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Information Structural Modeling

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Abstract

The article explores information structural modeling. Information structural modeling includes two types. The first type of structural modeling is used when studying the surrounding world. The second type of structural modeling is used when constructing new structures and modifying known structures. Information structural modeling is based on the features of data used in computer science. Structural modeling is figurative modeling. It has two features. The first feature of the modeling is that all types of data are treated as areal data. The second feature of structural modeling is that models have a dual formal and graphic or visual form. Structural modeling uses a set-theoretic and systems approach. Structural modeling is applied to data, technologies and systems. These types of structures are different and require different modeling techniques. Many objects have a hierarchical structure. This is due to the hierarchy of the surrounding world and the nesting of objects. Information structural modeling is a complex type of modeling. It is much more complex than formal modeling or symbolic modeling. Information structural modeling has two forms: figurative and formal. When constructing a figurative or visual form, it is necessary to solve the problem of the information content of the image. There is always complete information correspondence between the formal structural model and the modeling object. Between the figurative structural model and the modeling object there is either a complete information correspondence or a partial information correspondence. The article shows an example of reducing a complex set to a hierarchical structure. This example shows that structural modeling reduces the complexity of systems and configurations.

Keywords: computer science, structure, structural modeling, structure depth, structure width, structure image, structural model, topology.

1. Introduction

Modeling and structural analysis (McAndrew, 2021) are fundamental tools for exploring the natural world. Almost all objects, systems, models and processes have a structure. The concept of system covers data systems and process systems, technology systems and objects. It is necessary to distinguish between constructing a structure and describing a structure. The structure is built in different ways. One approach to describing the structure is the use of topology. However, topological description is possible only with a known structure. Therefore, the construction of the structure either precedes information modeling or is carried out during the modeling. Systematic study of many processes and phenomena includes determining their structure (Ruben, 2018; Rakhmonov et al., 2020). The most famous example is an algorithm. The construction of an

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algorithm is the formation of its structure. Construction of a control scheme requires the formation of a control structure. A fixed structure is a sign of system stability (Kan et al., 2020). A fixed structure reflects a set of stable connections. Stability is invariance to changes within certain limits. Relationships (Tsvetkov, 2016) are usually not reflected explicitly in the structure.

To check stability, variation of structure parameters is used. The invariance of the structure is checked when its parameters change. One approach to checking invariance is the use of correlative analysis (Tsvetkov, 2012; Makowski et al., 2020). This analysis shows the presence of structure dependence or its absence when its parameters change. Information structural modeling (ISM) is a type of information modeling. It performs an auxiliary or information modeling support function. The study of this type of modeling is an actual task.

2. Discussion and results

Features and tasks of ISM

ISM is divided into two types. The first type is used in environmental research. It is based on onomasiological modeling and detailing of the modeling object.

The second type of structural modeling is used after completion of the first type of modeling. The second type of structural modeling is used to find the components of a structural model and build a new structure based on them. The second type of structural modeling is used when modifying known structures. Structural model and structure can be considered synonymous.

Structural modeling is about finding and fixing connections. Structural modeling also uses relationships. In structural modeling, paradigmatic and syntagmatic relationships are used (Elsukov, 2019). Syntagmatic relationships reflect the "width" of the structural model. Paradigmatic relationships determine the "depth" of the structure. When constructing the structure, dichotomous division is used (Deshko, Tsvetkov, 2023; Tsvetkov, 2014a). The structural description (Ivanciuc, Balaban, 2000) of the model and system includes simplifications of reality. The construction of the structure can be carried out on the basis of a systems approach, based on structural modeling. Building a structure begins with identifying the parts, and then the relationships and connections between the parts of the object. In this case, composition relations and order relations are taken into account.

Information structural modeling is a type of information modeling. The basis of information modeling is applied computer science (Polyakov, Tsvetkov, 2002). Information structural modeling is divided into two types. The first type of ISM is used when studying the surrounding world and unknown phenomena. The second type of ISM is used when examining existing models and structures with the aim of changing them. Both types of modeling involve the construction and transformation of information models. Both types of modeling involve manipulation of models' images. The image of a model is its visual or graphic representation. Model images in computer science are depicted using four basic graphic classes: point, linear, areal and volumetric. Therefore, structures in structural modeling can be point, linear, areal, volumetric and hypervolume. Point structures usually represent various fields, for example, the density field.

Not all elements of the formal structure are transferred to the structural model. This is due to the requirement to reduce the load on the visual channel of human perception of information. A figurative structure or graphic model sets the task of making the structural model informative. This problem is also currently being solved in different ways and has not been completely solved.

In topology, only linear images and descriptions are used. Therefore, topology methods do not cover the entire variety of structural modeling.

An example can be given from the field of geoinformatics. Many geographic information models have a cartographic (visual) form of representation, which has a structure. In this case, structural modeling manifests itself in two qualities: modeling the structure of a separate information object; modeling the stratified structure of a collection of related objects, which is called a cartographic composition.

In computer science there is a direction of structural modeling associated with the modeling of technological schemes and algorithm structures.

Figurative structural models have different geometric characteristics: length, width, type of object, coordinates of starting, ending and intermediate points. Spatial network models have topological characteristics: capacity, connectivity, proximity, risk level. In geoinformatics and computer science, the coordinate group of data is called metric, and the remaining data is called attribute.

Structural modeling uses spatial information relationships. Information structural modeling generates information resources, digital models (Nesterov, 2023), cognitive maps (Peer et al., 2021) and three-dimensional models.

ISM uses qualitative spatial reasoning to support structure modeling (Wallgrün, 2012). ISM in the spatial field forms spatial knowledge (Tsvetkov, 2015). ISM includes heuristic modeling, cognitive and simulation modeling

In many cases, ISM is a group simulation. It works not with individual models, but with a group of models that describe a figurative group situation.

Each structural model is organized dually. It has a figurative form of presentation. The image is stored in a special file.

The figurative form allows for a flat visual and three-dimensional representation of objects. Visual representation is related to cognitive modeling. The visual form of the model allows for cognitive analysis. Information structural modeling in the study of new phenomena includes the following types of stages:

- Analysis of the initial information set.
- Specifying the image space for constructing a structural model.
- Application of elements of structural reflection of reality. Most often these are point, linear, areal and volumetric elements
- Construction of accurate models in image space.
- Construction of linear models in image space. The unit of linear models is a straight line segment
- Construction of areal models in image space. The unit of areal models is the area element. Most often this is a pixel or tile.

Construction of three-dimensional models in image space. The unit of volumetric models is the volume element or voxel.

- Grouping of figurative models into layers.
- Define relationships between layers. Determining which layer is higher and which is lower.

Structural imagery modeling involves the application of set theory to evaluate the relationships between objects in different layers. The composition of figurative models is built according to the onomasiological principle (Bolbakov et al., 2022). The structure of figurative models is built on a semasiological principle (Glynn, 2015). The elements of the structure of models are different types of information units (Tsvetkov, 2014b).

Information structural model

The structure of information structural models has a special type of organization – a composition of parts and elements (information units). Structure is determined by the connections between parts and elements.

The information structure exists in the information field. In this field, the structure is the supporting information model. An information structure is often part of a complex information model. The information structural model has syntax and semantics. Syntax and semantics determine the laws of structure, behavior and content of the structural model.

An information structural model can be considered as a model of a complex system. The structural model simplifies the analysis, construction and verification of a complex system. There is an information correspondence between the components of a complex system and the information structural model. Connections are identified at the initial stage of structural modeling. An information structural model can have several formal descriptions: formal, set-theoretic, conceptual, functional, systemic, technological. The information structural model of a complex system is characterized by a number of features (Kader et al., 2020). Important features of the structural model are:

System functionality of the structure.

Local structure functionality

Subsidiarity of parts of the structure

Connectivity of parts of the structure

Stability of the structure. When several elements are removed from a structure, the structure retains its functionality.

The predominance of internal structural connections over external connections. This dominance sets the boundaries of the system.

Relative dependence of the structure of the system on its parts. This is the case for emergent structures.

Hierarchy of structure.

The information structure is not a new type of structure. It is built on the basis of known structures. The main basic types of structures are: hierarchical, network and matrix, network centric. Trinitarian structures are often used, which define complexity and are an element of a complex system. The most common is a hierarchical structure. One of the reasons for its popularity is the ease of human analysis.

The formation of a hierarchical structure in relation to geographic information modeling occurs as follows. The initial information set (M) is stratified and divided into levels (B). Vertical connections are established between the levels (C). The levels are detailed into horizontal parts (K). The structured set M* consists of levels.

$$M \to M^*(Bi, C)\ i=1\ldots n \quad (1)$$

$$Bi \cap Bj = \varnothing,\ j \neq I \quad (2)$$

$$Bi \subset M^* \quad (3)$$

$$Bi \to Bi^*(Ki1\ Kij\ Kim)\ j=1\ldots m \quad (4)$$

$$Ki1 \cap \ldots \cap Kij \cap Kim = \varnothing \quad (5)$$

$$Kij \subset Bi^*\ Kij \subset M^* \quad (6)$$

$$Bi^*1 \cap Bi^*j \cap Bi^*n = \varnothing \quad (7)$$

The implication in formula (1) means structuring. An asterisk indicates a structured component. Expression (1) says that the original set M is transformed (→) into a structured set M*, which consists of levels (B) and vertical connections between them (C). Expression (2) indicates that the levels do not intersect. Expression (3) suggests that the levels can be considered as subsets of the set M*. Expression (4) says that the area levels are transformed into structured levels (Bi*), containing horizontal parts (Ki). Expression (5) says that the horizontal parts of the levels do not intersect, that is, they are independent. Expression (6) suggests that the horizontal parts of the levels can be considered as subsets of levels and a subset of the structured set. Expression (7) indicates that the structured levels of the hierarchical system do not intersect.

Figure 1 shows the structural model of the hierarchical system. The figure shows the paradigmatic relationships that define vertical connections (C). They go vertically and set paradigmatic connections. There are connections between the levels. There are also connections between levels and their parts. There are no connections between the parts. There are only relationships between parts of levels. The connections are shown by lines; the relationships are not shown in Figure 1.

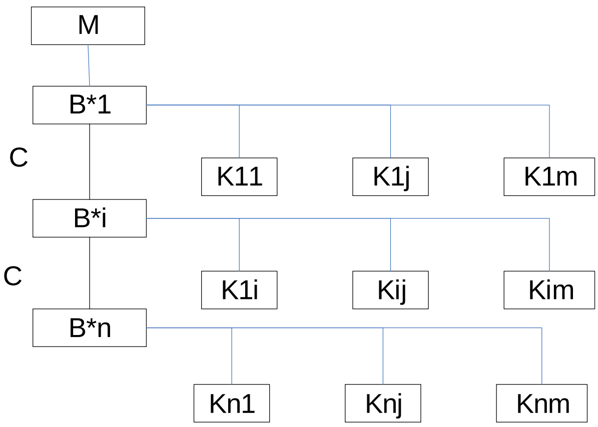

Fig. 1. Hierarchical information structure

Structural information modeling is performed using systems theory. Systematic studies of structures (Mesarovic, Takahara, 2006) lead to the need to develop a systemic mechanism for structural modeling. In a broad sense, structural modeling is based on topological methods, set theory, mathematical methods for describing nonlinear dynamic systems, simulation modeling, functional modeling, stratification methods, finite element method and others.

Structural modeling (Bentler, Chou, 1987) using the systems approach (SMUSA) is the main method for checking the correctness of the structure. SMUSA identifies cause-and-effect relationships between model units. SMUSA is concerned with systems, mathematical, simulation and functional modeling. SMUSA's objectives include:

- creating the object structure and its model;
- assessment of structural characteristics;
- modeling of information connections;
- modeling of timing characteristics.

The modeling trends at SMUSA are characterized by two types of modeling: structural modeling; functional modeling.

Purpose of SMUSA: construction and modification of structures of geographic information models, information processing processes, information storage systems, information processing systems and other systems. SMUSA includes the problem of optimizing structural connections.

Structural modeling using set theory

Structural modeling can be done using set theory. This method is simple, but is rarely used. The main reason is that it uses a cognitive and heuristic approach. Let's look at an example. Figure 2 shows the set M with the main subsets P, X, Y, Z, which form a complex configuration. Such a set can be called a complex set.

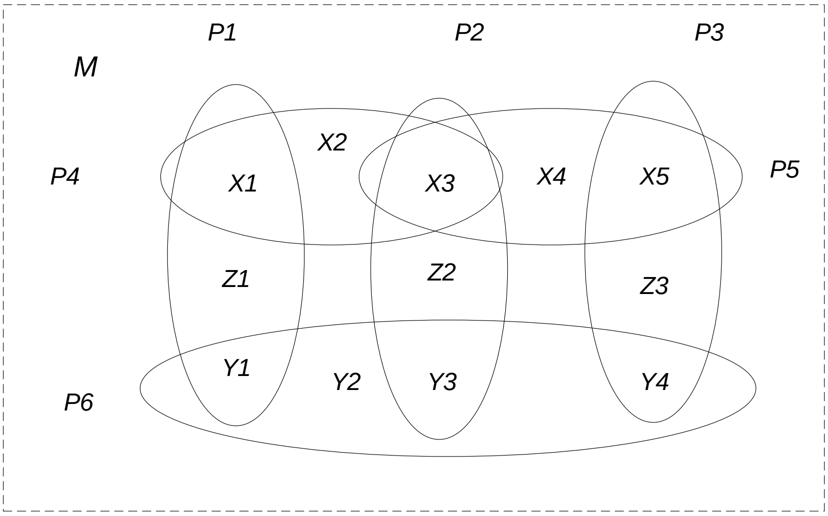

Fig. 2. Example of a complex set

Based on visual analysis and modeling, it is possible to transform the image in Figure 3 into a set of expressions. All subsets belong to the set.

$$P1 \subset M;\ P2 \subset M;\ P3 \subset M$$
$$P4 \subset M;\ P5 \subset M;\ P6 \subset M$$

A complex set is formed by combining subsets

$$M = P1 \cup P2 \cup P3 \cup P4 \cup P5 \cup P6.$$

The set M contains parts that are not included in the subsets P.

$$M \cap [P1 \cup P2 \cup P3 \cup P4 \cup P5 \cup P6] \neq \varnothing$$

Subsets do not intersect with each other

$$P1 \cap P2 = \varnothing;\ P2 \cap P3 = \varnothing$$
$$P4 \cap P6 = \varnothing;\ P5 \cap P6 = \varnothing$$

Subsets are formed as a union of parts X, Y, Z.

$$P1 = X1 \cup Y1 \cup Z1;\ P2 = X3 \cup Y3 \cup Z2;\ P3 = X5 \cup Z3 \cup Y5$$
$$P4 = X1 \cup X2 \cup X3;\ P5 = X3 \cup X4 \cup X5;\ P6 = Y1 \cup Y2 \cup Y3 \cup Y4$$

The parts are divided into two categories. Parts that are determined by direct transformations

$$X1 = P1 \cap P4;\ X3 = P2 \cap P4 \cap P5;\ X5 = H3 \cap H5$$
$$Y1 = P1 \cap P6;\ Y3 = P2 \cap P6;\ Y4 = P3 \cap P6$$

The second category of parts are those that are calculated using auxiliary constructions.

X2=P4-X1-X3; X4=P5-X3-X5; Y2=P6-Y1-Y3-Y4

Based on the calculations carried out, Figure 3 shows the structure of the system. The structure of a complex set is reduced to a hierarchical form, convenient for computer analysis

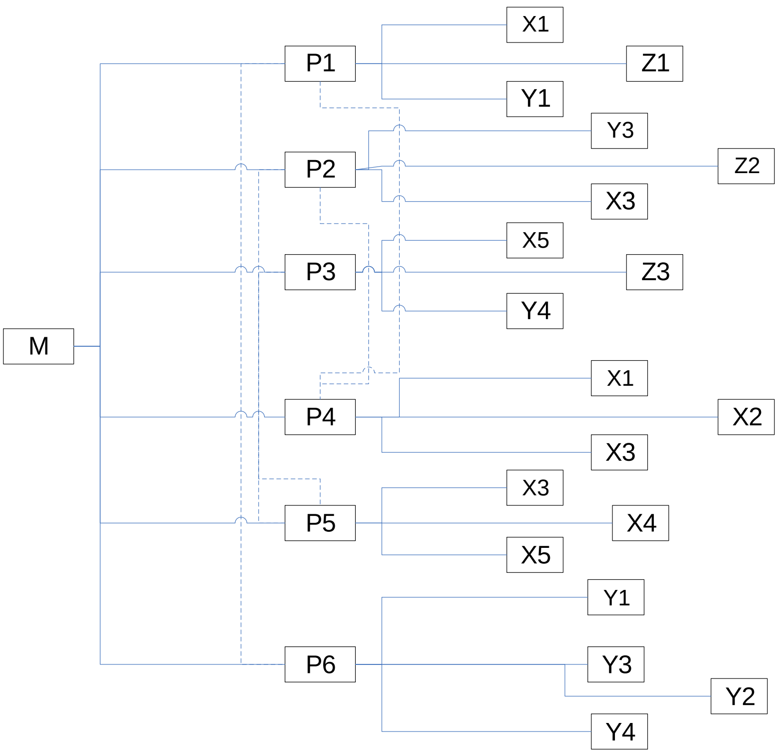

Fig. 3. Complex set structure

The structure of this model is hierarchical. The initial set of the system has a network structure. In a hierarchical system, connections exist only on the basis of paradigmatic constructions. In this system there are paradigmatic connections and syntagmatic connections. There are no syntagmatic connections in a hierarchical system. The model in Figure 3 is a decomposition of the original model in Figure 2. Structural modeling allows for decomposition.

3. Conclusion

Structural modeling in computer science is related to pattern modeling. Structural modeling leads to the construction of a structural model. The structural model is the result of structural modeling. Structural modeling uses images, connections and relationships. Connections are depicted explicitly, relationships are present implicitly. The main relations of the structural model are paradigmatic and syntagmatic relations. Syntagmatic relationships reflect the “width” of the structural model. Paradigmatic relationships determine the “depth” of the structure. When constructing the structure, dichotomous division is used. The general theory of structure construction has not yet been formed. In each application area, the structure is created using different methods. Methods for constructing a structure depend on the tasks of a given subject area and on the types of data used to solve problems. Structural modeling works with different types of data. Data images have four types: linear, areal, network and volumetric. Structural modeling uses a systems and set-theoretic approach. Structural modeling uses stratification when working with complex structures.

Information structural modeling has two forms: figurative and formal. There is always complete information correspondence between the formal structural model and the modeling object. There is a complete or partial information correspondence between the figurative structural model and the modeling object. This situation poses two problems in figurative structural modeling. The first task is to assess the information content of the structure image. This problem is also currently being solved in different ways. The second task is to choose a method for reducing a complex object into an image of a structural model. The construction of an information structural model uses: informational, figurative and functional characteristics. The systematic approach to structure formation is the main one in information structural modeling.

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