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## Articles

# A Decision Support Information System

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**Abstract**

The article explores a decision support information system. The information system is intended for the management of educational institutions within the Ministry of Education and Science of Russia. The information system is interpreted as a decision support system. The taxonomy of information systems in the field of education is given. The types of management technologies in the field of education are described. The difference between the main goals of commercial and public universities is shown. Management goals set the dynamics of management. A sectoral area has been identified, which is the prerogative of the Ministry of Education. The article describes one of the industry information systems created as part of the assignment of the Ministry of Education. It is designed as a specialized decision support information system with a special interface for ministry employees. The basis for the operation of such a system and its interface is information modeling. The need for additional use of GIS for the operation of such a system is shown. The use of GIS is due to the fact that universities form a geographically distributed system, for the management of which it is necessary to use spatial information. Spatial information is necessary when managing industrial property. The principles of operation of the system are described. The information system diagram is described. The application of information modeling for the operation of the system is shown, using the example of the "property map" geoinformation model. The results of the work are put into practice.

**Keywords:** management, decision support, information systems, information resources, information models, information technologies.

## 1. Introduction

Information systems perform a variety of functions. Information systems (IS) have a dual application. On the one hand, IS creates information resources for solving applied problems and managing any organization. Such IS are called resource IS. On the other hand, IS is a management tool and a management resource. Such IS are called managed. In modern conditions of big data (Deepa et al., 2022; Lyovin, Tsvetkov, 2017), large volumes of data and the presence of contradictory information in them require compression of information and the formation of not one management decision, but a set of complementary management decisions. ISs that compress information are called selective. ISs that make several control decisions and help select a decision

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based on the situation are called decision support systems (DSS) (Casal-Guisande et al., 2023). Having a big data problem requires the use of DSS.

The sectoral education system is a complex distributed system. The applications of IS in education are varied. In industry education, resource-based IS, managed IS, selective IS and DSS are used. Information systems that combine different information systems are called integrated information systems (IIS). Some IIS (Gonzálvez-Gallego et al., 2015) include DSS. At the industry management level, DSSs are integrated systems.

A distinctive feature of education management is corporate governance (Jiang, Kim, 2020) of universities. Therefore, IS in education is used within the framework of corporate industry management. IIS and DSS are used complementary to the processes of globalization of society and informatization of education (Tsvetkov, 2005a). IS in the field of education is used within the framework of the state strategy for informatization of education. Moreover, this position applies primarily to state universities. Commercial educational institutions have relative freedom to choose a strategy and financial independence. The set of goals they have is the same, but between commercial and public universities there is a difference in the main goals. The main goal of a public university is to provide good training to students. The main goal of a for-profit university is survival. A state university is part of the state unified university system. A commercial university is an autonomous entity in the education market. This difference sets a difference in the purposes of managing educational institutions. This difference determines the difference in the specialization of information systems that are used for management in universities. For public universities there is a special department, which is a sectoral department. Within the framework of sectoral management of higher education, private management policies of individual educational organizations are allowed within certain limits. But the general management for state universities is the management of industry-specific university real estate by the ministry as an independent object of management. Accordingly, specialized IIS and DSS are created for such management. This article is devoted to such information systems.

Specialization of university IP.

Informatization of higher education is part of the informatization of society. It represents a general trend in the development of higher education. Informatization in a broad sense (Tsvetkov, 2005a) is implemented through the use of IS and information technologies. Informatization in the narrow sense is implemented through the creation and use of specialized information systems.

Specialized IS is used by the teacher, by the student, by the Ministry of Science and Education, and by the university. On the part of the teacher, IS is used in teaching, in eliminating the information asymmetry of the student's knowledge, for developing practical skills, and for testing. On the student's part, IS is used for additional preparation, as a reference system, for self-testing, and for information search for educational information resources. On the part of the university administration, specialized IS are used to manage educational processes, to manage personnel, and to manage property within the framework allocated by the Ministry of Education. The university administration has the right to manipulate property within the framework of the standards of the Ministry of Science and Education and the laws of the Russian Federation. On the part of the Ministry of Education, IS is used to analyze educational statistics, for retrospective analysis of the activities of universities, to identify trends in training and for corporate management of industry property, to coordinate the actions of universities and the Ministry for property management. This gives grounds to talk about IS at different levels.

The tasks of information systems at different levels differ significantly. University information systems are aimed at teaching, managing educational processes as decision-making systems. Information within the university is more structured and formalized. Therefore, it is relatively easier to process. Information that is used comfort in the ministry is significantly larger in volume, more diverse and part of it contains uncertainty. The ministry's information systems are aimed at analytical activities and decision support. Therefore, at the ministry level, a decision support information system (DSS) is used. In practice, the DSS interface operates in two modes: the IS use mode and the manager consulting mode. In the ministry, decisions are made not individually, but collectively. This leads to the need to introduce elements of corporate governance into the DSS.

## 2. Results and discussion

### Features of management of state educational organizations

Management of organizations subordinate to the Ministry of Education of Russia is based on a management complex that uses management theory taking into account the characteristics of state educational organizations and the availability of information educational space (Eliseeva et al., 2016).

Information educational space is a feature of education management. It can be sectoral and within a separate university. The second feature of state educational organizations in Russia and educational organizations in other countries is that they belong to the social sphere. It follows from this that educational organizations (in all countries) are subsidized. Consequently, public educational organizations cannot be compared or equated with commercial, profitable organizations. The social orientation of state educational organizations requires the use of different criteria to assess their effectiveness than for assessing the effectiveness of commercial firms. The first criterion suggests itself – eliminating the shortage of personnel in sectors of the national economy. The second criterion may be the performance of graduates in the form of scientific and technical developments accepted for implementation. But so far such criteria are not applied.

State educational organizations create labor and intellectual resources, without which any state will not be able to develop. Unfortunately, to date, no methods have been created in the field of economic development to assess the effectiveness of educational organizations. Many methods for assessing the effectiveness of educational organizations use a cost approach rather than a resource approach.

In fact, the management of educational organizations is aimed at meeting the information needs of the state to create qualified specialists and the information needs of the population for educational services. The state is both a consumer of the Ministry of Education's products and an organizer of the education system. The key parameters for managing an educational organization and the entire education system are the need for education of the population and the state's needs for human resources.

The interest of the consumer of educational services is aimed at obtaining qualified specialists. Interest on the part of the educational organization is aimed at sustainability, economic survival and enhancing the brand of the educational organization. Currently, consumers of educational services (organizations in sectors of the national economy) cannot directly influence the sustainability and economic survival of educational organizations. Such influence occurs only through the Ministry of Education and Science.

Economic interest on the part of the Ministry of Education and Science is aimed at balancing the costs of education and the production of qualified specialists. Organizational interest on the part of the Ministry of Education is aimed at creating a self-developing education system and self-developing educational institutions. Management of educational organizations is one of the forms of education management.

Modern management of educational organizations relies on information support. Information technologies have changed the management mechanism of educational organizations towards their digitalization. Information support for education management within the Ministry of Education is characterized by an increase in the volume of information, which reflects the problem of big data and the need to take it into account in management. Technologies for managing educational organizations use classical management technologies (Schonwalder et al., 2003) and special educational management technologies (Bhaskar et al., 2020). Educational management uses spatial planning and even geoinformatics methods. The increasing complexity of management within an industry is driving the use of multi-criteria analysis (Dean, 2020) for management. Modern management models include consideration of sustainability criteria. Three factors are considered key indicators of sustainability: environmental, economic and social. A systematic approach to managing the education system leads to the need to use models of complex organizational and technical systems (Zilberova et al., 2020) as a basis for managing universities.

### DSS in the field of education.

DSS are systems that combine models of spatial control, situational control, known decision-making methods and decision generation models. Decision generation models include precise mathematical models and reasoning methods based on expert knowledge. IS PPR from the standpoint of system analysis can be determined by the set:

$$DSS = < EO, M(EO), F(EO), CC, T, F(DSS) >, \quad (1)$$

In expression (1) DSS is a decision support system; EO = {EO1, EO2, ... , EOn} – a set of educational institutions in parametric form or a descriptive form of educational institutions; M(EO) – a generalized model of an educational institution as a connected integral set of parameters used for management; F(EO) = {F (EOi),..., F (EOn)} – set of functions for managing educational objects; CC – control conditions, T – control tasks; F(DSS) – DSS system modification function. This component is responsible for the self-development of IS PPR and makes it an adaptive self-improving system

The generation of solutions within a specific EO model is supported by models and inference rules. The transition from one solution to another is motivated by a violation of the control conditions of the SS. The transition is carried out by reacting to the corresponding change in the condition parameter.

The main task of DSS is to help the staff of the Ministry of Education to maintain balance in the education system and support the educational institution to function in a planned (regular) state. The control process has a simple form.

$$(CC \wedge T) \rightarrow DSS \rightarrow R \quad (2)$$

In expression (2) SS control conditions; T – control problems; R – actual control result. The effectiveness of management is assessed based on the actual results.

The DSS framework includes the following components: a corporate governance interface for ministry employees; consulting interface, which includes information and human resources represented by consultants. Decision-making uses Federal databases and Federal information systems, such as the cadastral system or the national property management system, the national fiscal system, all-Russian statistics and others.

Decision-making uses databases of the Ministry of Education, which store educational statistics by year and educational programs. The DSS itself includes a geographic information system as a mandatory component. Educational management is spatial, so the use of GIS and geoinformatics is mandatory. Educational management is spatial, therefore it is necessary to apply methods of spatial economics (Tsvetkov, 2013). Management uses current regulatory documentation at the Federal and industry levels. Control actions change the reporting parameters of an educational institution. As follows from the diagram, the control is multiple. That is, not one object is managed, but many objects of the education system, including educational institutions and auxiliary institutions. Of particular importance is the management of the property complex of the education system.

Information modeling in management

Information modeling (Cheng, 2016) is a fundamental method of cognition and a means of solving many applied problems. Information modeling is the basis for the formation of information resources (Tsvetkov, 2005b) for the tasks of education and management. Information models for management support, which served as the basis for the formation of management modules in IS PPR, are given as follows: information model "property card"; information procedural model "support for coordination of lease and gratuitous use"; information model "accessibility of facilities of organizations subordinate to the Ministry of Education and Science of Russia for people with limited mobility"; information procedural model "use of real estate" information descriptive model "easement"; information procedural model "administration of the receipt of part of the profit into the federal budget after paying taxes and other obligatory payments; information procedural model "state assessment", information model "inspection reports"; information procedural model "agenda formation"; information procedural model "coordination of write-off of federal property." During the preparation of reports of more than 1500 pages, many information models were described. Therefore, it is impossible to describe even part of the models within one article.

As an example, consider the "Property Map" information model. This is a visual spatial model that is created using geoinformatics methods. The model is created using GIS tools and is an electronic thematic map generated using a geographic information system and web technologies. Property map is an interactive web map of the complex of organizations subordinate to the Ministry of Education and Science of Russia, which includes all educational organizations. These organizations are presented on the map as real estate objects and land plots owned by subordinate organizations.

The property map information model acts as one of the tools of the functional module "Management of educational objects", and is also a tool for obtaining information on objects of the property complex in other functional modules. This model serves as the basis for constructing an algorithm and creating the "Property Management" functional module. The "Property Management" functional module is the main tool for drawing up a map. Data on objects of the property complex are entered into the system by employees of subordinate organizations with the formation of an up-to-date database on the property complex

When you launch the "Property Management" functional module and select the "Map" section, an overview map of Russia is loaded (Figure 1) with icons placed on it that integrate educational objects with digital symbols. The numbers indicate the total number of objects per given unit of area.

**Fig. 1.** Property card

Scaling the map entails scaling the integrating icons by dividing the overall integrating icon into a group of icons, displaying the number of objects corresponding to the icon per given unit of area. In order to increase the clarity and readability of the map, different colors are used to indicate icons displaying a certain number of real estate objects on the map: the red color of the icon means the number of objects per unit area greater than 100, the yellow color of the icon means the number of objects per unit area from 10 to 100 green – the number of objects per unit area up to 10.

With a further increase in scale with the transition to the map scale, at which individual buildings of objects of educational organizations are displayed, the integrating icons with the number of objects are replaced on the map with separate markers - icons indicating individual objects. The electronic map provides general information on objects indicating their number:

1. Cultural heritage sites, land plots;
2. Objects registered with the state cadastral register; objects in respect of which the ownership of the Russian Federation has been registered; Objects registered in the register of the Russian Federation;
3. Organizations with capital construction projects: educational schools, educational institutions of secondary vocational education, preschool educational institutions, educational institutions of additional vocational education, scientific institutions, government institutions, other organizations, higher education, unitary enterprises, cultural institutions

The "Property Map" model within the framework of the "Property Management" functional module is implemented as an independent interactive tool, with the ability to view data on real estate objects and land plots of subordinate organizations with their geographic location. The property map has been successfully integrated into various sections of the IAS "Monitoring" related to objects of the property complex, visualizing their spatial localization and allowing to obtain additional information on objects (rent, free use, assignment and redistribution of property, unfinished construction objects, etc.) with ensuring transition to the object page. The main purpose of the model is visualization of the state and integration of different types of information into a form convenient for decision-making. The model is associated with numerous reference books and makes it possible to obtain extensive reference information.

## 3. Conclusion

The management of educational organizations uses a complex of technologies and systems. Along with the general principles of managing organizations in the field of education, the social component is important. The social component is more important than commercial benefits. Factors of the social component can be taken into account during expert assessment. Therefore, only decision support systems that allow alternative management options are applicable for education. The decision support information system is not rigid and deterministic. It is adaptive and self-developing (Gural, 2014). Such a system is the core of a complex organizational and technical system that has proven itself in managing complex corporations and organizations. The decision support information system is the basis of situational centers. Its main advantage is the combination of human intelligence and experience with computer analysis and processing. This work was carried out within the framework of a state assignment on the completed topic "Methodological and information and consulting support for processes of increasing the management efficiency of organizations subordinate to the Ministry of Education and Science of Russia." The results of this work made it possible to systematize information about educational institutions and build models based on it. The models made it possible to improve the analysis of information, highlighting it at different levels of management. All this together has facilitated the work of the ministry and increased the reliability of decisions made.

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# Ontological Models of Information Retrieval

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**Abstract**

The article explores ontological models. A special type of models is considered. related to information retrieval. The ontological model of information retrieval is a specific model. The information design model is the closest model to an ontological model from a number of information models. The ontological model of information retrieval is generalized and allows for information uncertainty. The connection between the semantic model and the ontological model is shown. The semantic model of information retrieval complements the ontological model. Semantic proximity is a mandatory component of the ontological model. The article describes three methods for forming ontological models in information retrieval: indicator method, probabilistic method, fuzzy method. It is shown that logical weight is only an indicator and a qualitative characteristic, while probabilistic weight is a quantitative indicator. The article introduces several types of weighting coefficients for ontological models in information retrieval. The article introduces the definition of an ontological model of information retrieval. Three key indicators of the ontological model are described. It is shown that the user's information needs in many cases are unclear, uncertain and depend on the individual characteristics of the user. The article introduces the concept of ontological proximity. The article shows the difference between contextual metadata and contextual metamodels. The article introduces the concept of direct and contextual information resource in information retrieval. The difference between these resources is shown. The contextual information resource is associated with the ontological model. The types of relationships for direct and contextual search results are shown. The principles of forming a semantic proximity graph, which is used in ontological models, are described.

**Keywords:** information set, morphological search, semantic search, ontological search, content.

## 1. Introduction

The term “ontological models” is widely used in different directions. One of these areas is information retrieval (Kurdukov, 2023; Vallet et al., 2005). Ontological models mainly use formal descriptions. Semantic Web, which uses ontological models, is used to search networks. The Semantic Web (Hitzler, 2021) uses a number of specialized languages: RDF Schema, Ontology Web Language, Resource Description Framework and others. Widespread work is being done to create tools for working with ontological models. All this emphasizes the relevance of the study of ontological models. In many works on the research and application of ontologies, the concept of

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ontology is given vaguely. Ontology in computer science is significantly different from ontology in philosophy. Conceptually they are the same. But morphologically they differ. Let us recall that ontology (Guarino et al., 2009) is usually called a formal conceptual description of a field of knowledge. Such a schema typically includes data structures, object classes, relationships and connections, rules and theorems, restrictions) adopted in this area. Ontologies are used in design and modeling. In the information field, ontology is a form of representing knowledge about reality. However, in practice, especially in the field of programming, ontology is reduced to private information or other models. The concept of universality disappears for such models. However, we can talk about a mature ontological approach (Falbo et al., 2002). This information retrieval approach uses the following concepts: semantic environment (Tsvetkov, 2014a), semantic proximity (Gadasin et al., 2022), ontological model, formal logic, semantic frames, semantic classification, intelligent annotation, semantic graph, hyper spatial analogue of language, latent semantic analysis, information-cognitive semantics (Tsvetkov, 2016) and others.

## 2. Results and discussion

### Features of the formation of ontological models

Methodologically, there are three approaches to the formation of ontological models: indicator or logical, probabilistic, fuzzy.

The indicator or logical approach to the formation of ontological models is based on the use of formal logic. He uses the concept of a logical predicate. The "disadvantage" in this approach is that it uses boolean variables. Logical variables have two oppositional values 0 and 1. As an indication of the presence or absence of an ontology, this approach makes sense. It is not suitable as a tool for describing ontology because it simplifies reality. For example, a picture of reality (image) can be described using black and white pixels. She will be rude. This picture corresponds to a binary black and white image. If you use gray halftones, you can get a gray halftone image. This is a more accurate depiction of reality. If you use colors and saturation, you can get a color photo that most accurately conveys the image of reality. A logical description using two values 0 and 1 is a black and white image of reality. This description is quite suitable for programming and computing, but is not suitable for describing the picture of the world (Heidegger, 1977; Tsvetkov, 2014b, Lazier; 2011).

The probabilistic approach to the formation of ontological models is based on the use of probability theory and is analogous to the formation of a halftone and color image of reality

The fuzzy approach to the formation of ontological models is based on taking into account fuzziness in the initial situation and the application of the theory of fuzzy sets. Its analogue is a photograph of a moving object with a blurred image. An example of the logical approach can be demonstrated with an example. The ontological model, denoted O, is given as a – tuple model

$$O= < C, P, I, L, T> \quad (1)$$

the parameters of model (1) are interpreted as follows: C – set of concepts; P – set of properties. Properties are expressed by two-place or one-place predicates. More precisely, a property is a one-place predicate, and a two-place predicate is a relation. However, a relation can be thought of as a property. Parameter I is a set of concept instances. The parameter L is a set of concept values and property values. The parameter T specifies the order on C and P. For the indication case, integer values of the weights are introduced (Tsvetkov, 2014c).

In accordance with parameter I, the semantic weight p is introduced. Semantic weight $p \in [0, 1]$ specifies the semantic proximity for the subject and object of the statement (relationship). This is where indicator properties appear. A boolean variable has the value 0 or 1 and has no values in between. Therefore, this approach suggests that intimacy either exists or does not exist. This model does not evaluate the degree or level of closeness. Analysis of this example shows a typical error in the use of logical values. Logical variables do not give the degree or level of strength of connections, but only state their presence or absence.

In our opinion, this drawback is eliminated by the probabilistic model. The weight in which has many values on the real interval [0-1], including the boundaries of the interval. In this model, two qualitative logical values “yes”, “no” are replaced by a set of quantitative values from the interval [0-1]. The quantitative value characterizes the closeness of belonging as it approaches one and the weakness of the connection as it approaches 0.

**Probabilistic ontology model**

To eliminate the shortcomings of the logical model, we propose an ontological model (OM), similar in structure to model (1)

OM <T, P (Re, Pr), MMT, SPV, Or >, (2)

In expression (2) T is a set of terms (signs); P – set of predicates (Re – relations, Pr – properties); MMT - set of meanings of terms; SPV – set of property values; Or is a partial order on the set T and P.

Using a set of predicates P, ontologies can describe various relationships between terms, their meanings and properties. Relationships are defined using simple statements

{s, Re, o*} (3).

In expression (3) s is the subject of the statement, o* is the object of the statement,

Re ∊ P is a predicate of the OM ontology. Let us define a set of characteristic weights.

Any property Pr ∊ P can be given a probabilistic morphological weight pm ∊ [0, 1], which specifies the morphological proximity between the subject and object of the statement. For pm = 1 – there is a complete morphological correspondence, for pm =0 there is a complete morphological discrepancy

Let us introduce the concept of a set of information search results RIR. r is a private search result, pat is a search query.

Pat→r (4)

Expression (judgment) (4) means that the request entails the appearance of a particular result of the request. We believe that any result of an information search r ∊ RIR can be given an interpretative weight rv ∊ [0, 1], which specifies the interpretive proximity between the request and the interpretation of the search result. For rv =1, the request and the result of the information search are fully interpretable. When rv =0, the result of the information search is completely uninterpretable. When rv = 0.5, the result of the information search is half interpreted.

We believe that any result of an information search r ∊ RIR can be given an information weight ri ∊ [0, 1], which specifies the probabilistic proximity between the information need (IN) and the search result. For ri = 1, the result fully satisfies the information need. This is a state of persistence. When ri =0 , the result does not completely satisfy the information need. This is a state of uncertainty. When ri = 0.5, the result of the information search satisfies the information need by half. You can conditionally estimate ri = 0.55 – there is formal relevance, ri = 0.8 – relevance.

The pattern can be formed as a set of terms, as a compound predicate, or as a certain semantic function of the values pat = sf (e). Since patterns are compiled by different people, for the same information need they can differ due to the cognitive and intellectual factors of the individual.

Any information search pattern pat ∊ T can be given a search weight pati ∊ [0, 1], which specifies the proximity between the information need and the pattern. For pati = 1, the pattern fully corresponds to the information need. For pati = 0.8, the pattern partially corresponds to the information need. For pati < 0.5, the pattern does not correspond to the information need. Here we can draw a parallel with correlative analysis

**Features of the ontological model**

Let us define the ontological model of information retrieval as the conceptual correspondence of search results to the semantic information needs of the user. It is advisable to analyze the features of this model.

The key indicator of the ontological model is the parameter "user information needs" (UIN or IN). By its formal name, IN is an information characteristic. The conditions for the formation of IN are associated with three factors:

information uncertainty (IU) (Ferracuti, 2022) in which the user finds himself;

user intelligence (individual's intelligence – II) (Wang et al., 2011);

user cognitive resources (cognitive resource – CR) (Christensen et al., 2020).

In fact, IN is informational and cognitive needs. Sometimes information search, especially in scientific research, is carried out using intuition. Intuition is characterized by information uncertainty and vaguely expressed formalism. It follows that the user's information needs in many cases are unclear, uncertain and depend on the individual characteristics of the user.

The second key indicator of the ontological model is the "conceptual correspondence" (CC) parameter. Conceptual correspondence is a generalized characteristic that allows for multiple interpretations. The basis for checking the truth of conceptual correspondence is comparative analysis. Conceptual correspondence is agreement on the most important parameters and inconsistency on less important parameters. Conceptual correspondence is always not a complete parametric correspondence.

The third key indicator of the ontological model is the "semantic needs" (SS) parameter (Veksler et al., 2007). This parameter is introduced as an alternative to morphological matching. The same form does not mean the same content. The same words can have different meanings. The content of the search is more important. than the form of presentation. The form of representation can be: a constant (yes/no, correct/incorrect), a relation (including modal relations), an analytical formula, a rule. output or table. It is not the form of presentation that is important, but the content of the model in relation to the user's request. Ontological needs are more general than semantic needs.

The search result contains information models and information resources. Let's call a direct information resource a resource described by a direct interpretation. A direct resource is created by the relationship between the parameters of the request property (a) and the result property (b)

$$\{a, Re, b\} \ (5).$$

For example:

$$a=b \ (6);$$

$$a \approx b; \ (7)$$

$$a \neq b \ (8).$$

Expressions (6), (7), (8) hold for formal parameters and for parameter values. Formal parameters are important for ontology. Parameter values are important for semantics. Expressions (6), (7), (8) are the most important relationships for evaluating search results. A model that consists only of properties and their values is parametric. If most of the search result parameters correspond to relations (6), (7), then such a result is relevant for the parametric model. Relation (7) characterizes the state of uncertainty. If most of the search result parameters correspond to relations (8), then such a result is not relevant.

An alternative to the direct resource and direct model is the context resource and context model. A model that consists only of relationships. is contextual. A model that consists of relationships and parameters is called mixed. Let's call it a contextual information resource, a resource described by statements.

$$\{ra, Re, b\} \ (9).$$

In expression (9) ra is the subject of the statement, b is the object of the statement, $Re \in P$ is a predicate of the ontology OM. Let's call a context metamodel a set of statements. As a rule, this is a postfix metamodel (Tsvetkov et al., 2020)

$$MMk= \{ti=< ra, Rei, bi>\}, \ (10)$$

where i=1 n – number of relations

$$b \in T \cup MMT \cup SPV \ (11)$$

An example of a simple relationship is

$$a=d; a=10; a>c; a<H; a \approx k. \ (12)$$

RIR contextual metadata is a set of weighted interpretations

$$Md= \{ti=< ra, Rei, bi, wi>\}, \ (13)$$

In expression (13) w is the weight. The difference between (10) and (13) is that in the first case the formal parameters are studied, in the second the values of the parameters. Ontological proximity is associated with semantic proximity, with interpretive proximity. The ontological similarity of the parameters is assessed by relations (6) (7). Let L1 be the number of parameters corresponding to relations (6) (7), and L2 be the number of parameters corresponding to relations (8), If

$$L1>L2 \ (14)$$

Then there is ontological similarity in parameters. Semantic proximity (semantic similarity) is determined by attributive characteristics Pr and contextual characteristics Re.

Let Sim(a, в) be the semantic proximity between (elements, resources)

a and b, where $a, b \in T \cup MMT \cup P$.

One method for calculating Sim(a, b) is based on graph theory. This method involves constructing an undirected graph SG from all relations (10), (13). The graph SG is formed in accordance with the principles:

use relations that have weighting coefficients other than zero ($w \in 0$);

the graph has subjects and objects of relations as vertices, and the edges of the graph are relations. The edges have weights w;

the graph admits an inverse relation, which replaces one relation and not two auxiliary ones;

the graph admits a symmetric relation that adds two edges with equal weights to the graph.

the graph has a route or PATH (a, b) as a set of edges connecting vertices a and b, taking into account their direction.

Semantic proximity is calculated as the optimal PATH (a, b).

In this case, the value Sim(a, b) between these vertices is calculated as:

$$Sim\ (a, b) = \min\ (Sim_{PATH}\ (a, b)),(15)$$

The value of semantic proximity is determined by the formula:

$$Sim_{PATH}\ (a, b)= \prod_{i=1}^{n} w\ (16)$$

Thus, the calculation of weights determines semantic proximity. Semantic proximity allows us to assess ontological proximity. However, these concepts are not equivalent. An ontology is a conceptual model and aims to use qualitative features and categories. The semantic model uses quantitative estimates of parameters.

## 3. Conclusion

The ontological model of information retrieval is a special model, unlike most information parametric models. Of the information models, the model of information design is closest to her. The ontological model includes a double environment – ontological and semantic. The ontological model primarily includes qualitative assessments and secondarily quantitative ones. The semantic model first of all includes quantitative estimates of parameter values and secondly qualitative ones. The semantic model works primarily with meanings. Ontological works with the qualities of features and meanings. The ontological model of information retrieval uses semantic proximity and complements it with ontological proximity. Semantic proximity is determined by parameter values. Ontological proximity is determined by qualitative characteristics. Currently, most ontologies are based on semantics. Therefore, information retrieval is actually about semantic correspondence rather than ontological correspondence. In our opinion, reducing the search for ontologies to semantic proximity is a narrowing of the concept of ontology. In our opinion, a promising direction for constructing ontological models of information search is correspondence theory (Bode et al., 2020).

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# Dichotomous Analysis

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**Abstract**

The article explores little-studied dichotomous analysis. Dichotomous analysis is used in practice to solve many problems. However, to date there has been little research into the theory of dichotomous analysis as a special type of analysis. Dichotomous analysis includes three stages: decomposition of reality, composition of models and study of the resulting models. Decomposition is implemented using dichotomous division. Three types of dichotomous division are described, which produce three types of division results. Dichotomous analysis has different implementations. Dichotomous analysis is divided into: oppositional, aggregative, elemental. Elemental dichotomous analysis is performed using onomasiological division. Onomasiological division allows us to obtain information units or elements of the system under study. The article explores three types of dichotomous decomposition: decomposition to the selection of only parts or elements; decomposition to the selection of parts and constructive connections between them, decomposition to the selection of parts and causal connections between them. The content of the levels of dichotomous division is revealed. A formalization of the dichotomous composition is given. The relationships between the objects of decomposition in dichotomous analysis are described. A structural diagram of dichotomous decomposition is presented. Dichotomous decomposition does not apply to all objects, but only to those that have the property of separation. The dichotomy can be interpreted as a property and as a method. To describe multi-level decomposition, we use the apparatus of tensor algebra. In dichotomous decomposition and composition, paradigmatic and syntagmatic relations are used. The article describes the mechanism for searching for connections in dichotomous decomposition. The Bradford Hill model was used for this purpose. This model is transferred from the field of medicine to the field of information field.

**Keywords:** analysis, dichotomous analysis, dichotomy, decomposition, composition, information.

## 1. Introduction

Dichotomous analysis includes three stages: decomposition of reality, composition of models and study of the resulting models. Dichotomous decomposition uses different types of division: oppositional division, dichotomous (aggregative) division and onomasiological division. Oppositional division is a special case of dichotomous division. Onomasiological division is more detailed than dichotomous division. Dichotomous division (Deshko, Tsvetkov, 2023) occurs to parts or elements according to the task. Onomasiological division is performed up to elements or information units. Division is the first step prior to analysis.

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Dichotomous analysis (Tsvetkov, 2014a; Tsvetkov, 2014b) uses primarily a qualitative approach and secondarily qualitative and quantitative approaches. In dichotomous analysis, dichotomous variables are used. Dichotomous variables are a generalized concept. Dichotomous variables are obtained by oppositional division (Deshko, Tsvetkov, 2021) (variables 1); with onomasiological division (variables 3) and with dichotomous division (variables 2).

Dichotomous variables are the basis of dichotomous analysis because they are the basis for forming models and putting forward hypotheses. Dichotomous analysis can be defined as analysis. based on obtaining and applying dichotomous variables. The initial material for division is the information set in the information field.

Dichotomous analysis can be divided into oppositional (dichotomy 1), aggregative (dichotomy 2), elemental (dichotomy 3). Opposition analysis uses opposition variables. Aggregate analysis uses aggregates or parts obtained by division. Elemental analysis uses elements (variables 3) obtained by division (dichotomy 3).

Variables 3 are formed on the basis of onomasiological division (Bolbakov et al., 2022) from the original information set. Variables 3 can be called onomasiological information units (Ozhereleva, 2014; Tsvetkov, 2014c).

The first stage of dichotomous analysis or dichotomous division is based on detail. Detailing is carried out using qualitative and quantitative analysis. detailing is complemented by modeling. This modeling uses features of similarities and differences (Zaphiris, Sarwar, 2006).

There is a difference between dichotomy 2 and dichotomy 3. The difference is that dichotomy 2 can occur as a one-time process. This process can be interrupted at any stage. The degree of detail of an object is subjective. Dichotomy 3 is carried out in stages until the division ends in indivisible elements or information units. Dichotomy 3 identifies relationships, of which the most important are cause-and-effect relationships. Cause-and-effect relationships are logically described through implicative relations. They can be expressed either by logical following (Etchemendy, 1988; Shapiro, 2011) or by a logical chain (Perdicoúlis et al., 2016; Deshko, Tsvetkov, 2022). Cause-effect relationships are used in information and geoinformation technologies for decision-making (Tsvetkov, 2019)

## 2. Discussion and results

### Features of dichotomy 3.

Dichotomy 3 is based on onomasiological division (Bolbakov et al., 2022). Onomasiological division is based on cognitive clustering, mathematical clustering or qualitative comparison of similarities/differences. Onomasiological division involves the identification of clusters and parts and the subsequent division of these parts until indivisible elements are obtained. Onomasiological division differs into three types.

1. Division until indivisible elements is obtained.
2. Division to elements with finding connections between parts and elements.
3. Division to elements, with finding connections between parts and elements and highlighting cause-and-effect relationships.

Type 1 division is called simple or "object" division. It is similar to breaking down a pile of bricks into individual bricks.

Type 2 division is called bonded division or "linked division". It is more complex compared to the division of the first type. It is similar to disassembling a mosaic painting into pieces for its restoration and subsequent restoration. Type 3 division is called cause-and-effect division. This division is the most complex, it is called the “causal-related” division. An example is the analysis of traffic flow in a metropolis and identifying the causes of traffic delays.

Dichotomy 3 uses the division procedure (Deshko, Tsvetkov, 2023) several times. Division is completed when indivisible elements are obtained. Indivisible elements in the information field are information units. Dichotomy 3 ends with the receipt of information units.

In the information sphere, the source material of dichotomy 3 is the information set. The initial onomasiological division is performed according to qualitative criteria (Kozlov, 2018). Qualitative analysis is the main method of division. In the final division, comparative analysis and the information correspondence method are used. By dividing different parts, similar objects or elements can be obtained. such similarities are revealed on the basis of comparative analysis. Comparative analysis is carried out using generalized and particular models, that is, at all levels of division.

Once the division is complete, the second part of the dichotomous analysis begins: generalization. comparison and modeling. The main tool for generalization and comparison is metamodeling (Tsvetkov i dr., 2020; Rogov, 2021; Tsvetkov et al., 2020). Metamodeling can be considered as ontological modeling. Comparison is performed by parameters, by connections, by a combination of connections and parameters, and by objects. In addition, comparative analysis is performed based on the states of objects. "Cause-and-effect" analysis is performed using correlative relationships (Tsvetkov, 2012). Comparative analysis of states uses the method to compare the current state of an object with the previous state.

Comparative analysis is essentially dichotomous. It performs pairwise comparison of features of compared objects or pairwise comparison of features of one object in different states. The identified similarity/difference serves as a basis for the presence/absence of a connection or pattern. Similarity/difference detection can be applied to a collection of objects. The presence of similarities provides grounds for combining objects into a group. Deep comparative analysis allows you to identify indirect connections or dependencies. Information comparative analysis uses information models. Primary comparative analysis is carried out upon receipt of primary fact-fixing models.

**Parameters for dichotomous analysis.**

Let us introduce the concept of information set (IS) and division object (O). Dichotomous division is multi-level. At the first level, the division object is divided into parts of the first level (DV1, DV2,... DVn) here n1 is the number of division objects (parts) at the first level.

$$DV1 \vee DV2 \vee \ldots \vee DVn1 = 1 \quad (1)$$

Any subsequent level is also subject to division. For example, the first level object DV1 can be divided into parts: DV11, DV12, ... DV1n1. here n2 is the number of division parts of object DV1 at the second level. For them there is a logical expression

$$DV11 \vee DV12 \vee \ldots \vee DV1n2 = 1 \quad (2)$$

To divide the DV11 object at the third level, you can enter a designation using small characters. The parts of the DV11 object can be the following: Dv, Dv2, ... Dvn3. For them there is a logical expression

$$Dv1 \vee Dv2 \vee \ldots \vee Dvn3 = 1 \quad (3)$$

In expression (3), n3 is the number of parts of the DV11 object. To divide the Dv1 object at the fourth level, you can enter a designation for the parts in the form of double numbers. Object Dv1 will have parts $Dv11 \vee Dv12 \vee \ldots \vee Dv1n4$. Object Dv2 will have parts $Dv21 \vee Dv22 \vee \ldots \vee Dv2m4$. Here n4 is the number of parts at the fourth level of object Dv1; m4 – number of parts at the fourth level of object Dv2. For them there is a logical expression

$$Dv11 \vee Dv12 \vee \ldots \vee Dv1n3 = 1 \quad (4)$$

$$Dv12 \vee Dv22 \vee \ldots \vee Dv2m4 = 1 \quad (5)$$

In expressions (4), (5) n4 is the number of parts of the object Dv1; m4 – number of parts of object Dv2. You can apply set-theoretic relations to the analysis of dichotomous parameters. Expressions (1)-(5) are conditions for the integrity of the dichotomous division. They can also be called integrity relationships. The relation of integrity in a dichotomous division means that the parts of the division of the same level in the aggregate represent an integral object. The object of dichotomous division can be an object of reality, an applied system (Demyanov, 2013; Tsvetkov, 2005), a model, a phenomenon.

Along with the relations of integrity for dichotomous parameters or parts of division, there are relations of belonging. For the first level, the relation holds.

$$(DV1, DV2, \ldots DVn1) \in O \quad (6)$$

For the second level there are relations

$$(DV11, DV12, \ldots DV1m1) \in DV1 \quad (7)$$

$$(DV21, DV22, \ldots DV2m12) \in DV2 \quad (8)$$

$$(DV31, DV32, \ldots DV3m13) \in DV3 \quad (9)$$

$$(DV41, DV42, \ldots DV4m14) \in DV4 \quad (10)$$

$$(DVm11, DVm12, \ldots DVm1mm1) \in DVn2 \quad (11)$$

For the third level there are relations

$$(Dv11, Dv12, \ldots Dv1m21) \in DV11 \quad (12)$$

(Dv21, Dv22, ... Dv2m22)∈DV12 (13)
(Dv31, Dv32, ... Dv3m22)∈DV13 (14)
(Dvm11, Dvm12, ... Dvm1m2m1)∈DVm1 (15)

Dichotomous parameters are not limited and can have any finite number, the number of which is determined by the division criterion. The number of dichotomous parameters of one level can be arbitrary and varies depending on the analysis criterion and the division criterion.

Dichotomous parameters of the same level are related by the inequality relation.

DV1≠ DV2; DV11 ≠ DV12; Dv11 ≠ Dv12 (16)

Dichotomous parameters of different levels are also related by the inequality relation.

DV1≠ DV11; DV2≠ DV12; Dv11 ≠ DV11 (17)

The inequality relation is not strict and binding. You may find that some parts are similar and some are the same. The main thing is the attitude of integrity and belonging. The particular structure of the dichotomous and onomasiological division is shown in Figure 1.

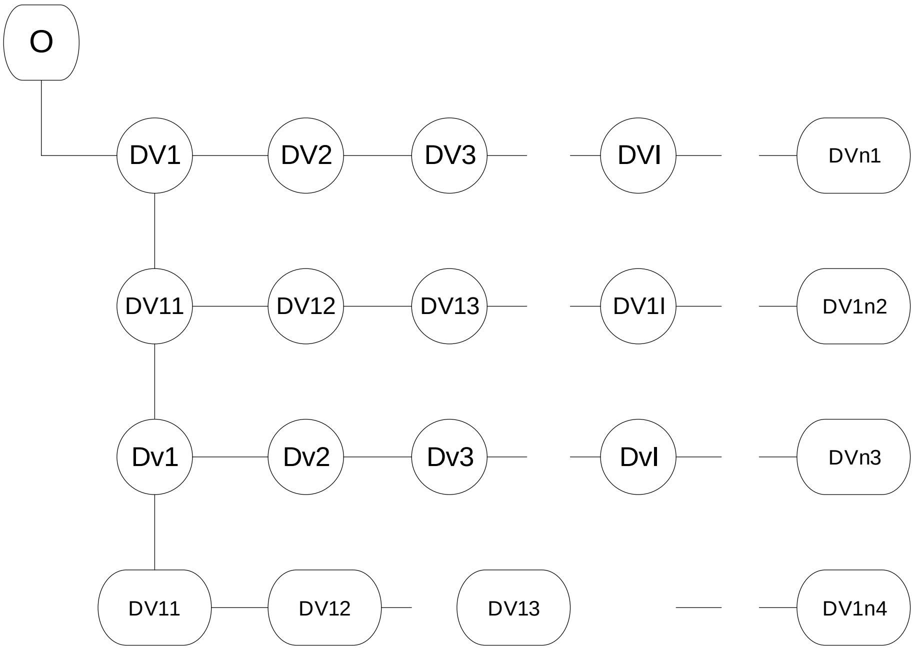


**Fig. 1.** Simple dichotomous decomposition

Figure 1 shows the recurrent decomposition procedure. Dichotomous division can end at any level. Onomasiological division continues until indivisible parts or elements are obtained. Dichotomy can be interpreted as a property. Dichotomous division is a method. Dichotomous division can be complete or partial. A complete dichotomous division is an onomasiological division into information units. Partial dichotomous division is a one-time division of an object into parts. Dichotomous division allows the formation of a structural model and helps to assess complexity.

To describe the dichotomy, you can use the tensor approach.

$D_i^j \in O$ (18)

In expression (18) j – means the division level; i - means the current number of the division element within this level. O – means the original object of division. D – denotes part of the dichotomous division. Notation (18) is more compact and is general for any number of levels. Levels can be identified with paradigmatic relationships (Elsukov, 2019).

Expression (18) describes the division part. It must be supplemented with a division index.

$N_i^j \in O$ (19)

The division index shows the number of division parts for the j-th level (i=1...n) and the total number of dichotomous parameters.

**Finding connections in dichotomous decomposition**

Finding parts is an explicit procedure. Finding connections includes explicit and implicit procedures. Implicit procedures are used when there are implicit connections. The onomasiological division is complete. Therefore, consider it as a generalization of the dichotomy.

The search for connections in onomasiological division begins with a correlative analysis. Correlative analysis (Tsvetkov, 2012), in contrast to correlation analysis, is aimed at identifying the presence or absence of connections between two objects. It includes several stages. The first stage includes simple questions: is there a connection or not?; is the connection possible or not?, what is the nature of this connection? This analysis is performed based on object parameters or object states. Accordingly, such connections are called: connection by parameters; state connection. Among many methods, natural language logic and qualitative argumentation are used (Miguel-Tomé, 2021; Piera, 2019). The use of qualitative argumentation creates more valid results of dichotomous analysis.

One of the qualitative criteria is the Bradford Hill criteria (Hill, 1965). They use state estimation. Bradford Hill did the diagnostics. Therefore, his methodology must be transformed into an information field. He proposed nine “aspects of association” for data analysis. In the information field they should be called factors. These became, over time, the fundamental principles of cause and effect. Therefore, they are called criteria for the presence of causality or effect.

Hill's nine aspects are: strength of association, consistency, specificity, temporality, biological gradient, plausibility, coherence, experiment, and analogy.

Strength of association is interpreted as “strength of connection.” The stronger the relationship between cause and effect, the more likely it is that the relationship will be cause and effect. There is a probabilistic logic to this criterion (Lonsky et al., 2021). Determining whether a connection is “strong” or weak is subjective. Therefore, cognitive logic is used to assess this factor (Savnykh, Tsvetkov, 2021).

The criterion of consistency is polysemic. It has different meanings. For example, consistency, consistency, density, composition. It is also interpreted as reproducibility and consistency. The essence of the criterion is that numerous studies and different methods indicate the presence of facts that show a stable connection between the two factors. This criterion is basic for identifying the presence of causation.

The criterion of specificity is the presence of distinctive factors that distinguish a given situation from others. The criterion must be interpreted as “situational specificity”.

The temporality criterion says that the appearance of a connection either depends on temporal factors or does not depend.

The term biological gradient should be interpreted as a gradient and differential dependence.

The criterion of plausibility is interpreted unambiguously as plausibility. Plausibility: the existence of a plausible explanation for the mechanism of a causal relationship increases the likelihood of its existence. It means there is evidence that a relationship is plausible or an explanation for the relationship. This criterion is developed by the Dempster-Shafer theory (Shafer, 1992). The method of reasoning with uncertain information, known as Dempster-Shafer theory, arose from a reinterpretation and development of the work of Arthur Dempster and Glenn Shafer in his book The Mathematical Theory of Proof (Shafer, 1976). More recent versions of the Dempster-Shafer theory include the Transferable Belief Model and the Theory of Hints.

The criterion of coherence is close to the concept of complementarity.

The experiment criterion means the need to confirm conclusions and reasoning using an experiment.

The analogy criterion requires reference to analogues as a means of confirming the reliability of reasoning. This criterion is associated with the theory of preferences (Tsvetkov, 2015), as a method for comparing analogues and confirming analogies.

All of the above criteria are conditional, since they are focused on medical diagnostics. In the information field they may have a different interpretation.

## 3. Conclusion

The main purpose of dichotomous analysis is to remove information uncertainty and build a structure. Dichotomous analysis can be considered as a type of structural analysis. It is necessary to distinguish between a dichotomous analysis and the result of a dichotomous analysis. The object of dichotomous analysis is everything, which is subject to dichotomous division. This is an object, a system, a model. The result of dichotomous analysis is a model and its description. This model can be descriptive or procedural. The importance of the model is determined by the objectives of the study. The result of dichotomous decomposition is dichotomous parameters. After division they represent a disparate aggregate. After analysis, they represent a complete system. Dichotomous analysis allows you to create systems of elements and assemblies. The results of dichotomous analysis are subject to certain conditions. Dichotomous analysis is a tool for constructing structure and a means of structural analysis. Dichotomous analysis with complex cause-and-effect division is a tool for cause-and-effect analysis. It allows you to find cause and effect. Depending on the purpose of the dichotomous analysis, different results are obtained. For the dichotomous there is the concept of level of analysis. The result of a dichotomous division is parts of one or more levels of division. The complete division is the onomasiological division. Dichotomous divisions can be systemic, cognitive and recurrent. The result of division is indivisible elements and parts at all possible levels of division. Dichotomous analysis awaits further logical and functional research

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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.

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

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

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

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

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

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

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

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.

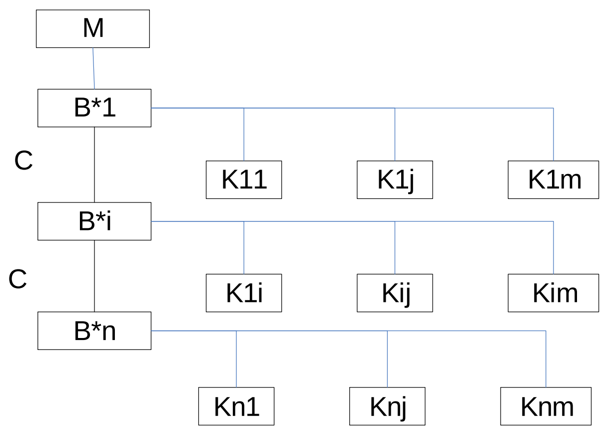


**Fig. 1.** Hierarchical information structure

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.

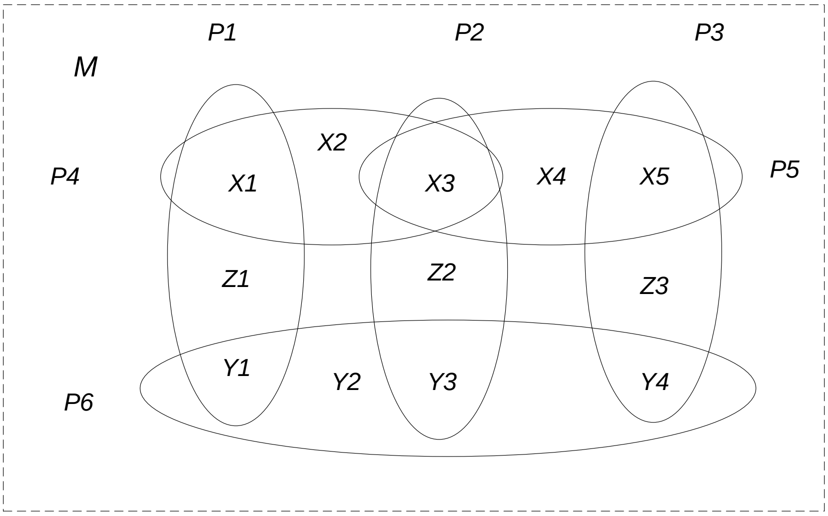


**Fig. 2.** Example of a complex set

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

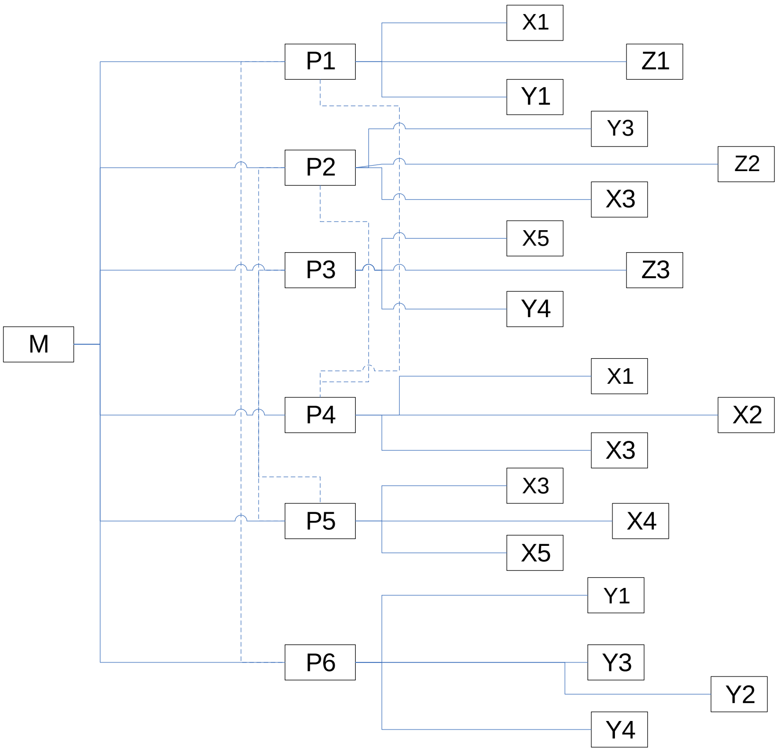


**Fig. 3.** Complex set structure

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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## Symbolic and Figurative Information Units

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**Abstract**

The article examines two important classes of information units. The multidimensionality of the use of different information units is shown. The article explores symbolic information and figurative information units. The similarities and differences in these groups are shown. The common feature is the systematization of information units into three types: symbols (elements), words and sentences. The divisibility criterion of the original information set determines the type of information unit. The difference between structural and semantic information units is shown. An onomasiological method for obtaining information units in the information field is described. A semasiological method for constructing models using information units in the information field is described. Information units are used in two directions: to detail the description of natural phenomena; for modeling or design. The difference between procedural and object information units is shown. An analysis of information units belonging to different areas is given: computer linguistics, computer language, complex system, information field. A set-theoretic description of information units of different directions is given. There is structural similarity between symbolic information units. It lies in the fact that information units of different types are divided into symbols, words and sentences. The article proves that information units can be considered as the result of analysis. The typological similarity between symbolic information units in linguistics, programming and systems analysis is shown. Figurative information units are more informative compared to symbolic information units. The qualitative difference between the figurative information units pixel and voxel is shown.

**Keywords**: computer science, information models, information units, symbolic information units, figurative information units, taxonomy.

### 1. Introduction

Information units are elements of the information field (Tsvetkov, 2014a). In information field theory, information units denote indivisible elements of the information field. Indivisibility is the main feature of information units. There are different criteria for divisibility and indivisibility. The divisibility criterion determines the type of information unit. Divisibility by structure determines structural information units. Divisibility into different types of meaning determines the types of semantic units.

Information units do not exist separately, but are always included in the system of information units (Ozhereleva, 2014). An example of a system of information units is the alphabet of any language. Many information units have a symbolic or formal representation. Such information units

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are called iconic or symbolic information units. There are information units that have a visual figurative representation. Such information units are called figurative information units.

Information units are used in two directions: to detail the description of natural phenomena; for modeling or design. The first direction is related to onomasiological (Bolbakov et al., 2022) modeling. The second direction is related to semasiological modeling (Gurgov, 2023).

Symbolic information units are used in discrete mathematics, applied computer science, logic, and applied geoinformatics. Information units are used in linguistics. Any language can be considered as a collection of information units. Symbolic information units are used in information theory (Ivannikov i dr., 2007).

Figurative information units are used in geometry, in programming, in spatial logic, in cartography, in Feynman diagrams, in design, in topology. Figurative information units are used to write processes as vector fields. There are studies describing information units (Markelov, 2014) or their application. However, to date no attempt has been made to write a general theory of information units. The importance of information units is great, but there is little theoretical research in this area. This determines the relevance of the study of information units.

## 2. Discussion and results

**Information units as a result of analysis**.

Any analysis involves division. Analytical division creates formal information units. Image analysis creates figurative information units. An example of a figurative information unit for describing the external environment is a pixel (Gibson et al., 2020), which is a flat object that forms part of a photograph of a snapshot or raster image. An example of an information unit for modeling the external environment is the voxel (Deng et al., 2021), which is a volume element. Figure 1 shows a flat and volumetric information unit.


**Fig. 1.** Pixel and Voxel

Pixel and voxel have two differences. The first difference is obvious: a pixel is a flat unit, a voxel is a three-dimensional information unit. The second difference between them is in application. The pixel describes the existing reality, that is, it is used for description. The voxel is used to construct a new reality, that is, for modeling.

Associated with the acquisition of information units is the direction of onomasiological information modeling, in which information units are obtained when studying objects. Onomasiological modeling in the information field explores objects and processes by breaking them down into elements. The opposite direction is semasiological modeling. Semasiological modeling in the information field creates models using information units. It is necessary to emphasize the difference in the application of onomasiology and semasiology in linguistics and in the information field.

Symbolic information units.

The description of symbolic information units can be done using a formal approach. From the standpoint of set theory, units are elements of sets. In the field of linguistics, the following types of linguistic information units are distinguished in order of increasing complexity: symbols, words, sentences, phrases. These same types are transferred to the information field. Symbols (elements) or the simplest structural information units have a description

$$x_o \in ANL \quad (1)$$

In expression (1) $x_o$ is an elementary structural information unit (element). The ANL set corresponds to the natural language alphabet. Symbols, as a rule, have no meaning. Symbols are characterized by morphology. Characters are obtained by structural division of text. Therefore, they are called structural information units.

Symbols form words, information units of a higher level. Words or semantic (Tsvetkov, 2014b; Nomokonov, 2015) information units have a description

$$x_1 \in Lex. \quad (2)$$

In expression (2) $x_1$ is an elementary semantic information unit - a word. The Lex set corresponds to the vocabulary of a given language. For example, the Bulgarian language has 35,000 words, the Russian language has 500,000 words. Languages may vary. There are many natural languages. These languages are spoken and written by people in different countries. There are artificial languages, for example, programming language, integrated circuit language, map language. Words as terms can form a semantic network. Elements of the semantic network are information units. The difference between the semantic information unit of a word is the presence of an interpretation for such a unit. This interpretation is called a determination or definition. The Lex set includes not only words, but also definitions for them. Words are obtained by semantic division of the text without taking into account terminological relations.

A sentence is a more complex information unit compared to a word. A sentence belongs to the class of composite semantic information units. Sentences are also called predicative information units. They have a description.

$$x_2 \in (x_1, Lex, Rel, Sint). \quad (3)$$

In expression (3) $x_2$ is a compound semantic information unit, a sentence, which includes words. The set (Lex, Rel, Sint) corresponds to the vocabulary of a given language, Rel is the terminological relationship between words, Sint is the syntax of a given language. The syntax of a language also determines the set of acceptable relationships between words, including syntactics. The syntax of a language determines the possibility of word formation and the formation of terminological relationships.

A phrase is a more complex information unit compared to a sentence or phraseological information units. They have an extended description.

$$x_3 \in (x_2, Lex, Rel, Sint, Con). \quad (4)$$

In expression (4) $x_3$ the compound semantic information unit is a phrase that includes sentences. The set (Lex, Rel, Sint, Con) corresponds to the vocabulary of a given language, a set of admissible relationships between words, a set of contextual expressions Con of a given language. In natural language, Con is expressed by pronouns, that is, substitutes for information units of words. This is done to keep the description compact and to avoid repetition in the description. There are relationships between symbolic information units.

$$x_0 \in x_1, Sint1 \quad (5)$$

$$x_1 \in x_2, Sint2 \quad (6)$$

$$x_2 \in x_3, Sint3 \quad (7)$$

In expression (5) Sint1 is the syntax for forming words from symbols. In expression (6) Sint2 is the syntax for forming sentences from words. In expression (7) Sint3 is the syntax for forming phrases from sentences and words. The considered division of information units belongs to the field of computer linguistics.

In the field of programming, groups of information units are also distinguished. Program operands or structural information units

$$y_0 \in APL. \quad (8)$$

In expression (8) $y_0$, the elementary structural information unit is an argument or a valid symbol of the programming language. The set of APLs corresponds to the alphabet of a programming language. Operators or semantic information units are described in (9)

$$y_1 \in Lex1. \quad (9)$$

In expression (9) $y_1$ is an elementary semantic information unit operator corresponding to a word. The Lex1 set corresponds to the vocabulary of operators of a given language. There are other semantic information units (machine words).

$$y_2 \in CC. \quad (10)$$

In expression (9) $y_2$ is an elementary semantic information unit – a machine command corresponding to a word. The set of SS corresponds to a set of commands on the computer

Sentences (program blocks or macro instructions) or composite information units have the form

$$y_3 \in (y_1, Lex1, CC, Rel, Sint). \quad (10)$$

In expression (10), y3 is a composite semantic information unit, a macro-command corresponding to the sentence. The set (Lex1, CC, Rel, Sint) corresponds to the allowable stock of sentences, in accordance with the allowable relations between Rel and the allowable syntax Sint.

In the field of systems analysis, there are also groups of information units. System elements or structural information units are the smallest units

$$z_0 \in ASys. \ (11)$$

In expression (11), $z_0$ is an elementary structural information unit of the system corresponding to the symbol. The set ASys corresponds to the alphabet of system elements. The next group of units is related sets of elements or composite information units

$$z_1 \in Lex1. \ (12)$$

In expression (12), $z_1$ is a composite information unit of the system corresponding to a word. The Lex1 set corresponds to the vocabulary of the constituent elements of the system. The system contains not only descriptive, but also procedural information units.

$$z_2 \in APSys. \ (13)$$

In expression (13) $z_2$ is a composite procedural information unit of the system corresponding to the procedural word. The set APSys corresponds to the alphabet of elementary processes in a given system.

There are blocks in the system.

$$z_3 \in (ASys, APSys, Lex1, Rel, Sint). \ (14)$$

In expression (13) $z_3$ is a composite procedural information unit of the system corresponding to the proposal. Set (ASys, APSys, Lex1, Rel, Sint). corresponds to the permissible supply of elements and blocks, in accordance with the permissible Rel relations between the elements of the system and the permissible Sint syntax for constructing the system structure.

In the field of systems analysis, there are two qualitative types of information units: structural and procedural. In linguistics, there is only one type of elementary information units.

In the field of information analysis or information field theory, groups of information units are also distinguished. Information field elements or symbolic information units

$$w_0 \in AF. \ (15)$$

In expression (15) $w_0$ is an elementary structural information unit of the field corresponding to the symbol. The set AF corresponds to the alphabet of field elements. Composite information units or information models have the following description

$$w_1 \in Lex1. \ (16)$$

In expression (16) w1 is a composite information descriptive unit of the field corresponding to the word. The Lex1 set corresponds to the vocabulary of the field's constituent descriptive elements. There are procedural information units in the field.

$$w_2 \in APr. \ (17)$$

In expression (17) w2 is a composite information procedural unit of the field corresponding to the word. The set APr corresponds to the alphabet of elementary field processes. In the field there are larger information units - blocks or enlarged information models

$$w_3 \in (AF, APr, Lex1, Rel, Sint). \ (18).$$

In expression (18) $w_3$ is a composite information procedural unit of the field corresponding to the sentence. The set (AF, APr, Lex1, Rel, Sint) corresponds to the permissible supply of elements and blocks, in accordance with the permissible Rel relations between the system elements and the permissible Sint syntax for constructing the model.

Thus, there is a typological similarity between symbolic information units. It lies in the fact that information units are divided into symbols, words and sentences.

**Figurative information units**.

Figurative information units are formed by dividing the original figurative set in the information field. As a rule, the original figurative set is heterogeneous. Division in the information field is performed from top to bottom, that is, from larger to smaller images. Begin dividing using categories or qualities. Figurative information units are easily modeled by areas or sets. The original heterogeneous set is divided into homogeneous sets or images. Complex and simple images contain information units.

The division of complex images into simple ones is carried out using the “similarity/difference” method. This method is implemented through cluster analysis. Within the cluster, division is performed using dichotomous analysis (Tsvetkov et al., 2018). Then I check the images within the cluster for dependence and independence. For this purpose, correlative (Tsvetkov, 2012) analysis and oppositional (Deshko, Tsvetkov, 2021) analysis are used.

As a result of dividing the initial information set of images, sets of simple images are obtained, which are checked for proportionality to different information units and models. Simple siu information units or image elements are not related to other information units of the same type.

$$(siu_i) \wedge (siu_j) = 0; i \neq j \quad (19)$$

Composite information units of images ciu are a linear combination of simple information units.

$$ciu = A1\ siu_1 + A2\ siu_2 + Ai\ siu_i \quad (20)$$

In expression (20), A1, A2, Ai are constant coefficients that are determined empirically. Block information units of images or IM models are a functional combination of simple and compound information units.

$$IM = F1(siu_i) + F2\ (ciu_k) + F3\ (siu_L, ciu_p) \quad (21)$$

Expression (21) structurally corresponds to expression (20). Figure 2 shows figurative information units. The number 1 denotes a figurative information unit, which is an analogue of a symbol. This is a point object.

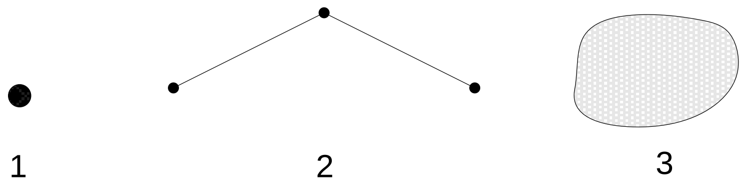


**Fig. 2.** Figurative information units

The number 2 denotes a figurative information unit, which is an analogue of a word. This is a linear object consisting of two straight segments. The number 3 denotes a figurative information unit, which is an analogue of a sentence. This is an areal object that describes a certain area.

The point figurative object $ox_0$ belongs to the set of points of this graphic language PL

$$ox_0 \in PL. \quad (22)$$

Unlike the symbol, the dot has an additional morphological characteristic – color. A linear figurative object (Figures 2, 2) or a composite figurative information unit ciu belongs to the set of lines of this graphic language PL

$$ciu \in PL. \quad (23)$$

It has a structure as a linear combination of simple segments.

$$ciu = A1\ siu_1 + A2\ siu_2 \quad (24)$$

Unlike the word, a linear object has additional morphological characteristics: color, line thickness, line type, length, orientation, starting and ending points, shape.

An areal figurative object (Figures 2, 3) or a composite information figurative unit aiu – an analogue of a sentence belongs to the set of areas of a given graphic language PL

$$aiu \in PL.$$

It has structure and shape. An areal object has additional morphological characteristics: color, border thickness, border type, perimeter, area, shading or filling type, shape. The areal figurative object is homogeneous, that is, it has the same shading or filling over the entire area.

## 3. Conclusion

Symbolic information units are simpler to describe compared to figurative information units. They contain less information uncertainty. Symbolic and figurative information units are similar in type. They can be thought of as symbols, words, and sentences. Information units act as standardized elements of analysis in the study of reality. Figurative information units have a larger number of parameters. Figurative information units are more informative (Nomokonov, 2015) compared to symbolic information units. Symbolic and figurative information units are standardized means of description when describing reality. This description applies to the general picture of the world. The use of information units is diverse. Information units are used as a tool to ensure the connection of the categories "information", "information resources", "knowledge". Information units are used as elements of semiotics. Semiotic signs are information units. Information units are used as elements of application systems. Information units are used as elements of decision-making processes and as elements of decision support processes. Information units serve as the basis for a comparative analysis of objects and processes. Information units serve as the basis for information design. Despite the widespread use of information units, they are not always called information units. This hinders the generalization of the experience of their application and the development of the theory of information units. The method of using information units is promising for solving many problems.

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# Complex Multi-Category Systems

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**Abstract**

The article explores the field of complex systems. The shortcomings of the existing theory of complex systems are noted. The article explores a special type of complex systems: large complex systems. Two concepts are introduced: a complex multicategory system and a local complex system. Large complex systems are divided into homogeneous and heterogeneous. Large heterogeneous complex systems include categorically different integral local complex systems as subsystems. A subsystem of an ordinary complex system does not have integrity, but is dependent on the main system. A local complex system has integrity. It can be used stand-alone or in combination with other systems. The content of complex systems is revealed based on comparison with simple systems. The article gives a formal description of a number of simple systems. A formal description of complex systems is given on the basis of the development of a description of simple systems. Four types of simple and complex systems are considered. The article identifies three types of emergence of complex systems and three types of structure of the system components. It is shown that emergence is a characteristic of complexity. The presence of a class of large complex systems is noted. This class includes a subclass of heterogeneous or hybrid systems. For this subclass, the concept of multicategory complex systems is introduced. the introduction of the term "multi-categorical complex systems" is justified. a number of properties and dependencies in complex systems are studied. The features of many categorical complex systems are described. The article gives a formal description of a complex multi-category system based on a systems approach. It is shown that the structure of a complex multicategory system is described by a multigraph. A feature of complex multi-category systems is the possibility of using corporate management technologies for local complex systems with the additional condition of their complementary behavior. The introduced models expand the application of the theory of complex systems in practical activities.

**Keywords**: complex systems, large complex systems, heterogeneous complex systems, categorical complex systems, complexity, emergence, simple systems, local complex systems.

## 1. Introduction

There are a number of gaps in the modern theory of complex systems. The traditional definition of a complex system as "a set of elements and connections" does not include the concept of complexity. One of the reasons is the variety of types of systems and types of complexity, another reason is the multidimensionality of consideration of complex systems. For example, there is an approach, which examines the relationships between parts of a system and the external

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environment. There is another approach that considers the behavior of the system and divides it into simple and complex. Both approaches use simplicity or complexity of description as criteria for complexity. It is believed that if a system is described simply, then it is a simple system. There is a subjective reason. It is more pleasant for a person to consider structures and easily structured models compared to poorly structured phenomena, which include complexity. The usual study of complex systems was limited to the triad of its components: elements, parts of the subsystem. This study of complex systems has so far bypassed large complex systems. Most theories of complex systems exclude the concept of simplicity and a simple system as a basis for comparison. In fact, complexity is a conditional concept, and it is determined from the level of simplicity. Another approach connects the complexity of systems with the presence of self-organization of the system or with the presence of emergence of the system. Synergistic effects are also a sign of complexity. Among the many complex systems, large complex systems are distinguished (May, 1972; Filip, 2008). Large complex systems use specialized complex systems as subsystems. Specialized complex systems can be of different types: complex information systems (Po-An Hsieh, Wang, 2007), complex technical systems (Leoshchenko et al., 2021), intelligent transport systems (Garg, Kaur, 2023), cyber-physical systems (Yaacoub et al., 2020), complex geographic information systems, multi-agent systems (Li et al., 2020), complex space monitoring systems (Kudzh, 2020), complex Earth-Moon system (Savinych, 2022) and others. Each variety of specialized complex systems has its own specifics, including modernization features. Specialized complex systems can be classified into different categories of systems. Large complex systems, composed of complex systems of different categories, should be called complex multi-category systems.

## 2. Results and discussion

### Complex and simple systems

Complexity is a conditional and comparative concept. Therefore, it is necessary to determine a certain level in relation to which complexity is assessed. The opposite of complexity is simplicity. Using a systems approach, it is possible to analyze simple and complex systems and give a comparative analysis of them. Both types of systems include elements, parts and subsystems.

A system element is an indivisible component in accordance with the selected divisibility criterion. An element is a structural element of a system, indivisible according to a given criterion. Important for the element is indivisibility and the criterion of divisibility.

Part of a system is a set of related elements of the system, selected on the basis of the unification criterion, which enters into certain relationships with its other parts. A part is a structural block of a system that combines elements to solve a problem. Important for the part is the appearance of a function for a group of elements. It is rare for a part to have or not have the property of emergence. Let's call this emergence the emergence of a part or emergence 1. This emergence characterizes the complexity of a part of the system.

A subsystem is the largest part of the system. It brings together a group of system components to perform a common function. The subsystem can perform independent functions. A subsystem is a structural block that combines parts to implement one system function. For a subsystem, the property of emergence may or may not exist. Let's call this emergence subsystem emergence or emergence 2. This emergence also characterizes the complexity of a part of the system. Complementarity of parts and subsystems allows solving system-wide functions

A system is a combination of subsystems and connections between them to perform a set of common functions or the main function of the system. a false system, as a rule, has the property of emergence. Let's call this emergence system emergence or emergence 3. The system has the highest level, subsystems have lower level complexity, and parts have the lowest complexity.

To compare with a complex system, consider a simple system. Most often, such systems are additive systems that do not have the property of emergence. To formally describe a simple system (SYS) and a complex system (CSYS), we will use the apparatus of systems theory. As the parameters under consideration increase, the formal description of the system model will become more complex. As a first description, consider a simple abstract system SYS as the first model

$$SYS1 = <E, PS, C, B>, (1)$$

In expression (1) E is the set of system elements; PS - many parts of the system; C – set of connections between parts and elements of the system; B is the set of system boundary points separating the system from the external environment. For simple systems, its parts and the system itself do not possess the property of emergence. Formula (1) describes a simple system as a set of elements and parts that interact with each other and with the environment. A more complex system model includes the structure of the system and its constituent structures

$$SYS2 = \langle PS, Str, E, C, B \rangle, \quad (2)$$

In expression (2) PS is the set of parts of the system. Str – system structure. E – set of system elements; C – set of connections in the system. B – system boundary, separating the system from the external environment. This definition indicates that a system consists of heterogeneous parts and has a structure. In this case, three types of structure are possible: structure of 1 subsystems, structure of 2 parts, structure of 3 elements. Complexity increases as we move from structure 1 to structure 3. For models (1), (2), the concept of complexity is not included, so they formally describe simple systems.

For a complex CSYS system there is a model.

$$CSYS1 = \langle Ps, PS, Str, E, C, B, R, Cx \rangle, \quad (3)$$

In expression (3) Ps is the set of subsystems of the system; PS – a set of parts of the system. Str – system structure. E – set of system elements; C – set of connections in the system. B – system boundary. R is a set of relationships between elements, parts and subsystems. Cx – one or more types of complexity. The complexity of Cx depends on the type of structure, on the number of elements, on the number of connections, on the number of relationships. This definition indicates that a system consists of heterogeneous parts, has structure, and has complexity.

A distinction can be made between a simple and a complex system. In a complex system, there are subsystems and a measure of complexity that may include emergence. Complexity can have different levels and belong to different components of the system. These are the particular complexities of the system components. General or integral complexity is a characteristic of a complex system. It can be considered as a function of particular complexities

$$Cx=F(Cv, Cp, Cr, Cd, Cc, Ccm, Cmd, Ca, Agc) \quad (4)$$

In expression (4) Cv is the volumetric complexity. associated with large amounts of data or system volume; Cp – procedural complexity associated with the complexity of processing and interpretation, as well as time constraints of processing; Cr – complexity of representation (representation); Cd – descriptive complexity associated with the complexity of describing the system; Cc – cognitive complexity of perception and use of the system; Ccm – computational complexity (if it is present in the system); Cmd – complexity of modeling in the system; Ca – algorithmic complexity of system behavior; Agc is the complexity of the interaction of system components with each other.

Expression (4) itself provides a systematic description of complexity. Many systems have an additional target parameter (G). A simple target-specific system will be described by a species model

$$SYS3 = \langle Ps, PS, Str, E, C, B, G \rangle, \quad (5)$$

In expression (5) the parameters are the same as in expression (2) with the addition of a target parameter. A complex target-specific system will be described by a model of the form

$$CSYS2 = \langle Ps, PS, Str, E, C, B, R, Cx, G \rangle, \quad (6)$$

In expression (6) the parameters are the same as in expression (3) with the addition of a target parameter. A complex system may have multiple goals, e.g. be multi-purpose (Tsvetkov, 2012).

Systems are divided into open and closed. For open systems there are system models.

$$SYS4 = \langle Ps, PS, Str, E, C, B, int, out \rangle, \quad (7)$$

$$CSYS3 = \langle Ps, PS, Str, E, C, B, R, Cx, int, out \rangle, \quad (8)$$

In expressions (7), (8) int is the set of inputs, out is the set of outputs of the system. The presence of system inputs and outputs separates the system from the environment and allows one to model the informational and physical interaction of the system with the environment. In many cases, the boundaries of an interacting system are quite difficult to determine. As a criterion for determining these boundaries, you can choose the strength of connections between elements. This allows you to select elements from the system, determine boundary (input and output) elements, and determine the boundaries of the system. A system exists only when the strength of connections between the elements of the system is stronger than the strength of connections with the environment. The inclusion of the cognitive factor Cog in the functioning of the system is typical only for a complex system.

$$CSYS4 = \langle Ps, PS, Str, E, C, B, R, Cx, Cog, int, out \rangle, \quad (9)$$

The inclusion of artificial intelligence methods AI in the functioning of the system is typical only for a complex system.

*CSYS5 = <Ps, PS, Str, E, C, B, R, Cx, AI, int, out >*, (10)

A complex system has the property of emergence, so it cannot be studied only on the basis of an analysis of its components, subsystems or elements. The study of a complex system by the decomposition method, that is, the method of decomposing the whole into parts, is insufficient, since it comes down to the study of only its individual parts. The study will be complete when the integration method is applied, allowing one to synthesize the whole from the elements of the system. This approach ensures the formation of a holistic view of a complex system. The presence of emergence (Em) of a complex system entails the appearance of its integral properties (integral PSoperties)

$CSYS(Em) \rightarrow CSYS($integral PSoperties$)$ (11).

Along with general differences, there are differences in parameters between complex and simple systems. The data volume of a complex CSYS system (Data Volume) is greater than the data volume of a simple SYS system (Data Volume)

*CSYS* (Data Volume)>> *SYS* (Data Volume) (12).

The physical volume of a complex system CSYS (Physical Volume) is greater than the physical volume of a simple system SYS (Physical Volume)

*CSYS* (Physical Volume)>> *SYS* (Physical Volume) (13).

The variety of data in a complex CSYS system (Data Variety) is greater than the variety of data in a simple SYS system (Data Variety)

*CSYS* (Data Variety)>> *SYS* (Data Variety) (14).

The number of components of a complex system CSYS (Components Number) is greater than the number of components of a simple system SYS (Components Number)

*CSYS* (Components Number)>> *SYS* (Components Number) (15).

The number of connections in a complex system CSYS (Connections Number) is greater than the number of connections in a simple system SYS (Connections Number)

*CSYS* (Connections Number)>> *SYS* (Connections Number) (16).

The adaptability of a complex CSYS system (adaptability) is higher than the adaptability of a simple SYS system (adaptability). In simple systems. as a rule there is no adaptability.

*CSYS* (adaptability)>> *SYS* (adaptability) (17).

The structure of a complex CSYS system (structure) is larger and more diverse than the structure of a simple SYS system (structure)

*CSYS* (structure)>> *SYS* (structure) (18).

The structure of a simple system is described by a planar or planar graph. The structure of a complex system is usually described by a multigraph or volumetric graph.

In reality, it is necessary to take into account that decision-making or problem solving by the system occurs within a certain permissible time interval - (ΔT). This is a dynamic characteristic of the system. The permissible time intervals of a complex and simple system are either proportional

$CSYS\ (\Delta T) \approx SYS\ (\Delta T)$ (19).

Or the permissible time interval of a complex system is less than the permissible time interval of a simple system

$CSYS\ (\Delta T) < SYS\ (\Delta T)$ (20).

Expressions (1), (2), (5), (7) describe simple systems. Expressions (3), (4), (6), (8), (9), (10), (11), (12) describe complex systems. Expressions (13) - (21) describe the comparative characteristics of complex and simple systems. Expressions (13) - (21) describe the comparative characteristics of complexity.

**Properties of a complex multicategory system**

The world is a system of systems. The solar system includes planets, each of which can be considered as a complex system. Human society can be viewed as a collection of qualitatively different systems. Any state is a complex system that includes different, smaller complex systems. The list can be continued, but the important conclusion is that there are systems of systems. There are special complex systems. which include other complex systems. They are called large systems. Large systems that consist of complex systems belonging to different categories can be designated as multi-category systems.

Multicategory complex systems have the following features. They are heterogeneous. They include entire systems as subsystems. They have the highest level of complexity among complex systems. The term "categorical" is due to the fact that the systems included in it may belong to different categories of systems and different categorical functions. Such incoming complex systems can be: complex data systems, complex computational processing systems, complex communication systems, complex information presentation systems, complex modeling systems, complex communication systems, complex robotic systems and others.

Most complex systems are homogeneous with respect to subsystems and parts. They have elements, parts, subsystems. However, for complex systems composed of other complex systems, such simple separation is not enough. It is necessary to introduce new gradations of division of complex systems which are composed of simpler complex systems. Such a gradation can be categories of system functionality.

A complex system that has categorically different complex systems as parts is called a complex multi-categorial system. This complex system is heterogeneous. It includes homogeneous complex systems that belong to different categories according to function and purpose.

There is systemic categorical theory. However, this theory is dedicated to non-deterministic systems. There is a theory of hybrid categorical systems (Ames, Sastry, 2006). It is much closer to the theory of many categorical systems.

It is possible to give a formal description of a multicategory complex system based on a systems approach. The multi-category complex system (CCSYS) is heterogeneous. It includes homogeneous complex systems (GCSYSi), which belong to different categories ($Cat_i$) according to function and purpose

$$CCSYS = < GCSYS_i\, [SS, PS, Str, E, C, B, R, Cx, G]\, Cat_i >, \quad (21)$$

Expression (21) describes the structural nesting of systems in a multicategory system. Expression (21) includes the following parameters: CCSYS – a complex multi-category system; GCSYSi is a homogeneous system included as a subsystem in CCSYS; index i shows the number of the homogeneous system within the categorical system; brackets characterize structural nesting; they mean that a homogeneous system can have its own set of parameters; Cat – denotes the category of a homogeneous system. The parameters of homogeneous systems are as follows: SS – a set of subsystems, PS – a set of parts of a homogeneous system, Str – the structure of a homogeneous system, E – a set of elements of a homogeneous system, C – a set of connections in a given system, B – the boundary of the system, R – relations of a homogeneous system, Cx – the total complexity of the homogeneous system, G – the intended purpose of the homogeneous system. Expression (21) describes a multigraph.

A specific feature of many categorical complex systems is the presence of an intersystem interface. Since the systems included in CCSYS contain qualitatively different interaction processes, for their joint activity it is necessary to coordinate the processes of information interactions of these systems. Such functions are performed by the intersystem interface.

It is necessary to note the difference between the intended purpose and the category of a homogeneous system. A complex system of one category can be used for different purposes. A complex homogeneous system may have several goals. In this case, it is multi-purpose (Tsvetkov, 2012). Local systems of different categories can be used for one common purpose. It is the last property that characterizes complex multicategory systems.

## 3. Conclusion

For quite a long time, systems theory developed in a simplified form as the theory of homogeneous systems. The development of science has shown the existence of heterogeneous complex systems. The development of science has shown the presence of systems that include complex systems. This leads to the concept of complex multi-category systems. Complex systems have varying degrees of complexity. Identification of a group of large systems in which systems are subsystems creates a group of many categorical complex systems. The term "categorical" refers to the use of complex systems of different categories to jointly solve a common problem. A group of many categorical complex systems is characterized by the heterogeneity of the systems included in it. The highest level of system complexity, the presence of an intersystem interface and a complex topological description in the form of a multigraph. There is no inter-system interface in conventional or homogeneous complex systems. Complex multi-category systems have a feature that is not characteristic of other types of complex systems. Complex multicategory systems include local complex systems which can function independently. For their joint actions it is necessary to develop an intersystem interface. Another feature of complex multi-category systems is the possibility of using corporate management technologies for local complex systems with the additional condition of their complementary behavior.

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## Extended Implicative Relations

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**Abstract**

The article explores extended implicative relations. Extended implicative relations use extended implication. Extended implication describes: relation, consequence, causation and operation. The article shows that extended implication can serve as a complexity assessment tool. The content of implicative information relations is revealed. Implicative information relations are a type of information relations. Implicative information relations describe statics and dynamics in the information field. Statics is about the relationships between information models and their parts. The dynamics of information implicative relations lie in the relationships between the inputs and outputs of information processes. The dynamics of information implicative relations lie in the relationships between the states of information situations and the states of objects in the information field. The formalism for describing implicate information relations and implicate relations is approximately the same in that case unless coordination and configuration parameters are applied. Implicative operational relations allow the assessment of procedural complexity. The difference between simple and complex implicative relations is shown. Complexity estimates for arguments and operations are shown. Taking into account the coordination and configuration of initial objects or sets allows us to expand the concept of implication and introduce the concept of "morphological implication". Morphological implication is used to describe the transformation operations of a company. The result of morphological implication depends on the relationships between the original sets or configurations. Morphological implication is used in spatial logic. In spatial logic, the results of implicative operations are diverse, since they depend on factors that ordinary logic does not take into account.

**Keywords:** relations, implication, extended implication, informational implication, morphological implication, spatial logic.

### 1. Introduction

Currently, there is growing interest in the problems of describing and modeling complexity and information description of processes and situations. Information description is divided into descriptive and procedural. Descriptive description is associated with information models and information relationships. The procedural information description is associated with information processes and information interactions. One of the universal means of description is implication. Its peculiarity is that it can describe information relations in a state and in a situation. This is a

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static model of application of implication. Implication can describe information processes and situation dynamics. This is a dynamic model of application of implication. Implication can describe connections. This is a dynamic – static model of application of implication. An implication is denoted by a single symbol, so it can be considered an information unit. In the social sphere, implication is often identified with the term "consequence" (Sorensen et al., 1998). In logic, implication acts as a logical connective. There are implicative relations (Doran, Martin, 2021). A related implication is the concepts of "derivability" or "followability" (Visser, 2022). The development of the concept of implication is "logic of bunched implications" – BI (Gheorghiu, Marin, 2021; Gheorghiu, Pym, 2023). The propositional version of BI arises from an analysis of the evidential-theoretic relationship between conjunction and implication; it can be seen as a fusion of intuitionistic logic and multiplicative intuitionistic linear logic. The naturalness of BI can be viewed categorically: models of propositional evidence. This suggests that implication and implicative relations can be applied in the theory of evidence and in the theory of cause-and-effect analysis. An extension of the BI method is the logic of linear temporal grouping of implications (LTBI) (Galmiche, Méry, 2023). Implication is used in temporal logic and modal logic. Overall, this is a fairly universal description tool. Implication is more often applied than researched. There are few works devoted to the study of implication as a universal description mechanism. This article fills this gap.

## 2. Results and discussion

**The variety of applications of implicative relations**.

Implicative relations are usually associated with logic and used in the logical field (Baiyere et al., 2020). However, implication is used in many ways. Implication has many interpretations that complement each other. Symbolically, the implication is displayed by arrows that indicate direct (1) or reverse (2) implication

$$A \rightarrow B, C \quad (1)$$

$$D, E \leftarrow F \quad (2)$$

Expression (1) can be interpreted as follows: event A entails events B, C. Expression (2) can be interpreted as follows: event F can have events D E as a cause. This example shows that implication is a tool for cause-and-effect analysis. In the causal aspect, implication describes the causal relationship between the premises and the conclusion.

Expression (1) can be interpreted differently: set A is divided into sets B, C. Expression (2) can be interpreted as follows: set F can have D E as subsets. This example shows that implication is a tool for structural analysis.

Expression (1) can be interpreted as follows: category A is divided into subcategories B, C. Expression (2) can be interpreted as follows: category F can have D E as subcategories. This example shows that implication is a tool for categorical or qualitative analysis

An implication can express a proposition. In this case, in expression (1) A is a condition sufficient for the fulfillment of corollary B, C. Corollary B, C is a condition necessary for the truth of premise A.

**Implicative information relations**.

In their simplest interpretation, implicative relations describe relations of logical consequence in a logical field. Implicative information relations are a type of information relations in the information field (Tsvetkov, 2014). Implicative information relations describe statics and dynamics in the information field. Statics lies in the relationships between information models, between parts of information models, between information units, between information situations and information structures. The dynamics of information relations lies in the relationships between the inputs and outputs of information processes. The dynamics of information relations lies in the relationships between the states of information situations and the states of objects in the information field. The dynamics of implicative information relations sets cause-and-effect relationships and connections.

Implicative information relations are used individually and in groups. Single implications describe one-time processes or one-time changes in states. In a group, implicative relations form chains or sequences. Sequences (Zaheer et al., 2020) are sequences that describe: sequential change: states, operations, transformations, argumentation, conclusions.

Implicative information relations are the transfer of implicative relations into the information field or a particular example of information relations (Cross, Sproull, 2004). The formalism for describing implicate information relations and implicate relations is approximately the same in that case unless coordination and configuration parameters are applied. Implicative information relations are denoted using the implication symbol. The implication is written using an arrow as

$$A \rightarrow B.$$

In such a notation, object A is called a premise, object B is called a consequence. Implication is interpreted in different ways, for example, as a logical connective approximating the interpretation "if..., then...".

In Boolean logic, implication is considered as a function of two variables. These variables are called operands, operations or function arguments. In general, an implication describes an operation. Using the example of implicate relations, we can evaluate operational complexity. Operational complexity exists in operations research. There are simple implicative relations that consist of one implication. A simple implicative relation consists of one implication and two arguments. This implication describes one operation between the arguments M1 and M2.

$$M1 \rightarrow M2 \quad (3)$$

Expression (3) describes the succession relation between an object M1 and another object M2. Expression (3) has a multi-valued interpretation. For example, the state of an object M1 entails another state of the same object M2. Situation M1 entails another situation M2. The computational stage M1 entails another computational stage M2. These implicative relations appear in the state space. In the information field, expression (3) can describe the transformation of model M1 into model M2.

Implicative operational relationships allow complexity to be assessed. There are complex implicative relations that are divided by the number of operations and the number of arguments. Complex implicative relations based on the number of arguments are given in (1), (2). Additionally, the following examples of complex implication can be given.

$$A, C \rightarrow B \quad (4)$$

$$(D, E, G) \rightarrow A, B, C \quad (5)$$

Argument complexity (Comp(arg)) or argumentative complexity appears in implicative relations that involve functions of several arguments

$$F(A1, A2, A3, An) \rightarrow B. \quad (6)$$

In expression (6), the greater the number of arguments, the higher the argument complexity (Comp(arg)). Complexity in arguments entails ambiguity of the result (consequence).

Operational complexity (Comp(n)) appears in implicate relations, which consist of chains of simple relations.

$$A1 \rightarrow A2 \rightarrow A3 \rightarrow \ldots \rightarrow An \quad (7)$$

Expression (7) is called a chain of operations. The greater the number of operations, the higher the operational complexity. The probability of events in the chain is determined using the formula

$$P(An) = P(A1)\, P(A2) \ldots P(An\text{-}1) \quad (8)$$

From expression (8) it follows that the longer the chain, the lower the probability of the last operation. Complexity of operations reduces the reliability of the final consequence An.

**Morphological implication**.

Taking into account the coordination and configuration of initial objects or sets allows us to expand the concept of implication and introduce the concept of "morphological implication". Morphological implication between objects is such an implication, the result of which depends on the morphology of the objects. A morphological implication includes two or more participant objects of the implication and a result object.

Taking into account coordination and configuration is necessary in the field of spatial information, in particular in geoinformatics. Let us consider the formation of a new object as an implication of set-theoretic or spatial objects. For example:

$$M1 \cup M2 \rightarrow M3 \quad (9)$$

Expression (9) says that the sum or union of objects M1 and M2 entails the creation of object M3.

If M1 and M2 are informational or parametric sets and they are connected by a union relation, then the result of the implication (output set M3) will depend on the set-theoretic relations between them. For example, if there is an overlap between the source sets M1 and M2, then the result of the implication or output set M3 has the form shown in Figure 1.

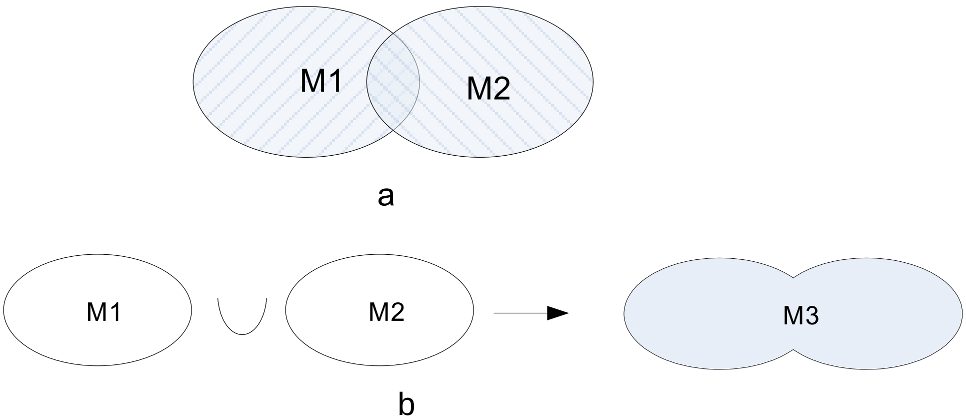


**Fig. 1.** Implicative relation overlap

Option "a" in Figure 1 shows the original set-theoretic relation between M1 and M2. Option "b" in Figure 1 shows the result of the implication or the output set M3. For this situation there is

$$M1 \cap M2 \neq \varnothing.$$

$$M3>M1;\ M3>M2.$$

If there is no overlap between the sets M1 and M2, but there is a tangency, then the result of the union will be different. Combining objects in the absence of overlap is shown in Figure 2.

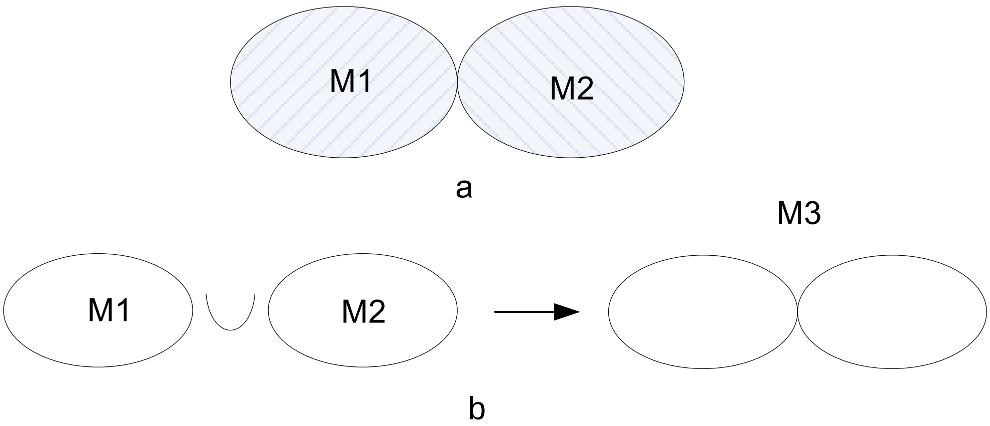


**Fig. 2.** Implicative relation association

Option "a" in Figure 2 shows the set-theoretic relation between M1 and M2. Option "b" in Figure 2 shows the result of the implication. For this situation there is

$$M1 \cap M2 = \varnothing;$$

$$M3=M1+M2.$$

The result of implication based on the union operation can be absorption (Figure 3).

Option "a" in Figure 3 shows the set-theoretic relation between M1 and M2. Option "b" in Figure 3 shows the result of the implication. For this situation there is

$$M1 \cup M2 \rightarrow M2=M3$$

In the set-theoretic formalism, Figure 3b corresponds to an expression that is not characteristic of arithmetic.

$$M1+M2= M2$$

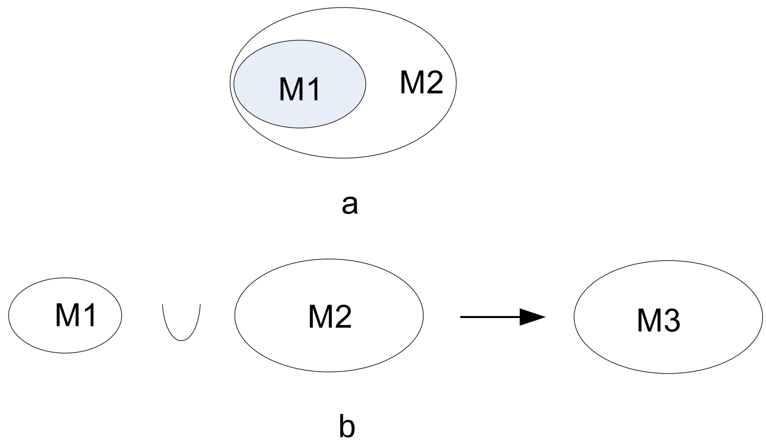


**Fig. 3.** Implicative relation absorption

Conclusion: the result of the implication when combining sets depends on the set-theoretic relations between the original sets M1 and M2. This feature requires the introduction of a new concept to distinguish between logical implication and set implication described in the examples given. This new concept is morphological implication. Morphological implication is an implication whose result depends on the morphology of objects and the set-theoretic relations between them. Figures 1b, 2b, 3b are examples of morphological implication. Morphological implication takes into account coordination parameters and configuration parameters. Coordination parameters are not taken into account in ordinary logic and set theory. Coordination parameters are taken into account in spatial logic. The result of morphological implication in spatial logic (Janoschka et al., 2020; Kudzh, Tsvetkov, 2020) differs for figures of different shapes (ellipses, squares, circles and bodies of arbitrary shape). In logic, the result of implication is the same, but in spatial logic the results of implicate relations are significantly different. Consequently, the formal application of the implication operator does not provide an unambiguous interpretation of the result. To apply implication in a "non-logical" sphere, additional information is needed for an unambiguous interpretation of the implicature relation. In particular, coordination information about the original sets is needed.

The information situations in Figure 1a, Figure 2a, Figure 3a show that the result of morphological implication changes depending on the type of relationship with the same functional connection between the arguments. Let us show that the result of the implication varies depending on the type of function or relations between the original sets.

Let's consider the situation in Figure 1a for another relationship between the original sets. In Figure 1, the set-theoretic relation "union" was used. Let's consider another relation "intersection". In Figure 4a the situation in Figure 1a is repeated, but a different result of the relationship is shown in Figure 4b.

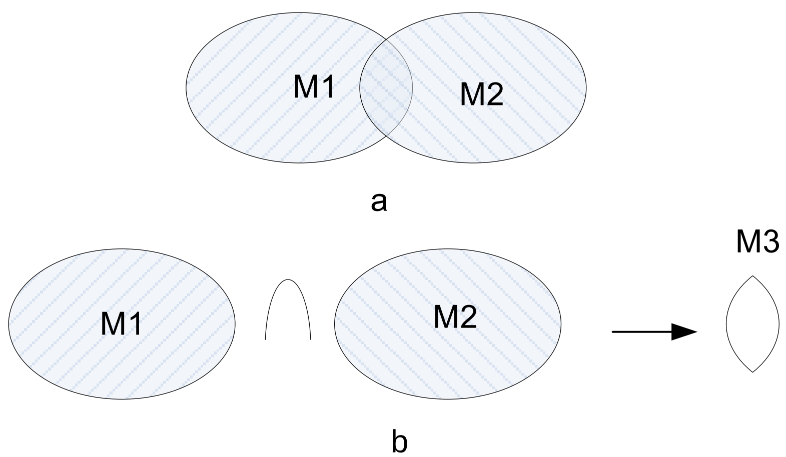


**Fig. 4.** Implicative relation at intersection

The implication in Figure 1 increases the output set M3 compared to the original ones. The implication in Figure 4 reduces the output set M3 compared to the original ones. Option "a" in Fig. 4 shows the set-theoretic relation between M1 and M2. Option "b" in Figure 4 shows the result of the implication. For this situation

$$M3<M1;\ M3<M2.$$

A comparison of Figure 1 and Figure 4 shows that the result of the implication set M3 is significantly different for the operation of union and intersection. It has a different morphology.

Configuration, together with coordination, also influences the result of implication. Figure 5 shows a situation similar to that in Figure 4, but with a different morphology of the original sets.

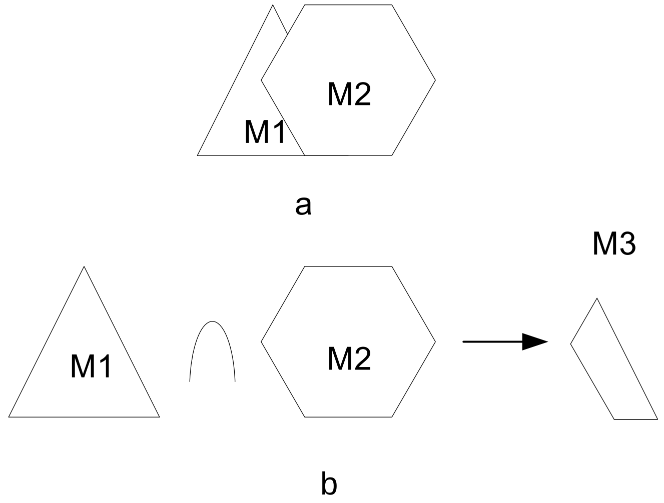


**Fig. 5.** Implicative relation of intersection with another morphology of original sets

Option "a" in Figure 5 shows the set-theoretic relation between M1 and M2. Option "b" in Figure 5 shows the result of the implication. A comparison of Figure 1, Figure 4 and Figure 5 shows that the result of the morphological implication of the set M3 differs significantly depending on the morphology of the original sets (arguments). Such a difference does not appear in set theory and ordinary logic. This difference is revealed by the methods of spatial logic.

Let's make another comparison. Let's take the situation in Figure 2a as the initial one, but replace the union operation with intersection. The result is shown in Figure 6.

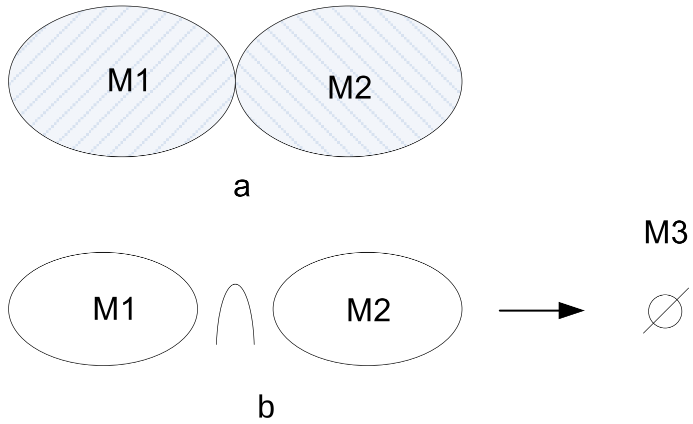


**Fig. 6.** Implicative relation when combining disjoint sets

Option "a" in Figure 6 shows the set-theoretic relation between M1 and M2. Option "b" in Figure 6 shows the result of the implication. The result of the implication, the set M3 in Figure 6 is an empty set, in contrast to M3 in Figure 2.

## 3. Conclusion

Implication can be considered as a relation, a consequence and an operation. Implication can be thought of as a cause-and-effect relationship. Morphological implication is an operation with sets, the result of which depends on set-theoretic and spatial relations between the original sets. Implication can take into account spatial relationships. In operations theory, implication can serve as a tool for assessing complexity. This complexity is related to operations and relationships. Implication can serve as a means of describing operations and processes. In combination with set theory and morphology, implication can serve as a tool of spatial logic. For this purpose, a new concept of morphological implication is introduced. Morphological implication exists in spatial logic. In spatial logic, the results of implicate relations are significantly different, since they depend on factors that ordinary logic does not take into account. In relation to information modeling, the article introduces the concept of "implicit information relations". Implicative information relations are relationships in the information field that exist between information models, between parts of information models, between information units, between information situations and information structures. Implicative relations in spatial information are multivalued and differ from implicative relations in classical logic. They are the subject of further research.

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