Development of Object's Structured Information Field with Specific Properties for Its Semantic Model Building

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Abstract

Implementation of applied artificial intelligence systems requires novel approaches to the formalization and modeling of domain knowledge. Collecting data about information objects, which represent components of intelligent systems, calls for creation of reliable information field of the object with predetermined restrictions. These restrictions affect the structure of the field and ensure its filling from the open Web environment. The paper proposes means and methods of pre-processing the data field (classification, clustering, associative relationships) and integration of accumulated resources. Also, we suggest a method of step-by-step development of the structure of the information field, which begins with the definition of the information object of research around which the field will be built. The problem of the reliability of information resources from which the information field is filled is solved by analytical methods and the method of semantic analysis of metadata. It's provided interpretation, recognition, and selection of reliable data relevant to the issue being solved. The issue of accuracy of data recognition and interpretation of accumulated data is solved on the basis of methods for calculating semantic proximity and semantic distance between semantic models. The practical implementation of the obtained results created a multi-agent e-commerce system based on the ontological approach.

Keywords

Information field, semantic model, reliable information, metadata, semantic similarity, adaptive ontology, ontology, thesaurus

1. Introduction

The creation of applied systems of artificial intelligence requires the formalization of knowledge about the information object. These ensure the successful solution of the issues, where semantic models (ontologies, taxonomies, and thesauruses) act as means of formalizing interoperable knowledge. To create semantic models of information objects, the developer needs reliable, dynamically updated information about the objects under study. For this purpose, semantically marked open information sources of the Web environment and OSINT technology [1, 2] are used. The accumulated information for the creation of semantic models is formed into a system – an information field. This requires, firstly, the development of the concept and structure of the information field, methods of pre-processing of the collected information (classification, clustering, associative connections, etc.), storage, automatic updating and evaluation of accumulated resources.

Modeling is one of the ways of learning about the real world and, firstly, it is related to the selection of the necessary information and the construction of a model. The information space is a model of the real world accessible to human consciousness. However, any information model reflects the real object only in a limited aspect – in accordance to the goal set by a person.

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One of the goals of our research was the development of a conceptual approach to the construction of a formal ontological model of an information object associated with a virtual information Web space. And also the creation of a structured reliable information field of this object as a basis for the construction of relevant semantic models in applied perception problems, recognition, interpretation and processing of these objects in IIT.

2. Development of information object's conceptual model

Information object (IO) is a representation (model) of a domain object in the information space. It's defines the structure, attributes, integrity constraints and, possibly, behavior of this object [3].

Thus, in modern IITs, the task of object recognition is transformed as follows: it is necessary to find intelligent objects (services, agents, ontologies, Internet resources, experts, etc.) that will be relevant to the given problem. Recognition is the selection, on the basis of the specified requirements, of some object from the multitude of existing ones for the most optimal solution to the given issue.

An information object (IO) is generated on the basis of an information model by "alienation" of information from the original object. Usually, IOs arise as a result of conscious or unconscious purposeful activity of people. But they can also be generated by computers (programs), for example, non-linearly interacting information flows in computer networks. Examples of objects can be individuals, certain objects or their parts, phenomena, events or processes associated with them.

An information object is an extension of a software object and an entity that contains information in the information system about any real or virtual object (subject, creature, event, process, etc.). That is a uniquely identified tangible or intangible real-world entity that describes its structure, attributes, integrity constraints, and possibly behavior. Figure 1 represents a taxonomy of information objects, where real objects are represented by their models in the information space.

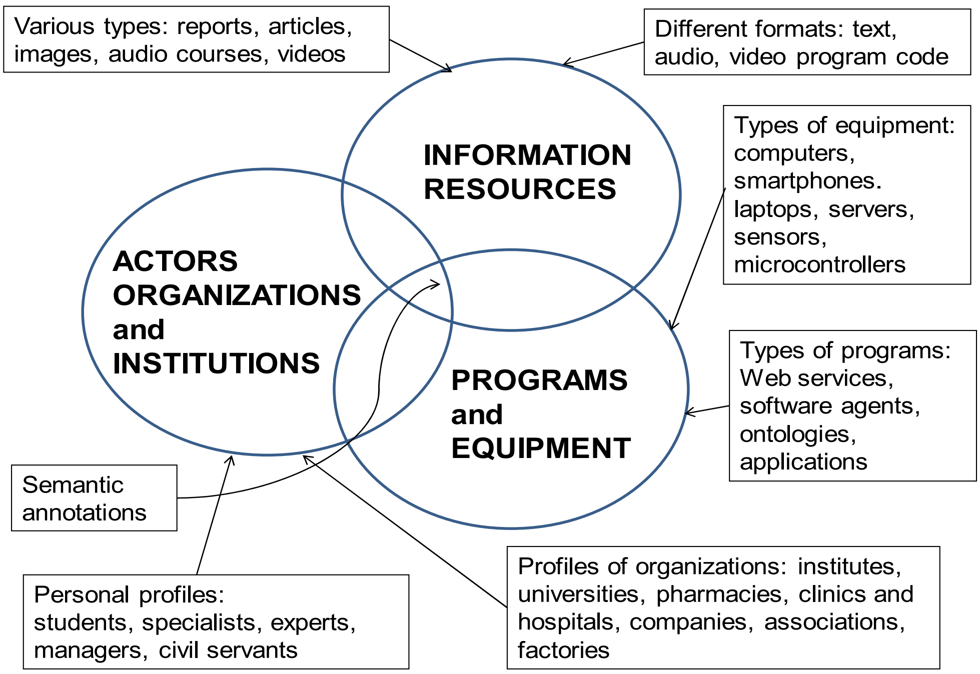

Figure 1: Taxonomy of information objects presented in a distributed Web environment

The problem of recognition is one of the most fundamental problems of computer science and the theory of intelligent systems, which is of great practical importance. IO recognition is a scientific issue, the purpose of which is the classification of objects into several categories or classes. That is, using the selection of significant features characterizing these data from the total mass of non-essential data [4].

The classical statement of the problem of recognition of IO [5] can be formulated as follows:

- is a given finite set of classes P, $P = \{p_j\}, j = \overline{1, m}$;
- is a given finite set of objects O, $O = \{o_i\}, j = \overline{1, n}$, each of which is known to be uniquely assigned to one of the classes with P: $\forall o_i \in O\ \exists p_i \in P: o_i \in p_j$;
- each object $o_i = \langle a_{i_1}, \dots, a_{i_k} \rangle$, from O has a set of k properties $A_q, q = \overline{1, k}$ such that $a_{i_q} \in A_q$;
- given classified subset of objects (training sample) $O_{Cl} \subseteq O$ such that $\forall o_i \in O_{Cl}$ is known to which class $p_j \in P: o_i \in p_j$ this object belongs.

It is necessary to determine to which classes all objects from O belong.

In the informational Web space, the problem of object recognition is directly related to information search and the purpose for which the user performs this search.

The problem of recognition in this case can be divided into several stages, as shown in Figure 2.

Stage 1. After analyzing the goal that has arisen before the user, it is necessary to determine to which class the IO he needs belongs.

There are several possible ways to do this:

- clearly select the class of the desired IO from the IO taxonomy (for example, "Web service", "employee", "article", "organization");
- set properties and restrictions for the searched IO in order to automatically detect this class in the IO taxonomy (for example, "age", "surname", "profession", "URL", "number of pages") – detection will be successful if the given the set of properties is not contradictory and can belong to one IO;
- specify examples of IOs belonging to this class by pointing to IO instances of this class (for example, "BMW" will identify the class "car", and "ISBN 978-3-659-56520-5" will identify the class "publication".

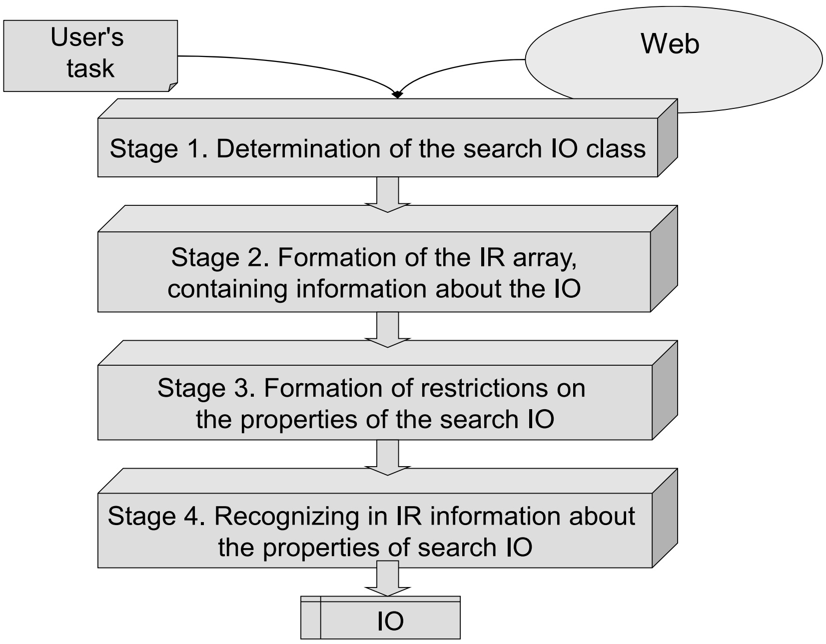

Figure 2: Stages of recognition of IP in the Web, where IP is an information resource

In addition to the description of the class $p_{IO} \in P$ to which the sought IO belongs, the relationships of this class with other semantically related classes of IO should be specified:

- subclasses $p_{subclass}$, $p_{subclass} \in P: \forall o \in p_{subclass} \Longrightarrow o \in p_{IO}$;
- superclasses $p_{upperclass}, p_{upperclass} \in P: \forall o \in p_{IO} \Longrightarrow o \in p_{upperclass}$;
- classes to which the properties of objects $o_i = \langle a_{i_1}, \dots, a_{i_k} \rangle$ from O $A_q, q = \overline{1, k}$ belong, if these properties are also classes $A_q \in P$.

Stage 2. Form an array of information, in which information about the IO should be found. For this purpose, you can:

- explicitly indicate the address of the repository of structured information of the selected class (for example, the address of the repository of ontologies or Web services);
- specify the search criteria in the Web (a search request that is forwarded to an external information and search system);
- specify a list of IRs relevant to the problem to be solved, which implicitly (unstructured) contain information about the recognized IR.

Stage 3. Form restrictions on IOs of the selected class that satisfy the user's needs. For this purpose, it is necessary – explicitly or implicitly – to link the properties of the IO with their acceptable or unacceptable values. The more precisely the class of the desired IO is specified at stage 1, the more detailed these conditions can be specified. For example, if at stage 1 it was determined that the PO belongs to the "people" class, then in the conditions you can specify his surname and age. But if the PO was assigned to the "employee" class, which is a subclass of the "people" class, then for him you can define the values of such properties as "profession", "place of work" and "experience".

Stage 4. Direct recognition of information about the sought IOs, which is reduced to the semantic marking of the set of IOs formed at stage 2 with concepts (properties) selected at stage 3.

At the same time, the methods of linguistic analysis For example, quite often when identifying IOs belonging to the "Web-service" class, it is an ontological approach that allows semantically annotating their inputs and outputs.

s, speech and image recognition (for the analysis of multimedia IRs) can be used. As well as knowledge management tools can be used. These are aimed at the automated use of knowledge about the structure of the searched IRs, presented in an interoperable form that allows automated processing.

In addition, for the interoperable representation of the knowledge of the relevant ProPs, it is advisable to use ontologies used as their formal models. Concepts of ontologies allow to semantically annotate the properties of classes and their values. For example, quite often when identifying IOs belonging to the "Web-service" class, it is an ontological approach that allows semantically annotating their inputs and outputs.

Ontology can be considered as a basis for representing the structure of an IO, that is, an ontology class, and various IRs as a source for creating instances of this object [6].

3. The concept of information field object's structure

There is such a phenomenon as implicit (or hidden) knowledge in information, which is important for working with the information object that interests us. This collected set of information about the object can be separated both from the object of research itself and from the researching subject (the subject of perception). The more knowledge we have about the researched object, the more effective the solution to the issue before us will be.

Creating applied artificial intelligence systems requires different levels of management, each of which requires specific types of information support. The relevant semantic models (ontologies, taxonomies, thesauri) are involved in applied systems of artificial intelligence. For creation of relevant semantic models of information objects, requires the construction of a reliable information field of this object. Where information field is a source of dynamic, constant updated information about the object.

"Information field" is a general concept, even during the study of a certain subject area (PrO). It requires clarification of the type and definition of the concept itself and its aspects. We will consider the information field as a set of information resources (IR) or information arrays. That is, highlight information with a certain degree of reliability, from certain points of view, of certain quality and value to the researcher, developer intelligent information systems (IIS). In general, an information field is a "repository" of all information coming from an information object. Information entering the information field can be structurally divided into separate subfields according to certain characteristics and signs and stored in the field, creating a so-called accumulative "data bank". At the same time, the information field about an object, event, phenomenon can be unlimited in time and space. The category "information field" as part of the concept "information space" can cover a certain limited amount of facts and events of the real world.

The information field as such is unlimited, but the limits of its perception depend on the capabilities and goals of the system or the researcher who uses it [7]. The information field of the object is a part of the information space, and therefore it follows some characteristics inherent in the space. That is, the field contains information relations and some elements of the field (sub-field), which are the result of revealed regularities and dependencies. The elements of the information field can be discrete and continuous and not necessarily numbers (these can be audio or video files, images, text documents, etc.) [8].

The term "information field" currently does not have a clear definition, so we will give examples of other definitions that are available in the scientific literature. "Information field" [9] is a field at each point of which one or more informationally defined parameters are defined. Such an indicator can be dichotomous (divided into two parts) [10], spatial-parametric [11], spatial, geographical [12], intellectual [13], etc. The information included in the information field can be characterized from the point of view of three aspects:

1. syntactic (structural) – structure, ways of organizing information;
2. semantic (semantic) – forecasting and modeling, strategies and approaches to modeling;
3. pragmatic – the value and relevance of information, its ability to influence processes related to information [14,15].

4. Methodology for development of information field structure

The first step in the method of developing the structure of the information field is the definition of the information object of research around which the field will be built. It is the information object that is the first of the restrictions imposed on the information field. In addition, quite often the researcher's initial knowledge of the selected object is minimal and over time it will be replenished dynamically in the process of system operation. Figure 3 shows the method of developing the structure of the reliable information field of the object.

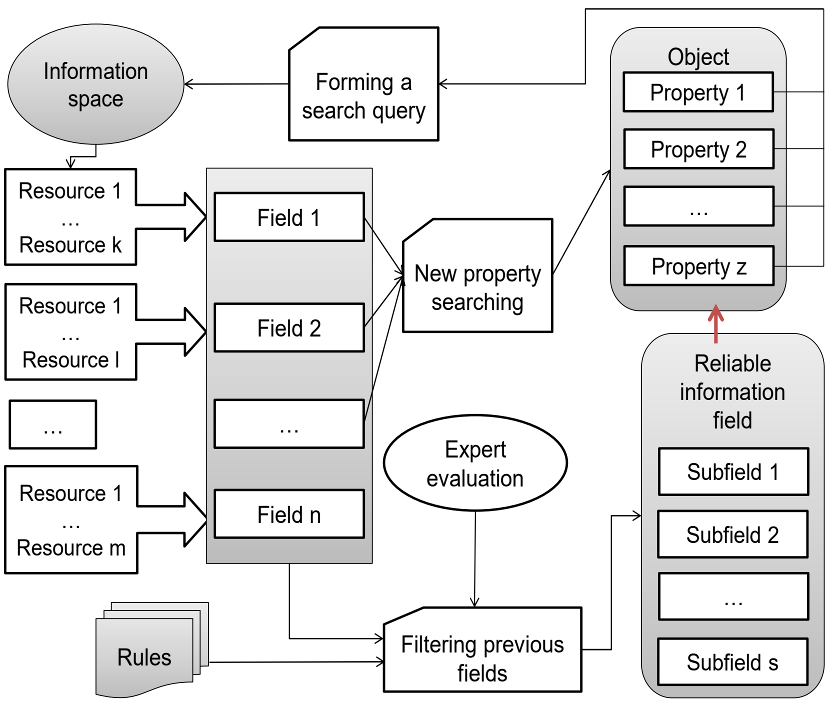

Figure 3: Methodology for developing the structure of the reliable information field of the object

This technique has certain steps to develop the object's information field and transform it into a reliable field.

I step. For the selected informational object, it is necessary to define at least one property $v_i \in V, i \in \{1, \dots, z'\}$ that the researcher needs to solve his problems or co-referent properties (a set of close properties), which can be represented by a set of equivalent properties marked by one value $w_g \in V, g \in \{1, \dots, z''\}$.

In linguistics, co-referentiality is a phenomenon that denotes the relationship between symbolic units, components of an utterance, when several components are referred to one object of extra-linguistic reality (referent). Co-referential properties will be understood as properties that depend not so much on lexical semantics as on the context. For example, "empty" and "clean" are not semantically close expressions, but for the concept "blank" these expressions will denote the same thing "blank with blank fields", that is, in being co-referential to the object "blank". All properties can be represented by a tree, class model, taxonomy, thesaurus, or dictionary.

II step. According to the selected property $v_i \in V$ or $w_g \in V$, a search request is formed for the open information space – Web environments. Namely, Internet resources (IR), electronic encyclopedias, electronic libraries, electronic explanatory dictionaries, Wiki resources, etc.

III step. Relevant resources are selected from the information space based on a search request regarding the selected property of the object IR_r, which are grouped into the previous field p_j^p.

IV step. The resulting field p_j^p is searched for a new property v_{i+1} or w_{g+1} a set of co-reference properties. A new property/set is added to the block of object properties V and checked for co-reference with already existing properties.

V step. Steps I-IV are repeated until the required number of object properties $V_z = \left\{v_i | i \in \{1, \dots, z'\}, w_g | g \in \{1, \dots z''\}\right\}, z = z' + z''$, as well as the required number of fields $p_j^p \in P^p, j = \{1, \dots, n\}$ for these properties are obtained. That is, the set P^p, conditionally divided into separate subfields, which differ in the sources of information generation and its character, will be our information field.

VI step. After forming the information field P^p, applying the rules and expert assessment of the source of resources to each $p_j^p \in P^p$, we filter information resources IR_r that are not relevant and have a low value or degree of reliability.

VII step. The filtered set P^p of subfields forms a new set P^d, which is already a valid information field with valid subfields $p_q^p, q = \{1, \dots, s\}$, i.e. $p_q^d \in P^d$.

4.1. Intellectual analysis of text using ontology

In order to obtain hidden knowledge available in information resources and electronic databases, it was decided to choose an ontology-based approach to text analysis [15].

To facilitate the process of searching and discovering knowledge from information resources, an ontology was developed. And to meet the requirements of Text Mining, general terms were defined that indicate the types of knowledge that can exist in information resources or electronic databases. Therefore, the created ontology covers the key properties and characteristics of the information object in order to link the information resource with a certain subfield of the information field. That is, this ontology is used to collect information about properties and characteristics. Ontology will help us find new information resources corresponding to a given property. It must be studied in order to determine unknown (additional) properties of the information object.

Knowledge discovery in text (KDT) can be defined as "a non-trivial process of identifying valid, novel, potentially useful and ultimately understandable patterns in unstructured data" [16]. It covers various types of information mining, clustering, data analysis methods and knowledge management. Knowledge discovery in text refers to the process of transforming unstructured or semi-structured text data into high-level knowledge or information. On the other hand, text analysis can be used to extract relevant information from an information resource or electronic database using a combination of natural language processing and data analysis methods. Text Mining uses semi-structured or unstructured data to extract information and further research to reveal implicit or hidden meaning in the text. Knowledge discovery in text (KDT) includes the following three steps:

1. Collection of documents: covers the identification and collection of documents from information resources for analysis.

2. Extraction and pre-processing of documents: the received documents need to be transformed into a form corresponding to the used method of text analysis, since the style of pre-processing and the technique of text analysis may differ for different types of documents. First, unwanted words or fragments are removed to reduce the size of the text, and then the document is converted into the required format. The finished processed document is used to obtain basic linguistic information related to its content.

3. Text mining: at this step, various algorithms and methods are used to extract metadata or high-level information to obtain patterns of behavior from the extracted information. Knowledge obtained using text analysis methods can be reviewed by experts to make the necessary changes.

After collecting the documents, we converted the text data into the appropriate format. Preprocessing of textual data is usually implemented to reduce redundant information and generate metadata. During the analysis of the text, non-informative words and unwanted texts are removed to reduce redundancy in the calculation and avoid information overload. After preliminary processing, it performed text analysis to extract patterns and valuable knowledge, i.e., for the successful implementation of Text Mining, it is necessary to build an ontology of common terms. Figure 4 shows the relationship between domain knowledge and expert knowledge of text analysis and the process of discovering knowledge in a text. Information obtained by text analysis is used to make changes to the list of object properties to increase the level of accuracy and completeness of the described object.

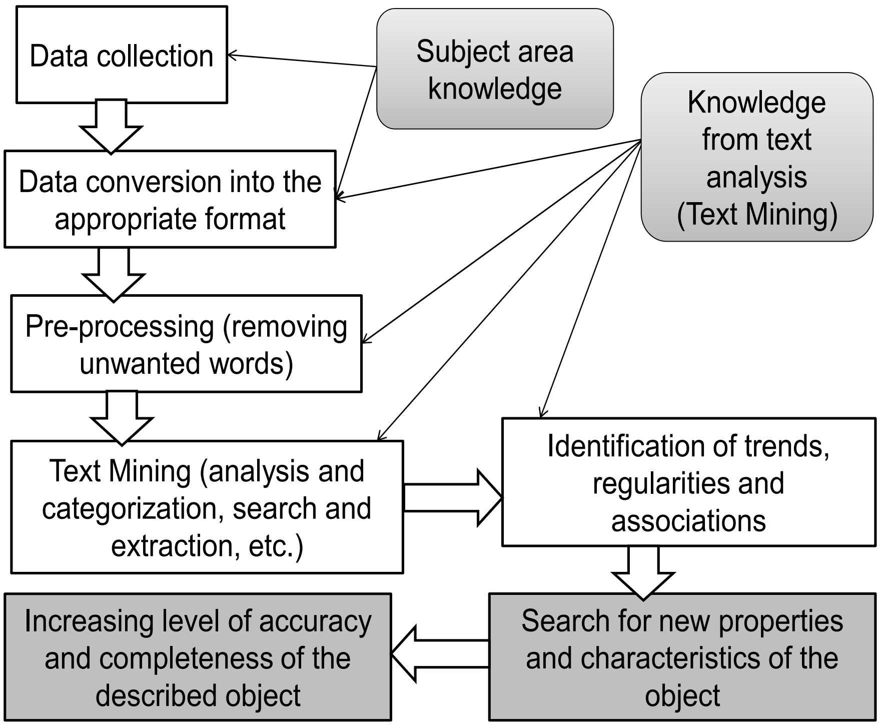

Figure 4: The relationship between knowledge of the subject area and expert knowledge of text analysis

Ontologies are semantic tools that help to formally represent the concepts underlying the text, and further reveal the taxonomic and semantic relationships that exist between the concepts. The concept of ontology was defined by Gruber in 1995 as a conceptualization of an area and a specification of this conceptualization. Ontology was used to present knowledge about the properties and characteristics of an information object. The Web Ontology Language (OWL) was used to represent the ontology because it offers a comprehensive framework for describing ontologies. OWL supports the following elements: Classes, Relationships (Taxonomic relationships), Properties of data types, Properties of objects, Individuals, and Constraints. The classes show domain concepts, and relationships define between classes and larger properties classes [17].

The concept of calculating the semantic similarity between two ontologies (semantic models) can be divided into four categories [14,18]:

1. semantic similarity based on attributes;
2. semantic similarity based on content;
3. semantic similarity based on distance;
4. hybrid methods.

Applying an attribute-based similarity algorithm inevitably leads to certain computational errors. For example, in reality, the reference model and the compared model may have no or null attribute values. A content-based similarity algorithm determines the similarity of two classes by comparing the content information contained in the classes' common parent node. But ignores the content information contained in the keyword itself. The main idea of distance-based semantic similarity algorithm is to quantify the semantic distance between two conceptual words in the ontology tree classification system. The main drawback of this method is the assumption that the distance of all edges in the system is equally important in ontological classification. Obviously, this assumption cannot be true - the importance of an edge is related to information about its location, as well as the type and strength of its connection [19].

We use the hybrid similarity mechanism to determine the similarity of models, which applies to the currently created ontology. The advantage of this mechanism is that it account both information about the position (distance, hierarchy) of the class in the ontology tree, and information about the content (content) containing the keyword itself.

Therefore, the solution to the issue of comparison of models consists in obtaining the most similar models to the given reference model. Thus, this process can be presented as five steps:

1. calculation of semantic similarity of attributes;
2. calculation of semantic correlation of attributes;
3. calculation of aggregated semantic similarity of attributes and semantic correlation;
4. derivation of model attribute weights;
5. calculation of weighted similarity of models.

4.2. Object properties co-reference checking

Checking the co-reference of the object's properties is presented as an iterative process. The one iteration corresponds to one pass through a set of input properties of the object and checking each of them for the presence of an equivalent, that is, the closest co-reference property [18]. If an equivalent property v^e is found for the property of the object v, they are combined and further interpreted as one property of the object. Within one iteration, the following actions are performed for each property of the object:

1. The degree of similarity is calculated. To compare properties, the proximity coefficient is entered $KB(v^1, v^2)$, where v^1 and v^2 are the properties of the object being compared. KB calculates the degree of similarity of properties v^1 with v^2.

$$KB(v^1, v^2) = KB_{nv} \cdot (1-k) + KB_t \cdot k,$$

where $KB_t \neq 0, k \in [0,1]$.

The property v^1 will be a standard, and v^2 a potential equivalent. KB_{nv} – the closeness of sets of relations: attributes and connections, KB_t will indicate the taxonomic closeness of the properties v^1 and v^2, which depends on the mutual location of the classes of the ontology corresponding to them in its hierarchical tree. The coefficient k regulates the level of influence of ontological and attributive factors on the final value and is determined depending on the issue [14,20].

2. A set of potential equivalents of the properties of the object v is built, that is, a set $Pek(v)$ consisting of all the properties of the object v^{e} that satisfy the given condition $U(v^e)$, $Pek(v) = \{v^{\mathrm{e}} | U(v^{\mathrm{e}})\}$.

3. The equivalent for the property v is selected. The property closest to v^{e} from the set $Pek(v)$ with the maximum value or close to the maximum value is considered the equivalent of the property $KB(v^{\mathrm{e}}, v)$. In the absence of such, we consider that it is mentioned for the first time. If it is impossible to single out a single equivalent, we will assume that the property v has no equivalent.

4.3. Assessment of information field reliability based on expert evaluation

To assess the resource relevance (usefulness) for IIS, it is necessary to determine its reliability. Credibility determines how much the IIS user can trust this resource. For evaluation, the characteristics of the resource source are used and the time of its existence in the information system is taken into account [21].

Let us assume, there is an information resource IR, and is D_i the i-th source that mentions IR. We denote the expert assessment of the source D_i as $E_i[-1,1]$. Expert assessment characterizes the expert's level of trust in information from a source D_i based on knowledge about this source. Expert assessment corresponds to borderline cases, $E_i = 1$ complete trust, and $E_i = -1$ complete mistrust. The value $E_i = 0$ indicates that the expert has no information about the source. In the absence of an expert assessment, the values are calculated using the formula $E_i = \frac{R-1}{R}$, where R is the number of different sources containing the resource.

Let's introduce the characteristic of the source, which expresses the possibility of obtaining reliable knowledge from it, which should be related to expert assessment

$$F_\alpha(E) = \left(\frac{E+1}{2}\right)^\alpha, \alpha = 1,2, \dots$$

We will assume that we know the average value of errors made during resource extraction. Then the average ratio of the errors made to the total number of extracted resources will be denoted by β. In general, it will be a function of some argument $\beta(t)$, but in the simplest case, it is a constant value.

Let's build a family of probabilistic characteristics of the source D_i using the function $F_\alpha(E)$ and parameter β

$$\gamma_\alpha^i = \beta\left(\frac{E_i+1}{2}\right)^\alpha.$$

Due to incomplete knowledge about the source γ^i the value may decrease, which will affect the credibility of the resource, in particular, accelerating the loss of its relevance. Also, over time, the information itself may become less relevant and, accordingly, less deserving of the user's trust. An indirect sign of the resource's loss of relevance is the long absence of references to the resource in new sources. Let's introduce the following function $T(t)$ that depends on time.

$$T(t) = \frac{1}{1+\ln(\tau+1)},$$

The value $\tau = t/\mu$, is a dimensionless time equal to t the ratio of the resource's existence time in the system to μ time required to reduce the reliability by a factor of one *l*. The value μ is selected from the expert's assessment of the rate of aging of resources in the subject area.

5. Conclusions

New approaches to the structuring of the object's information field have been developed based on the taxonomic presentation of selected characteristics of the object. It's done in order to build its semantic model for recognition purposes and adaptation to the specifics of the issue being solved.

The adaptation of the ontological models issue and the information object is based on their semantic proximity with the application of the weights of concepts. The relations are used in the problems of recognition of information objects.

The assessment of the resources reliability from the open WEB environment is carried out on the basis of expert assessments and by application of rules that correspond to the given problem.

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