# Software Framework for the Development of Intelligent Systems with Integrated Spatially Referenced Data

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***Abstract*—The paper considers a software framework for designing intelligent systems with integrated spatially referenced data, built on the principles of ostis-systems. The structure of the software framework is described, the description of the main components and their interaction is given. Design stages and methodology of designing this class of intelligent systems are considered.**

***Keywords*—OSTIS, intelligent system with integrated spatially referenced data (ISRD), software framework, design stages, design methodology**

## I. Introduction

Systems with integrated spatially referenced data are an effective tool in the emerging global trend of organizational and technical support for the digital development of society, which is achieved through the introduction of information and communication technologies and advanced production technologies in sectors of the national economy and spheres of society. To this end, the Republic of Belarus has developed and approved the State Programme 'Digital Development of Belarus' for 2021-2025 [1], [2], and the projects envisaged for implementation include the use of artificial intelligence technologies. The key objectives of this program are:

- create favorable conditions to ensure and support the processes of digital development;
- improve the national information and communication infrastructure and services provided on its basis;
- improving the implementation of government functions through the creation of a comprehensive digital infrastructure for interdepartmental information interaction, the formation of a modern system for the provision of public services based on the principles of proactivity and multichannelization of their provision;
- ensuring the availability of education based on the application of modern information technologies both to improve the quality of the educational process and to prepare citizens for life and work in the digital economy;
- improving the quality of medical care for the population, accessibility of services provided by the health care system, awareness of the population about the state of health, epidemiological situation on the basis of modern technological solutions;
- development of digital economy tools in various sectors of the national economy, providing for the application of advanced production technologies in production and foreign economic activity processes, formation of necessary conditions for preserving and improving the competitiveness of Belarusian enterprises in the global market;
- improving the level of comfort and safety of life of the population through the creation and implementation of "smart cities" technologies, including systems for remote monitoring and accounting of the housing stock, energy consumption, environmental conditions, video analytics and other;
- improvement of the information security system ensuring legal and safe use of solutions implemented as part of the digital development of the Republic of Belarus, building trust, ensuring conditions for safe provision and receipt of electronic services (formation of "digital trust").

According to the Decree of the Council of Ministers of the Republic of Belarus of April 21, 2023 No 280 "On measures to implement the Decree of the President of the Republic of Belarus of April 7, 2022 № 136" [3] artificial intelligence is a set of technological solutions that allows to imitate human cognitive functions (including self-learning and search for solutions without a predetermined algorithm) and to obtain in the performance of specific tasks the results comparable to the results of human intellectual activity, and includes information-communication.

Currently, there is a surge of work in the field of creating intelligent question-answering systems based on generative models of artificial intelligence, using neural networks, and dialog using chatbots such as ChatGPT. However, despite the possibility of supporting dialog with the user, such systems cannot generate answers using spatial data because they are not trained on such a set of information. In addition, the generated answers may be unreliable ('fake'). For example, a question like 'What is the distance between house 15 on Kirov Street in Minsk and house 204 on Pushkinskaya Street in Minsk (a fictitious address with a non-existent street and house)?' different chatbots generated either a specific answer, which in reality cannot be, or a reference to the use of cartographic services.

The above circumstances indicate the current demand for a class of intelligent systems with integrated spatially referenced data.

The technology that allows to realize the tasks of digital development of society is the open complex technology of development of intelligent systems based on semantic networks [4] (OSTIS technology - Open Semantic Technology for Intelligent Systems). The main provisions and principles of this technology are described in [5], the principles of creation and unified design models in [6], [7].

OSTIS technology is based on the following principles [8]:

- orientation on semantic unambiguous representation of knowledge in the form of semantic networks having basic theoretical-multiple interpretation, which provides the problems of diversity of forms of representation of the same meaning, and the problems of ambiguity of semantic interpretation of information constructions;
- use of associative graph-dynamic model of memory;
- use of agent-oriented model of knowledge processing;
- realization of OSTIS technology in the form of intellectual Metasystem IMS [9], which itself is built on OSTIS technology and provides design support for computer systems developed on OSTIS technology;
- ensuring in the designed systems a high level of flexibility, stratification, reflexivity, hybridity, compatibility and, as a consequence, learnability.

Systems built on this technology are called ostis-systems, and the universal abstract language of semantic networks (SC-code) or semantic code is used as a language tool for knowledge representation. In this case, knowledge bases of ostis-systems have semantic representation, and the knowledge and skills interpreter is a library of agents that process the knowledge base and manage situations and events in this knowledge base [8].

At the same time, the systems developed using this technology do not have the disadvantages of systems based on generative models (ChatGPT [10] type systems), because it is not the generation of new data, which are similar to the training data, but the relationships between the actual data and knowledge of the subject area are established, which ensures the reliability of conclusions based on knowledge.

For the design of intelligent systems with integrated spatial data on the basis of technology OSTIS proposed, described in the works [11], [12] semantic model ISRD, based on the ontology of spatial objects, provided user communication in the formal language of questions [13], [14] and developed means of automation and information support of the design process of this class of systems, including the formation of components ISRD [15].

An important point that reduces the ISRD development time on the one hand, and on the other hand — increases their functionality, is the availability of tools for designing such systems. In this case, the technology of ISRD design should be oriented to the multiple use of functional components of the system in order to reduce the time of design and development of application systems. Thus, this study is about creating a software framework for designing intelligent systems with integrated spatially referenced data.

Designing semantically compatible intelligent systems with integrated spatially referenced data requires the development of software tools on the OSTIS – Ostis Geography platform to implement spatially referenced data and subsequently use them in applied intelligent systems to solve problems to be solved in specific subject areas.

## II. Structure of an intelligent system with integrated spatially referenced data

The structural diagram of the program complex is presented in Figure 1.

The development concept assumes that some of the tools and components being developed are necessary for the development of various ISRD class application systems. Therefore, ready-made components can be reused. Such components can be information components, such as knowledge bases, as well as software components, such as problem solver agents or viewers and editors included in user interfaces.

Due to the above circumstances, we will distinguish the minimum set of components necessary for the design of an ISDS, which we will call the ISRD core. The ISRD kernel consists of [15]:

1) Knowledge base:
   - ontology of terrain objects and phenomena;
   - characteristics of terrain objects and phenomena;
2) Problem solver:
   - stack of mapping agents:
     - agents for calculating geometric features,
     - agents for determining the type of localization,

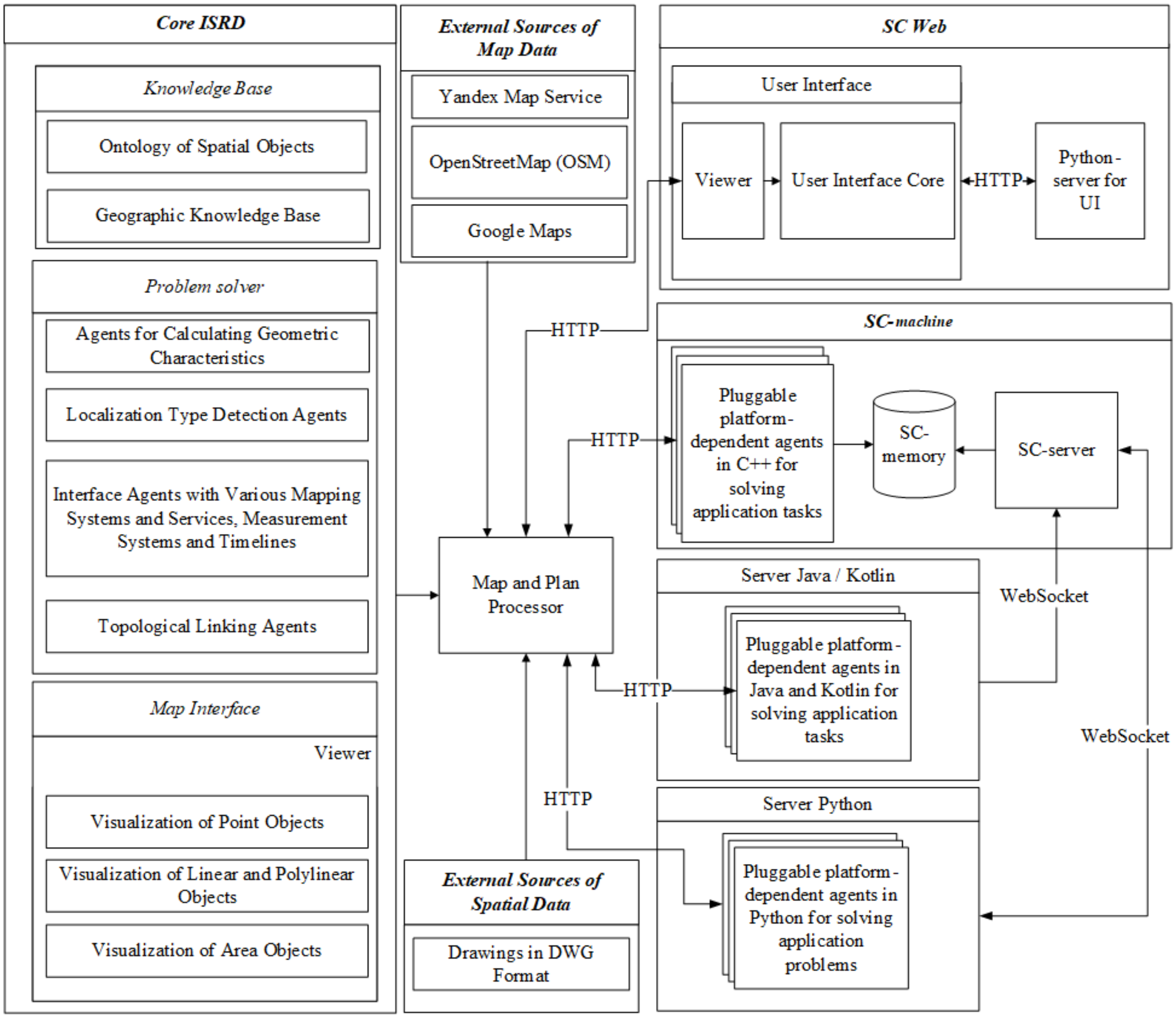


Figure 1. Program Complex Structure.

   - agents for interfacing with various map systems and services, measurement systems and time intervals,
   - agents for establishing topological relationships;
 - search agents,
 - sophisticated search agents,
 - logical inference agents,
 - transaction calculation agents;

3) User interface:
 - map interface:
   - work with point objects,
   - work with linear and polylinear objects,
   - work with area objects;
   - map viewer.

The software package includes a module for implementation of spatially referenced data (map processor). The task of the map processor is to represent such data from external sources, such as map services, registers and cadastres that use spatial data in the form of drawings. Such data are translated into semantic memory for further processing by software agents to derive inferences.

Implementation of spatial data from external data sources is performed by the map and plan processor. The input of the map and plan processor receives data from external sources and is semantically linked to the knowledge stored in the knowledge base. If there is no necessary terrain object or plan corresponding to the input data in the knowledge base, a fragment of the knowledge base with the description of the terrain object or spatial object is formed in the knowledge base. The processor of maps and plans also performs geocoding for further use in the process of output as a result of work of agents providing solution of the set tasks in some subject area. The following types of platform-dependent agents are supported: in C++, Java (Kotlin) and Python. In addition, the possibility of implementing agents in the basic knowledge processing language SCP (Semantic Code Programming) internal to OSTIS-systems is supported.

The ISRD core includes subject-independent components of knowledge bases, problem solver and map interface, i.e. such components, the information about which or the way of processing or displaying do not depend on the subject area. For knowledge bases, such components include the ontology of spatial objects, as well as the knowledge base of terrain objects, for which geocoding and semantic linking with characteristics (semantic attributes) have been performed earlier. As subject-independent components of the problem solver there are agents for calculating geometric characteristics, determining localization types, agents for interfacing with various cartographic systems and services, measurement systems and time intervals, agents for establishing topological relationships.

## III. Map query using spatially referenced data from OpenStreetMap service

The peculiarity of the software toolkit is to provide access to external cartographic or spatial data, which are provided by cartographic services. In this case, the cartographic data collected by the community of interested users include almost complete description of terrain objects of the entire Earth, thus there is no need to collect cartographic material in the design of application systems, but verification and selection of spatial data existing in the map service [11]. Due to this fact, there is no need to store a huge amount of data, because spatial data are stored in map services, and the task is reduced to the selection of necessary for solving the problems of the subject area map data, or spatially related data. A typical situation of interaction is considered in Figure 2 for the case when the external map service is based on OpenStreetMap technology and requests to the map service are realized in the Overpass query language [16].

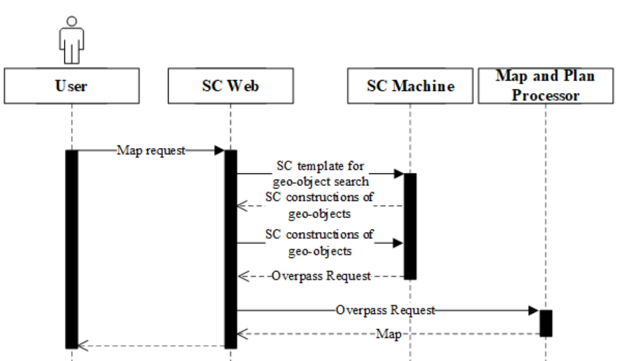


Figure 2. Interaction with external map service OpenStreetMap.

## IV. Cartographic query when using spatially referenced data from the Yandex.Maps service

Displaying the results on the map, implemented using the Yandex.Maps service [17], is performed in a specialized sc-window. For this purpose, data in the WGS-84 coordinate system are represented in the YMapsML data format (xml-format for geodata representation developed by Yandex).

The transformation sequence is shown in Figure 3 and includes the following steps.

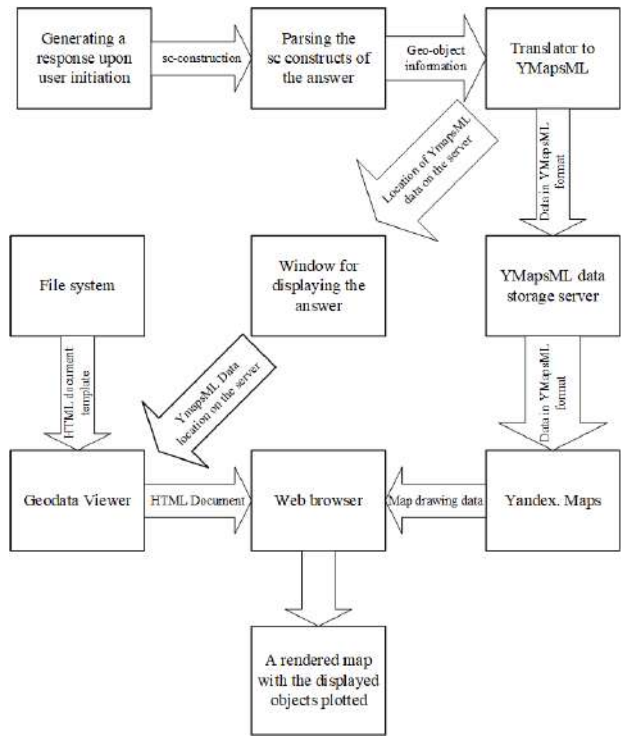


Figure 3. Sequence of converting the response to the user into a map view

**Step 1** *Parsing the sc-construction of the answer.* This step highlights the *coordinate** relation bundle.

**Step 2.** *Determining the type of object localization.* This step determines one of three localization types: point object, linear object, area object, depending on the number of coordinate pairs in the coordinate relation bundle*.

**Step 3**. *Select the name of the geographic object* for the purpose of further geocoding and determining to which class of terrain objects the searched object belongs.

**Step 4.** *Form a description of the displayed geographic object* as a map object in the form of xml markup in the YMapsML geodata representation language. For example, for geocoding the object of the city of Minsk, considered as a point object we will have:

<ymaps:GeoObject>
<gml:name>
Minsk

```
        </gml:name>
        <gml:description>
            city
        </gml:description>
        <gml:Point>
            <gml:pos>
                27.548621 53.903364
            </gml:pos>
        </gml:Point>
    </ymaps:GeoObject>
```

**Step 5.** *Forming a unique name* of the xml document and sending it to the ymapserver.appspot.com server under this name. The generated document name is stored in the contents of the sc-window node, which is in a set of sc-windows for outputting map data with YMapsML format.

**Step 6.** *Upload from the server* using JavaScript API of the "Yandex.Maps" service, generated in step 4 xml-document and map rendering.

## V. Displaying information about a terrain object

The display of information about the terrain object is performed by means of OSTIS [9] Metasystem and map interface and includes the following steps:

- search for semantic neighborhood of a given terrain object (i.e. spatial relations between a given terrain object and other terrain objects, as well as geosemantic characteristics of a given terrain object;
- determine geographic codes of territorial terrain objects, in which a given terrain object is located, as well as other terrain objects connected by spatial relations with a given terrain object;
- obtaining cartographic data on territorial terrain objects and their correlation with information on territorial terrain objects in the knowledge base;
- determination of terrain object class;
- visualization of semantic neighborhood of a given terrain object in the map language.

## VI. Design methodology for intelligent systems with integrated spatially referenced data

For the purpose of mass development of intelligent systems with integrated spatially referenced data, the design methodology of this class of systems is included in the means of automation and information support of design. Based on the design principles of semantically compatible intelligent systems, the design methodology of intelligent systems with integrated spatially referenced data includes the following design stages.

**Step 1.** *Deployment of OSTIS technology components* for the design and operation of systems designed in accordance with the open integrated technology for the development of intelligent systems based on semantic networks.

**Step 2**. *Deployment of components of the core of intelligent systems with integrated spatially referenced data*.

At this stage, the components of the ISRD core are deployed, which is necessary to install the developed components of the spatial object ontology, the problem solver, including the main agents for processing spatially referenced data, the question language interpreter, and the software components of the mapping interface. The use of the ISRD core components allows to create at this stage of design the application systems with minimal functional purpose.

**Step 3.** *Formulating the knowledge base.*

In this stage, the knowledge base is built, which consists of the following sub-stages.

**Substep 3.1.** *Compiling the table of contents of the knowledge base of the designed semantic reference system, structuring the knowledge base and dividing it into elementary fragments - atomic sections with indication of atomic section types.*

**Substep 3.2.** *Compiling a question book that includes a formal language record of all question types included in the system.*

**Substep 3.3.** Create a list of key objects of the subject area. Concepts, definitions, and terms act as objects in various subject areas.

**Substep 3.4.** *Create a knowledge base ontology, i.e. a complete description of all the objects included in the system, specifying their properties, relations, use cases, etc..*

**Step 4.** *Integration of knowledge bases with spatial knowledge.* Selection of cartographic material for a given terrain area, translation and loading into the knowledge base with the establishment of topological relations between terrain objects using the ontology of terrain objects.

At the 3rd and 4th stages, the knowledge base is filled with knowledge of the subject area with linkage to the cartographic material, i.e. recording of all initial texts of the knowledge base of the designed semantic reference system. Such texts include answers to all types of questions from the collection of questions and texts of atomic sections of the knowledge base of the intelligent system.

**Step 5.** *Development of problem solver components.*

If necessary, development of additional agents required to solve the tasks of the subject area is performed.

**Step 6.** *Integration with generative intelligence models (large language models, or LLM models).*

If necessary, generative intelligence models are plugged in.

**Step 7.** *Implementation.*

This stage involves final specification of the knowledge base of the semantic reference system and certification of the developed ip components (intellectual property components that can be used in re-design).

The evolution of ISRD class application systems in their development and design stages is shown in Figure 4.

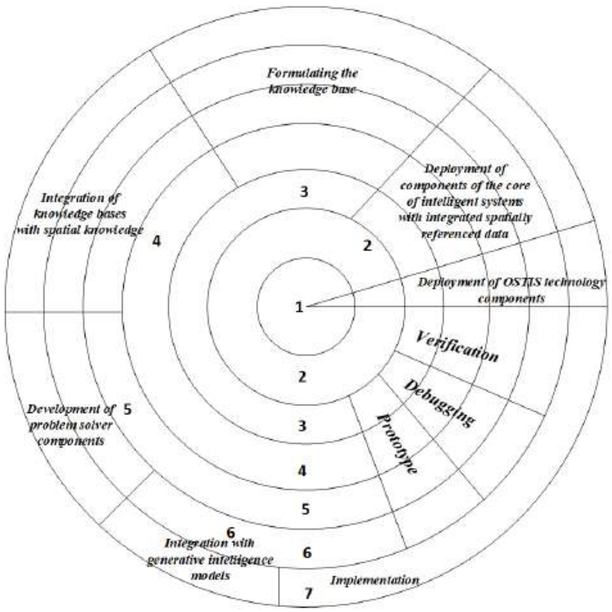


Figure 4. Design stages of intelligent systems with integrated spatially referenced data.

At stages 3-7 of design, the ISRD developer can decide to return to any previous stage, which corresponds to the rapid prototyping technology, when a prototype of the system with minimal functionality is created and the ISRD functionality is subsequently built up. In this case, the prototype with minimal functionality is obtained after the 2nd stage of design, i.e. after the deployment of components of the core ISRD.

Thus, it is possible to get ready-to-use prototypes of intelligent systems faster due to the use of evolutionary and incremental design methodology of ISRD class application systems.

For a fixed area, the same spatially related data are used in different application domains: epidemiology, construction, environmental protection, creation of digital twins of enterprises, mobile robotics systems, etc., which makes it necessary to align ontologies of subject areas with terrain objects and phenomena and thus provides a vertical (subject-oriented) level of ISRD design.

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## ПРОГРАММНЫЙ КОМПЛЕКС ДЛЯ ПРОЕКТИРОВАНИЯ ИНТЕЛЛЕКТУАЛЬНЫХ СИСТЕМ С ИНТЕГРИРОВАННЫМИ ПРОСТРАНСТВЕННО-СООТНЕСЕННЫМИ ДАННЫМИ


Самодумкин С. А.



В работе рассматривается программный комплекс для проектирования интеллектуальных систем с интегрированными пространственно-соотнесенными данными, построенных по принципам ostis-систем. Описана структура программного комплекса, приведено описание основных компонентов и их взаимодействие. Рассмотрены этапы проектирования и методика проектирования данного класса интеллектуальных систем.



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