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Application of Logical Output Means on Ontologies to UFO Models of Subject Domains

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Abstract: The development of ontological engineering as an independent and promising research area involves the improvement of existing and the development of new, more effective approaches for ontology creation. The research in this area are focused on the reduction of expert "manual" labor share during the creation of ontologies, the provision of flexibility and the simplicity of change and result scaling. Thus, the researchers developed a new approach to the construction of subject domain ontologies, assuming use of visual graphic analytical models as a source of knowledge about a subject area in terms of "unit-function-object" approach (UFO model). The results of performed study allowed to make the conclusion about the relationship of system object approach (UFO-approach) principles and ontological engineering and in particular about the possibility of UFO model conversion in a formalized description of ontologies using specialized languages.

Key words: Logical output means, subject domains, UFO models, labor flexibilty, manual

INTRODUCTION

Now a days a lot of attention is paid to the development of computer processing of knowledge contained in the visual models of subject domains. In particular, an urgent task is the search of a universal method of inference using graphic analytic UFO models that allow to perform the processing of the knowledge accumulated in these models, regardless of a model subject area and specifics. While in a general case the UFO models may represent a broad range of subject areas, the inference tasks can be solved by the development of ontology on the basis of UFO model and the application of the appropriate inference means to it. Let's consider this method in a more detailed way.

MATERIALS AND METHODS

The background of ontology inference means application to UFO models: As we noted, the results of studies (Slobodyuk *et al*., 2013; Kondratenko and Matorin, 2016a, b) allow you to use inference mechanisms on formal ontology representations to solve the problem of knowledge withdrawal using UFO models. In these researches, they proposed the method of ontology development based on visual graphic analytical UFO models of subject domains. In particular, the method and the algorithm of subject domain UFO model presentation using the formal language of RDF (Resource Description Framework) ontology representation (Hebeler *et al*., 2009a, b) proposed by the researchers. It offers great opportunities in the field of UFO model computer processing. A formal presentation of visual graphic-analytical model as RDF language code formed in this case as well as the modifications based on it, allows to make an original UFO model machine-readable. The presence of several notations in RDF language, the conversion between which is possible with rather widespread special software, allows you to use the most convenient one in a particular case. For example, N-Triples notation is a more convenient one for a man's perception, while the notation RDF/XML is closer to XML format which allows to use it in information systems and specialized software tools including the use of processing by current XML-parsers.

This method of processing contained in UFO models of knowledge about a subject area allows to perform the process of logical inference on ontologies which are based on the specified models. On the basis of inference mechanisms and knowledge gaining from the ontologies created on the basis of UFO models, intelligent information systems may be developed including the elements of expert systems and decision making support systems.

Let us consider the method of logical inference in detail using the visual graphic analytical UFO models by their integration with formal ontology record means. This method is based on the idea of knowledge extraction

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contained in any UFO models, their conversion to a form for which the use of mechanisms and software means of logical inference on ontologies is possible. The components of this method are the following steps (stages):

- The extraction of subject area knowledge from a computer graphic-analytical system-object model
- The presentation of extracted knowledge using a formal language of ontology record, that is in the form suitable for machining
- The application of logical inference tools (a query or a solver language) to obtained formal representation of the ontology, built on the basis of UFO model

Indeed, the UFO model contains a set of knowledge on a subject domain which may be presented in the form of certain facts which are systematized using the classification proposed by Slobodyuk (2014). The ability of such a set of facts extraction about the subject area is grounded with an appropriate adaptation of UFO-approach formalization means (Kondratenko and Matorin, 2016a, b). Thus, a computer graphic analytical UFO model can be considered as a source of knowledge about a subject area.

In addition to the knowledge contained in this model explicitly and the benefit extracted from it in the process of an ontology development the UFO model may extract new subject domain knowledge. The use of appropriate mechanisms and algorithms is necessary for their obtaining (output). Typically, these mechanisms can be automated and special software is developed on their basis. However, the use of such algorithms and software is possible only to a formalized representation of knowledge source, i.e., to UFO model. As the solution of logical inference problems on UFO models is proposed on the basis of developments, existing for similar problems of inference ontology solutions it is proposed to use an ontology built on the basis of the analyzed UFO model of a subject domain using the above described method as a knowledge base.

In other words, the proposed method of knowledge inference using graphic analytical UFO models is based precisely on the transition from an analyzed UFO domain model of a subject domain to the ontology and the application of appropriate mechanisms to obtained formal description of a created ontology. The experience of the world research community allows to use in this case the best ontology application practices to solve applied tasks.

Classification of logical inference problems on UFO models: Let's determine the major problems of logical inference built on the basis of UFO model ontologies which can be useful during the solution of problems in applied fields. Such problems can be roughly grouped according to the type of data on which they are built. Depending on a subject area and the knowledge extraction target the formulation of tasks may vary. Then, the classification of typical inference tasks on ontologies is presented, built on the basis of UFO models. Objectives based on relation data:

- Bond classification development
- Display of a list of subclasses for a given class of relations
- The obtaining of full information about a given class of relations

The tasks on the basis of node data:

- The obtaining of detailed information on a given unit.
- Determination of the feature, balancing the specified unit
- The obtaining of information about an object which occupies this unit
- The display of port list (all, input and output) of a given unit
- Determination of units with the ports similar to specified ones
- The development of empty/occupied port list of a specified unit

The problems based on the data about functions:

- The display of detailed information about a specified function
- Drawing up of unit list balancing by a given function
- Obtaining of unit list that implement a given function

Objectives on the basis of data about objects:

- The display of detailed information about a given object
- The output of unit list occupied by a specified object
- The obtaining of functions, implemented by a specific object

The tasks on the basis of UFO element data in general:

- The drawing up of the list of specified function inputs and outputs (based on data about a unit, its ports and its balancing function)

- The obtaining of information about the connections between two specified UFO elements (based on the information about the units, their ports and model relations)
- The development of interaction chains between specified UFO elements (based on the data about units, their ports and existing model connections)

It should be noted that this classification describes only the basic, the most common problems that may occur during the processing of UFO models. Depending on a particular applied task the above mentioned list may be supplemented by specific examples of logical inference problems based on UFO models. Nevertheless, the proposed classification allows to systematize the main types of solved tasks and determine the most appropriate means and tools for their solution.

RESULTS AND DISCUSSION

Logical inference tools based on ontologies and their benefits: Now a days, the use of ontologies in applied information systems is actually a separate research area in which principles, approaches, algorithms and the libraries and software tools on their basis were developed to carry out a logical inference on ontologies, many of which can be used to implement logical inference based on UFO models.

One may determine query languages such as DQL, N3QL, RDFQ, RDQ, RDQL, SPARQL as one of the most common means of knowledge processing contained in ontologies. The most studied and widely used among them is SPARQL (SPARQL Protocol and RDF Query Language), the language for data query presented on RDF Model and the Protocol for these queries and their response transfer. This language is a W3C consortium recommendation and it is regulated by the relevant documents (Harris and Seaborne, 2010). Queries formed on the basis of SPARQL language, have the structure similar to database queries using SQL (Structured Query Language), the language of data management in relational databases. The results of SPARQL-queries to RDF-graphs can be presented in different formats such as XML, Json as well as CSVi and TSV. Query languages to a formal presentation of ontologies on RDF are applied successfully to solve the problems of explicit knowledge fragments obtaining contained in ontology. So, the problems 1.2, 2.2-2.6, 3.2, 3.3, 4.2, 4.3 of earlier given logical inference task classification can be solved based on UFO models.

More sophisticated tools designed, in particular, to bring new knowledge from ontologies are also called solvers (reasoners) in literature (Abburu, 2012; ChuangLu, 2012; Dentler *et al*., 2011). In order to perform logical inference based on ontologies the solvers can be divided into the following types:

Table 1: The accordance between concepts in descriptive logics and OWL language

Concept in description logics	Concept in OWL
Concept	Class
Role	Property
Individual	Object
Knowledge base	Ontology

- On the basis of rules (o-device)
- On the basis of resolutions (the search of contradictions): KAON2
- On the basis of semantic display (semantic tableau, algorithm display): FaCT ++, HermiT, Pellet

In its turn among the solvers based on rules they determine subtypes depending on the used algorithm: forward-chaining and/or backward-chaining. The first subtype solvers are based on the original (already known) facts, deriving new ones from them. These tools are used to perform specific queries to the available data or to obtain a special, well-known type of knowledge. The solvers based on "backward-chaining" are intended to verify a determined fact for the compliance with their original data.

Most of the existing tools, the solvers are designed to work with ontologies represented by OWL language. The method of ontology development based on UFO models allows you to obtain a code in RDF/XML notation of RDF language that can be converted into OWL code. This, in its turn, provides the use of a wide range of tools, particularly intended for working with OWL solvers, for logical inference ontology developed on the basis of UFO models.

Let's consider some features of tools designed for knowledge output based on the data submitted by OWL formats. Since, OWL language is based on description logics the literature (Horrocks *et al*., 2011) provides the following matching of concepts (Table 1).

As Table 1 shows, in the case of representation using OWL language and logical inference operation performance ontology can be taken as a knowledge base. They specify a set of terminological axioms (TBox) and a set of statements about individuals (ABox) in such a knowledge base, according to the general provisions of description logics. TBox contains the data (axioms) of the following types:

- The axiom of concept nesting, an expression of the form $C \subseteq D$ where C&D are arbitrary concepts

- The axiom of concept equivalence, an expression of the form C≡D where C&D are arbitrary concepts
- Similarly, the axiom of role nesting is the expression of the form R⊆S where R&S are arbitrary roles
- Role equivalence axiom, the expression of the form R≡S where R&S are arbitrary roles

An important aspect is the support of logical inference by existing solvers in ABox domain, i.e., the output of knowledge about objects (individuals). According to the survey, presented by ChuangLu (2012), this functionality is implemented in the tools FaCT ++, HermiT, RP, TrOWL (REL). Accordingly, when an existing solver is selected for logical inference application tasks based on ontologies several factors must be considered:

- Supported algorithms
- The availability of logical inference task solution support in ABox domain
- Supported description logics
- Solution cost (free or commercial software)
- Used and permissible data formats
- A programming language in which a tool is implemented
- Integration capabilities into their own software

Besides, an important selection criterion of logical inference tools is the ability of their modification. In particular, the principles and provisions of UFO-approach as well as the possibility of this method use for ontology development in various subject areas necessitate additional configuration of these instruments. This setting is based on the specification of additional rules (algorithms) of logical inference, taking into account the peculiarities of a domain and the principles of UFO-approach. Therefore, the applied information systems require the use of any known existing but modified and supplemented by the tools of logical inference, or their own solvers, tailored to these characteristics.

Using the existing mechanisms and instruments a logical inference based on ontologies by special transformations of subject domain UFO models, allows us to solve a number of significant problems inherent to the heuristic processing of subject domain models. In particular, such a mechanism of knowledge processing and knowledge extraction from UFO models has the following advantages: there is no need to form an initial knowledge base manually.

UFO models of a subject domain thanks to the simplicity of UFO-approach and the comfort of software tools that support its principles in modeling, can be developed as by a separate (external in respect to a simulated environment) expert analyst so as by an immediate expert in an analyzed area. In any case, the resulting subject domain UFO model contains an expert knowledge and the understanding of this subject area. As a logical conclusion is performed on the basis of ontology built by well-defined transformations of an original UFO model formal submission, this model is the starting knowledge base. In this case, the need in separate processes of an initial knowledge base development disappears which allows you to save time and expert efforts.

Flexibility and scalability of knowledge base: The update of existing data about a subject domain may be performed in the form of change introduction into an initial UFO model. At that the introduced changes are translated into the generated ontology based on UFO model according to which the logical conclusion about necessary knowledge is carried out. Accordingly, such a structure has a simple modification and broad capabilities of original data expansion.

Applicability for complex problem solution concerning the analysis of subject domain models: In the case of complex subject domain analysis the final UFO models can be quite cumbersome and difficult for a man's perception. Often the visual analysis of a complex graphical-analytical model does not allow to obtain the necessary information contained in such a model or in a derived model quickly and correctly. The development of ontology on the basis of UFO model and the implementation of a logical inference based on it allows you to automate and greatly simplify the analysis of complex volumetric models of subject areas.

The solution of logical inference application using UFO models: Let's consider the ways of logical inference task basic types on ontologies, built on the basis of visual graphic analytical UFO models of a subject domain. As we noted earlier, the problems of logical inference on ontologies, built on the basis of UFO models can be roughly grouped according to a classification.

Some of the tasks listed in a classification are proposed to solve using a specialized query language SPARQL to the formal presentation of ontology. SPARQL language for necessary triplet search allows you to create a query, the syntax of which is similar to SQL syntax. For example, a typical case requiring the use of SPARQL language is the search for information about an object occupying a given unit. A similar problem can be summarized as follows: it is required to find the triples of the following form in the code of RDF language ontology:

"an object occupies a unit" where a specific unit of an original UFO model serves as an object. With regard to a described object search task which occupies a particular unit of an original UFO model the following SPARQL query is developed:

```
PREFIX ufo: < http://www.ufo-toolkit.ru/>
SELECT INo
WHERE
{
INo ufo:represents INu.
};
```

where INo is the Object of some UFO element, INu is the Unit of this UFO element.

A list of predicate subjects is drawn up as the result of such a request satisfying the query "template" specified in a term body. The obtained concepts are the desired objects occupying a given unit of UFO element. More complex tasks of logical inference require the application of flexible tools which allow the use of complicated rules (algorithms) including specialized, user-defined ones or included in ontology. In particular, this tool is the language of semantic web rules SWRL (Semantic Web Rule Language). The rules written by the use of SWRL, consist of a consequent and an antetsendent, i.e. of a header and a body, respectively. A consequent is true when an antetsendent is empty or all of its components are true. Let us consider a number of practical problems which can be solved using the language of rule output SWRL which is applied to the formal presentation of ontology using OWL language or syntactically compatible notations of RDF language. In order to ease a man's perception let's use Human Readable Syntax, the so-called "man readable" SWRL syntax that allows you to represent SWRL rules in the following form: antetsendent (a body, a condition)⇒consequent (a header, an effect). The inclusion of facts of the following form "function converts an input" in ontology.

In this case, in order to obtain a fact a logical conclusion is required based on available data. In particular, the information is used about the balancing of a specific unit function as well as about the presence of a particular incoming relation in a unit. Since, the first fact can be included in ontology within one of two kinds ("The function balances a unit" or "a unit is balanced by function"), it is necessary to use two SWRL-rules presented:

$$\text{balances}(\text{INf},\ \text{INu}) \wedge \text{hasInputRelation} \\ (\text{INu},\ \text{INLi}) \Rightarrow \text{translateInput}(\text{INf},\ \text{INLi})$$

$$\text{isBalancedBy}(\text{INu},\ \text{INf}) \wedge \text{hasInputRelation} \\ (\text{INu},\text{INLi}) \Rightarrow \text{translateInput}(\text{INf},\ \text{INLi})$$

Where:
INf = The function of some analyzed UFO element
INu = The Unit of this UFO element
INLi = One of the input links of Unit of this UFO element

The inclusion of facts like "function provides output" in ontology. This problem is similar to the one described previously. The only difference is that the facts of an output relation presence are used in the second part of the rule. SWRL-rules displaying the fact "function provides output" are shown as:

$$\text{balances}(\text{INf},\ \text{INu}) \wedge \text{hasOutputRelation} \\ (\text{INu},\text{INLj}) \Rightarrow \text{giveOutput}(\text{INf},\ \text{INLj})$$

$$\text{isBalancedBy}(\text{INu},\ \text{INf}) \wedge \text{hasOutputRelation} \\ (\text{INu},\text{INLj}) \Rightarrow \text{giveOutput}(\text{INf},\ \text{INLj})$$

where, INLj is one of the output links of unit of analyzed UFO element. The inclusion of the facts like "An object occupies a unit" in ontology. In XML-representation of UFO models generated by the most common software product for subject domain modeling with the use of UFO-approach "UFO Toolkit", the presence of an object as a UFO element component is described as a "derived" characteristic in relation to the function (a nested XML unit). Therefore, during the automation of a UFO model conversion in the structure of ontology description language the fact like "A unit occupies an object" can be derived from the other ones, previously formed ontology triplets describing a unit and a function. For example, in order to display the fact about the attitude of an object and a unit it is required to have the fact of a unit function balancing and the fact of realization by this function object. Taking into account possible variations of specified fact record we get four SWRL rules for the output of the described fact:

$$\text{realizes}(\text{INo},\ \text{INf}) \wedge \text{balances} \\ (\text{INf},\ \text{INu}) \Rightarrow \text{represents}(\text{INo},\ \text{INu})$$

$$\text{realizes}(\text{INo},\ \text{INf}) \wedge \text{isBalanceddBy} \\ (\text{INu},\ \text{INf}) \Rightarrow \text{represents}(\text{INo},\ \text{INu})$$

$$\text{isRealizedBy}(\text{INf},\ \text{INo}) \wedge \text{balances} \\ (\text{INf},\ \text{INu}) \Rightarrow \text{represents}(\text{INo},\ \text{INu})$$

$$\text{isRealizedBy}(\text{INf},\ \text{INo}) \wedge \text{isBalanced} \\ \text{By}(\text{INu},\ \text{INf}) \Rightarrow \text{represents}(\text{INo},\ \text{INu})$$

where, INo is the object of analyzed UFO element. The consideration of multiple decomposition levels (UFO element is a part of another item which is several levels above).

In the case when the information about UFO element as the part of another UFO element decomposition located on more than one level above should be included in ontology directly SWRL-rule of the following type is applied:

$$\text{isPartOf}(\text{INu}_i^{n-2}, \text{INu}_j^{n-1}) \wedge \text{isPartOf}$$
$$(\text{INu}_j^{n-1}, \text{INu}^n) \Rightarrow \text{isPartOf}(\text{INu}_i^{n-2}, \text{INu}^n)$$

Where:

INu^n_i = The Unit of some UFO element

INu^{n-1}_i = The Unit of some UFO element on the first decomposition level

INu^{n-2}_i = The Unit of some UFO element on the second decomposition level

Determination of units with similar ports to the specified ones. This task is solved by the cyclic processing of each fact concerning the presence of an incoming or an outgoing port of the first compared unit. The rules are used during this test (for incoming and outgoing ports, respectively):

$$\text{hasInputPort}(\text{INu1}, \text{INL}_i) \wedge \text{hasInputPort}$$
$$(\text{INu2}, \text{INL}_i) \Rightarrow \text{hasSamePort}(\text{INu1}, \text{INu2})$$

$$\text{hasOutputPort}(\text{INu1}, \text{INL}_i) \wedge \text{hasOutputPort}$$
$$(\text{INu2}, \text{INL}_i) \Rightarrow \text{hasSamePort}(\text{INu1}, \text{INu2})$$

The following SWRL structure is applied for unit search one of which has an output port and the other one has an input port of one type:

$$\text{hasInputPort}(\text{INu1}, \text{INL}_i) \wedge \text{hasOutputPort}$$
$$(\text{INu2}, \text{INL}_i) \Rightarrow \text{hasSamePort}(\text{INu1}, \text{INu2})$$

$$\text{hasOutputPort}(\text{INu1}, \text{INL}_i) \wedge \text{hasInputPort}$$
$$(\text{INu2}, \text{INL}_i) \Rightarrow \text{hasSamePort}(\text{INu1}, \text{INu2})$$

where, INu1 and INu2 are the Units of two analyzed UFO elements. SWRL rules allow flexible configuration of new data logical inference about a subject area based on existing facts (triplets). This presented list of practical tasks is not an exhaustive one and can be extended for each individual case. Therefore, experts during the development of a subject domain ontology can supplement it with new facts, including them directly in the very description of ontology using a formal language that allows easy scalability and the ability of a prompt supplement of ontologies by necessary "standard" knowledge.

The described means may be used either individually or complexly. An example of the second option may be the logical conclusion on the knowledge contained in the UFO model of a complex software product. This product is a specific platform which provides the tools for a rapid creation of web-based applications, taking into account the specifics of a subject area. The experts engaged in the development of applications using this platform, are faced with large amounts of semi structured and often weakly documented information on the practical experience of the platform use, tips, an order of work and applied platform tools. In order to simplify the search and sometimes to display the necessary knowledge a visual graphic analytical UFO model is used, a fragment of which is shown on Fig. 1.

Often, when a new application is created and configured an expert requires a list of system objects that need to be set up to implement a desired functionality (or a list of objects which will be affected by changes). A manual search for an answer to this question is the alternate view of the settings concerning a number of potentially related objects in a system and the search for the information concerning a meaningful relation with other objects in this context. This procedure takes a long time and attention from an expert. At the same time, a developed UFO model can experience the conversion method in a formalized description of ontology using EDF language that allows you to use a set of tools for logical inference based on ontologies. In particular, in order to solve a described problem, it is supposed to perform a number of SPARQL-queries and the use of SWRL-rules described above which represent the following algorithm in general (Fig. 2).

Summary: The method of ontology development proposed by the authors and based on UFO models in addition to the solution of ontological engineering tasks can also indirectly apply the knowledge processing tools contained in ontologies, to the underlying system-object models. In particular, the transformation of a UFO model in a formalized representation of ontology allows us to apply the existing methods and logical inference tools on ontologies for the resulting description such as SPARQL query language and SWRL rules. These means as well as their supporting software can be successfully used for logical inference application solution based on UFO models that confirm the presented examples of processing problem solutions and knowledge output based on visual graphic analytical model of a complex specialized software configuration.

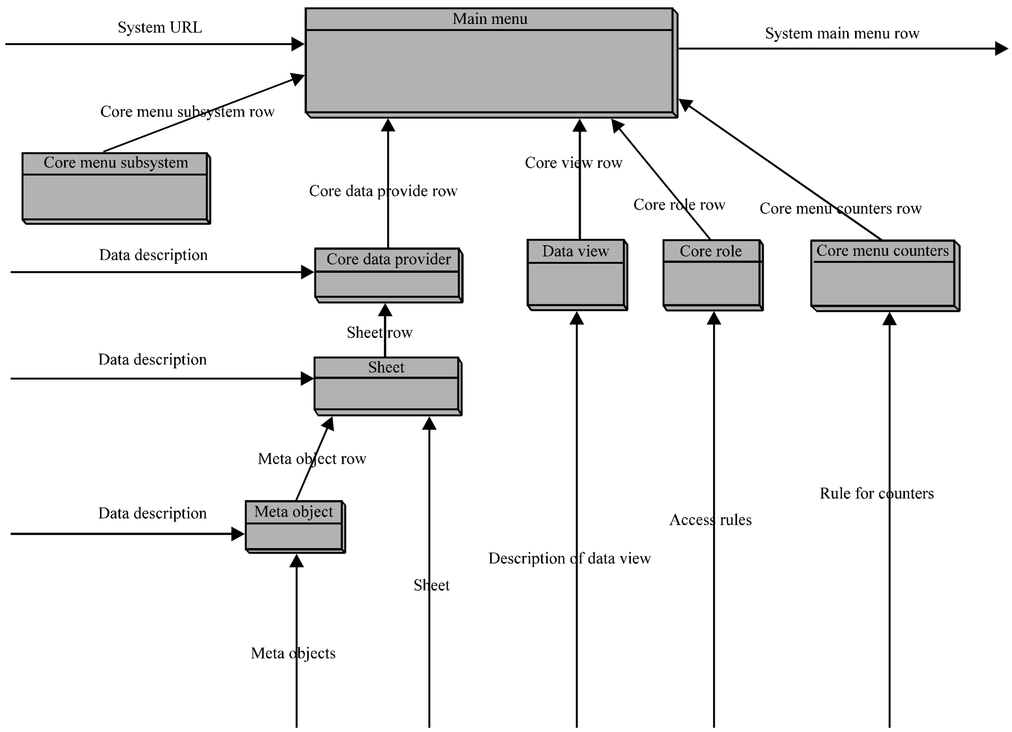

Fig. 1: Part of UFO model to create a web-application by special platform

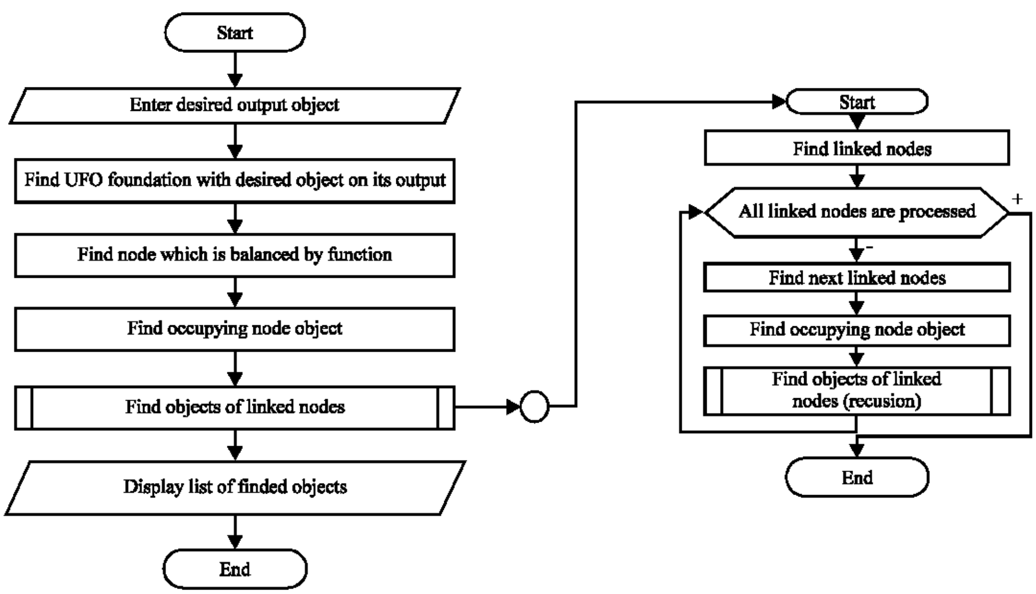

Fig. 2: Flowchart of the algorithm for search platform's components which are using for some application feature implementation

CONCLUSION

The presented results show that the method of ontology development using graphic-analytical system-object models as a source of knowledge about a subject domain also makes it possible to solve the problems of logical inference using such models.

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