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The Concept of Functional Connectivity of Measurements of Geo-Informational Space of the Region

V. V. Khramov[a*], S. O. Kramarov[b], S. A. Roshchupkin[c]
[a] Southern University (IMBL), Rostov-on-Don, Russia
33a/47 Nagibina Ave., Rostov-on-Don 344068, Russia
[*] vxpamov@inbox.ru
[b] Surgut State University, Surgut, Russia
1 Lenina St., Surgut 628412, Tyumen Region, Russia
[c] Bunin Yelets State University, Yelets, Russia
28 Kommunarov St., Yelets 399770, Russia

Abstract

This article discusses the basics of the concept of the unique geo-informational space (UGIS) as an objective reality of the world around us. The main concepts of space, field, region, and territory that are relevant for this area of research, namely, as an informational space, are clarified. Taking into account the hierarchy and multidimensionality of information in general and the information space in particular, the scheme for its study as a System of Systems is proposed. At the same time, there are problems of functional connectivity of both individual multidimensional information objects of this space and functional connectivity of hierarchical layers, each of which will have its own unique features and interpretations of data, information and knowledge.
For the formation of properties of problem-oriented cross-sections of UGIS and their relationships, when describing the processes of information exchange and mutual influence, a hexagonal lattice is proposed as a basic consideration. The algorithms for describing individual information objects and hierarchical layers based on functionally related hexagonal elements that allow the use of a modified apparatus of cellular automata, soft information models, and fuzzy logic are proposed. As an example, the so-called "gravitational model" of the connectivity of the elements of the UGIS is used. The authors believe that such (or similar) nonlinear model is adequate to the information features that are characteristic of socio-economic processes and systems and can be applied at the level of regions and individual territories. The proposed variants of the soft model of UGIS in relation to the socio-economic problems of the region allow us to solve the problems of forecasting the dynamics of these processes and development. The approaches to the formation of the architecture of such a model and its implementation in the framework of a fuzzy knowledge base are discussed.

Keywords: informational space, functional compatibility, multi-dimensionality, dimensions, functional connectivity, entirety.

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Концепция функциональной связности измерений геоинформационного пространства региона

В. В. Храмов[1*], С. О. Крамаров[2], С. А. Рощупкин[3]
[1] ЧОУ ВО «Южный университет (ИУБиП)», г. Ростов-на-Дону, Россия
344068, Россия, г. Ростов-на-Дону, пр. М. Нагибина, д. 33А/47
[*] vxpamov@inbox.ru
[2] БУ ВО «Сургутский государственный университет», г. Сургут, Россия
628412, Россия, г. Сургут, ул. Ленина, д. 1
[3] ФГБОУ ВО «Елецкий государственный университет им. И.А. Бунина», г. Елец, Россия
399770, Россия, Липецкая область, г. Елец, ул. Коммунаров, д. 28

Аннотация

В настоящей статье рассматриваются основы концепции единого геоинформационного пространства (ЕГИП) как объективной реальности окружающего нас мира. Уточняются основные понятия пространства, поля, региона, территории, которые представляются актуальными для данного направления исследований, а именно, как информационного пространства. Учитывая иерархичность и многомерность информации вообще и информационного пространства в частности, предлагается схема его исследования как System of Systems. При этом возникают проблемы функциональной связности как отдельных многомерных информационных объектов этого пространства, так и функциональной связности иерархических слоев, для каждого из которых будут иметь место свои уникальные особенности и трактовки данных, информации и знаний. Для формирования свойств проблемно-ориентированных сечений ЕГИП и их взаимосвязей, при описании процессов информационного обмена и взаимовлияния, предложена гексагональная решетка в качестве базового рассмотрения. Предложены алгоритмы описания отдельных информационных объектов и иерархических слоев, основанные на функционально-связанных гексагональных элементах, допускающих применение модифицированного аппарата клеточных автоматов, мягких информационных моделей и нечеткой логики. В качестве примера используется так называемая «гравитационная модель» связности элементов ЕГИП. Авторы полагают, что такая (или ей подобная) нелинейная модель адекватна тем информационным особенностям, которые характерны для социально-экономических процессов и систем и может быть применена на уровне регионов и отдельных территорий. Предлагаемые варианты мягкой модели ЕГИП применительно к социально-экономическим проблемам региона позволяют решать задачи прогнозирования динамики этих процессов и развития. Обсуждаются подходы к формированию архитектуры такой модели и ее реализации в рамках нечеткой базы знаний.

Ключевые слова: информационное пространство, функциональная совместимость, многомерность, измерения, функциональная связность, целостность.

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Introduction

One of the most important concepts used in the process of transforming socio-economic systems within the framework of the project "Digital Earth" is the Unified geo-informational space (UGIS). Taking into account that there isn't currently no unambiguous interpretation of some terms, we will fix the variant of their use in this work.

The concept of space itself is interpreted "as an objective reality, a form of existence of matter characterized by length and volume"[1] [1]. Among the many known spaces, we note the information and geographical spaces. Among the many known spaces, we note the information and geographical spaces. Moreover, the last place occupies a central place in the Earth Sciences. It is understood as "the form of existence of geographical *objects and phenomena* within a geographical cover; a set of relations (including informational – *author's note*) between geographical objects located on a specific territory and developing over time"[2]. It is assumed [3] that space, like any complex system (more precisely, System of Systems), includes three components – matter, energy and information [3, 4], the description of each of which reflects its own characteristics of the whole system in general[2] [5].

In turn, *the territory* is earth (ground, two-dimensional, surface) [6], a space with defined boundaries. And, finally, *a region* is a generalized name for physical-geographical, political, socio-economic, etc. zoning of any taxonomic rank; a significant territory with some community of natural and other conditions.

Based on the goals of this study, we will consider in more detail the pragmatic properties of the geo-informational space model, which characterize the degree of usefulness of the information available in it for the practice of solving socio-economic problems.

Properties of a soft model of geo-informational space

The properties of the UGIS model, that prove its usefulness, first of all, "include the presence of meaning (semantics), relevance (and novelty). These properties encourage UGIS to develop, to self-organize and compare one information to another one" [6], generate new knowledge, using including "interoperability is the ability of two or more information systems or components to exchange information and to use the information obtained as a result of the exchange"[3] [7].

In recent years, quite a lot of systems have appeared, that implement certain elements of the geo-informational space and claim to be "local" [8] UGIS within certain regions of Russia. There were studies of stratification of geo-informational space [1, 6], the formation of "semantic layers", however, in relation to one, "their" territory. The issues of interrelations and mutual influences of socio-economic objects were also studied, mainly within the same territory.

For further description, we note the requirements formulated in official documents [5,7,9] for the model [5,7,9] for the *model* (according to the above terminology) of the unified geo-informational space, in relation to a specific territory.

Model named at present as "The unified geo-informational space consists of the following main components:

— information resources containing data, information and knowledge recorded on the appropriate media;

— organizational structures that ensure the functioning and development of a unified information space, in particular, the collection, processing, storage, distribution, search and transfer of information;

— means of information interaction between citizens and organizations that provide them with access to information resources based on appropriate information technologies, including software and hardware and organizational tool and regulatory documents" [9].

For coordinated work of UGIS model all its components must have interoperability, which is interpreted as "the ability of two or more information systems or components to exchange information and use the information obtained as a result of exchange" [7]. And taking into account the fact that information systems of the UGIS model should not be interoperable, and although they "work according to independent algorithms, do not have a single control point, and the overall management is determined only by a single set of standards — the interoperability profile" (p.3.1.9, [7]), we have to deal with System of Systems [10]. Accordingly, the task appears to determine the requirements for these standards, criteria for their adequacy to the problems being solved, on the one hand, and the adequacy of the functional relationships of the real UGIS and its model at least at the level of semantic layers.

The variant of semantic classification for UGIS layers may be set by the following table 1.

Table 1. **Classification of the measurable layers of UGIS model**

Dependency	**Classes**
On time ***t***	static
	dynamic
On the dimension of the modeling object	point
	linear
	polygonal
On the changeability of significant aggregated object properties $\boldsymbol{S_i}$ within the boundaries of its spatial position	objects with permanent properties
	objects with variable properties
On the function of spatial interaction $\boldsymbol{F_V}$	autonomous
	depending on the environment parameters within the territory
	depending on the environment parameters of the entire GIS

[1] Nefyodov S. P., Khlebnikova T.A. Technology for Creation and Updating of an Integrated GIS-environment. In: *Proceedings of the XXIII International Cartographic Conference*. 4-10 August, Moscow; 2007. Available at: https://icaci.org/files/documents/ICC_proceedings/ICC2007/html/Proceedings.htm (accessed 19.06.2020). (In Eng.)

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Dependency	Classes
On the form of the assignment of functional relations	analytical
	experimental
	statistical
	defined by experts
On type of visual representation	on geographical map
	on the map of Kohonen
	on a virtual image

Features of the nonlinear model of interaction of objects

The limited distribution of the interaction of objects can also be represented by a quadratic relationship, many researchers think this influence inversely proportional to the square of the distance from the object border — the so-called "gravitational" model [8,9]. In the generalized form of the model of spatial influence set by the membership function, it has the following dependence

$S(i,j) = S(i)\ (1-k(j)\ r^{n}(i,j)))$,

where n — order of the influence function.

Research has shown that for identification of physical processes of propagation (mutual influence) of objects, a soft model of propagation of this influence is convenient, which can have the form:

$S(i,j)= S(j)\ \exp(-a(j)r(i,j)\ln b(j))$,

where $S(i,j)$, $S(j)$— degree of influence.

By changing parameters $b(j)$ and $a(j)$ within the framework of the accepted model, it is possible to adapt the influence functions to experimental data by performing parametric identification of the rate of change of this influence in the required ranges.

If the connectivity functions reflect the fact of mutual influence of socio-economic properties, the model parameters are usually determined by expert evaluation methods, or experimentally, using fuzzy neural systems. "The use of expert assessments, which are unclear, is a certain compromise. To determine these functions, as well as to determine the coefficients of significance or weight of the influence of objects, we use the method of transition from non-strict, approximate expert estimates of the impact of objects on the surrounding area to an analytical form of presenting these estimates based on the use of continuous standard membership functions"[6].

The set of works showed that soft models adequately describe the properties of functional interconnection [4, 11] of layers of geo-informational space and can be applied to implement pragmatic goals in the socio-economic systems of the region. To build a decision support system for regional development, it is advisable to use a methodology for assessing the socio-economic state of the territory as its aggregate (and multidimensional) property (potential) to ensure the harmonious implementation of production, economic and social activities. This potential of the territory is determined by features of the territory and the physical and socio-economic impact on the territory of unified geo-informational space by the entire set of objects, in the informational projections, are located both on this territory and outside of it in their information projections. The example of this fact is the so-called "virtual enterprises", the number of which is constantly increasing in the world [8].

To develop a detailed methodology for taking into account the mutual information influence of natural and artificial objects in different regions when assessing the socio-economic properties of the territory, it is necessary to form a developed knowledge base. The authors considered these issues when developing the principles of relationship of separate semantic layers on the example of the so-called digital plan schemes (DPS) [11].

Digital plan scheme as the simplest implementation of the model of interaction of socio-economic objects of the territory

The DPS itself can be used in space monitoring systems for objects in the study area to identify their condition through targeted processing of satellite images obtained from various sources using additional (ground-based) data and the formation of problem-oriented digital images (including virtual) of territories. The method of forming such an image, proposed by the authors, includes identifying objects on the ground based on the original map material, determining the classification code, obtaining metric information about these objects, corresponding *semantic* information about the media in the file system, specifying the nature of localization, size, and *quality information,* including the number of metric points and characteristics of the object, the value of their code and numerical values of these characteristics. In this case, repeat the specified operations for each of the objects are repeated. In order to ensure the universality of stored information, speed of processing and reliability of its results, vector design of the source and reference information in the form of basic semantic layers with geographical and spatial reference, as well as geometric reference data and geographical reference of the metric points of each object based on remote sensing data, aggregating the information of the semantic layers in accordance with the requirements of interoperability to the output information — thematic DPS [11].

The method of forming a cognitive two-dimensional space-a digital plan — scheme of the territory can be represented by schemes of algorithms of the main procedures for its implementation.

[1] The System performs data mining (IAD) on the presented images and forms the initial semantic layer of the DPS.

[2] The intelligent system creates a virtual image of territory objects that corresponds to a specific socio-economic task.

[3] The complex query is generated based on the properties of the elements of the created DPS. For properties of elements that reflect semantic content, the appointment (selection) descriptors using the thesaurus of subject area is produced, using the thesaurus of subject area, which are included in the conditional part of the query.

[4] The set of descriptions (solutions) of problems is formed, containing algorithms (operators) of the solution, which are ranked according to the selected fuzzy proximity measure.

[5] The algorithms corresponding to their ranked descriptions are selected sequentially.

[6] The situation of task descriptions obtained after each algorithm is analyzed. The decision is made to continue the IAD.

[7] The automated formation of the DPS is carried out.

Development of ways to account for geo-information in socio-economic systems

In the early stages of the theory of spatial planning and assessment of the success of placement of socio-economic objects, models were used in which the spatial factor was taken into account mainly through additional transport costs. Models of spatial placement

(Weber, Tunen, Lesh, Kristaller, etc.) were more demonstrative and informative than practical. Attempts at later stages of research to cover and take into account the most significant natural, infrastructural and socio-economic properties have transferred the problems of spatial planning to the plane of macroeconomics. In recent decades, there have been studies related to the transfer of solutions to such problems in the information plane.

In a number of studies, "gravitational" models of mutual influence propagation were proposed to solve local problems of managing socio-economic development of the territory [6, 12]. The corresponding economic and mathematical modeling provides new fundamental opportunities in solving problems of placement and subsequent logistics, which have a spatial nature. However, firstly, these models are general at this stage, and secondly, they take into account the influence of important, from an information point of view, objects only in this territory[4] [13,14].

Non-orthogonal models of interaction of socio-economic objects

Even at the beginning of the formation of spatial research of socio-economic orientation (as shown above, Kristaller, Lesh, etc.), many scientists paid attention to the prospects of using non-orthogonal (triangular and hexagonal) lattices in the spatial description of the properties of territories and objects located on them. In this study, when forming the concept of the Unified Geo-Informational Space, non-orthogonal lattices, including irregular ones (Delaunay triangulations), found their important place.

Many (more than three dozen) works of the authors are devoted to the description of useful properties of non-orthogonal lattices in the description of territories, individual objects on them, and morphological characteristics of semantic relief structures. We note in this paper one original approach to the use of such lattices for the identification of extended socio-economic objects.

Figure 1 shows an example of using the Freeman chain code to identify an object by its contour on a hexagonal raster.

Using the Freeman chain code for connectivity 6 (Fig. 1, a), the contours of objects are selected (Fig. 1, b).

In this case, the EV has six possible directions (Fig. 1, a), and the expression for calculating the next EV code has the form:

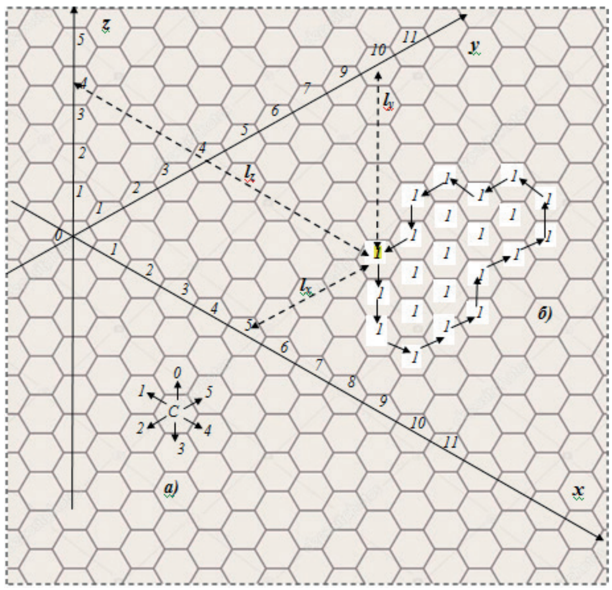
$$\gamma(i + 1) = \mathrm{mod}\ 6\ (\gamma(i) + k + \alpha), \quad (1)$$

where k — the number of neighboring pixels that belong to the object;

α = 2 – a six-part constant, and summation is made on modulo six.

Than, the x, y, and z coordinates for each point that belongs to the contour (Fig. 2, b) are determine, the starting points for traversing polygons are selected, which are used as the extreme ones: {min x(min y(min z))}. Thus, selected contour point having a minimum value z is selected, if there are several identical, the one that has the minimum value y is selected, if there are several, the one which has the minimum value x is selected.

Then, the circumvent is performed relative to these starting points of the external contour of the item, fixing the parametric description of the contour $x(s)$, $y(s)$, $z(s)$}, s =, where S is contour length in pixels. For the example shown in Fig. 1, b, these parametric descriptions can be presented in the form of Table 1 and Fig. 2.

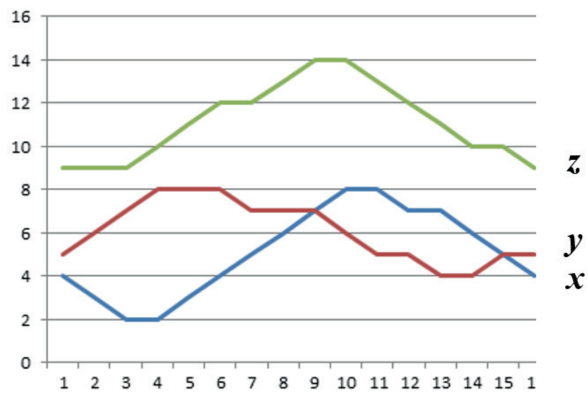


F i g. 1. Features of the hexagonal raster

T a b l e 1. **Indices of the coordinates**

Freeman code	1st reverse counter (x)		2nd reverse counter (y)		3rd reverse counter (z)	
	+	–	+	–	+	–
0	0	0	1	0	1	0
1	1	0	0	1	0	0
2	1	0	0	0	1	0
3	0	0	0	1	0	1
4	0	1	1	0	0	0
5	0	1	0	0	0	1

[4] Khramov V.V., Gvozdev D.S. Intellectual information systems: Intellectual data mining. Rostov State Transport University, Rostov-on-Don, 2016. (In Russ.)



F i g. 2. Parametric description of the contour

The Laplace transformations of these parametric descriptions allow you to generate features for recognizing the outline of an object[5] [15-17].
The calculated coefficients are consistently used as input parameters of the neural network. A pre-trained three-layer neural network receives an array of shape attributes sequentially as input. Taking into account information from all sources, a decision is made to identify the object [18,19].
In addition, using non-orthogonal rasters the integrity and dynamics of the development of a single geo-informational space as a complex System of Systems and the new properties inherent in this integrity, in particular, emergence, are still not taken into account [20-23]. At the moment, no research has been conducted on the impact of a holistic UGIS on the functioning of a separate information object in a given territory.
To solve pragmatic problems of spatial planning and management, it is necessary to perform two types of tasks: analysis, when the existing socio-economic condition of territories is studied [15], and synthesis, when the problem of territorial placement of various socio-economic and technological object is solved [24-27].

Conclusion

The analysis of existing approaches to spatial modeling of information objects of socio-economic systems in order to manage their state and development is carried out. The trends in research and modeling of information connectivity of objects of these systems are identified, and the problems of increasing the efficiency of economic and social activities are shown, the solution of which will allow to harmonize the design and management of territorial complexes.
The main directions of research in the field of development of manageability of territories based on the use of the properties of the unified geo-informational space are shown.

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About the authors:

Vladimir V. Khramov, Leading Research Scientist, Southern University (IMBL) (33a/47 Nagibina Ave., Rostov-on-Don 344068, Russia), Ph.D. (Engineering), Associate Professor, ORCID: http://orcid.org/0000-0003-1848-8174, vxpamov@inbox.ru

Sergey O. Kramarov, Chief Researcher of the Institute of Economics and Management, Surgut State University (1 Lenina St., Surgut 628412, Tyumen Region, Russia), Dr.Sci. (Phys.-Math.), Professor, ORCID: http://orcid.org/0000-0003-3743-6513, maoovo@yandex.ru

Sergey A. Roshchupkin, Associate Professor of the Mathematical Modeling and Computer Technology Department, Institute of Mathematics, Natural Science and Technology, Bunin Yelets State University (28 Kommunarov St., Yelets 399770, Russia), Ph.D.(Phys.-Math.), Associate Professor, ORCID: http://orcid.org/0000-0002-1672-4383, roshupkinsa@mail.ru

All authors have read and approved the final manuscript.

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Об авторах:

Храмов Владимир Викторович, ведущий научный сотрудник, ЧОУ ВО «Южный университет (ИУБиП)» (344068, Россия, г. Ростов-на-Дону, пр. М. Нагибина, д. 33А/47), кандидат технических наук, доцент, ORCID: http://orcid.org/0000-0003-1848-8174, vxpamov@inbox.ru

Крамаров Сергей Олегович, главный научный сотрудник, БУ ВО «Сургутский государственный университет» (628412, Россия, г. Сургут, ул. Ленина, д. 1), доктор физико-математических наук, профессор, ORCID: http://orcid.org/0000-0003-3743-6513, maoovo@yandex.ru

Рощупкин Сергей Александрович, доцент кафедры математического моделирования и компьютерных технологий, институт математики, естествознания и техники, ФГБОУ ВО «Елецкий государственный университет им. И.А. Бунина» (399770, Россия, Липецкая область, г. Елец, ул. Коммунаров, д. 28), кандидат физико-математических наук, доцент, ORCID: http://orcid.org/0000-0002-1672-4383, roshupkinsa@mail.ru

Все авторы прочитали и одобрили окончательный вариант рукописи.