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

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***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 cyber world and cyber-conjugated physical, social and mental worlds. Computer science and information science, as holistic fields, have respectively played important roles in computerization and informatization. Similarly, it is necessary for there to be a corresponding field for cyberization. Cybermatics is proposed as such a holistic field for the 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 and rationale for, and significance of, the proposed field of Cybermatics, what it is and what 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

Over the 200 years since the Industrial Revolution, the human ability to compute and communicate have been extended to machines, initially by mechanical means, but latterly by computers and communication devices such as telephones and wireless 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 these 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 addition, these non-human things are also feasibly capable of sensation, processing information, interaction, cognition, and even thinking and taking autonomic actions. As a result, we are stepping into a completely new world environment of 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 this development in 1995, and also depicted a smart world [5] with smart u-things [6] and ubiquitous intelligence [7] in 2005. This new world environment will extend to such a range of things and apply to such a variety of contexts that it will bring about revolutionary change in almost every facet of human life and society.

In essence, the profound change brought about by this new world environment will be due to the ubiquity of digital things, existing in the digital space called cyberspace and by digital entities called cyber entities. Both constitute a digital world called cyber world that can be configured to closely correlate to and further reshape various ordinary things/entities in conventional physical, social and mental spaces/worlds.

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 ordinary things/entities in physical, social and mental worlds may also be cyberized to possess corresponding cyber entities as mappings [3], counterparts [8] or components [9] existing in the cyber world with digital explosions and digital clones [10].

Such cyberization is beginning to take place in diverse fields such as embedded computing, Internet of Things (IoT), cyber-physical systems (CPS), social networks/computing, ubisafe computing [11], wearable systems [12], smart objects [13], smart environments [14], smart city [15], smart agriculture [16], Internet economy [17], cyber security [18], cyber physics [19], cyber psychology [20], and cyber individual (Cyber-I) [9]. Computing cloud [21] can be regarded as an enormous distinct cyber entity, a common resource infrastructure of computation and storage to support the diverse

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systems mentioned above and cyberization in general. Big data [22] is one of the common features of these cyberized systems, and its technologies will play a very important role as a core foundation in the process of the cyberization.

Ongoing cyberization will not only result in the continuous evolution and formation of the digitized cyber world, but also the emergence and development of cyber-conjugated physical, social and mental worlds. That is to say, we are now at the transitional stage between conventional worlds and 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 unprecedented in human history and human beings will never have experienced their like.

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 of human life, we believe that it is also necessary to create a corresponding holistic field for cyberization. Therefore, we name the field specifically created for the systematic study of cyber-enabled new worlds *Cybermatics*. This field includes cyber science, physics, sociology, psychology, medicine, life, engineering, technology and so on. Cybermatics can be regarded as a more comprehensive field in which all cyber-related researchers share common research topics and further coordinate work on key problems in the novel cyber world and cyber-conjugated new worlds. It is expected that ultimately, with the joint efforts of all cyber-related scientists and researchers, systematic knowledge about cyber-enabled worlds can be gathered so as to deeply understand the basic properties of the new worlds, explain their phenomena scientifically, predict their behaviors precisely, and develop and use their technologies more effectively.

Based on this vision, we organized a Cybermatics congress in 2013 [26], edited a special focus on Cybermatics in the Science China Journal in 2014 [27], and wrote a paper to address 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 a detailed explanation of the trend from computerization, informatization to cyberization, and then in Section III examine the implications of cyberspace and the cyber world that lead to cyber-enabled worlds containing various cyber entities. We describe the concept and possible coverage of Cybermatics in Section IV, and discuss relations between Cybermatics and other fields in Section V. Finally, we outline our perspective on Cybermatics in the last section.

II. The Trends from Computerization, Informatization to Cyberization

If dated from the ENIAC, the first electronic computer in the modern sense, made in 1945, computer history has existed for seventy years. To the present, computers have become increasingly common in our daily life, working, learning, entertainment and other activities. They are used not only for computation, but also as ways to process information so that computation-information integrated systems or devices, e.g., smartphones, have brought about revolutionary change to our lives and the world. All this change is due to two fundamental trends, computerization and informatization. This change is still ongoing, probably to an even more profound extent, since another trend, cyberization, has emerged. In the following section, we further explain how these trends have come about.

Weiser and Brown summarized modern computing history as the histories of three formats: the mainframe computer (MC), the personal computer (PC) and the ubiquitous computer (UC), which correspond to three relationships between humans and computers: many-to-one, one-to-one and one-to-many [29]. They described the typical usage and role of computers in each of the three eras. Moreover, we think it is also very important to define the most essential characteristics of each of three eras so as to understand what has taken place over the seventy years of computing history. In Fig. 1, we try to summarize these essential characteristics in terms of their computational element, existing form, main purpose, processing content, central goal, basic goal, and the corresponding fields of study for each of the MC, PC and UC eras.

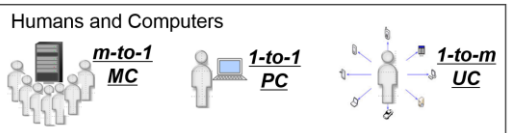
Mark Weiser's Three Relations in Three Computing Eras	Humans and Computers 		
Comp Element	Mainframes	Personal Computers	Things + Clouds
Existing Form	Large/Stationary	Small/Portable	Invisible/Ubiquitous
Main Purpose	Computation	Information	Cyberization
Proc. Content	Numbers/Data	Media/Stream Data	Context/Big Data
Central Goal	Fast/Precise	Rich/On-demand	Aware/Autonomic
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, groups of people, mainly experts, shared the use of one large stationary computer, primarily for computation to process numbers or pure data [30]. In the PC era, each of larger numbers of people can possess a small computer, either in desktop form, or in a portable form such as a notebook/tablet, for use which extended beyond computation to information interaction and the provision of media content, especially streamed audio/video data [31]. In the UC era, each person may be surrounded by many computers, which are much smaller, and even invisible, since they may be embedded into ordinary things, and act as these things' cyberization elements that are able to compute with support of clouds. A computer's behavior had to be passive in the MC era for fast and precise computation by 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 autonomic services because it would be impossible for a person to interact with so many computable things surrounding them and generating so much data, i.e., big data, in various forms.

Computerization has been taking place since the MC era, and informatization started in the PC era. These processes are still ongoing and achieve greater and greater performance in carrying out computation and processing information. Now cyberization is emerging in the UC era. Unlike the cases of computerization and informatization, in which many computational and informational elements are made available and applicable as systems, machines and devices in the real world, in the case of cyberization, pure digital cyber things are synthesized or generated which further conjugate with, i.e., integrate, embed or blend computational and informational elements into ordinary things to extend and enhance them, while still retaining their original functions in daily use.

Computer science, as a holistic field of study to computers and their applications, was born in the MC era. Information science, or informatics, was born in the PC era, and is a broader field based on but beyond computer science, further combining information acquisition and processing theories as well as technologies. From the review of computing history above, it is quite evident that another holistic field should come into being in the UC era. It seems rational to name it Cybermatics to correspond to the cyberization process in the UC era, in parallel with the respective fields of computer science and information science or informatics in the MC and PC eras.

III. Cyberspace, Cyber World, Cyber-enabled Worlds and Cyber Entities

Before fully describing the general concept, characteristics and coverage of Cybermatics in the next section, it is first necessary in this section to examine the implications of cyberspace and the cyber world, and to further discuss what our worlds will be and how the things in these worlds will change during the process of cyberization.

A. *Cyberspace*

Inspired partially by Wiener's 1948 book 'Cybernetics' [32], the term "cyberspace" was first used by Danish artist S. Ussing and architect C. Hoff in their collection of work "Atelier Cyberspace" in Copenhagen in 1969 [33]. Their work was a 'sensory space' – a physical room that could sense and adapt to human and other influences in this room. In the1980s, this term appeared in W. Gibson's cyberpunk science fiction [34], in his short story 'Burning Chrome' [35], and novel 'Neuromancer' [36]. He described cyberspace as "a graphic representation of every computer in the human system." The term "cyberspace" started to become popular and, in the 1990s came to mean global digital networks and connections due to the spread of the Internet and the Web [37].

Although cyberspace became a buzzword from 2000 and several tens of definitions have been posited, to date there is no accepted definition. Recently, M. Mayer, et al, declared 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 definition is used, cyberspace has to possess two basic characteristics: data storage and flow among computers or computational elements that are interconnected locally and globally by networks, as well as being a network of networks. When associated with specific meanings, data can be regarded as information. Therefore, cyberspace can also be regarded as a global infrastructure or a gigantic system in which information can be stored and around which it can be channeled.

B. *Cyber World and Cyber-enabled Worlds*

The term "cyberworld" first appeared in the film "CyberWorld 3D" in 2000 [39]. So far there are few definitions of cyberworld, though it has been used for various purposes, such as a company name [40] and a course 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. In 2005, J. Ma, the main author of this paper, states that "A cyber world is a digitized world created on cyberspaces inside computers interconnected by networks including the Internet" [5]. On realizing their great potential and importance, Kunii, Ohmori, Ma and others organized the first international Symposium on Cyber Worlds [43] in Tokyo in 2002. This symposium has become an annual international conference [44] since 2003.

Similar to a physical space in which various and numerous real things exist, the cyberspace can also be an independent 'place' for the existence of digital things that are made up of digital substances, i.e., data and information. We can simply state that cyber world is one world including cyberspace and all the digital things in cyberspace. The cyber world will further expand along with the enhancement of the cyberspace and increase in number of digital things.

The cyber world is completely unprecedented to human society, and exists 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 into an ordinary thing in the physical, social or mental spaces/worlds, as we have previously described when discussing ubiquitous computing (UC). As a result, the cyber world not only emerges as a novel world, but also as interconnected physical, social and mental worlds to form cyber-connected worlds as shown in the middle of Fig. 2.

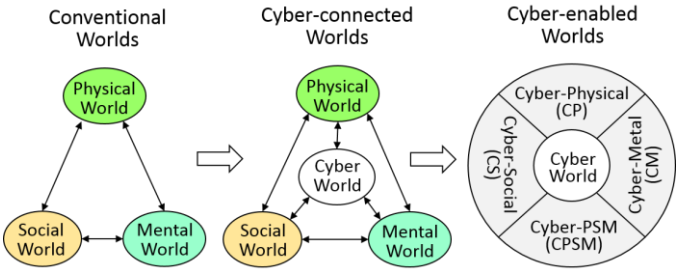


Fig. 2. Conventional worlds and the cyber-enabled worlds.

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, as shown on the right in Fig. 2. In fact, the artistic work "Atelier 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 intervention. The basic feature of the 'sensory space' is almost the same as current studies on smart space [45] such as smart room [46] and smart office [47]. So, what Ussing and Hoff wanted to express through the "Atelier Cyberspace" was not a gigantic global system for data storage and flow in terms of the current understanding of cyberspace, but actually a conjugation of cyber technologies and real spaces, which bears a resemblance to our cyber-conjugated worlds. There are already many other studies about such conjugations as a cyber-physical system [48], a cyber-social system [49], and a cyber-mental brain [50].

It is fairly certain that there will be more and closer conjugations of the cyber world and the conventional worlds. That is, cyberization is a global evolutionary trend in which the formation of cyber-enabled new worlds, including the emerging cyber world and cyber-conjugated worlds, will profoundly reshape and revolutionize the world we live in to change greatly the way we live our lives.

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 augment the cyber world. To correlate more closely with the terms cyberspace, cyberization and cyber world, the digital things that function in cyberspace can be termed cyber entities. We may generally define a cyber entity as 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 shown conceptually in Fig. 3.

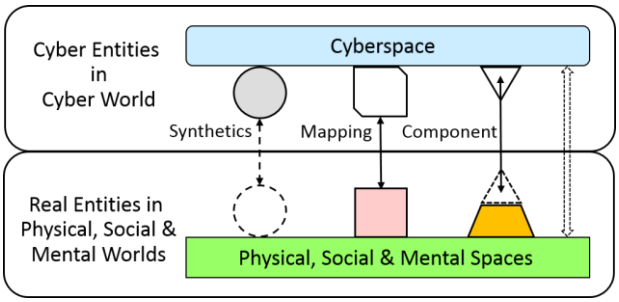


Fig. 3. Entities and their relations in cyber, physical, social and mental worlds.

A synthetic cyber entity, such as the circle with solid line in Fig. 3, may or may not have a counterpart in any of three conventional worlds, and thus the circle in conventional worlds is drawn with a dotted line. A real entity, depicted as the filled square in conventional worlds in Fig. 3 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 as an unfilled and incomplete square in the cyber space in Fig. 3. A real entity may contain a digital component depicted as the triangle in Fig. 3, the hardware of which may exist with the entity, but the data and software of which will, like its cyber entity, reside in cyber world. The cyberspace can be also seen as a special or super cyber entity that exists in parallel or may have some relationship with conventional physical, social and mental spaces.

Many different kinds/forms of cyber entities exist, 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, and are able to be interconnected via cyberspace. These behave rather differently than they do in their 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 these can also be conjugated with entities in physical, social and mental worlds. It is the existence and conjugation of such cyber entities, emerging rapidly in the novel cyber world, 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, the physical sciences, the life sciences, social sciences and earth sciences, 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 with each other to form interdisciplinary or transdisciplinary fields, for instance, biophysics and robotics.

The universe now contains special things, 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 element. The process of cyberization 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, which we have called Cybermatics, corresponding to the cyberization bringing about cyber-enabled new worlds. In the following section, firstly the concept of Cybermatics and its linguistic origins are 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, attributes, identification, structures, models, representations, relationships, interconnection, interaction, intelligence and evolution of cyber entities. The study of Cybermatics is to build and organize the body of knowledge related to cyber entities, as well as their practical technologies and applications.

The word "entity" derives from the Latin word, *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 entity 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 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 an IT related prefix, and may cover, or be related to other prefixes such as *e-*, *i-*, *u-*, *info-*, *net-*, etc. It is also used in 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 describe a thing willing/able to be, behaving like or having cyber characteristics. In a linguistic sense, "Cybermatics" can be understood as a field in which cybermatic things, i.e., various cyber entities existing in cyber-enabled worlds as distinct phenomena, are studied.

Note that the term 'Cybermatics' is spelt similarly to the term 'cybernetics', that is "the trans-disciplinary approach for exploring regulatory systems, their structures, constraints, and possibilities" [57], and which has a different focus and scope to Cybermatics, although its spelling and pronunciation are very similar. Comparisons between the two fields are drawn after the next subsection. The breadth of the field of Cybermatics is very large as described in the next subsection.

B. General Coverage of Cybermatics

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

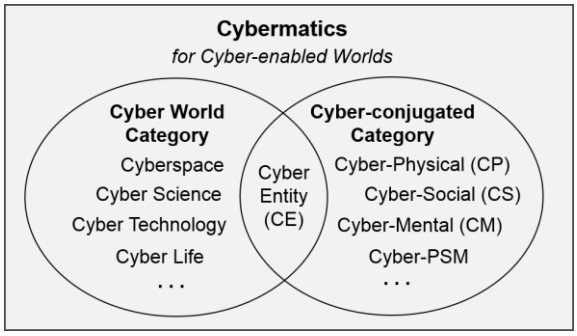


Fig. 4. The general categories of Cybermatics for cyber-enabled worlds.

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 is covered in this category and studied as a new but different space from existing spaces with conventional temporal-spatial characteristics. Cyber science is the scientific study of cyber entities (CEs) to build systematic knowledge about them, while cyber technology is the application of this knowledge in the design, development, implementation and application of cyber entities. Although the life features are not necessary attributes of cyber entities, cyber life will definitely be 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 includes the following areas.

- 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 objects, vehicles, homes, 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, properties and practice of such CS conjugation, as well as the discovery of new social phenomena 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 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 has an immensely broad reach. This is because Cybermatics is envisaged as the study of the new cyber world and its conjugations with physical, social and mental worlds, in which many phenomena are as yet undiscovered, and which will present diverse and challenging problems. 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 cyber-enabled worlds. Besides, the cybermatic research areas suggested in each of the categories and sub-categories are not exhaustive 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 certain that other category approaches may arise and additional cybermatic areas will appear in subsequent years.

V. Relations between Cybermatics and Other Fields

It will be obvious that many items in the lists of cybermatic categories and areas given in the last section are not new, and have either already existed for a number of 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 will not replace these existing fields and areas but amalgamate all diverse cyber-related studies, inspire further new studies and organize them organically to form a holistic field in order 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 physical, social and mental worlds due to the accumulation of knowledge and rapid progress in many fields and areas of study. In the following, we discuss respectively the possible relationship of Cybermatics with computer and information sciences, other typical fields and some emerging research areas.

A. Relations with Computer and Information Sciences

As we have seen in our brief discussion of seventy years' of computing history, computer science emerged from the MC era, information science or informatics emerged from the PC era, and Cybermatics is extremely likely to emerge in the current UC era. However, it cannot be said that any one of these fields is superior to the others. The scope of information science appears broadest, but information processing relies largely on effective data computation, which is the main subject of computer science. Often it is extremely difficult to define the exact differences between the two due to their great amount of overlap and connections between their research areas. This is similarly the case for Cybermatics, which definitely has much overlap and a close relationship with computer and information sciences.

However, the most remarkable difference between the three is the research object on which each subject focuses. Computer science focuses more specifically on data, whilst information science focuses mainly on information, and Cybermatics is concerned primarily with cyber entities. 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 term 'entity' as an abstraction of a dataset or an informational unit. Cybermatics regards a cyber entity not only as a digital entity existing in the cyber world but also as a possible organic part of a real entity, so that the two entities are integrated into a completely new entity 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 conventional physical, social and mental worlds, a development which has been extensively researched in various fields of study. So, Cybermatics is naturally has relationships with many other fields or disciplines. Among them, Cybernetics is the most related to the proposed field of 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 1948 book "Cybernetics", and defined it as the study of control and communication in the animal and machine [32]. Nowadays there are many definitions of cybernetics since it is interwoven with many other fields/disciplines that study systems containing closed signaling loops with feedback controls [57]. A cyber entity or a collection of cyber entities, especially cyber-physical, cyber-social and cyber-mental or other cyber-integrated entities, may also form a system with a feedback control. Hence, the knowledge of cybernetics will surely be useful for studying cyber entities and their properties from the viewpoint of system feedback control and of the new dimensional cyberspace. Nevertheless, 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 myriad systems. What's new in Cybermatics is the emergence of the cyberspace as well as that of cyber and cyber-integrated entities. In one sense, Cybermatics can be studied as a special branch of system science [63] taking this cyber existence into consideration. Network science [64] is the study of network representations of physical, biological, and social phenomena, and will be one of the 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 of the world, Cybermatics will also be related to other fields/disciplines, such as sociology, psychology, ecology, the life sciences 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 systems, smart objects, smart city, social networking/computing, green computing [65], crowd sourcing [66], hybrid intelligence [67], digital brain [68], digital clone [69], Web science [70], Internet science [71], cyber ecology [72], cyber patters [73], cyber warfare/defense [74], and cyber privacy [75]. The appearance of these new areas partially implies the coming of cyberization as well as the cyber world and its conjugation with physical, social and mental worlds. However, these emerging areas focus only partially on aspects of cyber entities in cyber-enabled worlds, and their studies are to a greater or lesser extent carried out discretely. Therefore, Cybermatics is aimed to offer a broader and holistic field to aggregate these emerging areas into a united cybermatic framework within which all cyber-related researchers can share their insights, identify common problems and find new directions for more comprehensive and systematic study of the 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 encounter new and exciting developments in ICT devices and services. The penetration of ICT technologies and their use in ordinary goods, the home, urban environments, and almost everywhere in the world, even inside the human 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 in the long term.

A major part of this new experience and change will be due to the emergence of the new cyber world created by cyberspace as well as the various cyber entities that can be further conjugated with numerous entities in the physical, social and mental worlds. Following computerization and informatization, cyberization has begun, and is taking us into 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 on forming systematic cyber-related knowledge for the better creation of the new cyber world, and the further understanding, prediction and reformation of present worlds.

In this paper, we have tried to first figure out the most fundamental emerging trend, i.e., cyberization, from examining seventy years' of computing history through the prism of Mark Weiser' three relationships between humans and computers, and then to examine Cybermatics as a natural field of study for cyberization by analyzing the corresponding relationships between computer science and computerization as well as between information science and informatization. To make the proposed Cybermatics more rational in cyber-related terms, we have checked the etymology and meanings of cyber, cyberspace, cyber world and cybernetics, and further identified the cyber-related things, named cyber entities, that should be the core research object of 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 the cyber world and the other for cyber-conjugated worlds. We further gave representative areas in each of these two categories and discussed the relationship between Cybermatics and other well established fields and recently emerging research areas.

However, there is much work left to further make the proposed field of Cybermatics more accurate and more complete. It is necessary to identity the most basic characteristics of so-called cyberization, as well as the cyber world and cyber-enabled worlds. Since cyber entities appear to be the core in cybermatic research, their exact concept and attributes should be well studied and defined to all. It is also necessary to study what a cyber-conjugated entity really means in practice, and how its cyber-physical, cyber-social and cyber-mental conjugations are actually conducted. Further refinements in the organization of cybermatic research areas are necessarily have to be made, and more detailed relationships 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 solely us, the authors of this paper to fully clarify the whole field Cybermatics with its huge and unknown new world environment. What we have presented in this paper is primarily just an initial introduction to Cybermatics. Hopefully, many others may also consider the questions raised in this paper so that all of us can work together to jointly establish this holistic field for the systematic study of the coming cyber-enabled new worlds.

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