Next-generation intelligent geoinformation systems

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***Abstract*—In the article, an approach to the building of intelligent geoinformation systems based on the OSTIS Technology is considered. The formal ontology of the syntax of the map language is explicitly set, which, in turn, allows establishing the types of map objects and setting spatial semantic relations; the formal ontology of the denotation semantics of the map language is set, which, in turn, allows establishing the semantics of displaying geo-entities on maps depending on the types of terrain objects; the formal ontology of terrain objects is set as a necessary condition for integration with subject domains in interests of GIS.**

***Keywords*—OSTIS, intelligent geoinformation system, private design technology, ontology**

I. Introduction

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

The problems solved by geoinformation systems are directly related to inventory, analysis, modeling, prediction, and management of the environment and territorial organization of society and are inherently intelligent, i.e. the solution of which is included in the subject of the research of intelligent systems. At the same time, the nomenclature of problems involves quite independent subject domains, for example, the organization of transport [1], dispatching and ensuring the safety of spatial processes [2], geology [3], [4], energetics [5], [6].

At the dawn of the origination of geoinformation systems, development groups independently developed formats for storing spatial data, display tools, as well as sets of cartographic materials for the corresponding area. The situation has changed radically after the creation of web applications built on the basis of cartographic services and technologies provided by Google (Google Maps product) and Yandex (Yandex.Maps), as well as the development of the OpenMapStreet [7] project, directed on obtaining and providing open source geographic information. Thus, it became possible for third-party applications to repeatedly access distributed sets of cartographic data and, accordingly, obtain metric and semantic characteristics of terrain objects, i.e. to organize the representation, storage, and usage of geospatial entities.

At the same time, the lack of a single unified method of encoding information for solving GIS problems has led to the fact that for various directions of GIS application, their own models are being developed, adapted to the applied subject domain and the feature of spatial data organization.

In particular, a team of developers led by L. Massel et al. [5], [6] proposed a methodological approach to the integration of Earth's remote sensing (ERS) data based on data and knowledge integration methods in systematic energy research. For this purpose, the authors have developed a theoretical model of hybrid data based on a fractal stratified model (FS-model) of the information space. The hybrid data model is based on developing a system of ontologies of the ERS information space, including a meta-ontology describing the layers of the FS-model and ontologies of certain layers (subject domains).

As a result of ontological modeling, an ontological space is created, including a set of ontologies, which should allow working not only with data but also with knowledge, including descriptions of scenarios of various situations, models, and software complexes, and integrating them into the IT infrastructure of interdisciplinary research.

In the work [4], it is proposed to allocate geoconcepts for the classification of geospatial entities and the development of geo-ontologies of subject domains, that are in the sphere of interests of GIS users, to solve problems in geology.

In order to expand the problems solved by geoinformation systems, to unify various types of information representation in GIS about space, time, and the Earth, it is necessary to integrate existing web geoservices and intelligent systems design technologies in order to design next-generation geoinformation systems as a class of intelligent computer systems based on a unified way of encoding information and interoperability (compatibility) which is a necessary requirement.

Within the OSTIS Technology, powerful tools have been developed that allow describing any kind of knowledge in a unified form, structuring the knowledge base according to various criteria, as well as verifying its quality and editing the knowledge base directly during its operation [8], [9]. The basis of the knowledge base built on the OSTIS Technology is a hierarchical system of subject domains and their corresponding ontologies. The ontology is interpreted as a specification for the system of concepts of the corresponding subject domain, while various types of ontologies are distinguished, each of which reflects a certain set of properties for the concepts of the subject domain, for example, *terminological ontology*, *logical ontology*, *set-theoretic ontology*, etc.

II. Proposed approach

Within this article, it is proposed to take as a basis the approaches developed within the OSTIS Technology for the development of ontologies of subject domains and propose a hybrid knowledge model that ensures the integration of data and knowledge of the subject domains in geoinformatics, that is, propose a private technology for designing intelligent geoinformation systems, formally clarify the description of geo-entities, denotational semantics of geo-entities, propose basic mechanisms for processing geo-entities, and integrate a cartographic interface to provide a dialog with the user based on the language of questions.

The systems developed on the basis of the OSTIS Technology are called *ostis-systems*. The *OSTIS Technology* is based on a universal method of semantic representation (encoding) of information in the memory of intelligent computer systems, called an *SC-code*. Texts of the *SC-code* (sc-texts, sc-constructions) are unified semantic networks with a basic set-theoretic interpretation. The elements of such semantic networks are called *sc-elements* (*sc-nodes* and *sc-connectors*, which, in turn, depending on orientation, can be *sc-arcs* or *sc-edges*). The *Alphabet of the SC-code* consists of five main elements, on the basis of which SC-code constructions of any complexity are built, including more specific types of sc-elements (for example, new concepts). Memory that stores the SC-code constructions is called semantic memory, or *sc-memory*.

As it was mentioned earlier, the basis of the knowledge base within the OSTIS Technology is a hierarchical system of subject domains and ontologies. From there, to solve the problems set within this article, it is proposed to develop a complex *Subject domain of geoinformatics and the corresponding ontology of terrain objects*.

The development of the specified family of sc-models of the subject domains in geoinformatics, as well as geo-ontologies, will allow:

- describing geo-entities explicitly, which, in turn, allows determining the types of map objects and describing the geosemantic elements characteristic to them: location, topology, proximity, orientation, dynamics;
- establishing a formal ontology of the denotational semantics of the map language, which, in turn, will allow establishing the semantics of displaying geo-entities on maps depending on the types of terrain objects;
- establishing a formal ontology of terrain objects as a necessary condition for integration with subject domains in interests of GIS;
- creating tools for analyzing (understanding maps) and translating them into the internal language of knowledge bases, which will provide an understanding of the cartographic information stored in geoservices in relation to a specific subject domain;
- forming in the future a *kernel* of intelligent geoinformation systems and a *library* of components of intelligent geoinformation systems, which will allow the usage of the designed components for the development of applied geoinformation systems.

Next, we will consider in more detail the fragments of sc-models and ontologies for the development of intelligent geoinformation systems.

III. Stratified model of the information space of terrain objects

In order to integrate subject domains with spatial components of geoinformation systems and, respectively, to increase the interoperability of components of intelligent systems, a hybrid knowledge model is proposed. By this model we will understand a stratified model of the information space of terrain objects, which is formally defined in semantic memory as follows:

$$S^{\mu}, \mu \in I = \{S_{PO\mu}, S_{OM}, E_{OM}\}, \qquad (1)$$

where I is a set of subject domains;

$S_{PO\mu}$ is an ontology of the μ -th subject domain;

S_{OM} is an ontology of terrain objects;

E_{OM} is instances of terrain objects.

In Figure 1, a geometric interpretation of the proposed hybrid model is demonstrated, where it is shown that the layer of instances of terrain objects is an integrating layer with subject knowledge of various subject domains in which specific terrain objects are already directly used. With such an organization of knowledge, it is possible to repeatedly use the developed ontology of terrain objects in different subject domain and, accordingly, to solve different applied problems.

IV. Formal description of geo-entities

In order to formally describe map objects, it is necessary to allocate the semantic properties of geo-entities. By the type of localization of map objects, areal, linear, multilinear, and point objects can be distinguished.

terrain object
=*cartographic object*
=*map object*
<= *subdividing**:

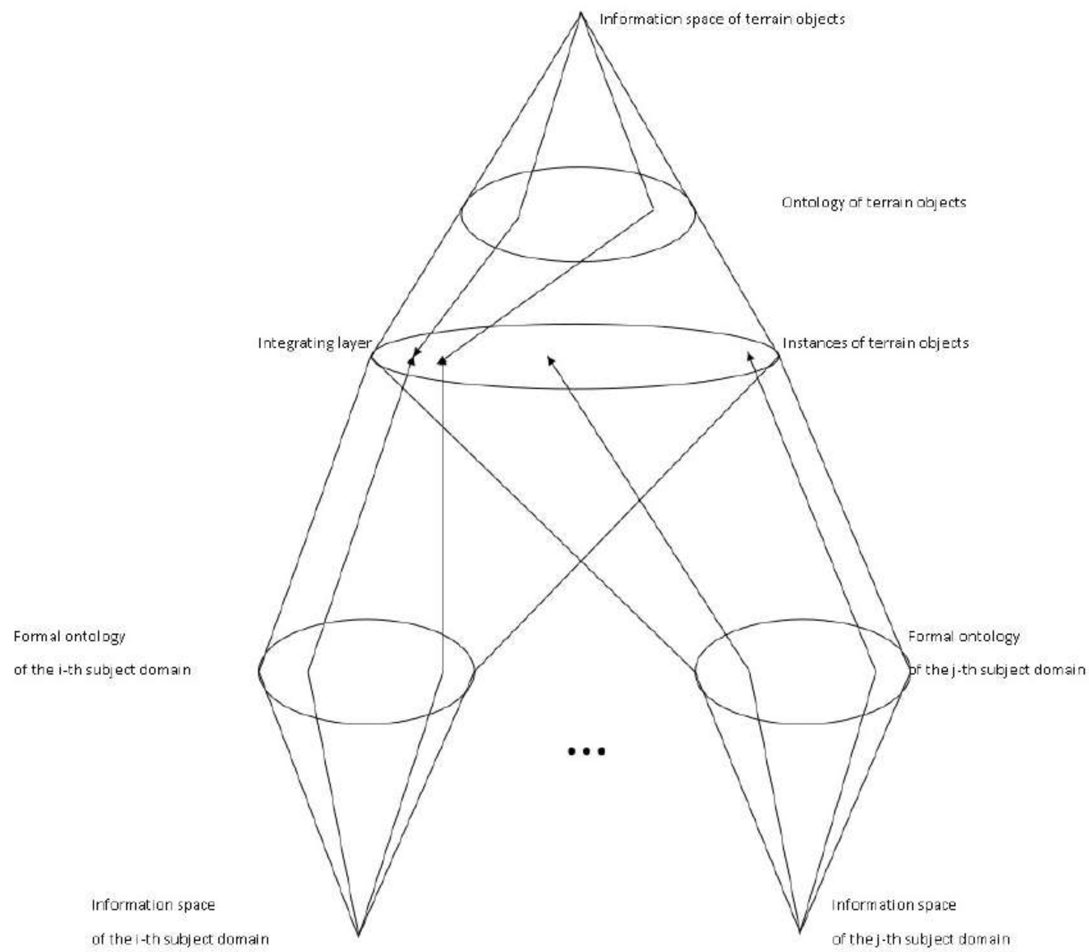

Figure 1. The stratified model of the information space of terrain objects

=*Subdividing by localization*
{
- *areal object*
- *linear object*
- *multilinear object*
- *point object*

}

Point objects are objects that cannot be expressed at the map scale. Linear and multilinear objects are objects whose length is expressed in a map scale, areal objects are objects whose area is expressed in a map scale. Accordingly, basic spatial semantic relations (SSR) are introduced over map objects, which, in turn, can be classified into three categories:

- cartographic (topological) relations invariant under topological transformations of relation objects;
- metric relations in terms of distance and direction;
- relations of spatial regularity described by prepositions before, behind, above, and below.

Accordingly, the following cartographic (topological) relations are introduced to establish spatial-logical connections.

cartographic relation
=*topological relation*
∋ *inclusion**
∋ *border**
∋ *intersection**
∋ *adjunction**

Thus, cartographic relations can be established between the above localities of terrain objects: *inclusion*, *border*, *intersection*, and *adjunction*.

V. Formal ontology of denotational semantics of the map language

In order to interpret the syntactic representation of objects on the map and establish the relation of connectivity and adjacency between objects on the map, it is necessary to clarify the denotational semantics of the map language, i.e. to indicate their semantics of display to the corresponding syntactic constructions of the map. So, for example, the topological relation of adjunction set over linear objects, depending on the type of the map object, can be interpreted as the adjunction of roads or the outlet of a river. In turn, for road map objects, topological relations, both adjunction and intersection, can be set with the corresponding denotation semantics, intersection or adjunction of roads, whereas for river map objects, only a topological relation of adjunction with denotation semantics, the outlet of one river into another, is possible.

VI. Formal ontology of terrain objects

The basis for building an ontological model of terrain objects is the classifier of topographic information displayed on topographic maps and city plans, developed and currently operating in the Republic of Belarus, NCRB 012-2007 [10]. In accordance with this condition, the objects of classification are terrain objects to which the map objects correspond, as well as the signs (characteristics) of these objects.

Let us set the subdivision of terrain objects on orthogonal bases, which corresponds to the location of objects in accordance with thematic layers in GIS.

terrain object
<= *subdividing**:
  =*Subdividing by object type*
  {
   • *water objects and hydraulic facilities*
   • *human settlements*
   • *industrial, agricultural, and socio-cultural objects*
   • *road network and road buildings*
   • *vegetation cover and soils*
  }

The ontology of terrain objects is a classification tree according to the hierarchy shown in Figure 2. Genus-species relations are set for each class of terrain objects.

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 obejcts has a unique unambiguous denotation. The classifier hierarchy has eight classification levels and consists of a class code, subclass code, group code, subgroup code, team code, subteam code, species code, subspecies code. Thus, thanks to the coding method, genus-species relations have already been set, reflecting the relations of various classes of terrain objects, as well as the characteristics of a specific class of terrain objects have been established. Due to the fact that the basic properties and relations not of specific physical objects but their classes are set, 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 an intelligent geoinformation system.

As an example, we will demonstrate a fragment of the formal description of the "River Naroch" object in the knowledge base.

relation of spatial-logical connections between terrain objects*
:= [class of connections that characterize the spatial-logical relative position between terrain objects]
⇒ *first domain**:
  terrain object
⇒ *second domain**:
  terrain object
⊃ *inclusion of terrain object**
  ∈ *oriented relation*
  ∈ *binary relation*
  ⇒ *code**:
    [91]
  ⇒ *requirement**:
    [The internal and external contours of the same object should be connected logically.]
⊃ *belonging of terrain object**
  ⊂ *belonging**
  ⇒ *code**:
    [205]
  ⇒ *requirement**:
    [It is set for objects or their parts that are not connected metrically but have an explicit logical connection.]
⊃ *neighborhood of terrain objects**
  ∈ *non-oriented relation*
  ∈ *binary relation*
  ⇒ *code**:
    [218]
  ⇒ *requirement**:
    [It is set for the object and its caption (proper name, explanatory caption, characteristics caption).]
⊃ *intersection of terrain objects**
  ⊃ *intersection of sets**
  ⇒ *code**:
    [298]
  ⇒ *requirement**:
    [Intersecting terrain objects must have the same coordinates of the intersection point.]
⊃ *adjunction of terrain objects**
  ∈ *oriented relation*
  ∈ *binary relation*
  ⇒ *code**:
    [298]

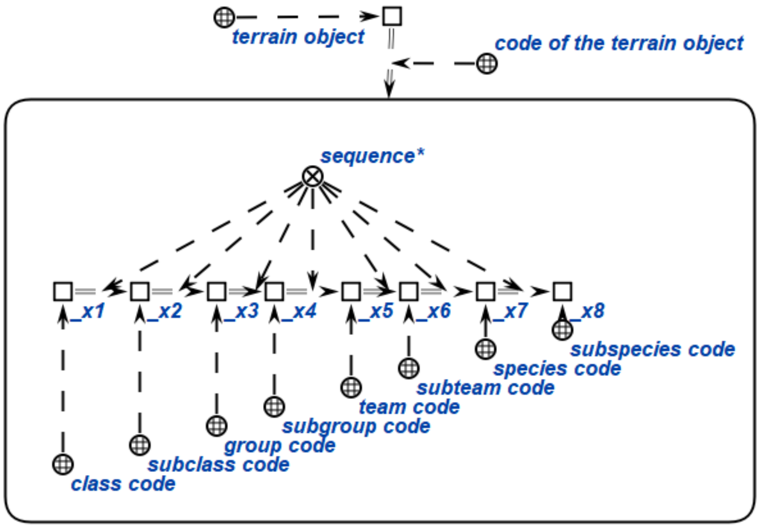

Figure 2. Hierarchy levels of classes of terrain objects

⇒ *requirement**:
[Adjacent terrain objects must have the same coordinates of the point at the junction.]

⊃ *extension of the terrain object**
∈ *oriented relation*
∈ *binary relation*
⇒ *code**:
[271]
⇒ *requirement**:
[The narrowed terrain objects must have common points on the frame of the nomenclature sheet (NS).]

terrain object parameter*
⊂ *parameter*
⊃ *relative height*
⇒ *code**:
[1]
⊃ *length*
⇒ *code**:
[2]
⊃ *absolute height*
⇒ *code**:
[4]
⊃ *depth*
⇒ *code**:
[7]
⊃ *distance*
⇒ *code**:
[24]

relation characterizing the property of the terrain object*
:= [class of relations that characterize a property or properties of a terrain object]
⇒ *first domain**:
terrain object
⊃ *vegetation type**
∈ *oriented relation*
∈ *binary relation*
⇒ *code**:
[62]
⊃ *border type**
∈ *oriented relation*
∈ *binary relation*
⇒ *code**:
[67]
⊃ *distributional pattern**
∈ *oriented relation*
∈ *binary relation*
⇒ *code**:
[78]

River Naroch
∈ *river*
⊂ *terrain object*
⇒ *feature codes**:
[4 5 9 31 33]
∈ *165*
∈ *absolute height*
⊂ *parameter*
⇒ *measurement on a meter scale**:
165 m
∈ *natural watercourse*
∈ *watercourse type*
⊂ *parameter*

∈ *natural watercourse*

∈ *watercourse type*

⊂ *parameter*

⇒ *proper name**:

[Naroch]

⇒ *proximity period**:

[May–September]

⇒ *water qualitative characteristics**:

[High water quality is also characterized by indicators of the hydrochemical regime. The mineral content in the water does not exceed 250 mg/l with a low amount of chlorides and sulfates. High transparency is combined with low coloration (5–7 °). The indicator of organic matter – permanganate oxidizability – does not exceed 5-7 mgO/l. Biogenic elements – nitrogen and phosphorus – are also characterized by minimal values.]

VII. Conclusion

In the article, an approach to the building of intelligent geoinformation systems based on the OSTIS Technology is considered. The peculiarity of this approach is the description of geo-entities and the definition of spatial semantic relations, the description of the formal ontology of the denotation semantics in the map language, which, in turn, allows establishing the semantics of displaying geo-entities on maps depending on the types of terrain objects. Special attention is paid to the formal ontology of terrain objects as a necessary condition for ensuring integration with subject domains in interests of GIS.

At the next stage of technology development, the results obtained will make it possible to make tools for analyzing (understanding maps) and translating them into the internal language of knowledge bases, which, in general, will provide an understanding of the cartographic information stored in geoservices in relation to a specific subject domain, as well as further form a *kernel* of intelligent geoinformation systems and a *library* of components of intelligent geoinformation systems.

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Интеллектуальные геоинформационные системы нового поколения

Самодумкин С.А.

В работе рассмотрен подход к построению интеллектуальных геоинформационных систем на основе Технологии OSTIS. Явно задана формальная онтология синтаксиса языка карт, что, в свою очередь, позволило установить типы объектов карт и задать пространственные семантические отношения; задана формальная онтология денотационной семантики языка карт, что, в свою очередь, позволяет задать семантику отображения геосущностей на картах в зависимости от типов объектов местности; задана формальная онтология объектов местности как необходимое условие для интеграции с предметными областями в интересах ГИС.

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