Models of Knowledge Creation Processes and Ontological Engineering: Combining Tacit and Explicit Knowledge

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1. Introduction: Models of Knowledge Creation Processes

- **The necessity of a better, more detailed understanding of knowledge creation processes in the knowledge based economy for the needs of today and tomorrow resulted recently in the emergence of many *micro-theories of knowledge creation,*** as opposed to classical concentration of philosophy on *macro-theories of knowledge creation* on a long term historical scale.
- Historically, we could count the concept of *brainstorming* (Osborn 1957, Clark 1958) as first of such micro-theories. However, since 1990 we observe many such new micro-theories originating in systems science, management science and information science, beginning with:
- *Shinayakana Systems Approach* (Nakamori and Sawaragi 1990),
- *Knowledge Creating Company* and the *SECI Spiral* (Nonaka and Takeuchi 1995),
- *Rational Theory of Intuition* (Wierzbicki 1997),
- *I^5 (Pentagram) System* (Nakamori 2000),
- *OPEC Spiral* (Gasson 2004) and several others. This can be counted as a recent revolution in knowledge creation theories, because **all of them** – including also an exceptional recent macro-theory of revolutionary changes in science by (Motycka 1998) that can be also interpreted as a micro-theory − **take explicitly into account an interplay of *tacit, intuitive, emotive,* and *preverbal* aspects with *explicit* or *rational* aspects of knowledge creation.**

1. Introduction: Models of Knowledge Creation Processes, 2

- Additional results concerning micro-theories of knowledge creation were obtained also in the 21st Century COE Program *Technology Creation Based on Knowledge Science* at the Japan Advanced Institute of Science and Technology (JAIST).
- For example, the brainstorming process was represented as the *DCCV Spiral* (Kunifuji 2004) due to the research in this Program.
- The concept of *Creative Space* (Wierzbicki and Nakamori 2006a) developed in this Program tries to provide a synthesis of such diverse micro-theories;
- The concept of the *Triple Helix* of normal academic knowledge creation characterizes main creativity processes at universities and research institutions;
- The idea of *Nanatsudaki Model of Knowledge Creation Processes* (Wierzbicki and Nakamori 2006b) tries to derive pragmatic conclusions from such analysis and synthesis.
- With all this concentration on describing diverse mechanisms or models of knowledge creation processes, **a *critical question arises: how to test, to justify by testing, such micro-theories of knowledge creation?*** The standards of testing theories belong to the episteme – the prevalent way of creating and justifying knowledge, characteristic for a given historical era or a cultural sphere; since the modern episteme has been subject to a destruction process, the above question becomes fundamentally difficult.

1. Introduction: Models of Knowledge Creation Processes, 3

- One of the ways of testing such theories is to derive from them conclusions concerning some practical problems and test whether such conclusions help in solving such problems.
- An example of such a problem is ontological engineering – constructing an ontology for a field of science, or for a scientific institution, even for a laboratory or a group.
- Thus, ways of combining *tacit, intuitive, emotive,* and *preverbal* aspects with *explicit* or *rational* aspects of knowledge creation suggested by the models of knowledge creation processes should be also useful when constructing an ontology
- In following, we concentrate on the concept of an ontology and on diverse approaches to ontological engineering.

2. The Concept and Ways of Constructing an Ontology

- In its original sense, ontology is a term in philosophy and its meaning is “theory of being” or “theory of existence”, see, e.g., Heidegger (1927). Ontology, however, is also given diverse other meanings, such as
- 1) a representational vocabulary which can be specialized to some domain or subject matter,
- 2) a body of knowledge describing some domain.
- 3) In the context of knowledge sharing, ontology is an explicit specification of conceptualization.
- 4) In contemporary computer science, ontology is defined as a formal language-like specification of a domain knowledge – actually equivalent to a taxonomy of concepts in a given field of knowledge, enhanced by a structure of hierarchical dependences and other links between concepts constituting the taxonomy, see, e.g., (Dieng and Corby 2000).
- ***Ideally, an ontology should provide:***
- *a common vocabulary,*
- *explication of what has been often left implicit,*
- *systematization of knowledge,*
- *standardization of terms,*
- *meta-model functionality* (providing a metalanguage for specific models in the domain).

2. The Concept and Ways of Constructing an Ontology, 2

- Actually, see, e.g., (Król 2007), these goals are not attainable: in order to have a formal meta-model, we need a meta-meta-model and so on, therefore we have to stop at some level of explication of basic assumptions and rely on an *hermeneutical horizon* – an intuitive perception what concepts and assumptions are basic and true and how we understand them.
- Thus, any ontology will achieve the ideal goals 1) … 5) only to a certain degree. Note, however, that this implies that any ontology can be re-engineered, corrected according to changes in the hermeneutical horizon.
- Thus, known ways of constructing ontologies can be treated not as absolute recipes, but hints how to proceed.
- There is a distinction of a **top-down approach** – actually, starting with an intuitive perception of the basic concepts in hermeneutical horizon and specifying them in detail subsequently – and a **bottom-up approach** – starting, say, with the concepts actually used in a given field of knowledge and trying to interpret them and their structural relations.
- The top-down approach starts with issues related to meta-model functionality (5);
- The bottom-up approach starts with issues related to systematization (3) and standardization (4).
- Obviously, we need a combination of both approaches in order to construct a useful ontology.

3. The Goals of Constructing Ontology of the COE Program

- We tried to construct the ontology of 21st Century COE Program *Technology Creation Based on Knowledge Science* at JAIST as a case study, with the following goals:
  - ➢ To clarify the use of the concept of Knowledge Science in this Program and make explicit (at least, as much as possible) assumptions about this concept that are often tacitly made (ideal goals 2, 5);
  - ➢ To represent a vocabulary of terms used in this COE Program, together with a systematization of terms used (ideal goals 1, 3);
  - ➢ To help in the development of a software system designed to support hermeneutic search of literature, and possibly in other projects related to the COE Program.
- The ideal goal 4) – standardization – is addressed only to limited degree, because of the heterogeneity of the interdisciplinary projects in the COE Program.
- Thus, we design ontology for COE program at JAIST not only for helping in the development of some projects of this program, but also make to clarify basic concepts for COE program itself.

3. The Goals of Constructing Ontology of the COE Program, 2

- To create ontology, we proceeded along several lines.
- First, we checked the terms and concepts used by the program leader in a paper presenting an introduction to the COE program, thus providing an top-down outline of COE ontology.
- Then, we collected 43 papers composed by COE project members, which have appeared either at an international conference or journal. We extracted the keywords from the papers and counted the frequency of keywords in the full paper by using a computer program.
- We chose the keywords with high frequency to supplement the outline of COE ontology. We chose also pairs of keywords occurring with non-zero frequency to make a simple QT clustering of them (Heyer et al. 1999) and compared the ontology emergent bottom-up from such clustering with the top-down outline of COE ontology.
- Finally, we took into account the reflection on knowledge sciences presented in a recent paper (Wierzbicki and Nakamori 2007) and used this reflection for corrections of the supplemented outline; this way, we finally created the ontology for COE program.
- To understand our result better, we reflected also about other possible views on such ontology and analyzed at least one possible application of the ontology.

4. Bottom-Up Classification and Specification: Keyword Analysis

- Even if you want to start with bottom-up approach, you must always have some top-down outline. To build an outline of the ontology of COE program, we started with the paper presenting an introduction to this program authored by the program leader (Nakamori 2004).
- After analyzing the purpose and sub-projects of the program, we selected the key terms and concepts mentioned in the paper and organized an ontology outline with three levels of branches.
- The first level included five main topics: ***knowledge science, systems science and methodology, education in knowledge science, knowledge creation,*** and ***management of technology.***
- In addition, we also referred to the program reports presented by the program leader in later periods to check and revise the outline.
- Furthermore, we collected the papers authored by COE project members – as many as were available. Since we had to limit this search to electronic files, we finally considered only 43 papers, which were either included in Proceedings of International Symposium on Knowledge and Systems Sciences (JAIST, 2004), or Proceedings of the First World Congress of the International Federation for Systems Research (Kobe, 2005), or in the International Journal of Knowledge and Systems Sciences (Issues 1 to 6).

4. Bottom-Up Classification and Specification: Keyword Analysis, 2

- Another attempt was a clustering of keywords based on their joint occurrence. We selected a simple QT (quality threshold) clustering algorithm, see, e.g. Heyer et al. 1999): if the frequency of occurrence of a pair of keywords equals or exceeds an assumed threshold *t*, the pair might be counted to belong to a candidate cluster; the largest of such candidate clusters is counted as an actual cluster, it is subtracted from the entire set of keywords, and the procedure is repeated on the remaining keywords.
- It turned out that the joint occurrence of keywords is not common, most frequencies of such co-occurrence are zero, thus the clustering was done at the threshold level $t = 1$.
- This way we obtained some clusters, but **they did not fit to the concepts developed top-down.**
- **Thus, the main difficulty of ontological engineering was identified: *how to fit bottom up and top down approach, how to combine expert tacit knowledge with explicit knowledge resulting from data?***
- We discussed several ways of resolving this difficulty (I. Kawakita method, etc.), but in actual application we resolved this intuitively, using again expert knowledge.

5. Top-Down Approach: a Reflection on the Concept of Knowledge Science

- ***Knowledge science*** (KS) is often confused with or tacitly assumed to be subordinated to ***knowledge management*** (KM), thus we first reflect on the origins and meaning of the second term.
- ***Knowledge management*** has much popularity in management science, but its technological origins are often forgotten. It was first introduced by computer technology firms in early 1980-ies – first in IBM, then Digital Equipment Corporation who probably was the first to use the term ***knowledge management* – as a computer software technology in order to record the current work on software projects.** This started the tradition of treating knowledge management as a system of computer technologies.
- Later this term was adopted by management science, and made a big career. This has led to two opposite views how to interpret this term, see, e.g. (Wiig 1997, Davenport and Prusak 1998):
  – **As *management of information relevant for knowledge-intensive activities***, with stress on information technology: databases, data warehouses, data mining, groupware, information systems, etc.
  – **As *management of knowledge related processes,*** with stress on organizational theory, learning, types of knowledge and knowledge creation processes.

5. Top-Down Approach: a Reflection on the Concept of Knowledge Science, 2

- The first view is naturally represented by information technologists and hard scientists; the second by social scientists, philosophers, psychologists and is clearly dominating in management science.
- Representatives of the second view often accuse the first view of perceiving *knowledge to be an object* while it should be seen as *knowledge related to processes;* they stress that knowledge management should be *management of people*.
- However, they miss the point that *management of people* should be also understood as *management of knowledge workers;* and knowledge workers are today often mostly information technologists, who should be well understood by managers.
- Thus, we believe that the two views listed above should be combined. Moreover, they incompletely describe what knowledge management is; there is a third, essential view, seeing knowledge management as the *management of human resources in knowledge civilization era,* concentrating on knowledge workers, their education and qualities, assuming a proper understanding of their diverse character, including a proper understanding of technologists and technology.

5. Top-Down Approach: a Reflection on the Concept of Knowledge Science, 3

- Management science specialists in knowledge management often tend to assume that *technology management* is just a branch of *knowledge management*.
- However, an essential meaning of the word ***technology is the art of designing and constructing tools or technological artefacts*** (thus, *technology* does not mean *technological artefacts,* although such a meaning is often implied by a disdainful use of the word *technology* by social sciences).
- Secondly, *technology management* might be counted as a kind of special *knowledge management,* but it is an older discipline, using well developed concepts and processes, such as *technology assessment, technology foresight* and *technology roadmapping*. Only recently, some of these processes have been also adapted to knowledge management.
- All the above discussion implies that we are observing now an emergence process of a new understanding of *knowledge sciences* that should include:
  - ***Epistemology and philosophy of science,***
  - ***Knowledge engineering,***
  - ***Management science and knowledge management,***
  - ***Sociological and soft systems science,***
  - ***Technological and hard systems science,***
- on equal footing, with a requirement of mutual information and understanding, this basic classification should be also reflected in the proposed ontology of the COE Program.

6. Final Proposal of the Ontology

- The following ontology of the COE Program can be proposed. It is organized as an inverted tree, with fourth-level branches corresponding to keywords found in the papers of COE Program members, and number in parentheses indicating the frequency of their occurrence:
- **General Category: Knowledge Science(s)**

1. Knowledge creation and transformation
   - 1.1 Theory of knowledge creation
     - 1.1.1 Knowledge transformation (conversion): knowledge sharing (40), conceptual knowledge (32), informal communication (19), shared informal space (10), cross-language text summarization (6), structured document (4), individual knowledge model (3), processes and spirals of knowledge (1), interdisciplinary communication, communication skill
     - 1.1.2 Environments to support knowledge creation (Ba): creative environment (1), Ba
     - 1.1.3 Organizational knowledge creation: organizational knowledge creation(17), ensemble learning (1),
     - 1.1.4 Academic and scientific knowledge creation: scientific knowledge creation (32), academic knowledge creation (14), a shortage of researchers (1), research planning (7), research philosophy
     - 1.1.5 I^5-System, a pentagram of knowledge creation: I-system (1),
     - 1.1.6 Theory of knowledge expression and integration: clustering (68), feature extraction (64), text summarization (44), text clustering (36), sentence extraction (23), Knowledge discovery (22), semantic similarity measure (17), knowledge integration (6),
     - 1.1.7 Creative space: a network model of knowledge creation: knowledge creation processes (17), creative space (44)
     - 1.1.8. Innovation: social innovation, regional innovation, regional revitalization system theory, methodology of regional revitalization, innovation in mature industries, pattern of innovation

6. Final Proposal of the Ontology, 2

- 1.2 Creativity and knowledge
  - 1.2.1 Tacit knowledge and creativity: tacit knowledge (35), explicit knowledge (26), knowledge reconstruction (23)
  - 1.2.2 The power and methods of stimulation of intuition in creative processes
  - 1.2.3 The role of emotions in creative processes
  - 1.2.4 Hermeneutics and creativity: knowledge reconstruction (23), adaptive agent (16),
  - 1.2.5 Debate and creativity
  - 1.2.6 Experiments and creativity
  - 1.2.7 Imagination and knowledge integration for creativity
- 1.3 Philosophy of knowledge
  - 1.3.1 Episteme of diverse cultural spheres: knowledge civilization era (17), industrial civilization (26),
  - 1.3.2 Emergence of new concepts in science and technology
  - 1.3.3 Hermeneutics, ontology and hermeneutical horizons

2. Knowledge representation, systematization, acquisition
   - 2.1 knowledge representation and integration
   - 2.2 Knowledge systematization
     - 2.2.1 Ontology of knowledge creation and management: ontology (34),
     - 2.2.2 International networking and knowledge mapping
     - 2.2.3 Knowledge interest profiles, methods of web search
   - 2.3 knowledge acquisition (data and text mining): data mining (47), text mining (13), information extraction (11), natural language processing (1), association rule mining (20),

6. Final Proposal of the Ontology, 3

3. Knowledge management
   - 3.1 knowledge management in business and industry
   - 3.2 knowledge management in academia: laboratory knowledge management (7)
   - 3.3 Information infrastructure for knowledge management: information retrieval (20), knowledge management system (8), electronic library, information science (33), information technology (31),
   - 3.4 Development and practice of knowledge management
4. Systems science
   - 4.1 Hard (technological, mathematical) systems science
     - 4.1.1 Mathematical complexity theory: Systems engineering (11)
     - 4.1.2 Hierarchical systems
     - 4.1.3 Systems of computerized decision support
     - 4.1.4 Multivalued logic (fuzzy and rough sets): rough sets (10)
   - 4.2 Soft (sociological, managerial) systems science and methodologies
     - 4.2.1 Systems thinking and soft systems methodologies: systems thinking (19); systems approach (18); systems concepts (10); soft system methodology (3); systemic thinking (2);
     - 4.2.2 Integration of social information in knowledge: informational revolution (8)
5. Education and knowledge science,
   - 5.2 Education in knowledge sciences
     - 5.1.1 Knowledge creators
     - 5.1.2 Knowledge coordinators: coordinator (1),
     - 5.1.3 Inter-school educational program: degree programs (18), knowledge management education (4), curriculum development (2), education for innovation, integrated science and technology course
   - 5.2 Distant and electronic education
     - 5.2.1 e-learning

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6. Management of technology
   - 6.1 Theory of technology management: management of technology (1),
   - 6.2 Technology assessment
   - 6.3 Technology foresight: technology forecasting (7), transportation fuel cell forecast (1),
   - 6.4 Technology roadmaps: roadmapping (45), roadmapping process (30), technology roadmapping (29)
7. Technology creation
   - 7.1 Theory and philosophy of technology: definition of technology (1), philosophy of technology (1), concept creation (16)
   - 7.2 Selected fields of technology creation
     - 7.2.1 Advanced research on biotechnology by knowledge creation theory: Protein interaction (33)
     - 7.2.2 Strategic knowledge creation on super molecule biomaterials: crystal structure determination (4),
     - 7.2.3 Strategic knowledge creation of nano-materials
     - 7.2.4 Research strategy on metal catalyst reaction
     - 7.2.5 Conditions for research and development coordination
   - 7.3 Cooperation with industrial and administrative sectors
8. Diverse related themes: Time series (142), machine learning (48), model selection (30), coreference resolution (16), workflow for process analyses (1), similarity measure (39), association rule (30), domain knowledge (11)

The above classification is naturally not absolute nor the ultimately final; it might be further enhanced and corrected as new data will become available.

7. Side-Views: Other Perspectives and Ontological Approaches

- Either before our work or at the same time, there are some related works in other perspectives for building an ontology or taxonomy, mostly in terms of knowledge management.
- Dr. Totok H. Wibowo (2006a, 2006b), a postdoctoral research fellow of COE Center, worked with other two colleagues to construct a Knowledge Map for the faculty members of School of Knowledge Science (KS) – using only top-down approach;
- In order to distinguish and describe KM technologies according to their support for strategy, Andre Saito et al. (2007) employed an ontology development method to describe the relations between technology, KM and strategy, and to categorize available KM technologies according to those relations. This study focused particularly on two sub-domains of the KM field: KM strategies and KM technologies – also using only top-down approach;
- Kun Nie (2007) is currently working towards a domain analysis of knowledge management as an organizational activity. He is trying to use domain analysis method to describe what KM really is and what is meant by KM. Domain analysis includes four main steps (Bjørner, 2006):

➢ Step1: Collecting domain knowledge/expert knowledge

➢ Step2: Simple data analysis and visualization of keyword relationships

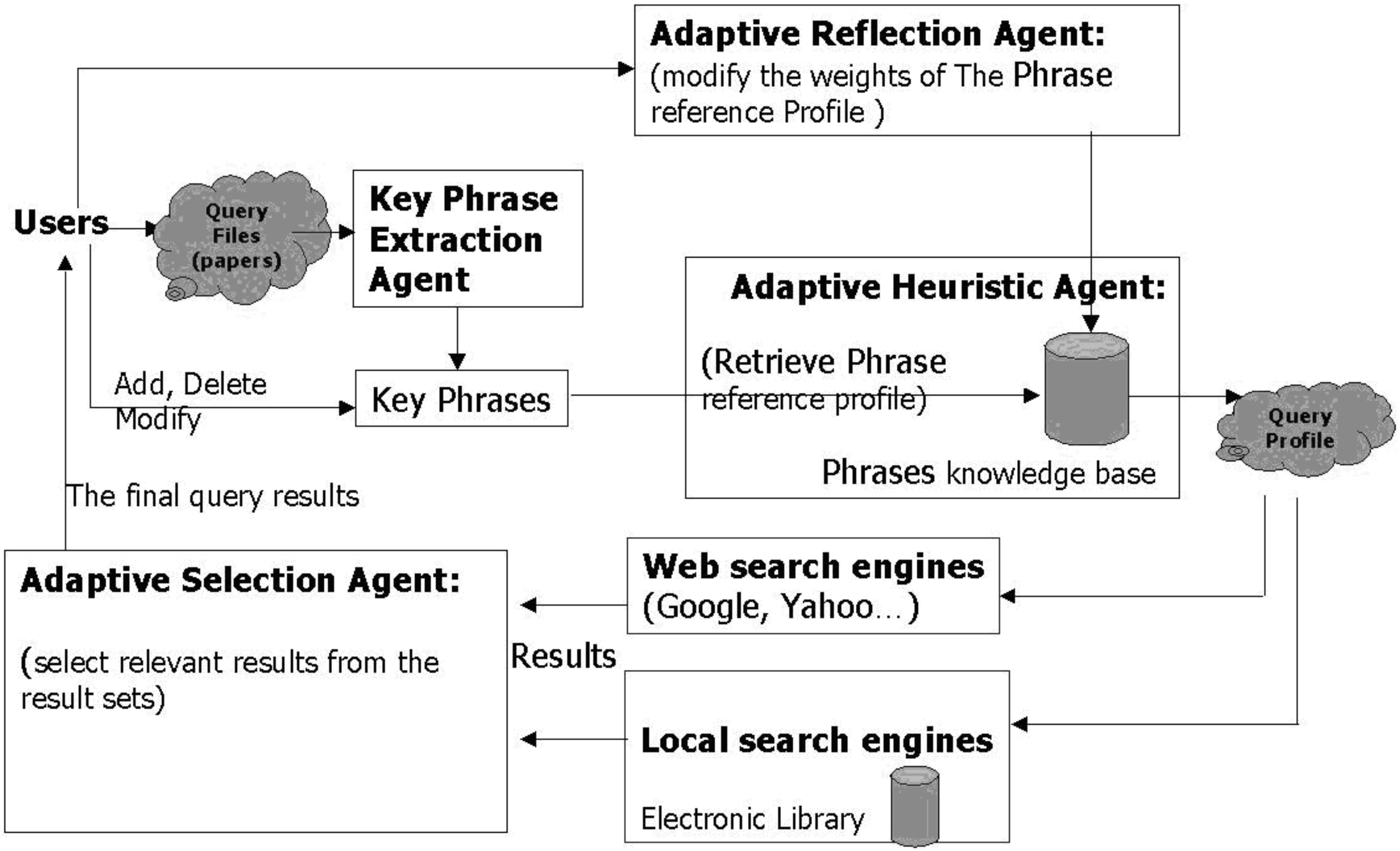
➢ Step3: Applying domain analysis (distribute the keywords in terms of the concepts of Entities, Events, Functions, Behaviours, Support Technology, Objectives, and Application)

➢ Step4: Results and conclusion

8. Applications: Adaptive Hermeneutic Agent (AHA) and Mind Mapping

- On the basis of the *Triple Helix Model,* in order to understand what aspect of knowledge creation process we should consider first and particularly, we conducted a survey at JAIST. Some specific diverse requirements as well as important factors have been discovered through the survey study, see (Tian and Nakamori 2005), (Tian et al. 2006). According to the survey results, one of important requirements for researchers is "plentiful information and knowledge resources for research". It confirmed the importance of the basic process of scientific knowledge creation — *Hermeneutics*.
- On the basis of requirements of users (researchers) and the phenomenon of *Hermeneutics,* a software tool for information and knowledge retrieval was designed, see (Ren et al. 2007), in order to help researchers in gathering and interpreting relevant knowledge or research materials. This software tool is called ***Adaptive Hermeneutic Agent (AHA)*****.** The AHA is equipped with a simple and intuitive search interface and uses familiar search syntax, such as used by popular search engines (like Google, Yahoo). The search support can be extended to the definition of queries that will be automatically executed by the system with a fixed period of time.
- ***The definition of a query by the user is helped by ontological information; actually, the ontology described above is used in AHA as a basis of defining queries*** that can be selected from this ontology, supplemented or modified, for example, by adding new keywords that are relevant to the searched topic. After the query is executed, the AHA can also filter the obtained results by using a reinforcement learning approach that relies on a profile of the user's interests. The AHA could also use a visual interface for the clustering and graphical presentation of search results. The following figure presents the modular structure of the AHA:

8. An Application: Adaptive Hermeneutic Agent (AHA), 2



8. An Application: Mind Mapping

- A Mind Map is actually a tree-structured ontology, constructed entirely in a top-down, intuitive way – see e.g. Kądzielski (2007), DSTIS Conference.
- Thus, Mind Mapping can serve as a tool helping in construction of the top-down part of a full ontology; the actual problem is to connect a Mind Map with the bottom-up part of keyword clusters.
- The natural way is to construct a Mind Map by a group of experts, then to show them results of a preliminary keyword analysis and clustering, ask them to provide names for the clusters and connect these clusters to the top-down Mind Map.
- This way will be tested in detail at the National Institute of Telecommunications in Warsaw, Poland.

9. Conclusions

- There are many contemporary models of knowledge creation processes, but an essential feature of them is the combination of tacit (intuitive, expert) and explicit (rational, resulting from data) knowledge.
- A process of constructing ontology of the 21st Century COE Program *Technology Creation Based on Knowledge Science* was presented together with one of possible applications – helping in the development of an adaptive hermeneutic agent (AHA).
- The construction of ontology is a complex, multidimensional process; we must combine bottom-up approaches (from recorded documents) with top-down processes (from intuitive hermeneutical horizon), also look from diverse perspectives to improve the final product.
- Nevertheless, the effort spent on ontology construction is profitable in terms of diverse possible applications (also in management) and of a creative illumination and enlightenment.
- An open question is what tools might be used to support the interaction between the top-down (expert, intuitive knowledge) and bottom-up (explicit knowledge mined from data). One of possible answers is a creative use of Mind Mapping.