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Spatial Knowledge Models

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Abstract

The article explores the field of computer science and geoinformatics, which apply and process spatial information. Spatial information serves as the basis for obtaining spatial knowledge models. A general knowledge model is an ontology. When using spatial information, a spatial ontology serves as a knowledge model. Spatial ontologies, which are models of spatial knowledge, are considered. Spatial ontologies are created using spatial knowledge models. The taxonomy of ontologies is shown. A dictionary ontology is described as a basic ontology, which is used in the construction of complex ontologies. The concept of ontological information units is introduced. The content of descriptive logic is revealed. The significance of an information field as a unifying information model is shown. Examples of a spatial descriptor are given. A mechanism for obtaining spatial ontologies based on spatial conceptual blending is considered. Conceptual blending in geoinformatics is a transfer of the ideas of conceptual blending from psychology. The significance of spatial relations for the formation of spatial ontologies is shown. An example of a spatial ontology might be the result of conceptual blending or an electronic map. Generally, these models may or may not be ontologies. The conditions for transforming spatial models into ontologies are given. It is shown that a spatial model is an ontology if it contains knowledge. A formal description of spatial composition and cartographic composition is provided.

Keywords: spatial knowledge model, ontology, spatial ontology, spatial conceptual blending, cartographic composition, spatial composition, ontological modeling.

1. Introduction

Information sciences, particularly computer science and geoinformatics, use different types of information models. The most important model in computer science and geoinformatics is the knowledge model. A knowledge model has many forms of representation. The traditional form of knowledge description is ontology (Chen et al., 2025). Ontology has a multi-level representation. The lowest level of an ontology is a dictionary. A dictionary can be viewed as a set of thematically related information units. If dictionary information systems form a single, consistent terminological system, then such a dictionary is an ontology. The vocabulary units of ontology vocabularies are ontological units. Complex ontologies are created based on dictionaries, or systems of ontological information units. A dictionary-level ontology is called descriptive. This ontology is constructed using descriptive logic. The term "descriptive logic" comes from the word descriptor (Latin descriptor "describing"). Descriptive logic is interpreted as "describing and consistent" logic. A descriptor, in one sense, is a phrase used to describe the semantic content of a term or model. Another meaning of a descriptor is a dictionary. In linguistics, a descriptor, as a

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phrase, represents a linguistic information unit. In the field of knowledge, a descriptor is a linguistic ontological unit. This information (geoinformation) unit is the basis for constructing linguistic information constructs in an information field. A linguistic construct can describe knowledge. In this case, the descriptor is an element of knowledge and ontology. The key to dictionary ontology is that it provides a consistent foundation for constructing composite knowledge models. The large amount of spatial information used to solve practical problems has led to the need to use it for cognition and management. This situation has led to the need to construct spatial ontologies (Strader et al., 2024; Bateman and Farrar, 2004). Spatial ontologies are a tool for cognition and knowledge acquisition in geoinformatics. A distinctive feature of knowledge in geoinformatics is the use of not only spatial ontologies but also geoinformation ontologies (Rosenberg, 2016). Spatial knowledge includes geoknowledge, spatial relations, and spatial ontologies. Spatial knowledge is often represented visually: digital images, electronic maps, and visual models. This article builds on the work of (Tsvetkov, Kurdyukov, 2024), which focused on spatial ontologies.

2. Discussion and results

Basic Knowledge Models

Basic knowledge models are lower-level ontologies. Alexander's taxonomy (Alexander et al., 1986) distinguishes three types of ontologies: static, epistemic, and dynamic. A static ontology is interpreted as a dictionary ontology. It uses description logic. This logic is also called terminological logic of concepts. It represents domain knowledge in a formalized form that eliminates ambiguity. To link models into a single system, either a rule system or a unifying model is used. Unifying models in computer science, geoinformatics, and the Earth sciences are the information field (Tsvetkov, 2014) and the information space.

In an information field, a descriptor defines the semantic meaning of a model or group of models within the terminological system of the knowledge domain being studied. In geoinformatics, one example of a descriptor is conventional cartographic symbols. The formal approach defines a descriptor as a description of a frame. Frames are also used to describe knowledge. Description logic (Baader et al., 2008) uses the concepts of "concept" and "role," which further links it to ontology and mathematical logic.

At the level of cognitive modeling, concepts are used to describe either categories or classes, for example: "text models," "point models," "linear models," and "areal models." A role is a description of the relationship between pairs of objects. For example, in urban settings, there is a binary relation "City (A) is the parent of Street (B)" or a binary relation "Owner (X) owns House (Y)," where X and Y can be substituted by arbitrary objects. Description logic formulates general statements such as "every owner is a subject," "every real estate is owned," "every city is located in a country".

The basic knowledge model is the information unit – the descriptor. A descriptor is associated with a word or sentence (phrase). By analogy with linguistic units, the concept of an ontological unit can be introduced. A related set of information units creates a more complex construct. For example, a set of related words creates a sentence. If such a sentence is free of contradiction, it is an ontological unit. Ontological units can be combined or mixed. This mechanism creates a new ontology if the resulting mixture is free of contradictions and united by a single theme. An example is an electronic map, which "mixes symbols of three types, inscriptions, and additional designations, all meeting the requirements of cartographic composition". An electronic map may or may not be an ontology. Everything depends on the new knowledge it contains. The basic knowledge model is an ontological information unit.

Mechanisms for constructing knowledge models.

Many geoinformation models have a visual representation. This visual representation has morphology and semantics (Tsvetkov, 2025). This property of geoinformation models enables the application of morphological and semantic modeling. Morphology can contain knowledge. Morphological modeling can create a new type of knowledge, that is, an ontology.

Conceptual blending (CB) is an example of a mechanism for constructing spatial ontologies. Conceptual blending can be interpreted as the blending of concepts. Concepts are a component of ontologies. This mechanism was originally unrelated to ontologies and arose in psychology as a cognitive technology. CB moved into the field of cognitive semantics, then into information modeling. Conceptual blending was developed by J. Fauconnier and M. Turner (2008). The theory of conceptual blending (Gregorcic, Haglund, 2021; Yoon, 2024) states that the relationships between cognitive situations are "blended" in the overall cognitive process of cognition. They view concepts as a factor of cognition.

The theory of conceptual blending in ontology theory asserts that the blending of ontological concepts creates a new ontology. In the modern understanding (Shahrokhi, 2024), this mechanism creates new knowledge. In geoinformatics, this mechanism creates morphological and semantic transformations. Conceptual blending uses the composition of morphologies. Cartographic composition is an analog of such a composition. The process of creating maps can be viewed as conceptual blending. It follows that a map constructed in this way is a spatial ontology.

A distinctive feature of morphological modeling is the presence of two approaches: onomasiological and semasiological. An electronic map is created using onomasiological modeling. In this approach, knowledge elements (information units) create a common complex knowledge model. Another approach is to first blend and then extract knowledge elements. This is semasiological modeling.

The description of spatial situations uses morphological representation as a set of images depicting real objects.

Conceptual blending theory is associated with cognition, and therefore it is associated with ontologies as tools for cognition.

Spatial ontologies are a broader concept than geoinformation ontologies. These ontologies are developed exclusively in geoinformatics. Spatial ontologies can be developed in geodesy, photogrammetry, cartography, remote sensing, image processing, geology, cadastral surveys, and so on. Such ontologies are used in transportation management (Levin et al., 2018) and real estate management (Gurgov, Kurdyukov, 2024). Spatial ontology is a type of information ontology (Tsvetkov, Kurdyukov, 2025). Transportation ontology (Kudzh, Kurdyukov, 2024) can be considered a type of spatial ontology.

Spatial Knowledge Models.

Spatial knowledge models have two main construction methods: informational and ontological. A spatial knowledge model (SKM) can be viewed as a new information model or as the result of ontological modeling and a special case of ontologies. A SKM in geoinformatics can be considered a special geoinformation model. Both types of models belong to the information field (Tsvetkov, 2014). A SKM in geoinformatics becomes an ontology if it contains knowledge.

An information ontology is an information model that contains knowledge and meets the requirements for constructing ontology. Accordingly, a spatial ontology is a geoinformation model that contains spatial knowledge. Spatial information models contain spatial relations (Savinykh, 2017).

Spatial relations are the basis for ontological modeling and the construction of spatial ontologies. Thus, a spatial ontology is interpreted as a geoinformation model that contains knowledge. There may be several geoinformation and spatial ontologies. The simplest geoinformation ontology is a terminological system of cartographic symbols.

Spatial ontology and geoinformation ontology can be epistemic, dynamic, or combined. When describing stationary objects such as maps, epistemic technologies, including vocabulary ontologies, are used. An epistemic ontology describes spatial situations. When studying dynamic processes such as traffic flows, dynamic ontologies or transport ontologies are used. Both ontologies are varieties of information ontology or ontology in the information field. A spatial knowledge model is often an epistemic ontology.

Conceptual blending as a procedure and spatial ontology.

Conceptual blending can be compared to classification since it has two meanings. The result of classification is a classification model. CB and classification as a technology describe certain processes. CB and classification as a result denote constructed models. CB as a result describes a spatial model, which is always an ontology.

Conceptual spatial blending exploits morphological similarities and differences. Conceptual spatial blending is feasible in the presence of figurative models. An important condition for conceptual blending is the presence of spatial relationships between the objects being blended. Spatial relationships are defined by a unified coordinate system.

In general, the process of conceptual mixing of figurative models (fm) can be represented in the form of a formal expression (1).

$$SR\wedge [fm1(x1, y1)\ STR\ fm2(x2, y2)\ STR\ fmn(xn, yn)] \rightarrow CB(x, y) \quad (1)$$

In expression (1) (x1, y1) is the set of points belonging to the spatial image fm1; SR is the spatial relations; fm is the spatial images, the number of which is equal to n; STR is a set-theoretical or logical operation; x, y is the set of points belonging to the result of conceptual mixing CB. The set of spatial images fmn(x, y) in combination with STR and with the relations SR forms the composition CB. Figure 1 shows examples of input spatial images fm1, fm2.

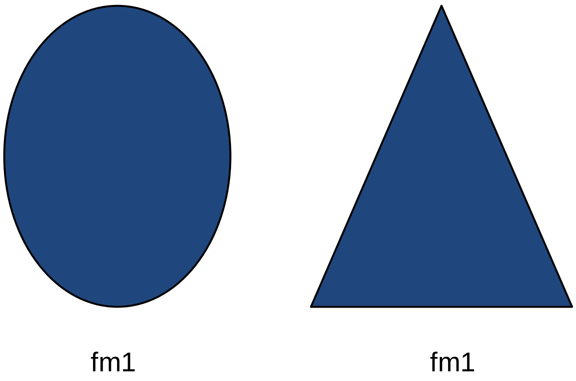

Fig. 1. Example of spatial images of concentrically related figures.

Figure 1 does not show coordinate systems because the geometric centers are connected. This spatial connection precludes the use of coordinate systems.

Figure 2 shows examples of conceptual blending during various blending operations.

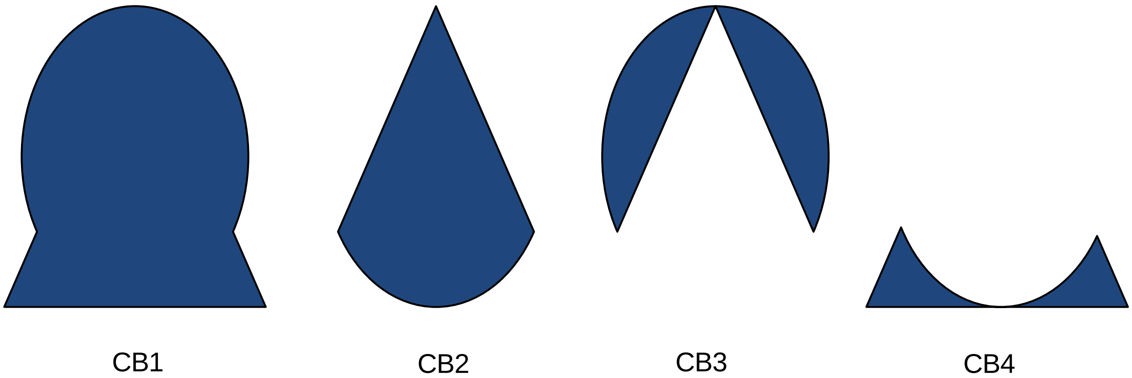

Fig. 2. An example of conceptual blending across different operations

The following operations were applied to Figure 2:

$$CB1=fm1 \cup fm2 \quad (2)$$
$$CB2=fm1 \cap fm2 \quad (3)$$
$$CB3=fm1 - fm2 \quad (4)$$
$$CB4=fm2 - fm1 \quad (5)$$

Expression (2) describes the union of the images fm1 and fm2 and the resulting conceptual blending result CB1. Expression (3) describes CB2 as the intersection of the images fm1 and fm2. Expression (4) describes CB3 as the difference between the images fm1 and fm2. Expression (5) describes the conceptual blending CB4 as the difference between the images fm2 and fm1.

In the given example, the spatial coordinates are defined such that the centers of the figures coincide. In this case, there is no need to introduce coordinate systems. The general conclusion is that conceptual blending creates a spatial composition as a new knowledge model.

Electronic map as a knowledge model.

An electronic map can be either a knowledge model or a spatial model. For example, a photograph is a spatial model and is not a knowledge model. It is a reflection of reality, like a mirror. A knowledge model is something that contains something new, and this newness is definitely knowledge.

Conceptual spatial blending (CB) as a spatial morphological procedure and conceptual blending in digital map construction as a spatially stratified procedure differ. All the conditions of spatial conceptual blending are preserved during digital map construction. In geoinformatics, conceptual blending can be implemented through overlay (Overlay Spatial Analysis) (Kumar, Akkinepally, 2024). This mechanism is used in the construction of digital maps in geographic information systems. The general scheme for digital map construction is more complex. It can also be interpreted as a process of conceptual blending of figurative basic cartographic models (fm).

$$A \wedge SR \wedge [fm1(x1, y1)\ STR\ fm2(x2, y2)\ STR\ fmn(xn, yn)] \rightarrow EM(x, y) \quad (6)$$

Expression (6) shows that the electronic map is realized with an additional parameter, order A, and the same conditions as conceptual blending. The set of spatial models fmn(xn, yn) forms a composition as the electronic map EM(x, y), which is a more complex version of conceptual blending. The electronic map EM and conceptual spatial blending CB have similar construction mechanisms but are qualitatively different. Additional conditions for constructing EM include four components: the presence of order (A) between the original spatial images; the presence of proportionality (Bolbakov, 2022) between spatial information images (this is not necessary for conceptual blending); the presence of a system of spatial information units; and the presence of a single coordinate system for all images.

In conceptual blending, the coordinate system can be replaced by non-fixed spatial relationships, such as the relationship between the centers of figures.

To emphasize the difference between EM and CB, we introduce the concept of a cartographic composition, which corresponds to expression (6). For conceptual blending, we introduce the concept of spatial composition, which is described by expression (1).

The order between spatial images affects the hierarchy of their spatial arrangement during conceptual blending. Many geographic information models are stratified and consist of layers. For a knowledge model, such as an electronic map, the bottom layer typically contains the "world ocean" layer. Next comes the "continents" layer, which represents areal objects. Next comes the layer for state boundaries, which is a linear feature. Lakes and rivers are then added, and so on. If the world ocean were superimposed on top, it would cover all objects, and the model would be uninformative. This suggests that spatial blending is not commutative, and it requires defining an order using cognitive modeling.

The presence of proportionality between information images suggests that geometrically proportionate objects, such as land parcels, cadastral plans, and so on, should be used in constructing electronic maps. Proportionality is interpreted as equal scale. That is, objects of equal scale should be blended. The state and a single plot of land or building cannot be confused. Proportionality is achieved by creating maps of a specific scale.

The presence of a system of spatial information units implies the presence of a basic vocabulary ontology in the form of a thesaurus or cartographic classifier. The spatial ontology created by conceptual blending is a complex object to perceive. A cartographic composition is an example. Reading it requires libraries of cartographic symbols and map design rules.

3. Conclusion

It has been shown that spatial relationships can be defined either through a coordinate system or through tie points of geometric images, such as geometric centers. It can be concluded that spatial blending offers an alternative to the coordinate system in the form of tie point assignment. The spatial composition of a single conceptual blend is implemented according to the principle of "figure-figure blending by tie points or by a common coordinate system." Cartographic composition is implemented according to the principle of "{coordinate system-figure}; {coordinate system-figure}; equal scales; {blending in a single coordinate system}." A prerequisite for creating a cartographic composition is the presence of a stratified hierarchy between the spatial images used to create the electronic map.

This study examines two types of knowledge models: conceptual blending (CB) and electronic map (EM). These spatial models are spatial ontologies. Conceptual blending technology is used in both models, but with varying degrees of detail and under different conditions. Conceptual blending technology can be defined as an ontological modeling technology. An electronic map, as a knowledge model, uses a system of vocabulary ontologies. A photograph, like an image in a mirror, is not an ontology because it does not have a vocabulary ontology.

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