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# Multilayer Geoinformation Data Access and Representation Model

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**Abstract:** In the study, the researchers consider the constraint of the existing geoinformation systems that is the use of one dominating model of graphic or spatial data representation and processing. Typically, the geospatial information processing (coordinate data area symbols, character and quantitative attributes) in the vector or raster models is to be complemented in accordance with the relations and connections between objects. However, the models do not support the full set of operations required for topological relations registration and filing. To add functionality to the geoinformation systems there has been developed the multilayer object representation model. It includes vector primitives for description of objects and the relations between them. These relations are defined in the form of graphs. This feature makes it possible to get more detailed information and to computerize the computation process of retrieval and control of topological relations and connections between objects.

**Key words:** Geoinformation data, topology, relations, database, complexing computing facilities, model

## INTRODUCTION

The Geoinformation System (GIS) is a computer system for collecting, storing, structuring and processing spatial-linked data. Historically originating in the course of the graphic and decision-making systems development the modern GIS systems have become much more complicated than the ‘software for geology, geography, cartography, etc.’(Wu *et al*., 2005). The GIS focuses on problem-analytical and optimization tasks connected with the visualization or graphical representation of spatial objects and connections and relations between them (Wu *et al*., 2005; Maiorov, 2014; Kumar, 2015). GIS are actively used in the field of ecology, environmental management, urbanization, geoinformation data mining, modeling of geo conflicts of various localization levels, etc. (Maiorov, 2014; Gutbell *et al*., 2018; Breunig *et al*., 2016). The GIS makes it possible to compose complex combined queries to data including a wide set of spatial relations between objects.

The problems of the development of mathematical models for GIS are studied by many scientists (Breunig *et al*., 2016; Wang *et al*., 2017; Jamali *et al*., 2017; Thomsen *et al*., 2008). In their research work the scientists pay attention mainly to the problems of transformation of matrix representations of graphics objects into a compact vector form. However, such mathematical methods separately do not provide the creation of the optimal solution when processing various types of geoinformation. This restriction determines the urgency of development of a generalized data domain model which will unify various types of information representations in GIS. Such generalized model will allow to unifying the computational processes of searching and control of topological relations and connections between objects and to using the obtained more detailed (supplemental) information in decision making.

## MATERIALS AND METHODS

**Basic operations; Problem definition:** The processing of the digital maps (plans) is one of the most important application fields of GIS. Here are the basic data handling operations performed in the Geoinformation Database (GDB):

- Request processing
- Associative search using mixed attributes
- Joining and visualization of objects and attributes
- Performance of common computation tasks (determination of lengths areas, volumes and heights of objects)
- Reporting, etc.

The standard (attribute) DBMS turn out to be almost useless when graphics (spatial) objects are concerned. A graphics object is characterized by reference to a certain coordinate system. The object is defined with a set of

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coordinates. Besides an object can have a certain shape and size which can be specified by a set of coordinates of characteristic (distinguished) points or polygons. Among such objects there are buildings, land, wells, roads, ponds forests and other natural and man-made zones, etc.

The GDB management system has been implemented to perform the basic operations in GIS. The typical elementary object on the execution level is a matrix of pixels and quantitative measures (attributes) for certain groups of pixels.

**The main components of the GDB are:**

- Map (structured collections of spatial objects of various geometrical types)
- Layer (topic (user's) views of a map)
- Table (sets of record of geoinformation objects and relations between them)
- Model (presentation of outputs combining various forms of spatial (graphic) and tabular information display)

The main objective of the generalized data domain model of is a compact and unified representation of various GDB components for basic operations performance and generating of supplemental information in GIS:

$$\text{Object} = \{\text{Map} \cup \text{Layer} \cup \text{Table} \cup \text{Model}\} \rightarrow \min$$

**Graphics objects presentation models:** In the general case, the spatial (coordinate) data models can be represented in raster or vector data models.

In the raster models, the initial geoinformation object is displayed as spatial cells that form a regular network of points. Each cell of the raster model corresponds to a certain area of the object surface which is similar in size but has different characteristics (such as color, density). In the raster models a 2D space element (a pixel (cell)) is used as an atomic model. The model cell contains one value averaging the characteristics of a certain object surface area. The ordered collection of atomic models forms a raster which in its turn is a model of a geoinformation object.

The raster model displays the information on what is located in one or another point of the territory. Consequently the main purpose of raster models is the continuous surface mapping. The amount of memory required for storage of geoinformation object spatial cells is the highest one. Therefore, the methods of compact description of heterogeneous information in spatial cells are of great interest. According to such researchers as K. Fu, J. Lyger, D. Finner one of the promising methods of the space-saver storage of graphics objects is their description in the form of a 2D production system generating a class of objects and making it possible to naturally implement the basic operations of changing the object geometric properties.

The vector data models are constructed on vectors that occupy part of the space in contrast to the raster models that occupy the entire space. In this case, objects are created by connecting points with straight lines, arcs of circles, polylines.

Area objects (areas) are defined by sets of lines. The effective processing of objects in the vector GIS is not connected with abstract lines and points but with objects containing lines and areas that occupy a spatial position as well as with complex relations between them. Therefore, the complete vector data model in GIS consists of a combination of the following main parts:

- Geometric (metric) objects (points, lines and polygons)
- Attribute data-attributes associated with objects
- Connections between objects

The vector models of graphics objects use a sequence of coordinates forming a line as an atomic model. The vector model of data representation is the most effective for the implementation of operations on linear and point objects.

The topological models are a type of the vector data models. In a general sense the term 'topology' means that the relations are stored in an object model. The topological relations are based on comparing the intersections of borders and internal areas of closed objects. The creation and processing of geometric primitives along with connections form the basis of the topological model.

The binary topological relation between the two objects A and B can be described as the intersection of point-sets of the object A (the set A0 is the inner area, the set dA is the boundary) and the object B, respectively (B0, dB):

$$RT(A, B) = |A0, B0, dA, dB|$$

In the simplest case, the elements of the topology included in the description of the GIS data models are determined by the relations between the elements of the main types of geoinformation data. The topological models allow to representing the map elements and the entire map as a whole in the form of graphs which creates the necessary basis for the structured setting of topological relations. Areas, lines and points are described with boundaries and nodes (arc/nodal structure). Each boundary goes from the initial node to the final one and it is known what areas are on the left and right.

## RESULTS AND DISCUSSION

**Multilayer model of graphics objects presentation:** The well-known concept of the graphics objects layerwise representation has been further developed in GIS for the multilayer representation of a geoinformation object. The principal difference is that the layers in GIS can be both vector and raster ones. At the same time the vector layers must necessarily possess one of the three characteristics of the vector data, i.e., the vector layer must be defined as a point, linear or polygon one. Another important difference of the layer representation of the geoinformation vector data is that they are object, i.e., they contain information on objects as a whole and not as single elements of an object as it is in the raster objects. The layers in GIS are a type of the digital map models that are constructed on the basis of combining (typing) spatial objects that have common properties. Among such properties there can be belonging to the same type of coordinate objects (point, linear polygonal ones), belonging to the same type of spatial objects (residential buildings, underground utilities, administrative boundaries, etc.), display at the map in the same color. The belonging of an object or a part of an object to a certain layer makes it possible to use and add group properties to the objects of the given layer which creates opportunities for the parallel processing of the typed objects of the layer.

Figure 1 shows a typical model of the data access arrangement in GIS. The model includes an attribute data analysis block (text/context analysis block), a geo basics for a graphic and geographical basis storage (geo basics), a graphic data analysis block (graphic data analysis block), a geoinformation database (Geo DataBase-GDB), a control system (control system). In the typical model of the data access arrangement in GIS the raster layers (raster layer) and the vector layers (vector layers) are connected in series which does not allow to obtaining raster and vector properties of graphics objects simultaneously.

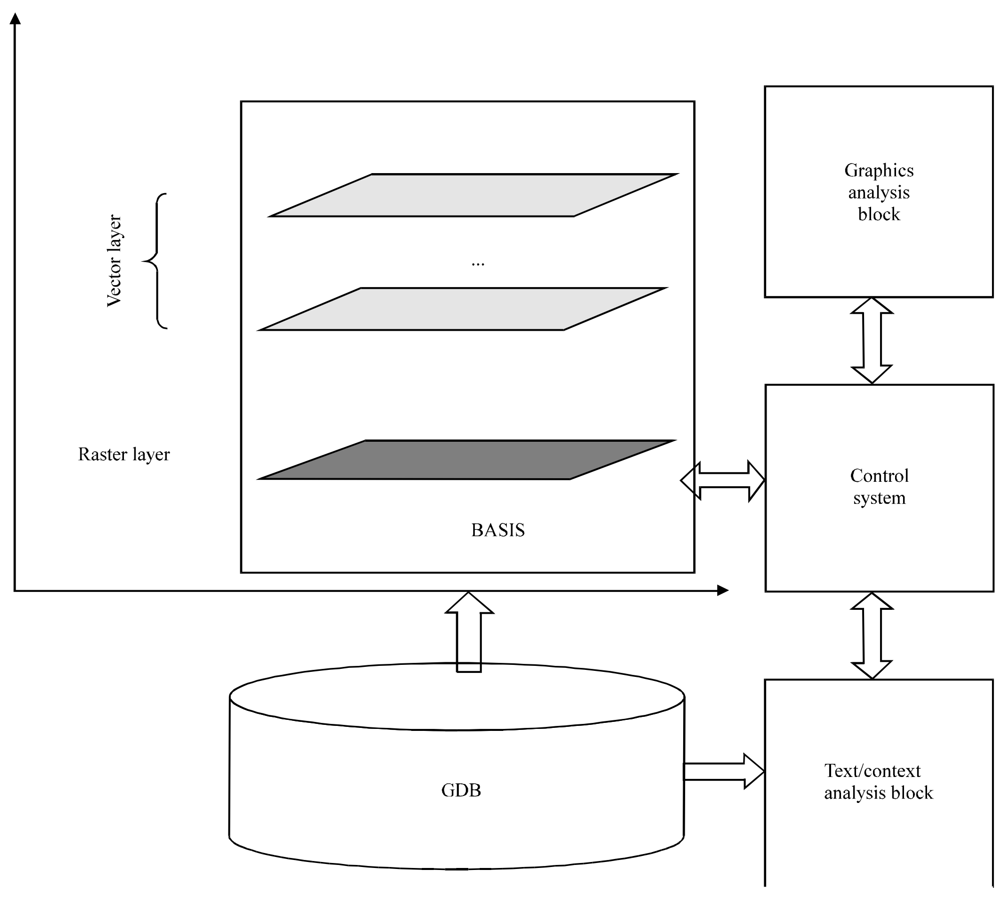


Fig. 1: Typical model of data access arrangement in GIS

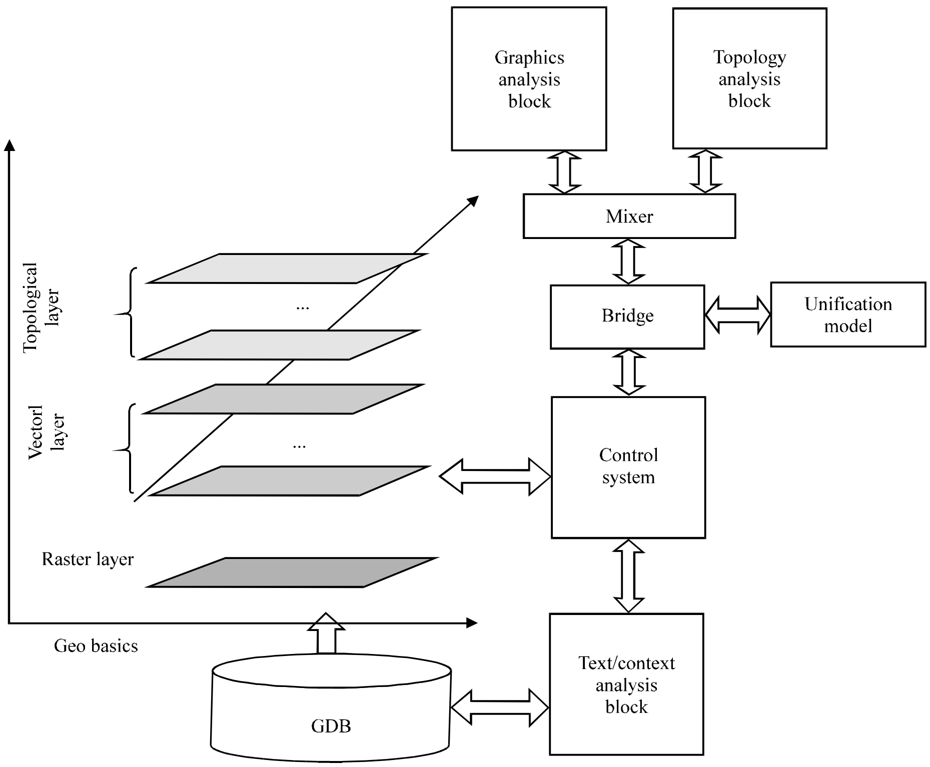


Fig. 2: Multilayer data access arrangement in GIS

The peculiarity of the multilayer model of data presentation and visualization is that GIS allows to working only with the vector typed layers and the raster is used as a substrate. This approach leads to the creation of a diverse set of vector projections that form layerwise vector spatial objects. The multilayer organization of a geoinformation object in the case of a flexible layer management mechanism makes it possible to significantly simplify the analysis and processing of the map data using data selection operations, group scaling, relocation, copying and setting of objects in a common layer. You can also impose a ban on editing the layer objects, prohibit their viewing or make them invisible thereby ensuring the selective 'transparency' of a geoinformation object.

The introduction of topological properties makes it possible to add functionality to GIS. This gives the opportunity to obtain a new layer with the identified relations or characteristics between objects on the basis of the spatial analysis using logical operations. This synergistic effect creates the basis for data mining of complexly structured geoinformation data.

The traditional object-oriented or topological approaches do not allow to efficiently processing graphics and semantics simultaneously in GIS which is difficult due to the huge amounts of information. It means that for GIS it is necessary to develop the unification methods with the possibility of identifying any necessary topological connections between objects and classes of objects. The classical approach to identification of topological relations is applied only for primitives or object instances. The reason of it is that the well-known GIS are not fully object-oriented ones. The object-oriented systems process not only instances of objects but their classes as well and these classes are connected into multi-level constructions by implementing the mechanism of properties inheritance.

Figure 2 shows the extended data access model in GIS. The distinctive feature of the intelligent GIS is a gateway element (bridge) and a graphic complexor of the graphic data (Mixer) which provide the simultaneous access to the raster, vector and attribute data. The unification models (unification models) allow to connecting heterogeneous parts into a single object with the required degree of refining which makes it possible to carry out the comprehensive analysis and interpretation of heterogeneous data in GIS.

## CONCLUSION

By means of the developed generalized model of representation of graphics objects and relations the topological characteristics can be visualized in the form of connected graphs. The graph maintains the structure of the model with all nodes and intersections. The vertices of the graph describing the map model correspond to the intersections of the extended objects and the edges of the graph describe the connections and relations between them. The topological characteristics of area objects can be represented using the coverage and adjacency graphs that allows to automating the computation process.

## RECOMMENDATIONS

Thus, the developed generalized model is the basis for automation of processing of topological relations between spatial objects.

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