Designing and Using Linguistic Ontologies in Intelligent Training Systems

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Abstract

The article discusses models and methods of knowledge representation in intelligent training systems, focused on the tasks of automatic processing of educational content and extracting the necessary information from it. The proposed approach considers extracting information from the educational content of the corresponding training course supported by an intelligent training system as a process of filling ontologies with information presented in the form of instances of domain concepts. To describe this process, appropriate models are proposed, in particular, such as a model for presenting educational content, a model for representing knowledge of an intelligent training system, and ontological models of facts.

Keywords 1

Educational content, intelligent training system, ontological model, information extraction.

1. Introduction

Automation of the processing and analysis of heterogeneous information (including educational (training), methodological, reference, additional, etc.) presented in natural language is one of the important areas of research in modern linguistics.

A special place is occupied by the problem of extracting information from subject-specific educational content, since this requires the involvement of expert knowledge about the subject area and the features of the language of this subject area.

This problem is closely related to the problem of the formation of the corresponding ontology and its replenishment [1, 2].

The replenishment of the ontology is understood as the automatic analysis of various sources and the filling of the found information with the educational content of the intelligent training system, based on the use of the ontology of the corresponding subject area.

Extracted information in such intelligent training systems is represented by instances of concepts and relations of a given ontology.

To solve this problem and its tasks, a variety of knowledge is used in a formalized form, such as:

- thesauri (WordNet, UkrainskijTlumachnijSlovnik-Tezaurus), explanatory-combinatorial dictionaries [3 – 5],
- annotated text corpora (for example, the national corpus of the Ukrainian language [6]), etc.

Working with knowledge requires the creation of technologies that automate the design process. Such technologies, when developing intelligent training systems, provide users (including non-programmers: methodologists, teachers, authors of educational content, etc.) with tools for modeling subject area that allow:

- abstract from the direct development of software components;

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- to concentrate on the issues of providing the intelligent training system with all the necessary knowledge;
- modeling of information extraction processes in terms of the corresponding subject area.

At present, the problem of modeling the processes of extracting information, as a rule, is reduced to solving specific problems.

This approach, unfortunately, does not allow us to single out the main aspects (technological, methodological, etc.) of solving such problems.

Therefore, the purpose of this work is to consider an approach to describing the processes of extracting information using model descriptions (in particular, ontological ones).

Ontological models of subject area allow:

- to formalize the interests of users of intelligent training systems (experts in the subject area, knowledge engineers, lecturers, students, methodologists, etc.);
- to form thematic dictionaries and thesauri;
- to represent the final result of the developed intelligent training system.

The ontological models of the subject area contain the necessary knowledge for the stage of semantic analysis of the educational content (training text).

The thesaurus, as a tool for describing the vocabulary (dictionary) of the subject area, makes it possible to characterize each term and its connections from the point of view of the peculiarities of its use in a given subject area [7 – 10].

In order to describe the formal-linguistic properties of objects and situations of particular subject area, it is necessary to use models that would contribute to:

- description of various options for presenting the same information in the educational content (training and methodological content, reference information, test questions, assignments for students' independent work, tests, etc.);
- modeling the process of extracting the information needed by users.

Among the models that are used to extract information from the educational content are [11, 12]:

- syntactic or semantic-syntactic control models;
- lexical-syntactic rules and patterns;
- ontology-based rules, etc.

These models make it possible to form the knowledge base of the developed intelligent training system, i.e. simulate the corresponding parameters of the system or its input data [13].

To model a holistic process of extracting educational information from a text, the use of the above models does not always lead to an effective solution of the set educational problems.

This is due to the fact that the presentation of textual educational information at all stages of its processing should be accompanied by appropriate models (structures), which should reflect the ambiguity of the natural language of the corresponding subject area [14, 15].

The paper proposes an approach to modeling the processes of extracting information from a text based on ontological models, which involves [16 – 18]:

- modeling of the knowledge base of the intelligent training system;
- the presence of models for the presentation of educational content (training text) in the process of its processing;
- description of information flows associated with the processes of extracting information;
- solving problems of disambiguation and resolution of coreference.

2. The ontological model of knowledge representation

A feature of the proposed approach to extracting information from the text is the use of knowledge about subject area, the use of lexical-semantic information and genre features of the educational content of the training course (courses).

Ontological linguistic models of knowledge include the use of:

- terminological dictionaries of the subject area, which define the lexical models of the sublanguage of the particular subject area;

- genre models of educational content (training text), which form the genre structure of the educational content (training text) source under consideration, narrowing the scope of search (extraction) of certain information;
- ontological models of facts that connect semantic-syntactic models that describe the structure of expressions accepted in the given subject area with the formal representation of information determined by the ontology of the subject area.

2.1 Terminological dictionary of the subject area

Terminological dictionaries of the subject area, being a component of the ontological linguistic model, are focused on automatic text processing and contain additional information that allows you to recognize terms in educational content (training texts) of the corresponding intelligent training systems.

Formally, the subject area terminological dictionary is defined by a system of the form

$<V, M_{ML}, S_{TF}, OM_{SA}>$,

where:

$V = S_L \cup S_T \cup S_{LT}$ – the set of subject terms, including:

S_L is the set of lexemes (each lexeme is associated with information about the entire set of its forms);

S_T is the set of multi-word terms, each of which is described by the pair

<L-gram, structure type>,

where:

the L-gram specifies the sequence of lexemes, and the structure type determines the L-gram element matching rule);

S_{LT} is the set of lexical templates used to recognize regular text fragments (such as abbreviations, abbreviations, symbolic (numerical, alphanumeric) designations of the subject area objects).

M_{ML} is the morphological model of the language, including the description of morphological classes and attributes (an attribute is divided into word-forming, inherent in all forms of the lexeme of the given class, and inflectional, distinguishing forms of one lexeme).

S_{TF} is the set of hierarchically related thematic features (each term is associated with the set of features with an indication of the link weight (value from [0,1]), which reflects the degree of belonging of the feature to the particular term).

O_{MSA} is an ontological linguistic (lexical-semantic) model of the subject area.

The ontological model of the subject vocabulary (dictionary) of the subject area should include a description of the structure of the semantics of terms and allow comparison of textual elements (lexemes, terms, lexical templates, etc.) with their semantic equivalents.

The proposed model includes grammatical, thesaurus and semantic information about the term, as well as descriptions of the structure of words.

Encoding semantic information about the word involves the use of the semantic class and the semantic attribute.

The hierarchy of *semantic classes* makes it possible to attribute a term to a certain level of this hierarchy.

The representation of the lexical meaning of each term of the corresponding subject area is based on the use of *semantic attributes*. Sets of term attribute values allow modeling the component semantic structure of a single word, a complex of words, a multi-word term.

The main components of the semantic structure of a term can be thesaurus descriptors.

If the term has more than one meaning, then the corresponding number of semantic articles of the word is formed, combining the semantic class and the set of semantic attributes with their values using the grouping mechanism.

The semantics of the term found in the text ensures the formation of the lexical object. The structure of the lexical object can be represented as follows:

```
LexObject
Name                    // Term name
Descriptor              // Descriptor name
```

Semantic // *Set of lexical-semantic classes*
Neg // *Presence of negation*
Attributes // *set of Semantic attributes*
Value // *Meaning or form in which the term occurs in the text*
Position // *Position of the term in the educational content*
Grammatics // Set of g*rammatical characteristics (parameters) of the term*

The *Name* parameter specifies the normalized form of the term, obtained using:

- morphological normalization (in the case of a one-word term),
- agreement of words in a phrase (for multi-word terms),
- the name of the lexical template (for symbolic-numerical constructions).

The *Descriptor* parameter specifies the name of the concept to which the term refers. In particular, the descriptor serves to form groups of synonyms in a given subject areas.

The field determines the lexical-semantic class of the term. The presence of several values in the *Semantic* field of the lexical object corresponds to the compound value of the term.

For example, the *8-bit* compound word has the lexical value of *Number* and *Units of Measurement*.

In contrast to the ambiguity when several lexical LexObject objects are *formed* (for example, objects with the semantics of *Action* and *Process*).

The field *Neg* specifies the presence of negation in the meaning of the term, which in the text can be expressed, for example, by the prefix *Not (Non)*.

The *Attributes* field specifies a set of semantic attributes to represent the structure of the term's semantics.

The *Grammatics*, *Position* and *Value* fields are determined by the dictionary and textual characteristics of the term.

2.2. Ontological genre model of educational content

The analysis and extraction of information from educational content uses the concept of a genre, which is understood as a set of meaningful and diverse formal linguistic aspects (logical-compositional and lexical-grammatical).

The ontological genre model of the educational content text can be represented by a system of the form

$O_{MG} = <G, F_{GS}, S_{LC}, V_G, M_G, P_G>$,

where

G is the genre type of the educational content (or its fragment);

F_{GS} is a set of formal genre segments (each segment is defined by a type, as well as its initial and final text positions);

S_{LC} is logical and compositional structure of educational content, determined by the many relationships between its fragments;

V_G is a dictionary of genre vocabulary of educational content in the corresponding subject areas;

M_G is a set of genre markers that are defined using terms from V_G;

$P_G: M_G \rightarrow F_{GS}$ is a set of genre patterns that link markers and pieces of educational content.

Genre features of educational content are transmitted by dividing it into meaningful fragments, which:

- include certain vocabulary (dictionary);
- have a certain structure;
- are implemented within certain formal segments.

S_{LC} is revealed using the lexicon of genre markers and patterns that highlight content fragments.

The markers are derived from subsection headings, introductory sentences, and lists included in the educational content of the respective intelligent training system.

Simple markers are mapped to terms in a subject dictionary or a group of terms (synonyms). Complex markers are formed on the basis of simple ones (alternatives, co-occurrence, nested use of markers are supported).

2.3 Ontological modeling of facts

Fact is empirical knowledge about objects, their properties and situations fixed in a statement. A fact can be described by a cognitive scheme that relates it to the concepts and relations of the ontology.

The fact model generates knowledge about the alignment of existing linguistic knowledge with subject knowledge.

This model fixes the formal-linguistic properties due to the linguistic features of the description of objects and situations of a particular subject areas.

The linguistic description of the fact is based on the semantic-syntactic model, which is given by a pair of the form

$<Lg, M_A>$,

where:

Lg is a generalized lexeme that characterizes a group of terms that has a set of semantic and grammatical features and given values of morphological attributes;

M_A is a grammatical sequence of actants describing models, where each actant specifies a set of valid combinations of semantic and grammatical characteristics of terms.

The proposed model may not contain syntactic restrictions and represent ontological relations or be described without semantic characteristics and correspond to syntactic models.

Generalized lexemes in models allow you to define many language constructs, variants of the relationship of words in expressions and vocabulary groups.

The ontological model of facts is given by the structure, which is described in terms of ontology classes or in terms of the semantic features of the dictionary.

Additionally, restrictions are imposed on the ontological features of the structure elements and their positions in the educational content.

Formally, the ontological model of facts is a system of the form

$O_{MF} = <S_{AF}, S_{SSM}, S_R, O_{Res}>$,

where:

S_{AF} is the set of fact arguments;

S_{SSM} is a set of semantic-syntactic models that arguments must satisfy;

S_R - set of restrictions (semantic and structural);

O_{RES} is a fragment of the ontology, in accordance with which the result of applying the fact model is formed.

Ontological models of facts can be divided into:

- object initialization models (required for the initial formation of ontological entities based on dictionary features),
- models for identifying links (modeling the process of "discovering" fragments of the ontology).

Below is an example of a model description for initializing objects of the *Algorithm* class, which can be represented in the educational content by the corresponding noun phrase.

Scheme Algorithm: segment *Clause*
    arg1 = Term: Algorithm(SemClass: Type)
    arg2 = Term: Algorithm(SemClass: Name)
    Condition PrePos(arg1,arg2), Contact(arg1,arg2)
→ Object: Algorithm (Type: arg1.Class & arg2.Class, Name: arg2.KeySort)

In this model, the terms must have the semantic class *Algorithm*, taking into account the hierarchy of trait inheritance in the dictionary, and the first term must have the semantic attribute *type*, and the second term must have *name*.

When applying this model, for example, to the phrase

sorting < Algorithm, SemClass: Type> *"Shell's algorithm"* < Algorithm, SemClass: Name>

an object is created – an instance of the *Algorithm* ontology concept, the algorithm type (for example, exchange sort) can be specified in accordance with the semantic attribute of the first or second term, the *Name* attribute of the object is filled with the name of the second term *KeySort*.

When searching for and identifying the characteristics of objects and their relationships, it is required to check the compatibility of semantic AND / OR grammatical features of objects.

Below is an example of a relationship building model according to the situation under consideration.

Scheme AlgorithmApplicationCondition: genre_segment <*group*>
arg1 = Object: AlgorithmClass()
arg2 = Object: Algorithm()
arg3 = Term: Parameter (SemClass: Task)
arg4 = Term: Parameter (SemClass: Time)
Condition genre_segment (arg2, arg3, arg4) <*description*>,
Contact(arg2, arg3), Contact_minute (arg2, arg4)
→ HasDestination(AlgorithmClass:arg1,Algorithm:arg2,Type:«Algorithm», Task:arg3,Time:arg4)

The conditions for applying a specific *Algorithm* to solve a specific problem are described by such characteristics as the name of the algorithm, its class of problems to which it is applicable, and the time it takes to solve the problem.

This information is contained strictly in certain genre fragments. Within the description fragment, the *description* of the parameters is expanded as text.

3. Ontological model of presentation of educational content

When modeling the process of extracting information, an important role is played by the presentation model of educational content (training text).

The essence of this model is:

- uniform support for all stages of processing of educational content, including semantic;
- using "external" annotation (rather than a tag system) synchronized with the educational content.

The educational content presentation model is a set of content coverages when the intermediate processing results are objects of the same type with a given projection on the content.

This approach allows you to visually interpret the results and highlight the knowledge that is contextually related to each element.

The educational content presentation model is defined as follows:

$OM_{ECP} = <C_A, C_L, C_G, C_{Th}, C_{IO}>$,

where:

C_A is a graphematic cover containing many atoms (an atom is an object associated with a fragment of educational content consisting of symbols of the same type); atoms are ordered by occurrence and are determined by serial number, initial and final positions;

C_L is a terminological coverage containing a set of lexical objects, the main parameters of which are:

- dictionary term;
- grammatical characteristics of the term;
- set of the semantic features;
- positions in educational content;

C_G is a segment (genre) coverage that reflects the logical and compositional structure of the educational content and includes many segments, the main parameters of which are:

- the type or formal segment of the genre model of the educational content;
- position;
- links with other segments that determine their relative position in the educational content;

C_{Th} is thematic coverage, which is determined by a set of thematic fragments;

C_{IO} is an information coverage containing a set of information objects, the main parameters of which are:

- an ontological object or an instance of a concept defined by the ontology of the subject areas,
- positions,
- a set of information dependencies of the object.

Depending on the problem being solved, other types of coverage can be distinguished. The presented model is focused on the tasks of semantic analysis and information extraction.

The main stages in the formation of an ontological model for the presentation of educational content are:

- preliminary preparation and processing of educational content (the result is, in particular, the formation of the structure of the training course, the construction of ontologies of the subject areas, etc.);
- analysis of educational content (the result is well-formed lexemes, sentences in the subject area language, graphematic coverage of content, etc.);
- conducting a lexical analysis of the educational content (the result is the terminological coverage of the content);
- carrying out genre typification and fragmentation of educational content (the result is segment coverage of content);
- carrying out thematic classification of educational content (the result is thematic coverage of content);
- carrying out a semantic analysis of the educational content (the result is the information coverage of the content).

The graphematic coverage of educational content is the result of its grammatical analysis, during which the content is divided into elementary atoms.

The main task of this stage is to group characters of the same type in a sequence and give them an interpretation: a word of a certain alphabet, a number, a punctuation mark, etc.

An important property of this representation is that the coverage elements define all possible element boundaries for all subsequent representations, i.e. in further processing, no atom can be "split".

The terminological coverage consists of vocabulary terms found in this educational content, taking into account possible homonymy and intersections of multi-word terms.

Terminological coverage of educational content (educational, training, methodological text, reference, etc.) is a lexical content model that is built on the basis of the lexical model of the subject area language and includes found terms with reference to the position in the educational content.

After the term is found, a lexical object is formed with a set of semantic attributes specified in the subject dictionary for the found term.

The segment coverage reflects the structural division of the educational content into logical (paragraph, sentence, heading, etc.) and genre fragments.

The genre coverage is one way of reflecting the formal structure of educational content. When analyzing educational content, splitting into genre fragments helps to narrow the search area for information of a certain type and improve the quality of analysis.

The thematic coverage is built over terminological and genre coverage. It defines the educational content boundaries of the training content areas for each considered subject of training courses implemented in intelligent training systems.

The formation of such areas is carried out on the basis of a dictionary, in which the correspondence between terms and thematic features is specified.

Thematic coverage element is defined as a piece of educational content that includes a cluster of terms related to one topic of the training course implemented in intelligent training systems.

Thematic segments help to narrow the search area for information of a certain type (educational and methodological information, control questions, assignments for independent work, tests, etc.).

The information coverage describes the found information in the form of a semantic network model of objects of the particular subject area.

The information coverage of the educational content represents the results of the semantic processing of the training course implemented in intelligent training systems.

To build an information coverage, it is necessary to have a data format that specifies the structure of the presentation and storage of the information received.

This structure must have a predetermined semantic interpretation. In modern approaches, the ontology of the subject area is used for this [19 – 22].

The educational content of the intelligent training system built on the basis of ontology is a set of instances of ontology classes.

The information coverage describes educational content in terms of information objects.

These objects are formed on the basis of concepts and must be associated with a specific instance of the ontology, which is already present in the content of the intelligent training systems or will be added.

Information objects are formed on the basis of fact models.

In this case, information dependencies are generated between the objects that act as model arguments and its result.

To accurately describe these dependencies, an attributive model for extracting information is used.

The advantage of such a model is:

- visualization of the results of the educational content analyzer;
- formal description of educational content processing algorithms and proof of their properties;
- using a formal description of algorithms as a top-level abstraction for their software implementation;
- ensuring the reliability of the result, which will allow a wide range of corpus studies.

4. Extracting information from educational content

When describing the processes of extracting information using:

- ontological models of facts,
- the attributes of objects;
- the relationships between them are used.

For a detailed representation of processes and reflection of information dependencies at the levels of objects and their attributes, an attribute model is used.

The attribute model is a logical data model designed to display relationships between properties or attributes of objects participating in the same process.

For correct modeling of information extraction processes, models should allow describing processes within which cycles do not occur.

The attribute model can be described as

$\langle S_{OM}, S_{AO}\ S_{L} \rangle$

where:

S_{OM} is a set of modeling objects;

S_{AO} is the set of attributes of the subject area objects;

S_{L} is the set of directed links between the attributes of the subject area objects.

In this case, an attribute can have only one incoming link and many outgoing links; and a relationship can only be established between attributes of the same type.

The proposed model has two practical applications:

- the model is the metamodel for modeling processes using fact models (for describing single models and their combination);
- the model is used to save the information dependencies between the objects of the information coverage of the educational content, which makes it possible to assess the degree of connection of the object with the context and to correctly remove the object from the educational content of the intelligent training system.

The task of extracting information in accordance with the proposed models for presenting educational content can be formulated as follows:

For a given quadruple

$\langle S_{O}, C_{I}, M_{LSA}, C_{TC} \rangle$,

where:

S_{O} is the set of the subject area ontologies,

C_{I} is the information (educational) content of the intelligent training system,

M_{LSA} is the subject area language model,

C_{TC} is the educational content of the training course (courses), build information coverage educational content that has the property of unambiguity and comparability with C_I.

Unambiguity is understood as the presence of no more than one interpretation of any fragment of a given educational content.

This means that if there are several options for parsing educational content, for example, in the case of homonymy, one option should be selected.

The property of comparability with the content of the system means that each information object included in the resulting information coverage must be uniquely associated with an ontology instance from S_O, which is ensured by the presence of specified key attributes.

The general scheme for implementing the semantic stage of analyzing and extracting information from educational content is as follows:

- the input of the analysis subsystem receives the results of the preliminary stage of processing the educational content in the form of terminological, segmental and thematic coverage;
- the knowledge base of the intelligent training system contains knowledge about the ontology of the subject area and the models of facts specified for this ontology;
- the result of the subsystem's work is the information coverage of the educational content, on the basis of which the resulting set of ontological objects is formed that describes the content of the training course in terms of the ontology of the subject area.

During the main analysis, the following main tasks can be distinguished:

- Extraction of facts based on ontological models of facts (technological support is provided by intelligent training systems that generates rules based on ontological models of facts and applies them to the input data).
- Resolution of coreference and search for referents of objects in the ontological content of the intelligent training system (all references to each ontological object are searched, coreferential groups of information objects are formed and possible conflicts are resolved; the solution of this problem is influenced by the degree of development of the ontology and the fullness of the educational content of the intelligent training system).
- Disambiguation resolution of educational content fragments (language ambiguity is the ability of a word or expression to have different interpretations, often conflicting with each other; conflicts are considered in the context of a given ontology).

The proposed approach is based on the informational connectivity of information objects extracted from the given educational content.

The conflict resolution subsystem of intelligent training systems must resolve all ambiguities in such a way that the intelligent training system is free from conflicts and at the same time preserves the maximum possible number of objects and relationships.

5. Conclusion

The approach to modeling the processes of extracting information presented in this work is essentially based on the knowledge of the subiect areas, formalized in the form of an ontology, which makes it possible to apply the methods of semantic and syntactic analysis without requiring complete correct syntactic parsing and grammatically correct educational content in the intelligent training systems.

The ontological model of knowledge representation in intelligent learning systems determines the general scheme for processing learning content.

The ontological model of knowledge representation includes a description of the subject vocabulary, genre models of the text and models of facts that allow modeling the processes of extracting information in terms of semantic classes of the subject vocabulary and ontology of the subject area.

The proposed attributive model allows the use of ontological methods for solving the problems of ambiguity and resolving coreference.

Thus, an original technique is proposed that allows users to design a learning content analysis system and simulate the extraction of information from the content of a learning course supported by an appropriate intelligent learning system based on the domain ontology.

Narrowing the scope of subject terms significantly reduces the ambiguity of educational content in intelligent training systems.

The use of ontologies in the identification and comparison of educational content objects makes it possible to obtain and apply implicit knowledge in training (education) i.e. information not contained in the educational content of the training course (courses) implemented in intelligent training systems.

The considered ontological models and their technological support provide end users of intelligent training systems^

- experts in subject area;
- linguists;
- knowledge engineers;
- students;
- teachers, lecturers;
- methodologists;
- stakeholders;
- software developers of intelligent training systems

with tools for modeling the processes of extracting information and designing systems for automatic processing of educational content.

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