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Current Issues Problems of Geoinformatics

I. N. Rozenberg[1], **S. K. Dulin**[2]

[1]Russian University of Transport (MIIT), Moscow, Russian Federation
[2]Institute of Informatics Problems, Federal Research Center "Computer Science and Control" of the Russian Academy of Sciences, Moscow, Russian Federation
* **Correspondence to:** Igor N. Rozenberg, i.rozenberg@geosc.ru

Abstract: Geoinformatics is a scientific discipline that focuses on natural, technical, and socio-economic spatial systems studied through computer modeling of localized objects and phenomena. The main goals of geoinformatics as a science are visualization, localization, and decision-making regarding spatial transformations of the environment. The structure of geoinformatics includes such sections as geosystem modeling, spatial analysis, and applied geoinformatics itself. The development of technologies for collecting, storing, converting and exchanging spatial and temporal data has led to the rapid development of GIS technologies and the emergence of a wide variety of industrial GIS aimed at processing geodata in order to make informed decisions. Currently, geoinformatics in many industries is perceived as a geoinformation industry, which implies the presence of its own equipment, the development of commercial software products such as GIS, a staff of experienced expert analysts and the organization of marketing. The paper highlights three of the most pressing problems faced by researchers in the field of geoinformatics over the past two decades: interoperability, digital transformation, and geodata fusion. The characteristic features of these problems and some aspects of their solution are considered.

Keywords: geoinformatics, GIS, geointeroperability, digital transformation, geodata fusion.

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Research Article

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1. Introduction

The current stage of geoinformatics development is characterized by solving three most pressing problems: ensuring geointeroperability, bringing informatization to the level of digital transformation, and synthesizing geodata [*Rozenberg and Dulin*, 2021]. A detailed review of these problems reveals that they are quite closely interrelated, and success in solving each of them has a significant impact on solving the rest. The ability to share geodata has been one of the main requirements since the development of the first GIS. Despite the fact that the past two decades have been very productive in terms of the development of geointeroperability, which facilitates the sharing of geographical data, geointeroperability has not yet become generally significant. Although the standards developed by ISO/TC 211 and the Open Geospatial Consortium (OGC) Inc. [*Open Geospatial Consortium*, 1999] provided the basis for its development, and in international organizations (Canadian Geospatial Data Infrastructure (CGDI), National Spatial Data Infrastructure (NSDI), Infrastructure for Spatial Information in Europe (INSPIRE), Global Spatial Data Infrastructure (GSDI) spatial data infrastructures emerged, geointeroperability is still in its early stages of implementation.

On the other hand, the Internet and the Web have developed tremendously over the past two decades. Currently, the Web is being upgraded to Semantic Web (or Web 3.0), evolving from Web documents to Web data, becoming an international open database.

2. Geointeroperability

The International Organization for Standardization ISO 19119 offers the following definition (https://www.iso.org/standard/53998.html): "Interoperability is the ability to connect, execute programs, or transmit data among various functional modules in a way that does not require the user to have knowledge of the characteristics of these modules."

For a geographical area, the following description of the term "geographic interoperability" applies (https://www.iso.org/standard/57465.html): "Geographical interoperability is the ability of information systems to 1) freely exchange all types of spatial information about the Earth and about objects and phenomena on, above and below the Earth's surface; and 2) share network software for managing such information."

It should be noted that this definition does not assume that each component uses the same data format (the coincidence of formats corresponds to the usually incorrect perception of interoperability by many people), but rather proclaims the ability to understand each other's format(s).

Semantic interoperability corresponds to human-level collaboration, and deals with the flow of work, the establishment of partnerships and collaborations, and the need to remove existing (national, local, organizational) barriers [*Dulin et al.*, 2014]. In other words, semantic interoperability becomes the ability of a collection of system components to (a) distribute information and (b) process it according to publicly available operational semantics in order to achieve a specific goal in a given context.

In the context of geoinformation, interoperability is directly related to GIS, which is the main environment for implementing geointeroperability.

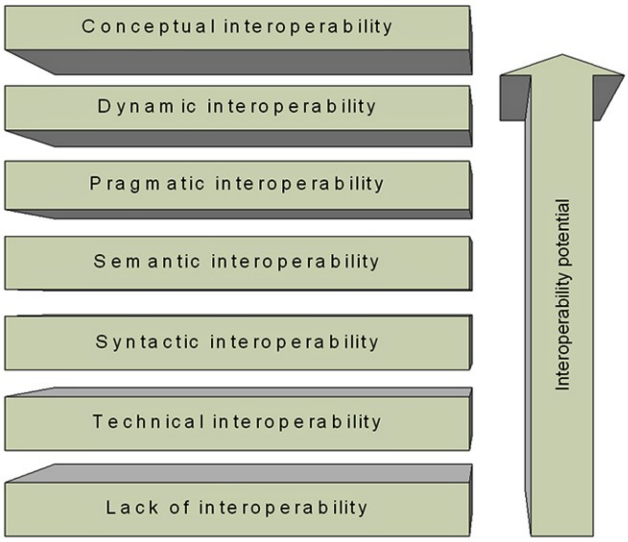

Figure 1. Interoperability levels.

Research in the field of geoinformatics points to the need to create interoperability models that can ensure that interoperability is established between systems in accordance with different goals and contexts [*Makarenko et al.*, 2019].

There are several approaches to the formation of GIS through interoperability models [*Makarenko et al.*, 2019]. Each approach has advantages and disadvantages in terms of achieving interoperability in a particular context. The main advantages of interoperability models are the ability to (a) define a common vocabulary that ensures consistency of semantics and analysis, (b) provide alternatives to suggestions regarding the structure of solutions, and finally (c) evaluate new ideas and add different options.

Examples of interoperability models that have been successfully applied in the GIS domain are – the Levels of Conceptual Interoperability Model (LCIM) and the Intermodel5. These models are mainly used at the highest levels of organizational interoperability out of the traditional seven levels: zero interoperability level, technical, syntactic, semantic, pragmatic, dynamic, and conceptual levels (Figure 1) [*Mohammad Saied et al.*, 2015].

3. Semantic Geointeroperability and Semantic Web

Geographic databases and user representations of real phenomena are characterized by high heterogeneity, which hinders effective geointeroperability. As a rule, heterogeneity is decomposed into four levels: system, syntactic, structural, and semantic.

Establishing semantic geointeroperability goes beyond simply being able to access geographic database information on a display or printed on paper. It requires more time, and the exact dictionary of geographical databases must be known in advance in order to get the relevant information [*Dulin et al.*, 2016].

Semantic interoperability is a key factor that allows interacting systems to understand data and process it based on this understanding. Interoperable systems represent components and tools in the lifecycle of product manufacturing and service delivery. Standards are one of the means to achieve semantic interoperability because they provide well-defined and consistent data requirements, although they are often so narrowly defined that they cannot provide the complete information model required for interoperability [*Gulyayev et al.*, 2012]. However, models related to standards can be easily integrated, providing a fairly broad domain model. The standards provide the necessary foundation for any interoperability. Creating intelligent infrastructures requires a more holistic exchange of information between different subject areas, which requires universal interoperability based on common semantic and ontological foundations with an unconditional availability of understanding.

Along with the problem of understanding in general, there is the problem of understanding the semantics of geodata [*Tarasov*, 2015].

Among the definitions of the concept of understanding for interoperability problems, the most appropriate is the following:: "Understanding (assimilation) – correlation, comparison of newly received information (text, image, speech, behavior, phenomenon, etc.) with already known, accumulated and structured information (i. e., basic knowledge) by means of cognitive structures, behavior patterns, concepts and categories of concepts; and its evaluation from certain positions, based on based on a certain sample, standard, norm, principle, etc. for example, the accumulated experience or circumstances in which the process of perception and understanding occurs, the features of the cognitive system/ cognitive style of a person" [*Tarasov*, 2015].

Misunderstanding is most often caused by the unfounded, non-obvious or lack of such a standard, and can also be caused by the emerging cognitive dissonance (in the terminology of information systems – a violation of the integrity of existing knowledge), as well as, in the case of the human understanding process, by subjective perception factors (unfavorable conditions for perception and understanding/assimilation of information). In the latter case, understanding may also occur with a delay rather than immediately, for example:

- after a certain period of time – there was time to "think" or favorable conditions were created for reflection;
- when conditions change – additional information was received, for example, certain events occurred, which supplemented, "pushed" previously misunderstood information, "put everything in its place".

Understanding (or more precisely, meaningful knowledge) makes it possible to perform actions with new objects based on already established skills and abilities; as well as reflect on the understood / learned information (knowledge), deduce various consequences from it.

Regarding the process of understanding (interpretation), we can formulate the following: the author (generator) expresses his subjective images or judgments in a formalized form (text, speech), and the interpreter restores this image or judgment in his own subjective context. This subjective context is determined by the subject's previous experience and the current circumstances in which the interpretation occurs. Thus, the language acts as a "universal ontology", which ensures the interoperability of subjects-native speakers (more precisely, users of the language).

For the generator, there is no (rather, it is invisible to it) problem of homonymy of words/terms (ambiguity of the word/term used), since it knows the meaning implied by it. But the interpreter faces such a problem and is forced to solve it either by relying on the context of the message, and if this does not help, then it is forced to use probabilistic (frequency) or fuzzy estimates (such as "the author probably meant the following" or "the author could have meant either this or that"'). The search for implicitly / vaguely expressed content occurs as a result of accessing knowledge relevant to this text (Figure 2).

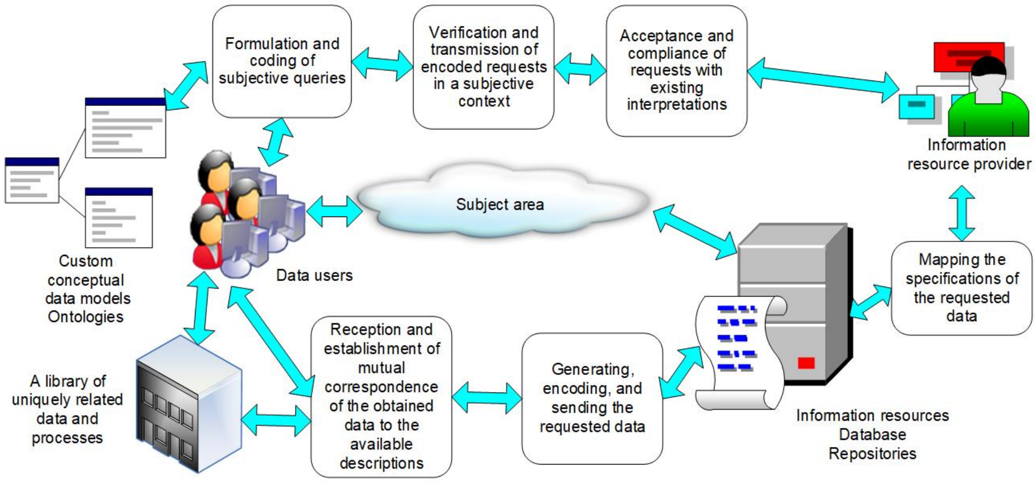

Figure 2. Structure of semantic interoperability.

Semiotic communication involves the participation of the sender and recipient of an information message, and in the process of communication, each of them acts as a generator or interpreter of the message.

Modeling semantics [*Dulin et al.*, 2016] is deeply embedded in the geointeroperability framework and thus provides a comprehensive description of semantic geointeroperability in general, which underlies the development of Semantic spatial data infrastructure and Semantic Web geospatial information.

Geointeroperability is the foundation for the development and implementation of Spatial Data Infrastructures (SDIs) [*Dulin et al.*, 2019]. The purpose of SDIs is to coordinate the useful exchange and sharing of geographic information using appropriate services.

In 2001 Berners-Lee the idea of Semantic Web was put forward. It was based on a proposal to modernize the Web from the document level to the data and information modeling level.

Semantic Web requires logical statements, classification of concepts, formal models, rules, and protocols of security and trust. The Semantic Web architecture has been described in detail in many publications. It is based on Uniform Resource Identifiers (URIs), Universal Character Set (Unicode), and eXtensible Markup Language (XML).

The idea of creating a geospatial Semantic Web was first introduced Egenhofer in 2002. It should expand the concept of Semantic Web, improving the semantic interoperability of geodata on the Web. But most importantly, establishing semantic geointeroperability requires that users and providers have a relevant understanding of the semantics of requests and responses. In the context of the Semantic Web, this feature is becoming more and more accessible.

During this time, efforts to standardize ISO / TC 211 and OGC and the development of geoinformatics provided a large part of the foundation for the creation of the geospatial Semantic Web. The international standards ISO / TC 211 have defined an ontology of geospatial concepts that are independent of applications. This ontology is the basis for describing geographic information, which includes concepts for describing geometry, topology, temporal information, spatial reference information systems, features, characteristics, behavior, relationships, quality, metadata, and services.

4. Aspects of digitalization

Currently, there is an intensification of digitization of geographic information and processing of digitized geographic information by GIS tools. Digital geodata, as experience shows, ensure the improvement of the activities of any company. However, most modern geodata are not interoperable: they are stored in isolated geodata databases, non-interoperable systems, and are used in restricted access programs. This makes it difficult to exchange geodata, and it is often impossible to analyze and interpret them.

Digitization, digitalization and digital transformation [*Hewlett Packard Enterprise*, 2023] – these are different processes that are used differently in different industries. However, in the field of IT, they usually mean the following:

- digitization means the transformation of some information resource from an analog representation to a digital one. For example, scanning manuscripts and storing them in an electronic library.
- digitalization means the introduction of a technological process in the field of technology and related software. The online shopping service on the Internet is an example of a digital business process that combines electronic purchase and delivery.
- digital transformation means that software-based processes are created that can evolve to increase the company's flexibility and competitiveness. The following definition can be given: "Digital transformation is the process of integrating digital technologies into all aspects of business activities, requiring fundamental changes in technology, culture, operations, and the principles of creating new products and services" [*Hewlett Packard Enterprise*, 2023].

When it comes to digital transformation, understanding the processes in the problem domain takes a significant amount of time and is much more difficult than simply adapting them to new digital technologies. In digital transformation, new solutions are being sought, as problems arise that are being solved with the help of new technologies. For example, a document is not just digitized, but processed and analyzed, and the question of whether a specific process is needed or whether it can be simplified using a new technology is studied.

Therefore, digital transformation is nothing more than solving problems with the best technical means. To a certain extent, this also applies to topics such as "agile design thinking", "brainstorming" and other creative ways of working, since they are necessary in order to expand the view of problems. You can solve them by technical means using new technologies only if you have an understanding of these problems.

Digitalization has led to the emergence of digital content. This content can be processed by digital processes, and new technologies will lead to the development of a digital business strategy. But digital transformation provides much more. Of course, digital content, digital processes, and a digital business model are essential, but digital transformation takes into account all aspects of production. Digital transformation is a work that needs to be carefully planned and takes a long time (3–5 years). Unlike digitalization, digital transformation does not just require enterprises to apply a large number of advanced technologies in their activities and cannot be completed in a single project.

The implementation of digital transformation development can be represented in the idea of three stages: I. Implementation of an information technology and service management system, II. Development and implementation of a service for analyzing the use, evaluation, and efficiency of digital technologies, III. Transition from a digital service to a service based on artificial intelligence, machine learning, and big data for managing digital technologies.

Complex GIS software can be roughly described as layers of spreadsheets containing data representing real geographical and spatial features, combined with tools for visualizing this data, as well as tools for manipulating data and creating new relationships and subsets of data. The Esri GIS system, in particular, supports three main views when working with geodata [*ESRI*, 2002] (Figure 3).

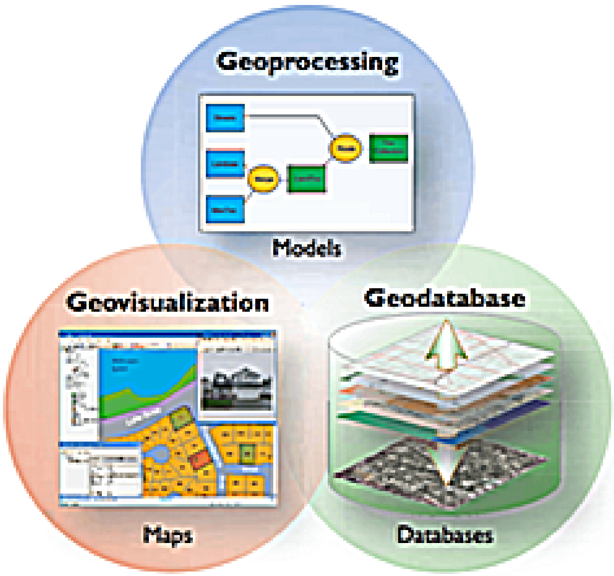

Figure 3. Three main views of geodata.

Geo data representation: GIS includes a BGA with geo data sets that contain geographical information in terms of supporting the general GIS data model (functions, rasters, topologies, networks, etc.).

Geovisualization View: GIS is a set of smart maps and other descriptions that show features of relationships between objects on the Earth's surface. Various map views of basic geographic information can be used as a “window to the geodata database” to support querying, analyzing, and editing information.

Geoprocessing View: GIS is a set of information transformation tools that form new sets of geodata from existing sets of geodata. These geoprocessing functions take information from existing geo sets, apply analytical functions, and place the results in new derived geo sets.

Since digital transformation involves the use of technologies to radically improve productivity, the digitization of all three representations should provide an appropriate level of software technology. Digital transformation means that we have managed to introduce a technology that starts completely new processes, and not just a new way of processing geodata [*Naseer et al.*, 2015].

Digital transformations have a significant impact on how specialists using geo-resources interact with each other within the existing geointeroperability, which is a key condition for implementing digital transformation [*Rozenberg et al.*, 2021].

Implementation of digital transformation of geodata provides at least four benefits: reduces the cost of maintaining the structure and consistency of geodata, improves the accuracy and adequacy of generated queries, increases the speed of executed transactions, and makes working with geodata more meaningful and efficient.

Digital transformation of geodata, which is possible only in the presence of semantic geointeroperability, requires preliminary digitalization of all geoinformation resources, which is complicated by the inherent heterogeneity of geodata. This requires accurate and up-to-date geodata about the location of spatial features, their properties and characteristics, their movement or change over time, and their interaction with other features. In other words, we are not talking about expanding attribute data, but about creating a spatial basis for digital transformation. The geographic information solutions obtained on this basis will allow both to organize and organize various information flows, as well as receive independent timely analytical reports on various spatial features and events taking place on the map [*Rozenberg et al.*, 2022].

Digitized geodata can be obtained as a result of using modern technical means of satellite scanning, sensing and positioning, or using aviation means of aerial photography of the earth's surface. Photogrammetry and mobile laser scanning make a significant contribution to the formation of geocontent [*Ruiz et al.*, 2011].

5. Geodata fusion

Fusion of spatial data from various sources available on the Web is the main task for modern applications that use information search on the web and are aimed at making decisions based on geodata [*Stankute and Asche*, 2012].

The rapid development of the Web from a data-driven variant to structures for serving a wide range of queries, along with the widespread adoption of mobile location-based devices, has greatly affected the understanding, availability, and use of geodata. As a result, the number of geodata available through the network is continuously increasing. Successful analysis of geodata sets requires methods for establishing relationships and combining geodata obtained from a variety of sources. It is becoming clear that once web services provide the fusion of spatial information from an arbitrary number of geodata sources, there will be a much greater processing potential than today's Spatial Data Infrastructures (SDIs)provide [*Dulin et al.*, 2019], which act only as spatial data delivery platforms available over the network. Spatial data fusion techniques play an important role in creating an integrated representation of distributed spatial data sources in the network. Since flexibility and interoperability are key factors in such geo-data integration, the use of standards is an indisputable requirement. Therefore, in addition to the geospatial standards established by the Open Geospatial Consortium (OGC) [*Percivall*, 2013], semantic web standards published by the World Wide Web Consortium (W3C) regarding related geodata [*Percivall*, 2023], are a good addition for formalizing and managing relationships between object characteristics as part of the fusion process. Although the SDIs and Semantic Web architectures are very different in terms of the applied technological processes and standards, they can complement each other.

The term “Data Fusion” is widely used in the field of electronic data processing and includes many different definitions and classifications. In 2010, when studying standards, information data fusion was defined as [*Stankute and Asche*, 2012] “the act or process of combining or combining data or information relating to one or more objects that are considered in an explicit or implicit knowledge structure in order to improve the ability (or reveal a new opportunity) to detect, identify, or characterize the objects in question.” Although research was initially focused on solving military intelligence tasks, synthetic decision-making has proven to be applicable in business, urban planning, and many other applied areas.

Open standards-based interoperability radically changes the role of data fusion in classical application domains, creating new ways to identify relationships in small-structure data.

In this paper, spatial data fusion is considered in relation to a variety of sources to extract meaningful information related to a particular application context. Therefore, understanding the geodata fusion proposed here includes what others describe as a fusion [*Huang et al.*, 2023], geo data integration [*Al-Bakri and Fairbairn*, 2012] or geo data concatenation [*López-Vázquez and Manso Callejo*, 2013].

Many fusion processes can be implemented in a closed architecture with a single software and hardware provider. However, without the use of open standards, many geodata and services are difficult to automate and scale. Standardized data, applications, and services provide an automated and interoperable geodata fusion environment, supporting secure geo sharing and transparent reuse of services for processing large volumes of geodata and unpredictable analytical queries.

Some elements of the preferred open structure of geographic information fusion based on geostandards are already being distributed to users. For example, Web Map Service [*Randall*, 2014] (WMS) provides map fusion. WMS presents maps as illustrated layers of images obtained from various sources in order to use the geographical overlay to create aggregated maps that meet the needs of users (Figure 4).

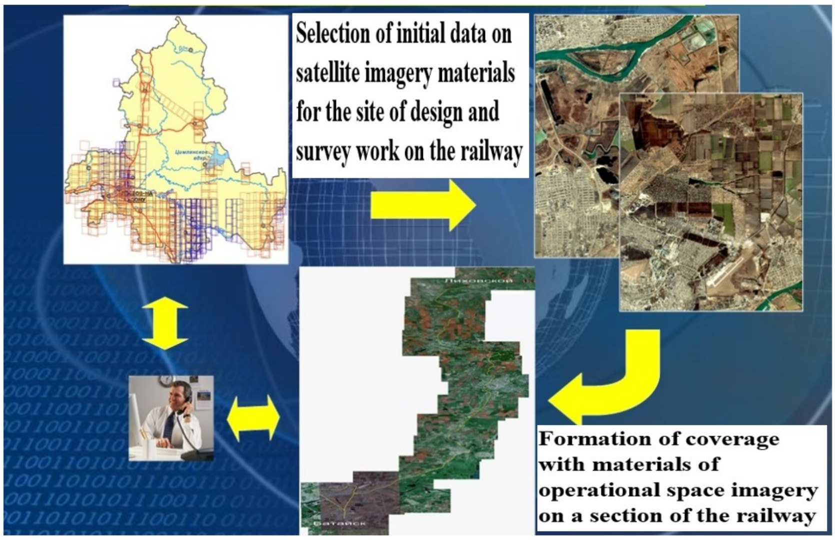

Figure 4. An example of geographic information fusion based on WMS the standard OGC. The map image is represented by sequentially generated levels of geospatial information synthesized into a single visualization.

In the study of geodata fusion, it is customary to consider three categories: comparison of observations and measurements (Observation Fusion); comparison of phenomena (Feature Fusion) and fusion of solutions (Decision Fusion) [*Ciuonzo and Salvo Rossi*, 2014].

As a result of the fusion of observations, multiple sensor measurements of the same phenomena are combined into a combined observation. Processes mappings thus, a combination of different sensor measurements is formed in the form of a well-described observation, while taking into account the inherent uncertainties of this process (for example, analyzing the client's signature or recognizing his face from different angles).

Basic requirements for mappings observations and sensor measurements include [*Ciuonzo and Salvo Rossi*, 2014]:

1. Build a system of sensors, necessary observations, and surveillance processes that meet the needs of users.
2. Determination of sensor capabilities and measurement quality.
3. Availability of sensor parameters that allow you to automatically determine the location of observations.
4. Determination of real-time observations in standard encodings, including encoding of measurement uncertainty, and parameters required for processing measurements.
5. Configure sensors to make observations of interest.
6. Generate and publish alerts that will be issued by sensors or sensor services based on certain criteria.
7. Object identification and classification.
8. Enabling it mappings observations and measurements provide access to the processing mechanisms and necessary information about the object.

Information for performing fusion can be obtained from both sensor observations and from people. Information as a result of observation can serve as input to processes mappings observations and dimensions, or it can be used to identify recognized objects whose characteristics are processed as input to the fusion process. Standards for mappings, observations and measurements have been used for a long time and have proven their viability.

Comparison of phenomena involves processing observations at a higher level of semantic properties of phenomena. This improves the understanding of the operational situation and clarifies the assessment of potential threats and impacts, allowing you to more correctly identify, classify, link and combine objects of interest. The processes of comparing phenomena include their generalization and aggregation. Aggregation technology includes useful options that allow you to work with imperfect, heterogeneous, contradictory, and duplicated geodata.

Service-oriented architecture (SOA) [*Naseer et al.*, 2015] it is well suited for supporting distributed services of phenomenon aggregation rules. Comparison of phenomena allows you to work with more powerful, flexible and accurate information resources than with those obtained from original sources.

Recommendations for comparing phenomena should be taken into account:

- To achieve a level of semantic interoperability, user profiles must be taken into account when processing geodata.
- Designing user profiles is a task that concerns not only the selection of appropriate input and output type definitions, but also the selection of appropriate classifications.
- Metadata in user profiles is required for registering in directories OGC, to quickly find and establish links with standardized structures.

Decision fusion initiates processes that support a person's ability to make a decision, providing an interoperable network service environment for situation assessment and decision support, using information from various sensors and information already processed.

Solution Fusion provides analysts with an environment where they can access interoperable tools using a single client interface to find, process, and use different types of data from different sensors and databases. Decision fusion involves the use of information from corporate geocommunities, which allows you to assess the overall situation and take advantage of the overall operational situation. Therefore, we can say that the information available for decision fusion is a collection of information from intellectual corporate capital. Sources of such information are people, documents, equipment, or technical sensors.

This information can be grouped as follows:

- Information received from people.
- Geospatial information accumulated in the form of geo resources.
- Information in the form of sensor signals.
- Information in the form of measurement data for various parameters.
- Information about open access geodata in any format.
- Information about scientific and technical intelligence geodata.

The development of decision fusion requires the development of standards for structured information, such as schema mapping methods with appropriate identification of mapping rules, and an increased emphasis on association processing, since the identification of associations between objects is at the heart of fusion. The most efficient environment for implementing these categories of fusion is an architecture with distributed databases and services based on a common core of geodata formats, algorithms, and applications [*Naseer et al.*, 2015].

Figure 5 shows an example of decision fusion that involves analyzing flood trends and causes in the Kargasok city area based on geodata from multiple sources. The decision fusion carried out in this study is a large-scale operation that includes both geodata received from a person from a mobile device, and geodata of the general situation from the center of the Ministry of Emergency Situations.

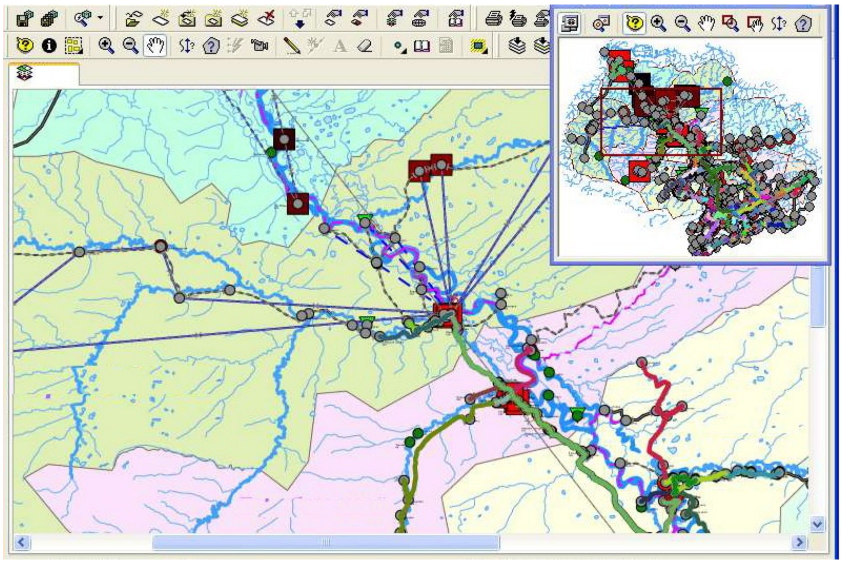

Figure 5. Fusion of solutions based on switching geodata from various sources.

6. Conclusion

Increasing requirements for joint processing of spatial data for various applications have revealed an urgent need for GIS scalability with supported geointeroperability.

To achieve semantic geointeroperability, it is necessary to develop both a geo-description matching system and a set of related services to ensure an efficient bidirectional communication process, where the user and the geodata provider interact through requests and responses, understanding each other through their knowledge and reasoning processes.

Digital geodata ensure the improvement of any company's operations. This period is marked by a large-scale digital transformation, and here we should note the need for geointeroperability to conduct digital transformation of geodata and the leading role of GIS in providing users with access to digitized geo-resources and in the process of integrating digital technologies.

Fusion of spatial data from various sources available in Web, is the main task for modern applications that use information search in the network and are aimed at making decisions based on geodata. Geodata fusion in distributed information environments with open standards-based interoperability radically changes the classical areas of data fusion, offering completely new ways to represent relationships.

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