Support of The Life Cycle of Intelligent Geoinformation Systems for Various Purposes

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***Abstract*—The article is dedicated to the particular technology for intelligent geoinformation systems design built on the principles of ostis-systems. The structural and semantic interoperability of geoinformation systems built using the proposed technology is ensured by the transition from the map to the semantic description of map elements.**

***Keywords*—OSTIS, intelligent geoinformation system, intellectualization, map, interoperability**

I. Introduction

In geoinformatics, fundamental knowledge about space, time, and the Earth is systematically organized on the basis of information encoding.

Unlike other classes of *information systems*, in *geoinformation systems*, the main object of research is knowledge and data about *terrain objects*, which are not only considered as spatial data and knowledge, but also are the integration basis for various *subject domains*. At the same time, the formalization of such *knowledge* and their representation in *knowledge bases* of *intelligent systems* requires the establishment of relations to describe the properties and patterns inherent in the *subject domain* under consideration and using *terrain objects*, the establishment of geometric characteristics capable of binding *terrain objects*, and also taking into account the temporal nature of the existence of *terrain objects*, which allows for a retrospective analysis. Taking into account the fact that *intelligent systems* are designed to meet *information needs of users*, this fact contributes to the expansion of *subject domains* and the addition of new functionality within the proposed particular *Technology for intelligent geoinformation systems design*.

According to the generally accepted definition, a *geoinformation system* is a *computer software system*, which provides input, manipulation, analysis, and output of spatially correlated data (geodata) about the territory, social and natural phenomena in solving problems related to inventory, analysis, modeling, forecasting, and environmental management, as well as territorial organization of the society [1].

Consequently, the very definition of the *geoinformation system* implies the need to implement intelligent problems:

- analysis problem
- modeling problem
- forecasting and environmental management problem

All these problems are intelligent and require decision-making support when they are implemented.

Within this article, fragments of structured texts in the SCn-code will often be used, which are simultaneously fragments of the source texts of the knowledge base, understandable to both human and machine. This allows making the text more structured and formalized, while maintaining its readability. The symbol "**:=**" in such texts indicates alternative (synonymous) names of the described entity, revealing in more detail certain of its features.

II. Requirements for intelligent geoinformation systems of a new generation

intelligent geoinformation system
:= [information system, the main object of research of which is knowledge and data about terrain objects, acting as an integration basis for solving applied problems in various subject domains]
⊃ *intelligent geoinformation ostis-system*
  := [intelligent geoinformation system developed according to the principles of the OSTIS Technology]

An important point that reduces the development time of *intelligent systems* on the one hand, and on the other hand increases the functionality of *intelligent systems* that use knowledge about *terrain objects* as integration is the availability of design technology and tools. At the same time, the *Technology for intelligent geoinformation systems design* should ensure the reuse of information and functional components of the system in order to reduce the design and development time for applied systems. Thus, it is about creating a particular *Technology for intelligent geoinformation systems design*. In this connection, the relevant problems are:

- design of spatial ontologies and the solution on its basis of the problem with *semantic compatibility* of *knowledge* of *subject domains*;
- solving the problem of metadata management and improving search, access, and exchange in the context of growing volumes of spatial information

and services provided by numerous sources of *geoinformation*;
- implementation of knowledge output using spatial and thematic information as components of *knowledge* about *terrain objects* using the *Question Language*;
- implementation of a *cartographic interface* in *intelligent ostis-systems* as a natural way for a human to represent information about *terrain objects*.

The constant evolution of models and means of ontological description of subject domains, using spatial and temporal components, their heterogeneity, and ambiguity, poses new challenges in terms of interaction, integration, and compatibility of various applied systems due to:

- the integration of *subject domains* and their corresponding ontologies (vertical level);
- expanding the functionality of the systems using reusable components of these systems (horizontal level), in particular, designing components for new territories and/or in a new time interval.

In order to implement the requirements represented, it is proposed to consider the map as an *information construction*, the elements of which are *terrain objects*, and to offer:

- the *Subject domain and ontology of terrain objects*;
- *Map Language Syntax*;
- *Denotational semantics of the Map Language*.

The transition from maps to their *meaning* is based on:

- the formal description of the *Map Language Syntax*;
- the formal description of the *Denotational semantics of the Map Language*.

At the same time, *semantic compatibility* of *geoinformation systems* and their components are provided due to the common ontology of *terrain objects*, which is necessary for the interoperability of *geoinformation systems* for various purposes and their components.

Thus, structural and semantic interoperability of geoinformation systems is ensured due to the transition from the map to the semantic description of map elements, that is, terrain objects and connections (spatial relations) between them.

The presence of these circumstances determines the existence of a scientific and technical problem of *intellectualization of geoinformation systems* and the creation of the *Technology for intelligent geoinformation systems design*, which are based on the principles of designing *ostis-systems*.

III. Systematization of problems solved by intelligent geoinformation systems

One of the ways to increase the efficiency of using information and computing tools is *intellectualization of geoinformation systems*.

Intellectualization of geoinformation systems implies:

- the possibility of end-user communication with the system on the *Question Language*;
- the use of various interoperable problem solvers with the possibility of explaining the solutions obtained;
- the use of *cartographic interface* to visualize the source data and results.

The implementation of the capabilities of *intelligent geoinformation systems* can be carried out using:

- *knowledge base management systems*;
- multimedia *knowledge and databases* by application areas;
- interoperable *problem solvers*;
- an intelligent *cartographic interface*;
- *expert systems* in various fields of human activities;
- *decision support systems*;
- *intelligent assistance systems*.

Intellectualization of geoinformation systems involves solving the following problems:

- the use of digital cartographic material and data from *remote sensing of the Earth* in problem-oriented areas [2];
- planning actions in a dynamically changing situation in conditions of incomplete or fuzzy data using expert knowledge [3];
- analysis of emergency situations and preparation of materials for decision-making on prevention or elimination of their consequences;
- creation of decision support systems for applied *geoinformation systems* of territorial planning and management [4];
- development of diagnostic expert systems for geological exploration activities with remote access to them;
- logistics planning, creation of expert systems and enterprise management software;
- creation of control and navigation systems;
- creation of *expert systems* for forecasting the occurrence and development of technogenic and natural situations: floods, earthquakes, extreme weather conditions (precipitation, temperature), epidemics, spread of radionuclides, chemical emissions, meteorological forecast, etc.;
- creation of *expert systems* for the selection of terrain compartments for the construction of various objects;
- creation of *expert systems* for planning the efficient use of agricultural land;
- creation of *expert systems* and software tools for geodata analysis;
- creation of image and picture recognition systems based on data from *remote sensing of the Earth*;
- creation of banks of digital cartographic information with means of remote access to them;
- image processing;
- retrospective analysis of events (see [5], [6];

- creation of *information search systems* for Earth sciences and geoinformatics;
- development of educational systems for training specialists and experts with means of remote access to them.

The complete solution of the above problems requires the use of open system standards and the use of ontologies of *terrain objects* as integrating elements of various *subject domains*.

IV. Main components of formal ontologies used in geoinformation systems

The main approach to ensuring semantic interoperability is the development of ontologies. The most frequently used ontologies in geoinformatics are usually considered as domain ontologies, which are commonly called geographical ontologies, or geontologies [7], [8]. One of the problems in the development of ontologies is a clear and unambiguous definition of the semantics of primitive terms (atomic elements that cannot be further separated). To solve this problem, the researchers proposed to justify the primitive terms of geontologies on the basis of geographical phenomena [9], [10].

In relation to subject domains, an ontology is the formalization of a certain area of knowledge based on a conceptual scheme with a structure containing classes of objects, their relations, and rules that allows for computer analysis. Accordingly, the ontology of the subject domain includes instances, concepts, attributes, and relations.

The subject domains for which the development of geoinformation systems is appropriate involve the construction of an ontology, which we will call geontology.

geontology
:= [ontology of subject domains, the object instances of which includes geosemantic elements]
:= [ontology of subject domains, object instances of which use spatially correlated data about the territory, social and natural phenomena]
⊂ *ontology*
∋ *terrain object class^*
∋ *spatial relation*

terrain object class^
:= [a class of geospatial concepts of natural or artificial origin, natural phenomena having common features (semantic attributes) that are characteristic of a certain terrain object class and describe the internal characteristics of the concept]

terrain object
:= [a certain element of the Earth surface of natural or artificial origin, a natural phenomenon that actually exists at the time under consideration within the localization area, for which the location is known or can be established, including the size and position of the boundaries, and signs are set, reflecting the semantic attributes of such an element, characteristic of a certain *terrain object class*, with set *spatial relations* reflecting connections with other *terrain objects*]

A feature of the *geontology* is the use of special elements for the formalization of subject domains that clarify the spatial characteristics of terrain objects, which we will call ***geosemantic elements***.

geosemantic element
⇒ *subdividing**:
{• *coordinate location of the terrain object^*
• *spatial relation*
• *spatial relation of the main directions*
• *dynamics of the state of the terrain object^*
}

geocoding
:= [establishing a connection between a *terrain object* and its *location*]
⊂ *action*

spatial relation
:= [class of relations that define the semantic properties of a terrain object in relation to other terrain objects]
⇒ *subdividing**:
{• *topological spatial relation*
• *spatial ordering relation*
• *metric spatial relation*
}

spatial ordering relation
⇒ *subdividing**:
{• *relation of location of terrain objects*
• *relation of the main directions of terrain objects*
}

relation of location of terrain objects
⊂ *oriented relation*
:= [allows determining what position one *terrain object* occupies in relation to another *terrain object*]
⊃ *terrain object is located in front of another terrain object**
⊃ *terrain object is located behind another terrain object**
⊃ *terrain object is located to the left of another terrain object**
⊃ *terrain object is located to the right of another terrain object**
⊃ *terrain object is located above another terrain*

*object**
⊃ *terrain object is located under another terrain object**
⊃ *terrain object is located closer than another terrain object**
⊃ *terrain object is located further than another terrain object**

relation of the main directions of terrain objects
⊂ *oriented relation*
:= [allows determining which main direction one *terrain object* occupies in relation to another *terrain object*]
⊃ *terrain object in relation to another terrain object occupies the main north direction**
⊃ *terrain object in relation to another terrain object occupies the main north-east direction**
⊃ *terrain object in relation to another terrain object occupies the main east direction**
⊃ *terrain object in relation to another terrain object occupies the main south-east direction**
⊃ *terrain object in relation to another terrain object occupies the main south direction**
⊃ *terrain object in relation to another terrain object occupies the main south-west direction**
⊃ *terrain object in relation to another terrain object occupies the main west direction**
⊃ *terrain object in relation to another terrain object occupies the main north-west direction**

metric spatial relation
:= [characterizes information about the distance between *terrain objects*]
⇒ *measurement**:
kilometer
⇒ *measurement**:
meter
⊃ *scale metric spatial relation*

geodetic coordinate system
:= [coordinate system used to determine the location of objects on the Earth]
∋ *example'*:
WGS84
:= [The world system of geodetic parameters of the Earth, 1984, which includes a system of geocentric coordinates, and unlike local systems, it is a single system for the entire planet]
∋ *example'*:
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V. Formalization of topological spatial semantic relations in geoinformation systems

Between instances of *terrain objects*, it is possible to establish *topological spatial relations*:

topological spatial relation
:= [*spatial relation* class, defined over *terrain objects* that are in relation of connectivity and adjacency between *terrain objects*]
∋ *inclusion**
⊃ *inclusion of a point terrain object in an area terrain object**
⊃ *inclusion of a linear (multilinear) terrain object in an area terrain object**
⊃ *inclusion of an area terrain object in an area terrain object**
∋ *border**
∋ *intersection**
⊃ *intersection of two linear (multilinear) terrain objects**
⊃ *intersection of linear (multilinear) and area terrain objects**
∋ *adjacency**

The "inclusion*" relation will be set between *area* and *linear*, *area* and *point*, *area terrain objects*. The "intersection*" relation will be set between *linear* and *area* and *linear terrain objects*. The "border*" relation will be established between *area terrain objects*. The "adjacency*" relation is established between *linear terrain objects*. For all *cartographic relations*, there are structures for storing them.

VI. Subject domain and ontology of terrain objects

For the purpose of *integration* of *subject domains* with spatial components of *geoinformation systems*, respectively increasing *interoperability* of these systems, a *hybrid knowledge model* is proposed. By this model we will understand a *stratified model of the information space of terrain objects* described in the work [11].

terrain object
⇒ *subdividing**:
Typology of terrain objects by topic^
= {
- *water terrain object (facility)*
- *populated terrain object*
- *industrial (agricultural or socio-cultural) terrain object*
- *road network (facility)*
- *vegetation cover (soil)*

}

The basis for building the ontological model of *terrain objects* is grounded on the classifier of topographic information displayed on topographic maps and city plans developed and currently functioning in the *Republic of Belarus* [12]. In accordance with this circumstance, the objects of classification are the terrain objects to which the map objects correspond, as well as the signs (characteristics) of these objects. For this purpose, in the ontological model, *terrain objects* are divided by localization type into: *area objects^*, *linear (multilinear) objects^*, and *point objects^*.

At the next stage of developing the ontology of *terrain objects*, we will set the subdivision of *terrain objects* on orthogonal bases, which corresponds to the placement of objects in accordance with thematic layers in *geoinformation systems*.

For each *terrain object*, the main semantic characteristics inherent only to it are highlighted. It should be particularly noted that metric characteristics do not have such a property. According to this classifier, each class of *terrain objects* has a unique unambiguous designation. The classifier hierarchy has eight classification stages and consists of the *class code*, *subclass code*, *group code*, *subgroup code*, *order code*, *suborder code*, *species code*, *subspecies code*. Thus, thanks to the coding method, generic relations have already been defined, reflecting the correlation of various *terrain object* classes, and the characteristics of a specific *terrain object* class have also been established. Due to the fact that the basic properties and relations are set not of specific *physical objects* but of their classes, then such information is meta-information in relation to specific *terrain objects*, and the totality of this meta-information is an ontology of *terrain objects*, which in turn is part of the *knowledge base* of the *intelligent geoinformation system*.

terrain object
⇒ *subdividing**:
  Typology of terrain objects by localization^
  = {• *point terrain object*
      ⇒ *inclusion**:
        • *well*
        • *light post*
    • *linear terrain object*
      ⇒ *inclusion**:
        • *bridge*
    • *multilinear terrain object*
      ⇒ *inclusion**:
        • *river*
        • *road*
    • *area terrain object*
      ⇒ *inclusion**:
        • *lake*
        • *administrative area*
  }

VII. Specification of the Map Language

The *Map Language* belongs to the family of semantic compatible languages – *sc-languages* – and is intended for the formal description of *terrain objects* and the relations between them in *geoinformation systems*. Therefore, the ***Map Language Syntax***, like *syntax* of any other *sc-language*, is the *Syntax of the SC-code*. This approach allows:

- using a minimum of means to interpret the specified *terrain objects* on the map;
- using the *Question Language for ostis-systems*;
- reducing the search to most of the given *questions* to searching for information in the current state of the *ostis-system knowledge base*.

Denotational semantics of the Map Language includes the *Subject domain and the ontology of terrain objects* and their *geosemantic elements*.

VIII. Automation tools for the intelligent geoinformation systems design

The design of intelligent geoinformation systems is carried out in stages. At the first stage, the knowledge base of the subject domain is formed and for this purpose an electronic map (voluntary cartographic information) is analyzed and translated into the knowledge base of terrain objects with the establishment of geosemantic elements for the corresponding territory. At this stage, it is determined, firstly, to which class the terrain object under study belongs and, further, depending on the type of object, the concept of a knowledge base corresponding to a specific physical terrain object is formed. Thus, many concepts are created that describe specific terrain objects for each class of terrain objects. It should be noted that it is at this stage of the formation of the knowledge base that semantic elements are established. At the second stage of designing an intelligent geoinformation system, the knowledge base obtained at the first stage is integrated with external knowledge bases. At this stage, in addition to geographical knowledge, knowledge of related subject domains is added, thereby it becomes possible to establish interdisciplinary connections. An illustrative example is integration with biological classifiers, which in implementation represent an ontology of flora and fauna objects. Such integration expands the functional and intelligent capabilities of the applied intelligent geoinformation system. Note that at this stage, homonymy is removed in the names of geographical objects belonging to the classes of settlements. For settlements of the Republic of Belarus, this is achieved by using the *system of designations of administrative-territorial division objects and settlements* and semantic comparison of geographical terrain objects is carried out according to the following principle:

- the terrain object class is determined;
- the terrain object subclass, species, subspecies, etc. is determined in accordance with the classifier of terrain objects, i.e. types of terrain objects in the ontology;
- the attributes and characteristics that are inherent in this terrain object class are determined;
- the values of the characteristics for this object class are determined;
- the homonymy of identification is eliminated;

- appropriate connections are established between the map object, the concept in the knowledge base with the established geosemantic elements;
- spatial relations are established between terrain objects assigned to certain classes.

CONCLUSION

Let us list the main provisions of this article:

- the development of geoinformation systems consists in their intellectualization, thereby expanding the range of applied problems using knowledge about terrain objects;
- it is proposed to consider the map as an *information construction*, the elements of which are *terrain objects*, thereby ensuring the structural and semantic interoperability of geoinformation systems due to the transition from the map to the semantic description of map elements, that is, terrain objects and connections (spatial relations) between them;
- ensuring semantic interoperability is achieved through the development of ontologies of subject domains, and the establishment of *geosemantic elements* allows setting spatial characteristics of terrain objects;
- availability of a particular *Technology for intelligent geoinformation systems design* provides the process of designing intelligent geoinformation systems built on the principles of ostis-systems.

ACKNOWLEDGMENT

The author would like to thank the research group of the Department of Intelligent Information Technologies of the Belarusian State University of Informatics and Radioelectronics for its help in the work and valuable comments.

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Поддержка жизненного цикла интеллектуальных геоинформационных систем различного назначения

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Работа посвящена частной технологии проектирования интеллектуальных геоинформационных систем, построенных по принципам ostis-систем. Структурная и семантическая интероперабельность геоинформационных систем, построенных по предлагаемой технологии, обеспечивается за счет перехода от карты к семантическому описанию элементов карты.

Received 01.03.2023