PhiNet of Things: Things Connected by Physical Space from the Natural View

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***Abstract*—Physical space appeared with the birth of the earth. With the emergence of social space, thinking space, and cyberspace (STCs), things in physical space are continuously enriched. Consequently, the PhiNet, an abstracted network concept such as relationships between things, is becoming more complex. Physical space plays a fundamental role in promoting the connection and development with the other three spaces. We think that PhiNet of Things (PoT) is a unified description of pure physical space and the evolving physical space affected by STCs. While the Internet of Things (IoT) is described from a cyber view, in this paper, the definition of PoT is put forward from a natural view. Besides, the evolution of PoT is identified by the time sequence in which the four spaces appeared. At each stage, research is carried out from two perspectives of things and PhiNet, and two specific examples are presented to illustrate the change process of things and the related PhiNet. In addition, two applications are listed to explain the usability of PoT in the current development stage. Finally, the paper gives the possible future development direction of PoT. The purpose of this paper is to illustrate the fundamental role of physical space in the continuous development through time sequence.**

***Index Terms*—Physical Space; PhiNet of Things (PoT); Natural View; Spaces Connection; Cross-spaces Characteristics.**

I. Introduction

PHYSICAL space appeared at the most beginning and has the most extended history. With the progress of society, thinking, and the development of science and technology, the emergence and expansion of social space, thinking space, and cyberspace (STCs) could further affect the physical space. Still they do not shake the fact that the physical space is the basic space. The proposal of Internet of Things (IoT) is an elaboration of spaces connection from a cyber view, and Internet is a logical network connected by a large number of hosts to connect physical, social, and thinking space, so that the world can become interconnected. Fig. 1(a) represents the process that takes cyberspace as the center which scatters outward to indicate the progress of cyberization. The proposal of PhiNet of Things (PoT) is to explain the connection and development of spaces from the new natural view of physical space, and PhiNet uses physical force, position context, and other relationships (such as affiliation, connection, etc.) to realize the connection of STCs, it is the superset of Internet. Fig. 1(b) represents the process that takes physical space as the center which converges inward to explain changes in this space. The conversion of view will make the focus of describing PoT and IoT completely different. Although these two concepts involve four spaces, the point in time described by IoT starts from the cyberization of the world, while the point in time described by PoT starts from the origin of the world. This conversion method will bring an intuitive feeling that PoT has a longer history, a more far-reaching impact, and a larger coverage than IoT.

Physical space is composed of things with different attributes, namely volume, form, and state, representing the material basis of this space. Similar to the term "existence" [1] in philosophy, things include tangible entities and intangible matters. With the emergence and development of STCs, things have evolved corresponding new characteristics, enriching and expanding materials' diversity. PhiNet is a collective term for connecting things through various forms, including tangible connections of entities, intangible interactions of virtual objects, and mutual influence of matters determined by things and their inherent attributes.

The proposal of PoT is a unified description of space development from a natural view, as well as a unified definition of things and PhiNet. Therefore, this paper is divided into four stages according to the appearance order of the four spaces to illustrate the corresponding characteristics and changes of PoT. In each stage, the basic components of PoT are used to show the impact of the new emergence space on existing PoT. This description method is used to reflect the fundamental role of physical space in the development and connection of spaces and to express the evolution process of things and PhiNet unified in PoT. Although the concept of IoT has been deeply rooted in the hearts of the people, no one mentions or studies how things and PhiNet between them that form the intelligent situation today have evolved. Illustrating this phenomenon and pointing out the usability of PoT in the current environment is the original intention of this paper.

Considering that there are many abbreviations in this paper, the mentioned abbreviations have been summarized in Table I. The main contributions of this paper as follows:

1) Defining PoT and expounding the significance of proposing PoT from the perspectives of things and PhiNet.
2) Describing the development process of PoT and its stage characteristics. For the sake of clarification, two examples of representative things in physical space,

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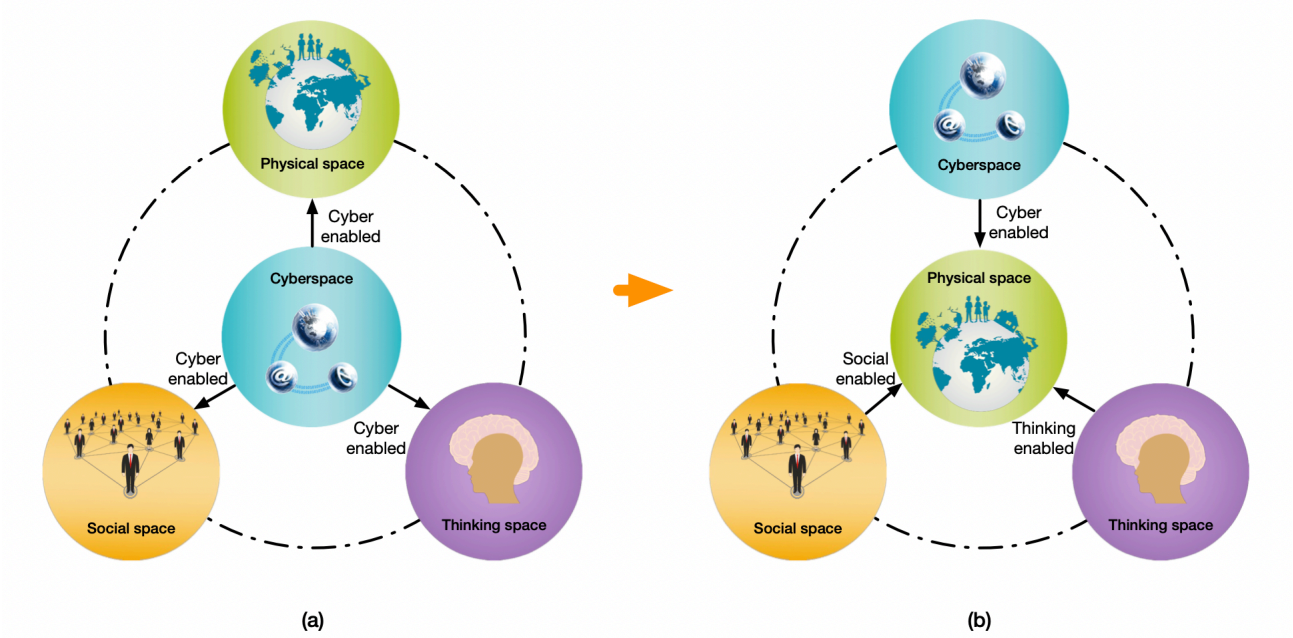

Fig. 1: Conversion from IoT to PoT: (a) Cyberspace view based IoT (b) Physical space view based PoT

namely *trees* and *viruses*, are used and discussed in detail.

3) In the fourth stage of PoT (i.e. cyber enabled PoT), two applications, namely *smart transportation* and *smart prevention and control system for COVID-19*, are used to reflect the embodiment of PoT in comprehensive applications.
4) Explaining the future development trend of PoT and discussing in detail how the rapid development of informatization and cyberization will affect the physical space and even the overall PoT.

The remaining part of this paper is organized as follows: Section II describes physical space, things, and PhiNet, respectively, gives a unified definition of PoT, and explains the characteristics of PoT at each stage. Section III introduces the PoT connotation of each stage in detail from the perspectives of things and PhiNet. Section IV presents some examples to describe PoT further. Section V explores two possible development trends for PoT in the future. Finally, Section VI summarizes the paper.

TABLE I: Abbreviations List

Abbreviations	Specific meaning
STCs	Social space,Thinking space, and Cyberspace
PoT	PhiNet of Things
IoT	Internet of Things
CPS	Cyber Physical Systems
CPSS	Cyber Physical Social Systems
CPPS	Cyber Physical Production Systems
CPHSs	Cyber Physical Human Systems
CPST	Cyber Physical Social Thinking Hyperspace
AIoT	Artificial Intelligence and Internet of Things
SIoT	Social Internet of Things
IoE	Internet of Everything
IoNT	Internet of Nano Things
IIoT	Industrial Internet of Things
CIoT	Cognitive Internet of Things
IoP	Internet of People
CeT	Cyber-enabled Thinking space
IoTk	Internet of Thinking
GC	General Cyberspace

II. Description of Physical Space, Things, PhiNet, and PoT

A. Physical space

Physical space is the basic space on which all things live and develop. The exploration of all kinds of things is also carried out in this space. It has the earliest generation time and the highest material richness. As for the question of what physical space is, humans have not stopped exploring it. For such a basic space, different people have different descriptions. For example, Wells expounded his views on physical space from scientist's perspective in the book "The Time Machine" [2]. He believed that this world is a four-dimensional space represented by the three-dimensional space in addition to time. Table II also lists descriptions, view, and range of physical space in other studies. In these descriptions, some of them belong to the macroscopic description of physical space [3]–[5], while the others are more inclined to the description of physical space in the Internet world [6], [7]. Different emphases of research cause different descriptions

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TABLE II: Different descriptions of physical space

No.	Descriptions of physical space	View	Range	Reference
1	The physical space is simply the unlimited expanse of the universe, in which all material objects are located, and all phenomena occur.	Natural	Whole	[3]
2	In the physical world, the passage of time is inexorable, and concurrency is intrinsic.	Natural	Whole	[4]
3	Physical space is the basic premise of the existence of all spaces.	Natural	Whole	[5]
4	The physical space includes the structure of the building, physical entities, and physical topologies.	Cyber	Whole	[6]
5	Physical space refers to natural and human-made systems operated in applications.	Cyber	Part	[7]

of physical space. However, they all mentioned descriptions of real things such as objects and infrastructure, which are important components of physical space. Besides, although different people have different descriptions of this space, they focus more on representing the real world, or the virtual and real world combined with the computer field.

In order to describe the physical space more comprehensively and objectively, its description should start from a macro perspective and cover the development of this space. Due to the emergence and development of STCs, physical space has also derived new characteristics and has an essential impact on developing the physical space components. In the view of this analysis and the existing descriptions, the physical space can be considered as a collection covering all objectively existing things. This is a macroscopic description of physical space, and the most important part of this space is "things".

B. Things

As the material basis of physical space, "what exactly things contain?" is a question widely discussed in philosophy. As early as the 5th century B.C., the ancient Greek philosopher Empedocles proposed that world's origin is water, fire, earth, and air [8]. In the 11th century B.C., Taoism attributed all things in nature to five kinds of substances, which resulted in the theory of five elements [9]. However, these are the descriptions of things that represent entities only.

The things pointed out in this paper no longer have only the literal meaning of things, entities, objects, etc., but also they are synonymous with existence in the philosophical sense. It is a general term for all existence with objectivity and authenticity.

Therefore, things in physical space refer to things in a general sense: tangible entities and intangible existence. They include not only traditional physical things but also the different forms of things produced with STCs. This description emphasizes that each thing represents a kind of things rather than a specific expression of a single object. When one thing wants to materialize its representation, it needs to add time and space characteristics. Through these two dimensions, the specific attributes of a specific thing will come into being. Fig. 2 is a visual description of this process. Although things can produce, be produced, and die out, they may have different development trends. From an overall perspective, the number and abundance of things have been on the rise, continually enriching and expanding the physical space. According to the descriptions of things, various spaces are themselves a kind of things.

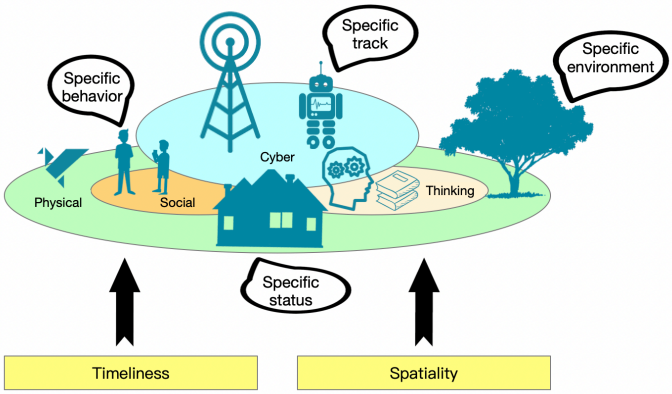

Fig. 2: Specific things under the action of timeliness and spatiality

C. PhiNet

PhiNet is determined by things and the intrinsic properties between them. Since things involve tangible and intangible aspects, PhiNet also includes the tangible connections, intangible interactions, and mutual influence between things. Tangible connections focus on the description of the display relationships between entities, such as component circuit connection. Intangible interactions focus on the description of the implicit relationships between entities and the relationships between virtual things, such as interpersonal relationships, mapping relationships, etc. At the same time, the mutual influence between things will also produce PhiNet, which is determined by their intrinsic properties. In the IoT, the Internet emphasizes the use of various digital technologies to connect things, such as electronic communications [10]–[12] and Radio Frequency Identification (RFID) [13], [14]. Socialnet in Social Internet of Things (SIoT) realized this kind of interaction through social relations [15]. PhiNet completely includes these connection ways and generalizes them to any objective relationships.

PhiNet represents not only the connection of things in physical space but also the connection between things generated by STCs. Because spaces also belong to things, it is also possible to use PhiNet to realize spaces connection: an important foundation for realizing spaces fusion and cross-space connection of things.

In some articles, the word such as "PhiNet", "Physicalnet" etc. were also mentioned, but the meaning is entirely different from here. Vicaire used the term "Physicalnet" in both of his

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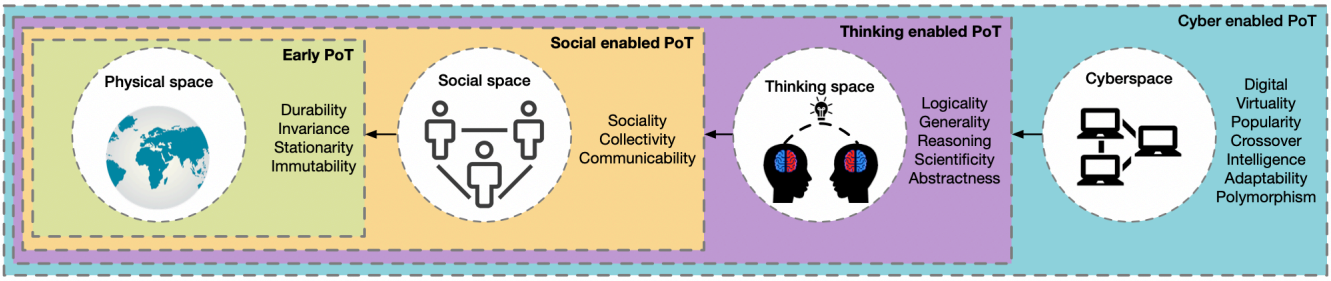

Fig. 3: The development process and stage characteristics of PoT

articles. One was the naming of the wireless network framework [16]; the other was the naming of pervasive computing framework [17]. In these two frameworks, sensors, actuators, and user devices could be understood as things, while data transmission and other activities could be understood as the PhiNet between things. Physicalnet can be regarded as a part of PhiNet for a specific field, but it cannot represent the whole PhiNet.

D. PoT

PoT will be a new concept based on physical space. The fundamental reason for the foundation of physical space is that PoT starts from this space and results from its continuous evolution. This development process coincides with the order of appearance of four spaces and continues to give PoT new characteristics as shown in Fig. 3. It can also be seen from Fig. 3 that every new space will have an impact based on the PoT of the previous stage, which makes the number of things and the complexity of PhiNet show an overall trend of expansion. In the research of IoT [18]–[20], Cyber Physical Systems (CPS) [21], [22], Cyber Physical Social Systems (CPSS) [23]–[25], Cyber Physical Human Systems (CPHSs) [26], Cyber Physical Social Thinking Hyperspace (CPST) [27], etc., the description of physical space was involved. However they were more inclined describe Internet, cyberspace, and cyber-enabled physical space. These studies referred to physical space, but they did not further explore the development of physical space, nor seemed to analyze the basic role of physical space from the perspective of things and PhiNet. In fact, the Internet profoundly affects the physical space, but all the construction and development depend on this space. For social space and thinking space, they are the subordinate spaces of physical space. Internet's role in these two spaces can also be regarded as an indirect impact on physical space. PoT is considered a description of multiple PhiNet composed of multiple things, through which the world becomes interconnected. Therefore, the two major factors that make up PoT are things and PhiNet with physical space as the central space. Accordingly, the definition of PoT is as follows:

Through physical enabling, social activities, ways of thinking, and network connection, a wide range of connections and interactions between things are generated.

The proposal of PoT is to look at the dynamic development and change of things and PhiNet under the influence of STCs and the physical space's connections from a natural view. Table III further clarifies the difference between PoT and other concepts. The definition of PoT is further explained as follows:

1) Development of things and PhiNet: The two compositions of PoT are developing and changing, which may go through a long evolution or be completed instantaneously like some chemical reactions. The interaction between things and their relative PhiNet may stimulate new paradigms or renew old paradigms. Therefore, PoT is not an eternal set, but a concept of development and change. Until now, PoT has been in a state of continuous expansion.

2) Cross-spaces characteristics of things and PhiNet: Things do not only exist in a specific space but also may be divided into different spaces due to internal factors such as attributes and states. The occurrence of this phenomenon will also cause PhiNet to exist in multiple spaces. Things and PhiNet, which have cross-spaces characteristics, are the prerequisites for achieving spaces integration and influence. If things and the PhiNet between them only exist in a certain space, PoT will not be formed. The concepts mentioned in Table III are also the result of things and relationships cross-spaces.

III. Development Stages of PoT

Nowadays, the massive number of things and complex PhiNet in PoT have not been formed in one day. They reached their current state through slow accumulation.

Things is the general term for objects that exist objectively, through different angles, thnigs can be considered to have different properties. For example, things can be divided into tangible (such as water, rock, computer, etc.) and intangible (such as gas, energy, fear, etc.). They can also be divided into abstract (such as perception, thinking, memory, etc.) and concrete (such as books, guitars, cups, etc.). With the emergence of STCs, there are new characteristics of things for a certain space, or new characteristics because of cross-spaces. Therefore, things can also be classified according to the development order of spaces, which are: 1) physical things; 2) social things; 3) thinking things; 4) cyber things. The characteristics generated by things are determined by the space in which they are located and will be applied to the PoT. Ofcourse, some of them have characteristics such as crossover, which is the result of things spanning multiple spaces at the same time. Take a computer as an instance, each part of a computer itself is a physical thing. While communicating with

TABLE III: Comparison between PoT and other concepts

Name	Main connecting objects	Connection mode	Basic space	Main technologies	Connection range	Explain
IoT	Humans, computer, daily supplies, etc.	Wired and wireless	Cyberspace	RFID, Wi-Fi, 4G, GPS, etc.	Cyberspace, physical space, social space, and thinking space	Committed to the interconnection of all things
AIoT	Humans, computer, daily supplies, etc.	Wired and wireless	Cyberspace	Deep learning, machine learning, etc.	Cyberspace, physical space, social space, and thinking space	Adding AI technology to IoT
CPS	Cars, home, industrial equipment, etc.	Man-machine interface, perception, etc.	Physical space	Computation, communication, control [21]	Cyberspace, and physical space	Dedicated to the integration of physical system, computing, and communication
SIoT [15]	Humans	Co-work relations, ownership relations, etc.	Social space	Cloud computing, edge computing, etc.	Cyberspace, physical space, and social space	Human centered network
CPPS [28]	Industrial components	Interactive engagement, modular interface, etc.	Physical space	Distributed computing, network-based systems, cloud abstractions, etc.	Cyberspace, and physical space	Industrial automation solutions
IoE [29]	People, data, process, and things	People to people, machine to machine, people to machine	Physical space, and social space	Sensor data processing, control automation, etc.	Cyberspace, physical space, and social space	No focusing on things, but the connection between things [30]
IoNT [29]	Medical instruments, human body, micro-devices, etc.	Nano-sensors, micro-gateway, etc.	Physical space	Electromagnetic nano-communication, nano-networks, etc.	Cyberspace, and physical space	Medical and environmental data collection by nanotechnology
PoT (this paper)	Land, animals, humans, devices, etc.	Clustering, blood relationship, regional, technology, etc.	Physical space	Food chain, laws, computer technologies, etc.	Physical space, social space, thinking space, and cyberspace	Cross-spaces connection based on physical space

another computer, it becomes a social thing. While recording one's ideas on a computer is a thinking thing, and finally while connecting to the network, it becomes a cyber thing. Therefore, when a certain space appeared and affected things, this influence might be independent of the previous space or cross-influential.

As for the PhiNet between things, corresponding changes have taken place with the appearance of other spaces and the change of things. PhiNet is equivalent to the relationships in the philosophical sense that reflect the interconnection between things and their characteristics [31], so PhiNet is objective and inherent in things. With the emergence and development of human society and thinking ways, scholars have begun to explore PhiNet in sociology (such as family relationships [32], [33], teacher-student relationship [34], etc.). When the cyberspace was created, the PhiNet also changed: it includes both machine-level connections (such as computer clusters [35]–[37], computer working groups [38], etc.), and data-level connections (such as parallel, cross, Cartesian product [39], [40], etc.). It can be seen that PhiNet can also be divided into four categories according to the development order of spaces: 1) PhiNet; 2) social PhiNet; 3) thinking PhiNet; 4) cyber PhiNet. Like things, PhiNet generates characteristics adapted to things with specific space, which will also be applied to PoT. These characteristics have been reflected in Fig. 3.

The impact of creating a new space on the previous stage promotes the evolution of things and PhiNet and the emergence and development of PoT. Therefore, exploring the evolution of PoT in detail can also be discussed in accordance with the timeline.

A. Early PoT

Since the birth of the earth, PoT has been produced with physical space. At that time, the components of PoT were extremely simple, and only a handful of things were involved. With the gradual formation of continents and oceans, the original form of the earth was created. Similarly, the PhiNet between things was very simple and did not have the characteristics of diversity. Due to the state of the physical space itself, many natural phenomena and physical effects that have occurred until now have been produced, so most of them have the characteristics of invariance (as shown in Fig. 4(a)).

B. Social enabled PoT

Water is considered to be the cradle of life, so life can be considered to begin in physical space. With the emergence and evolution of life forms, social space based on physical space began to be formed. Social groups, as opposed to individuals, are a combination of individuals. Research on social groups focus on, but not limited to, humans [41]–[43]. With the deepening of research, some scholars have found that plants [44] and animals [45] also have social structures; even the

most selfish bacteria have been found to play different social roles in groups [46]. Therefore, social space does not only refer to human beings, but also includes other species with social behaviors.

Forming a group depends on the PhiNet between individuals. Different species rely on different PhiNet when forming groups. For example, bacteria can be grouped by competition [46], plants can be grouped by different fungi [47], and animals can be grouped by blood relationships. At the same time, PhiNet can also be generated in different groups [48], [49] to maintain the mutual relationships between groups and form a larger group.

As a subordinate of physical space, social space has brought PoT its first major development. Under the influence of such a space, PoT exhibited various characteristics such as sociality. After enriching its things and PhiNet, it began to develop from decentralization to aggregation (as shown in Fig. 4(b)).

C. Thinking enabled PoT

The successive appearance of language, imagination, and religion has made humans the top species in social space, then urged the creation and development of thinking space. Perhaps the gene's accidental mutation changed the way of connection in the Homo sapiens brain, which opened the prelude to the cognitive revolution [50]. With the emergence of thinking space, human beings began to understand and touch the world more comprehensively, and record these findings in different forms. Words, books, paintings, music, etc. are all things produced under the influence of thinking space, which enhances the richness of PoT, the connotation, and the depth.

This space created by people also has a profound impact on human relative PhiNet. Human PhiNet is no longer limited to blood, geography, etc., but also shows the connections under the influence of thinking. Taking painting as an example, in the development process, many factions, such as abstractionism, impressionism have been formed. The division of different factions formed different groups, which in turn produced different PhiNet. The emergence of thinking space, relying on human evolution, makes PoT orderly and civilized (as shown in Fig. 4(c)).

D. Cyber enabled PoT

The commissioning of the first commercial mass-produced computers UNIVAC-I in 1951 marked the official arrival of the computer era [51]. In 1984, Canadian fantasy novel writer Gibson first proposed the terms cyberpunk, cyberspace in *Neuromancer* [52], and included computers, networks, etc. into this space. Cyberspace is a unified description of the computer world that has given different meanings over time. The emergence and development of this space have a significant impact on PoT. Thus, some characteristics, such as virtualization and digitization, have also emerged (as shown in Fig. 4(d)). From the perspective of things, cyberspace's influence can be attributed to two types, namely non-mapping things and mapping things.

1) Non-mapping things: This kind of things appears with the emergence of cyberspace. Before that, these things were not reflected in PoT, so they can be considered as a kind of new existence. Some of these things can be seen as real products driven by demand, such as arithmetic logic units (ALU) for computing function, various storage devices for storage, gateway and routing for data transmission; some of them can be regarded as digital and virtual abstraction entirely composed by cyber elements [5], [53]. These non-mapping things with significant cyber characteristics plays an important role in the information and computerization world.

2) Mapping things: These things came from the thinking enabled PoT. Because of cyberspace's role, these things have been given new characteristics of cyberization, digitization, and virtualization, which are an important material source for developing cyber enabled PoT. With the miniaturization of sensors and popularization of electronic tags, more and more things have begun to connect the digital world, providing material possibilities for cross-spaces connection.

The impact of physical space is mainly reflected in the entities aspects: hardware, chemical industry [54], daily necessities [55], and household appliances [56], all of which can realize cyberization. They are equivalent to the u-things, smart things proposed in [57]–[59], that is, any ordinary physical things can be connected to the cyberspace. While the original attributes are retained, the physical things will also be given new characteristics such as digitalization and intelligence. When the mapping is converted, the physical entity will have a one-to-one correspondence with the cyber entity. This correspondence can be reflected by various identities, such as universal product code (UPC), and QR Code.

Social space is a general term for all groups with social behaviors, not limited to humans. If only considering the impact of cyberspace on society from the aspect of things, the most important problem is to solve how social groups are mapped into the cyber world. For animals and plants, this mapping process can be realized by binding cameras and sensors on their own, together with RFID, GPS, and other technologies [60], [61]. For human groups, this mapping process has more abundant implementation methods. Registration in a social network, login in the game world, and speech in a virtual community can be regarded as completing a process of mapping to the cyberspace. As the mapping of physical entities, people can also use various codes to complete this process. When the mapping process cannot be completed with codes, this process can be completed using unique human characteristics (such as physiological characteristics, and behavioral characteristics), or even abstract characteristics [62].

The ability to present abstract things such as thinking, consciousness, emotion, and imagination in a digital form reflects the cyberspace's influence on thinking. With the advent of brain science [63], brain-computer interfaces [64], brainsmatics [65], and other technologies, the realization of the expression of abstract things in cyberspace has changed from being possible to being able. Meanwhile, some methods began to simulate human thinking mode, such as using deep learning in recognition. Deep learning is a kind of technology realized by simulating the connection mode of human brain

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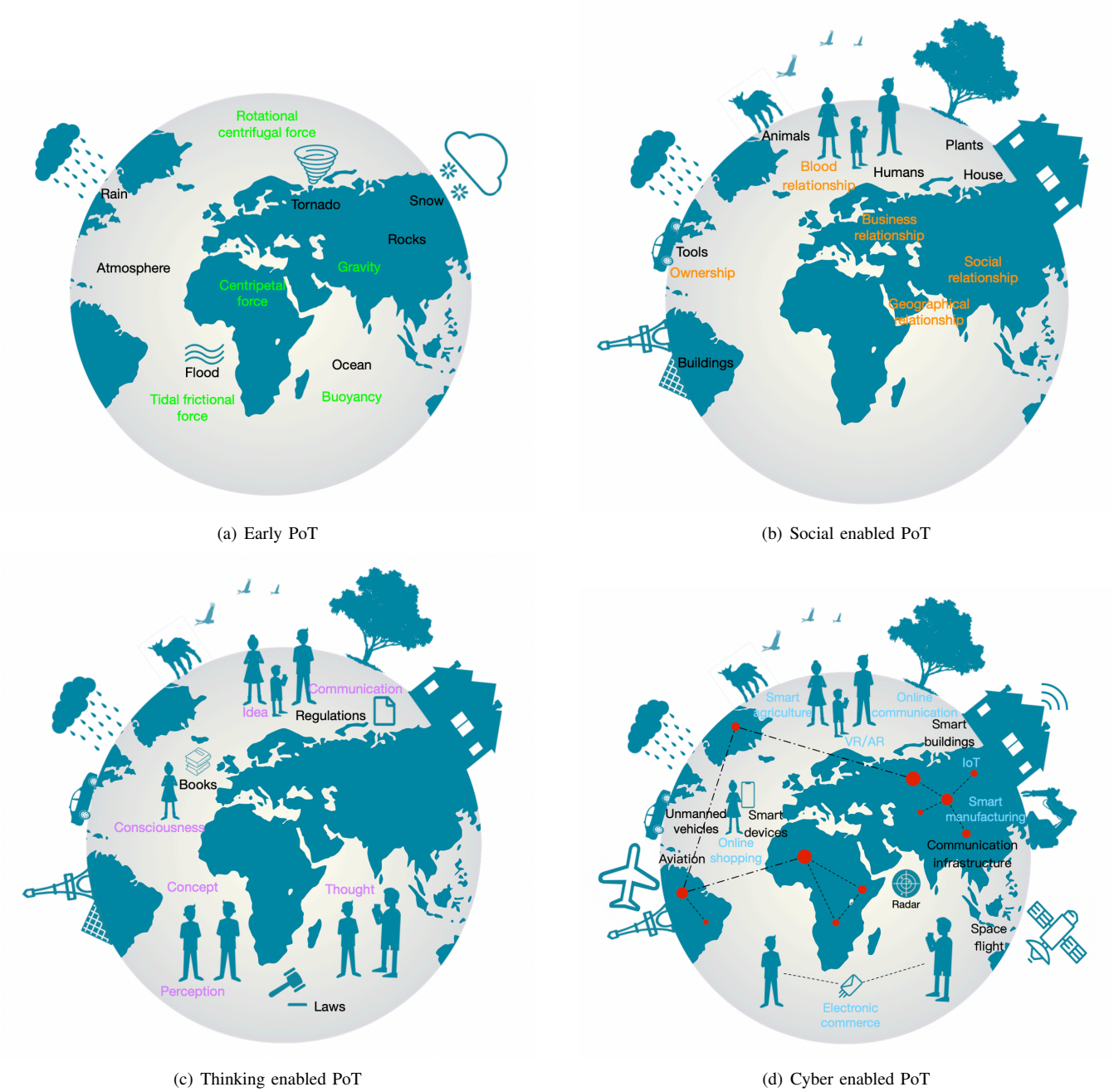

(a) Early PoT

(b) Social enabled PoT

(c) Thinking enabled PoT

(d) Cyber enabled PoT

Fig. 4: The four development stages of PoT

neurons [66], [67], which is also an important embodiment of moving human thinking mode to cyberspace.

The emergence of cyberspace not only produced new PhiNet between things, but also had an important impact on the established PhiNet in the last stage of PoT.

3) The emergence of new PhiNet: The appearance of PhiNet is reflected in the non-mapping things. Take the three-layer structure of IoT as an example. In the perception layer, there are different PhiNet because of the organization, type, and other factors of data, such as the hierarchical organization of data-information-knowledge [68], the linear, tree, and other structures formed by the connection of data elements. In the network layer, network nodes can be divided into different groups according to factors such as coverage, network topology, transmission media, etc., and each node plays a different role in the group. In the application layer, applications can be divided into several application clusters according to application content and application methods. In order to accomplish the same task goal, the applications in these clusters cooperate with each other. These new PhiNet revolve around data, hardware, and related technologies, corresponding to the non-mapping things that appeared after the cyberspace was generated. They make the non-mapping things not isolated nodes, but complex networks of information interaction and mutual cooperation.

TABLE IV: State changes of things and PhiNet in PoT

Development stage	New situations of things	New situations of PhiNet
Early PoT	Water, fire, rock, soil, magma, ammonia, methane, carbon dioxide, radioactive elements, metallic elements, chemical elements, natural disaster, weather, etc.	Time-space relationship, universal gravitation, chemical reaction, rotation and revolution, fission and decay, physical action, etc.
Social enabled PoT	Microbial community, plant community, flora, shoal of fish, algae, animal community, human beings, etc.	Competition relationships, belonging relationships, blood relationships, geography relationships, interest relationships, food chain, interaction between groups, etc.
Thinking enabled PoT	Thought, idea, attitude, psychology, concept, sense, mentality, books, articles, laws, administrative regulations, etc.	Political relationships, love relationships, mutual perception, association and recollection, suspicion, mutual inference, etc.
Cyber enabled PoT	Mapping: individual status, cars, bikes, glass, doors, windows, electric light, etc.	Correspondence, interlinkage, tree structure, graph structure, loop, node communication, human-machine interaction, data transmission, information sharing, device awareness, etc.
	Non-mapping: sensors, graphics renderer, transmission equipments, gateway, terminal, etc.	

4) Impact on established PhiNet: The mapping of things to cyberspace produced new characteristics that will cause changes in the established PhiNet between them. This is the inevitable result of cross-spaces connection. In physical space, seemingly unconnected physical things may become an interconnected entity due to data transmission and cooperation after cyberization. Such an entity can be for a certain range of activities (such as houses [69], gyms [70], and workshops), it can be for a certain field (such as Industrial Internet of Things (IIoT) [71], and Cognitive Internet of Things (CIoT) [72]), or it can be full space coverage (such as IoT [73]). To realize this process, it is inseparable from the support of technologies such as sensor networks [74], ubiquitous computing [75], etc., and it is also inseparable from the support of new PhiNet. The proposal of CPS is an important manifestation of the deep integration of computer technology and physical space [21]. In this system, how to realize the interconnection and intercommunication of various resources and accomplish the goal more efficiently has become the primary issue that needs to be considered. It should be noted that the mapping from physical entities to cyber entities is also a PhiNet in itself.

The emergence of cyberspace also has a great impact on social PhiNet. The society here refers to the social group composed of people. The PhiNet between people will no longer be divided solely by traditional factors. Under the influence of cyberspace, people can build PhiNet through social networks [76], service categories [77], social media interaction [78], and other ways. This impact on PhiNet is not only reflected in the communication level. The social attributes, such as rights, values, attitudes, and obligations can also be reflected in the digital world. The mutual influence and deep connection between cyberspace and social space have inspired the proposal of some new concepts. As proposed by SIoT, it was believed that the integration of the IoT and social networks is feasible and reasonable [15]. It is an important manifestation of unifying the things and PhiNet of socialization into a whole under the effect of cyberization. The proposal of Internet of People (IoP) was based on IoT [79], rationally considered people's vision, and took proactive measures based on people's ideas to avoid interference with continuous work.

The emergence and development of technologies combined with thinking (such as emotional computing [80], and AI), provide support for the realization of perception, cooperation, sharing, learning, and decision-making between multi-agents. Thoughts, concepts, value orientations, etc. no longer appear in the thinking space and become the key to the realization of interconnected things under cybernetization. Cyber-enabled Thinking space (CeT) [81], and Internet of Thinking (IoTk) [27] described exactly how to achieve abstract expression and collaboration in cyberspace.

The development of PoT has gone through four main stages, and each stage is a further expansion of the things and PhiNet in PoT. Currently, PoT is in the cyber enabled stage. This form is caused by things development and cross-spaces PhiNet. It is also the environment where we currently live. Everyone can feel the impact of the integration of the four spaces on production and life. The proposal of Internet of Everything (IoE) is a further expansion of IoT [82]. It pointed out that everything in the future world should be mapped into the digital field, which was the ideal performance of deep integration of cyberspace, objects, people, perception, and computing; meanwhile better services can be achieved through interconnection. The research content of General Cyberspace (GC) [5] and CPST [27] also took the integration of the four spaces as the starting point, expounding the significance of this integration for future development.

However, same as IoT, IoE, GC, CPST, and other studies viewed current developments from the view of cyberspace. It is undeniable that at each stage, the derivative or new space has a significant impact on the development of PoT. However, the fact that cannot be ignored is that all developments start from

physical space. Physical space is the source of the generation and development of PoT and the original intention of its concept. Whether from the perspective of things or PhiNet, the fundamental role of physical space is undeniable. These system prototypes and theoretical basis are built on the basis of physical space. In each development, things and PhiNet are different in form. Table IV summarizes their new situations.

IV. Viewing PoT from examples

Section III summarized the emergence and development of PoT from a macro and overall perspective. In order to better understand the actual development process of PoT, this section starts from reality and describe PoT's development in detail. Table V uses *trees* and *viruses* as two examples to specifically show the things and PhiNet involved in each stage of the PoT. Table V can be regarded as a concrete manifestation of Table IV, which is a detailed description of the development of PoT and a reflection of the stage characteristics in a more intuitive way.

At present, human beings are in a cyber enabled PoT state, and this state will become the long-term living environment of mankind. In this living environment, things and PhiNet can be divided into four categories determined by the characteristics of the space they belong to. In particular, *smart transportation* and *smart prevention and control system for Corona Virus Disease 2019 (COVID-19)* are used as examples to explain the things and PhiNet involved in the various spaces that make up the PoT. This description is shown in Table VI.

In a comprehensive application, things and the PhiNet between them can be classified according to the space in which they are located in order to achieve different usage methods, usage purposes, and usage effects. However, this division is neither mandatory nor unique. For example, a motor vehicle with sensors can be regarded as things in physical space or things in cyberspace. This is the result of dividing things from different perspectives and positions. It is also applicable to PhiNet. When things are divided into different angles, they focus on different perspectives and have different PhiNet. For example, a motor vehicle with sensors focuses on the description of mechanical parts in the physical space, and focuses on the description of perception in the cyberspace. The cross-spaces division of things and PhiNet also proves that PoT has the characteristics of crossover. Based on this fact, the connections between spaces also appear crossover, which is a prerequisite for close interaction between spaces. PoT is such a unified description based on physical space which has been developed during the process of STCs appearing and connecting.

V. The future trend of PoT

At present, the environment we live in corresponds to the fourth stage of PoT, and the fusion range of the four spaces is gradually expanded, affecting the characteristics of things and PhiNet in a crossover manner. At this stage, cyberspace is the most important factor affecting the development of PoT. For the future development of PoT, reasonable inferences need to be given based on various current signs. For this reason, we believe that the future of PoT will show two trends: adaptive development and adversarial development.

A. Adaptive development

With the rapid development of sensor size, data transmission speed, and other factors, the influence range and intensity of cyberspace are obvious to all. Large industrial manufacturing, military equipment, small daily necessities, and sundries may all be affected by cyberspace and produce new characteristics. Taking train tickets as an example, China is currently advancing the process of paperlessness. In the future, users do not need to use paper tickets. Instead, they can achieve rapid verification through various methods such as ID cards and face recognition to achieve the purpose of entering the station. This is an important example of cyberspace affecting physical space, and it even shows a tendency to assimilate.

Therefore, we have reasons to believe that the role of cyberspace in the future will further increase, and even a state of assimilation will occur. This influence will cover both things and PhiNet, which can be felt from the PoT description of the fourth stage. We can imagine the state of human life after the adaptive development: in the morning, people can use the intelligent assistant to clean the room and prepare breakfast; after going out, they can take the driverless cars that have been arranged on the mobile phone to go to the company; in the process of going to work, the staff may give the prepared speech to the operator, who will operate the remote conference and realize communication instead of them; when the weather is rainy, the city's intelligent drainage system will open to ensure that there is no water on the road; when returning home from work, the virtual technology is used to realize cloud shopping and fitting, and the virtual doctor will do health examination; during the night sleep, monitoring system can be used to detect the safety of the whole family.

When the adaptive development is completed, the world will show a high degree of intelligence, collaboration, and digitization. Besides, the processing of most events will not be achieved manually. In human social circles, highly intelligent robots may appear and even be given citizenship. In thinking space, there could be some works created by highly intelligent machines. At that time, PoT will be transformed by the cyber world, appearing completely different from the current production and life scenes, the boundaries of each space will be blurred, and even the phenomenon of assimilation will become more obvious.

B. Adversarial development

Contrary to adaptive development, PoT may be on the path of adversarial development in the future, which is the result of spatial heterogeneity due to spaces connection to a certain extent. Although the integration of the four spaces continues, no one can give a specific answer to the degree of this process. Unlike social and thinking spaces derived from physical space, although cyberspace depends on physical space, it has a certain degree of independence. As a result, in the process of development, PoT may not be able to adapt to certain developments in the cyberspace, resulting in some perceptible discordant

TABLE V: Trees and Viruses as study cases to show the changes of things and PhiNet in the development of PoT

Specific things	Development stage	The forms of things and PhiNet at each stage
Trees	Early PoT	**Things involved:** sunshine, water, air, climate, etc.
		PhiNet involved: gas emission and absorption, nutrient absorption, photosynthesis, etc.
	Social enabled PoT	**Things involved:** birds, herbivores, saprophyte, bacteria, mammals, etc.
		PhiNet involved: plant population (forest, park), competition (sunshine etc.), cooperation (shelter from the wind etc.), food chain, shelter, etc.
	Thinking enabled PoT	**Things involved:** description, view, varieties, etc.
		PhiNet involved: trim, conjecture of value, photography, evaluation, etc.
	Cyber enabled PoT	**Things involved:** sensor, temperature detector, humidity detector, moisture detector, etc.
		PhiNet involved: trees networking, intelligent scenic spot, intelligent irrigation, fire monitoring, etc.
Viruses	Early PoT	**Things involved:** protein, nucleic acid, nutrient substance, lipid envelope, etc.
		PhiNet involved: stress response, self-replication, division, etc.
	Social enabled PoT	**Things involved:** medicine, protective clothing, disinfectant, medical devices, etc.
		PhiNet involved: plague, influenza, human-to-human transmission, cross-infection, etc.
	Thinking enabled PoT	**Things involved:** fear, guess, deduction, recollection, etc.
		PhiNet involved: microscopic imaging, mechanism analysis, track, traceability, etc.
	Cyber enabled PoT	**Things involved:** electron microscope, digital medical imaging, doctor workstation, etc.
		PhiNet involved: sentiment analysis, information processing, scientific, technological, and international cooperation, etc.

phenomena. For example, the artificial waste heat generated by various industrial activities and the random disposal of hardware waste containing harmful substances are important factors causing global warming. These impacts will send early warnings to human beings, such as extreme natural disasters, sea level rise, species extinction, and other ways, and transmit the discomfort of PoT caused by excessive development of cyberization.

At the same time, this adversarial development is also reflected in the situation where humans and machines cannot live in harmony. Although machines are getting smarter and more autonomous, the harm to people caused by them is not rare. The collision event of Uber refitted car, the event of robot out of control hitting child [83], and the extreme behavior of AI will all affect the process of deep integration of cyberspace into PoT. Whether robots can be granted citizenship, whether humans can accept the emergence of intelligent machines in their social circles, and whether intelligent machines can normally survive in the PoT environment are all important signs of adversarial development. The ethical problems caused by machines and the wave of unemployment will further reject the deep integration of cyberspace and fail to achieve a new situation of adaptive development.

In addition, cyberspace also brought some other open issues in the development of PoT, including security of privacy, medical supervision, high-performance weapons, electronic fraud, public opinion orientation, etc. If these issues cannot be adequately addressed, they will become important factors that encourages adversarial development of PoT. Humans are also actively looking for potential solutions to alleviate the conflicts caused by spatial heterogeneity and technological abuse. For example, the United States proposed the *Future*

TABLE VI: The embodiment of PoT in comprehensive applications

Applications	Examples of things	Examples of PhiNet
Smart transportation	**Physical things:** auto parts; non-motor vehicles; road signs; motor vehicles; red street lights, etc.	**PhiNet:** motor vehicle system (partnership, mechanical movement, energy conservation).
	Social things: motor vehicle drivers; non-motor vehicle drivers; pedestrians; stray cats and dogs, etc.	**Social PhiNet:** accident conflicts (interest relationships); vehicle ownership issues (belonging relationships, interest relationships).
	Thinking things: driving quality; road driving standards; lane design; driving concept; traffic laws; regulations, etc.	**Thinking PhiNet:** punishment according to law (political relationships); irregular behavior education (judgment, political relationships).
	Cyber things: smart transportation equipment; visual sensors; bus center servers; unmanned vehicles; vehicle terminals; hazardous materials detection sensors, etc.	**Cyber PhiNet:** dangerous goods detection platform (device awareness, data transmission, information sharing, node communication).
Smart prevention and control system for COVID-19	**Physical things:** medical warehouses; epidemic prevention materials; precision diagnostic equipment; medical equipment; medical materials, etc.	**PhiNet:** material attributes (inherent relationships); drug response (chemical reaction); regional isolation (physical action).
	Social things: logistics organizations; patients; close contacts; voluntary organizations; communities, etc.	**Social PhiNet:** collaborative therapy (interest relationships, cooperative relationships); close contact tracking (blood relationships, geography relationships).
	Thinking things: understanding of viruses; epidemic prevention concept; panic psychology; herd psychology, etc.	**Thinking PhiNet:** discussions on the epidemic (association and recollection); prevention and control policies (political relationships, inference).
	Cyber things: material tracking sensor; electronic reporting system; big data collection platform; information release platform, etc.	**Cyber PhiNet:** data collection, statistics, and predictions related to the epidemic (data transmission, information sharing); correct guidance of public opinion (node communication, human-machine interaction).

of Artificial Intelligence Act in 2017, which will become an important measure to regulate AI. Russia officially launched the *Sovereign Internet Law* in 2019 to strengthen its control over the country's Internet. Other countries are also strengthening the supervision of data security, technology applications, etc., to minimize friction in the development of spaces to pave the way for the adaptive development of PoT.

The purpose of interconnection and integration between spaces is not to completely replace or annex other spaces, but to coordinate the development of spaces and jointly benefit the earth. PoT is currently moving in the direction of adaptive development, and many scenes that can only be seen in science fiction movies are gradually becoming a reality. Nevertheless, we cannot ignore that the cause of the adversarial development has emerged, and it has become more acute and obvious with the progress of cyberization. To achieve a stable and harmonious development of PoT, it is necessary to fully consider and actively solve these obstacles while pursuing integration, so that the world will eventually achieve a situation of survival and development based on physical space and harmonious integration of multiple spaces.

VI. Conclusion

Starting from the natural view and centering on physical space, this paper proposed a brand-new concept: PoT. We described things and PhiNet in PoT in chronological order, and uses two examples to visualize this process. We also listed two applications to show the usability of PoT in the current environment. Finally, the future development of PoT was proposed and prospected. Through the concept of PoT, this paper aimed to demonstrate the fundamental role and importance of physical space. There is reason to believe that the degree of richness, connectivity, and collaboration of PoT will be further improved under the cooperation of various

spaces, and a series of measures, policies, and methods will provide strong support for this process.

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