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GEOMATICS I

GIS

CONTENTS

The notes on GIS provide the basic concept useful to understand in which way this technique can be used to merge together data of different nature in a common spatial reference system to exploit possible causes of diseases.

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GEOMATICS I

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1. Introduction

At all times, knowledge about the spatial orientation of physical objects or, simply speaking, their geographical position was essential for people. For example, primitive hunters have always known the whereabouts of their prey, and the life or death of explorers and pioneers directly depended on t ir knowledge of geography. Likewise, modern society lives, works, and collaborates based on information about who is located and where. Applied Geography in the form of maps and information about space helped to make discoveries, promoted trade, improving the safety of human life for at least the past 3000 years, and maps are among the most beautiful documents that tell the history of our civilizations (Fig. 1).

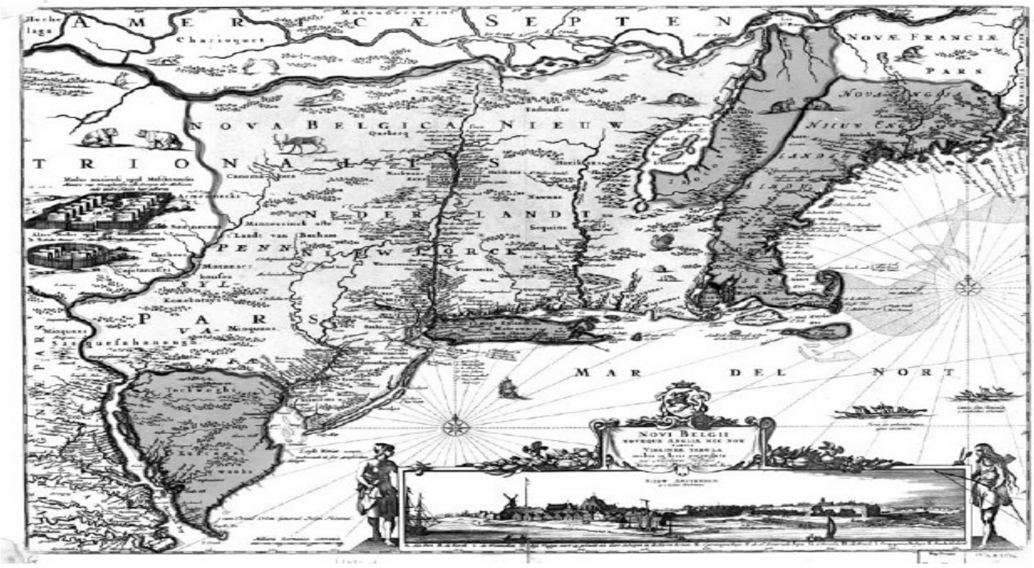


Fig.1 - Map of New England drawn in 1685 by Nicholas Whischer.

Most often, our knowledge from the field of geography is applied to solving everyday problems, such as finding the right street in an unfamiliar city or calculating the shortest walking path to your place of work. Spatial information helps us efficiently produce agricultural products and industrial goods, heat, and electricity, and arrange the entertainment we enjoy.

For the last thirty years, humanity has intensively developed tools called geographic information systems (GIS) designed to help expand and deepen geographical knowledge. GIS allows us to accumulate and use spatial data. Some GIS components are exclusively technological skies; they include state-of-the-art spatial data repositories, advanced telecommunications communication networks, and advanced computer technology. However, there are other straightforward methods of GIS. For example, they use a simple pencil and a piece of paper to verify fictitious cards.

Like many aspects of our lives over the past fifty years, the process of accumulating and using spatial data has been dramatically transformed by the intensive development of microelectronics. The GIS software and hardware platform is the leading technological result since the acquisition and processing of spatial data were significantly accelerated in the past three decades and continue to develop relentlessly.

2. General information about Geographical Information Systems

2.1. The concept of geographic information systems

A geographic information system or geoinformation system (GIS) is an information system that provides the collection, storage, processing, analysis, and display of spatial data and related non-spatial data, as well as obtaining information and knowledge about geographic space based on them.

It is believed that geographic or spatial data make up more than half of the volume of all circulating information used by organizations engaged in various activities that need to consider the spatial distribution of objects. GIS is focused on providing the possibility of making optimal management decisions based on spatial data analysis.

The keywords in the GIS definition are spatial data analysis or spatial analysis. A GIS can answer the following questions:

- What is in the given area?
- Where is the area that satisfies a given set of conditions?

Modern GIS has expanded the use of maps by storing graphic data in separate thematic layers and the qualitative and quantitative characteristics of their constituent objects in the form of databases. Such an organization of data, in the presence of flexible mechanisms for managing them, provides fundamentally new analytical opportunities.

2.2. "Data", "information", "knowledge" in geographic information systems

Concretizing the terms "data," "information," and "knowledge" about operating them in an information system, it can be noted that, having much in common, these concepts differ in their essence.

Data is a set of facts known about objects or the results of measuring these objects. The data used in GIS are characterized by a high degree of formalization. Data is, as it were, a building element in creating information since it is obtained in data processing.

About GIS, information is understood as a set of data that determines the measure of our knowledge about an object.

In this context, knowledge can be viewed as the result of the interpretation of information. The most general definition: knowledge is the result of cognition of reality, which has been confirmed in practice. Scientific knowledge is distinguished by its systematic nature, validity, and high degree of structuring.

Information systems can be seen as an effective tool for obtaining knowledge.

Differences between the terms "data," "information," and "knowledge" can be traced in the history of the development of technical systems. First, data banks appeared, later information systems, then knowledge-based systems appeared - intelligent systems (expert systems).

Currently, the software market presents several types of systems that work with spatially distributed information; in particular, these include methods for computeraided design, automated mapping, and GIS. Compared with other automcomputerizedems, GIS has developed tools for analyzing spatial data.

2.3. Generalized functions of GIS systems

Most modern GIS performs complex information processing using the following functions:

1. Entering and editing data;

2. Support for spatial data models;

3. Storage of information;

4. Transformation of coordinate systems and transformation of cartographic projections;

5. Raster-vector operations;

6. Measuring operations;

7. Polygon operations;

8. Operations of spatial analysis;

9. Various types of spatial modeling;

10. Digital relief modeling and surface analysis;

11. Output of results in different forms.

2.4. GIS classification

GIS systems are developed to solve scientifically and applied problems of monitoring environmental situations, rational use of natural resources, as well as for infrastructural design, urban and regional planning, taking prompt measures in emergencies, etc.

Many tasks that arise in life have led to the creation of various GIS, which can be classified according to the following criteria:

By functionality:

- full-featured general-purpose GIS;
- specialized GIS is focused on solving a specific problem in any subject area;
- information and reference systems for home and information and reference use.

The architectural principle of their construction also determines the functionality of GIS:

- closed systems - do not have expansion options; they can perform only the set of functions that is uniquely defined at the time of purchase.
- open systems are easy to adapt and expandable, as they can be completed by the user using a special apparatus (embedded programming languages).

By spatial (territorial) coverage:

- global (planetary);
- nationwide;
- regional;

- local (including municipal).

By problem-thematic orientation:

- general geographic;
- environmental and nature management;
- sectoral (water resources, forest management, geological, tourism, etc.);

By way of organizing geographic data:

- vector;
- raster;
- vector-raster GIS.

2.5. Data sources and their types

The sources of data for the formation of GIS are:

- cartographic materials (topographic and general geographical maps, maps of administrative-territorial division, cadastral plans, etc.). Information received from maps is georeferenced, so using it as a base GIS layer is convenient. If there are no digital maps for the study area, then the graphic originals of the maps are converted into digital form.
- remote sensing data (RSD) are increasingly being used to build GIS databases. ERS primarily includes materials obtained from space carriers. For remote sensing, various technologies for receiving images and transmitting them to the Earth are used; pages of imaging equipment (spacecraft and satellites) are placed in different orbits and equipped with other equipment. Thanks to this, images that vary in visibility and detail display objects of the natural environment in different spectral ranges (visible and near-infrared, thermal infrared, and radio range). All this leads to various environmental problems solved using remote sensing. Remote sensing methods include aerial and ground surveys and other non-contact methods, such as hydroacoustic surveys of the seabed relief. The materials of such surveys provide both quantitative and qualitative information about various objects of the natural environment.
- materials of field surveys of territories include data from topographic, engineering, and geodetic surveys, cadastral surveys, geodetic measurements of natural objects performed by levels, theodolites, electronic tacheometers, GPS receivers, as well as the results of surveying territories using geobotanical and other methods, for example, research on animal movement, soil analysis, etc.
- statistical data contain data from state statistical services for various sectors of the national economy, as well as stationary measuring observation posts (hydrological and meteorological data, information on environmental pollution, etc.)).
- literary data (reference publications, books, monographs, and articles containing various information on certain types of geographical objects).

In GIS, only one type of data is rarely used; it is often a combination of various data for any territory.

3. Main components of GIS

The requirements for the GIS components are determined, first of all, by the user, who is faced with a specific task (accounting for natural resources or managing the infrastructure of the city), which must be solved for a particular territory, which differs in natural conditions and the degree of its development.

3.1. Technical support

Hardware is a set of hardware used in operating a GIS: a workstation or a personal computer (PC), information input-output devices, data processing, and storage devices, and telecommunications facilities.

A workstation or PC is the core of any information system. It is designed to manage the operation of a GIS and perform data processing processes based on computational or logical operations. Modern GIS can quickly process vast amounts of information and visualize the results.

Data entry is implemented using various technical means and methods: from the keyboard, digitizer or scanner, or external computer systems. Spatial data can be obtained by electronic geodetic instruments, using a digitizer and scanner directly, or from image processing results on analytical photogrammetric devices or digital photogrammetric stations.

Devices for processing and storing data are concentrated in the system unit, including the central processor, RAM, external storage devices, and the user interface.

Data output devices must provide a visual representation of the results, primarily on the monitor, as well as in the form of graphic originals obtained on a printer or plotter (graph plotter); in addition, data export to external systems is mandatory.

3.2. Software

Structural GIS software includes *essential and application* software.

The underlying software includes operating systems (OS), software environments, network software, and database management systems. Operating systems are designed to manage computer resources and processes that use these resources. Currently, the central operating systems are Windows and Unix.

Any GIS works with two types of data - *spatial and attributive*. For their maintenance, the software must include a database management system for those and other data (DBMS), modules for managing data input and output, a data visualization system, and modules for performing spatial analysis.

Applied software tools are designed to solve technical problems in a specific subject area and are implemented as separate applications and utilities.

3.3. Information support

A set of information arrays, information coding, and classification systems. Information support consists of implemented solutions for the types, volumes, placement, and forms of information organization, including the search and evaluation of data sources, data entry methods, database design, maintenance, and meta-support. A feature of storing spatial data in a GIS is its division into layers. The multilayer organization of an electronic map, with a flexible layer management mechanism, allows you to combine and display much more information than on a conventional map. Spatial position data (geographical data) and associated tabular data can be prepared by the user or purchased. Spatial data infrastructure is essential for such data exchange.

Legal documents determine the spatial data infrastructure, mechanisms for organizing and integrating spatial data, and their availability to different users. A spatial data infrastructure includes three essential components: basic spatial information, spatial data standardization, metadata bases, and a data exchange mechanism.

4. Structures and data models

4.
1.4.

4.1. Displaying real World objects in a GIS

The objects of the real world considered in geoinformatics differ in *spatial, temporal, and thematic characteristics.*

Spatial characteristics determine the position of an object in a predetermined coordinate system; the main requirement for such data is accurate.

Temporal characteristics fix the time of the study of the object and are essential for assessing changes in the object's properties over time. The main requirement for such data is relevance, which means the possibility of their use for processing; irrelevant data is outdated data.

Thematic characteristics describe various properties of an object, including economic, statistical, technical, and other properties; the main requirement is completeness.

Spatial and attribute data types represent spatial objects in a GIS.

Spatial data is information that characterizes the location of objects in space relative to each other and their geometry.

Spatial objects are represented using the following graphical objects: *points, lines, areas, and surfaces.*

Object descriptions are carried out by specifying the coordinates of objects and their constituent parts.

Point objects are such objects, each located only at one point in space, represented by a pair of X and Y coordinates. Depending on the mapping scale, a tree, a house, or a city can be considered such objects.

Linear objects are presented as one-dimensional, having one dimension - length, the width of the thing is not expressed in this scale or is not significant—examples of such objects: rivers, boundaries of municipal districts, and contour lines.

Areas (polygons) are areal objects, represented by a set of pairs of coordinates (X, Y) or a group of objects of the line type, which are a closed contour. Such objects can be represented by territories occupied by a particular landscape, a city, or an entire continent.

Surface - when describing it, adding height values to area objects is required. Restoration of surfaces is carried out using mathematical algorithms (interpolation and approximation) on the initial set of coordinates X, Y, and Z.

Additional nonspatial data about features form a set of attributes.

Attribute data are qualitative or quantitative characteristics of spatial objects, usually expressed in alphanumeric form.

Examples of such data: geographical name, species composition of vegetation, soil characteristics, etc.

The nature of spatial and attributive data is different, respectively. The methods of manipulation (storage, input, editing, search, and analysis) for these two components of a geographic information system are also different. One of the main ideas embodied in traditional GIS is the preservation of the connection between spatial and attribute data while storing them separately and, in part, processing them individually.

The general digital description of a spatial object includes name; location indication, property set; relationships with other objects. The name of an object is its geographic name (if any), its conditional code or identifier assigned by the user or the system.

Similar objects according to spatial and thematic features are combined into layers of a digital map, considered separate information units, while it is possible to combine all available information.

4.2. Data structure

To represent spatial data in a GIS, *vector and raster* data structures are used.

A *vector* structure is a representation of spatial objects in the form of a set of coordinate pairs (vectors) that describe the geometry of objects (Fig. 2).

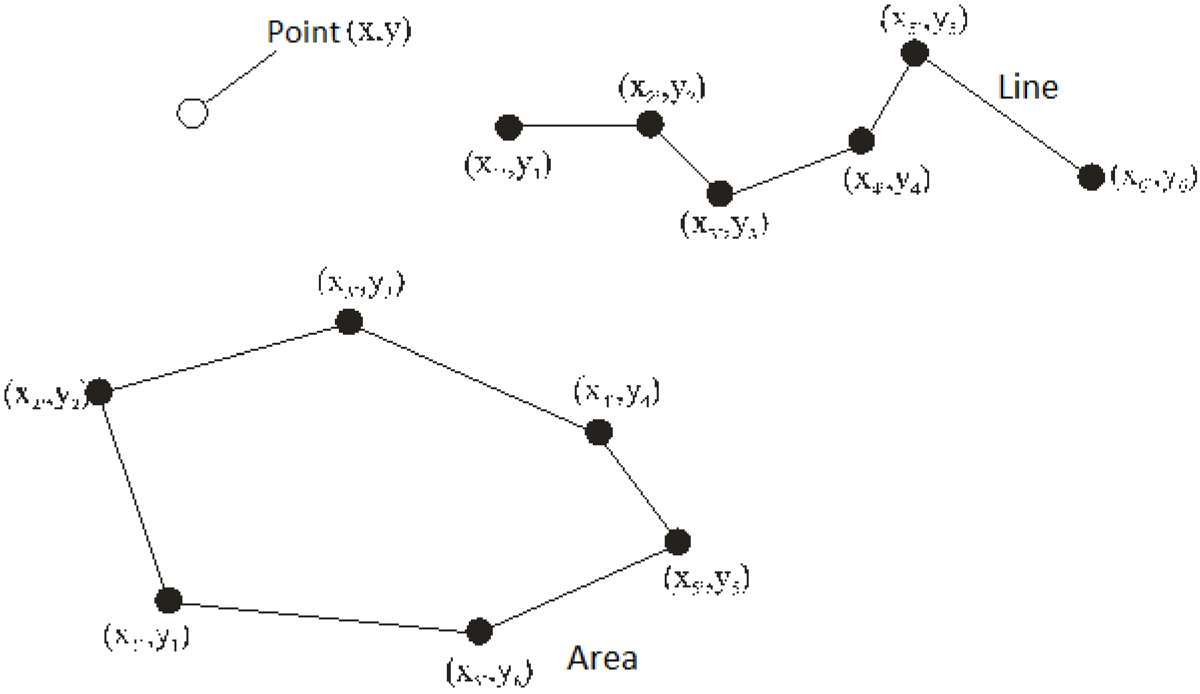


Fig. 2 - Vector representation of spatial data.

The raster data structure assumes data representation in a two-dimensional grid, each cell containing only one value that characterizes the object corresponding to the raster cell on the ground or the image. An object code (forest, meadow, etc.), height, or optical density can be used as such a characteristic.

The precision of raster data is limited by cell size. Such structures are a convenient means of analyzing and visualizing various types of information.

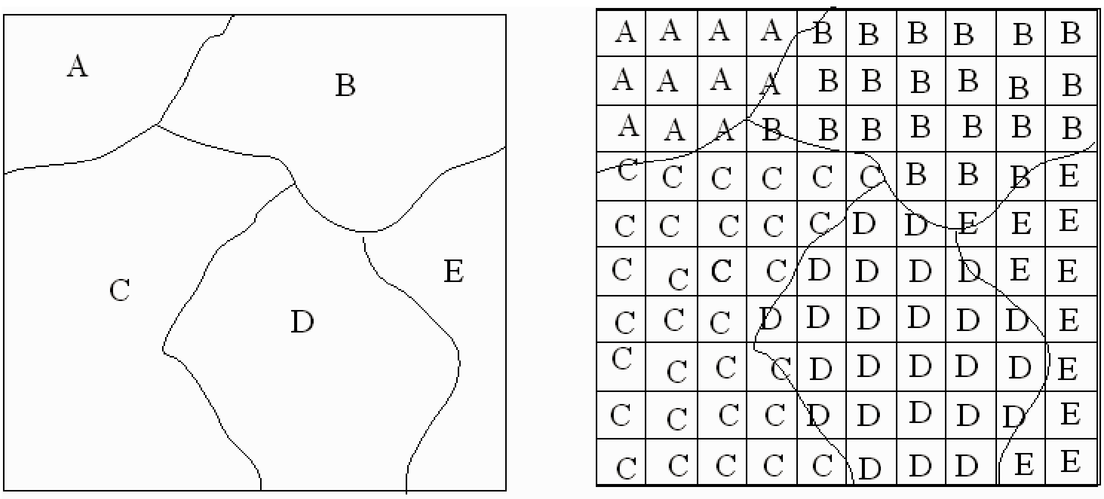


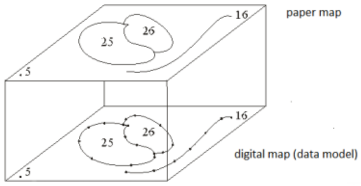
Fig. 3. Raster data structure

Various data models have been developed to implement raster and vector structures.

4.3. Data models

Spatial data models are logical rules for a formalized digital description of spatial objects.

Vector data models. There are several ways to combine vector data structures into a vector data model that allows you to explore relationships between objects of the same layer or between objects of different layers. The simplest vector data model is the "spaghetti" model (Fig. 4). In this case, the graphic image of the map is translated as "one to one."

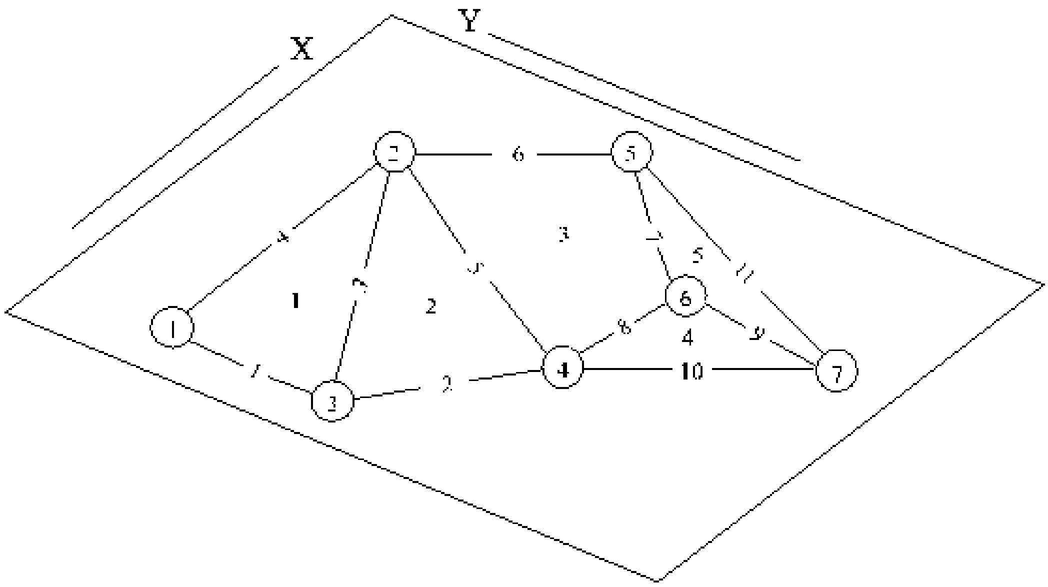


Object	number	Position
Point	5	One pair of coordinates (x,y)
Line	16	Set of pairs of coordinates (x,y)
Area	25	Set of pairs of coordinates (x,y), first and last match

Fig. 4. "Spaghetti" model

This model does not describe the relationship between objects; each geometric object is stored separately and is not associated with others; for example, the common boundary of objects 25 and 26 is recorded twice, although using the same set of coordinates. All relationships between objects must be calculated independently, complicating data analysis and increasing the amount of information stored.

Vector topological models (Fig. 5) contain information about the neighborhood, the proximity of objects, and other characteristics of the relative position of vector objects.



Node File			Area file	
Number Arc	Area numbers	List of arcs	Area numbers	List of arcs
1	19	6	1	1, 4, 3
2	15	15	2	2, 3, 5
3	27	13	3	5, 6, 7, 8
4	24	19		

Arc file				
Number Arc	Right Polygon	Left Polygon	Initial node	End node
1	1	0	3	1
2	2	0	4	3
3	2	1	3	2
4	1	0	1	2
5	3	2	4	2
6	3	0	2	5

Fig. 5. Vector topological data model

A set of nodes and arcs describes topological information. A node is the intersection of two or more arcs, and its number is used to refer to any angle to which it belongs. Each turn begins and ends either at the point of intersection with another arc or at a node that does not belong to other arcs. Arches are formed by a sequence of segments connected by intermediate points. In this case, each line has two sets of numbers: pairs of middle point coordinates and node numbers. In addition, each arc has its identification number, which indicates which nodes represent its beginning and end.

Other modifications of vector models have also been developed; in particular, there are unique vector models for representing surface models, which will be discussed below.

Raster models are used in two cases. In the first case - to store the original images of the area. In the second case, for operational analysis or visualization, for storing thematic layers, users are not interested in individual spatial objects but in a set of points in space with different characteristics (elevations or depths, soil moisture, etc.).

There are several ways to store and address individual raster cell values and their attributes, layer names, and legends.

When using raster models, the issue of raster data compression is topical, for which the methods of group coding, block coding, chain coding, and representation in the form of a quadtree have been developed.

4.4. Data formats

Data formats determine how information is stored on a hard drive, as well as how it is processed. Data models and data formats are related in some way.

There are a large number of data formats. It can be noted that many GIS supports the main raster data storage formats (TIFF, JPEG, GIF, BMP, WMF, PCX), as well as spot, GeoTIFF, which allows transferring information about linking a raster image to absolute geographic coordinates, and MrSID for compression information. The most common vector format is DXF.

All systems support the exchange of spatial information (export and import) with many GIS and CAD systems through the central exchange formats: SHP, E00, GEN (ESRI), VEC (IDRISI), MIF (MapInfo Corp.), DWG, DXF (Autodesk), WMF (Microsoft), DGN (Bentley). Only a few domestic systems support Russian exchange formats - F1M (Roskartografiya) and SXF (Military Topographic Service).

Quite often, a vector format is preferred for the efficient implementation of some computer operations and, for others, a raster one. Therefore, some systems implement the ability to manipulate data in both formats and the functions of converting vector to raster, and vice versa, raster to vector formats.

4.5. Database and management

The digital data about spatial objects form a set of spatial data and constitutes the content of databases.

Database (DB) - a set of data organized according to specific rules that establish general principles for describing, storing, and manipulating data

Creating a database and accessing it (on request) is done using a database management system (DBMS).

The selected database model determines the logical structure of the database elements. The most common database models are hierarchical, network and relational, and object-oriented.

Hierarchical models represent a tree structure, in which each entry is associated with only one access at a higher level.

Such a system is well illustrated by the plant and animal classification system. An example is the structure of information storage on PC disks. The central concept of such a model is the level. The number of group sets and their composition depend on the classification adopted when creating the database. Any of these records are accessed by traversing a well-defined chain of nodes. With such a structure, it is easy to search for the necessary data, but if the description is initially incomplete or there is no search criterion, then it becomes impossible.

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Network models were designed to address some of the shortcomings of hierarchical models. In the network model, each entry in each network node can be associated with several other nodes. The entries that make up the network structure contain pointers that locate other related entries. This model allows you to speed up access to data, but changing the design of the database requires considerable effort and time.

Relational models collect data into unified tables. The table is given a unique name within the database. Each column is a field named after the attribute it contains. Each row in the table corresponds to an entry in the file. The same area can appear in more than one table. Since the rows in the table are not ordered, one or more columns are defined whose values uniquely identify each row. Such a column is called a primary key. Foreign keys support table relationships. Manipulation of data is carried out using operations that generate tables. The user can quickly enter new data into the database, combine tables by selecting individual fields and records, and form new tables for display on the screen.

Object-oriented models are used if the geometry of a particular object is capable of covering several layers, the attributes of such things can be inherited, and specific methods are used to process them.

To process data in tables, additional information about the data is needed; they are called metadata.

Metadata - Data about data: catalogs, directories, registers, and other forms of description of digital data sets.

5. Data input technologies

5.1. Database and management

In accordance with the technical means used, two methods of data entry are distinguished: digitalization and vectorization. A digitizer is used for manual input of spatial data. It consists of a tablet (table) with an electronic grid, to which is attached a device called a cursor. The cursor is similar to a graphical manipulator - a mouse, it has a sight placed on a transparent plate, with the help of which the operator performs precise guidance on individual elements of the map. The cursor has buttons that allow you to fix the beginning and end of a line or area border, the number of buttons depends on the level of complexity of the digitizer. Digitizers come in a variety of formats and provide a resolution of 0.03mm with an overall accuracy of 0.08mm at 1.5m. There are automated digitizers that provide automatic line tracking.

Scanners are the most widely used for data entry. They allow you to enter a bitmap image of a map into a computer. There are various types of scanners that differ: by the method of supplying the source material (flatbed and broaching (drum type); by the method of reading information (transmission or reflection); by radiometric resolution or color depth; by optical (or geometric) resolution. The last characteristic is determined by the minimum size of the image element, which is distinguished by the scanner.

The process of digitizing a bitmap image on a computer screen is called vectorization. There are three ways to vectorize: manual, interactive and automatic. With manual vectorization, the operator circles each object on the image with the mouse, with interactive vectorization, some of the operations are performed automatically. So, for example, when vectorizing contour lines, it is enough to set the starting point and direction for tracking lines, then the vectorizer will track this line itself until it encounters ambiguous situations, such as a line break, on its way. The possibilities of interactive vectorization are directly related to the quality of the source material and the complexity of the map. Automatic vectorization involves direct conversion from raster to vector format using special programs, followed by editing. It is necessary because even the most sophisticated program can incorrectly recognize an object, take, for example, a symbol for a group of dots, etc.

5.2. Transformation of original data

Scanned source maps were created in a specific cartographic projection and coordinate system. When digitized, this complex projection is reduced to a set of spatial coordinates. Therefore, it is necessary to convert the map to its original projection. To do this, information about the projection used is entered into the GIS (usually a GIS allows you to work with a large number of projections) and a number of transformations are carried out. The three main ones, which are often performed at the same time, are translation, rotation, and scaling.

Translation is simply moving the entire graphical object to another location on the coordinate plane. It is performed by adding certain values to the X and Y coordinates of the object:

$$X' = X + T_x, Y' = Y + T_y$$

Scaling is also very useful, since maps of different scales are often scanned, for this they use the ratio:

$$X' = X \cdot S_x, Y' = Y \cdot S_y$$

Rotation is performed using trigonometric functions:

$$X' = X\cos\theta + Y\sin\theta, Y' = X\sin\theta + Y\cos\theta$$

All necessary transformations can be performed using these three basic graphical operations on the coordinates of the reference points.

5.3. Entering remote sensing data

In GIS, not primary remote sensing materials obtained during the survey are used, but derivatives formed as a result of their processing. Satellite data is pre-processed digitally to eliminate radiometric and geometric distortions, atmospheric effects, etc. To improve the visual quality of source images, procedures can be applied to change brightness and contrast, filtering to eliminate noise, or to emphasize contours and fine details. When using aerial photographs, one should pay attention to the distortions caused by the angles of inclinations of the images and the terrain, which can be eliminated in the process of transformation or orthophoto transformation.

6. Spatial data analysis

6.1. Problems of spatial analysis

Spatial analysis tools include various procedures for manipulating spatial and attribute data that are performed when processing user requests. (For example, operations of overlaying graphic objects, tools for analysing network structures or selecting objects according to specified characteristics).

Each GIS package is characterized by its own set of spatial analysis tools that provide a solution to specific user tasks, at the same time, a number of basic functions can be distinguished that are inherent in almost every GIS package. This is, first of all, the organization of the selection and association of objects in accordance with the given conditions, the implementation of computational geometry operations, the analysis of overlays, the construction of buffer zones, and network analysis.

6.2. Basic functions of spatial data analysis

Selecting objects by request: the simplest form of a request is to get the characteristics of the object indicated by the cursor on the screen and the reverse operation, when objects with given attributes are displayed. More complex queries allow you to select objects by several criteria, for example, by the distance of some objects from others, matching objects, but located in different layers, etc.

SQL queries are used to select data according to certain conditions. To execute queries of varying complexity, it is possible to use mathematical and statistical functions, as well as geographic operators, when compiling queries, allowing you to select objects based on their relative position in space (for example, whether the analyzed object is inside another object or intersects with it).

Generalization of data can be carried out according to the equality of the values of a certain attribute, in particular for zoning the territory. Another way of grouping is to combine objects of one thematic layer according to their placement inside polygonal objects of other thematic layers.

Geometric functions: these include calculations of the geometric characteristics of objects or their relative position in space, while using the formulas of analytical geometry on the plane and in space. So for areal objects, the areas occupied by them or perimeters of the boundaries are calculated, for linear objects - lengths, as well as distances between objects, etc.

Overlay operations (topological overlay of layers) are one of the most common and effective means. As a result of superposition of two thematic layers, another additional layer is formed in the form of a graphic composition of the original layers. Given that the analyzed objects can be of different types (point, line, polygon), different forms of analysis are possible: point to point, point to polygon, etc. The most frequently analyzed is the combination of polygons.

Building buffer zones. One of the means of analyzing the proximity of objects is the construction of buffer zones. Buffer zones are areas (polygons), the boundary of which is at a given distance from the boundary of the original object. The boundaries of such zones are calculated based on the analysis of the corresponding attributive characteristics. In this case, the width of the buffer zone can be either constant or variable. For example, the buffer zone around the source of electromagnetic radiation will have the shape of a circle, and the pollution zone from the chimney of the plant, taking into account the wind rose, will have a shape close to an ellipse.

Network analysis allows the user to analyze spatial networks of connected linear objects (roads, power lines, etc.). Typically, network analysis is used to determine the nearest, most profitable path, determine the level of network load, determine the address of an object or route at a given address, and other tasks.

6.3. Analysis of the spatial distribution of objects

Analysis of the spatial distribution of objects. In fact, in many cases, it is necessary to know not only the amount of space occupied by objects, but also the location of objects in space, which can be characterized by the number of objects in a certain area, for example, the distribution of population. The most common methods for analyzing the distribution of point objects. The measure of a point distribution is density. It is defined as the result of dividing the number of points by the value of the area of the territory on which they are located. In addition to the distribution density, it is possible to estimate the shape of the distribution. Point distributions occur in one of four possible variants: uniform (if the number of points in each small subdomain is the same as in any other subdomain), regular (if the points separated by the same intervals throughout the area are located at the grid nodes), random, clustered (if the points are collected in tight groups).

Point distributions can be described not only by the number of points within subregions. Local relationships within pairs of points are often analyzed. Computing this statistic involves determining the average distance to the nearest neighbor point among all possible pairs of nearest points. This method allows estimating the degree of sparseness of points in the distribution.

Line distribution is also estimated from the density. Typically, calculations are performed to compare different geographic areas, for example, by the density of a hydrographic network. Lines can also be judged by proximity and possible intersections. Other important characteristics are orientation, directionality, and connectedness.

Analysis of the distribution of polygons is similar to the analysis of the distribution of points, however, when assessing the density, it is not the number of polygons per unit area that is determined, but the relative proportion of the area occupied by the polygon.

7. Surface modeling

7.1. Surface and digital model

The basis for the presentation of data on the earth's surface are digital elevation models.

Surfaces are objects that are most often represented by Z height values distributed over an area defined by X and Y coordinates.

Digital elevation models (DEMs) are used for computer representation of earth's surfaces.

DEM is a means of digital representation of the earth's surface shape.

The construction of a DEM requires a certain form of representation of the initial data (a set of coordinates of points X, Y, Z) and a method of their structural description, which allows restoring the surface by interpolation or approximation of the initial data.

7.2. Data sources for the formation of the DEM

The initial data for the formation of the DEM can be obtained from maps - by digitizing contour lines, from stereo pairs of images, as well as as a result of geodetic measurements or laser scanning of the area. The first method is the most common, because. collection of images by stereopairs is laborious and requires specific software, but at the same time it allows to provide the desired degree of detail in the representation of the earth's surface. Laser scanning is a promising modern method, yet quite expensive.

7.3. Interpolations

The construction of a DEM requires a certain data structure, and the initial points can be distributed in space in different ways. Data collection can be carried out by points of a regular grid, along structural lines of the relief, or randomly. Primary data with the help of certain operations lead to one of the most common structures in GIS for representing surfaces: GRID, TIN or TGRID.

TIN (Triangulated Irregular Network) - an irregular triangulation network, a system of non-overlapping triangles. The vertices of the triangles are the original anchor points. The relief in this case is represented by a polyhedral surface, each face of which is described either by a linear function (polyhedral model) or by a polynomial surface, the coefficients of which are determined by the values at the vertices of the triangle faces. To obtain a surface model, you need to connect pairs of points with edges in a certain way, called Delaunay triangulation (Fig. 6).

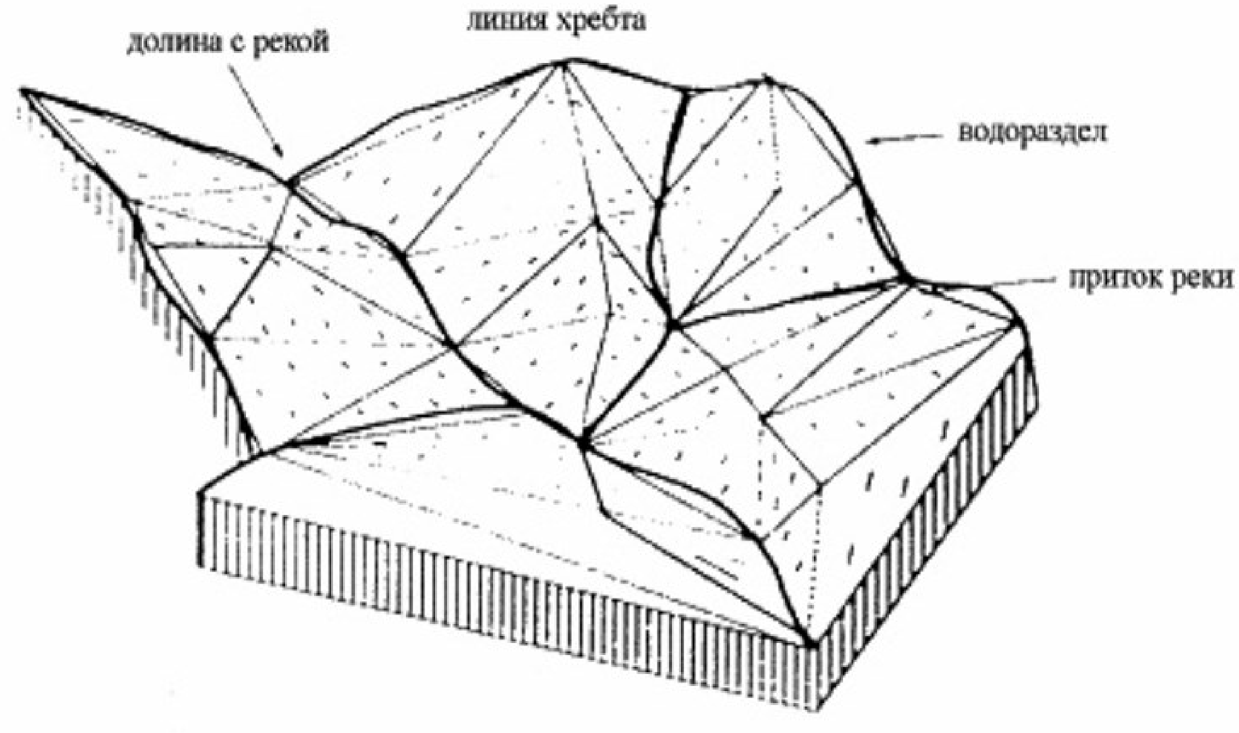

Fig. 6 – TIN model

Delaunay triangulation in application to two-dimensional space is formulated as follows: a system of interconnected non-overlapping triangles has the smallest perimeter if none of the vertices falls inside any of the circles described around the formed triangles (Fig. 7).

The resulting triangles are as close as possible to equilateral. Each of the sides of the formed triangles from the opposite vertex is visible at the maximum angle from all possible points of the corresponding half-plane. Interpolation is performed along the formed edges.

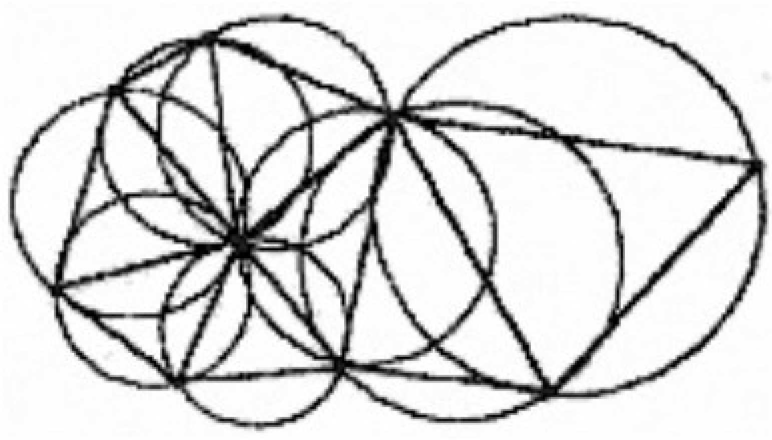

Fig. 7 – Delaunay triangulation

A distinctive feature and advantage of the triangulation model is that there are no transformations of the original data in it. On the one hand, this does not allow the use of such models for detailed analysis, but on the other hand, the researcher always knows that this model does not contain introduced errors that models obtained using other interpolation methods sin. This is the fastest interpolation method. However, if in the early versions of most GIS the triangulation method was the main one, today models in the form of a regular matrix of height values are widely used.

GRID - model, is a regular matrix of height values obtained by interpolation of the original data. For each matrix cell, the height is calculated based on interpolation. In fact, this is a grid, the dimensions of which are set in accordance with the requirements of the accuracy of a particular problem being solved. The regular grid matches the ground, not the image.

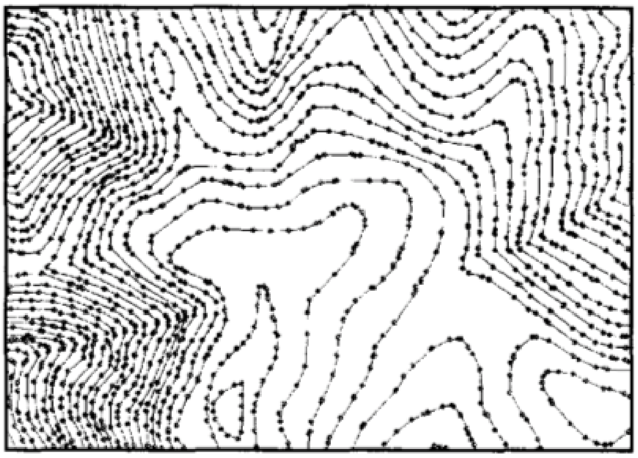

Fig. 8 – Density of points in the GRID model

TGRID (triangulated grid) is a model that combines elements of TIN and GRID models. Such models have their own advantages, for example, they allow the use of additional data to describe complex landforms (cliffs, rocky ledges).

Restoration of surfaces is implemented on the basis of interpolation of the initial data.

Interpolation is the restoration of a function on a given interval from its known values of a finite set of points belonging to this interval.

Currently, dozens of surface interpolation methods are known, the most common are: linear interpolation; inverse distance weighting method, kriging; spline interpolation; trend interpolation.

Kriging. An interpolation method based on the use of mathematical statistics methods. Its implementation uses the idea of a regionalized variable, i.e. a variable that varies from place to place with some apparent continuity, so cannot be modeled by just one mathematical equation. The surface is considered as three independent quantities. The first is a trend that characterizes the change in the surface in a certain direction.

It is further assumed that there are small deviations from the general trend, such as small peaks and troughs, which are random, but still spatially related to each other.

Random noise (like boulders). Each of the three variables must be handled separately. The trend is estimated using a mathematical equation that most closely represents the overall change in the surface, much like a trend surface.

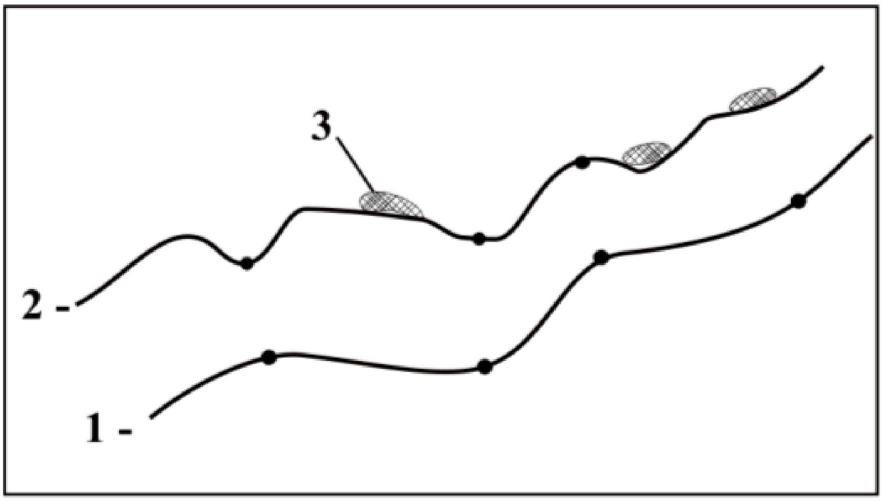

Fig. 9 – Elements of kriging: 1- trend; 2- random but spatially related heights fluctuations; 3- random noise

The expected height change is measured by a semi variogram, which plots the distance between readings on the horizontal axis and semi-dispersion on the vertical axis. Semi variance is defined as half the variance between the heights of the original points and the heights of neighbouring points. A curve of best fit is then drawn through the data points. The dispersion at some point reaches a maximum and remains constant (the limiting radius of the correlation is revealed).

Method of inverse weighted distances. This method is based on the assumption that the closer the initial points are to each other, the closer their values are. To accurately describe the topography, the set of points to be interpolated from must be chosen in a certain neighbourhood of the point being determined, since they have the greatest influence on its height. This is achieved in the following way. Enter the maximum search radius or the number of points closest in distance from the initial (determined) point. Then the value of the height at each selected point is given a weight calculated depending on the square of the distance to the point being determined. This ensures that closer points contribute more to the determination of the interpolated height than more distant points.

Trend interpolation. In some cases, the researcher is interested in general surface trends that are characterized by a trend surface.

Similar to the inverse distance weighting method, the trend surface uses a set of points within a given neighbourhood. Within each neighbourhood, a best fit surface is constructed based on mathematical equations such as polynomials or splines.

Trend surfaces can be flat, showing a general trend, or more complex. The type of equation used or the degree of the polynomial determines the amount of surface waviness. For example, a first-order trend surface will look like a plane intersecting the entire surface at some angle. If the surface has one bend, then such a surface is called a second-order trend surface.

Spline interpolation. The possibility of describing complex surfaces using polynomials of low degrees is determined by the fact that during spline interpolation, the entire territory is divided into small non-intersecting sections. Approximation by polynomials is carried out separately for each section. Usually a polynomial of the third degree is used - a cubic spline. Then a general "gluing" function is constructed for the entire area, with the specification of the continuity condition on the boundaries of the sections and the continuity of the first and second partial derivatives, i.e. the smoothness of gluing polynomials is ensured.

Smoothing with spline functions is especially convenient when modelling surfaces complicated by discontinuous faults, and allows avoiding distortions such as "edge effects".

8. Technology for construction of digital survey models

8.1. Core Processes

The main processes for constructing a DEM from maps are:

1. Converting source maps to bitmaps, i.e. scanning. When scanning, it is important to choose the resolution of the resulting image, an excessively high resolution requires large amounts of memory to store the original information, at the same time, the resolution must provide the necessary accuracy of information collection, which is determined by the goals of DEM formation.
2. Installation of raster fragments. Mounting or "stitching" is the joining of several free-form images into one in such a way that the boundaries between the original images are invisible. During installation, raster data is georeferenced. GIS has various modules to solve this problem.
3. Vectorization of a raster image. Vectorization or digitalization of contour lines can be performed in manual, semi-automatic and automatic modes. For various GIS, separate modules have been developed that implement this task in automatic modes, for example, Map Edit.
4. Formation of the DEM. DTM is created based on interpolation methods and can be presented in different formats.
5. Visualization of results. DEM provides visualization of information about surfaces in different forms.

8.2. Process accuracy requirements

In general, we can say that the more initial points, the more accurate the interpolation will be, and the more likely the constructed surface model will adequately display the earth's surface. However, there is a limit to the number of points (discreteness), because for any surface, an excessive number of points usually does not significantly improve the quality of the result, but only increases the amount of data and computation time. In some cases, redundant data in individual areas can lead to an uneven surface representation and hence uneven accuracy. In other words, more points do not always improve accuracy.

Of course, the more complex the surface, the more reference points are required. And for complex features, such as depressions and river valleys, additional points are required to ensure a representation with sufficient detail. A special problem of point interpolation at the border of the study areas, for example, the border of a map sheet. In this case, a large area of overlap between adjacent sheets should be used for interpolation.

8.3. Using DEM

Digital elevation models (DEMs) are important for solving a number of applied environmental problems. For forecasting emergency situations, such as floods, assessing the degree of landscape change, etc. Based on the results of the DEM analysis using GIS tools, maps of the angles of inclination (slopes) of the terrain and slope exposures are obtained, longitudinal and transverse profiles are formed in a given direction, and visibility zones are assessed with designated viewpoints, etc. Different forms are used to display the DEM.

9. Methods and means of visualization

9.1. Digital maps and atlases

Visualization (graphic reproduction, display) - generation of images, including cartographic, and other graphics on display devices (mainly on a monitor) based on the conversion of initial digital data using special algorithms.

Maps remain the most compact and familiar way of presenting geographic information.

An electronic map (EC) is a cartographic image rendered on a monitor based on digital maps or GIS databases.

An electronic atlas (EA) is a visualization system in the form of electronic maps, an electronic cartographic product that is functionally similar to an electronic map. Supported by software such as cartographic browsers that provide frame-by-frame viewing of raster images of maps, cartographic visualizers, desktop mapping systems. In addition to the cartographic image and legends, electronic atlases usually include extensive text comments, tabular data, and multimedia electronic atlases - animation, video sequences and sound.

Tables and graphs, including various characteristics of objects (attributes) or their ratios, can be used as independent or additional to other visualization tools.

Animations are used to show dynamic processes, i.e. sequential display of drawn static images (frames), as a result of which the illusion of a continuous change of images is created.

9.2. Cartographic ways to display the results of data analysis

To display the results of data analysis in GIS, a number of methods are implemented that are used when creating thematic maps.

The method of dimensional symbols (icons) - the analysed characteristics of objects are displayed with special symbols, the size of which conveys quantitative information, and the shape and colour convey qualitative information.

Qualitative or (quantitative background) method - in this case, data with similar values are grouped and the created groups are assigned certain colours, types of symbols or lines.

Point method - a visual tool is a set of dots of the same size, each of which has a certain value of a quantitative indicator.

Bar and circular localized charts - allow you to display the ratio of several characteristics, while the charts are geo-referenced (for example, at the point where the observation post is located, they show the ratio of pollutants).

The isoline method is one of the most widely used ways to display various indicators. With their help, isohypse maps (topographic and hypsometric), isotherm maps, isobars, isocorrelates, etc. are formed. With the help of isolines, territories are distinguished that are characterized by the same properties (temperatures, pressure, precipitation, simultaneity of occurrence of events, equal magnitude of anomalies, equal speeds of tectonic movements and etc.).

At the same time, two groups of isolines are distinguished: true isolines (characterize a continuous change in an indicator, these include horizontal lines) and pseudo isolines that display data of a statistical nature (for example, discrete values from emission sources). To represent the isolines, different visual means are used: lines of different types, thicknesses and colours, layered background colouring (or hatching) of the gaps between the isolines.

9.3. 3D visualisation

A three-dimensional surface image (3D-surface) is a means of digital three-dimensional representation of surfaces in the form of wire diagrams, while using various types of projection, while the image can be rotated and tilted using a simple graphical interface.

Raster images can be generated to display the relief from DEM data.

Raster surface (image) - is formed according to the Grid-model, while each pixel is assigned a value proportional to the height of the corresponding grid cell.

Shadow relief (analytical hill shading) is a raster display of the DEM, during the formation of which, in addition to the height of each section of the grid of the Grid model, the illumination of the slopes is taken into account.

Implemented the possibility of combining 3D - surfaces with other thematic layers. To achieve realistic display of terrain objects, 3D surfaces are combined with cartographic or orthoimages.

Virtual Terrain Model (VMM) is a terrain model containing information about the earth's surface topography, its spectral brightness and objects located in the given territory, designed for interactive visualization. HMM allows you to provide the effect of presence on the ground, can be displayed as a three-dimensional static scene (3D view) or in the flight simulation mode over the terrain, when the observer is at a point with specified coordinates.

10. GIS information management

10.1. General information

GIS information management uses many of the concepts and characteristics of standard information technology architecture that work well in a centralized enterprise computing environment. For example, GIS datasets can be managed in relational databases like other corporate information. To operate with data stored in a database management system (DBMS), modern application interaction logic is used. Like other transaction-based enterprise information systems, GIS are widely used to constantly change and update geographic databases. However, GIS technology has a number of important features.

10.2. GIS data is complex

GIS data is typically large and includes a large number of large elements. For example, a simple database query to fill out a typical commercial form will return several rows of data, while creating a map would require hundreds or even thousands of records to be queried from the database. In addition, the amount of displayed vector or raster graphic information can be many megabytes. In addition, GIS data has complex relationships and structures, such as transportation networks, area topography, and topology.

10.3. Compiling GIS data is a non-trivial, specialized process

To build and maintain graphical datasets in a GIS, advanced editing tools are required. And to maintain the integrity and behaviour of geographic vector objects and raster, they need specialized processing based on special geographic rules and commands. Therefore, compiling data into a GIS is costly. This is one of the reasons that encourages users to collaborate on GIS datasets.

10.4. GIS transactional system

As with other database management systems, a GIS database is constantly updated with a variety of data. Therefore, a GIS database, like other databases, must support such transactions. However, GIS users have some special transaction requirements. One of the main conditions is the ability to support long transactions.

In a GIS, a single editing operation can change many rows of data in many tables. Users should be able to undo and redo editing operations. An editing session can last for hours or even days. Often, editing must be done on a system detached from a central, shared database.

In many cases, major database updates are carried out in stages. For example, in an application to utilities, this work usually includes such stages as "development", "proposal", "acceptance", "reconstruction" and "surrender". This process is largely cyclical.

The technical task is first compiled and transferred to the engineer, then gradually modified as the individual stages are implemented, and, finally, all the changes made are returned back to the corporate database.

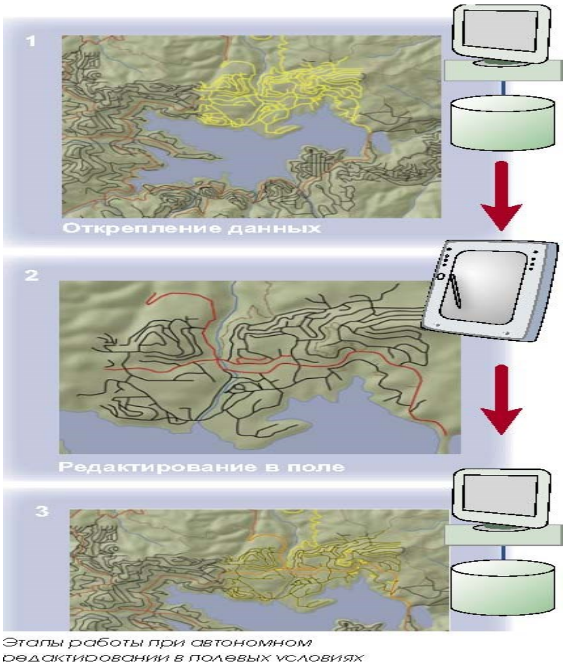

Fig. 10 – Distributed geographic databases

The workflow for updating and transferring data can take days or months. However, the GIS database must still be available to support day-to-day operations and ongoing updates, and users must be able to access their versions of the shared GIS database. Here are more examples of data management workflows in GIS:

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Offline editing: Some users need the ability to “detach” fragments of a GIS database and replicate (move) them to another location on an independent, separate system. For example, to edit some data in the field, you need to take some data with you, edit and update it on site, and then push the changes to the main database.

The regional database can be a partial copy of the corresponding "piece" of the main enterprise GIS database. These databases must be synchronized periodically to share changes made to each of them.

10.5. Replication with indirect (soft) link

Soft-link replication within a DBMS. Often users want to keep their GIS data context in sync across multiple database copies (called replicas), with each location maintaining its own local database updates. From time to time, users want to move these updates from each replica of the database to others and synchronize their content. However, the DBMS can be different (for example, SQL Server™, Oracle® and IBM® DB2®).

11. GIS- Distributes information system

11.1. General Information

Today, in most geographic information systems, layer and table data comes from different organizations. Each organization develops a more or less significant part, and not all, of the information content of its GIS. Typically, at least some of the layers of data come from external sources. The need for data is an incentive for users to obtain new data in the most efficient and fast way, including by purchasing database parts for their GIS from other GIS users. Thus, the management of GIS data is carried out by several users.

11.2. Interoperability

The distributed nature of GIS implies a wide range of interoperability between many GIS organizations and systems. Collaboration and collaboration among users is very important to GIS.

GIS users have long relied on mutually beneficial data exchange and sharing activities. A real reflection of this fundamental need is the ongoing effort to create GIS standards. Adherence to industry standards and general principles of GIS construction is critical to the successful development and widespread adoption of this technology. The GIS must support the most important standards and be able to adapt as new standards emerge.

11.3. GIS networks

Many geographic datasets can be compiled and managed as a common information resource and shared by the user community. In addition, GIS users have their own vision of how popular datasets can be exchanged over the Web.

Key Web sites, called GIS catalogue portals, allow users to both post their own information and search for available geographic information for use. As a result, GIS systems are increasingly connected to the World Wide Web and gain new opportunities for sharing and using information.

This vision has been ingrained in people's minds over the past decade and is reflected in concepts such as the National Spatial Data Infrastructure (NSDI) and the Global Spatial Data Infrastructure (GSDI). These concepts are constantly being developed and gradually implemented, not only at the national and global levels, but also at the level of districts and municipalities. In a generalized form, these concepts are included in the concept of Spatial Data Infrastructure (SDI).

The GIS network is essentially one of the methods for implementing and promoting the principles of SDI. It integrates many user sites, promotes the publication, search and sharing of geographic information through the World Wide Web.

Geographical knowledge is inherently distributed and poorly integrated. All the necessary information is rarely contained in a single database instance with its own data schema. GIS users interact with each other to get the missing parts of their GIS data. Through GIS networks, it is easier for users to establish contacts and exchange accumulated geographic knowledge.

Fig. 11 – GIS network

There are three main building blocks in a GIS network:

• Metadata catalogue portals where users can search and find GIS information according to their needs

• GIS nodes where users compile and publish sets of GIS information

• GIS users who search, discover, access and use published data and services.

11.4. GIS portal catalogues

An important component of a GIS network is a GIS portal catalogue with a systematic registry of various data storage locations and information sets. Some GIS users act as data stewards, compiling and publishing their datasets for sharing across organizations. They register their info sets in the portal directory. By searching this directory, other users can find and access information sets they need.

The GIS Catalogue Portal is a Web site where GIS users can search and find the GIS information they need. The capabilities provided depend on the set of GIS data network services, mapping services, and metadata services offered. Periodically, a GIS catalogue portal site may survey the catalogues of its associated member sites in order to publish and update one central GIS catalogue. Thus, a GIS catalogue can contain links to data sources available both on this site and on other sites. It is assumed that a series of such catalogue nodes will be created, and on their basis a common network will be formed - the Spatial Data Infrastructure.

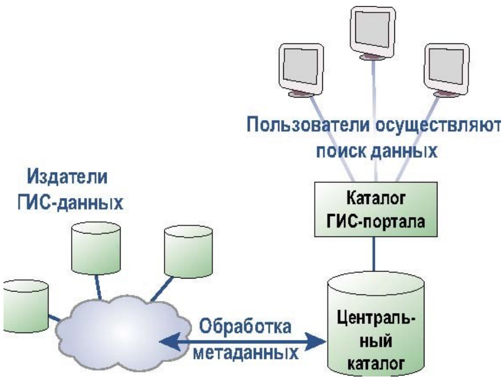

Fig. 12 – GIS portal catalogues

GIS data and services are documented as catalogue entries in the GIS portal catalogue, which can be searched for candidates for use in different GIS applications.

One example of a GIS catalogue portal is the US government portal (Geospatial One-Stop, see www.geodata.gov). This portal will enable governments at all levels and the general public to access geographic information more easily, faster and at lower cost.