Approach to automating the construction and completion of ontologies in a scientific subject field

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Article Info

ABSTRACT

Domain ontologies facilitate the organization, sharing, and reuse of subject areas. Building a software ontology is labor-intensive and time-consuming. In the process of obtaining a software ontology, it is required to analyze a huge number of scientific publications relevant to the software being modeled. The process of ontology replenishing with information from a huge number of scientific publications can be facilitated and accelerated through the use of lexical-syntactic patterns of ontological design. In this paper, we consider the possibility of automated construction of scientific subject area ontologies based on a heterogeneous patterns system of ontological design. This system includes ontological design patterns and is intended for ontology developers. System also includes automatically built lexical and syntactic patterns, which help to automatic replenishment of the ontology with information extracted from natural language texts.

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1. INTRODUCTION

Currently, to formalize and systematize data and knowledge in scientific subject areas (SSA), ontologies are actively used, which make it possible to describe scientific knowledge area or scientific discipline, including characteristics of research objects and subjects, applied scientific methods, ongoing projects and obtained results [1]. This study investigated the effects of using ontology, which allows for the completeness and accuracy of identifying factual information, which, in turn, will provide the possibility of more adequate automated processing and analysis of SSA. The ontology developing process usually consists of some stages, where one of the main is ontology terminological part construction, involving to development of concepts taxonomies, relationships, their properties description, ontology replenishment. The completion of the ontology presupposes the addition of instances of concepts and relationships to it. With this approach, the first stage sets the ontology skeleton and the second stage fills with content. To make ontology which

would sufficiently fully describe SSA, it is required to analyze a huge number of scientific publications and information resources containing information in the modeled area. To make this process easier and speed up, developing methods of ontology automatically replenish based on natural language texts [2]–[5] and web documents [6]–[8]. To automatic text processing (ATP) uses clustering-based approaches, which use well-known clusters, statistical methods and template-based approaches, which use linguistic patterns. However, for working well a clustering based approach requires large text corpora, which is why methods based on linguistic patterns are more common nowadays [9], [10].

Hearst [11] proposed the idea of the possibility of semantic links automating construction based on diagnostic contexts, which are presented in lexical and syntactic patterns form. This method, also known as Hearst patterns, is intended for processing unstructured texts in English. It was widely used to extract generic relations and involved extracting ordered pairs of words from a collection of documents corresponding to a variety of pre-compiled patterns. Hearst's approach has been used and improved by many other researchers, and has also been applied to other languages.

A number of papers propose a formal apparatus for recording lexical and lexico-syntactic patterns. Thus, in study [12], an XML language schema is formulated to formalize the lexical-syntactic patterns used to replenish ontologies. The Alex system [13] and its development tool DigLex [14] provide fairly flexible means of describing words and phrases in the form of patterns, which are then used to automatically recognize these units in text. They expand the capabilities of traditional lexicographic systems: the template description language supports the use of alternatives, template references, repeaters, context conditions, and distant context. The language allows you to write rules not only for recognizing text objects, but also for determining their lexical and semantic attributes. However, the Alex and DigLex languages do not have built-in tools for indicating the grammatical features of recognized lexical units and grammatical coordination of several units necessary for unambiguous identification of language constructions (for example, noun phrases). The lexico-syntatic pattern language (LSPL) proposed in [15], which allows you to specify the grammatical properties of its elements, does not have this last drawback. Some research devoted to solving the problem of full automatic or semi-automatic replenishment of the ontology rely on patterns that reflect the linguistic structures found in the texts into similar ontology elements (relations, concepts, samples of instances and relations). These are lexical-syntactic patterns that use lexical representations and syntactic information [16], [17] or lexical-semantic patterns that combine lexical representations with syntactic and semantic information during the extraction process [18], [19].

The paper describes an approach to automating the replenishment of SSA ontologies, based on the use of lexical-semantic patterns (LSP) as an extension of the lexical-syntactic patterns of ontological design. One of the features of this approach is that LSP used in it are automatically built based on ontology design patterns (ODP) of other types [20], [21], included in an ontology development automation system based on heterogeneous ODP [22], [23]. Based on experience, we would like to note that before developing and applying process patterns for Kazakh language, should be carried out serious scientific research and analysis, because patterns are very much dependent on the grammatical features of the language [24], [25].

2. METHODOLOGY FOR CONSTRUCTING SCIENTIFIC SUBJECT AREAS ONTOLOGY BY KNOWLEDGE ENGINEERS

Any SSA ontology contains descriptions of the inherent system of concepts, tasks, methods of information processing and analyzing, and, accordingly, descriptions of relevant information resources. In this context, it is convenient to represent the ontology of SSA as a system of interconnected ontologies: of knowledge ontology, problems ontology and scientific internet resources ontology as shown in Figure 1. Figure 1 shows an example of ontology of SSA "Automatic text processing", which includes systematization of modern methods of automatic text processing, their properties descriptions and relationships, their application methods and areas, information resources, and publications. The ontology of the knowledge area specifies a system of concepts and relationships intended for a detailed description of the modeled SSA and the scientific and research activities carried out within its framework. The problems and methods ontology describes the problems solved in this SSA, and methods for solving them.

Building a specific SSA ontology using basic ontologies and ODP system includes two levels: i) construction of SSA ontology components based on basic ontologies. At this level, the specialization of the structural content patterns and logical patterns presented in the basic ontologies is carried out for a specific SSA; and ii) replenishment of the SSA ontology by specifying structural logical patterns and content patterns presented in basic ontologies or obtained from them by specializing them for a specific SSA. The use of such patterns not only improves the quality but also greatly facilitates the development of an ontology since it can involve experts in the modeled area who do not have the skills of ontology modeling. To assess the quality of the ontology was developed methodology, on the basis of which the involved experts carried out an experimental assessment of the created ontology, including an assessment of the degree of agreement of the experts.

A pattern specialization can include renaming, names clarification and values of its properties (Attributes and Relationships). The patterns specialization using structural logical pattern "binary attributed relation" is shown in Figure 2. In this pattern, the service class Relationship with attributes is the main one. Other base classes are associated with it, which model the arguments of a binary relation through the links "is an Argument" and "has an Argument". But at the same time, in each pattern (in the labels of the links) there should be only one such argument at a time. The properties of the class Relationship with attributes "has an Attribute" and "has an Attribute from the Domain" model the attributes of a binary attributed relationship. In general, this type of relationship may not have attributes that are reflected in the relationship labels representing these properties. Figure 3 shows an example of specification of the content pattern "ATP methods". This pattern was used to represent information about ATP [26].
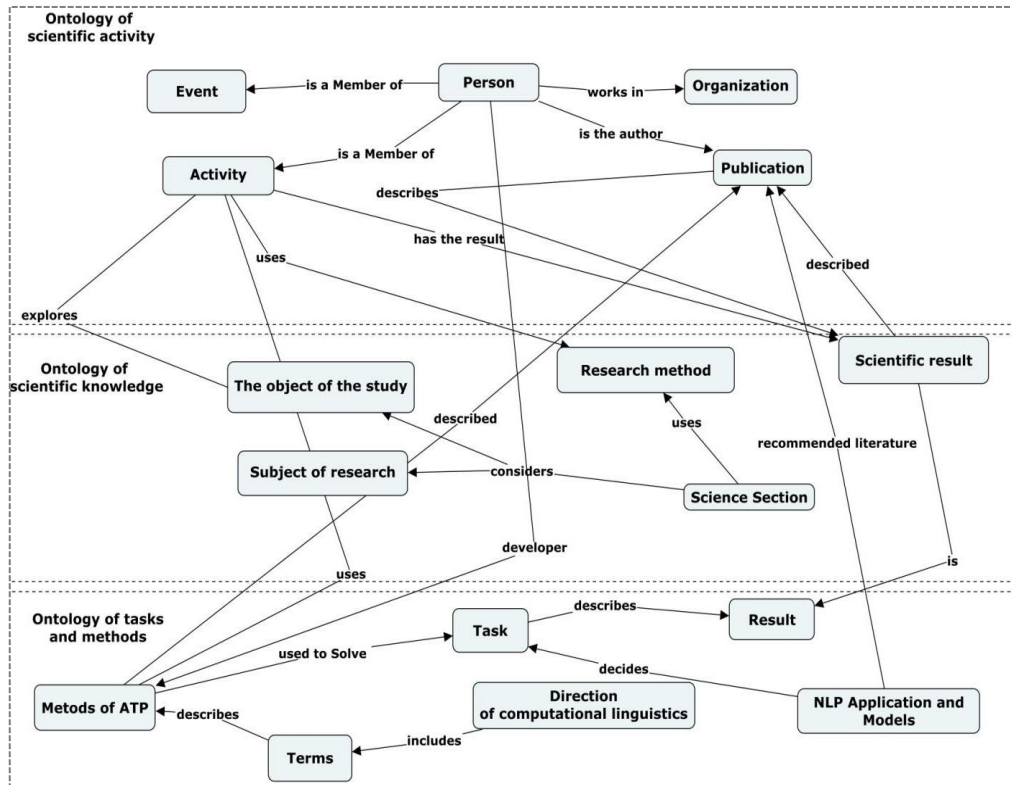
Figure 1. Example of ontology of a scientific subject area
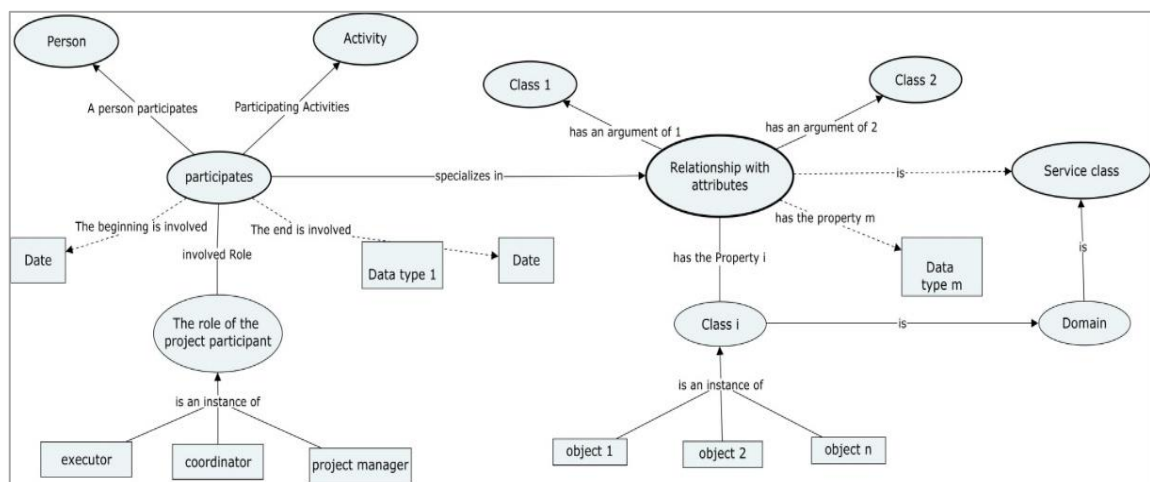
Figure 2. The pattern of a binary attributed relationship and an example of its specialization

Software specialists replenish the ontology with actual data–class objects and their properties, and in this process, the use of content patterns when replenishing the SSA ontology is supported by a special data editor as shown in Figure 4 [27], [28]. In the ontology updating process, user selects the desired class from the presented hierarchy of ontology classes. The editor finds the corresponding pattern by the name of the class and builds a form based on it, containing fields for filling in the properties of an object of this class by the user. Editor can also interpret relationships with attributes that are described by the pattern in Figure 2. Owing to this, user has the opportunity to work with the properties of an object set using such relationships as with "ordinary" object properties. A slight difference is the need to set the appropriate attribute values for such a relationship.
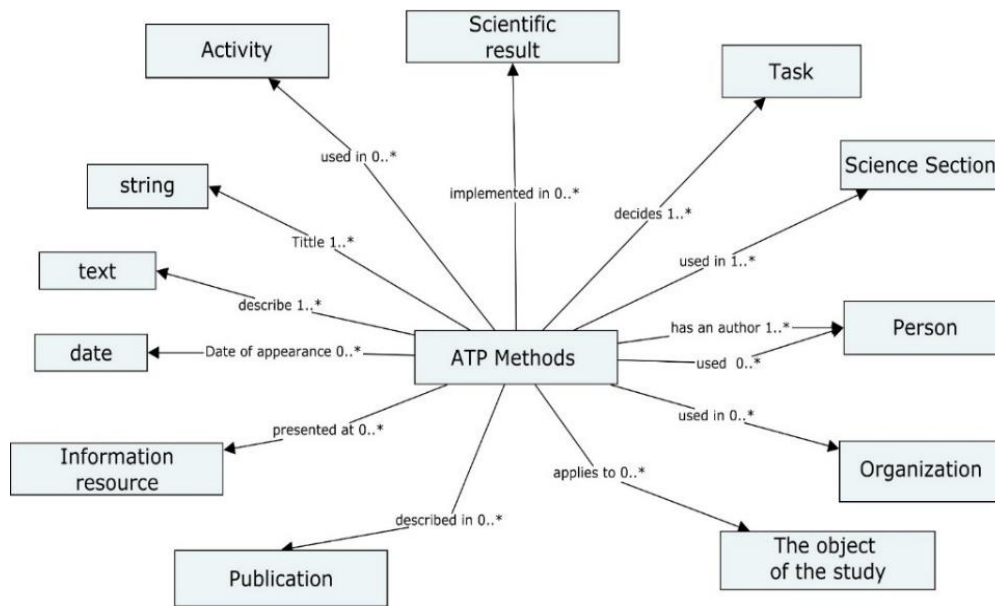
Figure 3. Specification of the content pattern "ATP methods"
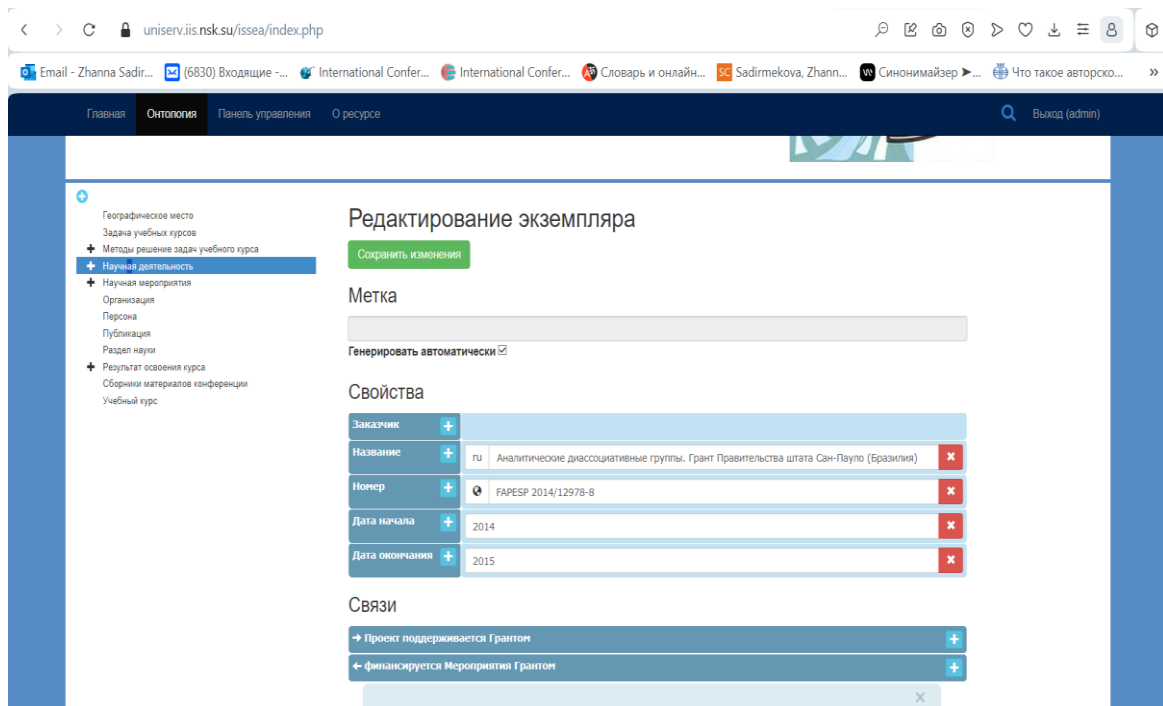
Figure 4. Data editor

3. REPRESENTATION OF LEXICO-SYNTACTIC PATTERN

To implement ontology replenishment automatically for each content pattern built LSP set. They describe various ways of presenting information in scientific texts, on the basis of which information is extracted. LSP are organized into a multi-level system, including terminological patterns (T-LSP) and information patterns (I-LSP). T-LSP are intended to describe elementary language structures and extract new terms. The scheme of information or facts extraction from the text and generating the corresponding them ontology is set using I-LSP. Here, facts are understood as form triples, where object is SSA entity found in the text, property is the name of the property of this entity, and value is the value of this property. When compared with an ontology, object correlates with an individual (instance) of some ontology class, property-with the name of a property of this class (this can be a "type" relationship connecting an individual with a class, an attribute name (datatype property) or relationship (object property), value-with the corresponding ontological meaning.

Each LSP implements form model, where arguments are a set of semantic arguments of a fact, which are associated with either SSA objects or terms (however, there are conditions that the objects have already been extracted with other I-LSP). Constraints are semantic, syntactic and/or positional conditions to arguments. Results describes the result of LSP applying, here the result can be either a generated fragment of ontology (for I-LSP) or a new term (for T-LSP).

In order to automatically replenish the ontology with the help of LSP, we need to ensure that the specific terms of this SSA are extracted from the text. For this purpose, subject dictionary and terminological patterns are used that make it possible to extract new terms (in particular, names of SSA objects or specific predicate words). The subject dictionary is created as an extension dictionary of general scientific lexicon and includes terms, phrases and words organized in accordance with software semantics. All information is stored in the dictionary entry, which will be needed to extract the term from the text and support subsequent stages of text analysis. Each subject dictionary term, founded from text, is supplied with semantic and morphological information, which is subsequently used in LSP application.

The considering dictionary described by the system of following type $D = <W, P, M, G, S>$, where W is set of lexemes, each of which is associated with information about its the forms of entire set; P is multi-word terms set and described by a pair, where N-grams specifies the lexemes sequence and the type of structure determines rules and vertex for matching elements of N-gram; M is language morphological model, it includes morphological classes description and their features; G is matching rules set for extracting multi-word terms; and S is problem-oriented system of lexical-semantic features.

The semantic component of the subject dictionary consists of two independent hierarchies of lexico-semantic classes: i) Universal hierarchy inherited from the dictionary of general scientific lexicon; and ii) Subject-oriented hierarchy created based on SSA ontology. To automatically generate a dictionary, a technique has been created for automatically generating a system of lexical-semantic characteristics based on the names of ontology elements. All dictionary terms are marked with attributes from subject-specific and/or universal hierarchy. The specific SSA terms in the dictionary of general scientific lexicon receive syncretic attributes with a simultaneously expressed meaning of a universal and subject lexical-semantic class. Thus, for the verb "use", four syncretic features have been identified, each of which includes the universal class Application in combination with ontologically determined features: *Method.is_applied_in*, *Method.is_applied_to*, *Method.is_used_in* and *Method.implements*. To describe LSP used dictionary lexico-semantic features (in arguments and/or results) as a way to refer to SSA terms with certain semantics, about which in the general case nothing is known in advance.

4. AUTOMATIC LSP GENERATION

LSP are automatically generating based on general scientific and subject lexicon dictionaries, ODP, and current version of SSA ontology. Figure 5 shows the interconnections diagram of system components which are participating in LSP generation. The LSP generation process begins with the creation and filling of a subject dictionary. From the ontology and description of the content pattern, terms are extracted and lexical-semantic classes are formed. All terms are marked with corresponding semantic features. Based on the analysis of content pattern structure, variables are signified in meta patterns and T-LSP and I-LSP are formed. With the help of the created T-LSP, questions of competency assessment are analyzed first, and then the texts of the scientific corpus. Competence assessment questions are expressed in natural language. They allow you to extract predicate terms and set initial syntactic constraints on the extracted facts, which can later be clarified based on the corpus of texts.

When generating I-LSP, key attributes information of ontology classes is required. In the examples above, the attribute Title was used, but ontology classes may have other key attributes (for example, the person class), which will require the creation of other typical patterns. I-LSP also requires clarification of

syntactic and positional restrictions based on examples of occurrences of I-LSP in the text corpus. For this, LSP is used, built on content patterns basis and general scientific lexicon dictionary intelligent information resources designed to systematize information about modern methods of automatic text processing and provide meaningful access to it. The work of the resource is organized on ATP ontology basics, which is its conceptual basis. Thus, from the ontological components of knowledge, we can distinguish knowledge about the software language necessary to information extraction from text and ontology replenishing, and also possible ways of linguistic description of ontological entities in texts. The acquired knowledge is implemented in LSP system, which will help to apply existing ATP technologies to automatically replenish the SSA ontology.
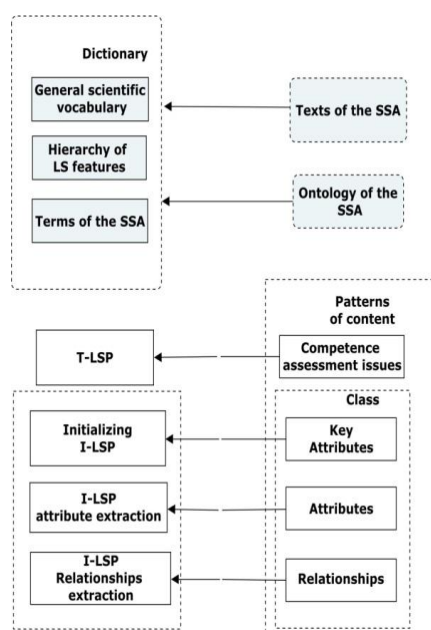
Figure 5. Scheme of LSP generation and interconnections of system components

5. RESULTS AND DISCUSSION

Our proposed approaching this study is usually based on the following methodological principles: i) automatic replenishment of the subject dictionary based on ontology and the corpus of texts and its markup using a system of semantic features, also based on ontology; ii) defining a small set of initial structural meta-patterns that establish conceptual contexts for extracting ontological information; and iii) automatic generation of a set of lexico-semantic patterns based on a set of structural meta-patterns that determine the lexical, semantic and syntactic properties of extraction contexts.

5.1. Analysis of the experimental research

An experimental test of the subsystem for automatically replenishing the ontology was for the SSA ontology "modern methods of automatic text processing". Experimental testing was carried out for the content pattern ATP Methods. Based on the current state of the ontology of this SSA and the description of the content pattern, ATP Methods automatically created a domain dictionary. The dictionary consists of 214 terms, which are marked up with 21 lexical-semantic features, and 34 T-LSP for new terms extracting (names of instance class and predicate words). To generate a hierarchy of lexical-semantic features, labels (*rdfs:label*) of attributes and relations of the class ATP Methods, as well as attribute values for instances of this and related classes, were used. To assess the quality of the obtained LSP, a corpus consisting of scientific publications in the Kazakh language with a total number of 53.9 thousand tokens was used. Using T-LSP found 111 occurrences and identified 73 unique terms, which was assigned by lexical-semantic class *Method.Name*. Of these, 70 terms were new (missing from the dictionary based on ontology). Similar T-LSP were used to extract the names of other individual classes associated with class ATP Method. Thus, for the class task, 42 occurrences of the template were found and 33 terms were identified, of which 30 were new. Among the erroneous results, one can note terms indicating the source, constructed according to the same syntactic rule.

To extract new predicate terms, T-LSP were used, built on meta-patterns that model the situation of an ontological connection between two objects. Thus, for T-LSP, which is used to extract predicate terms belonging to the class *Method.Solves.Problem*, 22 entries were found in the corpus and terms such as were identified: set, allow to construct, allowed to select, look for solutions, and allow to solve. A total of 38 new predicate terms were found. The overall accuracy of the T-LSP was assessed by three experts and averaged 73.97%, with inter-rater agreement estimated at 81.74%.

6.   CONCLUSION AND FUTURE WORK

In this paper, we have described our proposed approach to automating the construction and replenishment of SSA ontologies based on heterogeneous ODP. Our study suggests that one of the features of this approach is that the process of developing and initial filling of SSA ontology is implemented by knowledge engineers and experts in SSA using content patterns and structural patterns. Further replenishment of the SSA ontology is carried out automatically using LSP built on the basis of included content patterns and the current version of the SSA ontology. The main difference between the proposed approach and approaches that also use LSP is that in it LSP are generated automatically.

This approach can be tested in ontologies development and updating process for different scientific subject areas, for example in the field of "Information system for scientific and educational activities" and "Intellectual information resource on modern methods of automatic text processing". It is planned to expand this approach in the coming future. To do this, the template system will be expanded with lexical and syntactic templates and thesaurus of the subject area.

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