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Cosmic Ontology

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Abstract

This article explores a new type of ontology, "space ontology." It introduces the concept of "space ontology" and substantiates the notion of "information spatial ontology" as a type of epistemic ontology. The aim of the work is to develop scientific and methodological foundations for constructing a space ontology as a specialized type of spatial ontology arising from the processing of space information. The concept of ontological modeling is introduced as a group of technologies for transforming information into knowledge. The evolution of the concept of ontology from a generalized concept to applied concepts and the solution of practical problems is briefly described. A taxonomy of spatial knowledge is presented. A taxonomy of spatial ontologies, including space ontology, is presented. The works of Guarino and Alexander serve as the basis for this taxonomy. The article demonstrates that a space ontology can be obtained based on information morphism, ontological information retrieval, and semantic correspondence. It is generalized that all procedures for obtaining ontology can be called ontological transformation. The importance of the "Eidetic Reduction" and "Categorical Intuition" methods as essential components in the formation of cosmic ontologies is substantiated. The significance and content of vocabulary ontology as a basis for constructing complex ontologies is revealed. The difference between constructing a formal upper-level cosmic ontology and a formal subject-level cosmic ontology is demonstrated. Ontology construction based on logical inference is described. The obtained results expand the methodological foundations of ontological modeling and the scope of application of spatial ontology in research related to the analysis of cosmic information.

Keywords: ontology, spatial ontology, cosmic ontology, informational spatial ontology, spatial information, ontological transformation, epistemic ontology.

1. Introduction

The term "ontology" was originally a purely philosophical term. It was interpreted as a description of the science of existence. This interpretation reflected the level of scientific development and the state of knowledge at the time. Subsequent centuries were characterized by the differentiation of the sciences and the formalization of knowledge. Attempts emerged to formally describe knowledge and apply it. Specific interpretations of ontologies emerged. The study of ontology as a specialized field is attributed to the works of the philosophers Goclenius (Lexicon Philosophicum) (Goclenius, 1980) and Lorchardus (Theatrum Philosophicum) (Rohregger, de Souza, 2021). The term "ontology" received significant use thanks to the work of Christian Wolff in Latin writings, particularly in his 1730 work "Philosophia Prima sive Ontologia." The next stage in the development of the concept was the work of Edmund Husserl and his student Roman

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Ingarden (Ingarden, 1960). In Ingarden's theory, ontology explores and describes possible objects and relationships. Ontology was interpreted as the science of formal knowledge, formed by concepts and conceptual models. E. Husserl introduced the concept of "formal ontology" (Husserl, 1912). This ontology was closer to practical activity, but its main focus was the generalization of scientific research. Husserl hypothesized that the object of ontology's study is categories. This, too, was a refinement of the original concept of ontology, but a generalization in relation to the modern interpretation of ontology. Husserl defined the fundamental method of ontology as eidetic reduction, combined with the method of categorical intuition. Eidetic reduction explores the immutable forms of cognition that underlie any empirical research. Categorical intuition is a form of direct, non-sensory perception of general relationships between objects (e.g., spatial relationships, belonging, part, and whole). One of the applications of categorical intuition is the technology of conceptual blending.

Categorical intuition is based on the qualitative analysis of categories and allows for the direct identification of the essence of an object or general categories without resorting to a detailed logical analysis of the situation. The importance of categorical intuition for the formation of spatial ontology is noteworthy.

The subsequent development of ontology research led to the concept of ontology models and ontology models in various subject areas. The field of space exploration provides grounds for speaking of cosmic ontology. The concept of "ontology" is currently widely used in various fields of activity (Guarino et al., 2009; Nesterov, Tsvetkov, 2024). According to the IDEF5 ontology research standard (Standard, 2025), an ontology includes: a vocabulary ontology; validation of ontology application situations; rules; and sanctioned inferences.

– A vocabulary ontology is a catalog of terms as a terminological system used in the subject domain of a given ontology.

– Rules (syntax) govern how terms can be combined into valid statements in this subject domain.

– Sanctioned inferences represent valid statements in the subject domain.

The emergence of an integrated model of the information field (Tsvetkov et al., 2023) has influenced ontology construction methods. Information ontologies have emerged as a type of information model. The widespread use of spatial information has led to the emergence of spatial ontologies and spatial information ontologies.

An information ontology is an information model of a subject ontology, including the structure of categories, their properties, and the relationships between them. This model describes information models of entities, their properties, and the relationships between them.

Scientific research has led to the concept of ontology as a model of new knowledge. Ontology as a knowledge model can be derived from heuristic reasoning. Such ontologies are supported by ontological information retrieval, cognitive modeling, and ontological information modeling.

Ontological information modeling is a method for formalizing domain knowledge with the goal of creating an information model of the ontology. Ontological information modeling can be considered a type of information morphism (Ozherel'eva, 2017). Information morphism, as a complex transformation, can result in the formation of an ontology.

It is necessary to clarify the distinction between information and ontological modeling. Information modeling always results in either new information or an updated existing information model. However, it does not result in the acquisition of new knowledge. Ontological modeling always results in the acquisition of new knowledge or new knowledge models.

A conventional ontology is obtained through reasoning, cognitive, or logical constructions. An information ontology can be obtained through computation, reasoning, composition, and conceptual blending (Savinykh, 2017). Ontology can be formed through the extraction of tacit knowledge (Sigov, Tsvetkov, 2015).

Spatial data processing often leads to the emergence of new knowledge, for example, the identification of hidden spatial structures, isolines, zones of influence, and spatial clusters – all of which cannot be obtained directly from the primary data. The emergence of such spatial knowledge corresponds to the properties of ontological inference. Despite the existence of works devoted to ontologies, the creation and application of geodata, the construction of spatial information ontologies as a class of epistemic ontologies is underrepresented.

2. Results and discussion

Space Spatial Knowledge

Space knowledge can be spatial or non-spatial. In this paper, we examine space spatial knowledge.

Publications have addressed the issues of spatial knowledge and geoscience. Research has been conducted on the relationship between the concepts of knowledge, geoscience, and space knowledge (Savinych, 2016). This provides grounds for introducing and exploring the concept of space ontology.

In space information analysis scenarios, a problem arises related to the insufficient coherence and generalization of existing spatial models derived from space information. This complicates the generalization of such models and the derivation of new knowledge from them. Space ontology is a model of space knowledge. It is built on the basis of logical inference, intuition, discourse, and reasoning. Space information ontology is an information model of space knowledge. This ontology is built on the basis of ontological modeling, formal logical inference, computation, and formal reasoning. With the growth of information technology and the emergence of big data, the creation of a space ontology is becoming important for optimizing the analysis of space information.

Figure 1 shows a diagram of the system of spatial sciences and spatial knowledge. The diagram is given in relation to space knowledge. Spatial knowledge is accumulated from geo-knowledge (Tsvetkov, 2016) and space knowledge. Geo-knowledge is formed from the Earth sciences. Space knowledge is formed from two sources.

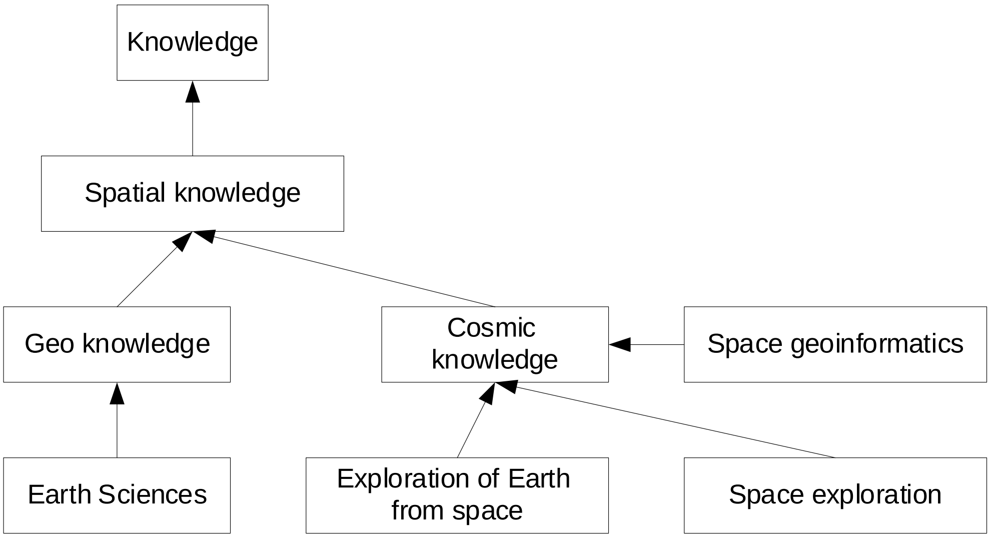

Fig. 1. Spatial Sciences and Knowledge System

The first source is related to Earth exploration from space. Its unique feature is that it is supported by geosciences and other terrestrial sciences: transportation, monitoring, geodetic networks, geodynamics, geology, satellite navigation, satellite altimetry, satellite geodesy, and visual instrumental Earth observations (Savinykh, 2020).

The second source of space knowledge is related to the study of outer space and celestial bodies. This complex of sciences includes space geodesy (Oznamets, Tsvetkov, 2019), astronomy, planetary altimetry (Tsvetkov, 2020), geodetic astronomy (Gospodinov, 2018), astrophysics, visual instrumental observations of space objects, and others. A new science linking these two fields is space geoinformatics (Bondur, Tsvetkov, 2015).

A taxonomy of spatial ontologies, including space ontology, is shown in Figure 2. The upper part of the diagram describes general ontologies. The lower part describes spatial ontologies, which include space ontology.

Currently, there are more than 20 interpretations of the term "ontology" (Ontology..., 2025). In relation to space ontology, the general part of ontologies includes four components: formal ontology; vocabulary ontology; epimestic ontology; dynamic ontology.

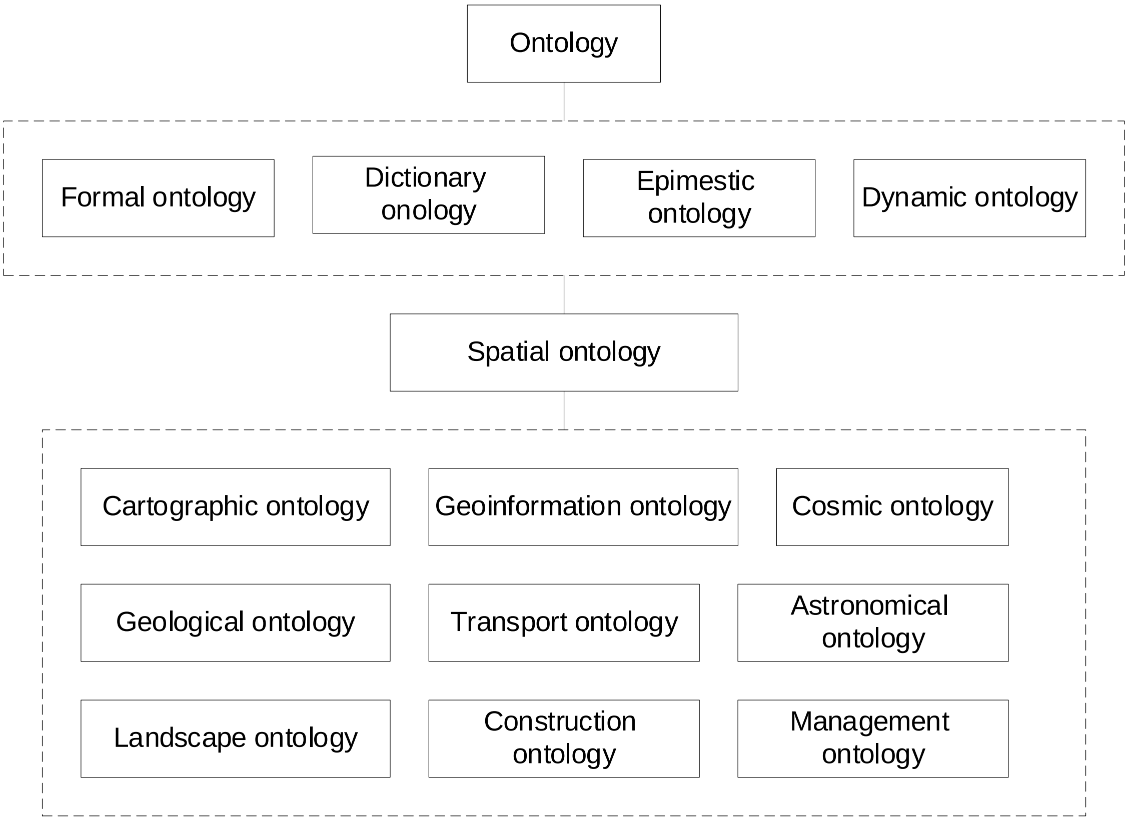

Fig. 2. Taxonomy of spatial ontologies

Formal ontology is an attempt to use formal methods to describe ontology in a generalized manner, in terms of descriptive descriptions of categories and concepts. Formal ontology has two forms of representation. The first form abstracts from a specific domain and considers knowledge in a generalized manner. It uses an approach based on the premise that in any subject area, there are phenomena that are perceived as conceptual objects, generalized associations, and generalized situations. This approach is based on the analysis and construction of general concepts. It is used in the construction of ontologies that utilize web semantics.

The second form of formal ontology is domain-specific and uses a formalism that takes into account the specifics of the subject area but is linked to general concepts and shared knowledge. This form takes the approach that conceptual objects and concepts have specific forms of realization in each subject area.

The other three ontologies (Figure 1) use physical parameters and differ slightly across subject areas. They correspond to Alexander's taxonomy (Alexander et al., 1986).

Vocabulary ontologies are associated with basic descriptions and the concept of information units. They are formed using linguistic mechanisms. Vocabulary ontologies are represented by descriptors and classifiers. For example, a classifier of conventional cartographic symbols. In the context of a vocabulary ontology, a relation is a component of an ontological model linking concepts and entities. A term is a specific descriptor related to an entity or process. A vocabulary ontology is a knowledge representation model based on description logics that enables the description of domain concepts. It represents a compromise between expressiveness and computational complexity, enabling the creation of consistent and understandable vocabularies. In its simplest interpretation, such an ontology is a dictionary.

Constructing a vocabulary ontology involves creating a catalog of descriptors (e.g., a dictionary of ephemerides) for a given domain. Creating a vocabulary ontology involves four tasks: 1) cataloging terms; 2) recording the conditions for using terms; 3) creating a syntax defining the rules for using terms to create assertions about the domain; 4) creating a coherent terminological system for the given domain. A vocabulary ontology includes elementary entities (vocabulary units), a grammar, and a model of behavior in the domain.

Epistemic ontology is associated with the term "episteme" (from the Greek episteme, meaning knowledge, and logos, meaning teaching). It serves a descriptive function for knowledge of a static situation or an unchanging phenomenon. Furthermore, it describes the knowledge that emerges through various discourses, for example, defining what is considered truth and which methods of cognition are acceptable and which are not. Additionally, it defines the relationship between ontology and epistemology, which studies knowledge as such (its nature, structure, boundaries, reliability, truth, and origin).

An epistemetic ontology forms conceptual constructs based on a vocabulary ontology. It can be defined as a formal representation of knowledge about a subject area, including a description of classes of objects, their properties, and the relationships between them. The main criteria for the formation of these ontologies are: the purpose of the ontology, the level of formal representation, and the degree of detail. Within this type of ontology, information ontologies (Wimalasuriya, Dou, 2010) are distinguished as information models of ontologies. A direction in the development of information ontology is the Semantic Web ontology. It is a formal, descriptive knowledge structure that defines concepts and the relationships between them in a specific subject area. It is a key technology of the Semantic Web, which is a superstructure on top of the existing World Wide Web and is aimed at recognizing the semantic content of data. The purpose of creating ontologies in the Semantic Web is to enable machine data processing, information integration, and support automated decision making.

Dynamic ontology also includes vocabulary ontology, but it focuses on elementary processes. It is defined as a formal representation of knowledge about processes in a subject area. Dynamic ontology describes the dynamics of the states of objects in a subject area, as well as the dynamics of situations in which the object of study finds itself. Dynamic ontology can be considered an event ontology. It is one way to describe knowledge about dynamic processes and transitions between system states.

Spatial ontology is a group of ontologies from different subject areas that utilize spatial information. Research on these ontologies has been conducted since 1991 (Schatzki, 1991). Space ontology (Bittner, Smith, 2003) falls within the field of spatial ontologies. Many spatial ontologies are an extension and a type of epistemic ontology. They represent a formal and explicit description of a domain of spatial knowledge as a structure of concepts, properties, and relationships between them. They are created for specific purposes in information systems, such as creating a semantic web or artificial intelligence. Other spatial ontologies are an extension and a type of dynamic ontology. Some spatial ontologies include a combination of dynamic and epistemetic ontologies.

Spatial ontology may take other forms than the Semantic Web, such as stream ontologies (Kurdyukov, 2024) and transport ontologies (Kudzh, Kurdyukov, 2024, Rozenberg, Tsvetkov, 2024). For example, an electronic map as an ontological model is used in transport management.

An information spatial ontology can be considered a specialized information ontology formed using spatial information. This determines its connection with geoinformatics and various types of spatial information modeling. Information spatial ontology is a derivative concept of information ontology, so it is appropriate to provide a brief taxonomy of the interpretation of information ontologies.

The conducted analysis of the interpretation of ontologies provides the basis for formulating the concept of cosmic ontology. Cosmic ontology is a subtype of spatial ontology, constructed using cosmic information and spatial relationships. Cosmic ontology can take the form of spatial models. One model of cosmic ontologies is the electronic star map, which is a knowledge model. In it, each symbol has specific semantics and meaning.

Cosmic ontology is being created as a tool for a deeper understanding and modeling of spatial data in space information systems (Savinykh, 2019).

Formal Representation of Space Ontology

Currently, mathematical processing of data and knowledge is widely used to construct ontologies (Kuznetsov et al., 2011). Mathematical models are universal, allowing them to be applied in various fields, while also enabling interdisciplinary knowledge transfer. For example, information entropy in the mathematical theory of communications and entropy in statistical physics have identical formal descriptions but have different meanings. Coulomb's law and the law of universal gravitation have the same structure but describe different domains and contain different parameters. Therefore, formally identical mathematical expressions can have different semantic meanings and are applicable in ontological modeling. Ontological modeling exploits the presence of commonalities or correspondences between entities defined in terms of formal logic. According to N. Guarino's classification of ontologies by purpose (Guarino, 2009), there are top-level ontologies, domain ontologies, task ontologies, and application ontologies. While this classification may be controversial, it can be taken into account.

According to Guarino, top-level ontologies include the most general concepts that are independent of specific domains and tasks (are common to them). Such concepts include "entity," "phenomenon," "object," "event," and so on. Domain ontologies describe concepts and relationships characteristic of specific domains (e.g., railway transport). Task ontologies include concepts and relationships th ships between concepts in the subject area. Rs can be viewed as R types; T – a set of vocabulary terms; EIs – a set of domain interpretation elements; IMs – information models of the subject area (space research area). Ru – rules applicable to modeling spatial scenarios. G – geometry properties (can allow storing measurement values or values for three-dimensional data in coordinates); SC – a coordinate system (together with tolerance and resolution values, constitutes the spatial reference of a class);

FTLSO is used to create a new class of spatial objects. SOSL is used to obtain specific knowledge in the subject area.

3. Conclusion

Interest in the problem of space ontologies is dictated by the development of space research. For intelligent technologies, knowledge, not information, is the basis of action. The primary purpose of space ontologies is the formation of spatial space knowledge.

There are information models of space objects that merely provide information. There are information models of space that contain knowledge. Such models are called space ontologies.

Space ontologies derive knowledge from a large, heterogeneous set of spatial data. Sometimes this set is redundant, incomplete, and sometimes contradictory.

Therefore, when constructing space ontologies, information compression and the elimination of inconsistencies are necessary.

It is shown that a space spatial ontology is formed as a structured knowledge model arising from space exploration and a combination of transformations. This model is based on logical, cognitive, algorithmic, and mathematical procedures.

It is substantiated that, provided certain criteria are met, an electronic map can serve as a form of ontology representation; however, not every cartographic model is an ontology. The principles of constructing an information spatial ontology based on information correspondence and information morphism are presented, connections with existing ontology classes are described, and the conditions under which spatial information models become knowledge carriers are highlighted. The presented scientific and methodological foundations for constructing a space ontology as a specialized type of ontology make it possible to expand the scope of application of spatial ontologies in the study of space objects.

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