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Creating Electronic Atlases using Spatiotemporal Data

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Abstract: The authors have developed a method for creating and using spatiotemporal data for electronic atlases, including the concept development, designing the database structure, developing methods for storing, processing and displaying data, as well as their implementation as a historical geoportal. The types of electronic atlases and their characteristics have been listed. The scenarios of using atlases have been considered, as well as a system of controlling, updating, and storing data with due consideration for their spatial and temporal component. The approaches to designing the database structure, indexing, retrieving, and protecting data have been provided. The implementation of the method will allow to obtain spatial data as cartographic works for any historical date and any territory, while the system of continuous data update will allow obtaining current cartographic information. The developed method addresses the issues of spatiotemporal data storage, update, and use in electronic atlas mapping, which will ensure the integration of multitemporal data into a single information space of the area under study.

Keywords: atlas, database, electronic atlas, geoportal, spatiotemporal data.

I. INTRODUCTION

At the moment, there is an active collection and accumulation of thematic data, including those constantly changing in time and space. Electronic atlases and atlas information systems are widely used for their visualization. The electronic atlas is understood as a system of electronic maps, which is a complex electronic cartographic work. Electronic atlases are the most popular and promising in the field of visualization and use of cartographic information today, providing multi-user access to information and, as a rule, located on the Internet using geoportal technologies.

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Maps of such an atlas are generated dynamically on the basis of spatial databases that store spatial and attributive information of cartographic and thematic objects and a map server – software that allows creating maps based on information from a database, established generalization rules, as well as information about the atlas layout and navigation. The structure of this type of electronic atlas, depending on its purpose, can be represented in one of two options:

– as a list of maps that are independent works. The electronic atlas of the Republic of Mordovia located on the geoportal of the Russian Geographical Society can be provided as an example [1]; and

– as a list of thematic layers superimposed on one vector multiscale general geographic map, which the user can switch as they wish. This approach is currently the most common. The electronic atlas of Switzerland [2] and the demographic atlas of Croatia [3] can be noted among atlases implementing this structure.

GIS atlases and atlas information systems with a focus on the industry are also developed. A GIS atlas is understood as an electronic atlas where geoimages are represented as layers of a geographic information system and analytical functions are present that allow combining and matching maps (layers) and carry out all kinds of analysis [4] – for example, conducting proximity analysis, estimating cartometric indicators, conducting forecasting, zoning, etc.

The existing electronic atlases usually contain the information provided at a particular point in time. However, the analysis of processes and phenomena often requires using not only the current state of the phenomenon under study, but also its dynamics over time. The spatiotemporal data are used to analyze and visualize changes in the spatial object over time. This type of data combines a chain of states of a spatial object (geometry and attribute properties) over time.

Supplying atlas mapping with spatiotemporal data implies not only input of spatial information with its subsequent use, but also tracking changes in this kind of information over time. It must be noted that there is no universal database management system for storing and processing all types of information today that is used in the modern atlas mapping, including its interactive form. Therefore, the goal of this article is to develop methodological issues on the organization, storage, processing and visualization of spatiotemporal data in relation to their use in electronic atlas mapping. The research is a part of implementing the concept of atlas mapping automation [5].

II. METHODS

A. General Description

The studies on the formation of spatiotemporal databases have been conducted for quite some time.

Serious research and the very formulation of the issue of changes in space and time were launched by Gail Langran in 1992. The studies of G. Langran [6] also relate to important topics of spaciotemporal systems and problems that are still being solved. A. Frank was the first to introduce the theory and methods of working with spaciotemporal structures in geographic space in 1992. Spatiotemporal structures differ not only in composition, but also in the type of changes. The type of changes in spatiotemporal data reflects a comparison of data models where the shape and size of an object can be changed. The models also reflect the ability to change the position of a spatiotemporal object. Morphology, topology, and attributes may or may not change over time, making up eight states [7]:

– change in geometry;
– change in topology;
– change in attributes;
– change in geometry, topology, and attributes;
– change in geometry and topology;
– change in geometry and attributes;
– change in topology and attributes; and
– no change.

B. *Algorithm*

The authors developed a method for creating and using spatiotemporal data for electronic atlases, based on the existing studies in the field of creating spatiotemporal databases (Fig. 1).

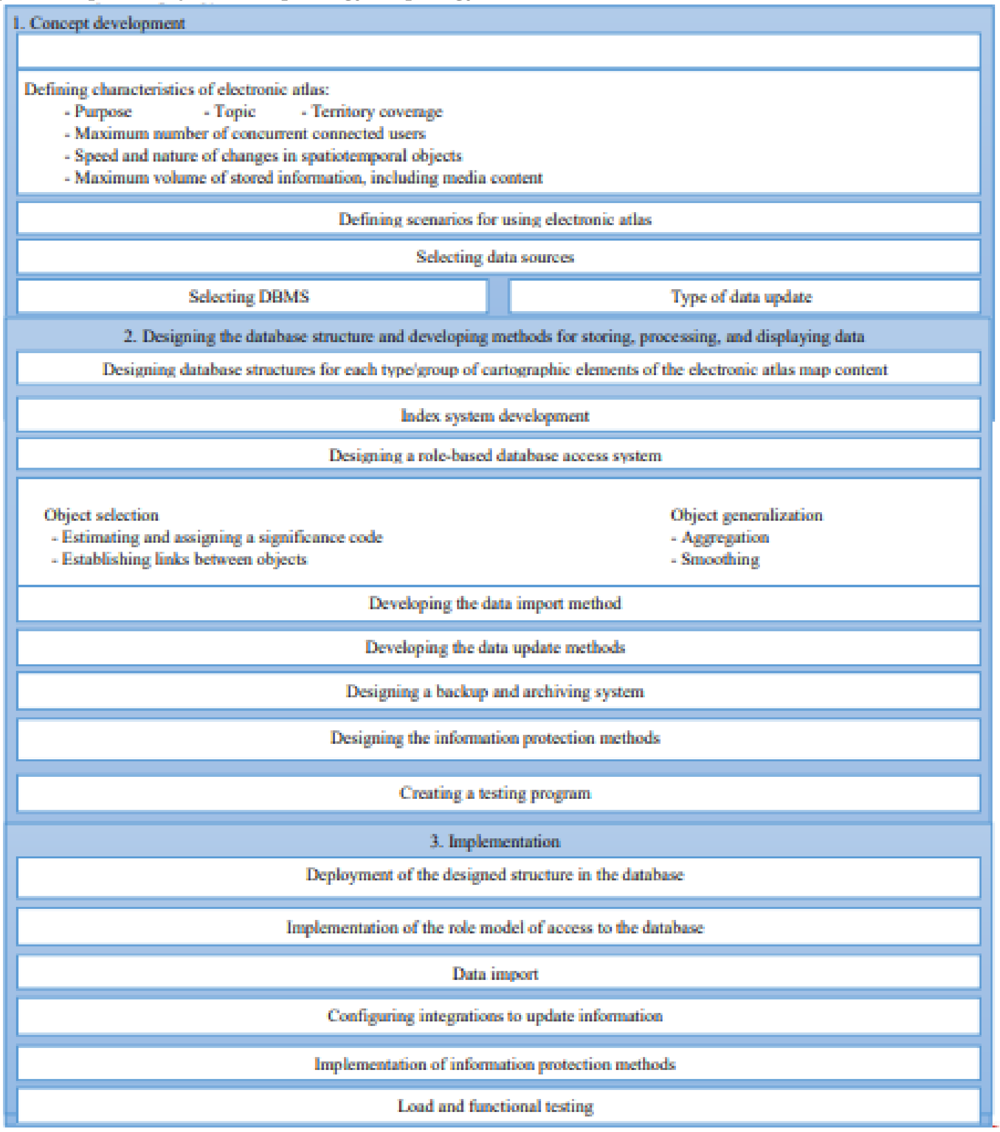

Fig. 1. Method for creating a spatiotemporal database for electronic atlases

Let us consider the stages of the method in more detail.

Concept development

The type of electronic atlas should be chosen at the initial stage of designing a spatiotemporal database, in order to determine the optimal method for its creation. It is proposed to distinguish the following types: 1) analogue (copy) of paper atlas; 2) local electronic atlas designed for single-user access and usually devoid of an automatic content update system; and 3) a multi-user electronic atlas intended for use on the Internet and built on a client-server architecture and a remote database,

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and also using mechanisms for automatically updating content via the Internet.

The following characteristics of the created atlas should be defined next:

– purpose of the atlas (scientific reference, analytical reference, educational, local history, marine navigation and geographical, road, tourist, military, or general use). The purpose influences the generalization tool setting, finite map rendering, choosing information protection measures, etc.;

– type of the atlas (general geographical, thematic, complex). This property mainly influences the internal structure of the spatiotemporal database. Given the dynamic nature of the requirements that are often presented to an atlas, it is recommended that the structure be laid for the complex atlas;

– territory coverage (world, individual countries and large regions, units of the country's territorial division, settlements). In case of a multiscale atlas, this property influences the size of the spatial database, and hence the speed of the search for cartographic objects and the display of cartographic information;

– maximum number of concurrent users connected. This property directly influences the hardware component of the spatiotemporal database;

– speed and nature of changes in spatiotemporal objects. This parameter influences the hardware component of the system even more and demonstrates how quickly the size of the database increases. Archiving is one of the programmatic measures to increase the load on the system. In other words, a small part of changes (the most relevant time sample – the last year, month, etc.) is available to the user in real time, while most of them (for example, an archive of changes that occurred with objects for five or more years) are only available upon request – with a slight delay. Special attention should be paid to the temporal generalization of spatial objects, when the most significant changes for a certain attribute are chosen from all changes to the object. This allows to provide a real-time access to the entire history of object changes, while displaying only significant changes, and a more detailed history of the changes may be provided with a delay upon request; and

– maximum volume of stored information, including media content. It is often impossible to determine even the approximate volume of information that will be stored in the database. It is usually sufficient to indicate at least an order of magnitude for the purposes of developing the concept of a spatiotemporal database (for example, tens of gigabytes or hundreds of terabytes). Upon reaching a certain threshold, the quantity transforms into quality and requires developing a highly loaded system. In this case, the threshold is estimated on the basis of a set of parameters, including the speed and nature of changes in spatial objects, the maximum projected number of concurrent connected users, etc.

Other required steps in the development of the concept of an electronic atlas are definition of scenarios for its use, selection of information sources and a database management system (DBMS), and determination of the nature of data updates.

The scenario of using electronic atlases is understood as a description of the sequence of user actions when using an electronic atlas. This will allow to most fully determine a sufficient number of attributes of spaciotemporal objects, the need for a search, etc.

The choice of information sources depends on the atlas purpose and type. In turn, the choice of information sources influences the nature of the data update, as well as the object composition of the data. State statistics services (for example, Rosstat data), industry, regional, and other databases, as well as search robots can be used as data sources. For example, both databases within the national or international spatial data infrastructure and specialized services of Internet search engines able to find an object from its image can be as a source of information about the geometry of spatial data.

The choice of DBMS depends on the range of parameters (cost, information security requirements, estimated amount of information, speed, nature, etc.). Moreover, one of the parameters (for example, cost) is often of the highest priority, and the choice is made due to it. It is advisable to use relational databases to create electronic atlases, and in some cases nonrelational databases, which are divided into the following types: key-value, document-oriented, object-oriented, graph.

The nature of data update is understood as the protocol and interface of interaction with the information source, the frequency of information update. The nature of the data update is determined both by the already considered characteristics (purpose and type of electronic atlas, data source, etc.) and additional restrictions.

C. Flow chart

Designing the database structure and developing methods for storing, processing, and displaying data

It is proposed that spatiotemporal data in the database under development with respect to atlas mapping are to be stored in decomposition form, when the essence of the object being mapped or the phenomenon and its attributes, which vary over time, are stored separately. To secure the connection of attributes for the same object, a unique number (identifier) of the object must be indicated in each attribute record, along with its value, start and end dates. Due to this identifier, all the attributes of the object described in the database are "assembled" into a single entity (Fig. 2).

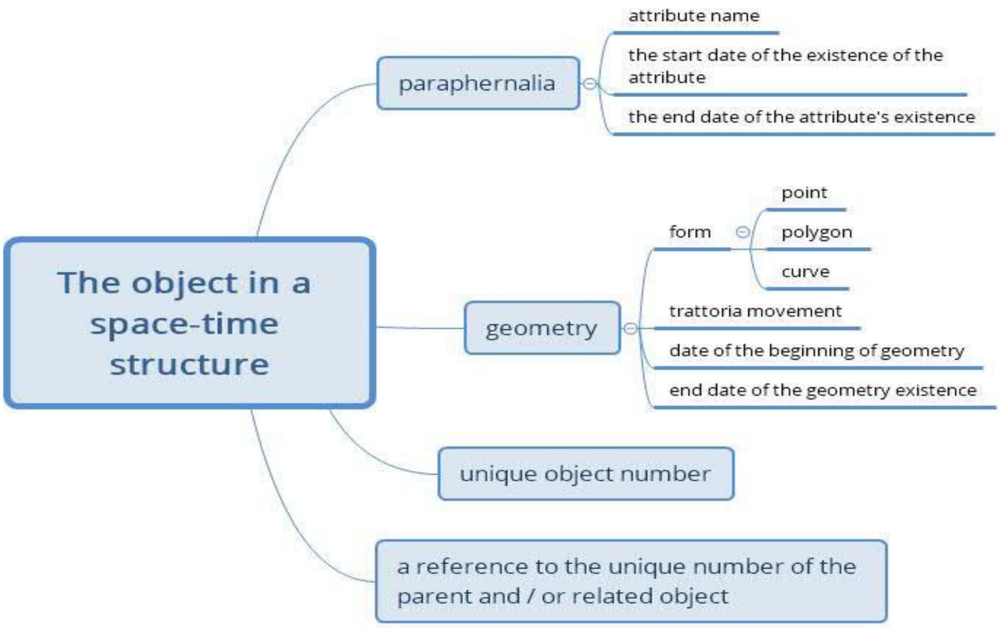

Fig. 2. Generalized diagram of the object structure

The proposed structure of the object for settlements in provided on Fig. 3, the attributes of which are the boundaries of the settlement, type, political and administrative significance, name, population, etc.

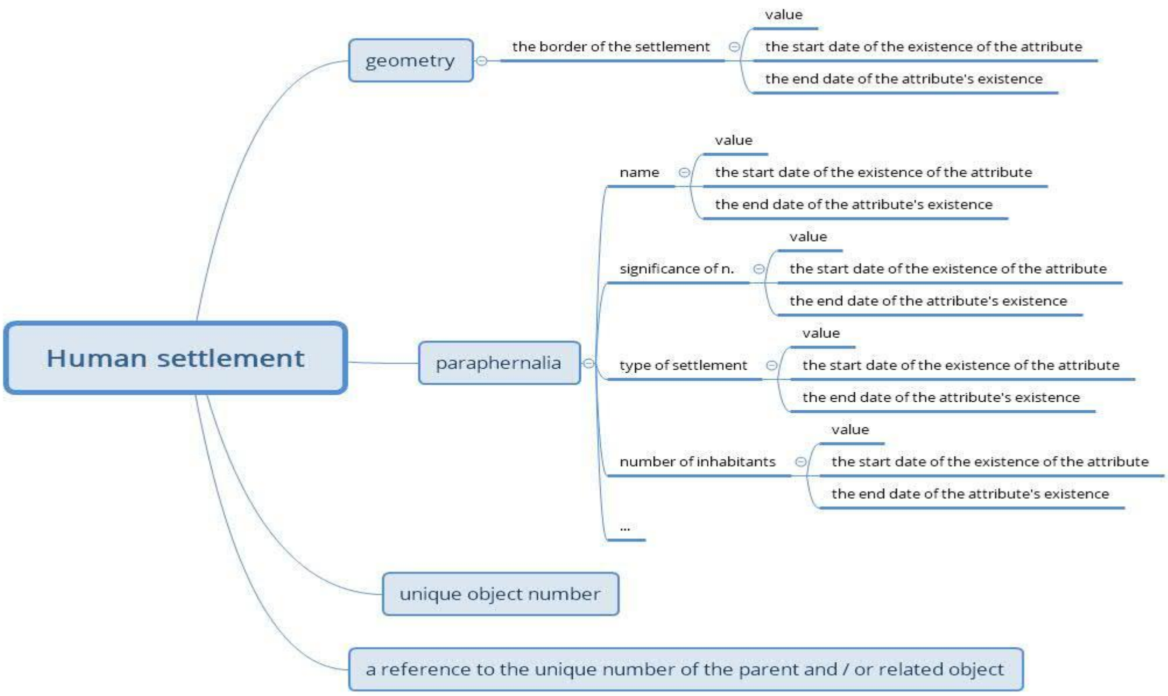

Fig. 3. A generalized diagram of the object structure by the example of a settlement

The advantages of this storage approach include the compact size of the database with quick access to all the object characteristics for any time period.

A relational database is suitable for storing the spatiotemporal data of electronic atlas mapping, which ensures the data integrity and consistency. Postgresql/PostGIS is an example of such a database. In some cases, the NoSQL database family can be used for attribute values that are collected by an automated method and often change, as it allows to record large data arrays. Examples are the collection of weather information from tens of thousands (or even millions) of weather sensors or the location data of millions of cell phones in real time. The drawback of the performance of this type of storage systems is that the data are stored only in a key-value relationship, without any connections between each other.

The electronic atlas also contains a large layer of information representing various media content (photos, video, audio, etc.) that cannot be stored and processed in conventional relational databases. It is proposed to store this information in file databases with a timestamp and space coordinate attached. A similar approach can be applied to any other type of information (for example, archival documents).

A tag system of toponyms (including obsolete names) should also be used for electronic atlas mapping. At the same time, the mutual spatial relationships of the toponyms (geotags) must be stored in a graph database (for example, in Neo4j). The archive of printed maps is an additional element of the storage system, which is filled in during the scanning, georeferencing of images, as well as the assignment of geotags.

An index system should be developed to ensure optimal search and retrieval of information according to the required criteria. Creating indices for textual and numerical information is a well-solved task, but indexing spatiotemporal data is a complex process. Various types of trees are used to solve this task (hierarchical data structures in which each node has descendants (children)):

– balanced branching trees in the external memory and families of B- and R-trees, in the first place;

– binary trees of spatial decomposition (k-d trees);

– regular multilevel grids based on octant and quadrant trees, as well as nested tetrahedral and hexagonal blocks; and

– metric trees for quick search of neighboring data elements in metric spaces (iDistance structures, coverage trees and BK trees) [8].

The issue of indexing intensively moving objects should also be mentioned. It seems possible to use existing studies considered in [9]–[15] to solve this task. For example, the following is proposed:

– use the MTSB tree [9] or MON tree [10] to index the trajectories of moving objects in time and space;

– use the TB tree [11] or SETI [12] to index the trajectories of moving objects with topological queries;

– use structures such as the RUM tree [13] to index the trajectories of moving objects with topological queries; and

– use the PMR quad tree [14] and the MOVIES data structure [15] to index queries predicting the near future position of objects.

As a result, each object is indexed by each of its attributes, with due consideration for the time axis and spatial position. Such an organization allows several types of main samples:

– data sampling by the borders of the territory being mapped for a specific time sample; and

– selection of data (attributes) by the object for a specific time sample.

Designing a role-based database access system is an important stage of the developed method. The role-based model is understood as one of the components of the database information protection subsystem, which allows combining users into groups and providing a specific set of rights (roles) to each group. The rights should be understood as the ability of a user to access data in a table, diagram, etc. As such, a role model is a collection of roles and user groups.

It is proposed to distinguish three main types of users when developing a role system for the designed database:

– administrators – users with maximum access rights (read and write) and able to create new users and database structures;

– users with read rights and limited rights to add/change data; and

– users with limited rights (the term "guest" is most often used for such a group). Such users usually have limited rights to read only a limited list of data and connect to the database without identification (username/password).

Development of an automated generalization system that solves the problems of selecting and generalizing objects is another important stage in processing the spatiotemporal data. It is proposed to estimate and assign significance codes, as well as establish topological relationships between objects in order to implement the selection of spatial objects. The significance code of the spatial object will allow to conduct qualitative selection in case of the scale reduction or building a thematic map. The topological relationships between objects are defined through a special attribute of a spatial object.

Object generalization includes aggregation and smoothing operations. The interval of the scale series of the map is indicated in addition to the time interval ("lifetime") to implement smoothing operations for each geometry. This approach allows to prepare the display of cartographic objects at different scales (for example, a marker for displaying settlements on a small scale and a polygonal object for large scales).

Tools for automatic searching for information on the Internet and storing it in the database after indexing information by time and space should be developed in order to ensure constant updating of the database with information that is freely available.

Implementation of a spatiotemporal database for electronic atlases

The spatiotemporal database structure is deployed using the modern database design software (for example, VisualParadigm), which allows not only to obtain a visual diagram of the database structure (including relationships between objects), but to automatically generate an SQL script as well. After running the resulting SQL script in the DBMS, all structural elements of the database (tables, schemas, views, etc.) are automatically created.

The role-based model of access to the database is implemented through assigning each user (or several users at once) a particular role, a username and a password, while reference information is recorded (for example, last name, contact phone number, etc.).

It is proposed to import data in an automated mode using special tools that allow importing data directly from various user formats (for example, excel spreadsheets or spatial data sets in *.shp format). The import process itself is reduced to choosing the source of information (file or file set), and the object in the database data structure to be imported in.

Information about the number of imported objects is displayed based on the results of data import, and a list of errors is generated if they occur during data import.

An important step towards automating the process of updating data is the DBMS integration with information sources. Integration is understood as connecting to a source of information via some program interface (API) to automatically feed information in case it is created or updated in the data source.

The information security methods for the developed database are implemented based on two basic concepts: identification (user authentication) and authorization (user authority verification). User authentication is generally performed by matching the username-password pair. Verification of user authority is made after identification and consists in checking their role and access parameters to the database. Moreover, users can be not only end users (people), but also automated systems, other DBMSs, etc.

There are the following main methods of information protection:

– ensuring the impossibility of access to information in the database for users who have not passed identification and authorization;

– ensuring the impossibility of gaining access to information about a username/password bundles to anyone (no possibility of creating an appropriate role, and the passwords are stored encrypted in the DBMS); and

– ensuring the impossibility of changing the user's role model in an unauthorized way and role.

The load and functional testing is carried out to confirm the fact that the developed database meets the required operation parameters specified at the design stage. The load testing checks the maximum number of concurrent connected users, and the maximum possible volume of received and stored information. The functional testing is done by running scripts that simulate connecting users and inserting data of the largest possible amounts of information. At this stage, the achievementы by the developed database of functions laid down at the design stage are determined.

III. RESULTS

The stages of the proposed method for creating a spatiotemporal database for electronic atlases were tested when creating a geoportal for mapping historical events on a cartographic basis (Fig. 4). A spatiotemporal database was designed as a result of the experiment, and its structure was deployed on Postgresql. Geoserver was used for rendering and displaying features, and the web page interface elements were configured using JavaScript.

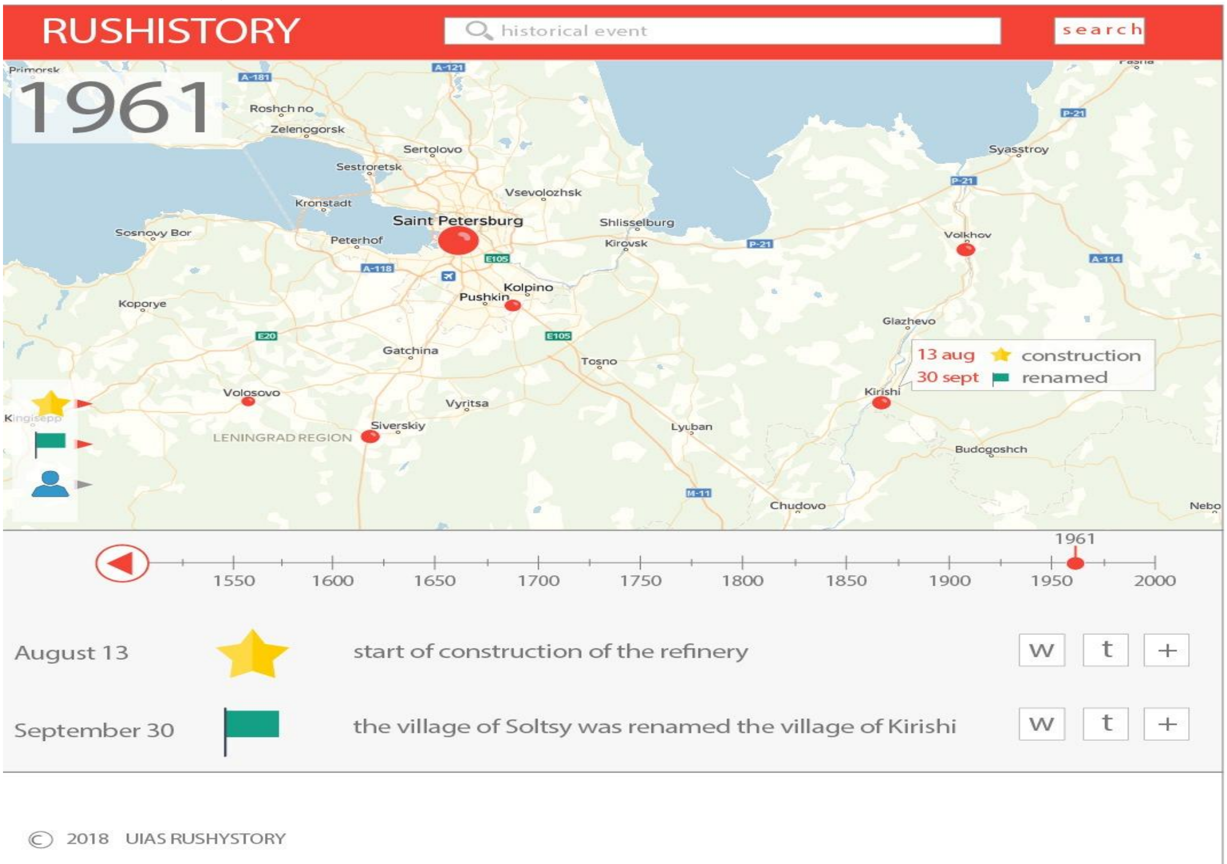

Fig. 4. Geoportal of historical events

IV. CONCLUSION

The developed methodological issues on the organization, storage, processing, and visualization of spatiotemporal data, as well as their use in electronic atlas mapping based on the development of geoportals will ensure the integration of multitemporal data into a single information space of the area under study. The proposed solutions will allow to structure large data volumes and visualize them as maps in the electronic atlas. On the one hand, maps created on the basis of spatiotemporal data will be as relevant as possible (in the ideal case, in real time), but on the other hand, they should display historical data for the entire time sample of observations (or a time sample upon users' request). The developed system of storing spatiotemporal data will also allow to efficiently save, process, and search through information of any type contained in an electronic atlas and having spatial and temporal marks.

The stages of the proposed method will be developed and tested primarily by the example of creating electronic complex atlases of individual regions of Russia.

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