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MODERN RESEARCH TOOLS ON THE "SOCIETY-NATURAL ENVIRONMENT" SYSTEM IN SOVIET GEOGRAPHY

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ABSTRACT

Potential uses of geographic information systems in research on the "society-natural environment" system are examined. New advances in Soviet geoinformation technology and needs for developing spatio-temporal modeling methods and computer "expert systems" are described. New techniques for representing the spatial characteristics of anthropogenic natural environment systems are characterized.

INTRODUCTION

Issues of environmental protection and rational use of natural resources receive great attention the world over. These problems are being discussed and tackled on the global, national, and regional scales. In our country, in particular, they have been reflected in State programs for developing the "complex of economic, organizational, and legislative measures for expedient and beneficial control over increasingly complex relations in the man-society-nature system" [1]. These concerns are within the framework of research into whole systems, the subject of inquiry in a number of sciences, geography included. At present there is a controversy as to whether it is ecology or geography that plays the key role in the study of anthropogenic-environmental systems. This problem is, in our opinion, clearly interdisciplinary.

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Geographic research fundamentally studies territory from physical, social, and economic geographic viewpoints, in light of ecological circumstances. This research helps develop recommendations concerning resources management, economic organization, patterns of settlement, and natural conservation. Keeping in mind A. G. Isachenko's argument [2] that socio-economic analysis does not exhaust the diversity of interactions in the "society-nature" system (and leaving aside the study of natural regularities), we shall discuss the "society-natural environment" system.

A number of terms which delimit the subject area of anthropogenic-environmental systems are proposed. One of these, "social ecology," has been used by many scientists, including geographers [3-11], in preference to available alternatives [3, 7, 11].

GEOINFORMATION SUPPORT

As with any research, study of anthropogenic-environmental systems involves collection and evaluation of the available initial data, once the objectives and problems have been spelled out. Yet such "information support" becomes problematic because of an interesting situation in geography: the information *explosion* exists side by side with information *hunger*. Some geographers complain about a *lack* of information, which results in simplifying the phenomena under study, hypothesizing too much, producing low-quality results, etc. Others, on the contrary, cannot cope with the vastness of data. The paradox is only an apparent one. More often than not, accumulated information is difficult to access and exchange, and is often shelved, literally and figuratively, because of departmental and even personal barriers. This, in our opinion, is one of the main constraints on geoinformation work, along with insufficient application of electronic technology. Unfortunately, even when plenty of information is available, it seldom is used rationally.

Although geographic information systems (GISs) have been created and applied for more than a quarter of century around the world, Soviet researchers regard these systems as something new in geography. For example, the first monographs on the subject appeared in our country as late as in the mid-1980s [12, 13].

GISs in their modern form have evolved from information retrieval systems and cartographic databanks. GISs were initially envisioned as the first stage of automatic map compilation, and were later extended to include mathematical-cartographic modeling and automatic map reproduction "blocks." GISs were then used in "map application," treating the map as a tool in more general geographic analysis for various users (e.g., [14]). Nearly all of the hundreds of GISs now in use around the world rely upon cartographic data as their main source of information, or have as their principal function the compilation of maps.

Note that the GIS and the map have much in common. For example, the GIS structure contains "territorial and sectoral" (thematic) blocks [12], and "metric and thematic" ones [15], called identification and classification blocks, respectively (e.g., [16, 17]). In the cartographic model these blocks may correspond to metric characteristics of the maps' base and a special or thematic category. In GISs, databases are processed and characterized in the computer by means of a system of symbols carrying conceptual information, registering spatial distribution, etc.

GISs are valuable outside of cartography itself in a variety of geographically based integrated systems studies in other sciences (geology, soil science, etc.). These studies, in turn, are essential for the overall study of anthropogenic-natural systems. This fact is especially emphasized in the model of knowledge underpinning GIS. Such a broad perspective on GIS is sometimes counterposed by a narrowly informational, solely technical approach, in which GIS is considered to be a filing system for accumulating and storing geographic data, a tool for identifying and describing the earth's surface and objects on it. This was an aim of geography in the past centuries, only now being implemented at the modern level of computer technology. As was aptly observed by Openshaw [18], this is merely a return to nineteenth century description by electronic means.

Instead, GISs may be thought of as interactive systems capable of collecting, systematizing, storing, processing, evaluating, and disseminating information, and as a tool for acquiring *new* knowledge about spatio-temporal geographic phenomena. Most of these systems are automated. One should note, however, that it may be possible in principle, if hardly expedient, to construct a GIS without the aid of computers.

The possibility of developing knowledge-based, semi-intelligent GISs, has raised questions about the potential for developing broadly integrative systems (e.g., [19, 20]) for solving problems of global environmental modeling and monitoring. The solution of problems in planning and resource management, such as the determination of ecological impacts of large economic projects [21-24], may require data at a finer level of detail (as in the WDDES project). For environmental sciences, information is said to be required at a one-kilometer level of resolution the world over [25].

Knowledge base development is currently under way. As M. V. Panasyuk notes [26], "Of special importance for geographers is the development of GIS with respect to extending intelligent functions, such as organization of interfaces in a limited natural language, automatic construction of programs (models) for set goals, understanding and interpretation of situations in the field of geographic environment management, etc. All this leads to the necessity of storing in GIS not simply the datasets, but, rather, the systems of knowledge reflecting our understanding of the geographic environment." In particular, the notion of frames is used in knowledge models. Here some semantic structure is produced in a computer. This structure resembles a crystal lattice whose nodes are filled with the frames corresponding to some definite notions. Changes in the frames engender responses of the whole system, with corresponding changes in the state and behavior of the system [27]. Such developments are in progress in the field of artificial intelligence [28-30]. We shall return to this subject in the subsequent exposition.

Judging by the literature, specific-problem-oriented GISs are currently most effective; yet the integrated problems of research into anthropogenic-natural environment systems require the development of general-purpose GISs with the capabilities of quick adjustment for solving both partial and more general problems (though a considerable increase in the cost of the corresponding GIS should be expected in the latter case). The majority of systems, however, will, in our opinion, be specific-problem-oriented but capable of mutual integration for addressing larger-scale problems.

The problems of territorial-temporal ordering of information—important for unifying the collection of data and establishing appropriate correspondences between the amount of data to be collected and the size of system under study—are as yet unsolved. In social and economic geography, data restricted to points and lines defined by a coordinate system is often transformed according to administrative or territorial divisions, or according to the dictates of natural phenomena, such as the contours of river basins. Analysis of environmental phenomena by administrative region is sometimes justified by appeals to regulatory requirements planners must adhere to (or think they must) or to the simple absence of data that is *not* organized by administrative region.

For organizing the data structure in GISs, the vector and raster formats are applied, sometimes in combination. Some interesting developments of these forms are available now. Thus, K. Brassel proposed a topological structure as a development of the vector format [31], and F. Bouille proposed the hypergraph-based data structure (HBDS) as a development of the raster format [32]. Since the raster representation of data requires large memory arrays, some specific algorithms have been developed that allow for use of area-variable networks [33-35]. To characterize the "society-natural environment" system, some special-purpose networks will apparently have to be designed. These networks may vary, for example, depending on the degree of anthropogenic impact on the natural environment [36], and should take into consideration the boundaries of anthropogenic-natural systems [37], without restricting the latter by the limits of either administrative-territorial or environmental units [38] (river basins [39] in particular).

MODELING PROBLEMS

Data processing is implemented on the basis of a system of mathematical models. Three types of models may be distinguished in geography. The mathematical models of the first type are constructed without a spatial organization of phenomena, and the results of implementing the models are not subjected to mapping. In the second type of models the results are mapped, but the spatial aspect is not taken into account at the stage of implementing the mathematical algorithms. And, finally, in the third type of models the mathematical calculations cannot be implemented without taking into account the spatial positions of phenomena [40]. The first type of models may be illustrated by modeling the production input-output ties of industrial enterprises, the second by cartographic representation of categories of agricultural land use, and the third by calculating "settlement field potential" characteristics.

The continued development of "spatial statistics" methods is important [41, 42], since much of the available mathematical statistics is not suitable for geographic purposes. The development of spatial mathematics (and, especially, spatial modeling) methods should be pursued; spatio-temporal modeling methods should be pursued even more strongly, considering the spatio-temporal character of many crucial geographic phenomena.

Mathematical cartographic modeling (involving the systems combination of mathematical and cartographic models within a "map compilation-use" system) is one kind of such spatio-temporal modeling. The combination modeling exploits the strengths of each component (for the mathematical component, better formalization and automation of studies; for the cartographic one, better spatial visualization). It should be borne in mind that in the course of mathematical-cartographic modeling one may construct not only elementary models consisting of a single link, but also complex ones, using, for example, chain-like, network, and tree-like topologies [43], where the mathematical models and maps are used alternatively, to allow for optimization of the modeling process, error detection, and correction. The existence of a considerable number of algorithms and concomitant advances in computer technology have made possible multivariate problem formulation, information support, and display of results, mainly in graphic form.

The problems in classifying anthropogenic-natural environment systems also deserve mention. One may agree that "mankind is now at the threshold of a new scientific and technological revolution associated with using informatics and artificial intelligence as a productive force of society. Therefore, classification as a method of generalizing and organizing knowledge acquires special significance. It is necessary for establishing the foundation of informatics and artificial intelligence. This foundation is constituted by knowledge bases which should include the knowledge accumulated by mankind in the spheres of science, technology, production, and culture. The time has come to sharply accelerate the construction of classifications, upgrade their quality and lower the costs of their production" [44].

The successes of geography in this field are well known; the new problems, however, require reevaluation and development of the theory and methods of classifications as applied to the "society-natural environment" systems. Emphasis should be given to the development of classifications on the basis of fuzzy sets [45]. In this case the assigning of territorial units to various taxa is estimated by the "degree of belonging" varying from 0 to 1. Special algorithms and geographic application methods have been developed [46-50].

CREATION OF ARTIFICIAL INTELLIGENCE

Artificial intelligence applications in geography have emphasized the simulation of some aspects of human thinking by means of so-called heuristic programs or by creating rudimentary "intelligent" systems [20, 22]. Some scientists believe that developments in the field of artificial intelligence are as important as all preceding scientific investigations [51]. Yet, advances in geography are still more modest than those in other domains, although some interesting results have already been obtained both abroad [52, 53] and in our country [54, 55]. In particular, from the general perspective of artificial intelligence research [28, 30, 56], it may be possible to assess phenomena approximately without decomposing them into parts amenable to traditional modeling. In this case the approximate description is given, whose details have to be "improved" by using the heuristic computer programs. The network of links between the "parts" of complex geographic phenomena, clearly assumes decisive importance here.

Academician G. S. Pospelov evaluated artificial intelligence research in four areas (simulations of creative thought processes, knowledge-based expert systems, novel computer-architectures, and robotics) [29]. He found of special interest the potentialities of advanced·information retrieval systems, computation-logic systems designed to implement problem-oriented "libraries" of models of geographic problems of various levels of complexity, and expert systems. The latter are especially useful when the phenomena under study cannot be formalized by means of mathematical models. Pospelov writes that "the structure of an expert system is usually composed of the following elements: an interface; a knowledge base which accumulates facts and production rules; a working memory area where the state of a system is fixed in the process of inference; a system for accumulating knowledge (e.g., from experimental data), and, finally, a system which explains to the user how and why this or that conclusion was drawn" [29, p. 93]. Expert system applications were reviewed by Bruking, Johnes, Kox, et al. [57], and those relevant to geography by Robinson, Frank, and Blaze [23]. In the field of the "society-natural environment" system research, the expert systems could be used in classification of states of anthropogenic natural environment systems, with special attention to regions experiencing ecological crises or catastrophes, and to rational forecasts of ecological changes.

GRAPHICAL MEANS FOR SYSTEMS REPRESENTATION

Graphical representation of systems is essential for geography. Scanning, satellite imagery, and other media are successful in this regard, especially for studying the dynamics of, for example, anthropogenic impacts on the natural environment [58]. The visualization of research results has been intensively developed in recent years, especially due to automation of the "map compilation-use" system. In the field of image reproduction automation, the necessity of rapid readjustment and rearrangement of technical systems and more flexible use of cartographic software has been recognized [59].

Representation of spatio-temporal characteristics of anthropogenic natural environment systems should also be mentioned. Slide-films and cartographic cinema and videofilms now extend the range of tools beyond the sequential examination of maps representing the system under study at different time periods. Beruchashvili describes the advantages and limitations of such pictorial representations of the dynamics of Georgian landscapes at one-day intervals [60]. Molochko discusses alternative representations of the dynamics of industrial pollutant emissions into the atmosphere [61]. Dutton surveys the spatio-temporal holographic imaging of settlement in the United States over 180 years [62], showing the whole process of population "spreading" from the east to the west. This technique is useful, for instance, in simulating pollution diffusion in the atmosphere or hydrosphere.

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