Knowledge Discovery for Interactive Dialogue Management with Geoinformation Service

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Abstract: The problem of adaptation of the geoinformation service to the increasing amount of knowledge and modification of the spatial database structure is analyzed in this article. The necessity to take into account the factors of changes in information basis is considered by a visualization of searching procedure and by analyzing spatial data of the geoinformation service. The paper proposes a method for solving the problem, based on the principle of the evolution of technical systems. In this problem the evolutionary principle considers the continuous rules generation procedure by the geoinformation service containing knowledge of useful cartographic objects for visual analysis. The rules are considered as hypotheses that require collective confirmation from the clients of the service. Confirmation of any rule is a selection of useful knowledge for further implementation. Thus, the proposed mechanism provides a continuous adaptation to a changing information environment through the development and rule selection. The mechanism of generation is analyzed and the structure of rules is determined. The mechanism of collective confirmation of rules is considered as well.

1 INTRODUCTION

Network geoinformation services are systems for the collective use of spatial data. The geoservice information database includes charts, maps, plans, earth surface photographs and other materials that reflect real-world phenomena and objects (Shashi and Hui, 2008). Depending on the field of application, geoservices have different sizes - from corporate to geoservices in Internet (Brimicombe and Chao, 2009). Geoservice of any size (scale) can be attributed to BigData systems . This feature is determined by the (appointment of any geographic information system, which consists in the continuous accumulation of data on the changing world around. The volume of spatial data is constantly growing, existing structures and their representations are changing (Yang at al., 2015), and new structures are emerging. Spatial data never become obsolete, only the relevance is changed with regard to the solution of specific applied problems. The use of spatial data is impossible without a set of special methods aimed at obtaining information useful for the solution of the problem. It is of great interest to develop some methods that can be used for visual representation and visual analysis of spatial data. Cartographic visualization is the most effective tool for solving complex informal problems. Software tools of special types of analysis (statistical, topological, morphological, network and many others) play an auxiliary role. They complement the virtual cartographic image that the map analyst develops (Belyakov et al., 2014).

The selection of useful information largely determines the final result of spatial data usage. In accordance with the principles of cartographic research (Shashi and Hui, 2008) the user should build a workspace of the geoservice information base. The workspace includes cartographic objects that are grouped into thematic layers and linked by links to external databases. The problem complexity of constructing a workspace is to select useful data from the BigData source. This source is the geospatial database. Unsatisfactory implementation of this problem entails losses caused by the adoption of inadequate decisions.

Let's consider a simple example. When planning the placement of a vending machine on the territory of a residential complex, the analyst is looking for cartographic data that to help evaluate the

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effectiveness of the decision. The intensity of the flow of people passing by the machines, the approximate share of potential buyers, the relative position of objects or phenomena, the size of the access zone for maintenance of the machine, the logistics capabilities of the placement point from the perspective of further business development have a complex effect on the efficiency of choice. In Fig. 1 shows the section of the working area of the analysis, which was formed on the basis of experience in solving the type of problems under consideration. The selected position of the vending machine is marked with the special sign. In Fig. 2 shows the important elements for analysis, which one of the analysts used to construct the solution. These elements are data on the density of cars in parking lots along highways. Since a number of standing cars greatly reduces the visibility of the vending machine by nearby people, this decision may be erroneous. Analyzing this example, you can see a potential opportunity to improve the quality of geoservice: one of its users found useful data, which, perhaps, can be successfully used by other analysts who solve similar tasks.

Figure 1: Example of the working area.

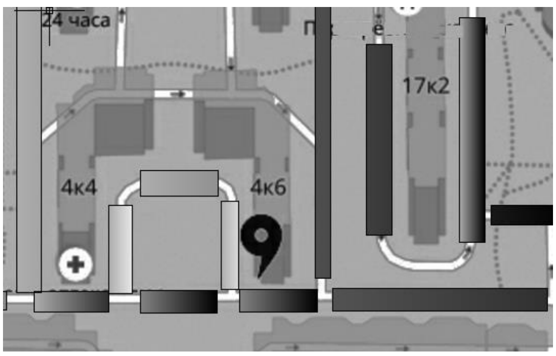

Figure 2: The important elements for analysis.

In this paper, an approach based on knowledge discovery is analyzed to improve the efficiency of visual analysis of maps and charts in an interactive mode of working with geoservice.

2 APPROACHES OVERVIEW

There are several approaches to solving the problem of selecting spatial data useful for analysis. The main idea of each approach is a special concept definition for the search and use of knowledge, which improves the quality of visual analysis of geodata.

The methodology of traditional cartographic research (Shashi and Hui, 2008) assumes the creation of a thematic map for solving a certain class of applied problems. The professional knowledge and experience of the cartographer, as well as fundamental knowledge of cartography, play a decisive role in this case. The search and generalization of maps of different subjects have a pronounced creative character. The result is unique cartographic works. The nature of this activity is very different from the procedures for searching and analyzing maps for solving specific applications. Therefore, the methodology adopted in the field of the search for and use of knowledge cannot be directly used.

Works on geo-visual analytics (Andrienko et al., 2013) examine the mechanisms for the formation of new cartographic representations that are adequate to the goals of analysis. The significance of a new view is determined by new knowledge and patterns that the analyst can identify. Software tools play an important role in scaling, aggregating and summarizing cartographic images. It can be concluded that the selection of abstractions and the development of tools for visual analysis of the generated image form the basis of the approach under consideration. So it is possible to obtain practically important conclusions and dependences (Andrienko and Andrienko, 2016). At the same time, manipulating the cartographic image for presentation system is a more general process. Perception of images by the user plays a decisive role in any way of displaying. The problem of reducing the utility of cartographic visualization with its complication in the work of this direction is not considered.

Neo-cartography (Faby and Koch, 2010) aims to display the surrounding world in real time. This approach is focused on presenting the real world with multimedia data. The user interface is intentionally simplified, which is important for geoinformation Internet services. A particular feature of this approach is the weakening of the connection with such important mechanisms for the synthesis of cartographic images as cartographic classification and generalization. Accordingly, interactive interaction has a specific semantic orientation, which makes it difficult to use the regularities of dialogue in traditionally constructed geoservices.

Research in the field of intellectual visualization (Pettit et al., 2008; Malczewski, 2004; Keim, 2002) aims to create procedures for the selection of useful information. As the analysis has shown, this problem is solved by the creation of complete ready-to-use information resources. At the same time, the problem of identifying knowledge remains little explored for constructing universal mechanisms for selection of thematic data in local areas of spatial databases.

The idea of collective usage of spatial data is studied in the framework of the direction of the creation of the Global Spatial Data Infrastructure (Li et al., 2012; Wang 2010). Here the main attention is paid to the technology of sharing spatial data and servicing the BigData data storage system. At the same time, the problems of discovering the patterns of using information in a dynamic database structure, the collective experience of rational selection of data remain outside the scope of research.

The research direction related to ensuring the quality of geodata, covering all stages of obtaining and using spatial data, is, from our point of view, the most promising (Hart and Dolbear, 2013; Ali and Schmid, 2014; Goodchild and Li, 2012; Fairbairn, 2015). Identifying and using knowledge to manage the quality of workspaces and solving application classes (Popovich et al., 2011) is an important but insufficiently studied problem.

The following works (Lughofer, 2011; Angelov, Filev and Kasabov, 2010; Angelov, 2012) are devoted to developing (evolving) systems. The mechanism of evolution suggests the accumulation of knowledge in real-time and automatic learning. This direction of building systems allows to realize autonomous adaptation to changing external conditions. The results of studies deal with the processing of numerical data streams and fuzzy rules of classification. It seems appropriate to extend this mechanism to the process of dialogue between clients and geoservice.

3 THE PRINCIPLE OF OPERATION GEOSERVICE

Geoservice is an intelligent information system that serves analyst users through software clients. Clients realize the functions of visualization of cartographic data obtained at the request of geoservice. The database of cartographic data and knowledge is stored on the server.

Consider in general the task of optimizing the dialogue that geoservice decides. Let $\Omega = \{\omega_1, \omega_2, .. \omega_n\}$ be the set of cartographic objects of the spatial database, and $w \subseteq \Omega$ is the workspace of the map created by the user to find the solution to the applied task. The complexity of the workspace (the number of cartographic objects in it) is usually much less than the complexity of the service database:

$$| w | << | \Omega | .$$

This ratio is achieved as a result of the user performing a sufficiently large amount of work on the selection of useful information. The reason for this is a significant redundancy in the spatial data stream generated by spatial queries (Shashi and Hui, 2008).

We denote by $I(w)$ the utility function of the workspace and by $q_1, q_2, .. q_n$ - the sequence of the software client's requests to the geoservice. Then geoservice must solve the problem:

$$\begin{cases} I(w) \to \max, \\ w \subseteq \Omega, \\ w = B \cup E, \\ B = \bigcup_i \omega_{q_i}, E = \bigcup_j \omega_{r_j}, \end{cases} \quad (1)$$

here ω_{q_i} is the set of cartographic objects received by the software client on request of q_i; ω_{r_j} is a set of cartographic objects selected according to the r_j rule from the geoservice knowledge base of the $R(B,\Omega)$. The B (workspace skeleton) set is a set of objects formed by the server at the client's request, and the E set is the set of objects that are the semantic addition of the skeleton. $r_j \in R(B,\Omega)$ rules define those cartographic objects that are selected from the spatial database and are entered into a workspace built from a number of cartographic objects of the skeleton B. Knowledge can be applied to an arbitrary set of objects. The result will be an image of reality in the context of the knowledge used. It should be noted that the utility $I(w)$ of the workspace is changed by varying the environment. For example, a car route constructed on request is presented in different ways in the context of transport of people or large-sized cargoes.

As shown in (Belyakov et al., 2014), the solution of the utility maximization problem is to find the classes, objects and relations that make up the set of the environment E, and specify a preference relation that allows us to establish a non-strict order on the set of its elements.

It should be noted that $R(B,\Omega)$ contains fundamental knowledge for solving an applied problem. This knowledge is distinguished by a high level of generalization and, for obvious reasons, does not take into account local factors important for mapping in specific contexts. For example, when implementing a logistics project, it is natural to display on the map a transport highway with the points of loading and unloading the vehicle. However, in some parts of the locality at certain times of the year, unfavorable weather conditions may occur. This will require knowledge of additional parking spaces, transshipment or repackaging of cargo.

Lack of special knowledge is an objective property of the geoservice knowledge base. This property will be preserved, despite any attempts to achieve completeness. The reason is the variability of the real world. In order to compensate for the incompleteness, it is proposed to use the possibility of temporarily disabling the intellectual support of the dialog in the normal operation of the service. This will allow the analyst to block "unreasonable" from his point of view the behavior of the system, as well as to indicate periods of use by the analyst of their own knowledge that improve the quality of the work area.

Geoservice, which solves problem (1), works as follows:

- software client establishes a connection to the server, having agreed the context. This determines the rules for creating the most useful images according to the user's professional identity. It is believed that the system has a description of sets of rules for several contexts. The default context is specified when the user logs on. The context does not change in the session, however, with the geoservice, the same user can set an arbitrary number of sessions;
- user-analyst sends $q_1, q_2, ..q_n$ queries, forming the skeleton B of the workspace. The skeleton environment is built on the server side by applying the $R(B,\Omega)$ knowledge base rules. The rules implement a reasonable strategy for building the most useful workspace. After processing each request, the server evaluates the utility $I(w)$ by changing the composition and number of environment objects so as to maximize the utility level;
- on the client side, the analyst uses visualization tools that are wrappers for standard scaling, panning, ang and views. Each wrapper uses the knowledge of the service to display the required portion of the workspace of the map. Intelligent selection of environment objects precedes the standard rendering operation;
- analyst has the ability to disable and re-enable intelligent geoservice support at any one time. Disabling means that the application of the $R(B,\Omega)$ rules is blocked. After that, the analyst continues to study and modify the workspace manually. The subsequent inclusion of intellectual support leads to the reorganization of the workspace: the created skeleton is provided with a newly constructed environment;
- session end means either the end of the work with the geoservice, or the transition to a new context of visual analysis. In the latter case, the skeleton of the completed session is saved. A new session represents the workspace in a new context by constructing the corresponding environment.

Analyzing the principle of geoservice, the following problems should be noted. The quality of the solution of the problem (1) is determined by the knowledge of $R(B,\Omega)$ about the objects, classes and relationships of the Ω spatial database. If the Ω structure is modified, i.e. there are previously unknown classes and instances of objects and relations, the management of the dialog is losing its effectiveness for two reasons. First, any new classes of objects and relations between them are absent as facts or rules of the knowledge base. Consequently, their re-use in subsequent sessions is impossible. Workspaces of analysis lose their quality due to the lack of relevant data. Secondly, there is an objective process of "obsolescence" of knowledge about the dialogue. The classes and instances of objects used for a certain period of time lose their significance and are interpreted as redundant. Since geoservices never delete the accumulated data (Shashi and Hui, 2008), the work areas are becoming increasingly redundant. Thirdly, the growth in the number of objects of known classes makes it increasingly difficult to select the most useful of them. Additional knowledge is required for an adequate selection of the most significant objects.

4 KNOWLEDGE DISCOVERY PROBLEM DEFINITION

Knowledge in the task of managing of interactive interaction is understood as information that allows the geoservice to efficiently select useful data into the workspace of the analysis. The geoserver in this case is considered as an evolving system (Angelov, 2012), which accumulates data in real time and self-learning.

The main source of knowledge is the work area, which is built by an analyst without intellectual support of geoservice. What can force a user to temporarily abandon it? Analysis shows that there can be three reasons.

The first reason is that geoservice does not use objects and relationships that are important from the point of view of the analyst. The information deficit is replenished by the analyst manually, and this must be done repeatedly in each session.

The second reason is connected with filling the work area with insignificant objects, which leads to an increase in redundancy. This leads to deterioration in the perception of the cartographic image, and to an increase in the laboriousness of manipulating the image in the process of its study.

The third reason is the unsatisfactory work function of changing the complexity of the workspace. As mentioned above, this function is an analog of the known scaling and panning functions with the only difference that when you execute them, the composition of the objects of the workspace changes. This is done to preserve its logical consistency. The unsatisfactory work of the function in question is that its integrity is violated.

A manually constructed fragment is a source of knowledge about the usefulness of a cartographic image. Obvious is the subjectivity of this knowledge, its ontological uncertainty and the vagueness of the evaluation of the actual material. For this reason, the following approach is proposed: at the moment when the intellectual support of the interactive dialogue is disconnected, fix the manually constructed work area, then, based on the analysis of the composition of the selected objects, generate product rules, and then evaluate their utility. Utility is confirmed by the repeated use of rules by users of the service.

5 RULES GENERATION PROCEDURE

The $K(B,\Omega)$ rules display knowledge of how the work area boundaries (w) are defined for a given skeleton B and the objects selected for analysis are ranked by significance. Order on a set of workspace objects is used to display the most important elements of the image when zooming and panning. Accordingly, it is possible the generation of several types of rules.

The rules for determining the spatial boundary have the form:

IF *Properties* (**Object**) *Corresponds* **Sample** THEN **BufferRadius** = Value.

Here, the Correspond relation establishes a way to map the attributes of the object selected by the Property (x) function to the reference value. The variable BufferRadius is used to build a spatial buffer for a given object. The construction of the buffer zone is a standard analytical function of geoinformation systems (Shashi and Hui, 2008), which consists in constructing the convex hull of a set of geometric primitives at a given distance (of a given radius). The buffer zones of individual objects are combined into a single buffer zone of the skeleton B . An example of such a rule may be:

IF *TypeOfObject* (**ObjectID**) = “Road” THEN **BufferRadius** = 40,

where *TypeOfObject (x)* function determines the type of the object by its identifier.

The rules for determining the temporary border are presented in a similar way:

IF *Properties* (**Object**) *Corresponds* **Sample** THEN **Interval** = Value.

Here, the variable Interval indicates a deviation relative to the set base point of time. This point, like the spatial coordinates of the analyzed area on the map, can change in the course of work.

The rules for defining semantic boundaries are of the form:

IF *Properties* (**Object**) *Corresponds* **Sample** THEN *AddToList* (**BorderElement**).

The *AddToList(x)* function adds instances of objects and relationships to the list that forms the semantic boundary of the workspace.

A spatio-temporal query to the geoservice database can be constructed from the result of applying the rules to skeleton B at any one time. The result of which is the addition to the skeleton of the environment E.

Rules of preference on the set of objects of the workspace have the form:

IF *Properties* (**Object1**) *Corresponds* **Sample1** AND *Properties* (**Object2**) *Corresponds* **Sample2** THEN **Object1** *ComparisonOperator* **Object2**.

By the designation *ComparisonOperator* is meant a possible variant of comparison - "more preferable", "less preferred", etc.

The above rules are used to describe the precedents of constructing the shell of the workspace. To evolve knowledge from individual facts to generalizations, rules of another type must be generated. The structure of these rules is determined by the logic of using cartographic information. Consider the following operations for generating rules: aggregation, generalization and transposition.

An aggregation of rules will be called an operation that leads to a new rule from several existing rules, which involves performing in some way all the actions of the original rules:

$$R_a = A(R_1, R_2, \ldots, R_k),$$

where A is the aggregation operator. An example of aggregation may be the disjunction of antecedents and the conjunction of the consequent of the original rules. The aggregating rule R_a is entered in the knowledge base, and rules $R_1, R_2, \ldots, R_k$ are deleted. The aggregation result is not reliable, but it looks plausible. A prerequisite for constructing an aggregating rule is the following:

$$\bigcap_{i,j=\overline{1,k}} w_{R_i} \cap w_{R_j} \neq \varnothing,$$

where w_{R_i} is the workspace in which R_i rule was previously built. In accordance with this condition, the aggregating rule R_a can be generated only for space-time and semantic areas that have "something in common".

The generalization of $R_1, R_2, \ldots, R_m$ rule set involves the construction of a general rule

$$Rg = G(R_1, R_2, \ldots, R_m),$$

where G is the generalization operator. As in the previous case, only the Rg rule remains in the knowledge base. Generalization also does not provide reliable knowledge, although it may turn out to be plausible. Unlike aggregation, generalization implies the existence of a correspondence between the objects of electronic maps of different levels of generalization. Thus, availability of ready maps of various levels of generalization is mandatory.

The transfer of experience between different work areas (transposition of rules) is based on a logical analogy. The operation of constructing $\tilde{R}_i$ rule similar to the previously generated R_i rule consists in applying the similarity operator

$$\tilde{R}_i = L(R_i).$$

This operator implements the principles of geographical classification of territories. An example is the proximity of the workspaces by geographical indicator - the relief or geophysical structure. The transfer of experience consists in the transformation of antecedent objects and consequent of the chosen rule into objects of another workspace. The operation of transferring experience is unreliable, but plausible.

6 CONFIRMATION OF RULES

The generation methods considered above give only hypotheses that require confirmation of their usefulness. The task of selecting useful rules is to evaluate the reliability of the generated rules and exclude unreliable (useless) rules from the knowledge base of the service. The criterion of reliability is the degree of collective recognition of the usefulness of the rule by users of the geoservice for a limited time. The time factor is necessary for the following reasons:

- time imitates the "aging" of knowledge. There is aging information on how to use spatial data, in contrast to spatial data itself. The objects and relationships used to solve the same problem change for many reasons over time;
- time pragmatically limits the usefulness of the rules to "the present time". Geoservice does not set out to develop fundamental rules, with

a value independent of time. Priority is given to locality and efficiency of knowledge;

- cartographic production regulates the regulatory periods for updating maps, schemes and plans. There is no such requirement with respect to the knowledge base. This means that periodically there is an objective need to develop new knowledge, which should ensure the adaptation of the service to the updated cartographic basis.

On this basis, pair (T^*, n^*), in which T^* is the duration of the confirmation time interval, and n^* is the number of confirmations, should be considered a measure of the confidence of the user service team in the usefulness of the rules. The rule is considered to be confirmed if, within the time $t \le T^*$ from the moment of the rule's appearance, $n \ge n^*$ precedents of its successful use are fixed. If at least one of the formulated conditions is violated, the rule is removed from the geoservice knowledge base.

Analyzing the proposed measure, it is necessary to note the following:

1) there is a high probability that collectively a useless rule will be confirmed for small n^* values. This is explained both by the psychology of user behaviour (the ability to tolerate "inconvenience") and the content of the workspace (in the area under investigation, the rules may appear weak). The probability under consideration decreases with increasing n^*, and for large values, confirmation of useless rules becomes impossible;

2) small values T^* lead to discarding useful rules. The reason for this may be insufficient intensity of geoservice use as a whole, or low activity of analysts' work with separate areas. Increasing the value of T^* reduces the probability of losing useful knowledge;

3) The limiting factor for values T^* and n^* values is the server performance. To identify and verify knowledge, a fixed proportion of productivity is assigned, which can be represented as the speed of confirmation of rules V. The values of the pair (T^*, n^*) cannot be chosen uniquely because $V = n^*/T^*$.

It should be noted that speed of information distribution in the social network can be used as a limit to the rate of confirmation of the rules. At present, there are a number of works devoted to mathematical models of information dissemination and the influence of users of social networks on each other (Isea and Mayo-García, 2015). Analysts-users of geoservice in many cases form professionally oriented communities that have all the attributes of a social network, which allows obtaining numerical values of the rate of distribution of rules.

Note also that the number of n^* confirmations accumulates as a result of the summation of not necessarily integers. As mentioned above, the R_k rule is confirmed if it is used to form the environment (E) of the current w work area and the user-analyst does not disable intelligent geoservice support. Since each rule has a spatio-temporal and semantic binding of w_{R_k} obtained at the time of generation, the confirmation should be estimated by the value:

$$n^+ = |w_{R_k} \cap w| / |w|.$$

Here, $|x|$ denotes the power of a set of cartographic objects in the region x.

If the rule is not confirmed, the total number of confirmations is subtracted from the value

$$n^- = |w_{R_k} \cap w| / |w_{R_k}|.$$

The above relations take into account the fact that the scope of each generated rule is limited.

7 CONCLUSION

The considered mechanism of using spatial data by geoservice gives an effect due to the spread of the experience of constructing workspaces for visual analysis. The mechanism is based on knowledge of the utility of individual objects and relationships subjectively identified by users. Due to this, the quality of information content of workspaces is increasing and the quality of decisions taken on the basis of spatial data is improved.

The advantage of the described principle is the exclusion of the rigid dependence of the operation of the geoservice software components on the structure of the spatial database. Traditionally, all the possibilities of forming workspaces are determined by the database schema. To use new information objects, you need to publish their description and modify the software components. The principles of using knowledge about new information objects considered in this paper are not limited to a specific database schema.

The experience of users, fixed by the rules, is of great importance in the process of geoservice adaptation to changing the structure of the information environment. Consequently, the quality of geoservice work depends heavily on the activity of users in the search and use of data. In this paper, we propose the operation of generating hypotheses based on existing rules to reduce this dependence. Even with a small experimentally confirmed material, many hypotheses can be constructed, which will then be tested by experiment.

Evaluating the effect of the proposed approach, we should pay attention to reducing the collective costs of finding useful information. It is known that the complexity of searching among *N* objects at best requires *O(logN)* operations. Such costs in the case of individual work are inevitable and are summed up for all users of the geoservice. When you reuse an element already found, the complexity is *O(1)*, which for the user community gives a significant gain.

Further research can focus on the generalization and transfer of the evolutionary principle to network services of another purpose.

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