "Cyberpunk", from Wikipedia, [Online]. Available: https://en.wikipedia.org/wiki/Cyberpunk

[35] *Burning Chrome*, from Wikipedia, the free encyclopedia. [Online]. Available: https://en.wikipedia.org/wiki/Burning_Chrome

[36] *Neuromancer*, from Wikipedia, the free encyclopedia. [Online]. Available: https://en.wikipedia.org/wiki/Neuromancer

[37] Cyberspace, from Wikipedia, the free encyclopedia. [Online]. Available: https://en.wikipedia.org/wiki/Cyberspace

[38] M. Mayer, L. Martino, P. Mazurier, G. Tzvetkova (2014, May), "Cyberspace Definition by Draft Pisa", [Online]. Available: https://www.academia.edu/7096442/How_would_you_define_Cyberspace

[39] CyberWord, from Wikipedia, the free encyclopedia. [Online]. Available: https://en.wikipedia.org/wiki/CyberWorld

[40] Mazak Cyber World, https://english.mazak.jp/news-events/cyberworld/

[41] Course CSCI E-45A (2015, fall), The Cyber World: Hardware, Software, Networks, Security, and Management, [Online]. Available: https://www.extension.harvard.edu/academics/courses/cyber-world-hardware-software-networks-security-management/14299

[42] T. L. Kunii, "The potentials of cyberworlds –An axiomatic approach-", Proceedings of International Conference on Cyberworlds, IEEE, pp.2-7, 2004.

[43] Hosei University (2002, Nov.), The First International Symposium on Cyber Worlds – Theories and Practices, Tokyo, Japan, [Online]. Available: http://cyberworlds-conference.org/

[44] CW Conference, The International Conference on Cyber Worlds, [Online]. Available: http://www.cyberworlds-conference.org/

[45] J. Ma, "Spacelog concept and issues for novel u-services in smart spaces," Keynote in the International Conf. on Future Generation Communication and Networking, IEEE Press, pp.89-92, 2008.

[46] C. Busso, et al, "Smart room: Participant and speaker localization and identification", Proceedings of IEEE ICASSP, 2005.

[47] C. L. Gal, J. Martin, A. Lux and J. L. Crowley, "Smartoffice: Design of an intelligent environment", IEEE Intelligent System, vol. 16, no. 4, pp. 60-66, 2001.

[48] W. Wolf and T. Georgia, "Cyber-physical systems," Computer, vol. 42, no. 3, pp.88-89, 2009.

[49] S. Wakamiya, R. Lee, K. Sumiya, "Exploring reflection of urban society through cyber-physical crowd behavior on location-based social network," Proceedings of DASFAA Workshops, pp. 168-179, 2012.

[50] A. Saniotis, "Future brains: An exploration of human evolution in the 21st century and beyond," *World Future Review*, p.5-11, June-July 2009.

[51] IBM Watson, The DeepQA Research, [Online]. Available: http://www.ibm.com/smarterplanet/us/en/ibmwatson/

[52] Science, from Wikipedia, the free encyclopedia. [Online]. Available: https://en.wikipedia.org/wiki/Science

[53] Entity, [Online]. Available: http://whatis.techtarget.com/definition/entity

[54] Entity, from Wikipedia, the free encyclopedia. [Online]. Available: https://en.wikipedia.org/wiki/Entity

[55] *Cyber*– prefix, the IT related suffix, from Wikipedia, [Online]. Available: https://en.wikipedia.org/wiki/Internet-related_prefixes

[56] *–matic* suffix, What does the suffix -matic mean? [Online]. Available: https://www.quora.com/What-does-the-suffix-matic-mean

[57] Cybernetics, from Wikipedia, the free encyclopedia. [Online]. Available: https://en.wikipedia.org/wiki/Cybernetics

[58] DBMS, Database Management System. [Online]. Available: https://en.wikipedia.org/wiki/Database

[59] VHDL, VHSIC Hardware Description Language. [Online]. Available: https://en.wikipedia.org/wiki/VHDL

[60] P. Chen, "Entity-Relationship Modeling: Historical Events, Future Trends, and Lessons Learned", Software Pioneers, Springer-Verlag. pp. 296–310, 2002.

[61] L. Thow-Yick, "The basic entity model: A fundamental theoretical model of information and information processing," *Information Processing and Management*, vol.32, no.4, pp. 477–487 1996.

[62] H.S. Tsien, *Engineering Cybernetics*, McGraw Hill, 1954.

[63] System Science, from Wikipedia, the free encyclopedia. [Online]. Available: https://en.wikipedia.org/wiki/Systems_science

[64] Network Science, from Wikipedia, the free encyclopedia. [Online]. Available: https://en.wikipedia.org/wiki/Network_science

[65] P. Mittal and N. Kaur, "Green computing – A survey", *International Journal of Computer Trends and Technology (IJCTT)*, vol.4, No.4, 2013.

[66] J. Howe, "The rise of crowdsourcing," *Wired magazine*, vol. 14, no. 6, pp. 1-4, Jun. 2006.

[67] Z. Wu and N. Zheng, "Hybrid intelligence", *Communications of China Computer Federation*, vol. 8, no.1, 59-64, 2012.

[68] R. Kurzweil, "Medical nanobots will connect brain to cloud computing," The Research Laboratory Online Brainchip for Mind Control. [Online]. Available: http://nanobrainimplant.com/

[69] J. Ma, "Digital clones: Possible or impossible?" The World Intelligence Congress, Keynote, Macau, 2012.

[70] Web Science, from Wikipedia, the free encyclopedia. [Online]. Available: https://en.wikipedia.org/wiki/Web_science

[71] Internet Science, from Wikipedia, the free encyclopedia. [Online]. Available: https://en.wikipedia.org/wiki/Internet_science

[72] J. Jorgensen and P. Rossignol, "Information assurance cyber ecology", DARPA Technical Report, AFRL-IF-RS-TR-2003-1, January 2003.

[73] D. Ball and G. Waters, "Cyber defence and warfare," Security Challenges, vol. 9, no. 2, pp. 91-98, 2013.

[74] A. Etzioni, *Privacy in a Cyber Age*, Palgrave Macmillan, 2015.

Jianhua Ma is a professor of the Department of Digital Media in Faculty of Computer and Information Sciences at Hosei University, Japan. Before joining the present university in 2000, he had 15 years' teaching and working experience at NUDT, Xidian University and University of Aizu (Japan). His research interests include multimedia, networks, ubiquitous computing, social computing, and cyber intelligence. He has published over 200 papers, and edited over 20 books/proceedings and over 20 journal special issues. He is a co-founder of IEEE Int'l Conf. on Ubiquitous Intelligence and Computing (UIC), IEEE Conf. on Cyber, Physical and Social Computing (CPSCom), IEEE Conf. on Internet of Things (iThings), and Smart World Congress (SWC).

Huansheng Ning received the BS degree from Anhui University in 1996 and the PhD degree from Beihang University in 2001. He is a professor in the School of Computer and Communication Engineering, University of Science and Technology Beijing, China. His current research interests include Internet of Things, Cybermatics, electromagnetic sensing and computing. He has published several books and more than 100 papers in journals, international conferences/workshops. He is a senior member of the IEEE.

Runhe Huang is a professor in the Faculty of Computer and Information Sciences at Hosei University, Japan. She received a Ph.D. in Computer Science and Mathematics from University of the West of England in 1993. She has been working in the field of Computer Science and Engineering since 1982. Her research fields include Artificial Intelligence and its Applications, Distributed Intelligence Computing, Big Data Ming and Service Computing, Mobile Computing, Ubiquitous Intelligence Computing, and Cloud Computing, Hyper-world Modeling. She is member of IEEE and ACM.

Hong Liu received her Ph.D. degree from the School of Electronic and Information Engineering, Beihang University, China. She works as a research fellow in the Research Institute, Run Technologies Co., Ltd. Beijing, China. She focuses on the security and privacy issues in wearable devices, vehicle-to-grid networks, cyber-physical-social system, and Internet of Things. She has published more than 20 papers in journals and international conferences. Her research interests include authentication protocol design, and security formal modeling and analysis.

Laurence T. Yang received his B.E. degree in computer science from Tsinghua University, China, and his Ph.D. degree in computer science from the University of Victoria, Canada. He is a professor in the School of Computer Science and Technology at Huazhong University of Science and Technology, China, and in the Department of Computer Science, St. Francis Xavier University, Canada. His research interests include parallel and distributed computing, and embedded and ubiquitous/pervasive computing. His research is supported by the National Sciences and Engineering Research Council and the Canada Foundation for Innovation.
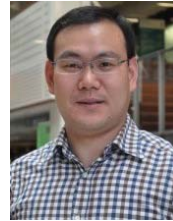
Jinjun Chen is an Associate Professor from Faculty of Engineering and IT, University of Technology Sydney, Australia. He holds a PhD in Computer Science and Software Engineering (2007) from Swinburne, a master degree in engineering (1999) and a bachelor degree in applied mathematics (1996) from Xidian University, China. His research interests include Big Data, Data Science, Cloud Computing, Security and Privacy, Data Intensive Systems. He has published more than 130 papers in high quality journals and conferences, including IEEE TSE, TC, TPDS, TSC and TCC, and ACM TOSEM and TAAS. He received IEEE Computer Society Outstanding Leadership Awards (2008-2009, 2010-2011), Vice Chancellor Research Awards, and many other awards.

Geyong Min is a Professor of High Performance Computing and Networking in the Department of Mathematics and Computer Science within the College of Engineering, Mathematics and Physical Sciences at the University of Exeter, United Kingdom. He received the PhD degree in Computing Science from the University of Glasgow, United Kingdom, in 2003, and the B.Sc. degree in Computer Science from Huazhong University of Science and Technology, China, in 1995. His research interests include Future Internet, Computer Networks, Wireless Communications, Multimedia Systems, Information Security, High Performance Computing, Ubiquitous Computing, Modelling and Performance Engineering..