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Uncertainty of Information and Cyber-Physical Space

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Abstract

The article explores the uncertainty of information space and cyber-physical space. The content of information space and cyberspace is revealed. A new point of view on information space is given. The difference between parametric information spaces and physical information spaces is described. The importance of spatial information in modern society and business is noted. Four types of different information spaces are identified. Virtual space is considered as one of the types of information space. The coordinate system is considered as one of the types of information space. The main purposes of information space are revealed. The analysis of information space shows the objective existence of information uncertainty in it. The reasons for the emergence of uncertainty in information space are shown. The relationship between the information field and information space is noted. The difference between these entities is shown. The importance of spatial relations as a prerequisite and as a factor of uncertainty in information space is noted. The relationship between information space and cyber-physical space is substantiated. The main function of information space is semantics or content. The main function of cyberspace is communication and management. The content of several types of cyberspace is revealed. Social cyberspace is highlighted. The article introduces the concept of partial information uncertainty. Particular information uncertainty characterizes an object, a process, and a situation. The existence of cognitive uncertainty is noted. The content of morphological uncertainty and semantic uncertainty is revealed. The article introduces the concept of spatial uncertainty. The concept of field uncertainty is introduced as a mass uncertainty characteristic of all objects in a given part of the information field or part of the information space. A taxonomy of factors influencing the emergence of uncertainty is provided.

Keywords: information space, cyberspace, types of information spaces, information uncertainty, information field, partial uncertainty, spatial uncertainty, field uncertainty.

1. Introduction

The current state of societal development is characterized by the growth of informatization (Bearman et al., 2023) and the expansion of digitalization. These general trends are well known. However, the fact that spatial information is acquiring increasing importance in modern society is rarely noted. The development of business and production is accompanied by the development of various information spaces and the development of cyberspaces. Information spaces exist in two types: parametric, in the abstract domain, and physical, associated with real space. Physical spatial information is used in construction, transportation (Tsvetkov., Oznamets, 2020), regional economics, and spatial economics (Curry, 2020, Tsvetkov, 2013). All areas encounter information

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uncertainty. Parametric spatial information is used in virtual models and virtual spaces. Cyber-physical spatial information is used in both virtual spaces and physical spaces. It follows that cyber-physical space connects abstract and physical spaces. This property is widely used in digital twin technologies.

Society's development is characterized by the growth of information volumes, including spatial information. The growth of information volumes creates the problem of big data (Himeur et al., 2023, Levin, Tsvetkov, 2017). The growth of information volumes, for example, in transportation is due to the increase in speeds (Connolly, Costa, 2020). Increasing speeds create a vast control space. The growth in information volumes is driven by the use of new data collection technologies, including mobile laser scanning (Gospodinov et al., 2024, Markov, Mitev, 2024) and digital railways (Tsvetkov et al., 2019). This growth in information volumes is driven by the increasing complexity of control situations (Connolly, Costa, 2020).

This growth in information volumes is driven by the use of cyber-physical systems (El-Kady et al., 2023) and information flows obtained through the Internet of Things (Soori et al., 2023). Cloud technologies (Marinescu, 2022) also generate and utilize large volumes of data. All of this increases the relevance of technologies that process and utilize large volumes of spatial information. The growth in information volumes and the increasing complexity of information in physical and parametric spaces entails increased information uncertainty.

2. Discussion and results

Implementation

Content of information spaces.

Information space is interpreted in various ways, and sometimes these interpretations are contradictory. The simplest model of information space is a coordinate system in real space. This model characterizes the information space as a shell for the objects it contains. This model describes a physical information space. No one disputes this model. A complement to the model of such a space is the model of the information field. The information field is analogous to physical fields and abstract fields. Physical information space exists alongside the information field.

Information space is defined as a global sphere in which information is created, transmitted, and consumed. This model is organizational and technological. Such an information space is not so much informational as organizational. It includes physical and non-physical components. Physical components include technical resources, physical infrastructure, physical networks, physical devices, and physical data. Non-physical components of organizational information space include information resources, software, algorithms, and interaction rules. Information space is defined as a virtual space in which virtual models and processes that do not exist in the real world are created. Virtual information space allows for arbitrary scales to be defined for a model of physical space. It allows for events to be slowed down or sped up, and for viewpoints to be selected that are difficult or impossible to select in ordinary space. Virtual information space allows for the flow of time to be set forward or backward. Closely related to virtual information space is immersive space, used in simulators and computer games.

There is a rare definition of information space as a coordinate system in abstract space (mathematics) or as a phased abstract space. This information space is abstract and parametric. Another definition of information space is the space in which mass media operate. This information space can be called mass information space.

The key is that there are different types of information spaces. Each type of space has its own spatial relationships. There is no single definition that describes all the different information spaces. The dogma of one-dimensionality does not apply here. Large volumes of information and the imprecision of measurements and descriptions create information uncertainty.

Analysis of cyberspace.

Cyberspace can be viewed as a modernization of information space. The emergence of the "Internet of Things" led to the coining of the term "Internet of Things space" (Jiao et al., 2021). It is this space that served as the foundation of cyberspace. The term "cyberspace" is polysemic and can refer to various entities.

The concept of "cyberspace" has become polysemic. Cyberspace, as an information space, denotes various entities. Therefore, it is necessary to clarify the specific cyberspace being discussed.

A comparison of information space and cyberspace reveals that cyberspace is a specialized type of information space.

Formally, the term "cyberspace" was introduced by William Gibson in 1982 (Clute, 1984). This term, coined in William Gibson's science fiction, describes cyberspace as a real digital environment and a concept of virtual reality in which people interact with technology and with each other. This generalized concept encompassed various entities.

The term "cyberspace" was officially adopted to denote the World Wide Web or Internet in the 1990s (Lippert, Cloutier, 2021). This meant that cyberspace is an information space whose core is a communications network. This interpretation of cyberspace was linked to its primary function: communication. This type of cyberspace is transborder. Let's designate this cyberspace as "cyberspace 1" or communication cyberspace.

The key aspects of this space are virtual reality and the information aspect. Virtuality is expressed in phenomena similar to the real world, but with new capabilities. The information aspect is expressed in the presence of information flows and data circulating in digital form.

In addition to communication in an open environment, the problem of information security has arisen (Tariq et al., 2023). To ensure information security, a cyberspace has been created that acts as a shell for another space or for a secure object. The key aspect of this space is ensuring information security. Let's designate this cyberspace as "cyberspace 2" or security space. It complements cyberspace 1.

The emergence of the Internet of Things has led to the inclusion of information collection and control functions in cyberspace. A key aspect of this space is real-time control. We will designate this cyberspace as "cyberspace 3" or management cyberspace.

The widespread influence of mass media, especially in interactive mode, has led to the emergence of "social cyberspace." One could continue analyzing the types of cyberspace, but it's easier to refer to the work (Tsvetkov, 2025a), which identifies seven types of cyberspace, excluding social cyberspace.

General conclusion: Information uncertainty is more present in cyberspace than in information space.

Specific information uncertainty.

Information uncertainty is typically attributed to individual objects or processes. This uncertainty is isolated or specific. It is simply defined as a state. An object's state of uncertainty is characterized by contradictory, incomplete, or imprecise information. A situation's state of uncertainty is characterized by the unpredictability of the situation's dynamics and the lack of complete knowledge about the situation. Uncertainty of a situation and an object can be caused by an excess of data that is difficult to analyze. Big data causes this uncertainty. These types of uncertainty are object-specific or isolated. This category includes cognitive uncertainty, caused by a low level of intelligence that precludes the subject's ability to analyze or make decisions. This is subjective uncertainty.

The concept of a "state of uncertainty" should be accepted. However, the concept of an "uncertainty factor" should be added to this characteristic. A state is a generalized concept. It states the presence or absence of uncertainty. An uncertainty factor allows one to find a cause-and-effect relationship between the uncertainty of a state and its causes. There are two other types of informational ambiguity that are little discussed: morphological ambiguity and semantic ambiguity (Tsvetkov, 2025b). Morphological ambiguity is independent of semantic ambiguity. Semantic ambiguity and morphological ambiguity depend on situational ambiguity, that is, on the situation in which the object finds itself.

Morphological figurative ambiguity arises when the object model is a visual image and there is a lack of information in its clear description or interpretation. For example, an object may have the shape of a circle or an ellipse. There is morphological ambiguity of reciprocity or spatial relationships. It is expressed in the fact that the intersection area of objects, due to their morphological ambiguity, may have different shapes and different sizes. An example of morphological figurative ambiguity is topological ambiguity. A topological model expresses the main properties from a topological perspective and excludes secondary properties. The main properties are structural relatedness and the possibility of topological transformation. Topology excludes properties such as metric dimensions and area. Topology precludes coordinate referencing of figures. Topological models contain metric and coordinate uncertainty. This determines the content of topological uncertainty.

Semantic uncertainty exists in semantic modeling and appears in processes that use semantics. One approach to assessing it is the Dempster-Shafer theory [3csf] or DST. It is called "Mathematical Theory of Proofs," but is actually a theory of assumptions and reasoning. It is permissible within certain conditions that allow the application of this theory.

Spatial or Field Uncerta

Uncertainty in information space differs from individual uncertainty. It has a number of additional factors. One cause of information uncertainty in cyberspace and information space is the problem of polysemy and terminological relationships. In cyberspace and information space, an additional cause of uncertainty arises in the form of uncertainty in the relationships between spatial objects. Spatial relationships can determine the uncertainty factor. For example, a train is a clearly defined object. A railroad track is a clearly defined object. A station is a clearly defined object. However, the train's arrival at the station may not be precisely determined due to stochastic factors during travel.

Closely related to uncertainty in information space is field uncertainty. Field uncertainty is a mass uncertainty characteristic of all objects in a given part of a field or part of space. Field uncertainty, which translates into uncertainty in information space, can be caused by interactions in the field that cause uncertainty in space.

An example is the Heisenberg Uncertainty Principle. This is a fundamental law of quantum mechanics, stating that it is impossible to simultaneously measure certain pairs of quantities, such as the position and momentum of a particle, with absolute precision: the more precisely one is known, the less precisely the other. This is not a limitation of our instruments, but a property of the very nature of quantum objects (their wave-particle duality). The uncertainty principle mathematically describes the lower limit for the product of the uncertainties of these quantities.

For information space and the information field, for cyberspace, there is spatial uncertainty that complements object or situational uncertainty. This uncertainty is determined by spatial relationships and spatial interactions. This uncertainty is determined by the fundamental properties of matter, such as the Heisenberg Uncertainty Principle or the "Law of Chiral Purity." The "law of chiral purity" is a fundamental observation in biology that life preferentially utilizes one of the mirror isomers (enantiomers): all amino acids in proteins are "left-handed" (L-amino acids), while sugars in DNA/RNA are "right-handed" (D-sugars). This property, called homochirality or chiral purity, is critically important for the functioning of biomolecules (proteins, DNA), but its origin and mechanism of occurrence in early life remain a mystery. Recently, this law has been studied in cybernetics and computer science for the possibility of cloning or the "purity" of cloning.

An example of spatial certainty and uncertainty is shown in Figures 1 and 2.

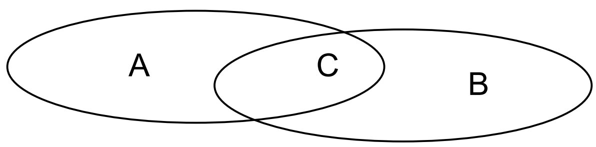


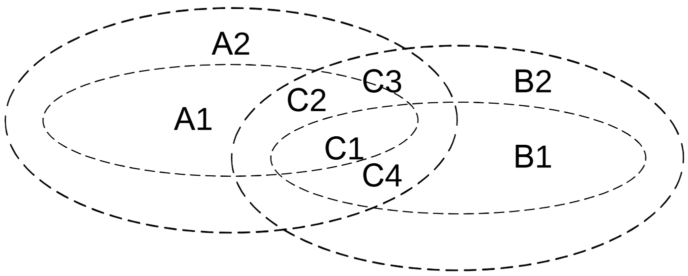
Fig. 1. Spatial Definition

Figure 1 shows three defined sets related by the relation

$$C=A \cap B \quad (1)$$

The definiteness of sets is shown by solid lines. Set C is uniquely defined as the intersection of distinct sets A and B.

Figure 2 shows a spatial situation with uncertainty. The uncertainty of sets is shown by the dashed boundaries of the sets.



The definiteness of sets is shown by solid lines. Set C is uniquely defined as the intersection of distinct sets A and B.

Figure 2 shows a spatial situation with uncertainty. The uncertainty of sets is shown by the dashed boundaries of the sets.

$$A \rightarrow A1, A2 \quad (2)$$

$$B \rightarrow B1, B2 \quad (3)$$

$$C \rightarrow C1, C2, C3, C4 \quad (4)$$

The resulting uncertainty is expressed through the set C. The intersection set is not uniquely defined and is estimated using the formulas.

$$C1=A1 \cap B1 \quad (5)$$

$$C2=A2 \cap B2 \quad (6)$$

$$C3=A1 \cap B2 \quad (7)$$

$$C4=A2 \cap B1 \quad (8)$$

Spatial uncertainty creates ambiguity in the description and representation of a portion of space. Spatial uncertainty can be represented as a discrete set of dimensions. Depending on the context, each of the expressions (5-8) has a most probable meaning. This uncertainty is resolved through additional contextual analysis.

3. Conclusion

There is no single definition that describes different information spaces. Analysis shows that four types of information spaces must be distinguished: physical, organizational, virtual, and mass. These types of spaces have different dominant spatial relationships and different primary processes. Cyberspace, as an information space, denotes different entities. It is necessary to clarify in each case which cyberspace is being discussed.

Information uncertainty is usually attributed to individual objects, situations, or processes. It is simply defined as a state. This uncertainty is called individual and can be: object uncertainty, procedural uncertainty, and situational uncertainty. The state of individual uncertainty is characterized by contradictory, incomplete, and inaccurate information. Uncertainty in information space and cyberspace differs from individual uncertainty. Uncertainty in the physical field and information field differs from the individual uncertainty of objects.

Spatial relationships in information space or cyberspace can cause uncertainty. Interactions in information space or cyberspace can cause uncertainty. Cognitive relationships in information space or cyberspace can cause uncertainty.

Uncertainty research has not yet led to a standardized concept of morphological uncertainty. Figurative morphological uncertainty visually reveals confidence intervals and uncertainty zones. Spatial uncertainty creates ambiguity in the description and representation of a part of space. Spatial uncertainty allows for the application of morphological assessment methods. Spatial uncertainty is related to field uncertainty. Field uncertainty allows for quantitative and functional assessments. Spatial uncertainty can be represented as a discrete set of sets.

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