Cyber-physical-social-information-thinking hyperspace: a manifold of cyberspatial entities

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Abstract

Purpose – This paper aims to establish a theoretic framework to provide a fundamental understanding of cyberspatial objects, their existence and their identification scheme while providing a connection between cyber-enabled spaces and cyberspace. It develops an avenue to quantify general philosophical and theoretical questions, precisely, inherently spatial basis that produces an unprecedented space–time continuum, in which cyber-enabled relations evolve.

Design/methodology/approach – Multidisciplinary theoretical approaches are needed to describe complex systems, which in this paper are integrated in a quest for the principles underlying the structural organization and dynamics of cyberspace. A theoretic framework is presented, and the spatial conception of cyber-enabled physical, social, information and thinking spaces and entities existence are provided.

Findings – With spatial objects and spatial properties, cyberspace is inherently spatial. Its basic constructs are founded on its spatial qualities and producing radical space–time compression, cyber-enabled spaces in which dynamic relations develop and thrive. The cyberspatial object operations are primarily built on foundations that depend on physical space and other spatial metaphors. Information space, basically missing in the literature, is an important part of cyberspace.

Research limitations/implications – This work suggested a novel analytical approach to describing cyberspace from broader perspectives and fields. Due to the novelty and divergence of cyber concepts, an interdisciplinary study and methodology are needed. Thus, more research toward theoretical direction could help many of the practical implementations of concepts.

Practical implications – The research is of particular significance in cyberspatial mechanics to describe the dynamics and behavior of cyber physical systems. For example, object-based analysis functions like spatial query, node pattern analysis, cluster analysis, spatial similarity analysis and location modeling.

Originality/value – Complementing the existing literature and defining information space to the research sphere, a theoretical framework providing a fundamental understanding of cyberspatial objects and the general cyberspace foundation has been proposed, resulting in a formalized concept of existence, interactions and applications and services, with respect to philosophy, science and technology, respectively.

Keywords Cyberspace, Cyberspatial object, Cyber-enabled spaces, Cyberspace–time, Cyber philosophy

Paper type Research paper

1. Background

Cyberspace is an unprecedented space related to the traditional physical, social and thinking space (Ning *et al.*, 2016; Ma, 2016; Ma *et al.*, 2016). It has evolved ubiquitously, intersecting many disciplines, attracting diverse attention and has a broad area of research that includes technical, strategic, operational, scientific, philosophical and sociological perspectives. In effect, various terms, synonyms and concepts evolve in parallel. The variations, especially as a semantic problem of definitions, lead to what Strate called cyberspace (s) (Strate, 1999) and Ning *et al.* called "General cyberspace–(GC)" (Ning *et al.*, 2018). Through cyberization (Ning *et al.*, 2016; Ma, 2016; Ma *et al.*, 2016), cyberspace is reconfigured from the reformation of the cyber-enabled world, which substantially influenced and revolutionized its conception. For example, "CyberSciTech" as an inter-disciplinary, transdisciplinary and multi-discipline consolidation of cyber science and cyber technology (Ma *et al.*, 2016) studies these emerging cyber-enabled spaces (CeXS), empirically adding to how we define the formalization of cyberspace (FC) (Kademi and Koltuksuz, 2020a). To study entities in cyberspace, their attributes, properties and behaviors, Ning *et al.* (2016) and Ma *et al.* (2015) coined "Cybermatics."

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An ontological existence, a core part of philosophy and an essential basis of the science and technology of GC, is a vital prerequisite for rigorous theories of cyberspace. In this regard, questions such as whether cyberspace is a space, what kind of space is it (Bryant, 2001) are to be investigated. With cyberspace depending on physical space, for example as "parallel" (Grosz, 2001, p. 76), the existing spatial theories may provide a clue, although cyberspace is not entirely absolute or relative (Wang *et al.*, 2003), but it is potentially both and beyond. It is spatially and physically associated with real-world infrastructures (Zook *et al.*, 2004) and with environments (Light, 1999). As a "time-dependent set of interconnected information systems and the human users that interact with these systems" (Ottis and Lorents, 2010), cyberspace has evolutionary dynamics (Wang *et al.*, 2016) and characteristics features (Ning *et al.*, 2016) that make it a spatial manifold of entities.

Converging on a cyber-enabled world (Ma *et al.*, 2015; Ning *et al.*, 2018), cyberspace conception needs to go beyond physical space, social space, and thinking space (CPST) to include information space. From the work of Ma *et al.* (2015, 2016) and Ning *et al.* (2020a, b, 2018, 2017, 2016) pioneering cybermatics and cyberization of computerization and informatization establishing a CPST, a subset of these district spaces and concepts is investigated from a variety of applications and contexts. Garvey (2021) argues on only two-dimensional space of physical space that enables the physical representation of information and thinking space. With Dhejim *et al.* (2018) proposing an architecture based on smart home residents' social and thinking entities while deliberating more of cyber entities in Dhelim *et al.* (2021) and Zeng *et al.* (2020) surveyed cyber-physical social systems (CPSS). The theoretical background and spatio-temporal conception of cyberspace need to be adequately investigated from much wider perspectives that includes information space and more. The literature, as further shown in Table 1, reveals that only few studies made a superficial mention of information space, such as Bytiak *et al.* (2021) and Zhao *et al.* (2021). Cyberspace is every information and object that exists within the time and space of the digital universe, and the theoretical perspectives of the spatio-temporal background of the multiple CeXS, including information space, are vital.

Table 1. Relevance of conventional spaces, entities and theoretic background in the literature

	Cyberspace conception						
	Physical space	Social space	Information space	Thinking space	Spatio-temporal	Entities/ objects	Theoretical background
Bytiak *et al.* (2021)		✓	✓		✓		
Zhao *et al.* (2021)	✓		✓		✓		
Garvey (2021)	✓			✓	✓		
Dhejim *et al.* (2020)	✓	✓		✓	✓	✓	
Kademi and Koltuksuz (2020a)					✓	✓	✓
Zeng *et al.* (2020)	✓	✓				✓	
Zhang *et al.* (2020)	✓	✓				✓	
Jiang *et al.* (2020)	✓					✓	
Zhang *et al.* (2018)	✓	✓				✓	
De *et al.* (2017)	✓	✓				✓	

This paper fills the gap by elaborating on a formalized conceptualization of cyberspace and from related disciplines, investigating the concepts of existence, interactions and applications and services, concerning philosophy, science and technology, respectively. Basically, (1) the essence of cyberspatial entities' existence from cyber philosophy, questioning the spatiality and the basis of ontological properties of cyber entities; (2) inter-disciplinary relations of CPST from philosophy, science, cyber information technology,

bridged by logic; (3) cyber-informational conjugation, which concerns how information entities are conjugated before thinking space; (4) cyber theoretical notions of dimensional space. In essence, this paper original contributions are:

(1) We establish a theoretic framework to provide a fundamental understanding of cyberspatial objects from an ontological basis and their identification scheme.

(2) We show the space and cyber entities' existence and provide a connection between cyber-enabled space and cyberspace.

(3) We develop a foundation for general philosophical and theoretical questions, precisely, inherently spatial basis that produces an unprecedented space–time continuum, in which cyber-enabled relations can develop and flourish. One of the questions addressed is how should cyberspace be conceptualized as space.

1.1 Cyber philosophy as the foundation of cyberspace disciplines

Philosophy studies the fundamental nature of knowledge, truth, reality and existence. It has three broad areas of research: ontology, epistemology and ethics. We mainly focused on ontology as it deals with existence– – addressing questions such as: "What is Cyberspace? Is it, or does it have dimension? Are there things in Cyberspace? Are things in Cyberspace properly called objects? Are such objects, or is Cyberspace itself substance(s) or process(es)? Is Cyberspace or the objects in it real or ideal? What is the categorical scheme of Cyberspace? How should Cyberspace fit into a broader categorical scheme?" (Koepsell, 2000). Epistemology, however, deals with knowledge. To what degree does spatial and social behavior in cyberspace affect behavior in the real world, and the implications of cyberspace for information generation and the epistemology of cyber-related information practices, including information utilization and management? The philosophy of information investigates the nature and basic principles of information, its dynamics, uses and science. It is also the application of information-theoretic and computational methods to philosophical problems (Floridi, 2002). Cyber philosophy, the intersection of philosophy and computing (Moor and Bynum, 2002), defines the existence of cyberspatial entities and space. As cyber science provides research on applications and services relating to information and communication technologies (ICTs), philosophy questions the problem of the existence of space and cyber-enabled entities (CeXE).

By existence, we mean the existence of spaces (physical, social, information), cyberspace and cyberspatial. This provides a basis for a well-defined cyberspatial object/entities, three categories of which are considered: Logical entities are objects existing only in virtue of demarcations induced by human cognition and actions, such as applications, virtual entities or simulated objects. Physical entities are tangible entities determining a possible flow pattern and the typical operations. Lastly, well-defined data (information) as an entity, which can be in the form of events or processes. Existence deprived of mathematical rigor is meaningless, the existence of an entity can be, for instance, by the spatial coordinate.

A formal and rigorous conception of cyberspace is combined research from various disciplines as cyber science, cyber information technology with a foundation from cyber philosophy. This research analyzes cyberspace and its spatial entities that are governed by a topological rule and instructional information that enables them to communicate. In Figure 1, four disciplines and how they related with each other is shown. The ontology questioning the existence of space and objects from the cyber philosophy discipline; the rules and principles governing these objects are defined from cyber science, informational and technical spectrum as applied and used in services and applications in cyber information technology. Cyber logic establishes a bridge from cyber philosophy to cyber science and subsequently to cyber ICT,

which applies systematic information and intelligence from cyber science in the design, development, implementation and application of the entities. The first question, therefore, is the essence and existence of space and entities. It precedes the emergence of physical systems from which events, processes and data are postulate. Describing the behavior of individual cyberspatial entities such as CPS, cyber science studies these entities and their interaction to create systematic information and intelligence about them for validated and verified methods to establish a model in cyberspace. Cyber logic or "Cyberlogic" (Ning *et al.*, 2017) defines rules of cyber and CeXE in CPST spaces from cyber philosophy to cyber science via computational logic, which helps in heuristic and analytic. Cyberlogic provides describes how these disciplines are related. For example, spatio-temporal logic in physical space and interrelation between agents in social space.

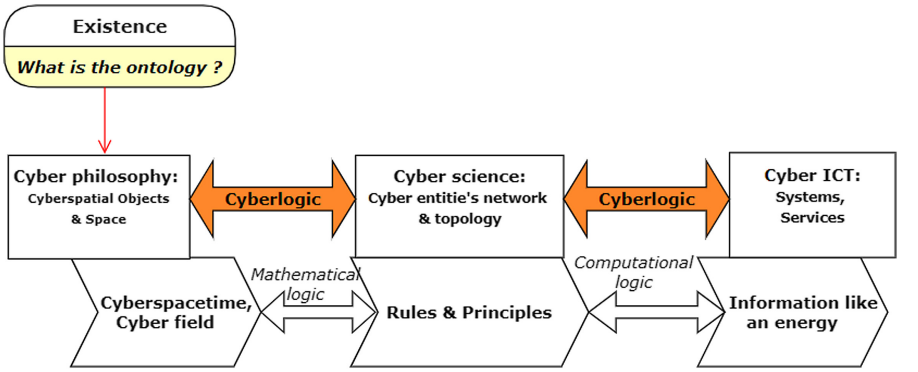

Figure 1.
Relationship between cyber disciplines, bridged by cyberlogic

Therefore, with the cyber philosophy as a basis of cyberspace conception, the following are reinforced:

(1) The comprehensive investigation of the conceptual nature and basic principles of cyberspace, including its topology, dynamics, functionality and its sciences; and

(2) The elaboration and application of theories such as information and graph-theoretic methodologies to philosophical issues.

2. Ontological existence of space and entities

Ontological questions as applied to phenomena such as cyber entities and space, which constitute cyberspace, are analyzed as an ontology of cyberspace. The things/entities, varying in properties and types, which can be observed using our consciousness and senses, are primarily known in conventional spaces (physical, social, thinking space) and accordingly conjugated in cyberspace. These entities have life cycles and are temporal (Dhelim *et al.*, 2020). The cyber existence is not merely a virtual abstraction of information and data as it includes physical space, social space, information space. We analyze the existence into two categories: (1) space existence is the physical-social-thinking (PST) space existence, CeXS and, ultimately, cyberspace as spatial manifold existence. (2) Cyberspatial object existence (ordinary cyber existence and cyber-enabled objects (CeO) existence).

2.1 The cyber-enabled physical, social information thinking (CPSIT) hyperspace

Cyberspace is related to conventional physical, social and thinking space. The physical space accommodates physical objects (e.g. machines, humans, things), cyberinfrastructures and

devices; social space is the provision of social connections, relations and interaction (Zeng *et al.*, 2020) socially interconnecting physical entities; and thinking space is a source of ingenuity and imagination existing outside physical form with no inherent spatial dimension. These spaces are transmuted or influenced by cyberspace as CeXS. These are cyber-enabled physical space (CePS), cyber-enabled social space (CeSS), cyber-enabled thinking space (CeTS) and cyber-enabled information space (CeIS): We consider the existential background of CeXS and cyberspace;

2.1.1 Cyber-enabled physical space (CePS) existence. Physical space is the basis of the existence of all spaces, postulating things in the real world and the physical universe. Cyberspace is physical and shares the essential characteristic of physical space, which embodies cyber-physical systems operating in geospace where geocentric coordinates locate objects from the axis of latitude, longitude and altitude, which also specify the physical location of a cyber object. From the considered geometry, space is a boundless three-dimensional (3D) extent with objects and events having relative positions, and Euclidean space and other similar hyperspaces are metric space that generalizes the notion of distance, such that two physical objects are well captured as either close to or farther away from one another. Similarly, in addition to being specified with various precision (adjacent, next to, far, etc.), objects occupied positions in cyberspace, and one can specify these positions in terms of an address in 3D Space and measure the distance. In addition to the geocentric indexes, spherical coordinates defined by using radial, azimuth and zenith angles, r, θ and $\varnothing$, respectively, can also be used to identify the physical location of a cyber-physical object. Consider a 3D manifold, $\mathbb{R}^3$, and let P_i^P be a physical (geospatial) location, the geocentric coordinates position objects along latitude, longitude and altitude (x, y, z), the physical distance between e_i^b and e_j^b is:

$$d_{i,j}^b = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2}$$

Where $P_i^P = (x_i, y_i, z_i)$ and $P_j^P = (x_j, y_j, z_j)$ are the physical position of e_i and e_j, respectively – Figure 2a. As with every geospatial object occupying space, cyber-enabled space is occupied by CeO, and similarly, has a georeferenced position as a service access point (SAP), wired addresses – last mile and wireless address – mobile content delivery networks (CDNs). Through these physical addresses, information is transmitted and physically actionable. Since $\{x, y, z\}$ coordinate references can be mapped to the geographic physical address, the corresponding position of CeO as geospatial addresses can be mapped to physical addresses.

2.1.2 Cyber-enabled social space (CeSS) existence. Social attributes such as affiliation, relationships, human behavior and ownership play a significant role for social entities. They concern social interaction and collective coexistence. The social space is where inter-relationships between these entities are made possible. Human social and organizational structure can be described in the social space (family, an organization are existence in this space). In essence, social space reflects the social connections that interconnect the physical entities in the physical space and is the essence and rules of CeSS and provides a framework for specifying the location of a social object concerning its organizational or operational role within the system. Traditionally, social interaction is any interaction between social entities such as organizations and communities, and in CeSS, the social relationship is specified as an interaction between individuals or physical objects.

Based on an enterprise model developed by Bayne (2006), social space value webs are 3D with interactivity, sustainability and accountability indexes, which are key operational features of any social relation. Consider a 3D manifold, $\mathbb{R}^3$, and let P_i^S be a Social (value web) position. To identify this position of a cyber-social object, let the index

f denote a specific federation, s as the position along the supply chain axis, and c to denote the entity's position along the command chain axis. The physical distance between e_i^S and e_j^S is:

$$d_{i,j}^S = \sqrt{(f_i - f_j)^2 + (s_i - s_j)^2 + (c_i - c_j)^2}$$

Where $P_i^P = (f_i, s_i, c_i)$ and $P_j^P = (f_j, c_j, s_j)$ are the social position of e_i^S and e_j^S, respectively. The coordinates are shown in Figure 2b.

2.1.3 Cyber-enabled thinking space (CeTS). Thinking space is the result of chemical reactions within our brains that bring about ideas, thoughts and emotions. Existence is not limited to only the real artifact but also includes abstract space. However, some abstract spaces, such as thinking space, have no spatial properties. They have no spatial dimension, and thinking is generally perceived differently, usually via visual representations. Also, the physical existence of thinking space is not always consistent with their content; for example, a mental image of an object may not necessarily exist as so in the brain. Finally, the identity of a cyberspatial object does not depend in any way on thinking space and therefore does not play a significant role. Thinking space is imaginative, and it needs to be defined on a sound theoretical and/or practical framework, for example, as information space, as a set of information or systems, consisting of information conceptualized within metaphorical spatial contexts. Therefore, information space is more meaningful and real than imagination as it is well defined.

2.1.4 Cyber-enabled information space (CeIS) existence. Information can be defined as mental activity (thoughts and memory), communication process, artifact or energy as information technologies are coupled with mental processes, physical entities, a human invention and the physical environment. While the mental perspective of information is confused with thinking, the most viable view is information perceived as a manipulated object (created, managed), making it tangible and measurable. The traditional notions of information have been altered by cyber technologies leading to an entirely new form of information, the state of cyberspace in the CeIS. Important organization of information within this space exists at any instant for every cyber-enabled physical entity. A framework specifying the locations of informational objects is defined with three indexes to the SAPs/the communications ports. Cyberspace information networks can be broken down into these indexes as addressees; the global network address, the subnetwork address and the specific SAPs.

Consider a 3D manifold, $\mathbb{R}^3$, and let P_i^I be an information (infospatial) location. To identify the information location of a cyber-enabled information object, let the index $g_i, s_i,$ and a_i, denote the global network address, the subnetwork address and the SAPs, respectively. Thus, the physical distance between information objects e_i^I and e_j^I on the cyber-enabled physical device is:

$$d_{i,j}^I = \sqrt{(g_i - g_j)^2 + (s_i - s_j)^2 + (a_i - a_j)^2}$$

Where $P_i^I = \{g_i, s_i, a_i\}$ and $P_j^I = \{g_j, s_j, a_j\}$ are the info-spatial location of e_i^I and e_j^I, respectively. The CeIS coordinates are shown in Figure 2c.

As the communication systems interact through messages as a function of time defined in a dimensional continuum, information space involves information sets (such as textual, graphical) organized within spatial contexts. It presents new spatial logics that differ from the classical Newtonian notion of space and distance.

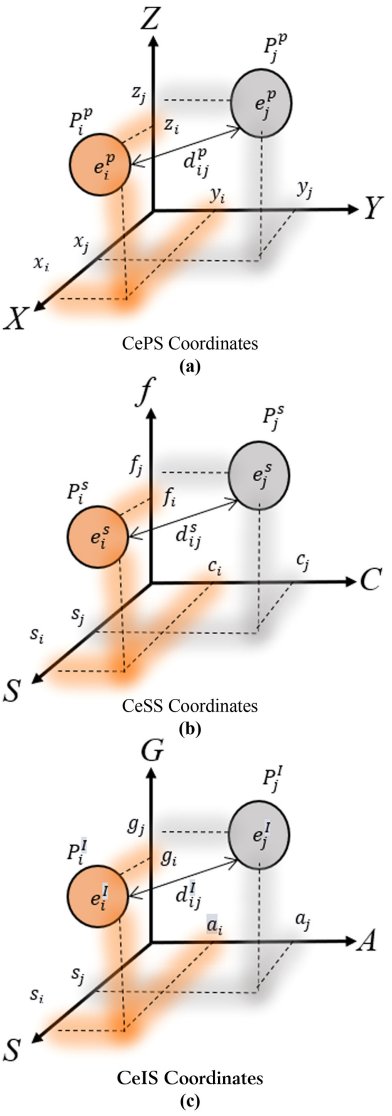

Figure 2.
CeXS coordinates

2.1.5 Cyberspace–time. As a product of dynamic relations and a dimensional manifold, cyberspace comprises cyberspatial objects. The cyberspace–time reference frame primarily has three spatial dimensions required to identify cyberspatial objects uniquely, and as the objects change state with time, the cyberspace–time model provides cyberspatial objects with 10 DOF cyberspace–time, used to describe cyberspace mechanics (Bayne, 2008). Space–time features can be utilized to identify objects based on spatial–temporal uniqueness. The dynamic variable, time, enabled cyberspace to be characterized by cyberspatial map dynamics (Kademi and Koltuksuz, 2020b). The cyberspatial object behaviors unfold in both cyberspace and time and require physical and social, and informational indices to be described. It is present in physical space (*P*), social space (*S*) and information space (*I*), and at a particular time, t_k.

Cyberspace consists of three primary dimensions represented as points (p_i^p, p_i^I, p_i^s), which are separate coordinates in three orthogonal (perpendicular) directions, respectively, as $\{\{x,y,z\},\ \{g,s,a\},\ \{f,p,c\}\} = P_i^\alpha(t_k)$. Figure 3 shows two cyberspatial entities e_i^α and e_i^β identified in their positions (p_i^p, p_i^I, p_i^s), and interacting and influencing one another's state through their communication and message transmission.

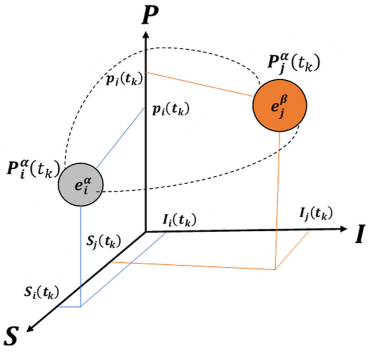

Figure 3.
CeXS–time dynamics

2.1.6 Cyberspace as hyperspace. Integrating these three different coordinate systems, cyberspace is a hypercube of at least 9D, hyperspace. With an orthographic projection, a compact, functional design of a system can be made. Cyberspace model based on hypergraph better describes distinct entities interacting through complex relationships in multi-layered relations of homogeneous and heterogeneous entities.

From hypergraph theories, which can describe multilayer and multi-dimension network problems, the nodes with a similar set from layer $n+i$ can be assembled as a new node at layer $n+i-1$ for $i = \{1,\ 2, \ldots 5\}$ five layers of entities (physical, logical, social, information and thinking entities). One layer is related directly to the adjacent layer. Figure 4a shows three layers of objects in CePS, CeSS and CeIS, layer $n+2$, $n+1$, and n, respectively. The corresponding hypergraph nodes are shown in Figure 4b – CePS is composed of cooperative services that enable CeSS to exert their function based on CeIS, dependent on CePS.

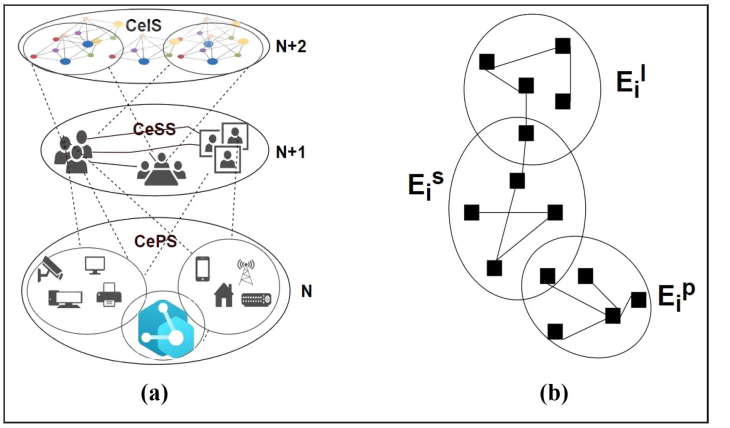

Figure 4.
CeXS as a layered network to hypergraph of cyber entities

The multilayer network of spatial entities is topology (T) of a pair of layers of entities (L) in their respective space and their relationship, connectivity ($\mathcal{C}$) given by:

$$\mathrm{T} = (\mathrm{L}, \mathcal{C});$$

$$\mathrm{L} = \{G^{\alpha}; \alpha \in \{1, \ldots, \mathrm{M}\}\}$$

$$G^{\alpha} = (E^{\alpha}, C^{\alpha})$$

$$E^{\alpha} = \{e_i^P, e_i^S, e_i^I\}$$

$$C^{\alpha} = \{c_{i,j}^P, c_{i,j}^S, c_{i,j}^I\}$$

$$\mathcal{C} = \{E^{\alpha\ \beta} \subseteq E^{\alpha} \times E^{\beta}; \alpha, \beta \in \{1, \ldots, \mathrm{M}\}, \alpha \neq \beta\}$$

Where G^{α} is the hypergraph of spatial subnetworks entities with hyperedges; C^{α} and a different set of entities; E^{α}. $\mathcal{C}$ is the set of interconnections between entities of distinct spaces, say G^{α} and G^{β} with $\alpha \neq \beta$. Here, the elements of each C_{α} are intra-spatial connections.

The set of entities of the physical space, G^P will be given by $E^P = \{e_1^P,\ e_2^P, \ldots e_n^P\}$, and their connection is given by an adjacency matrix: $A^{[P]} = (a_{ij}^P) \in \mathbb{R}^{N_p \times N_p}$ where:

$$a_{ij}^p = \begin{cases} 1 & if \quad \left(e_i^p, e_j^p\right) \in C^p \\ 0 & otherwise \end{cases}$$

$$\text{For } 1 \leq i, j \leq N_p \text{ and } 1 \leq M.$$

The interlayer adjacency matrix $C^{p\,s}$ is the matrix given by: $A^{[p,s]} = a_{ij}^{p\ \ s} \in \mathbb{R}^{N_p \times N_s}$.

$$a_{ij}^{p\,s} = \begin{cases} 1 & if \quad \left(e_i^p, e_j^s\right) \in C^{p\ \ s} \\ 0 & otherwise \end{cases}$$

These definitions consider the connectivity in distinct space; the features of the connections and the relationships between entities that belong to the same or different layer. For an integral spatial framework, an arbitrary mathematical model of space is considered. For instance, an extension of Euclidian space to include the networked properties of cyberspace. Assuming combinatorial *space (CG),* a union of mathematical spaces $(E_1^{\alpha}; R_1)$, $(E_2^{\alpha}; R_2)$, $\cdots$, $(E_m^{\alpha}; R_m)$,) for an integer m, with underlined graph structure G^{α}:

$$G^{\alpha} = (E^{\alpha}, C^{\alpha})$$

$$\mathcal{C}G = \left(\bigcup_{i=1}^{m} E_i^{\alpha} \bigcup_{i=1}^{m} R_i\right)$$

A combinatorial Euclidean space is a combinatorial system $\mathfrak{E}\mathrm{G}$ of Euclidean spaces R^n with an underlying structure G^{α}.

2.2 The cyber-enabled physical, social thinking information (CPSTI) entities

An entity, which is a thing existing as itself, as an object, actually or potentially, concretely or abstractly, physically or virtually (Mccarthy, 2018, p. 50), is an object, an agent or set of objects that exist in its world and can be identified. The existence primarily refers to the existence in conventional space (PST) that conjugates cyber entities, which are entities related to real entities or synthesized (may not directly correlate with the real PST space) entirely by other cyber elements. While physical existence mainly describes the existence of an object made up of matter or energy; social existence is the result of the totality of

communication and interactions of the objects, and the thinking existence is directly associated with neural activities such as imaging. Cyberspace permeates physical space, social space, information and thinking space and objects in PST are mapped to cyberspace, conjugated as the CeXE in cyber-enabled PST spaces by the process of cyberization. For instance, the internet of things (IoT) connecting a physical object to cyberspace processes.

2.2.1 Cyber-enabled physical entities' existence. The physical entities that form the cyberspace fundamental infrastructures is a subset of the physical Space. CePS constitutes cyber entities related to physical objects. The objects, equipped with various sensors and actuators, are tasked with monitoring and controlling events related to both cyber and physical objects according to protocols established by rules of cyber entities interactions. Typical examples are the IoT, "u-things" and "smart things."

2.2.2 Cyber-enabled social entities' existence. Social space enables social relationships and connections between physical entities reflected in the social entities such as human social organizations, social IoT (SIoT), economic ties; communities of mutual interest, alliances and ecosystems.

Let $e^{\phi} = \{e_1^P, e_2^P, \ldots e_n^P\}$ be the physical devices, $e^S = \{e_1^S, e_2^S, \ldots e_n^S\}$ be the set of social entities on e^{ϕ} using $S = \{s_1, s_1, \ldots s_n\}$ set of services, applications or Web documents. To model the social relationship that holds among the social entities and consequently between the physical entities, we consider four relationships: (1) co-position (P); when the entities are located at the same physical positions; (2) co-work (W): for objects in the same application or performing the same task to achieve a defined goal; (3) ownership (O): entities have the same owner; and (4) social (SO): entities that interact when the social connection happens:

$$R\left(e_1^S, \ldots e_i^S\right) = \left\{\mathrm{P}\left(e_1^S, \ldots e_i^S\right), W\left(e_1^S, \ldots e_i^S\right), O\left(e_1^S, \ldots e_i^S\right), SO\left(e_1^S, \ldots e_i^S\right)\right\}$$

$R(e_1^S, \ldots e_i^S)$ take a binary value (1 if there is a relationship, 0 otherwise). For example, $R(e_1^S, e_2^S) = \{1, 1, 1, 1\}$ means that the two entities are present in the same location, in the same application, same owner and have social relations. The social relationships are used to classify the socially connected device or entities' communities and then cluster their users according to their common interests. When the social space is described using graph structure, the vertices represent the social entities and the edges represent social relationships.

2.2.3 Cyber-enabled information entities' existence. Information can be quantified using a fundamental unit. For example, a digitized image has the same number of pixels that are preserved. Data (texts, images, audio, program, sequences of texts.) are an example of an information entity, which are addressable and can create a particular pattern. For an aggregate unit, let b_i be the number of binary digits required to store the ith set of data, d:

$$H_i(d_i) = b_i$$

$$H_i(d_i) = \log_2 N$$

Where N is the number of data with the same number of units as the ith text. The information is the collection of data and is additive; therefore:

$$H(d) = \sum_{i=} H_i(d_i) \text{ bits}$$

Shannon entropy, which is a measure of the information in a message for a variable X, is defined as:

$$H(x) = -\sum_{x=1}^{N} P(x) log_{2^P}(x)$$

Where $p(x)$ is the probability that X is in the state x, and $p \ log_2 p$ is 0 if $p = 0$.

3. Discussion

Cyberspace has been approached from different disciplines and approaches, and not much has been done in formulating characteristic dynamics, complexity, multidimensional and multi-temporal features in a solid foundation. A basic correlation between cyberspace and existing theories from various fields enables defining the spatio-temporal concepts and to explain the principles governing the evolution of cyberspace. Cyberspace constitutes dynamic networks of various interacting entities and the principles underlying its structural organization and dynamics are derived from fundamental ontological answers and its spatial qualities that produce a distinct space–time. This bottom-up approach could describe, categorize and help in analyzing its inherent properties.

3.1 Spaces convergence

Cyberspatial objects are closely conjugated with objects in the traditional space. Real entities have a cyber existence and are interconnected, which is the bedrock for establishing social relations and information communication. The physical space is everything existing in space and time, and the physical infrastructures enable cyber physical space and entities. The social space reflects the social relation that interlinks physical entities, which enable cyber social connections exhibited by the social entities. Information space is a representation of knowledge in a conceptual space with entities interacting together. The basic element of thinking space are ideas, thoughts, etc., not physically present but physically manifested. All these traditional spaces form a space, the cyber part of which are CeXS and all of which ultimately form cyberspace. In Table 2, the conventional spaces, corresponding CeXS and accommodated CeXE, are listed.

PST spaces	CeXS	CeXE
Physical space (PS)	CePS	Cyber-enabled physical entities (CePE)
Social space (SS)	CeSS	Cyber-enabled social entities (CeSE)
Information space (IS)	CeIS	Cyber-enabled information entities (CeIE)
Thinking space (TS)	CeTS	Cyber-enabled thinking entities (CeTE)
Space	Cyberspace (CS)	Cyberspatial entities (CE)

Table 2. Cyberspace and entities conjugation with other *spaces*

The conception of cyberspace is firstly more of a philosophical question that needs scientific answers. The cyberspace manifold includes all CeXS (physical space, social space, information space and thinking space) and every object existing in the manifold (e.g. physical objects such as computers, wearable devices, robots, etc.; social network/services and relationships; thinking existence such as internet thinking, big data, etc.; information, data, etc.) – Figure 5. Cyberspace is a multi-dimensional space that is challenging to define as it has distinct types of entities such as abstract and concrete. However, the entity's behavior evolves, and cyberspace–time describes the dynamics of cyber physical systems (CPS) – an information system whose behavior has a direct effect on physical space.

The reformation of the conventional spaces, cyberization, involves using communication and computer technologies to interconnect devices, objects and computers. As philosophy provides the foundation of theoretical consideration, the physical space made the existence of every other thing possible. Through computerization, information and communication technology is installed to get cyber enabled physical objects. This allows economic and social relations to prosper. The information resulted from human socialization and devices are digitalized and fed to the machines for better processing. Figure 5 highlights the actual conjugation of cyberspace, PST spaces, cyber-enabled PST spaces and cyberspatial objects.

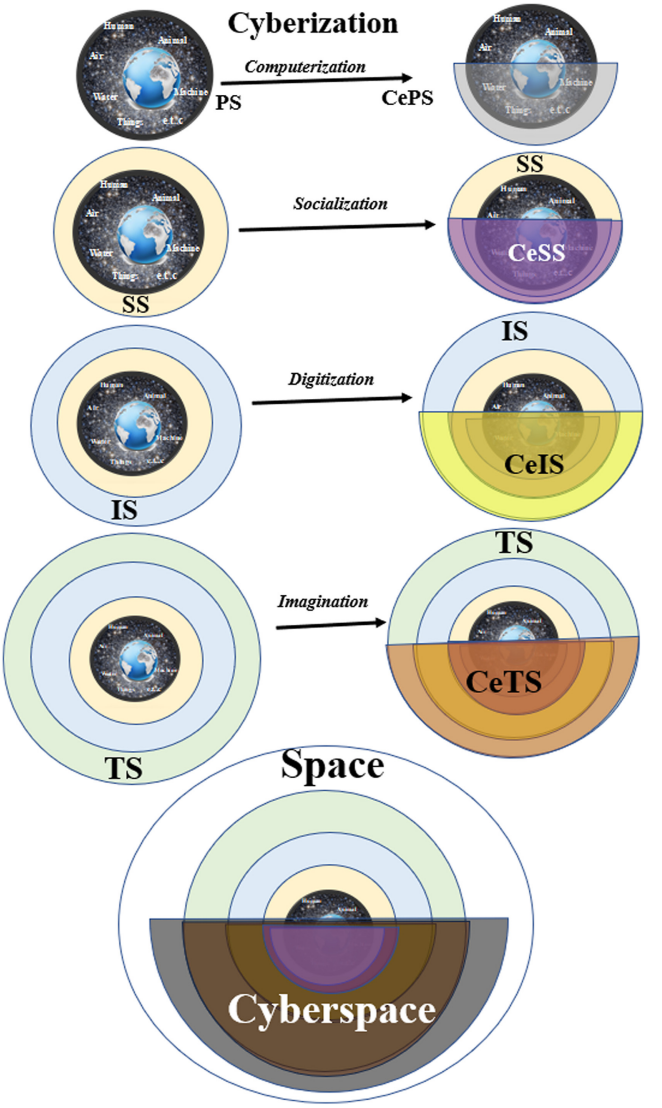

Figure 5.
Cyberization, and PSIT spaces and cyber-enabled PSIT spaces convergence

3.2 Cyberspatial entity identification

We define cyberspace as populated by discrete, identifiable objects, each with a cyber-referential address. Decomposing cyberspace into cyberspatial objects such that each object is identifiable, describable and relevant. This object can be extended to include events, processes, digital data (such as files, data sets, metadata). Therefore, the cyberspatial object (cyber entities, events, processes, digital data) define by (1) unique identity (ID), (2) spatial embedment (*S*), (3) properties (attributes (*A*) plus operations/interaction (O). This is denoted by $CO_i = \{ID_i, S_i, A_i, O_i\}$: cyberspatial object's unique identity, ID_i; set of attributes, $A_i = \{a_{i,1}, a_{i,2}, a_{i,3}, \ldots a_{i,n}\}$, occupying a space, $S_i = P_i^{\alpha}(t_k)$; and allow certain operations O_i.

Giving that the identity and behavior of cyberspatial objects are defined at the intersection of physical, social and information domains, we can classify cyberspatial object unique identity as shown in Figure 6 into ID-based; for objects with an existing identity number and non-ID-based; for objects without any available ID but identifiable based on space-time information, behavior or attributes. The space–time information has been defined, to a reasonable level of precision, as an object's spatial extent at a time. Other objects need further addressing to be performed by using other algorithms that identify unique features or behaviors (B).

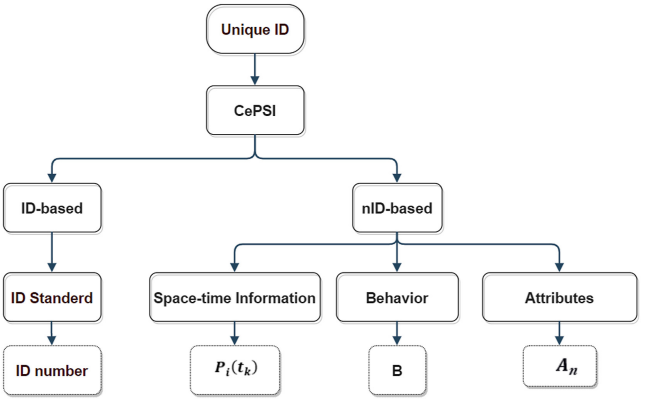

Figure 6.
Cyberspatial object unique ID scheme

Non-ID objects are identifiable by the space–time information, behavior and attributes. The features of the object are related to the structure of the embedding space. Cyberspatial objects are located at the intersection of cyber-enabled physical, social and information (CePSI) space, which are represented in at least 9D space, Figure 3. Every cyberspatial object is describable – has information about itself, the totality at any time of which constitutes its state. They are either inert or active. The dynamics part of it is the functionality, which could be a response to interaction or surroundings. A collection of attributes expresses the state, while the dynamic is determined by a set of operations that the object can perform under appropriate conditions. The operations are represented by procedural functions (methods) that may be invoked to self-organize, learn, react or interact. An interaction denotes the object's ability to converse with the user and other objects in input, output, control and feedback. Examples of operations that can be performed on areal objects are addition, deleting, updating, movement and transformation.

A distinct type of cyberspatial object is an event that is the occurrence of interest that happens at a particular time, e.g. interrupt, attack and logs. The events are classified as punctual, interval, point and field events. The punctual event (E) represents any change in attributes, temporal or spatial status of an object at a specific time point. The interval event (E), an event such that an object's attribute or spatial status remains the same for a time interval. The point event (PE) is for an event whose occurrence can be estimated to a location point (x; y; z). Field event (FE) is defined by a function, where the occurrence location is a collection of points, made up of at least two or more points events. Collected cyber events can then be mapped into cyberspace. For example, a cyber event, say, $\varepsilon = \{ID^{4s}_{xx2}, ID_{PE}, \langle e^P_1, e^P_2, e^P_3 e^S_i \rangle\}$ has an ID of xx*2* at *4s* time from point event group (PE) and concerns three physical entities and one social entity.

4. Conclusion

Cyberspace, as a "parallel" universe to our physical one, interpenetrates physical, social, information and thinking space and consists of objects that can be identified at the intersection of the these conventional space's. It is simultaneously physical, tangible, real and present in geospace, informational, present in info-space and social, with organizational social and political presence in socio-space. The rigorous characterization of cyberspace is founded by philosophical questions that are investigated from a scientific view and realized in the form of information and communication technology. Objects in the conventional spaces are cyberized with some kind of cyber existence, leading to cyber-enabled hyperspaces. To establish a holistic understanding of cyber-related fields to build systematic knowledge, a philosophical question of the existence of spaces and entities from the existing theories is studied and a close conjugation is shown.

However, information space is not part of the current literature of the transdisciplinary integration and convergence of conventional space to form CeXS. We have shown that information is complementary to the cyber-enabled space because it is like energy to the spaces and the entities and is vital for the dynamic and topology of cyberspace. It is has been found that cyberspace is a hyperspace of cyberspatial objects whose behavior unfolds in cyberspace time. Cyberspace is inherently spatial; its basic constructs are founded on its spatial qualities, producing radical space–time. The cyberspatial object operations are primarily built on the foundations that depend on the physical space and other spatial metaphors. Part of the implication of this research is its significance in cyberspatial mechanics to describe the dynamics and behavior of cyber physical systems. For instance, object-based analysis functions like spatial query, node pattern analysis, cluster analysis, spatial similarity analysis and location modeling.

In this paper, we have also highlighted additional features and further research questions for a general theory of cyberspace such as:

(1) The identification of cyberspatial objects along with their spatial features.

Philosophical questions and existence that will explain the structure, models and representation of cyberspace. For example: how should cyberspace be conceptualized as space? Are there objects in this space? What is the categorical scheme of cyberspace? Moreover, ultimately "What is Cyberspace?"

(2) The cyberspatial object interconnections and interaction.

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