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Ontology-based approach to decision-making support of conceptual domain models creating and using in learning and scientific research

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Abstract. The paper presents an approach to knowledge management in learning and scientific research that allows increasing the availability of expert knowledge and reducing semantic noise during knowledge transfer. The availability of expert knowledge is ensured by transforming them from implicit into explicit form (in the form of Semantic Link Network). The reduction of semantic noise is achieved through the integration of knowledge in different forms and their personalization for different groups of knowledge recipients. In the paper, the tasks of decision-making support are formulated which should be performed by the knowledge management system on the base of the proposed approach.

1. Introduction

In learning and scientific research, knowledge management is the main and most important process. Knowledge management implies creation (identifying as well as stimulating the creation) of new knowledge, storage, transfer (and sharing), and knowledge applying [1]. Explicit knowledge is stored in various types of documents - textbooks, books, presentations, diagrams, audio and video works, etc. Tacit knowledge (for example, a culture of thinking, experience, skills, intuition) is stored in the brain neural structures of teachers and researchers and it is difficult to fix these types of knowledge on the material media. There are also potentially explicit knowledge that is not yet fixed in material form but can be transformed into some explicit form. Usually, for the acquisition of explicit knowledge, the methods of "collecting stuff (content)" are used, meanwhile, for implicit knowledge - the methods of "connecting people". This paper considers the problem of decision-making support in the context of management of explicit and potentially explicit knowledge.

Main participants of the knowledge management process in learning are teacher and student. Teachers usually act as experts, i.e. the owners of domain knowledge. They also act as knowledge managers, who know where knowledge is located and who connect people with knowledge to those who need it. They capture and codify tacit knowledge so as facilitate its reuse, and transform user needs into knowledge requirements. Students usually act as recipients (users) of knowledge. In scientific research, some researchers participating in the knowledge management process act as experts and knowledge managers, while others act as recipients. Each participant of the knowledge management process has an individual cognitive style [2] and current knowledge of the domain, which affect the efficiency of creating and transferring knowledge.

2. Knowledge Management Issues in Learning and Scientific Research

In learning and scientific research, two main knowledge sources are available - document collection and expert knowledge (knowledge of teachers or researchers). Often, a collection consists of a large number of disparate, heterogeneous and contradictory documents. Documents can have different forms of information presentation (text, numeric, graphic, combined, etc.). They are usually presented in a well-known informal language. Its main advantage is high availability but the disadvantage is a



rather high semantic noise. Semantic communication noise is a type of disturbance in message transmission that interferes with the message interpretation. It is generated by the content or semantic errors, and message distortions during their encoding/decoding. Semantic noise arises from the cultural factors, incorrect use of the language, and also perceptual filters or psychological deflectors [3].

Expert knowledge is implicit and potentially explicit knowledge. Implicit knowledge can only be gained by connecting people (for example, telling the stories, sharing and discussing the problems and opportunities, discussing the best practices, and talking over the lessons learned, etc.). The main disadvantage of this knowledge source is non-replicability.

Potentially explicit expert knowledge can be transformed into an explicit one, however, this process implies the advantages and disadvantages inherent for explicit knowledge. Also, experts often can not code their knowledge in explicit form effectively.

3. State of the Art: Approaches and Tools for Knowledge Management

There is a wide range of various tools for support of knowledge management [1]:

- electronic libraries (such as ACM Digital Library, IEEE Xplore Digital Library, SpringerLink, ISI Web of Sciences) are widely used in scientific research for access to high- quality peer-reviewed scientific papers, but they provide access only on subscription base and do not support semantic search in the subject domains;
- reference management tools (such as EndNote, Mendeley, RefWorks) record and utilize bibliographic citations for scholars and authors;
- mind mapping and concept mapping software tools for visual models creation (such as MindManager, MindMap, CMap) which allow visualizing the human mental models;
- cloud storage services (such as Dropbox, Google Drive service) offer secure cloud storing, file backup, and file sharing.

The current trend in Knowledge Management is to integrate various software tools in the complex knowledge management system. As a result, the following tools listed below are being created: Organizational Memory Information System (this system functions to provide means by which knowledge from the past is brought to bear on present activities, thus resulting in increased levels of effectiveness for the organization [4]), Semantic Web Portals (such as OntoWeb, Esperanto), Intelligent Information Systems [5]. These systems provide access not only to information resources of a specific domain but also to structured knowledge about the domain itself.

The semantic link network (SLN) has been widely used in the field of Knowledge Management. SLN is a network that represents semantic relations between concepts [6]. SLN can be considered not only as a tool for integrating heterogeneous information from different sources but as a significant knowledge source as such.

Among the applications developed for Knowledge Management, the most widely used method of knowledge representation and operating is an ontology. An ontology formalization is given in a logical (formal) language, which describes a structure of the world that considers all objects involved within the domain of study, their possible states and all relevant relationships between them [7]. Ontology representation in a formal language (such as OWL 2) allows: a) performing an unambiguous description of the ontology; b) proving its consistency; c) creating new knowledge that was not explicitly embedded in the ontology; d) handling various requests to ontology. However, logical language is complicated for human perception, that increases the semantic noise when encoding/decoding knowledge.

To improve the perception of ontology by a human, the ontology can be represented as a visual graph [8]. Such visual mental models use and combine the functions of the left and right brain hemispheres to achieve a holistic and visual presentation of the idea [9]. On the one hand, graphical interpretation of knowledge allows compressing the knowledge, and on the other hand - stimulating

thinking, that in general increases the efficiency of knowledge decoding, in particular during learning [10].

However, existing visual representations of ontology (such as Graphol, OWLGrEd, VOWL) are either difficult for human perception or limited in their expressive possibilities. One of the ways to improve the visual presentation of ontology is the use of the cognitive frames. The cognitive frame refers to the visualized fragment of ontology, which allows transmitting adequately the knowledge of a target concept to the user [11].

4. Ontology-based Decision-making Support of Knowledge Management in Learning and Scientific Research

4.1. Knowledge Storage

The knowledge memory consists of two knowledge repositories - the collection of documents and SLN collection.

The documents usually represented with well known informal language with large expressive possibilities (text, numerical, graphical, audio, video and combined forms of information presentation). It allows presenting different types of knowledge [10] for a wide range of users (knowledge recipients) with different needs and cognitive styles. On the other hand, the authors of these documents (domain experts) can express their knowledge in the form corresponded to their own cognitive style.

For each user group with a similar profile, an SLN is created for a certain domain. The SLN contains WHAT-knowledge [10] about the domain structured into a single mental model and answers some focus question. The focus question determines the context, main subject, and boundaries of the scope of knowledge being studied. Each SLN fragment (specific concept and/or specific link between specific concepts) is assigned an assessment of the importance of this fragment in terms of sensemaking of the SLN as a whole. In particular, this assessment is used for overview SLN when it is visualized. To reduce the semantic noise associated with encoding and decoding of SLN, the SNL is presented both in the visual language ORM 2 and the formal language OWL 2. The visual representation of the SLN is used by the human, and the formal representation is used by the computer.

The visual language ORM 2 is chosen because it is widely used to create conceptual database models and has great expressive capabilities, ORM 2 is more expressive than the UML.

OWL 2 is intended to describe knowledge in the form of ontologies, that can be interpreted by a special program - reasoner. Reasoner allows validating the consistency of knowledge, deriving new knowledge which was not embedded in the ontology explicitly, and responding variously to formalized queries to the ontology.

To reduce the semantic noise, SLN encoding/decoding using visual and formal languages should take into account the following two aspects. The first one: the coding and decoding of knowledge should be performed in terms of well-recognized structures of WHAT-knowledge, i.e. using WHAT-knowledge patterns. And the second one: because visual representation of the SLN is a strongly connected graph with many nodes, edges, and labels for various purposes, the interactive visualization is necessary. Ben Shneiderman formulated the visual information seeking Mantra: overview first, zoom and filter, then details on demand.

In addition to the knowledge repositories mentioned above, for each SLN a conceptual index is required, which stores the set of links between knowledge fragments in SLN and documents (and documents fragments) in which this knowledge is described. Each link is associated with an assessment that reflects the usefulness of the document as a description of the knowledge piece in terms of the user profile and focus question. The assessment takes into account the quality of knowledge coding for the user group and the semantic noise that occurs when knowledge decoding. As a result, the assessment of the usefulness of the same document will be different for users with different profiles and for different SLNs.

In addition, the fragment of SLN can be associated with the document collection that describes the fragment of knowledge at a sufficient level.

The specific SLN and specific conceptual index are applicable only to the one user group with a certain knowledge level, identical needs, and cognitive styles. The user profile includes: knowledge / competence, which the user already has, and their level; user cognitive style; knowledge / competence with their level required to be acquired. The user profile should be consistent with the focus question.

Thus, for each group of users (knowledge recipients) with the same profile, we have some cognitive information space (CIS) [12] that includes focus question, user profile, SLN, document collection, and conceptual index. The cognitive information space defines the representation of a certain domain from the point of view of this user group. It should be noted that a common document collection is used for the different cognitive information spaces. To search for a specific CIS, all its components (or their fragments) can be used, except the document content.

4.2. Knowledge Creation

Cognitive-information space creation process (Fig. 1, 2) includes the steps below.

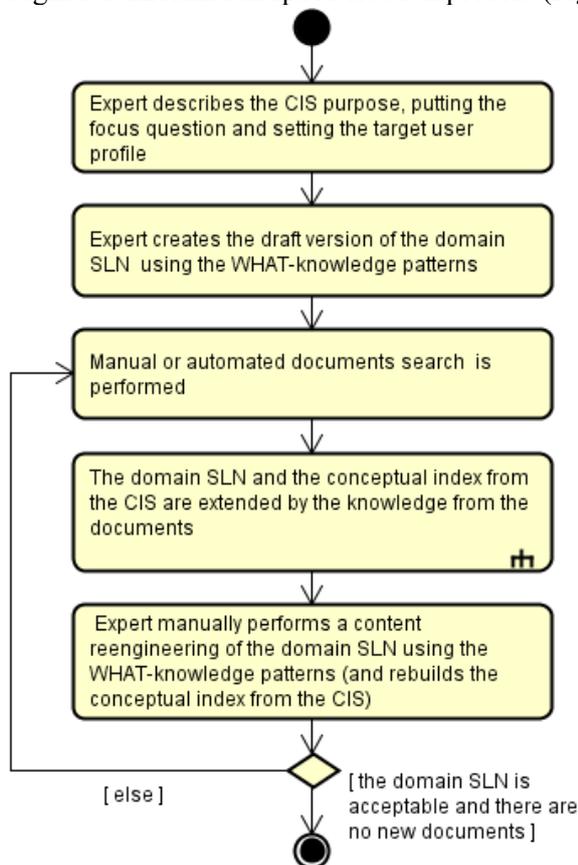


Figure 1. CIS creating

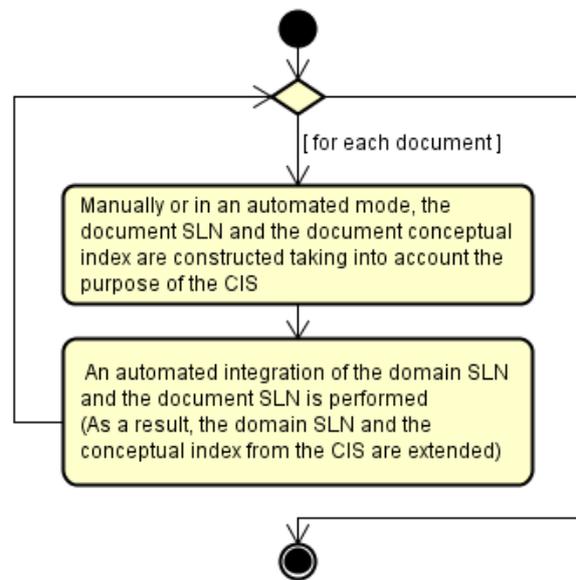


Figure 2. Extending domain SLN with the knowledge from the document

Step 1. Expert describes the CIS purpose, putting the focus question and setting the target user profile.

Step 2. Expert creates the draft version of the domain SLN (this step can be skipped) based on the expert knowledge for a specific user group. The SLN is created in a special editor with the ORM 2 visual language using the WHAT-knowledge patterns. The editor automatically translates the visual representation of SLN into formal OWL 2 ontology. In the process of SLN creation, reasoner automatically validates the ontology consistency, and editor performs partial validation of the

knowledge completeness. If possible, detected errors are corrected by an expert, but their complete elimination is not necessary on this step.

Step 3. Manual or automated document search is performed for a more detailed description of knowledge from the SLN. The document search is performed in the already existing document repository, in electronic libraries, the Internet and other sources. This paper does not discuss the document search methods.

Step 4. For each document found and pre-selected manually or in an automated mode, its SLN and conceptual index are constructed taking into account the purpose of the CIS. Automated SLN building for the document is performed using ontology generation methods. For manually and automatically SLN building, WHAT-knowledge patterns are used. Additionally, validation on inconsistency and partly on the completeness of knowledge is carried out automatically. If possible, detected errors are corrected by an expert, but their complete elimination is not necessary on this step.

Step 5. An automated integration of the domain SLN and the document SLN is performed. As a result, the domain SLN and the conceptual index from the CIS are extended. Additionally, validation on inconsistency and partly on the completeness of knowledge is carried out automatically. If possible, detected errors are corrected by an expert, but their complete elimination is not necessary.

Step 6. If necessary, expert manually performs a content reengineering of the domain SLN using the WHAT-knowledge patterns. Additionally, validation on inconsistency and partly on the completeness of knowledge is carried out automatically. If possible, detected errors are corrected by an expert, but their complete elimination is not necessary.

Step 7. The process of building the domain SLN and the conceptual index continues until an acceptable result is obtained in terms of the purpose of the CIS, and all the knowledge inconsistencies are eliminated. After that, the CIS is published for users.

Step 8. After publication of the CIS, the expert continues to improve the domain SLN and the conceptual index by adding new documents. It can also perform content reengineering of the domain SLN.

In order to effectively implement the process of creating the CIS, the Knowledge Management System should provide decision-making support for the following tasks:

- The domain SLN and document SLN creation and content reengineering by an expert. The system should support a) the experts' use of the WHAT-knowledge patterns which are relevant to the encoded knowledge and b) the encoding of complete consistent knowledge in accordance with the WHAT-knowledge patterns.
- Automated document SLN creation. The system should: a) provide the expert with a preliminary set of concepts and relationships, and b) create document SLN based on the concepts and relationships chosen by the expert using WHAT-knowledge patterns. At the same time, the experts labor costs for reengineering of the SLN obtained should not exceed the labor costs for its creation from scratch.
- a) Automated creation of the preliminary document conceptual index without usefulness assessments; and b) automated redefining the conceptual index of the document in the reengineering of the document SLN.
- Automated integration of domain SLN and document SLN. System should: a) determine the alignment between the concepts and relationships of the domain SLN and the document SLN; b) correctly expand the domain SLN on the expert request by including concepts and relationships from the document SLN (according to the WHAT-knowledge patterns) and c) correctly extend the conceptual index of CIS when extending the domain SLN.

4.3. Knowledge Transferring and Sharing

CIS learning process (Fig. 3) includes the steps below.

Step 1. The user automatically searches for a suitable CIS. To search, the user sets his profile and keywords that describe his knowledge needs. As a result, a ranked list of CIS is generated. The CIS assessment takes into account the similarity between the profile of the current user and the profile of

the target user of the CIS, the presence of keywords in the CIS and in the focus question. Next, the user reviews the CIS (focus question, target user profile and the SLN) and selects the best one.

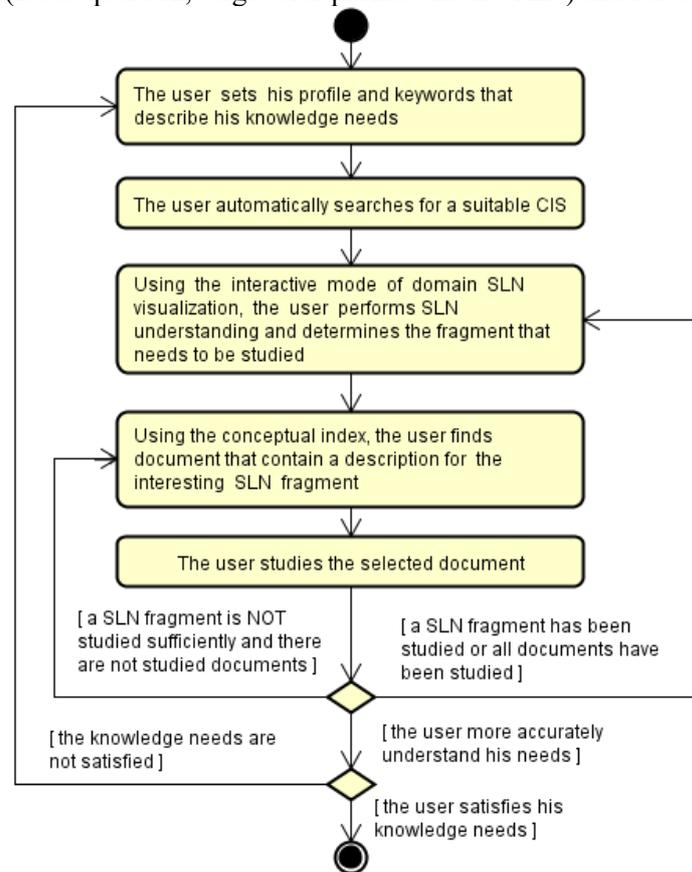


Figure 3. CIS learning

Step 2. Using the interactive mode of domain SLN visualization, the user performs a preliminary SLN understanding and determines the fragment that needs to be studied the first. The interactive visualization mode includes the following mechanisms: a) high-level SLN overview in the form of a graph, when only nodes and edges with the maximum importance assessments are displayed; b) show / hide nodes on the request of the user, taking into account the assessment of their importance; c) filtering nodes and edges of the graph; d) setting the focus point by setting the geometric center of the visible area of the graph; e) changing the visibility of the visual characteristics of nodes and edges.

Step 3. Using the conceptual index the user finds documents that contain a description for the interested SLN fragment. Looking through the usefulness assessments of the documents, and their content, the user decides which document should be studied the first.

Step 4. After studying the selected document, the user decides to return to Step 3 and continue studying other documents for the given SLN fragment, or return to Step 2 for re-understanding domain SLN and find a new fragment for study.

Step 5. The study of the domain SLN and related documents continues until the user satisfies his knowledge needs. On the other hand, after some immersion in the domain, the user can more accurately formulate his needs and return to Step 1.

In order to effectively implement the process of CIS learning Knowledge Management System should provide decision-making support for the following tasks:

- Automatic ranking CIS collection based on the search criteria. When evaluating the CIS, the system should take into account the user profile, his needs (expressed by a set of keywords), the

purpose of the CIS (defined as the focus question and the target user profile), and the content of the domain SLN.

- Visualization of the domain SLN taking into account the settings specified by the user (such as level of details, focal point, geometric scale, concepts and relationships filtering), and the assessments of importance of knowledge fragments from the SLN specified by the expert.
- Ranking documents that describe knowledge pieces from the SLN, selected by the user. When evaluating a document, the following criteria should be taken into account: a) the amount of knowledge that describes the document, and b) its usefulness in describing this knowledge.

5. Conclusion

The paper presents an approach to knowledge management in learning and scientific research, which increases the availability of expert knowledge and reduces semantic noise during knowledge transferring.

The availability of expert knowledge is ensured by transforming them from an implicit into an explicit form (in the form of SLN).

The reduction of semantic noise is achieved through the integration of knowledge in different forms and their personalization for different user groups. We propose to integrate the following knowledge sources. The first knowledge source is the structured expert WHAT-knowledge, it is presented in the form of SLN, which is encoded both with the visual language ORM 2 and the formal language OWL 2. The second knowledge source is a document collection that contains various types of knowledge. Each document is presented in a well-known informal language in various forms (text, graphic, etc.). To integrate these knowledge sources, the conceptual index is used and, as a result, the cognitive information space is generated for a certain user group. This CIS is personalized because SLN and conceptual index are created for each user group.

The paper defines the decision-making tasks that the Knowledge Management System should support using the proposed approach.

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