RIGA TECHNICAL UNIVERSITY

Vita GRAUDINA

INVESTIGATION AND IMPLEMENTATION OF INTEGRATION OF KNOWLEDGE CARTOGRAPHY TECHNIQUES AND INTELLIGENT CONCEPT MAP-BASED KNOWLEDGE ASSESSMENT SYSTEM

Summary of Doctoral Thesis

Riga 2011

RIGA TECHNICAL UNIVERSITY
Faculty of Computer Science and Information Technology
Institute of Applied Computer Systems

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DOCTORAL THESIS
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The defence of the thesis submitted for doctoral degree of engineering science will take place at an open session on November 21, 2011 in Meza Street 1/3, auditorium 202, Riga Technical University, Faculty of Computer Science and Information Technology.

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APPROVAL

I confirm that I have developed this thesis submitted for the doctoral degree at Riga Technical University. This thesis has not been submitted for the doctoral degree in any other university.

Vita Graudina……………………………….. (signature)

Date: ……………………………………..

The doctoral thesis is written in Latvian and includes introduction, 4 chapters, and conclusions. The main text is 194 pages, it contains 101 figure and 16 tables. The bibliography contains 217 references. 10 appendixes are added in the separate volume.

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INTRODUCTION

Nowadays socioeconomic needs of highly qualified knowledge workers [GRU 2001] also affect learning which is not anymore just memorising and storing facts and finite conclusions but independent process of cognition to learn how to learn, to think critically and to analyse. In addition, more important than knowledge and information are skills to use them for generating new knowledge [CAS 1996].

Knowledge society causes additional duties and responsibility of workers [KOĶ 2007]: 1) more frequently workers need to solve previously unexpected and unusual problems creatively, because the ratio of routine procedures in task solving reduces; 2) creation of knowledge-intensive products are in each field of industry, occupation and activity; 3) human ability to create effectively and use knowledge is highly valuated in rapidly changing environment.

Wherewith, skills of system thinking and non-routine problem solving become more important, which are among skills humans have to have to be successful in the society of this century [HIL 2008]. System thinking is characterized by understanding how the systems work, judgement and decision making, analysis and evaluation of a system [RUI 2009]. By contrast, non-routine problem solving skills have several characteristics [RUI 2009] – meaningful pattern recognition and understanding, problem diagnosis, information organization into schemas, track keeping of problem solving, acquisition of related information as well as creating new and innovative solutions.

Analysing science teaching and 21st century skills, Ruiz-Primo has come to conclusion that, firstly, conceptual schemes are not taught at once, but over long time period; secondly, introduction of new conceptual knowledge is quite complex because current structure has to be changed; and, thirdly, conceptual knowledge is not isolated definitions but a system of interrelated concepts [RUI 2009].

Following changes in the society learning also changes. It becomes more focused on an individual and his/her own needs and student-centred learning has become the important pedagogical idea of this time. A student plays the main role with his/her learning needs there and a teacher is not the only information provider [LEA 2003]. One of the main characteristics of student-centred learning is student’s responsibility for the own learning process and self-assessment is important activity helping a student to become responsible for his/her learning results [ONE 2005].

Each student is important but it is not possible to give an individual approach and to make a regular knowledge assessment with rich feedback to each individual learner during learning in auditoriums with a large number of students; therefore usage of computer-based solutions is very important. These solutions allow adaptation to different needs of students during a learning process [ANO 2007a]. To assess system thinking and structural knowledge there is a need of such knowledge assessment mechanisms which, firstly, allow visualizing knowledge structures and, secondly, there exist methods to evaluate them.

During analysis of literature made in doctoral thesis it was found that knowledge assessment process is not appropriate to needs of modern society and there are several problems – firstly, insufficient amount of assessment of structural knowledge and system thinking; secondly, lack of step-by-step evaluation of mastered knowledge; thirdly, lack of computer-based support in assessment of structural knowledge, especially, automated comparison of answers submitted; fourthly, tasks used are not suitable for assessment of all levels of knowledge.

Intelligent concept map-based knowledge assessment and self-assessment systems can help to solve abovementioned problems, because they support evaluation of structural knowledge, make step-by-step knowledge assessment, support adaptation to the level of student's knowledge, providing individually suitable tasks and rich feedback which helps to eliminate errors and misconceptions in student's knowledge.

Motivation of the research

Research field of computerized concept map-based knowledge assessment is quite new, however such kind of systems are important in context of learning in the 21st century when understanding of knowledge and concepts interrelations, meaningful learning, critical thinking and metacognition becomes the main learning objective instead of memorizing of a large amount of facts.

Topicality of the doctoral thesis is related to the fact that teachers need to invest additional work for preparing of tasks, feedback and learning materials for the use of these systems with full value. Therefore, importance of re-use and integration of artifacts captured in these systems, as well as supporting teachers during the use of the system increases. In addition, during operation of the system a certain amount of artifacts is captured that can be used also outside knowledge assessment systems.

The goal of the thesis

The goal of the thesis is to explore knowledge cartography techniques, to find the most suitable technique for integration with intelligent concept map-based knowledge assessment system IKAS, as well as to develop algorithms and tools for extending its functionality.

The tasks of the thesis

In order to achieve the goal of the thesis the following tasks are specified:

- To explore concept maps and the diversity of their tasks, for preparing a range of tasks that can extend adaptation abilities to the learner's knowledge level.
- To summarise information about concept map drawing and evaluation tools and their impact on teachers workload, if tools are used in teaching.
- To analyze functionality of the intelligent concept map-based knowledge assessment system IKAS and to identify how to support a teacher in the system's usage.
- To explore knowledge cartography techniques and their usage in the learning process and to find the appropriate techniques for a computer-based knowledge assessment system with automated answer evaluation, without use of natural language processing methods.
- To perform analysis and systematization of definitions and classifications of the selected knowledge cartography techniques.
- To analyze use of selected knowledge cartography techniques in computer-based tutoring and knowledge assessment systems for extending their functionality.
- To develop algorithms for transformation of the selected knowledge cartography techniques into concept maps and concept maps into the selected techniques.
- To develop an algorithm for adaptive delivery of learning materials in a concept map-based knowledge assessment system with knowledge remediation.
- To develop a method for merging several concept maps to extend the analysis of learner's errors and remediation actions and to get the overview of related study subjects.
- To implement the developed algorithms into a prototype for integration with the intelligent concept map-based knowledge assessment system IKAS.
- To approbate the developed algorithms.

Research objects

The research objects are concept maps, knowledge cartography techniques, especially ontologies and concept map-based knowledge assessment and self-assessment systems.

Research subject

The research subject of the doctoral thesis is evaluation of knowledge cartography techniques, focusing on use of ontology in concept map-based knowledge assessment and self-assessment systems to reduce a teacher's workload, to automate acquisition of input data, and to find learning paths and learning materials needed for the correction of knowledge.

Scientific novelty

The scientific novelty is as follows:

- The developed methods and algorithms for an ontology transformation into a concept map and a concept map transformation into an ontology.
- The developed algorithm for generation of recommendations for a teacher about information included in learning materials.
- The developed method and algorithm for adaptive learning material delivery in the concept map-based knowledge self-assessment system based on the developed mathematical formalism for determination of learning objects generality.

Theoretical value

The theoretical value is as follows:

- It has been determined how the diversity of the concept maps affects a variety of concept map-based tasks and their adaptation facilities in learners' knowledge assessment and self-assessment.
- The formal method has been developed for comparison of the degree of concept map-based tasks difficulty.
- Knowledge cartography techniques have been explored and it is determined that ontologies are the most appropriate for integration in the intelligent concept map-based knowledge assessment system IKAS.
- Information about ontology definitions and classification schemas has been systematized and lay out, resulting in determination of ontology definition consistency to ontology properties, and the division of ontology classification schemas has been established.
- It has been evaluated how use of ontologies can extend functionality of the intelligent concept map-based knowledge assessment system IKAS

Practical significance

The practical significance of the thesis is as follows:

- The tools for ontology transformation into a concept map and a concept map transformation into an ontology have been developed which are integrated into the intellectual knowledge assessment system IKAS.
- Tools' approbation has been performed for developed concept maps and ontologies for study module of artificial intelligence.

Approbation of the obtained results

6 presentations on the main results of the research have been made (4 of them in foreign countries and 2 in Latvia):

1. International Conference on Computer Systems and Technologies (CompSysTech'11), Vienna, Austria, June, 16-17, 2011.
2. The 3rd International Conference on Concept Mapping (CMC 2008), Tallinn, Estonia and Helsinki, Finland, September, 22-25, 2008.
3. The 48th Scientific Conference of Riga Technical University, Riga, Latvia October, 10, 2007.
4. E-learning Conference'06: Computer Science Education, Coimbra, Portugal, September 7-8, 2006.
5. Conference on Information Systems Development 2006 (ISD 2006), Budapest, Hungary, August, 30 – September, 2, 2006.
6. The 19th European Conference on Modelling and Simulation (ECMS 2005), Riga, Latvia, June, 1-4, 2005.

The main results of the thesis have been presented in 10 scientific papers:

1. Graudina V. Algorithms for Knowledge Remediation in Concept Map Based Assessment System. The 2nd International Workshop on Intelligent Educational Systems and Technology-enhanced Learning (INTEL-EDU 2011), October 6, 2011, Riga, Latvia (accepted for publishing)
2. Graudina V., Grundspenkis J. Algorithm of Concept Map Transformation to Ontology for Usage in Intelligent Knowledge Assessment System. International Conference on Computer Systems and Technologies (CompSysTech'11), June, 16-17, 2011, Vienna, Austria, pp. 109-114, (will be indexed in: ACM Digital Library, Scopus, DBLP)

3. Graudina V., Grundspenkis J. Concept Map Generation from OWL Ontologies. The 3rd International Conference on Concept Mapping, September, 22-25, 2008, Tallinn, Estonia and Helsinki, Finland, 2008, pp. 173-180. (indexed in: Microsoft Academic Search)

4. Graudina V. OWL Ontology Transformation into Concept Map. In Scientific Proceedings of Riga Technical University, 5th Series, Computer Science. Applied Computer Systems, Vol. 34, 2008, pp.80-91.

5. Graudina V. An Overview of Ontology Usage in Computer-Based Tutoring Systems. Annual Proceedings of Vidzeme University College: ICTE in Regional Development, 2007, pp. 70-77. (indexed in: EBSCO HOST)

6. Anohina A., Graudina V., Grundspenkis J. Using Concept Maps in Adaptive Knowledge Assessment. Advances in Information Systems Development "New Methods and Practice for the Networked Society". USA: Springer, 2008, pp. 469-479. (indexed in: SpringerLink)

7. Anohina A., Graudina V., Grundspenkis J. Intelligent System for Learners' Knowledge Self-Assessment and Process Oriented Knowledge Control Based on Concept Maps and Ontologies. Annual Proceedings of Vidzeme University College „ICTE in Regional Development", 2006, pp. 1-8. (indexed in: EBSCO HOST)

8. Graudina V., Grundspenkis J. Conceptual Model for Ontology-based Adaptive Assessment System. The 3rd E-learning Conference-Computer Science Education, September, 7-8, 2006, Coimbra, Portugal, 2006, pp. 1.13-1.-1.13-6.

9. Graudina V. Variety of Definitions and Classifications of Ontologies. In Scientific Proceedings of Riga Technical University, 5th Series, Computer Science. Applied Computer Systems, Vol. 22, 2005, pp. 181-192. (in Latvian).

10. Graudina V., Grundspenkis J. The Role of Ontologies in Agent-Based Simulation of Intelligent Tutoring Systems. The 19th European Conference on Modelling and Simulation, June, 1-4, 2005, Riga, Latvia, 2005, pp. 446-451.

In addition to results of the thesis the author has published also the following papers:

1. Lukasenko R., Graudina V., Grundspenkis J., Computer – Based Plagiarism Detection Methods and Tools: An Overview. International Conference on Computer Systems and Technologies (CompSysTech'07), June 14-15, 2007, Ruse, Bulgaria, 2007, pp. IIIA.18.1-IIIA.18.6. (indexed in: ACM Digital Library, DBLP, Scopus)

2. Graudina V., Grundspenkis J. Agent-Based Systems, Their Architecture and Technologies from Logistics Perspective. In Scientific Proceedings of Riga Technical

University, 5th Series, Computer Science. Applied Computer Systems, Vol. 26, 2006, pp. 159-174.

3. Graudina V., Grundspenkis J. Technologies and Multi-Agent System Architectures for Transportation and Logistics Support: An Overview. International Conference on Computer Systems and Technologies and Workshop for PhD Students in Computing, June, 16-17, 2005, Varna, Bulgaria, 2005, pp. IIIA.6-1-IIIA.6-6.

4. Graudina V., Grundspenkis J., Valkovska I. Usage of Frame System for Modelling of Intelligent Tutoring System Architecture. Annual Proceedings of Vidzeme University College „ICTE in Regional Development", 2005, pp. 105-109. (indexed in: EBSCO HOST)

Results of the thesis have been included in the reports of 8 scientific projects. These projects are:

1. „Development of Ontology-based Methods and Algorithms for Comparison and Merging of Concept Maps of Different Related Study Courses" (project manager J.Grundspenkis, 2011, research project financed by Riga Technical University).

2. „New Information Technologies Based on Ontologies and Transformations" (project manager J.Barzdins (University of Latvia), 2010-2013, National Research programme's „Development of Innovative Multi-functional Materials, Signal Processing and Information Technology for Competitive Science-intensive Products" project).

3. „Development of Conceptual Model for Transition from Traditional Software Development into MDA-Oriented" (project manager O.Nikiforova, 2009, research project financed by Riga Technical University).

4. „Development of an Intelligent Applied Software Based on Distributed Artificial Intelligence and Web Technologies" (project manager J.Grundspenkis, 2009-2012, grant of Latvian Academy of Science).

5. „Development of Prototype for Software System Class Structure Generation Tool" (project manager O.Nikiforova, 2008, research project financed by Latvian Ministry of Education and Science and Riga Technical University).

6. „Development of an Ontology-based Intelligent System for Task Generation in the Form of Concept Maps and Knowledge Assessment" (project manager J.Grundspenkis, 2007, research project financed by Latvian Ministry of Education and Science and Riga Technical University).

7. „Intelligent System for the Effectiveness Analysis Support of Process-oriented Learning" (project manager J.Grundspenkis, 2006, research project financed by Latvian Ministry of Education and Science and Riga Technical University).

8. „Integration of Intelligent Agents and Knowledge Management Techniques for Intelligent Support of Study Process" (project manager J.Grundspenkis, 2005-2008, grant of Latvian Academy of Science).

Structure of the thesis

The thesis consists of introduction, 4 chapters, conclusion, bibliography and 10 appendixes (in separate volume). The main part of the thesis contains 194 pages, 101 figures and 16 tables. Bibliography contains 217 sources of information.

In the *introduction* motivation of the thesis, research goals and tasks have been defined and novelty, practical value of the thesis and approbation of the main results have been described as well.

A use of concept maps and its computerized support has been explored in *Chapter 1*. It includes a study of use of concept maps, their diversity, the diversity of tasks, pedagogical appropriateness of concept mapping, use of concept maps in knowledge assessment, as well as software for different tasks with the concept maps.

Chapter 2 is devoted to analysis of knowledge cartography techniques, resulting with conclusion that an ontology is the most suitable for integration in the intelligent concept map-based knowledge assessment system IKAS. Therefore this technique is analyzed in details to find possible directions of IKAS improvement, taking over ideas from the research on ontology usage in computer-based tutoring systems.

The developed algorithms for extension of the intelligent concept map-based knowledge assessment system IKAS are described in *Chapter 3*. The algorithms for a concept map transformation into an OWL ontology and an OWL ontology transformation into a concept map are shown. The extension of IKAS with knowledge remediation is also described.

In *Chapter 4* implementation, operation and approbation of the defined algorithms for extension of IKAS using known already developed hardware ontology and teacher's created concept map for the study course "Fundamentals of Artificial Intelligence" is described.

In the *conclusion* the main results of the research and conclusions made as well as possible future work have been presented.

The thesis has *10 appendixes*: 1. Types of concept map tasks; 2. Concept map tasks, sorted by the degree of task difficulty, starting with the simplest; 3. Descriptions of specific concept map drawing tools; 4. Descriptions of concept map-based knowledge assessment systems; 5. Descriptions of ontology classification schemas; 6. Examples of an OWL ontology transformation into a concept map; 7. The hardware ontology; 8. The resulting ontology of “Fundamentals of Artificial Intelligence” concept map transformation; 9. Composition of learning path; 10. Merged ontology.

1. CONCEPT MAPS IN KNOWLEDGE ASSESSMENT

Despite active research in the field of concept maps there is still relatively small number of research results on knowledge assessment with the concept maps. Therefore in Chapter 1 the use of concept maps in knowledge assessment and it computerized support is explored. Subsection 1.1 contains a study on the use of concept maps, their diversity, diversity of tasks, pedagogical appropriateness of concept mapping and the use of concept maps in knowledge assessment. The aim of this subsection is to establish how diversity of concept maps affects diversity of concept map-based tasks, which could be used in adaptive knowledge assessment and self-assessment systems with automated concept map evaluation. The Chapter 1.2 is dedicated to software supporting different concept mapping tasks in order to explore the involvement of a teacher and his/her workload using such tools in the learning process, paying particular attention to the intellectual concept map-based knowledge assessment system IKAS developed at Department of Systems Theory and Design of the Faculty of Computer Science and Information Technology of Riga Technical University, whose functionality is extended in result of the development of this thesis.

1.1. Concept maps and their use

The term "concept map" is known for several decades, when at the seventies of the previous century Joseph Novak from USA started to use them [NOV 1972] [NOV 1984]. He also suggested 4 primary processes related to pedagogy where to use concept mapping - the teaching process, where the teacher structures the presentation of the required study material, curriculum planning process, learning process, where the learner structures information for processing it, as well as knowledge assessment process [NOV 1990].

Mathematically, a concept map is representation of cognitive structure in the form of a graph where vertices with names correspond to concepts, but arcs or links show the relationships between two concepts. A concept is defined as [CAN 2008]: "a perceived regularity or pattern in events or objects, or records of events or objects, designated by a symbol, usually a word”. In turn, linguistic linking phrases, usually verbs, are attached to arcs.

Analysis of literature has proved that concept maps correspond to principles of modern pedagogy. Their use in the learning process helps students link the procedural knowledge with declarative one, leading to structural knowledge [JON 1996]. Their use in knowledge assessment allows the learner himself, as well as teachers to track and evaluate the development of the learner's cognitive structure [VAN 2005], [AND 1998].

In the thesis the summary about concept map usage made by Barbara Daley et al. in 2008 [DAL 2008] is continued. Proceedings of two more concept mapping conferences CMC2008[1] and CMC2010[2] have been analysed. As a result it is concluded that Daley's findings of research directions have remained (teaching and learning, knowledge assessment and evaluation of concept maps, knowledge management, the software for work with concept maps, teacher professional development, which includes the use of concept maps and concept maps as research methods). At the same time following new additional directions are found:

- Formalization of concept maps, computer-based processing, the concept map analysis and theories about concept maps [MIL 2008], [KOZ 2008], [EPL 2008] [ROM 2010], [SIM-2008], [KOW 2010], etc.;
- Use of concept maps in other fields (not only education) [SAL 2008], [SAN 2008], [KYR 2008], [CEL 2010], etc.

However, there is still a small number of research on concept maps used in computerized knowledge assessment, remediation of errors and misconceptions, and development of supporting software, as well as there are no overviews about different variations of the concept maps (except for the [AHL 2004], in which the main attention is paid to the concept map use in different countries, rather than to a diversity of the concept map elements). For this reason a diversity of concept maps is analyzed in the doctoral thesis and further it is continued with research on its impact on the diversity of concept map-based tasks.

It is concluded that the diversity of concept maps is influenced by the following elements (Fig. 1.1.):

- A topology underlying a map (linear, cyclic, hub/spoke, net/network, hierarchical tree and hierarchical cross-link structure [SAF 2003], [DER 2004] [AHL 2004], [YIN 2005]);

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[1] The 3rd International Conference on Concept Mapping. Tallinn, Estonia, Helsinki, Finland, September, 22-25, 2008 (http://cmc.ihmc.us/cmc2008/cmc2008Program.html)

[2] The 4th International Conference on Concept Mapping. Viña del Mar, Chile, October, 5-7, 2010 (http://cmc.ihmc.us/cmc2010/CMC2010Program.html)

- A type of a graph underlying a map (directed/undirected);
- Linking phrases which determine a type of the relation between concepts (static/dynamic [SAF 2003], causative/non-causative [MIL 2008], quantified/non-quantified [MIL 2008]);
- Link homogenity/heterogenity, i.e., do links have the same weight (importance) [ANO 2006b], [GRU 2009];
- Linking multimedia objects to concepts and arcs [BRI 2004].

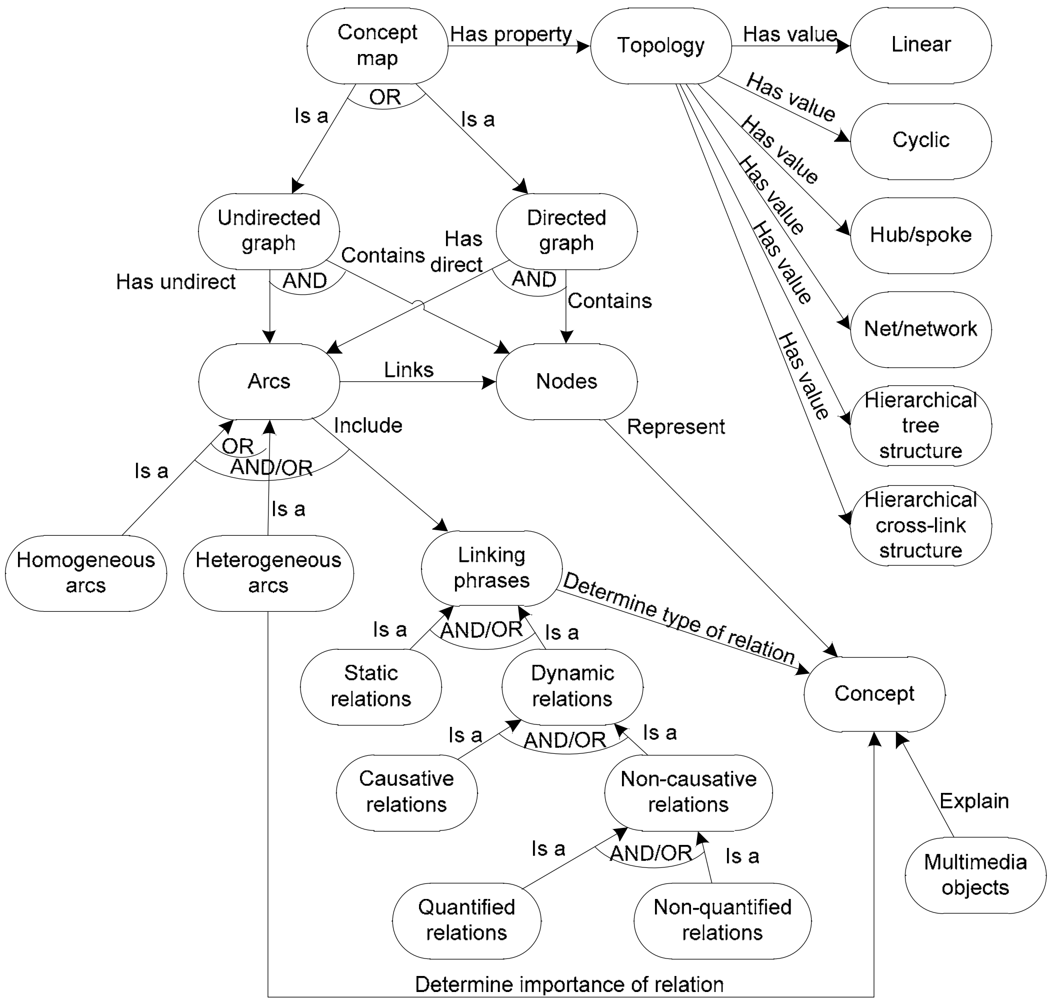

Fig. 1.1. The diversity of concept maps

Although since Ruiz-Primo and Shavelson’s review on use of concept maps in knowledge assessment [RUI 1996] series of new studies [CHA 2001], [DAR 2005], [AKK 2005] [GRA 2006], [GOU 2008], [GRU 2009], etc., have emerged, but still main focus is made on concept maps in the learning process instead of knowledge assessment regardless a concept map as methodological technique of assessment facilitates each learner's cognitive activity, because information acquired is processed in accordance with each individual's understanding and ability to structure the acquired learning content [ANO 2007b].

Therefore a summarizing study about types of tasks in knowledge assessment based on concept maps has been made in the doctoral thesis. The most general division of tasks is into composite and simple tasks. In composite tasks concept maps are just one of the assessment components [ROJ 2008], [WEH 2008]. On the contrary, in simple concept map tasks other types of tasks are not used at all. In the thesis only the simple concept map-based tasks are analyzed in detail, because composite tasks consist of simple tasks together with some other ways of assessment which is out of the scope of this thesis. This is due to the fact that the thesis focuses on the development of additional functionality for the intellectual knowledge assessment system IKAS already implemented [ANO 2006b], [GRU 2009]. Its basic conception is knowledge assessment tasks for automated evaluation which require neither natural language processing nor teacher's involvement in the evaluation process.

The diversity of concept map tasks is determined by the fact that a task consists of a combination of: 1) task demands which define task statement, what student needs to do; 2) task constraint, which defines what student may / may not do; 3) task content structure which is intersection between task statement and constraints and the structure of the problem domain, i.e., how the problem domain affects a task [RUI 1996]. Task demands are related to the task statement, which determines the type of the task [GRU 2011]: 1) fill-in-the-map (insert concepts/linking phrases in the given structure of the concept map); 2) construct-the-map; 3) some other tasks, such as "evaluate correctness of concept map".

Four categories of constraints on sets of concepts and linking phrases determine diversity of fill-in-the-map and construct-the-map tasks [GRU 2011]:

1. A complete set – the student receives all concepts and / or linking phrases must be placed into the structure of the concept map (fill-in-the-map tasks) or he/she needs to define relationships themselves (construct-the-map tasks).
2. A partial set – the student receives only a part of concepts and / or linking phrases as a list or as already placed in the concept map structure. The student himself has to define the missing concepts and / or linking phrases.
3. A full up set – the student receives not only those concepts and / or linking phrases that are relevant to his/her task but also additional terms and / or linking phrases that are misleading, because they are incorrect or irrelevant to the problem domain.
4. An empty set - the student needs to define all concepts and / or linking phrases.

Introduction of abovementioned constraints on concept and linking phrase sets significantly increases a range of concept map-based tasks, which makes it possible to adapt them to each learner's individual level of knowledge and abilities. Having analysed possible task demands and task constraints on fill-in-the-map and construct-the-map tasks, it is found that there are 108 kinds of tasks (Appendix 1 of the thesis). 34 kinds of tasks do not require natural language processing providing automated evaluation of answers, since a student receives complete/full up sets of concepts and/or linking phrases. the type of constraints for concept and linking phrase sets, as well as information about elements already inserted in the structure of the concept map given to the student is indicated (Table 1.1) for each task type. In addition the coefficient of the degree of task difficulty is experimentally determined for each element. It is possible to sort two or more tasks according to the degree of task difficulty if the elements given in the task statement are indicated and coefficients of marked elements are summed up. The arrangement of all 108 types of tasks is given in Appendix 2 of the thesis. The larger is the sum of coefficients, the more complex is the corresponding task.

Table 1.1

Elements of the concept map-based tasks and their coefficients of the degree of task difficulty

Set of concepts				Set of linking phrases				Structure							
Complete	Partly	Full up	Empty	Complete	Partly	Full up	Empty	Not given	All concepts are inserted	Part of concepts are inserted	No concepts are inserted	All linking phrases are inserted	Part of linking phrases are inserted	No linking phrases are inserted	Linking phrases are not used
2	7	5,2	14	1	3,7	2	7,2	26	0,4	2,8	9	0	2,2	4,1	0,5

Obviously, concept map tasks are different and therefore applicable to different needs of knowledge assessment (simple and complex tasks). In addition, a diversity of the concept map-based tasks and possibility of arranging them according to the degree of task difficulty allows applying them in the adaptive knowledge assessment [ANO 2008]. The available literature shows that so far there formal methods for comparison of the degree of task difficulty are not developed. There are only Ruiz-Primo's study [RUI 2004] on impact of the directness to the degree of task difficulty, Yin et al.'s work [YIN 2005] on comparison of two types of tasks, as well as Lukashenko & Anohina-Naumeca's work [LUK 2010], where students can receive tasks with six different degrees of task difficulty according to their results.

In result of analysis of concept map use and application fields described in this subsection it is concluded that there is relatively small number of research on computer support for the concept map building and usage in knowledge assessment, so the next subsection provides a summary of such software.

1.2. Software support for concept mapping

Nowadays tasks related to concept mapping are supported by quite a lot of software [KMH], [CIM 2003], [HOE 2003], [CAÑ 2004], [DAR 2005], [ANO 2006b], [GOU 2008], [GRU 2009], etc. They support a variety of activities related to concept mapping tasks. The main difference between these tools is connected with complexity of offered functionalities. In the simplest case it is only a concept map drawing, in the complex case it is also the evaluation of developed concept maps, including their analysis and feedback delivered to learners. Usually concept map evaluation tools include also the drawing function:

1. The concept map drawing function provides a concept map creation in a digital format, which can be edited, added, modified and maintained. With this function both students and teachers build the concept maps for different learning objectives, for example, teachers - as explanatory material, a summary of topic or curriculum, students - as the assessment, displaying concepts learned and links between them, or a summary of literature read. The software provides the concept map drawing, easier modification of layout, as most tools maintain links between elements of a concept map, as well as management of large concept maps and their sets.
2. The concept map evaluation function is related to analysis of learners developed concept maps, comparing with the teacher's created standard concept map, or any other method of evaluation, and providing feedback about learner's knowledge. Moreover, depending on the system's functionality, a learner receives feedback ranging from only a quantitative score, such as how many concepts are properly linked, to a rich feedback, which gives recommendations for a student how to prevent errors and improve knowledge.

Concept map drawing tools are suitable for use in teaching and learning, if there is no need to assess the created concept maps. Otherwise, these tools require from teachers the same effort as hand-drawn concept map assessment. The evaluation tools in their turn require definite teacher workload, which is related to the task preparation (construction of standard concept maps, i.e., concept maps, which are used for evaluation of students concept maps), and preparation of materials needed for feedback and help given to a student. The doctoral thesis summarizes 5 tools exactly for concept map drawing and 5 evaluation tools, which are described in more details in Appendixes 3 and 4, respectively.

According to the fact that teachers need to work hard to prepare tasks and especially to author materials necessary for informative and remedial feedback, it has been defined how to support teachers in these activities in the doctoral thesis:

- To obtain standard maps, their fragments or drafts from existing course descriptions and ontologies, bodies of knowledge, fields' classifiers and taxonomies, and concept maps and similar knowledge structures built in other systems in order to reduce a teachers' workload for task preparation;
- To derive explanations of concepts, definitions and examples derived from already existing learning materials;
- To offer learning materials after evaluation of student's answers for remediation of identified knowledge gaps, taking into account set of necessary prerequisites;
- To use knowledge captured in a system for further more precise answer evaluation;
- To audit courses, their modules or study programmes using merged standard concept maps.

Solutions have been searched for abovementioned directions of development in the doctoral thesis, and they have been integrated into the intellectual concept map-based knowledge assessment system IKAS [ANO 2006b], [GRU 2009], and teachers have to invest a lot of work to provide its functionality.

The IKAS system is based on the idea that the teacher creates a concept map for his/her course and sets the task parameters, for example, the degree of task difficulty for the first task. The system uses a teacher's created concept map as a basis for a task generation and as standard to compare student concept maps submitted as answers. The IKAS system divides course in phases and performs evaluation at the end of each phase. At each stage a student solves one concept map-based task, which is available in 6 difficulty levels and is changed in the next phase depending on the student's performance. After evaluation, the teacher and the student receive feedback on the evaluation results.

Summary and conclusions of Chapter 1

- Although concept maps are used widely and relatively for a long-term in pedagogy and correspond to its modern ideas, there is no state of art research on the concept map diversity. Therefore, components of concept maps and their properties that affect their diversity are identified in the doctoral thesis.

- Mathematical formalism that allows qualitative comparison of degrees of task difficulty, extending the adaptation options is found during constitution of concept map-based task range.
- To use entirely computerized concept map-based knowledge assessment tools, teachers have been loaded with standard map creation and feedback authoring. Therefore development directions of the concept map-based knowledge assessment system IKAS have been identified to reduce teachers' workload, extend functionality to knowledge remediation and reuse of concept maps already captured.

2. KNOWLEDGE CARTOGRAPHY TECHNIQUES IN COMPUTER-BASED LEARNING AND KNOWLEDGE ASSESSMENT

Based on findings about IKAS development directions in the previous chapter, in Subsection 2.1 knowledge cartography techniques are analysed in order to find the most suitable one for extending IKAS functionality. Subsection 2.2 describes systematization results of ontology definitions and classifications, and overviews use of ontologies in computer-based tutoring systems. In subsection 2.3 possibility of using ontology merging for concept map merging is appraised. Directions of IKAS' development using ontologies are identified in Subsection 2.4.

2.1. Overview of knowledge cartography techniques

In this subsection mind maps [BUZ 1996], [ASH 2009], [TIP 2009], knowledge maps [GRE 1999], [TAN 2005], argument maps [TWA 2004], [OKA 2008b], [ROW 2008], topic maps [PAR 2002], [OLS 2006], [MAT 2008], semantic nets [SOW 1992], [HEL 2002], conceptual graphs [AMI 2008], [SOW 2008] and ontologies [GRU 1995], [GRA 2005b], [JOV 2007] are analysed. The first three techniques have their origins in the field of teaching and knowledge management, while the other four techniques are related to knowledge engineering, which is a sub-field of artificial intelligence. Thinking maps [HYE 2004], [HYE 2008], dialogue maps [CON 2006], [OKA 2008b], as well as [BUC 2008] question, consultation, gestalt, and issue maps mentioned in the research are not analysed. Techniques used by only one author or a team of authors are not included. Mainly these techniques are implemented in specific tools and are not used outside them. Similarly, techniques that represent specific knowledge only, such as UML diagrams known in software engineering are not covered in the thesis, because additional learning to master these techniques is needed for their complete usage.

An overview of analyzed knowledge cartography techniques is represented in the Table 2.1. For each technique constituent elements are listed, whether the technique is used in learning or knowledge assessment, and whether the technique can be used for automated knowledge evaluation.

Table 2.1

Overview of knowledge cartography techniques

#	Technique	Elements included in structure	Use in learning process	Use in knowledge assessment	Use in automated evaluation
1.	Mind map	– Concepts – Hierarchal links – Graphical elements (optional)	+	+	-
2.	Knowledge map	– Nodes representing different information – Relations between nodes – Graphical objects	+	-	-
3.	Argument map	– Different type nodes – Relations between nodes	+	+	-
4.	Topic map	– Topic nodes – Topics relations – Resources about topics	+*	-	-
5.	Semantic net	– Concepts – Links	-	-	-
6.	Conceptual graph	– Concept nodes – Link nodes – Relations between nodes	+*	-	-
7.	Ontology	– Concepts – Hierarchal links – Linguistic links – Logical restrictions	+*	+*	+*

* - in computer-based tutoring systems is used only as technological mean, not as a part of process, for example, learner does not solve task related to particular technique of knowledge cartography

As a result it is concluded that from knowledge cartography techniques, ontologies are the most appropriate for integration in the intelligent concept map-based knowledge assessment system IKAS, because: 1) they have some structural similarity to concept maps, despite the fact that the ontology structure is much more expressive and more complex; 2) ontology is not restricted by subject, as they can be used for any type of subjects, both humanitarian and exact; 3) the integration of ontology in a knowledge assessment system would enable to implement functionality, which ontologies provide in tutoring systems, such as structuring learning materials, and generation of more informative feedback already; 4) similarity between an ontology and a concept map does not exclude mutual transformation, thus allowing use of already existing ontologies as the basis for concept maps used in knowledge assessment systems, and use ontology processing methods and tools to process concept maps in knowledge assessment systems; 5) there is not enough research on the ontology use in the knowledge assessment systems.

2.2. Research on the ontology use in tutoring systems

Since there is a lot of research about ontologies, it has led to the diversity of definitions and classifications, therefore in the doctoral thesis the task has been set to perform analysis and systematization of definitions and classifications and analysis of ontology use in computer-based tutoring and assessment systems.

After analyzing and evaluating 17 ontology definitions, whether they include all ontology's properties (minimum, typical and advisable) [LAS 2001] it is concluded that the most complete definitions are Hendler's [HEN 2001] and Gruninger & Fox's [GRU 1995] ontology definitions. They name ontology components (concepts (realities), semantic linkage, properties, relations, constraints and behaviour) and refer to use of ontology in artificial intelligence (ontology includes inference rules and has a formal description).

Researchers from computer-based tutoring system's community have accepted T.Gruber's definition of ontology [DOA 2006], [MIZ 2000], [LEE 2005], [BOY 2007] that "ontology is an explicit specification of conceptualisation" [GRU 1993]. However, the most appropriate definitions of ontology in context of tutoring systems are Hendler's and Gruninger & Fox's definitions mentioned already, because they state clearly that constituent elements of ontology are used in tutoring systems, as well as formal description of ontology and inference rules are required.

Ontology classifications also have a wide diversity. Almost every author talking about the ontology classification, offers his/her own classification schema that suits best to his opinion about the most correct, most appropriate and tangible ontology classification. Van Heijst et al. offers to divide ontology classification schemas based on two dimensions [VAN 1997]: 1) the amount and type of structure of conceptualization, 2) the subject of conceptualization.

17 ontology classification schemas (for detailed schema description, see Appendix 5) have been analysed in the doctoral thesis and classification of van Heijst has been extended.

As a result 2 groups of ontology classification schemas and their subgroups are introduced [GRA 2005b]:

- Domain dependent ontology classification schemas;
- Domain independent ontology classification schemas, which can be divides as:
    - Representation structure dependent ontology classification schemas;
    - Concept content dependent ontology classification schemas.

Classification schemas analyzed in the doctoral thesis are systematised in accordance with the created classification and represented in a graphical form. In addition, the concept content dependent classification schemas associated with generality of concepts included in the ontology are analyzed in detail to determine the problem domain independent schema. The possible classification schema combination for more precise ontology classification is also pointed out [GRA 2005a].

Despite the different names ontologies used in computer-based tutoring systems fit to the van Heijst's ontology classification [VAN 1997]. Ontologies are divided into representation, general, domain and application ontologies there. In many cases, developers of tutoring systems have given a more accurate name to the ontology (rather than, for example, application or domain ontology), which reflects concepts it contains or usage goals better. Abovementioned ontology classification is extended by domains often used in tutoring systems' ontologies, which corresponds to the selected classification categories (Fig. 2.1).

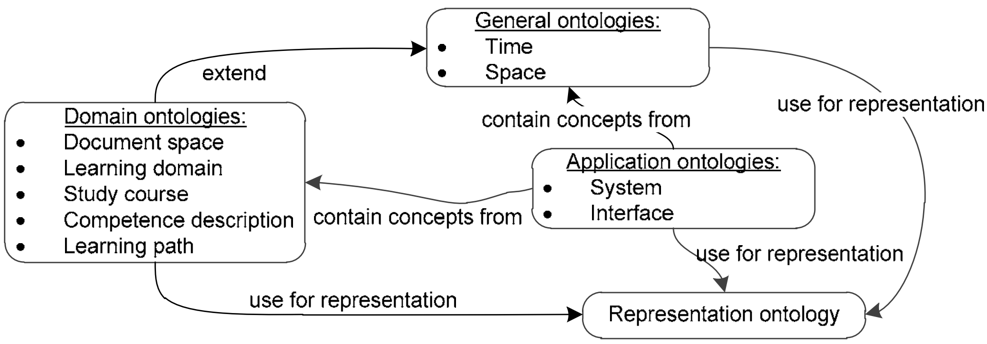

Fig. 2.1. Ontology domains used in computer-based tutoring systems

Besides identification of ontology types used in computer-based tutoring systems, ontologies as metadata for learning material description are also studied. It is concluded that the ontology together with traditional learning material metadata standards gives the best results for learning material description. Literature on use of ontology in authoring tools and other applications for tutoring systems is summarized. It is concluded that ontologies are used in all components of the intelligent learning systems, where they describe the problem domain knowledge, which is used for course content, topics, keywords and metadata for learning materials.

2.3. Ontology merging possibilities

In the Chapter 1 as one direction of IKAS improvement "*to audit courses, their modules or study programmes using merged standard concept maps*" is proposed. Therefore possibilities of merging ontologies are researched and evaluated to determine whether it is possible to adapt them for concept maps combination or merging.

Ontology matching has been studied in the thesis which is related with finding correspondences or relations between elements from several ontologies [EUZ 2007]. Alignment is obtained as a result from matching which contains correspondences between elements of ontologies. In order to find ontology alignment a degree of similarity between elements should be found, therefore similarity measures are summarized in the thesis.

Protégé plug-in PROMPT [FRI 2000] has been recognized in the thesis as the most appropriate among available and working ontology merging tools. It provides merging of two OWL ontologies, despite the fact that this plug-in is compatible with previous generation of Protégé tool and the new ontology has "redundant" data (related to the ontology storage format in that generation of the Protégé). The ontology utility tool MergeUtil has been implemented in the doctoral thesis to solve the drawback mentioned.

2.4. Applications of ontologies for extension of IKAS functionality

The most significant direction of IKAS improvement, using the ontology, is related to the system's transformation from a knowledge assessment system to a knowledge assessment and / or self-assessment system with knowledge remediation because ontologies have already been proven to be an appropriate mechanism for learning material description, indexing and personalization of learning paths in tutoring systems [GRA 2007].

Taking over the research experience of the use of ontology in tutoring systems, ontologies can be used in the IKAS system for modelling the pedagogical knowledge used for a student error analysis and ensurance of its correction, as well as for support of teacher in his/her efforts to prepare learning materials; a student modelling describing his previous knowledge, progress, learning behaviour and style, preferences, thereby improving IKAS adaptation to each particular student; course content combined with learning materials used and other types of assessment, feedback and dialogue. However, in relation to these IKAS development directions further research on their usefulness is required, but it goes beyond this thesis.

This is the reason why the thesis deals with such IKAS functionality extension tasks as development of ontology and concept maps mutual transformations to facilitate the teacher and to use ontology-processing tools for concept maps, as well as the development of methods for the concept map analysis for recommendations of learning object content, course and personalized learning path generation.

Respectively, algorithms required for extending IKAS functionality are developed in the thesis. They are based both on ontology integration into IKAS and concept map analysis and processing of knowledge remediation.

Summary and conclusions of Chapter 2

- As a result of analysis of knowledge cartography techniques it is concluded that the integration of ontologies and concept maps is possible, because ontologies and concept maps have some similarities, i.e., classes and instances of ontologies are similar to concepts from concept maps, while relations between classes and instances in ontologies are similar to links between concepts in concept maps.
- The most appropriate definitions are found to define ontologies used in tutoring systems which include ontology components and point to ontology use in artificial intelligence.
- After analysis of ontology classification schemas, it is concluded that they fall into four different and distinct ontology classification schema groups. Created division systematises majority of the existing ontology classification schemas. In the doctoral thesis the resulting division has been applied for ontology classification used in tutoring systems.
- Summarizing the literature on the use of ontologies in intelligent tutoring systems, descriptions of metadata of learning materials and learning material authoring, it is concluded that the ontology can be used in any system component, which requires knowledge formalization, as it is in the case of intelligent tutoring systems.
- To solve a task how concept maps captured in the IKAS have to be merged into one, in the thesis ontology merging methods and tools has been analysed to find out whether they are applicable to concept map merging. As a result, it is concluded that after transformation of concept maps into ontologies, the methods and the tools for ontology merging can be used for concept map merging.

3. ALGORITHMS FOR FUNCTIONALITY EXTENSION OF CONCEPT MAP-BASED KNOWLEDGE ASSESSMENT SYSTEM

In this Chapter algorithms for functionality extension of concept map-based knowledge assessment system IKAS have been defined. In Subsection 3.1 correspondence of OWL ontology elements to concept maps is described. Subsection 3.2 defines the algorithm for an ontology transformation into a concept map. Subsection 3.3 defines the algorithm for a concept map transformation into an ontology. The algorithms that extend the IKAS to a knowledge self-assessment system and a system with knowledge remediation are defined in Subsection 3.4. Mutual transformations between concept maps and ontologies are defined for ontologies described in OWL language and concept maps stored in IKAS supported format. OWL language has been chosen because it has been now recognized by the W3 Consortium as the standard[3] for describing ontologies and one of the most commonly used ontology language.

3.1. Correspondence between ontology elements and concept map elements

After analysis of OWL language syntax and semantics [OWL 2004a], [OWL 2004b], [OWL 2004c], [LAC 2005], [OWL 2009a], [OWL 2009b] and ontologies described in OWL, correspondence between OWL ontology elements and elements of concept maps has been defined [GRA 2008b].

General correspondence between OWL ontology and a concept map is shown in Fig. 3.1, where it is illustrated which ontology elements directly corresponds to concept map elements, i.e., all ontology classes, instances, data type properties and values of data type properties are concepts and object properties correspond to links in concept maps. Besides these elements there are found and summarized also other OWL constructs which describe different properties of these elements that influence element transformation into a concept map, for example, a construct defining that one class is a subclass of other class.

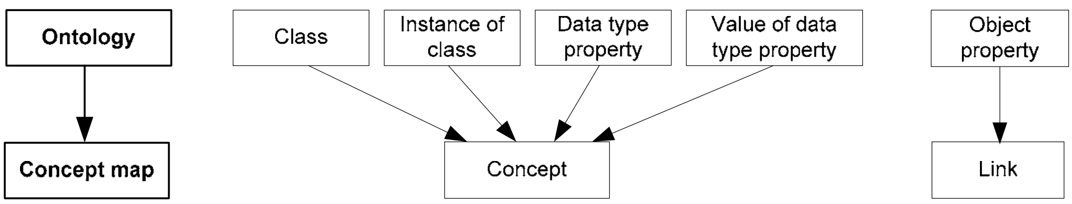

Fig. 3.1. Correspondence between an ontology and a concept map

[3] http://www.w3.org/standards/techs/owl#w3c_all

3.2. The algorithm for an ontology transformation into a concept map

All cases of ontology transformation have been divided into 3 groups:

- Hierarchal relations between classes and instances – include cases related to finding of ontology classes and their instances and establishing hierarchal relations, i.e., relations between a class and a subclass, between a class and its instances, Boolean relations between classes, synonyms of classes and instances, distinctions of classes and instances.
- Semantic relations between classes and instances – include cases related to finding of object properties which define semantic relations between classes/instances.
- Property relations for classes and instances – include cases related to finding of data type properties for classes/instances.

During operation of the algorithm from the ontology saved in the text file an extended incidence matrix is obtained, where names of concepts and their interrelations are stored showing the name of the link (linking phrase) and its direction. In addition, this matrix is extended with one more column where data about a type of concept or a label of concept type (root class – class without superclasses, subclass, instance, property or value) are stored. Basic steps for concept map generation from an ontology are the following: [GRA 2008a]: **Step 1:** Read an ontology file and check OWL syntax. **Step 2:** Find all classes (begin creation of an incidence matrix). **Step 3**: Find subclasses of each class (for particular class add the link "is a" which goes from a subclass to a superclass in the matrix, add labels to root classes). **Step 4:** For each class check intersection, union and collection with other classes (add the link "is a" in the matrix between appropriate classes). **Step 5:** For each class check complement relations to other classes (add the link "is not" in the matrix). **Step 6:** Find instances of each class (add instances and links "is instance of" between appropriate classes and instances which go from an instance to a class in the matrix, add labels to instances). **Step 7:** Find data type properties for each class and instance (add properties and links "has property" between appropriate class/instance and a property in the matrix, add labels to properties). **Step 8**: Find values for each data type property (add properties' values and links between a data type property and its value "has value" in the matrix, add labels to values). **Step 9:** For each class, instance and data type property check equivalence (add the link "is synonym" in the matrix between appropriate elements). **Step 10:** Find object properties for each class/instance (add appropriate links between classes or instances in the matrix). **Step 11:** Check if an object property is inverse, symmetric or transitive (extend the matrix with appropriate links). **Step 12:** Find hidden relations (relations which can be inferred using reasoners and are not directly defined in the ontology). **Step 13:** Perform correction of concept and link names (replace understrike sign "_" with space). This is needed because spaces between words in the names of ontology elements are not allowed and usually they are replaced with "_". **Step 14:** Display completed incidence matrix as a graph and save in XML accordingly to format used in the IKAS.

Detailed descriptions and flowcharts for each step needed for relation transformation between classes and their instances, semantic and property relations [GRA 2008a], as well as for integration of obtained concept map into the IKAS are given in the thesis. Examples for all three transformation groups are included in Appendix 6.

3.3. The algorithm for a concept map transformation into an ontology

As a result of analysis of concept maps it is concluded that for making transformation from a concept map the latter should have oriented links because it allows determining hierarchical and semantic relations. In addition, links between concepts must be with linking phrases which allows identification of the link type. Moreover, it is needed to consider restrictions of OWL language for naming, for example, the same name can be used only once, i.e., there can not be several classes with the same name. Also there are series of symbols which cannot be used as the first symbol in element names, and the use of space symbol is prohibited.

The algorithm for a concept map transformation into an ontology should determine the type of relation between concepts and based on the type it should be identified which ontology elements correspond to related concepts. The mechanism built in the algorithm determines the type of concepts, i.e., it has information how to determine type of relation and ontology elements from the name of link. In Fig. 3.2 schematically is shown that exactly linking phrase determines the type of concepts related and only semantic (linguistic) and "part-whole" relations are directly transformable into object properties.

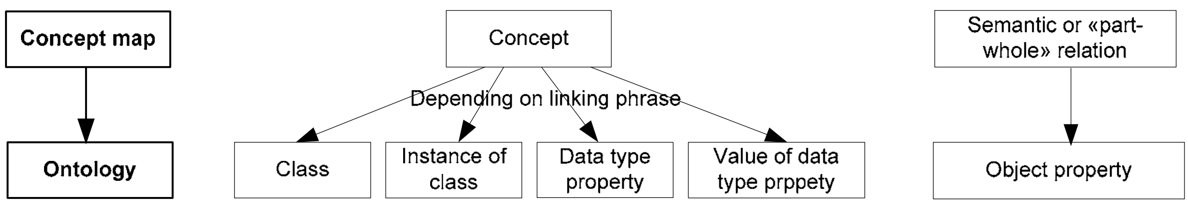

Fig. 3.2. Correspondence between elements of concept map and elements of ontology

In a concept map it is possible to determine the following types of relations: *the hierarchal relation*, where two classes are related with linking phrases "is a", "is subclass", "is subset"; *the instance relation*, where a class is related to an instance with linking phrases "is instance of", "is example"; *the whole-part relation* where two classes are related with the linking phrase "is part of"; *the hierarchal kind relation*, where two classes are related with the linking phrase "is kind of"; *the property relation*, where a class or an instance is related to a property with linking phrases "characterises", "has property", "has property (object-property)"; *the values property*, where a property is related to its value with the linking phrase "has value"; *the compliment relation,* where two classes are related with the linking phrase "not"; *the semantic or linguistic relation*, where two classes or instances are related with any other linking phrase.

The algorithm for a concept map transformation into an ontology consists of 7 steps [GRA 2011a] during which all elements of concept map are handled to determine their correspondence to ontology elements and to make appropriate ontology constructions. The first 6 steps analyse linking phrases included in a concept map. As a result, the type of related concepts is determined and is added to the ontology according to it. Step 7 finds synonyms for concept map elements because they are not defined with links but stored in the structure of XML file. **Step 1:** Find all concepts related with hierarchal relations. **Step 2:** Find all concepts related with instance relations. **Step 3:** Find all concepts related with property relations. **Step 4:** Find all concepts related with value relations. **Step 5:** Find all concept related with complement relations. **Step 6:** Find all concepts related with part-whole or semantic relations. **Step 7:** Find all synonyms defined for concepts and linking phrases. The appropriate OWL code is written in each step according to the determined pair of concepts.

Detailed description and flowchart of each step, as well as fragments of OWL code are given in the thesis.

3.4. Algorithms for knowledge remediation

Two algorithms should be added to the IKAS to extend it with remediation function: the algorithm for learning object subgraph generation and the algorithm for course and personalised learning path generation [GRA 2011b].

After a teacher has created a concept map, the software generates recommendations. They contain information which learning objects should be added so that the system can be used not only for knowledge assessment, but also for self-assessment. The knowledge self-assessment mode, unlike the assessment mode, is supplemented with learning materials to support a student in correction of errors and misconceptions. A teacher receives recommendations based on a concept map created that contains information which concepts and links should be described (explained, illustrated) in the particular learning object. Recommendations about content of learning material are developed based on modern pedagogical ideas that structural knowledge should be taught. Wherewith a learning object is not related to a single concept but to two or more related concepts, thus revealing their interrelations. In addition it is important that a student discovers not only propositions (pairs of related concepts) but also wider subgraphs, such as the class with all its subclasses.

Each learning object belongs to one of the following types of subgraphs which include a concept and all its direct subconcepts (the linking phrase "is a"); a concept and all its instances (the linking phrase "is instance of"); two or more concepts related with linking phrases "has property" and "has value"; two or more concepts related with the linking phrase "has synonym" or the linguistic linking phrase, i.e., any other linking phrase which is defined by a teacher. In the doctoral thesis the algorithm is defined and described as well as its flowchart is drawn.

For each type of the linking phrase different cardinalities between source and target concepts are determined using the extended incidence matrix:

- For the linguistic linking phrase (except for "part of") searches N:M (all source concepts and all target concepts).
- For the linking phrases "is a", "is instance of" and "is part of" searches N:1 (for each target concept find all source concepts because the direction of the link is from a specific to a general concept).
- For the linking phrase "has property" searches 1:N (find all properties of one source concept). Besides, the learning object should include all values of each property, therefore for the linking phrase "has value" searches 1:N. Thus, the learning object includes a concept with all its properties and values.
- For the linking phrase "has synonym" searches a subgraph which includes source and target concepts and other concepts connected with them interrelated with the linking phrase "has synonym".

When the algorithm is finished a teacher receives a list of learning objects, and concepts and linking phrase(s) which should be included in each learning object in the form defined in the thesis. Once learning materials are created and added to the concept map it is required to arrange them into learning paths, thus ensuring that the student receives learning materials in the order that best suits for improvement of his/her knowledge. A learning path or a sequence of learning material delivery is associated with the place of learning material in the curriculum, namely, learning materials are arranged so that prerequisites are taken into account. The system generates initial learning paths, and the teacher may change them according to his/her opinion, for example, if some more prerequisites are needed or a teaching strategy requires it.

The learning path generation algorithm is shown in Fig. 3.3. Learning objects are sequentially added to a learning path and arranged in levels, based on their ranking of generality. The most general object is the object which concepts are related with the semantic relation, containing concepts with high local degrees (the sum of incoming and outgoing arcs) and containing root concepts. Generality ranking is obtained by double order of learning object set. Firstly, they are put in descending order according to a number of root concepts in a learning object. Secondly, they are sorted in descending order according to the generality (the coefficient of the relation type + the maximal local degree of concepts included in a learning object, taking into account only links between concepts included in this learning object+ the number of concepts in the learning object). Values for the coefficient of the relation type are determined experimentally as follows: 6 – the linguistic relations between classes; 5 – the hierarchal, the part-whole or the complement relations; 4 – the instance relations; 3 – the linguistic relations between instances; 2 – the property and value relations for classes, synonym relations between classes or properties; 1 – the property and value relations for instances or synonym relations for instances.

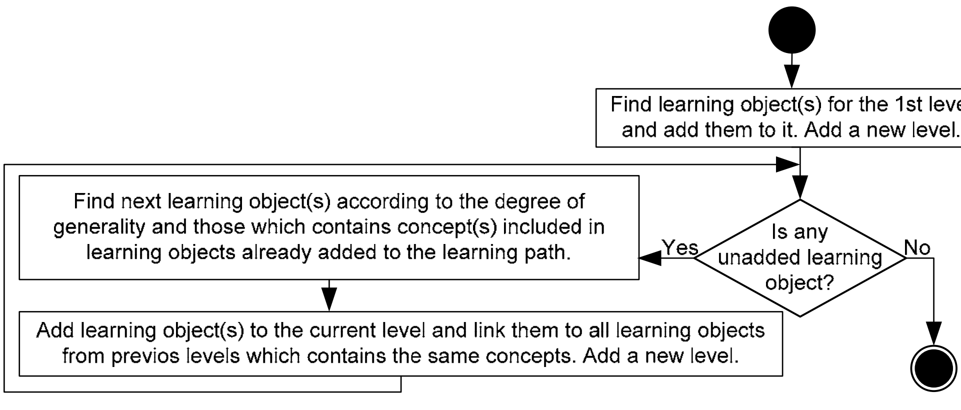

Fig. 3.3. The algorithm for learning path generation

After a student has developed his/her own concept map, the system evaluates it and makes a personalized learning path based on the student's mistakes. The algorithm takes into account propositions where a student has made mistakes. In the previously generated learning path graph the longest path with connecting learning objects is found. It begins in the highest level and contains a learning material needed for remediation. In case the graph does not contain paths, i.e., a number of related learning objects, then individual learning objects are delivered to student, starting with the most general.

Summary and conclusions of Chapter 3

- The algorithm for an OWL ontology transformation into a concept map is defined, described and flowcharted. The extended incidence matrix is defined to provide the operation of the algorithm. It represents names of concepts, their interrelations, including the linking phrases and direction, as well as concept type labels.
- The algorithm for concept maps created with the IKAS transformation into OWL ontologies is defined, described and flowcharted. During the development of this algorithm it is concluded that the transformation from concept maps is possible but it is not fully automatable. This is due to the fact that there are not formal constraints in concept map building, such as, for example, that two property concepts may not be related with the semantic link, and it is not possible to include all these cases in the algorithm. Therefore an ontology expert must examine the concept maps and conclude, whether they satisfy ontology rules and if corrections needed are to be made.
- The algorithm which supports a teacher in learning material authoring for inclusion of information facilitating system thinking is defined, described and flowcharted. It is based on the idea that a learning material is not about concepts themselves, but their interrelations.
- The algorithm for generation of course and personalized learning paths is defined, described and flowcharted.
- Mathematical formalism for determination of learning objects generality needed to generate learning paths of the course is defined.

4. DEVELOPMENT AND APPROBATION OF THE EXTENDED IKAS

Implementation, operation and approbation of algorithms that extend the IKAS functionality is described in this chapter. The tool OntoJK for an ontology transformation into a concept map, the tool JKOnto for a concept map transformation into an ontology, MergeUtil utility for merged ontology file handling has been developed in the doctoral thesis. Subsection 4.1 describes new operation scenarios with the IKAS using developed extensions. Subsection 4.2 describes technologies used for tool development. Operation examples using the developed algorithms and tools are demonstrated in Subsection 4.3.

4.1. User interaction scenarios with the extended IKAS

Using the algorithms described in the previous chapter, the IKAS functionality has been expanded with three new operational scenarios:

1. The use of ontologies for standard concept map acquisition [GRA 2006], [ANO 2006a].
2. Concept maps transformation into ontologies, after that using ontology merging tools and transforming a merged ontology into a concept map, to get a merged concept map of initial concept maps.
3. Extending the IKAS functionality to ensure student knowledge remediation.

In addition, the first scenario is compatible with the third, allowing to extend IKAS functionality simultaneously for both the use of ontology and the introduction of knowledge remediation. **Step 1:** The scenario begins with a teacher's decision to add a new standard concept map, followed by a decision about one of the possible alternatives: a) open the concept map editor in the IKAS and modify an existing concept map, b) open the concept map editor in the IKAS and create a new concept map from the scratch, c) open an ontology repository and choose an ontology, which would be transformed into a concept map, d) add a new ontology which would be transformed into a concept map, which is downloaded from the Internet, a system using ontologies or is constructed by a teacher and transform it into a concept map. **Step 2:** In cases of alternatives c) and d) the IKAS performs an ontology transformation into a concept map and displays it to a teacher. **Step 3:** If a teacher wants, he/she can make changes to a generated concept map. **Step 4:** The system generates recommendations for a teacher what information should be included in learning materials. **Step 5:** A teacher creates learning materials. **Step 6:** The IKAS generates a learning path graph which corresponds to the particular concept map and if a teacher wants, he/she can make changes in the path. **Step 7:** A teacher sets the task parameters, such as publication date and the initial degree of task difficulty.

From a student’s perspective in this extended IKAS operation scenario the only change is the fact that after submission of an answer, he/she receives learning materials, delivered in order that depends on mistakes made. By contrast, in the second scenario a teacher’s interaction with the IKAS is ambiguous, since acquiring a merged concept map, it can be used for various purposes, for example, as the study course audit to verify that everything included in a subject’s description is included in the standard concept map used for assessment in this course.

4.2. Technologies used in development of prototypes

Three prototypes of tools are implemented with the defined algorithms that extend the IKAS functionality:

- **The tool OntoJK for an ontology transformation into a concept map**

Application programming interface Jena[4] is used to access OWL files, which is implemented for exactly such purposes. Chosen application programming interface determines that the tool is written in Java. Each ontology file is read in an ontology model m, which has different methods. Main of them to access elements of ontology are: `m.listHierarchyRootClasses()` – finds all root classes; `rootcls.listSubClasses()` – finds all subclasses for class `rootcls`; `m.listClasses()` – finds all classes; `cls.listEquivalentClasses()` – finds all synonyms for class `cls`; `cls.listInstances()` – finds all instances for class `cls`; `m.listObjectProperties()` – finds all object properties; `m.listObjectProperties()` – finds all data type properties; `p.listDomain()` – finds domain for property `p`; `p.listRange()` – finds range for property `p`. Lists of particular elements are returned using mentioned methods, after that iterators are used to assess each element in the list.

- **The tool JKOnto for a concept map transformation into an ontology**

This tool also is written in Java language using the application programming interface Jena, which allows not only to access data in the OWL files, but also to record new information in OWL files. Main methods for ontology definitions are following: `m.createClass(String uri)` – creates a class with the name `uri`; `m.createDatatypeProperty(String uri)` – creates data type property with the name `uri`; `m.createObjectProperty(String uri)` – creates object property with the name `uri`. The method `class.addSubClass(Resource cls)` is used to add a subclass to a class. The method `class.createIndivudual(String uri)` is used to add an instance to a class. The method `p.addDomain(Resource cls)` is used to add a domain to a property and `p.addRange(Resource res) is used` to add a range to a property.

- **The tool MergeUtil for merged ontology file handling**

The tool MergeUtil is written in Java and it deletes redundant data from the file merged ontology is saved in. These data are not used further in any ontology usage and processing. Ontology merging is performed using the ontology editor Protégé v.3.2 with the

[4] http://jena.sourceforge.net/ (accessed 29.05.2011)

plug-in PROMPT. Redundant information in a merged ontology is related to data storage techniques used in Protégé tools of the third generation. Following tags and data included within them have been deleted from a merged ontology:

```
<owl:Class rdf:ID="_DUMMY-FRAMES-METACLASS">;
<owl:Class rdf:ID="_DUMMY-FRAMES-METASLOT">;
<owl:Class rdf:ID="_TEMPORARY-ITEMS">;
<owl:ObjectProperty rdf:ID="_REFERENCES>.
```

4.3. Examples of use of tools and algorithms

In this subsection examples of an ontology transformation with the tool OntoJK, a concept map transformation with the tool JKOnto, knowledge remediation support and ontology merge with the tool Protègè using plug-in PROMPT and the file utility MergeUtil are demonstrated.

- **An ontology transformation into a concept map using the tool OntoJK**

The tool OntoJK transforms an ontology into a concept map using the algorithm defined in Chapter 3.2. Depending on the language used for element naming, it is possible to change linking phrase language from Latvian to English and vice versa. It is needed for concept maps generated from English to keep all linking phrases in English, too. Moreover, it is needed also for those linking phrases which are not represented in ontologies directly (called as default phrases), for example, "is a", "has property", "has value" and their equivalents in Latvian. The tool has three menus which provide following actions: *„File"→„Open ontology..."* provides possibility to choose ontology for transformation; *„File"→„Save As CMAP"* saves a generated concept map to XML format compatible with the IKAS; *„File"→„Export to IKAS"* exports a generated concept map to the IKAS; *„File"→„Exit"* exits the tool; *„Settings"* sets a language (Latvian or English) for default linking phrases; *„Help"* gives the user manual of the tool. When a generated concept map has been displayed it is possible to move elements manually making concept map more tangible.

To demonstrate operations of the tool OntoJK a concept map has been generated from hardware ontology[5] (included in Appendix 7). The generated concept map is represented as a graph (Fig. 4.1.).

[5] http://monet.nag.co.uk/cocoon/monet/publicdocs/ontologies/hardware.owl

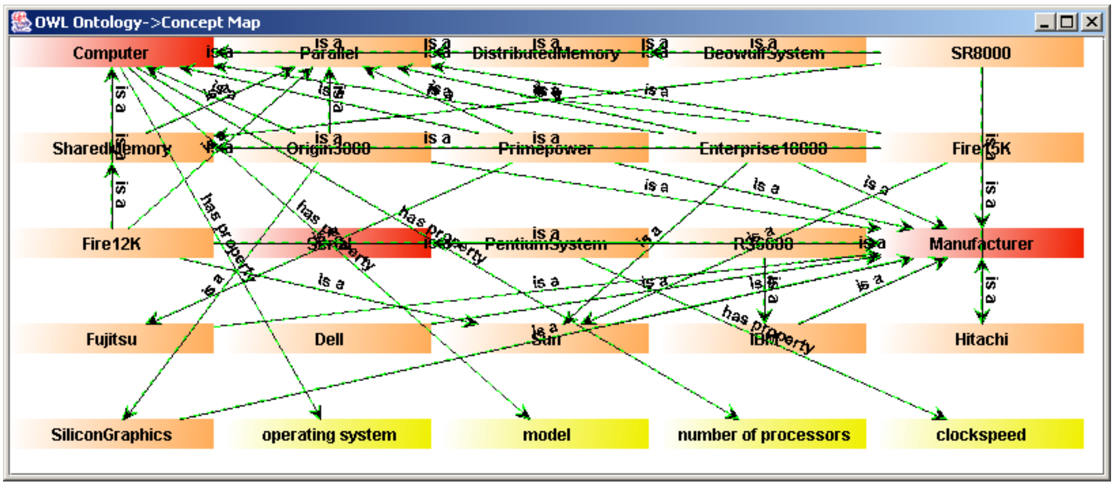

Fig. 4.1. A window with the concept map generated from hardware ontology with original layout

Comparing with the existing ontology editor CmapTools COE which offers transformation from an ontology to a concept map, or more precisely, an ontology visualisation as a concept map, practical usage of the OntoJK proves that concept maps generated by the developed tool are more appropriate for use in knowledge assessment, because they do not have redundant data as it is in case of CmapTools COE. The latter, for instance, represents such redundant elements as the concept „Things which" or explanation added to the link „Object property", etc.

- **A concept map transformation into a ontology using the tool JKOnto**

The tool JKOnto provides transformations of concept maps created with the IKAS. The tool is based on the algorithm defined in the Chapter 3.3. The concept map created for the 1st phase of the study course "Fundamentals of Artificial Intelligence" (FAI 1.1) is used to demonstrate the tool's operation (Fig. 4.2.). Since formal restrictions do not exist for concept map building but exist for ontologies, several non-compliances to the ontology are found in the demonstration example:

- Link between two concepts which are properties exists in the concept map. OWL doesn't allow such construction therefore mentioned relation has been deleted from the concept map.
- Elements' names in the concept map contain symbols forbidden in OWL. Those symbols are square brackets and a number as the first symbol in the element's name. Therefore brackets have been deleted and a number is written with letters.
- Since in an ontology there can not be several semantic links which are going from different classes for semantic links with identical names, indexes are added according to principles described in the thesis.

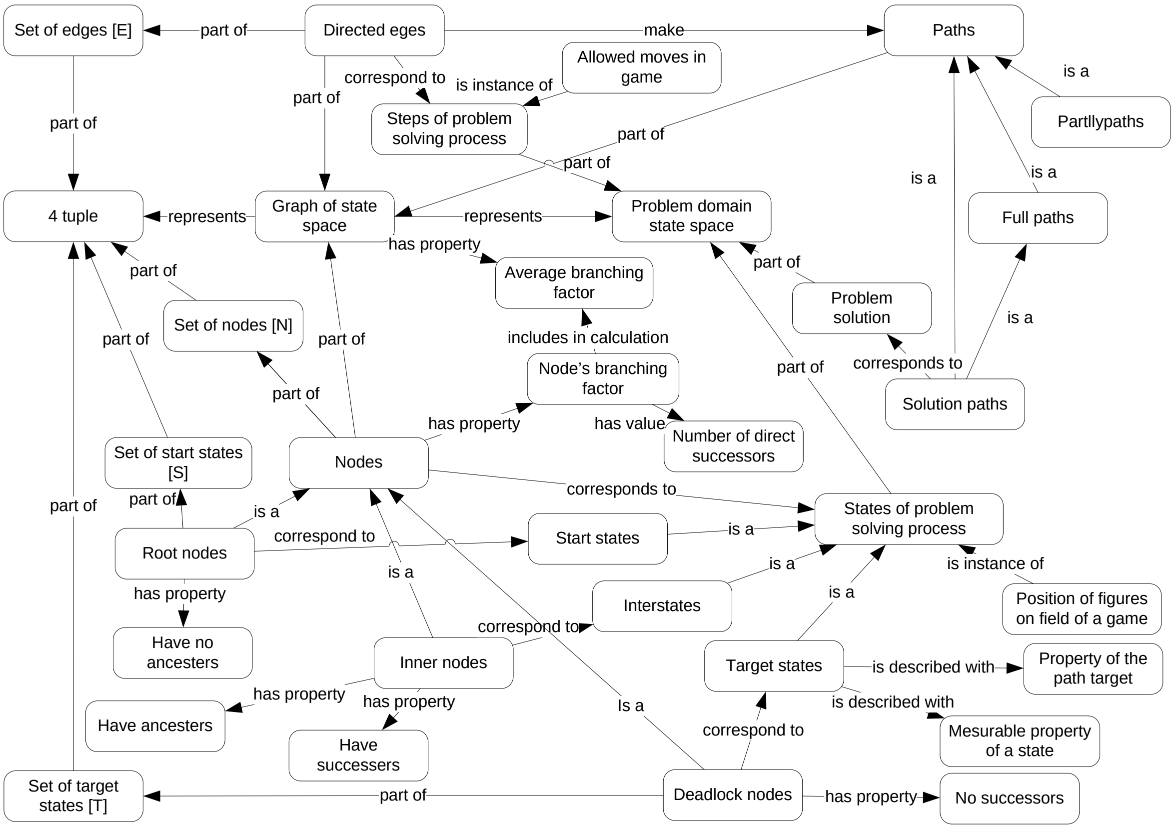

Fig. 4.2. Teacher's created concept map FAI 1.1

A full code of the ontology generated from the concept map FAI 1.1 is added in the Appendix 8.

- **Operation examples of algorithms for supporting knowledge remediation**

In the doctoral thesis an example is described which is based on the concept map for the study course „Fundamentals of Artificial Intelligence" and a concept map submitted as a somebody's answer. All divided learning object subgraphs, the generated learning path and the personalized learning path for the student have been included in the Appendix 9. An example of the small concept map with divided learning object subgraphs #1-#4 added to the learning path of the course according to the algorithm described in the Chapter 3.4 is given in Fig. 4.3.

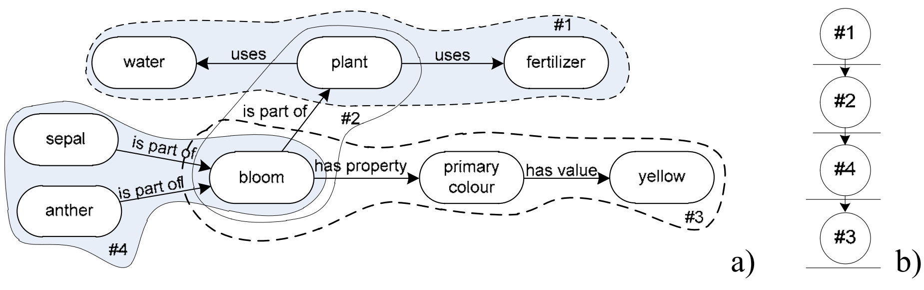

Fig. 4.3. A concept map with divided learning object subgraphs a) and the corresponding learning path b)

- **An example of ontology merging**

Fragments of the concept maps for the study courses “Fundamentals of Artificial intelligence” and “Artificial intelligence” are used to demonstrate an example of the ontology merging. The first concept map is for the subject of bachelor studies, and the second is for master studies. A topic about algorithms for state space search is in both subjects and both are related to a concept “state space search”. Before merging, the concept maps have been transformed to ontologies, then the ontology editor Protègè together with the plug-in PROMPT has been used. The OWL file with the merged ontology is handled with the utility MergeUtil developed in the thesis to delete redundant data. A fragment from the merged ontology is shown in Fig. 4.4. The full code of it is included in the Appendix 10.

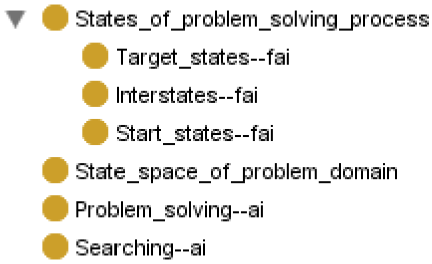

Fig. 4.4. A fragment of the merged ontology

Despite that ontology merging is supported with tools however user involvement in the merging is necessary. In addition the algorithm used in the plug-in PROMPT is sensitive to small syntactic differences in element names. Therefore a user needs carefully track merging and manually indicate syntactically different but semantically identical elements which are needed to be merged.

Summary and conclusions of Chapter 4

- Operation scenarios of the IKAS users after the IKAS extension have been described.
- The tool for an ontology transformation into a concept map (OntoJK) with the algorithm defined in the Chapter 3.2 has been implemented.
- The tool for a concept map transformation into an ontology (JKOnto) with the algorithm defined in the Chapter 3.3 has been implemented.
- The utility MergeUtil for handling files with merged ontologies to solve drawback of the ontology editor’s Protégé plug-in PROMPT has been implemented.
- The approbation of all defined algorithms and corresponding tools has been performed with concrete examples.

- The results of the approbation show that the developed algorithms and the corresponding tools provide necessary transformations and ontology merging. However it is not possible to get results fully automatically due to the lack of formalisms concept map builders use and create constructions which are not possible to transform in ontology, for example, semantic relation between two data type properties.

MAIN RESULTS AND CONCLUSIONS

The goal of the doctoral thesis is to explore knowledge cartography techniques, find the most suitable one for integration with the intelligent concept map-based knowledge assessment system IKAS, and develop algorithms and tools for extension of its functionality. In order to achieve the goal of the thesis the following tasks have been solved:

- Concept maps and diversity of concept map-based tasks have been explored. A formal approach for qualitative comparison of the degree of task difficulty has been developed extending the spectrum of used tasks in the IKAS. A list of 34 tasks which can be used for the IKAS has been prepared. The whole list of tasks contains 108 tasks which have been sorted according to the degree of task difficulty.
- Software for a concept map drawing and evaluation has been explored. As a result, it is concluded that standard concept map creating and learning material authoring for rich feedback are main processes which increase teacher's workload during the usage of such systems.
- The IKAS system has been analysed and directions of the IKAS improvement has been identified. They are related to: 1) acquisition of standard concept maps and their fragments from already existing knowledge structures; 2) mining of concept explanations, definitions and examples from already existed learning materials; 3) extension to self-assessment mode offering learning materials after students' answers evaluation for remediation of detected errors and misconceptions taking into account needed prerequisites; 4) use standard concept maps captured in the IKAS for more precise evaluation of students' answers; 5) merge captured standard maps for a study course, a module or a whole programme audit.

To find solutions for developing the IKAS improvement the following tasks have been performed:

- The knowledge cartography techniques (mind maps, knowledge maps, argument maps, topic maps, semantic networks, conceptual graphs and ontologies) has been analysed and it has been concluded that an ontology is the most appropriate for usage in computer-based tutoring and knowledge assessment systems with automated answer evaluation;

- Ontology definitions have been analysed according to included properties and Hendler's and Gruninger&Fox's definitions have been found as most appropriate for defining ontologies used in tutoring systems because they indicate components of ontology (concepts (realities), semantic linkage, properties, relations, constraints and behaviour) and refer to the use of ontology in artificial intelligence (ontology includes inference rules and has a formal description);
- Ontology classifications have been systematised and division of ontology classification schema has been made as well as schema analysis from the viewpoint of domain independence.
- All classification schemas analysed have been divided into four different and distinct ontology classification schema groups (domain dependent ontology classification schemas, domain independent ontology classification schemas. The latter can be divided as representation structure dependent ontology classification schemas and concept content dependent ontology classification schema.)
- Types of ontologies used in computer-based tutoring systems have been determined and they have been compared to van Heijst's classification of generality where ontologies have been divided as representation ontologies, general ontologies, domain ontologies and application ontologies; it has been concluded that in the computer-based tutoring systems all types of ontologies have been used except representation ontologies;
- Literature on the use of ontologies in intelligent tutoring systems, metadata descriptions for learning materials and learning material authoring has been summarised and systematised. In result the conclusion has been made that it is possible to use ontologies in every component of intelligent tutoring systems where knowledge formalization is needed.

To develop the IKAS's improvements, the following tasks have been solved:

- The algorithm for an OWL ontology transformation into a concept map is defined, described and flowcharted. The extended incidence matrix is defined to provide algorithm's operation. This matrix represents names of concepts, their interrelations, including the linking phrases and directions, as well as concept type labels.
- The algorithm for transformation of concept maps created in the IKAS into OWL ontologies is defined, described and flowcharted.

- The algorithm for supporting a teacher in learning material authoring to include information facilitating the system thinking is defined, described and flowcharted. It is based on the idea that a learning material is not about concepts themselves, but their interrelations.
- The algorithm for a study course and a personalized learning path generation is defined, described and flowcharted and mathematical formalism for determination of learning objects generality used in a course learning path generation is defined.

To test the developed algorithms in operation:

- The tool OntoJK for an ontology transformation into a concept map has been implemented;
- The tool JKOnto for a concept map transformation into an ontology has been implemented;
- The utility MergeUtil for handling files with merged ontologies to avoid drawback of the ontology editor's Protégé plug-in PROMPT has been implemented;
- Approbation of the developed algorithms and corresponding tools has been carried out using concept maps of the particular study courses and ontologies.

Directions of research in near future are as follows:

- Development of methods for a concept map usage in audit of study programmes for analysis of study course relatedness;
- Finding of solutions for large scale concept map visualisation;
- Adaptation of applications of ontologies in tutoring systems into elements of knowledge assessment systems.

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