- analysis problem 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;
- implementat ion 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 use of *cartographic interface* to visualize the source data and results. the possibility of explaining the solutions obtained.

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**.

terrain object
⇒ *subdiving**:
{• 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]
⇒ *subdiving**:
{• topological spatial relation
• spatial ordering relation
• metric spatial relation
}

spatial ordering relation
⇒ *subdiving**:
{• 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*

metric spatial relation

:= [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′:
CK-95

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

⇒ *subdiving**:
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