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Editorial

Cyber-Physical Society—The science and engineering for future society

The physical space provides material basis for the generation and evolution of living beings. Humans have created various artefacts and spaces to realize the meaning of life. Social space has been evolving with the development of human beings. Humans have invented versatile technologies and created cyberspace with development of information technology. Cyberspace is being linked to versatile individuals in physical space and social space. A complex space of cyberspace, physical space and social space — Cyber-Physical Society (CPSoc) — is being formed. Exploring CPSoc needs a new methodology since the principles and methods specific to cyberspace, physical space and social space will not be suitable for exploring the new space. It is necessary to explore the basic concept of CPSoc, its distinguished characteristics and scientific issues. Research on CPSoc will lead to the revolution of society, science and engineering.

1. Introduction

Human beings will live and develop with Cyber-Physical Society (in short CPSoc), which consists of cyberspace, physical space and socio space. An early notion of large-scale human–machine interconnection environment that unites physical space, virtual space and mental space was proposed in 2005 [1], which is actually a scientific definition of CPSoc. The harmony of the nature, society, environment and cyberspace was pointed out: "*Networks pervade the nature, society, and virtual worlds, giving structure and function to a variety of resources and behaviours. Discovering the rules that govern the future interconnection environment is a major challenge. Ideally, this environment will be an autonomous, living, sustainable, and intelligent system within which society and nature evolve cooperatively. It will gather and organize resources into semantically rich forms that both machines and people can easily use. Users will cooperatively accomplish tasks and solve problems by using the network to actively promote the flows of material, energy, techniques, information, knowledge, and services in this environment*". A brief history of the development of CPSoc was introduced in [2].

In 2010, the term Cyber-Physical Society was used to represent the ideal of future interconnection environment for the first time [3,4]. A complex Semantic Link Network was proposed as the method for semantic networking in CPSoc: "*Humans are able to observe and participate in social processes, to think, and to know the effect of establishing a relation. Humans can also actively select appropriate relations and persons according to requirement, situation and social rules. Machines are obviously limited in these abilities. Various graph-based models have been used to connect resources in the cyberspace*". Two fundamental issues were proposed: (1) "*machines know little relation in human society and the nature, data structures in machines are for machines to process not for humans to read, so it is not realistic to expect machines to discover socio and natural laws and resolve relevant issues without human instruction*", and (2) "*machines are hard to know the effect of establishing and making use of relations, and to explain computing result according to society and the nature*". The major cause is that machines do not have any worldview. "*Connecting various networks and machines with nature, society, and human minds can create a new environment where individuals have semantic images to enhance mutual understanding.* "

The definition of CPSoc was given in [5]: "*Cyber-Physical Society is a multi-dimensional complex space that generates and evolves diverse subspaces to contain different types of individuals interacting with, reflecting or influencing each other directly or through cyber, physical, socio and mental subspaces. Versatile individuals and socio roles coexist harmoniously yet evolve, provide appropriate on-demand information, knowledge and services for each other, transform from one form into another, interact with each other through various links, and self-organize according to socio value chains. It ensures healthy and meaningful life of individuals, and maintains a reasonable rate of expansion of individuals in light of overall capacity and the material, knowledge, and service flow cycles*".

CPSoc is an existence in form of a complex space. It is also a science and engineering of developing and managing the new complex space.

Cyber-Physical-Socio Intelligence studies intelligence in the complex space, concerning human intelligence, socio intelligence, machine intelligence, and complex intelligence [5]. Research needs to incorporate relevant research progresses on the nature, information, and society [6–9].

2. Separation

The world evolves with separating and fusing spaces. The following are some great separations [5]:

(1) *The separation of mental space from the physical space*. With the generation and development of human beings, individual mental spaces are gradually separated from physical human bodies. Individual mental space consists of thoughts (including commonsense, concepts, rules, methods, principles, and theories) and imagination (derivation of links through thoughts). Thoughts propagate through links between individuals and self-organize to reflect the mental space. As the effect of mental space development, an artefact space is gradually separated from the natural physical space. Human life is more and more

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in the artefact space and gradually away from the natural physical space. Modern cities have been developing with including more and more artefacts such as buildings, roads, and tools.

(2) *The separation of society from the natural physical space*. Society is a space that contains socio individuals (humans, artefacts created and used by humans and events), relations between individuals, worth, authorities, and rules of activities. The dynamics of many socio phenomena are driven by individual human actions.

(3) *The separation of symbol space from mental space and artefact space*. Since thoughts are intangible, humans have to find some tangible things to communicate with each other for life. They used physical individuals like stones to count number, and they used drawing to represent what they had in mind. They created symbols to indicate and understand thoughts. The development of symbol language represents the progress of human society. More subspaces of the symbol space were created. Some symbol spaces were structured in mathematical languages, while others were structured in natural languages. Mathematicians have created many abstract spaces such as Euclidean space and Hilbert space. Humans have created a huge document space, which keeps expanding through times. More importantly, humans have the ability to link symbols to the mental space and to the physical space.

(4) *The separation of cyberspace from symbol space and artefact space*. Cyberspace extends symbol space and artefact space to reflect more of other spaces. It not only enables humans to read documents distributed around the world easily but also facilitates communication and computation. Humans are making great efforts to extend and enhance cyberspace [10,11]. Different from other spaces, cyberspace can perform a certain artificial intelligence and can establish link between spaces.

Some individuals like paintings are passive, but some like robots can behave according to programs pre-designed by humans. Individuals have mappings in different spaces. Human bodies belong to the physical space, behaviours belong to social space, and thoughts belong to mental space. Human behaviours weave various networks through individuals. For example, the Internet, mobile networks, and sensor networks are connected through human behaviours.

Humans have created various artefacts and Cyber-Physical Systems such as aeroplanes and robots. Aeroplanes can sense and record some flying data such as location, height, temperature, and fuel, and they have communication ability and can even autopilot according to pre-designed route and program. Space station and space shuttle are advanced Cyber-Physical Systems. Different from Cyber-Physical Systems, Cyber-Physical Society concerns the structure and function of the complex space consisting of cyberspace, physical space and social space, and the study of its laws and principles.

Science and engineering develop with separating disciplines, which have become finer and finer. It is the critical time to think from the origin and study the laws and principles over disciplines.

3. Semantic image and dimension

Various interactions between individuals form and evolve the structure of spaces. In cyberspace, machines connect one another to collect, calculate and transmit data. It contains more and more data, which indicates physical space, social space and itself to a certain extent [3]. Essentially, only human can understand the information of the spaces and build the images (semantic images) in mind. Cyberspace plays the role of extending human sensation to cyberspace, physical space, and social space. There is a big gap between the semantic image of human and data in cyberspace. Human–machine symbiosis is a way to build a complex system that can maximize the ability of both human and machine [12].

A phenomenon of falling apple represents a semantic image from the following layers:

(1) *Reflection layer*, i.e., data that can be captured by photo or video.
(2) *Commonsense layer*, e.g., apple is fruit.
(3) *Concept layer*, e.g., physical concepts: force f, the mass of an object m, and acceleration a, as well as gravity.
(4) *Rule layer*, e.g., rule of multiplication.
(5) *Method layer*, e.g., multiplication operation.
(6) *Principle layer*, e.g., $f = m \cdot a$.
(7) *Theory layer*, e.g., physics.

CPSoc will extend the ability of humans to reflect the physical space, to conveniently interact with each other, to classify/cluster/locate individuals, to search/surf/zoom in cyberspace, and to locate/reason/navigate in mental space. A falling apple in the physical space will be able to link to different devices in cyberspace, which incur relevant semantic images in the mental space.

CPSoc has three essential dimensions. The first dimension consists of two facets: *thought* and *individual*. Individual is the abstraction of natural resources, humans, and artefacts. The second dimension consists of four facets: *time*, *space*, *relation* and *worth* [1]. The third dimension consists of four facets: *classification*, *interaction*, *influence*, and *transformation*. Classification is a basic mechanism to recognize, organize and manage individuals [13]. Interaction is a process of physical action and reaction, socio behaviours, thought exchange or information transmission that changes the statuses of involved individuals.

4. Super link

Different from Web of things, Internet of Things, and Cyber-Physical Systems [14–16], CPSoc will be equipped with *super-links* to facilitate interaction through spaces [2,5].

Semantic Web is to create machine-understandable semantics in cyberspace [17]. Semantic link is to reflect social relations in cyberspace [4]. Superlink network reflects various relations and dynamicity in CPSoc. It takes the following form: p_i—l: $c \rightarrow p_j$, where p_i and p_j are individuals or classes in one space or in different spaces, l represents the specification of the link between two points, and c represents the type of content or material that can be transmitted from p_i to p_j. In super-link network, a node in any space can link to any node in any space, link can be of any type suitable for transmitting a certain type of information and influence can be in or through spaces. Changing node or link will influence the linked nodes in real-time.

Humans weave super-link network consciously and unconsciously in lifetime and from generation to generation. It evolves and dynamically reflects semantics through operations. The evolution of the network forms patterns. A key operation may transform patterns. The effect of operation on the network can be estimated. Interactions form temporal interaction nets through the networks. Super-links enable interactions to pass through spaces, for example, text or image of apple in cyberspace can link to an apple in supermarket or on an apple tree through sensors, and can further link to the physical concepts like gravity. The CPSoc concerns both category and individuals: One tree will be different from the other tree, and one apple will be different from the other apple. Connecting these spaces can answer *what*, *where*, *why*, *when*, and *how* from different spaces [4,5,18]. Rules on super-links support complex reasoning [5].

5. Influence

In CPSoc, different spaces obey different laws, physical laws do not hold in cyberspace and socio space, but individuals in different spaces can interact with each other or influence one another following some common laws. Influence occurs and propagates when individuals or links are added or removed. The influence of one individual on another through super-link can be measured by their ranks and the times of effective interactions between them. Socio influence can be measured according to the extent of transforming the pattern in the super-link network. The extent can be measured by the number of individuals who change their communities or obviously change the behaviours of certain number of individuals due to influence. Socio preference influences the formation of patterns.

Any individual has *potential energy* in socio network. It influences other individuals through super-links. It can be measured by its centrality in the socio network considering the times of interaction through its links. The potential energy of a community can be measured by its population and density considering both structure and interaction. The potential energy of an event can be measured by the number of involved individuals and the centrality of individuals.

Physical motion, socio behaviour, and cyber operation have *motion energy*. An operation's motion energy can be measured by the *number of individuals who have changed their communities* and the *total number of individuals*. The motion energy originates from thought in mental space. History tells us that a thought may transform the structure of a society. The motion energy of operation is sensitive to operation order.

The potential energy and the motion energy co-exist and co-evolve Cyber-Physical Society [5].

6. Distinguished characteristics

Cyber-Physical Society has the following major distinguished characteristics:

(1) *Real-time multi-space situation aware*. Life Web pages will be the first stage of development from the World Wide Web to Cyber-Physical Society. Texts and photos in personal Web page will be displayed in real-time and through multi-dimensional senses such as time, location, event, audio and video about the person. People with different privileges can view information from different dimensions and different scales. Further, the individual to be viewed can know the viewer, sense the viewer, and further presence virtually to events. Resources in different spaces can be self-organized in a multi-dimensional classification space.
(2) *Super-link*. Super-links will be interactive channels, which will be able to transmit material, content and control information to realize real-time interaction between individuals cross spaces.
(3) *Multi-space influence and measure.* Individuals in different spaces will influence one another positively or negatively. For example, unhealthy individual or community in once space will influence the health of individuals or communities in another space. For human individuals, influence of unhealthy or sub-healthy will come through multiple spaces. Measure in one space (e.g., physical space) is usually not suitable for another space (e.g., social space). A general measure needs to be explored in the study of Cyber-Physical Society.
(4) *Cross-space coordination*. Human individuals can know their own statuses when interacting with others. The statuses include health, current micro physical space, socio attributes, individuals who were or are trying to super-link their status, socio energy, and the lifetime semantic images of individuals under privilege constraints. Privacy will be respected.
(5) *Pervasive undetermined interaction*. Different from control processes and computer algorithms, Cyber-Physical Society works with pervasive interactions between individuals within and cross spaces. Pre-designed interactions follow rules in different spaces.
(6) *Lifetime semantics*. Cyber-Physical Society will reflect individuals, communities, interactions and events at multiple semantic layers and link semantic elements in different layers. Different from digital archival, CPSoc preserving is real-time, lifetime, and at multi-semantic layers.
(7) *Multi-dimensional*. Humans often use orthogonal space to locate an object in the physical space. In cyberspace, zooming is an effective means to navigate through different view levels and reduce the scope of destination. Semantic Link Network carries out triangle reasoning and navigation [4]. Semantic communities at different levels support zooming on semantic link network to obtain semantic views of different abstraction levels. The Resource Space Model locates resources in multi-dimensional classification space and supports zooming on classification hierarchies [13,18]. The integration of the classification space and the semantic link network supports navigation with the features of triangle reasoning/navigation, orthogonal locating, and zooming through spaces.

Humans weave and maintain super-links between spaces, evaluate and evolve socio values, and make final decisions to change personal statuses and to influence the evolution of the spaces in Cyber-Physical Society at certain probability. Humans will play roles in the loop and out of the loop [19,20].

Fig. 1 depicts multiple networks that operate a CPSoc. Modern city is a typical example of CPSoc, where people communicate through information flow network and knowledge flow network, use various equipments supported by energy flow network, influence through relational network, move through traffic network, and live with material (e.g., food and gas) flow network. The coordination of these networks structures an efficient society.

7. Scientific issues

The fusion of cyberspace, physical space, and socio space will fuse sciences and technologies specific to single space to form a new theory and method for studying and developing Cyber-Physical Society. Research will significantly influence current sciences and technologies. The following are some scientific issues.

(1) *Methodology*. Natural sciences concern the structures and laws of natural systems. Information technologies are about past, e.g., software and hardware are pre-designed, information retrieval is to get past data, and the statistical approaches calculate past data. Cyber-Physical Society connects not only physical space, socio space, cyberspace and mental space but also past, present and future. New methodology should change the progress of science and technology, break boundaries of existing disciplines, and be more insightful and predictable on the nature, socio, humans and culture and on mutual-influence. The aim is a harmoniously evolved Cyber-Physical Society and its sustainable development.
(2) *Extension of thought*. It is a challenge to link thought to thought, and link thought to sketch, to design, and further to the process of production. This concerns modelling and mapping between cyberspace, physical space, mental space, and socio space.
(3) *On-demand services through multiple spaces.* Different types of resources could be fused on demand to provide services through logistics of materials in physical space, information in cyberspace, knowledge in mental space, human and financial resources in social space. Logistic processes will leave semantic images in cyberspace and can be adapted according to the change of demand.

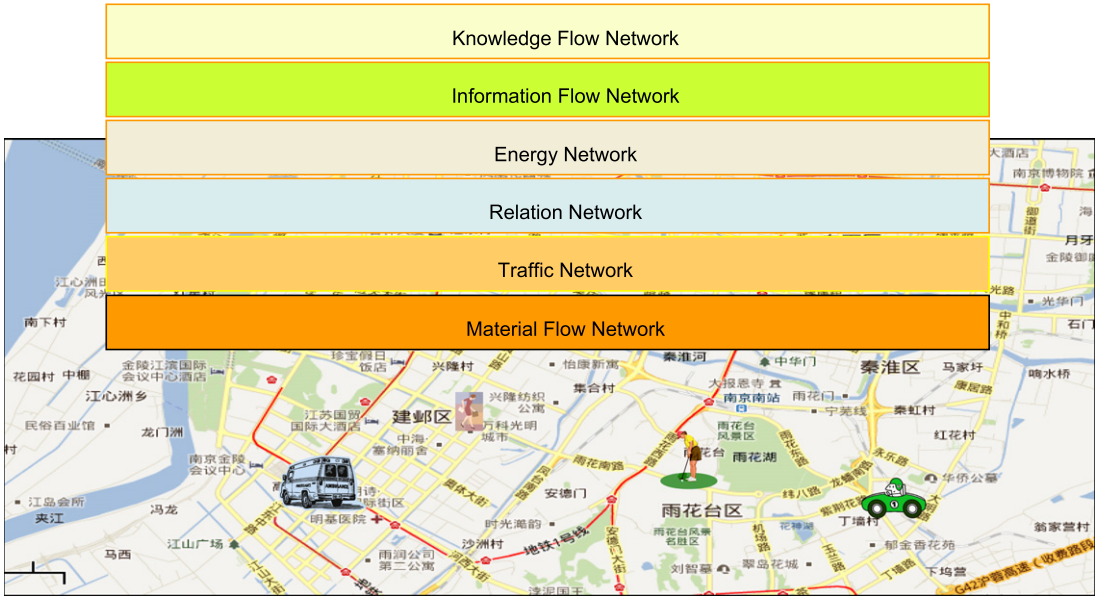

Fig. 1. Various networks of multiple layers in Cyber-Physical Society.

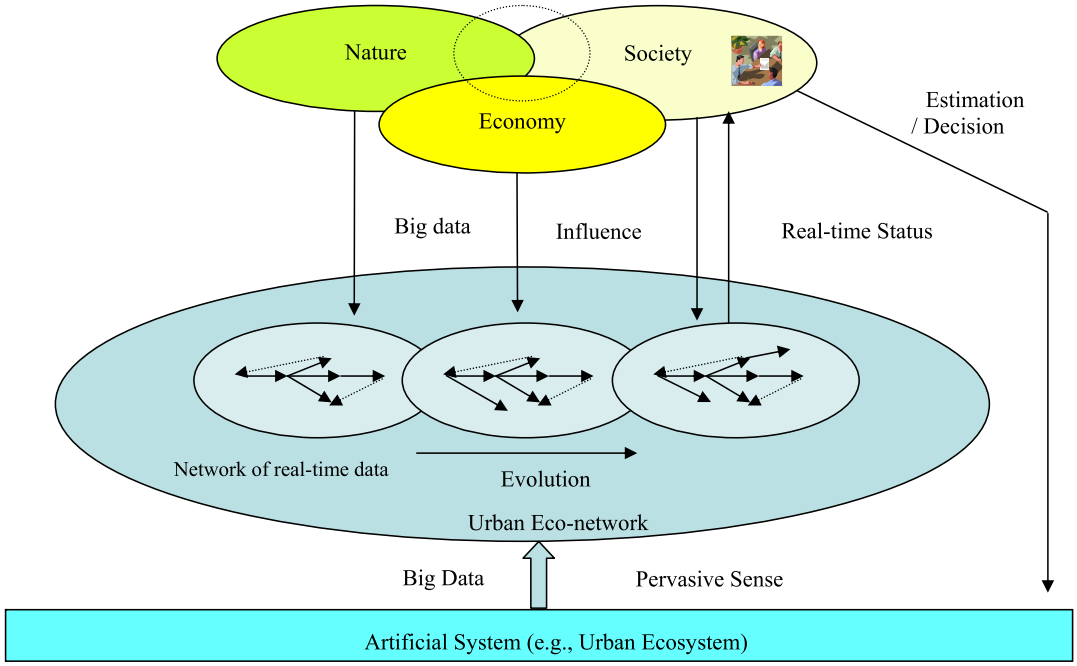

Fig. 2. Real-Time networking and decision making.

(4) *Cyber-Physical-Socio laws*. Study concerns competition, symbiosis and cooperation laws among individuals and among communities in the evolution process of the Cyber-Physical Society, as well as laws of networking, evolving and influencing the super-linked CPSocio networks [21,9].

(5) *Principles of interaction, transformation and flows*. Research concerns the principles that individuals in different spaces interact with each other, transform from one form into another, and coordinate through appropriate information, thought, service, material and energy flows. Principles, laws and methods of reflection, interaction, influence, and cross-space reasoning and explanation.

(6) *Reflexive, self-organized and self-adaptive architecture*. Cyber-Physical Society needs a reflexive, self-organized, and self-adaptive Cyber-Physical architecture that can preserve semantic images of itself and various individuals in lifetime and manage various activities and processes. It enables socio activities and processes, physical individuals, thoughts as well as human physiological, psychological and mental status to be super-linked to create a panoramic interconnection environment for well-being and development.

(7) *Real-time real-world modelling*. Building appropriate model by collecting and analysing data is the core of modelling. However, it is not feasible in large-scale dynamic CPSoc, because of the following reasons:

- Data reflects past status of the real-world or even may not correctly reflect the real-world.
- Modelling process takes a long-time. The created model may not reflect the changing real-world.
- Modelling is an abstraction of the real-world, there may have different ways of abstraction, and its quality depends on human.

- Explanation of modelling result relies on the model designer. Modelling heavily relies on designer's knowledge. Different from traditional modelling, the real-time paradigm needs no mathematic model. Actually, it is hard to quickly build a model on big data, but establishing links between data is easier.

Fig. 2 depicts the scenario of real-time simulation through real-time networking on data. Data is continually collected through sensors deployed in the physical space (e.g., temperature meters and cameras) and in socio space (e.g., ticket machines and mobile phones). Smart mobile phones will play more important roles in collecting data about humans. The cyberspace holds, links, and displays data as network. Reasoning on links may be carried out through domain rules. Decision can be made with the reference of real-time data network. Users can operate the network (e.g., add/remove links) to observe the effect of operation before or after making decision. The effect of decision may change the network, which in turn influence the following decision. With interaction among the natural physical space, society and economy, the data network keeps changing. So, it is a close-loop of sensing, networking, operating and decision making.

Traditional modelling is based on model design, which may take a long time and the correctness is hard to be guaranteed. Real-time modelling in Cyber-Physical Society is based on the network of data, especially big data. Exact model is not necessary to run the system. Users can make decision through the experiment on data. The method for real-time modelling needs to be explored.

8. Comparison with Internet of Things and Cyber-Physical Systems

8.1. Internet of Things and Cyber-Physical Systems

Internet of Things (IoT) is to create an Internet-centric network of various devices (Radio-Frequency Identification tags, sensors, actuators, mobile phones, etc.), which is expected to interact and cooperate with each other for common goals through unique addressing schemes [14]. Similar to IoT, Web of Things (WoT) is to connect various devices and objects to the Web through Web standards [15].

A Cyber-Physical System (CPS) is a system featuring a tight coordination between computational and physical components. Embedded computers and networks monitor and control the physical processes. The physical components of such systems introduce safety and reliability requirements. The design of CPS needs to embrace physical dynamics and computation in a unified way [16].

IoT is to extend the Internet to connect physical objects through sensors. CPS is to extend embedded system to include physical objects into computing system. The ideas empirically represent aspirations of developing the future interconnection environment. Recent development shows that the two ideas are attracting research interests and investments. New techniques and methods developed through research and application will help to develop the future interconnection environment.

There are several previous ideas similar to IoT and CPS. Tennenhouse proposed Active Network and Proactive Computing and called for getting physical and getting real when developing next-generation networks [19,20]. Weiser envisioned that computers become so ubiquitous that people are unaware of their existence (e.g., ubiquitous computing) [22]. Actually, Herbert Simon identified the importance of bridging physical domain and virtual domain half-century ago [23]. Many applications employed sensors and actuators to get data and control machines before the terms of IoT and CPS were coined. Therefore, IoT and CPS are not essentially new concepts from historical point of view, they can be regarded as the development of relevant techniques.

8.2. Problems

Using sensors and actuators to connect the physical world to the computing world has the following two critical problems:

(1) Can sensors get the real of things?
(2) Can machines make sense of data if big data can be captured?

Humans design sensors to collect data of physical objects. The capability of sensors depends on two factors: understanding of the object and the physical world, and technology, e.g., transformation from physical characteristics into electronic characteristics. At current stage, humans are still far from understanding the physical space, and the state-of-the-art technology is not able to get the real information of things. For example, sensors cannot get real symptom and link symptom to illness.

Humans make sense of things in a multi-dimensional context, including individual experience, language, history and culture [5]. Even big data about things can be sensed, machines still cannot make sense of data because machines do not have this complex context. The gap between big data and the real information needs to be bridged by incorporating experience, rules given by human and reasoning over rules. Humans can establish various models to reduce the gap and can minimize the gap in particular applications, for example, the semantic link network is to make sense of network [4,2,9,5,13,18]. However, models and theory sometimes cannot reflect the real due to the limitation of human understanding of the real world.

8.3. Relationship between CPSoc, IoT and CPS

CPSoc is a complex space consisting of cyberspace, physical space and social space. Links between spaces are established through various explicit interactions or implicit influence between spaces. Principles and methods in cyberspace, physical space or social space may not be suitable for the new space. We need to explore new principles and methodology. It has gone beyond the scope of previous ideas including Simon's idea, active network, IoT and CPS. Sciences, technologies and human society will develop towards a harmoniously evolved Cyber-Physical Society.

Although Licklider described the way to coordinate man and machine [12], his idea was limited in individual man and computer rather than society, ubiquitous networks, and physical space. Actually, human society plays very important role in forming and evolving the complex space.

Fig. 3 depicts the structure of CPSoc and the relationships among CPSoc, IoT and CPS. Great challenge is not just to computer science and information technology but also to the whole sciences, technologies and engineering.

CPSoc holds humans, machines and physical space. It enables humans to work efficiently, know more about the real, and understand each other. Previous research on semantics, knowledge and Grid can be extended to explore the foundation of CPSoc [24,25].

9. Conclusion

How our future living space is like is a major concern of sciences. Cyber-Physical Society (CPSoc) is a science, technology and engineering for the future society. Research will lead to the revolution of science, technology, engineering and society [5,18].

(1) *Science*. The formation of scientific thought in individual mental space and propagation through mental spaces can be retrieved through rich and vivid historical semantic images, so do research activities involved in physical space and socio space. This will greatly help scientific research since scientists can access research objects and thoughts as well as their formation processes through super-links. This means that scientists can

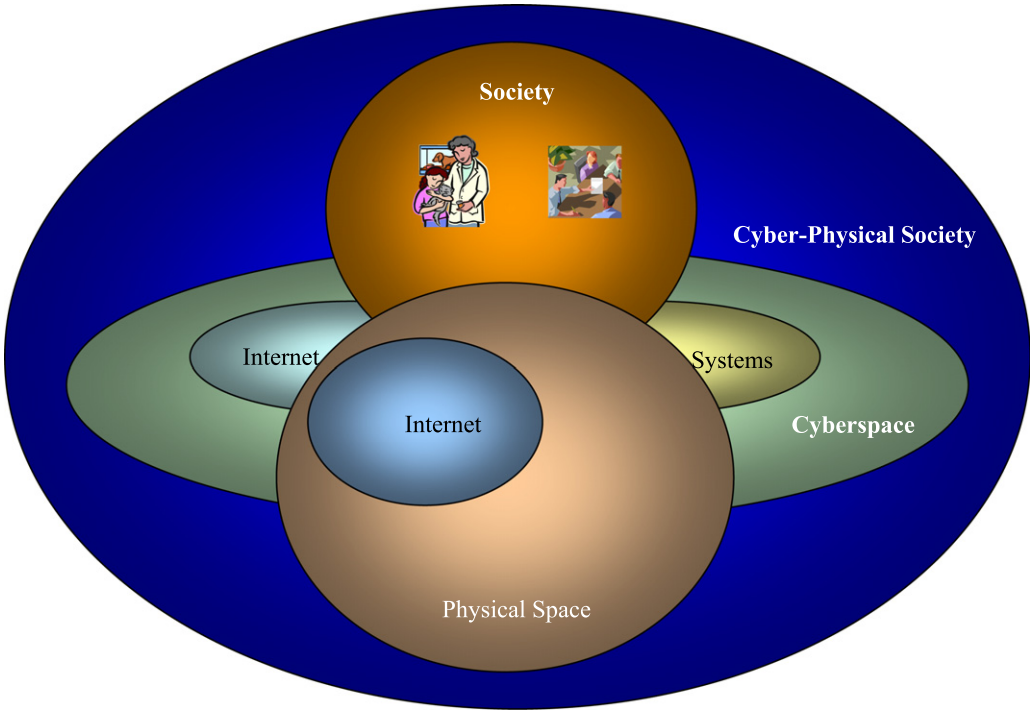

Fig. 3. A Complex Space of Cyberspace, Physical Space and Social Space.

not only communicate with peers but also access thoughts of scientists through time. Scientists can not only use language to express thoughts but also link thoughts to symbols in papers, to research process, and to possible applications. This will also lead to a revolution of publication. Currently, some publishers allow authors to attach slides to papers. In the future, live scenarios will be embedded in papers, which demonstrate research processes including experiments. Scientific thoughts will effectively influence society through super-links between spaces.

(2) *Education*. Students can learn natural physical principles and socio knowledge not only from linguistic description and mathematical description in textbooks but also from live physical phenomena or socio events through super-links. How to sense various physical phenomena and social events are challenging issues. Knowledge is formed, enhanced and rebuilt through interaction between coherent motions in and through spaces. Questioning, answering and explaining will be carried out through spaces.

(3) *Engineering*. Artificial systems will be linked to manufacturers, ideas, design processes, and manufacturing processes while interacting with humans (designers, engineers and users). The statuses of systems can also be monitored in lifetime so that necessary maintenance can be carried out on time to ensure healthy status. Function, structure, designer, owner, developer, and even economic, ecological and socio effects will be accessible. All spaces will cooperatively reflect the formation processes of artificial systems when they are required, designed, built, sold, used, and recycled.

(4) *History and culture*. Individuals, family trees, thoughts, and socio events will be reflected and preserved as semantic images that can be accessed through times. Evidences of historical and cultural research will be easily available. Both material culture and non-material culture will be preserved not only in physical space but also in cyberspace and social space virtually. Recommendation or evaluation will be explained from historical and cultural point of view. Science fiction will not only exhibit imagination in text and cyberspace but also super-link to history and culture.

(5) *Society and life*. Society will be safer and life quality will be higher as the status of key individuals, communities, and events will have semantic images that can help make precaution. Health of individuals can be detected and evaluated on time, and evaluation results can be super-linked to measures. Evaluation result will be super-linked to socio influence through time. Cyber-Physical Society will also help individuals to fulfil all aspects of the meaning of life: love, work, entertainment, etc.

(6) *Green and harmonious social environment*. Cyber-Physical Society will be efficient and low carbon as it will ensure optimal coordination between knowledge flow, information flow, material flow, energy flow and value flow through spaces. The cycle between consumption and production can be established to minimize the waste of material and energy with awareness of the super-links between materials, socio requirements, innovation, influence, production, and physical space. The energy cost of computing will be taken into account in multiple spaces rather than just in cyberspace. Human will be in the Cyber-Physical-Social process to co-evolve with cyberspace, physical space and social space [8]. Human will also be out of the process to develop mind and foresee the future.

(7) *Interactive virtual presence*. Individuals can interact with each other through spaces. Children at home can feel the presence of their parents who are in office through multiple types of super-links, and parents can know the situations of children, and be alarmed when special cases happen. Senior people can feel the presence of their children and relatives who live in different places. Patients in rural areas can see doctors in major cities and obtain treatment through super-links.

(8) *Multi-space optimization*. Making optimization in multiple spaces is important in Cyber-Physical Society. For example, energy supplies will super-link to requirements, road maps, real-time energy consumption situation, parking spaces, and environmental status. Traffic jam will be avoided through knowing real-time situation and certain socio priority. Vehicles can be guided to appropriate parking according to intentions and minimization of energy consumption.

The revolution of Cyber-Physical Society will also bring security issue. As human behaviours will influence the physical space and society through cyberspace, security will be cross spaces. Another issue is how to keep a sustainable development of cyberspace so that it can harmoniously evolve with society, otherwise it may form negative influence on society. The complex space evolves with various interactions for cooperation and isolation.

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