CPST: A New Existence Theory for the Digital Age from Ternary to Quaternary—Ten Years of Evolution and Its Philosophical Foundations

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Abstract

This paper systematically reviews the decade-long development and theoretical connotations of the Cyber-Physical-Social-Thinking (CPST) space theory, originally proposed by Chinese scholars in Science China Information Science in 2015, from 2015 to 2025. The advent of the digital age has profoundly transformed the modes of human social existence, yet mainstream system frameworks, from CPS (cyber-physical systems) to CPSS (cyber-physical-social systems), still lack explicit modeling of the dimensions of "thinking" and "cognition." This paper also identifies the 2012 question of the "Internet of Thinking" as an intellectual origin. CPST theory defines cyberspace, physical space, social space, and thinking space as four fundamental analytical dimensions, and characterizes the interactions among these four elements through six coupling channels, thereby providing a categorical framework for ontological research in the digital age. This paper explains the theoretical evolution of CPST from the scientific framework of IoT to General Cyberspace and Cyberology, illustrates its scope of application through cases such as the smart city brain, AGI-enabled IoX, national sovereignty, and social governance, analyzes the theoretical positioning of CPST as the ontological foundation of Cyberism and Cybersophy, and reviews six types of explosive challenges involving information, connection, application, identity, relationship, and service. On this basis, this paper discusses the testability and limitations of CPST, its relationship with existing philosophical frameworks, the scope of its external adoption, and the non-strictly causal nature of the relationships among the "six explosions." This paper argues that CPST has the dual nature of an engineering analytical framework and a research program for digital ontology, providing a testable and extensible theoretical proposal for the construction of China' s independent knowledge system.

Full Text

CPST: A New Existence Theory for the Digital Age from Ternary to Quaternary—Ten Years of Evolution and Its Philosophical Foundations

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Abstract This paper systematically reviews the ten-year development and theoretical connotations, from 2015 to 2025, of the Cyber-Physical-Social-Thinking (CPST) spatial theory originally proposed by Chinese scholars in *Science China*

Information Science in 2015. The advent of the digital age has profoundly changed the way human society exists, yet mainstream system frameworks, from CPS (cyber-physical systems) to CPSS (cyber-physical-social systems), still lack explicit modeling of the dimensions of "thinking" and "cognition." At the same time, this paper takes the 2012 question of the "Internet of Thinking" as an intellectual source. CPST theory defines cyberspace (also called network space), physical space, social space, and thinking space as four fundamental analytical dimensions, and uses six coupling channels to depict the interactions among the four elements, thereby providing a paradigmatic framework for research on existence theory in the digital age. This paper interprets the theoretical evolution of CPST from the IoT scientific framework to General Cyberspace (broad cyberspace) and Cyberology (cyberspace studies), and uses cases such as the smart city brain, AGI-enabled IoX, national sovereignty and social governance to illustrate its scope of application. It analyzes CPST' s theoretical positioning as a foundation for Cyberism (cyberspace studies) and Cybersophy (cyberspace philosophy), and sorts out six explosive challenges involving information, connection, application, identity, relations, and services. On this basis, the paper discusses the testability and limitations of CPST, its relationship with existing philosophical frameworks, the scope of external adoption, and the non-strict causal nature of the "six explosions" relationship. This paper argues that CPST possesses the dual nature of an engineering analytical framework and a research program in digital ontology, providing a testable and extensible theoretical proposal for the construction of China' s independent knowledge system.

Keywords Cyber-Physical-Social-Thinking (CPST) space; quaternary space; digital ontology; Cyberism; Cybersophy; philosophy of technology; artificial intelligence (AI); Cyberology

1 Introduction: The Digital Age Calls for a New Framework of Existence Theory

1.1 From CPS to CPSS: The Absence of the Cognitive Dimension

Cyber-Physical Systems (CPS), since being formally proposed by Lee and others in the late 2000s, have long been the dominant paradigm for understanding the integration of computation and physical processes[1]. The core contribution of CPS lies in enabling system designers to acquire a systematic vocabulary for describing how software-controlled actuators and sensor data are fed back into algorithms.

However, as the Internet of Things (IoT) has expanded from connected devices to connected cities, transportation, healthcare, industry, and human-centered services, the limitations of CPS have become increasingly apparent. Around 2010, Wang Feiyue proposed Cyber-Physical-Social Systems (CPSS), recognizing that human activities and social dynamics fundamentally shape system operation[2]. Social media, crowdsourcing, and participatory sensing have made the social dimension impossible to ignore.

Yet a key gap remains. Whether CPS or CPSS, neither explicitly models "thinking" —the processes of thought, reasoning, consciousness, and intentionality that drive human behavior and machine intelligence. A smart grid designed under CPS can model power flows and sensor networks, but it does not have

vocabulary to describe the cognitive processes of the operators who monitor it. A CPSS urban mobility model can capture social patterns, but it cannot distinguish a commuter who cognitively participates actively in route planning from one who is in an "autonomous driving"state—and this distinction is crucially important for system intervention design.

1.2 The Proposal of "Internet of Thinking" in 2012

The breakthrough of this cognitive gap began in 2012. At the World Intelligence Congress 2012 held in Macao, "Internet of Thinking (思维互联网)"was listed as one of the Top 10 questions for future intelligent computing (Q23: "Is it possible to have 'Internet of Thinking'?", see [3]; for details, see the Top 10 Questions voting-results page: https://wi-consortium.org/blog/top10qi/). This question pointed directly to a fundamental theoretical need: if the Internet of Things is ultimately to connect all things, should "thinking" —whether human thinking or machine thinking—become an explicit dimension within this connection framework?

Three years later, the answer made its official appearance in the form of CPST theory.

1.3 Positioning and Contributions of This Paper

In 2015, in *Science China Information Science*, we formally proposed the theory of Cyber-Physical-Social-Thinking (CPST) space [4], taking Thinking as an analytical dimension parallel to Cyber, Physical, and Social. Against the backdrop of the rapid development of large language models, autonomous intelligent agents, and brain-computer interfaces, explicit modeling of the thinking domain shows theoretical and engineering value for further discussion.

This paper is the first systematic review and interpretation in Chinese of CPST theory. Its aim is to present the theoretical connotations, development trajectory, application scope, and philosophical extensions of CPST, and to analyze the theoretical positioning of CPST as Cyberism (赛博学) and Cybersophy (赛博观), for which a theoretical foundation exists.

The "ten-year evolution" referred to in this paper specifically denotes the theoretical development of CPST from its formal proposal in 2015 to 2025; the 2012 "Internet of Thinking" question is listed separately as the ideological source, and related results published in 2026 are used to explain subsequent extensions and are not counted within the ten-year review window. This paper provides a conceptual argument for the distinction among the four spaces and makes an initial comparison with existing philosophical frameworks; its non-axiomatized rigorous formalization and empirical validation remain subjects for future research.

2 The Theoretical Connotations of CPST: Four Spaces and Six Coupling Channels

2.1 Definitions and Boundaries of the Four Spaces

The CPST framework conceptualizes reality as four mutually connected yet mutually distinct spatial domains.

Cyber Space (C) encompasses all digitized existence: networks, databases, algorithms, cloud infrastructure, and software systems. For Internet of Things architects, this is the most familiar domain—the data pipelines, message brokers, APIs, and processing engines form the backbone of any interconnected system. Edge computing nodes, serverless functions, and container orchestrators all belong here.

Physical Space (P) contains the material world: sensors, actuators, devices, buildings, vehicles, and the physical laws that constrain them. In the Internet of Things, P is the source where data are generated through perception, and it is also the place where systems produce effects through execution. Physical processes have inertia: buildings cannot change their thermal mass instantaneously, and vehicles cannot stop instantaneously.

Social Space (S) captures human interactions, relationships, communities, and organizational structures. This includes user behavior, community dynamics, cultural norms, institutional policies, and the collective patterns that emerge when humans interact with technology. Social Space explains why the same Internet of Things system deployed in two different cities may produce markedly different results—not because the technology differs, but because the social background and demands are different.

Thinking Space (T) is the originality of CPST. It includes both biological cognition (human reasoning, emotions, situational awareness, tacit knowledge, intuition) and artificial cognition (machine-learning models, AI planners, neural networks, and future AGI systems). Thinking Space

including partially observable representations constrained by ethics, attention, beliefs, intentions, preferences, trust, risk perception, emotions, interpretations, and value judgments.

2.2 Why "Thinking" Is Not Equivalent to "Society"

A common question is: Is Thinking merely a refinement of Social? We argue that it is irreducible for three reasons.

First, ontological independence. An independently operating AI agent processes data and involves the dynamics of the Thinking space, yet it has no participation in Social space at all; the same is true of a person thinking alone. Cognition operates through internal representations, reasoning, and learning mechanisms, and these mechanisms are ontologically different from social processes. Social space concerns roles, institutions, norms, and collective relations, whereas thinking space concerns the cognition, meaning, intentions, interpretations, and value judgments of individuals and collectives.

Second, typical time scales differ but overlap. Cognitive processes are usually manifested as relatively rapid perception, judgment, and learning, whereas social processes may involve longer-cycle relationships, norms, and institutional evolution; this difference helps distinguish modeling levels, but it does not constitute a basis for strictly separating the two.

Third, engineering effects. Treating Thinking as an independent dimension enables architects to separately specify cognitive requirements (decision latency, explainability, attitude-perception thresholds) and social requirements (user acceptance, regulatory compliance, cultural adaptation), thereby producing clearer system specifications and more testable designs[^5].

2.3 Six Coupling Channels

The power of CPST lies not only in the four dimensions themselves, but also in their interactions. Six paired channels connect the four spaces:

C-P channel: classic IoT coupling—sensors flow from Physical to Cyber, and execution commands flow from Cyber back to Physical. Digital twins are a typical form of bidirectional C-P coupling[^6].

C-S channel: the connection between social platforms and computing infrastructure—recommendation algorithms, social-media analytics, crowdsourcing platforms.

C-T channel: the connection between AI models and cognitive tasks in Cyber space—reinforcement learning based on human feedback (RLHF) is a typical example.

P-S channel: how the physical environment shapes social behavior, and vice versa.

P-T channel: through brain-computer interfaces, embodied AI, and tactile feedback, cognition is directly connected to the physical world.

S-T channel: how social interaction shapes cognition, and how cognitive processes drive social dynamics. In an IoT context, when the operations team of a monitoring distributed system develops a shared mental model that improves or worsens its collective performance, this is the operation of S-T dynamics.

2.4 From Channels to Enabling Technologies: IoT, IoP, and IoTk

The six coupling channels of CPST are not abstract concepts; they correspond to three major enabling technologies of the Internet.

The Cyber-Physical (C-P) channel corresponds to the Internet of Things (IoT). The technical core of the C-P channel consists of sensing and driving devices such as sensors, RFID, and actuators. Its function is to realize mapping and interaction between the physical world and the digital world, and it is the foundation of applications such as smart cities and intelligent manufacturing. In the CPST framework, IoT plays the role of the "perception-execution" layer.

The Cyber-Social (C-S) channel corresponds to the Internet of People (IoP). The technical core of the C-S channel consists of social-computing infrastructure such as social media, online communities, and crowdsourcing platforms. Its function is to connect human social behavior with digital services, and it is the technical foundation for social governance and public-opinion analysis. In the CPST framework, IoP plays the role of the "connection-interaction" layer.

The Cyber-Thinking (C-T) channel corresponds to the Internet of Thinking (IoTk). The technical core of the C-T channel consists of cognitive interface technologies such as brain–computer interfaces (BCI), neuroimaging devices, and affective computing. Its function is to explore the perception and analysis of cognitive activities, and it is a frontier direction for human–machine integration and personalized services. In the CPST framework, IoTk plays the role of the "cognition-understanding" layer.

CPST is not an unfounded conjecture; it is supported by the three major technological pillars of IoT, IoP, and IoTk, providing a unified technical and conceptual framework for understanding the digital age.

2.5 Digital-Existence-Theoretic Interpretation of CPST

From the engineering framework, CPST further proposes a digital-existence-theoretic interpretation: it uses physical existence, social existence, thinking existence, and cyber existence to organize the objects, processes, and relationships of the digital era. This four-dimensional division enables CPST to differ from CPS/CPSS, which mainly focuses on engineering coupling, and provides a broad framework for cross-space analysis. It should be emphasized that the four spaces are mutually distinct and not reducible to one another; this is the theoretical claim proposed in this paper, and its boundaries, operational definitions, and empirical validity still need to be tested through formal expression, comparison with alternative models, and cross-scenario studies.

3 CPST' s Decade-Long Evolution (2015–2025): From Concept to System

3.1 Intellectual Origins and Formal Proposal (2012–2015)

In 2012, "Internet of Thinking" was proposed at the World Intelligence Congress[^3], providing a direct intellectual source for CPST theory. In 2015, we published a paper on the CPST framework in *Science China Information Sciences*[^4], for the first time establishing the Cyber-Physical-Social-Thinking four-space structure. The core insight of the paper was that the Internet of Things should not be understood merely as a "network of things," but rather as a network integrating the four elements of "human–machine–things–thinking." Subsequently, CPST was positioned as a systematic scientific and technological framework for the "cyber-enabled new world" [^7].

3.2 Expansion and Deepening Period (2016–2021)

General Cyberspace (2018): We defined cyberspace in the broad sense as "cyberspace and cyber-enabled space" [^8], providing a unified container for the four spaces–the cyber-enabled physical space (through IoT), the cyber-enabled social space (through social platforms), and the cyber-enabled thinking space (through AI and human–machine interaction).

Cyberentity and Cyberlogic: The concept of the cyber entity (Cyberentity) provided CPST with a concrete entity-level operational unit. Research on cyber-entity security highlighted the identity, security, and trust requirements of cyber representations in IoT; research on cyber-entity consistency revealed that cross-space representations must remain aligned in Cyber, Physical, Social, and Thinking contexts[^9]. Research on cyber logic (Cyberlogic) added a reasoning layer to this entity foundation[^10].

External applications and comparative studies also emerged during this stage. In 2016, Zhu et al. used the CPST framework for the modeling and computation of geological information service systems[^11]; in a 2019 review of digital twins, Barricelli et al. listed CPST as one of the frameworks discussed in parallel with CPS, CPSS, and HCPS[^12].

External methodological research related to CPST also unfolded in such directions as intelligent-space design, CPS integration, and big-data fusion. Zeng et al. proposed the HyperspaceFlow system-level intelligent-space design method[^13]; Darwish and Hassanien reviewed the development of CPS design, methods, and integration[^14]; Atat et al. systematically sorted out the combination of big data and CPS[^15]; Kademi and Koltuksuz proposed an extended hyperspace representation including cyber, physical, social, information, and thinking[^16].

3.3 Systematization and Application-Expansion Period (2022–2025)

Cyberology (2022/2023): We proposed a discipline and interdisciplinary hierarchical system based on CPST space[^17], connected CPST with the metaverse and generalized cyberspace, and systematically studied the disciplines related to the existence, phenomena, laws, and applications of cyberspace and their development trends.

In international academic discussions, Macias and Navarro (2022) positioned CPST as a "conceptual paradigm of the complex hyperspace expected by modern IoT society" [^5]. Mendhurwar and Mishra summarized CPST as "CPS augmented with social, thinking technologies" and used it to analyze blockchain architectures in the Industry 4.0 value chain[^18].

In addition, the surveys by Zhou et al., the systematic literature review and formalization study by Yilma et al., and the classification study by Pasandideh et al. cited and discussed CPST-related work respectively in the overall progress of CPSS, systematic expression, and classification frameworks[^19–^21]; De et al. incorporated it into the discussion of related frameworks in a survey of urban big-data systems[^22]. The 2023 Cyberology paper has also appeared as an independent recommended reading in research on next-generation CPS education[^23].

In terms of knowledge fusion and intelligent modeling, Yang et al. reviewed representation learning, knowledge fusion, and reasoning in CPSS[^24], and Li et al. summarized a reinforcement-learning framework for cyber-physical-social AI[^25]. In the area of human factors and social technologies, related policy papers have discussed IoT-social technology coordination[^26], cognitive sensing and computing in industrial environments[^27], human-centered design of interactive clothing and CPS[^28], and gender bias between virtual space and real space in social media[^29].

The application topics in these policy documents also cover the cyber-social-technical-cognitive model for smart ports[^30], a data-driven CPSS framework in social manufacturing[^31], knowledge-based virtual modeling of Industry 4.0 manufacturing processes[^32], technologies and national strategies for Industry 4.0[^33], and smart cities supported by digital twins[^34].

4 Generality and Influence of CPST

4.1 Universality of the Theoretical Framework

CPST proposes a general category framework that can be used to describe complex systems involving four-dimensional interactions among Cyber, Physical, Social, and Thinking. The four-dimensional structure is not aimed at a single application domain, but provides a common analytical method for cross-spatial problems in different domains.

Compared with frameworks such as CPS, CPSS, Digital Twin, Metaverse, and Parallel Intelligence[^35], CPST explicitly lists the six pairwise coupling channels among the four spaces, and therefore can incorporate the intertwined influence of cognitive processes and social processes into the same analytical structure. In their review of digital twins, Barricelli et al. listed CPST as one of the frameworks discussed in parallel with CPS, CPSS, and others[^12], indicating that this framework has already entered the literature of related conceptual comparisons.

4.2 Breadth of Application Domains

Discussions of CPST applications have involved fields such as philosophy, science and technology, health care and cognitive security, the humanities and social sciences, and industry applications. Table 1 summarizes representative directions supported by the public literature.

Policy documents in the direction of security and privacy involve IoT security, fusion of CPSS differential-privacy data, comparisons between cloud and blockchain IoT, fog-computing security, and metaverse security[^36-^40]. The urban and public-service direction includes the influence of ICT on urban spatial structure, situation awareness in crisis management, IoT-driven Health Care 4.0, and smart-city infrastructure supported by 5G and fog computing[^41-^44]. The 2023 VirtualClassroom applies cyber-physical-social space to immersive teaching systems[^45].

4.3 Typical Cases: Smart City Brain and Network Synthesis

4.3.1 Hangzhou City Brain The Hangzhou City Brain is a typical case of the collaborative operation of the four CPST spaces[^55].

In **physical space**, the system connects more than 4,000 traffic sensors, surveillance cameras, and environmental monitors distributed across the urban road network. In **cyberspace**, a centralized data platform receives data in real time at a rate exceeding 100 GB per day, applies machine-learning algorithms for traffic prediction, accident detection, and signal optimization, and generates actionable recommendations. In **social space**, the system integrates commuting behavior patterns extracted from mobile-phone data, public feedback channels, event schedules, and institutional policies of traffic-management departments. In **thinking space**, AI planning algorithms generate route recommendations and signal-timing adjustments, while human traffic managers exercise judgment in edge cases that AI cannot handle—for example, abnormal events, interactions with construction areas, or situations in which social norms override traffic rules. The managers override AI recommendations when local knowledge indicates that this is necessary, while the AI learns from these overrides through a structured feedback loop.

Public data show that during its early pilot phase, the Hangzhou City Brain controlled 128 intersections over the course of the previous year, and the average speed of vehicles on related roads increased by 15.3%[^56]. As of 2020, official Hangzhou data reported that the city’ s national ranking for traffic congestion had dropped from 2nd to 35th[^57]. These results come from different time periods and pilot scopes, and therefore can only serve as examples of the phased governance effects of the Hangzhou City Brain; they should not be merged into a unified “past three years” performance···

Table 1 Overview of application domains of CPST theory.

Application category	Subdomain	Representative application direction	Supporting literature
Philosophy	Digital ontology	A paradigmatic framework for "what exists" in the digital age	This paper
Philosophy	Cyberism	A theory of the relationship between humans and cyberspace	[46]
Philosophy	Cybersophy	Humanity' s "fourth view" in the digital age	[47]
Philosophy	Confucian interpretation of the Eastern quadripartite philosophical system	An Eastern quadripartite philosophical system based on CPST space	[48]
Science and technology	Internet of Things	A scientific and technological framework for IoT	[4]
Science and technology	Cybermatics	Systematic research on cyber-enabled new worlds	[7]
Science and technology	Cyberology	A disciplinary system based on CPST space	[17, 23, 45]
Science and technology	General Cyberspace	A unified container for cyberspace and cyber-enabled space	[8, 16]
Science and technology	Artificial General Intelligence (AGI)	An IoX architecture enabled by AGI	[49~51]
Science and technology	Digital twins	A framework parallel to CPS and CPSS, and applications in smart cities	[12, 34]

Application category	Subdomain	Representative application direction	Supporting literature
Science and technology	Industry 4.0 / blockchain	Industrial value chains and social manufacturing	[18, 31~33]
Science and technology	Geographic information systems	CPST modeling and computation	[11]
Hygiene, health, and cognitive safety	Cyber-Syndrome	Formation, classification, rehabilitation, and prevention of Internet-related disorders	[52]
Hygiene, health, and cognitive safety	5G/CPSS engineering	Human uncertainty modeling and smart-city infrastructure	[37, 44, 53]
Hygiene, health, and cognitive safety	Medical health	IoT-driven Health Care 4.0	[43]
Hygiene, health, and cognitive safety	Security and privacy	IoT, CPSS, fog computing, and metaverse security	[36~40]
Humanities and social sciences	National governance	National sovereignty and social governance based on CPST space	[54]
Humanities and social sciences	Cognitive governance	Digital sovereignty, information sovereignty, and cognitive sovereignty	[54]
Humanities and social sciences	Human-centered social computing	Human factors, social technology, and virtual–real spatial behavior	[26~29]

Application category	Subdomain	Representative application direction	Supporting literature
Industrial applications	Smart city	Research on smart-city brains and related urban systems	[22, 34, 44, 55]
Industrial applications	Intelligent manufacturing	Blockchain, social manufacturing, and knowledge-based virtual modeling	[18, 31~33]
Industrial applications	Smart port	A cyber-social-technical-cognitive collaborative model	[30]

effectiveness indicators. From the perspective of CPST, the staged outcomes described above involve the collaboration of algorithmic optimization (cyberspace) and the judgment of traffic managers (thinking space), but this interpretation still requires independent validation of the human-machine collaboration process.

4.3.2 Cyber-Syndrome

Cyber-Syndrome is another type of case in which CPST acts across spaces on individual health and social relationships[58].

Cyber-Syndrome research defines it as physical, social, and thinking disorders caused by excessive or problematic contact with cyberspace, and discusses its formation, classification, rehabilitation, and prevention[52, 58]. In **physical space**, it may manifest as bodily symptoms such as dizziness, neck pain, headache, and obesity. In **cyberspace**, excessive or problematic use of social media, mobile computing, and online games is a direct cause. In **social space**, it may manifest as social isolation, social impairment, and damage to real-world social relationships. In **thinking space**, it may manifest as loneliness, depression, anxiety, as well as impaired information filtering and rational decision-making capacity[58].

Taking pathological electronic-game use as an example, a two-year longitudinal study covering 3,034 primary and secondary school students in Singapore showed that the proportion of pathological game use was about 9%; longer gaming time, lower social competence, and higher impulsivity were risk factors for subsequent occurrence, while depression, anxiety, social phobia, and declining academic performance may appear as subsequent outcomes[59]. This case shows that

Cyber-Syndrome simultaneously involves cyber activities, physical health, social connections, and cognitive-psychological states, and therefore can be analyzed within the CPST framework as a cross-space coupling problem.

4.4 The universality and salience of scientific problems: from the "six explosions" to a systematic response by CPST

CPST theory is not only an explanatory framework, but also a systematic response to a series of fundamental scientific challenges in the era of the Internet of Everything. These challenges can be summarized as the "six explosions" —together, they constitute the historical background and problem context in which CPST theory emerged.

4.4.1 The "six explosions": systemic problems in the era of the Internet of Everything

When CPST theory was proposed in 2015, it originated from a deep insight into several "explosive" trends in the era of the Internet of Everything. In subsequent research, we gradually identified and systematically elaborated six types of explosive phenomena:

Table 2 Systematic responses of CPST to the six "explosions".

Explosion type	Core challenge	CPST response
Information explosion	The types and numbers of perceived objects exceed the limited perceptual capacity of sensors	The four-dimensional space provides a basis for taxonomy
Connection explosion	The number and dynamics of inter-entity connections are overloaded	Structural modeling of the six coupling-channel types
Application explosion	Application scenarios proliferate; requirements become fragmented and personalized	CPST provides a unified cross-domain language
Identity explosion	The identity-identification needs of heterogeneous entities become diversified and heterogeneous	The Cyberentity framework provides unified management

Explosion type	Core challenge	CPST response
Relationship explosion	The types of connections extend from physical to socio-cognitive	C-S, S-T, and C-T channels cover multiple relationships
Service explosion	Inter-service dependencies far exceed device connections	CPST supports the transition from IoT to IoX[^61]

Information explosion. With the widespread deployment of RFID, sensors, cameras, and other perceptual devices, the number of perceptible physical objects is growing exponentially. From the traditional "objects with IDs"to "objects without IDs," as well as the environments in which objects are located, all need to be perceived, modeled, and connected[^60]. In the Internet of Everything era, the perceptual objects and environmental information faced by sensors are explosive, which poses a fundamental challenge to traditional methods of object identification and modeling.

Connection explosion. In IoX systems, the number and types of connections among entities are increasing rapidly. Diverse and dynamic connections—from device to device, device to person, person to person, person to service, service to data, and so on—make traditional point-to-point connection models difficult to adapt[^60]. The connection explosion is closely related to the growth of cross-spatial relationships, but the two do not constitute a fixed one-way causal relationship.

Application explosion. IoX application scenarios have expanded from environmental monitoring and smart homes to smart cities, the industrial Internet, smart healthcare, intelligent transportation, precision agriculture, and other fields. The fragmentation and personalization of application requirements mean that the same underlying infrastructure must support differentiated requirements for service quality, security and privacy, and real-time performance[^61].

Identity explosion. Perceptual objects in IoX environments require some form of identity identification to enable addressing, communication, and services. Massive heterogeneous devices, non-ID objects, and dynamic temporary identities make identity requirements diverse and heterogeneous; as a result, traditional single-identity models are difficult to apply[^9]. The identity explosion involves not only technical implementation, but also the ontological question of how digital entities are recognized and persistently referred to.

Relationship explosion. In the four-dimensional CPST space, relationships among entities have expanded from pure physical connections or data connections to multiple types such as social relationships, cognitive relationships, trust relationships, and value relationships. The connection explosion is the underlying driver of the relationship explosion, while the relationship explosion is the socio-cognitive extension of the connection explosion. The relationship explosion makes the modeling, reasoning, and governance of cross-domain relationships a core challenge[^51].

Service explosion. Compared with the explosion of device connections, the explosion of associations between services is even more evident. The application explosion drives the service explosion: massive applications give rise to massive services, and dependencies, combinations, conflicts, and coordination among services constitute complexity far beyond the device layer. The transition from IoT to IoX is, in essence, a transition from "device connection" to "service intelligence" [^61].

Overall, the information explosion, connection explosion, and application explosion correspond respectively to the perception layer, communication layer, and application layer of the ubiquitous interconnection system, reflecting a progression of complexity from object perception, to network connection, to scenario application; the identity explosion, relationship explosion, and service explosion correspond to the spatial integration of CPST, embodying the systemic challenges brought about by heterogeneous-entity identification, the interweaving of multiple relationships, and cross-spatial service collaboration.

4.4.2 Intrinsic associations among the "six explosions"

For ease of organization and analysis, the six types of explosion may be arranged in the sequence of information explosion → connection explosion → application explosion → identity explosion → relationship explosion → service explosion. This sequence represents a way of unfolding the problem framework, and does not indicate a strict one-way causal chain that has been empirically verified.

From the perceptibility, connectability, and availability of everything to the identifiability, relatedness, and intelligence of everything, this sequence provides a heuristic form of organization. In different systems, the six types of challenge may occur in parallel, promote one another, or form feedback loops; a later type of challenge does not necessarily take the preceding type of challenge as a sufficient or necessary condition.

4.4.3 CPST: systematic responses to the "six explosions"

The six challenges of CPST provide a unified category framework for identifying the spaces, entities, and coupling relationships involved in these challenges.

The six types of explosions may simultaneously involve the four spaces of Cyber, Physical, Social, and Thinking. The potential value of CPST lies in providing a unified analytical framework covering the four-dimensional space, thereby placing issues of perception, connection, application, identity, relations, and services within the same overarching structure for discussion. The sustained expansion of CPST since 2015 can be understood as a systematic response to the challenges associated with the era of the Internet of Everything.

4.5 Critical Evaluation and Open Questions

At present, CPST mainly functions as a framework for conceptual integration and systems analysis. The four-dimensional space and cross-space coupling relationships still need to be operationalized. In particular, for the thinking space, there is still a lack of unified observable variables, measurement scales, and cross-scenario benchmarks. Therefore, this paper does not regard the four-dimensional division as a closed ontology that has already been empirically verified; rather, it treats it as a research program that remains to be formalized, quantified, and comparatively tested.

In terms of its conceptual genealogy, CPST is comparable to Popper' s three-world theory, which distinguishes the physical world, the subjective mental world, and the objective knowledge world[^62], and it also intersects with Floridi' s philosophy of information in its systematic study of the concepts of information, information processes, and information environments[^63]. The distinction of CPST lies in explicitly differentiating cyberspace from thinking space and in using six pairwise coupling channels to serve engineering analysis. However, whether this four-dimensional distinction is irreducible still needs to be tested through alternative-model comparisons, boundary cases, and empirical studies.

Existing literature shows that CPST has already entered topical reviews, systematic literature reviews and formalization, classification studies, and comparisons with CPS/CPSS concepts[^5,^14,^19–^21]. Related citing papers have also discussed big-data fusion, knowledge representation and reasoning, reinforcement learning, and extended hyper-spatial representation[^15,^16,^24,^25]. In terms of applications, it covers areas such as urban big data, digital twins, Industry 4.0, 5G-enabled CPSS, and social manufacturing[^12,^18,^22,^31,^53].

To distinguish extensions within the authors' team from external citations, this paper used the DOIs of three anchor papers—the 2015 CPST framework paper, the 2016 Cybermatics paper, and the 2023 Cyberology paper—as three anchor points[^4,^7,^17], and conducted cited-reference searches in the Web of Science Core Collection on July 24, 2026. The three anchor points yielded a total of 144 citation relationships; after deduplication, there were 129 papers. After further excluding 30 papers authored by Huansheng Ning or Ning Huansheng, 99 external citing papers remained. The citation counts by anchor point were 34, 67, and 2, respectively, among which 4 cross-anchor duplicates had already been removed from the total count. This result indicates that CPST-related literature has formed an identifiable basis of external citations. However, citation relationships themselves do not equal theoretical endorsement, substantive adoption, or empirical validation; judgments about influence should still distinguish background citations, conceptual comparisons, and methodological applications, so as to avoid directly generalizing citation counts as evidence that broad consensus has already formed.

5 CPST as a Philosophical Foundation: Supporting Cyberism and Cybersophy

5.1 CPST as the Ontological Basis of Cyberism and Cybersophy

The theoretical extension of CPST to the philosophical level is built upon the overarching structure of the four-dimensional space. This structure provides a premise for discussing the types of existence and their interrelations in the digital age, rather than repeatedly proclaiming an already closed and completed ontology. In this sense, CPST provides an existential and ontological foundation for Cyberism (the study of the relationship between humans and cyberspace) and Cybersophy (the study of cognition and value in the digital age).

5.2 Cyberism(赛博学): A Doctrine Studying the Relationship Between Humans and Cyberspace

Cyberism（赛博学）is clearly defined as a doctrine devoted to studying the relationship between humans and cyberspace (network space)[^46,^48,^64]. It systematically expounds such fundamental issues as cyber philosophy, cyber science, and cyber logic; several questions concerning "human beings" in cyberology; technological development, society, and cognition in cyberology; and the diseases and health problems brought about by survival in cyberspace[^46].

CPST' s distinction among the four spaces—Cyber, Physical, Social, and Thinking—provides overarching support for treating the relationship between humans and cyberspace as a relatively independent philosophical issue, so that the relevant discussion is no longer merely a simple extension of the relationship between humans and physical space or between humans and social space.

On this basis, within the narrative framework of Eastern philosophy, an Eastern four-dimensional philosophical system of "Confucianism, Buddhism, Daoism, and Cyberism" is proposed—placing Cyberism（赛）alongside Daoism（道）, Confucianism（儒）, and Buddhism（释）[^48]. Related research forms four categories of issues around sensory interaction, social civilization, cognitive security, and existential meaning, and conceptualizes them as analytical levels ranging from bodily perception, collective order, and autonomy of mind and intellect to the questioning of meaning.

5.3 Cybersophy: the "Fourth View" of the Digital Age

Cybersophy was first proposed as the "fourth view" of the digital age, following the traditional three views—worldview, outlook on life, and values[^47]. With the deep development of digital technology, humanity is facing comprehensive challenges to its cognitive frameworks, ethical systems, and value coordinates. Cybersophy aims to provide humanity in the digital age with a systematic cognition-value framework[^47].

CPST provides the ontological foundation for Cybersophy. The four-dimensional spatial structure makes the "cybersophy view" not merely an extension of worldview in the digital age, but a new dimension of contemplation with an independent ontological foundation. CPST answers "what exists," while Cybersophy answers "how to know and how to live" —together forming a logical progression from facts to values.

5.4 A Trinity Theoretical System

CPST, Cyberism, and Cybersophy together form a theoretical analytic path from "existence → relation → value" :

CPST = ontology: answers "what exists in the digital age"—the four-dimensional space and its irreducible ontological structure.

Cyberism = relational theory: answers "what is the relation between humans and cyber space" —a specialized doctrine studying the relationship between humans and cyber space[^46].

Cybersophy = axiology: answers "how to know and how to live in the digital age" —humanity' s "fourth view" in the digital age[^47].

The interconnection among the three provides an original framework for philosophical research in the digital age; its explanatory power and scope of application still need to be further tested in cross-cultural and interdisciplinary research.

6 Outlook: The Next Decade

6.1 Theoretical Deepening

The further formalization of CPST' s ontology is the primary task. Subsequent work may focus on the four-dimensional space and its six pairwise coupling channels to establish OWL/RDF-style formal expressions and logical reasoning implementations, so as to support concept-consistency checking and machine intelligence.

Existing CPSS research has already proposed reviews of knowledge representation and reasoning[^24], reinforcement-learning architectures[^25], and the data-driven 7C framework[^31]; these works can provide model objects and methodological references for the formal comparison of CPST' s four-dimensional space.

The further formalization of thinking space is likewise crucial—it requires standardized metrics, benchmark datasets, and validation tools[^5]. In addition, cross-cultural philosophical dialogue needs to be carried out so that it can be understood and applied in different civilizational contexts.

6.2 Engineering and Standardization

From theory to engineering, a series of operable outcomes are needed:

CPST design checklist: a checklist that IoX architects can attach to system requirements documents.

Vocabulary for thinking-space metrics: decision latency, explainability index, cognitive load, trust-calibration score, etc.

CPST-compatible reference architecture: extending existing standards such as ISO/IEC 30141[^65].

Engineering verification may prioritize IoT, cloud-blockchain, and fog-computing scenarios with clear security and privacy requirements[^36,^39,^40]. CPSS data integration, Health Care 4.0, and smart-city infrastructure can be used to verify cross-space data, services, and human-factor collaboration[^37,^43,^44].

6.3 From Chinese Originality to International Dialogue

In its first decade from 2015 to 2025, CPST formed a continuously expanding research lineage, entered the international academic field of vision, and established a recognizable external citation foundation. Related citation topics have expanded from systems methodology to human-centric computing, social manufacturing, and smart cities[^14,^28,^31,^34], and have extended to

medical health and immersive education[^43,^45]. The next stage needs to expand the comparison, testing, and revision of CPST by independent researchers and different application fields, and to promote its movement from an original Chinese concept toward broader international academic dialogue and industrial application.

7 Conclusion

The decade-long evolution of CPST reviewed in this paper refers specifically to 2015–2025. The 2012 question of the "Internet of Thinking" constituted the intellectual source; thereafter, studies on the four-dimensional spatial framework—General Cyberspace, Cyberology, Cyberism, and Cybersophy—gradually expanded, forming a research lineage extending from an Internet of Things scientific framework to an interdisciplinary theoretical system.

Over the past decade, the core achievements of CPST can be summarized in three points.

First, it proposed the four-dimensional analytical framework of digital existentialism. It organizes the objects and relationships of the digital era in terms of cyber existence, physical existence, social existence, and thinking existence, and treats the boundaries and coupling among the four as problems that can be continuously tested.

Second, it demonstrated the possibility of cross-domain applications. Research on the smart-city brain, AGI architectures, national governance, Industry 4.0, digital twins, and 5G communications has provided different types of application and comparison cases for CPST[^12,^18,^53,^55]. Externally cited literature has further covered social manufacturing, digital-twin smart cities, Health Care 4.0, and immersive education[^31,^34,^43,^45], but its cross-domain applicability still requires more comparative research and empirical validation.

Third, it proposed a theoretical linkage from existence and relations to value. CPST provides an existential foundation for Cyberism and Cybersophy; together, the three form an analytical path of "existence → relations → value."

CPST is an exploration by Chinese scholars in theoretical innovation in the digital era. Against the background of building an independent knowledge system, its ten-year course provides a discussable pathway: starting from concrete engineering problems, gradually forming an interdisciplinary theoretical framework, and accepting comparison, testing, and revision through international academic discussion.

The next decade has only just begun.

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CPST: From ternary to quaternary ontology for the digital age—Ten-year evolution and philosophical foundation

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Abstract This article systematically reviews the ten-year development (2015–2025) and theoretical content of cyber-physical-social-thinking (CPST) space theory, originally proposed by Chinese scholars. The digital age has profoundly changed the conditions of human and social existence, yet mainstream frameworks from cyber-physical systems (CPS) to cyber-physical-social systems (CPSS) still lack explicit modelling of thinking and cognition. It also treats the 2012 question of an "Internet of Thinking" as the theory' s intellectual origin. CPST defines cyber, physical, social, and thinking spaces as four basic analytical dimensions and uses six coupling channels to characterize their interactions, thereby providing a categorical framework for research on digital ontology. The article traces the development of CPST from an Internet of Things scientific framework to General Cyberspace and Cyberology; illustrates its application scope through Hangzhou City Brain, AGI-enabled Internet of X, and national sovereignty and social governance; analyses CPST as the ontological foundation of Cyberism and Cybersophy; and reviews six challenges concerning information, connection, application, identity, relationship, and service explosions. It further discusses testability and its limitations, relations to established philosophical frameworks, the scope of independent adoption, and the non-deterministic character of the proposed relations among the six challenges. CPST is therefore presented as both an engineering-analytical framework and a research programme for digital ontology that remains open to empirical testing and theoretical extension, as well as a testable and extensible theoretical proposal for the development of an autonomous Chinese knowledge system.

Keywords Cyber-Physical-Social-Thinking (CPST) space, quaternary space, digital ontology, Cyberism, Cybersophy, philosophy of technology, artificial intelligence (AI), Cyberology