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Spatial Knowledge Ontologies

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Abstract: The paper describes spatial knowledge ontologies and shows that spatial knowledge acquisition is realized on the basis of a system of associated ontologies. The paper shows that the system of ontologies is created based on integration and presents the integration diagram of different ontology levels. Features of each ontology level are described and the peculiarities of the spatial knowledge ontology are covered at each level.

Key words: Knowledge · Spatial knowledge · Spatial information · Configuration knowledge · Ontologies · System of ontologies · Integration of ontologies · Spatial knowledge ontologies

INTRODUCTION

The study on spatial knowledge is carried out since 60s of the last century [1, 2]. Over a long time this problem was associated only with artificial intelligence. Geoinformatics appeared in the 90s. The integration of geoinformatics and artificial intelligence methods of obtaining, study and spatial knowledge representation started since this time [3]. Spatial knowledge is also studied in psychology, education and cognitive graphic art. Study [4], which formulates the concept of spatial and temporal knowledge, can be considered an epoch-making work. Such a concept is relatively new in the field of artificial intelligence. In geoinformatics [5], conversely, the spatial and temporal information is the basis for modeling and solving applied problems since the emergence of this field of science. Therefore, integration of artificial intelligence and geoinformatics approaches [6], when obtaining spatial knowledge, are of particular interest.

MATERIALSA AND METHODS

Ontologies are the main and recognized methods of acquiring knowledge. This paper considers an ontological approach as a major one. Acquisition of spatial knowledge is implemented using system of ontologies. Here information modeling and information models are one of the research methods.

An important aspect of the current work is the account of the differences between the methods of artificial intelligence (AI) and geoinformatics. This difference consists in the fact that AI uses any information, whereas geoinformatics uses only geoinformation. This means that AI may include any kind of information, which should be structured and meet certain conditions. This difference is noted in the current paper.

Main Part: The theory of artificial intelligence highlights procedural and declarative knowledge. Spatial knowledge complement these kinds of knowledge by configuration component or configuration knowledge. Spatial knowledge can be regarded as a subset of knowledge. Spatial knowledge (*SK*) as a subset of knowledge is an association of declarative (*D*), procedural (*P*) and the configuration (*C*) knowledge.

$$SK = D \cup P \cup C \tag{1}$$

Sets *D* and *P* have empty intersection $D \cap P = \varnothing$ and therefore are disjunctive. Spatial knowledge has another component, called configuration component. This component distinguishes spatial knowledge from the knowledge used in artificial intelligence. It allows one to correlate the knowledge with space points.

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Spatial knowledge as a subset is formed on the basis of synthesis of declarative, procedural and configuration knowledge; see the expression (1). Configuration knowledge includes a description of the spatial objects shape and their orientation [4].

Acquisition of new knowledge is one of the main tasks of such research areas as artificial intelligence and geoinformatics [3, 5]. Information collections in any field are usually divided into two groups. One group describes the facts, while the other deals with interpretation of the facts [7]. The first group is called fact-fixing and the second one is called the interpreting group. Both groups complement each other.

Holistic perception of the collected information and the subsequent acquisition of knowledge require creation of the rules for interpreting information. There are three types of these rules: axiomatic, empirical and productive.

Axiomatic rules of interpretation are based on a system of axioms of interpretation language and reduce any new knowledge to the system of basic provisions. In this approach, the main thing is the basis or system of axioms, which are explanatory factors. As a result, researcher interprets new facts using known basic provisions. This approach can be called explanatory.

Empirical rules or rules of thumb are based on a system of concepts and relations, subjectively imposed by the researcher. They are determined empirically. Such rules may not be suitable for other conditions. They give only the interpretation of the particular situation, for which the researcher sees the beginning and the result. The main thing in this approach is to identify the major relationships and trends between facts that are visible to the researcher. This causes the subjectivity of concerned approach.

Productive rules of interpretation are based on a system of inference rules. These rules of interpretation are derived based on analysis of the structure and relationships between the elements of the language pattern. The main thing in this approach is the use of the inference mechanism, which may lead to the results and identify the facts previously unknown to the researcher. This approach is objective one.

The accumulated information has a value when it is given to a form suitable for processing and interpretation. The solution to this problem is associated with the knowledge extraction and representation problem [2], as well as spatial knowledge presentation [4, 8, 9]. Up to date, ontology is the most effective means of extracting knowledge. Ontologies are also a means of overcoming the semantic gap [10].

Ontology (from Classical Greek *Ontos* – the heart of the matter, *logo* - the doctrine, the concept) is a term that defines the doctrine of being, of heart of the matter, in contrast to the *epistemology,* which is theory of knowledge or cognition. The term "ontology" was introduced by H. Wolff (1679-1754). The term was introduced to the philosophical literature by the German philosopher R. Gokleniusom (1547-1628). Originally the ontology was a part of metaphysics and was considered as a science not associated with logic, "practical philosophy" and the natural sciences. Its subject was the study of abstract and general philosophical concepts, such as, being, substance, cause, effect, phenomenon, etc. [6]. This implies that with the development of society, the ontology content has changed from the abstract to the concrete subject-matter. Emergence of different ontologies eventually led to the appearance of ontologies of various designs and tasks.

The following definitions have proliferated with the development of information technologies and intelligent systems.

Ontologies are the exact specification of a conceptualization [11]. Subsequently, this definition has been specified.

Ontologies are a formal precise specification of a shared conceptualization [12].

The *conceptualization* is understood as a result rather than a process. This is an abstract model of phenomena (processes) in the world, compiled by identifying the essential features of these phenomena.

Unambiguousness in the ontological approach means that the types of concepts used and restrictions on the application areas of these concepts are defined explicitly.

Formality in the ontological approach means orientation of ontology for computer representation that eliminates the use of natural languages.

Shared use means that the ontology describes general knowledge rather than personal knowledge. This property means that one uses the knowledge, accepted by a group or community. This condition results in the concept called ontological agreement.

Ontological agreement is a scope of dictionary and a set of rules for interpretation of terms that are sufficient for shared use of terms and concepts proposed by different people.

Ontology always refers to concepts taken from the ontological agreement and included into the dictionary (thesaurus). Conceptualization, as an abstract model, is independent of language. Though ontology, representing this conceptualization, refers to the concepts, defined in the dictionary and is dependent on the language used.

Ontology may be considered as a system of entities. Such a system is connected by universal dependencies such as "common–private", "part–whole", "cause–effect", etc. In addition, the ontology, as a system of entities, can be bound by special dependencies, specific to the subject area.

Entities in the ontology are determined by a variety of knowledge representation means, such as frames and slots, which are bound by restrictions, stipulating the permissible combinations of their meanings. Products, logical, algebraic, tabular and other dependencies may serve as restrictions.

In practice, the system of ontologies provides a framework for the knowledge description and extraction. System of ontologies can be considered as a subject field model, which uses all the means of knowledge representation that are relevant to concerned area.

Spatial knowledge ontology is the ontology, used for acquisition of spatial knowledge taking into account features of the spatial information, namely, spatial relationships, as well as the spatial information structure [13].

Ontology is the basis of the subject field model and the basis for building of problem-oriented thesaurus. In such a scheme, ontology connects knowledge about the world and the language into a particular scope of activity. Ontologies bind the following important aspects [14].

- They define the formal semantics of information. This makes it possible to generate information to be processed by information and computer science methods.
- Ontologies define the semantics of the real world. This makes it possible to associate the information, provided for processing, with visual information in a form, perceived by a human.
- Ontologies can be considered as complex procedural and substantial information units. Procedural information unit is a unit that describes the dynamics: either the process or part of it. The substantial information unit describes statics: the fact, object or its element.

Purpose of the system of ontologies is integration of information. At that, ontologies, as information units, are integrated into a single system. The process of integration of ontologies into the system can be either bottom-up or top-down. Bottom-up process consists in creating simple ontologies of the lower levels and the gradual transition to more complex ontologies of the upper levels.

Top-down process of ontologies integration consists in creation of abstract ontologies of the upper levels and the gradual transition to more specific ontologies of the lower levels. The basic idea of the ontologies integration process is creation of ontology diagram, allowing one to solve practical problems of acquiring knowledge, based on the diagram, associating abstract ideas with real processes in the subject field. This ontology diagram may be universal for different types of knowledge, as well as special, taking into account the features of the subject field and the resulting knowledge.

Bottom-up approach of ontology integration is quite difficult. Currently, there are no methods that would create a complete system of knowledge ("Model of the World"). Therefore currently the top-down approach in the integration of private ontologies is usually employed.

The processes of ontology construction and integration are using axiomatic, empirical and productive interpretation rules. This means that when constructing and integrating ontologies one uses a dictionary. It is convenient to use just one top-level ontology instead of relying on agreements, based on the intersection of different ontologies of lower levels.

According to N. Guriano [15], A. Gangeni, D.M. Pisanelli and G. Steve [16], ontologies are divided into the following concepts: the representation ontologies, common ontologies, intermediate ontologies, top-level ontologies, subject field ontologies, task ontologies and application ontologies.

For spatial knowledge these concepts are objectified and replaced by other concepts that are synonymous, but better reflect the nature of spatial knowledge ontologies. They are represented by the diagram, which is given in Figure 1.

Conceptual ontologies are on the upper level. Conceptual ontologies define the basic ideas and concepts that underlie the spatial knowledge representation. Conceptual ontologies are associated with one or more problem areas. Their main objective is reflection of problems using concepts and conceptual models. Conceptual ontologies define the problem area.

The next lower level is formed by the aspect ontologies. Aspect ontologies concretize the fundamental aspects of conceptualization, for example, such categories as "kind", "whole" and "cause".

Further specification of the ontology leads to a lower-level ontologies, i.e. relations and concepts ontologies, which include common concepts and relations that are typical for a particular subject field. They may play the role of interface between the various sub-regions of the subject field. Relations and concepts ontologies associate concepts and aspects with each other.

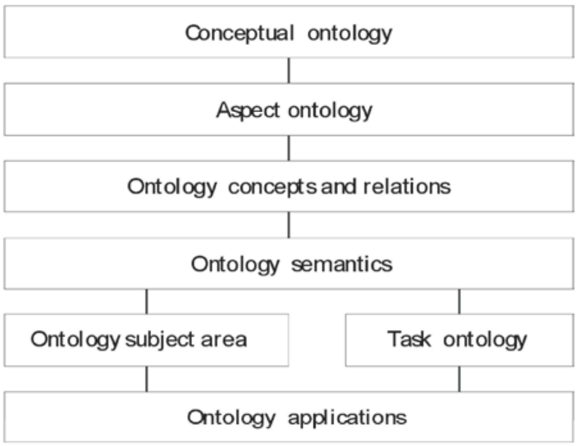

Fig. 1: Types of spatial knowledge ontologies

The next lower level forms semantic ontologies. Semantic ontologies fill top-level ontologies with specific meaning. They define specific meanings of concepts of common and intermediate ontologies.

When passing to the lower level, semantic ontologies are converted into two types of complementary ontologies: subject field ontology and task ontology.

Subject field ontologies include special concepts of this knowledge area. These ontologies can be called the substantive ontologies. Subject field ontologies allow construction of dictionaries and thesauruses with due regard to ontological agreements.

Task ontology describes the tasks or processes in this knowledge area. These ontologies can be called procedural.

Commutatively, this level defines the ontologies of subject field substances and processes. Substance is not a process and a process is not a substance. Consequently, the ontologies of this level complement each other and together provide a comprehensive "subject field pattern" of the spatial knowledge.

Application ontologies form the lowest level. They are a working tool for spatial knowledge acquisition. In terms of modeling, one may say that the application ontologies are differentiation of subject fields and tasks ontologies.

Each problem domain is characterized by a certain behavior pattern of the objects of subject field. Models of subject field and problem areas are associated with the intensional and extensional knowledge representation.

The extensional part contains specific facts concerned the subject field. The extensional representations describe specific objects from the subject field, specific events occurring in it, or specific events and processes.

The intensional part contains charts, used to describe the communications and relationships between facts or data. The intensional representations fix those laws and communications, which must be satisfied by the described components of subject field within a given problem domain.

Knowledge of the subject field together with a model, describing their acquisition in the ontology system, forms a private model of the problem domain. For the chart, shown in Fig. 1, spatial knowledge ontology is characterized by its peculiarities.

At a conceptual level, spatial knowledge is defined by morphological and topological features, as well as hierarchic relations between spatial objects.

Aspect ontologies of spatial knowledge concretize the aspects of conceptualization into general categories, such as "class", "whole" and "cause", as well as special categories like "place", "time" and "topic".

Relations and concepts ontologies include common concepts and relations that are typical for a given subject field [3, 17]. These are holonymy and meronymy relations, as well as the ISA AKO relation [18].

ISA relation comes from the English «is a». It is said that the set (class) classifies its items (e.g. street is part of the urban area). Sometimes this relation is referred to as «member of». ISA relation suggests that the properties of the object are inherited from the set.

For ISA there is an inverse relation - «example of» or «example». Therefore, the process of generating elements out of a set is called samplification.

The relation between set and AKO subset comes from the English «a kind of», for example, "urban areas are a subset of the urban district". Difference of AKO relation comparing with ISA relation is that the ISA is a relation of "one to many", whereas AKO is a relation of "many to many". A complete description of spatial relations is given in [19].

At the level of semantic ontology, paradigmatic relations are used for the concepts (objects) of the same hierarchic level, as well as syntagmatic relations between the adjacent hierarchic levels. For hierarchical systems syntagmatic relations are defined by the rule "one to many".

Subject field ontology of spatial knowledge contains specific terms of this knowledge area. Typical are such concepts as the spatial set, linear and areal objects, strata (layers), spatial classification, spatial hierarchy, spatial model, digital model, information situation, information position [20], dynamic model, etc.

Task ontologies of spatial knowledge describe specific tasks. Examples of such tasks include overlay, associative link, multiform presentation, logic operations of spatial sets, display by conventional signs, digital simulation, etc.

Application ontologies of spatial knowledge are often implemented at the level of CAD (Computer Aided Design) software packages and GIS (Geographic Information Systems), or business graphics systems. These systems are designed to work with spatial information and its presentation.

Final Part: Current status of spatial knowledge acquisition reveals the need to integrate AI techniques and geoinformatics methods for the holistic formation of spatial knowledge.

Spatial knowledge acquisition should be based on an integrated system of ontologies. The above system of ontologies serves the basis for knowledge acquisition on the ground of both the entire system and each particular level of the system.

CONCLUSIONS

Ontologies are mandatory means for describing the knowledge and acquisition of spatial knowledge. Acquisition of spatial knowledge is based on a multilevel system of ontologies. It is remarkable that each level of the ontology system allows one to create knowledge, "peculiar" for a given level. Aggregate of ontologies at all levels allows one to solve practical problems. Upper level ontologies allow solution of scientific problems on generalization and analysis. The integrity of a spatial knowledge is determined by use of the entire ontology system. In this case, the spatial knowledge will be associated with the knowledge concepts of other problem domains and be transferable, comparable and interpretable.

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