Cognitive Style Affecting Visual Ontology Design

KOMET Project Results

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Abstract: The paper presents the main results of research performed within the KOMET (Knowledge and cOntent structuring via METhods of collaborative ontology design) project that was aimed at developing a novel paradigm for knowledge structuring. By knowledge structure we define the main domain concepts and relations between them in a form of graph, map or diagram. Knowledge structures represent conceptual models. This approach considers individual cognitive styles and uses recent advances in knowledge engineering and conceptual structuring; it aims at creating new consistent and structurally holistic knowledge bases for various areas of science and technology. Research into correlations between the expert's individual cognitive style and the peculiarities of expert's subject domain ontology development has been completed. Implications for practice are briefly delineated.

1 INTRODUCTION

One of the main objectives of the research process is achieving maximal effectiveness from the creation, transfer and dissemination of new knowledge. This effectiveness can be measured by the quality and speed of memorization of the principal concepts of a particular domain and of the relationship between these concepts. Wide evidence exists that the use visual thinking to address the subject of study is positively connected with the quality and speed of memorization, and thus with the effectiveness of knowledge dissemination. Visualization working as a cognitive tool also facilitates communication within research communities.

Special interest in such forms of knowledge codification can be observed in education science, especially within learning where the students are engaged in group knowledge sharing and co-creation processes with continuous feedback.

This paper presents the main results of the KOMET (Knowledge and cOntent structuring via METhods of collaborative ontology design)) project which was devoted to developing methods of using visual ontology design in research and education with regards to the respondents' individual cognitive styles. All the 79 respondents were graduate students of the School of Computer Science of Saint Petersburg Polytechnic University. Almost all the students had 1-2 years' experience of research in computer science, and were in their fifth year of study on the Masters programme. The preliminary results of this study were partly discussed in Gavrilova et al. (2013). The domain "informatics" was chosen as all the students are young professionals in this area. We use the term as synonym to "computer science".

During the last decade, visual knowledge representation has become one of the key considerations in knowledge engineering methodology, and it is strongly associated with ontology design and development. These ontologies, which form a conceptual skeleton of the modelled domain, might serve various purposes such as better understanding, knowledge creation, knowledge sharing, and collaborative learning, problem solving, seeking advice, or developing competences by learning from peers. Recently, the ontological engineering perspective has gained interest in many research domains, such as medicine, business and computer science (Schnotz, Kurschner, 2008; Pfister, Eppler, 2012; Oltramari, Ferrario, 2009; Brochhausen et al., 2011). These studies rely heavily on theory and tools from knowledge engineering analysis that already has a long-standing tradition in the knowledge-based systems domain (Mizoguchi, Bordeau, 2000).

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2 RELATED WORK ON ONTOLOGY ENGINEERING AND MAPPING

This project was targeted at developing a paradigm of data and knowledge structuring with regard to individual cognitive styles, using recent advances in knowledge engineering and conceptual structuring, aimed at creating structurally holistic knowledge bases for various areas of science and technology.

This aim was decomposed into such objectives as:

- research of correlations between the expert's individual cognitive style and the peculiarities of the expert's subject domain ontology development,
- research of formal ontology evaluation methods from the cognitive ergonomics point of view.

The idea of using visual structuring of information to improve the quality of understanding and mentalization among research colleagues is not new (Shneiderman, 1996). For more than twenty years, concept mapping (Grosslight et al., 1991; Sowa, 1984; Jonassen, 1998; Conlon, 1997) has been used to compile maps and mental models that support the process of knowledge sharing.

Many scholars, especially those who also teach sciences courses, operate as knowledge analysts or knowledge engineers by making visible the skeleton of the studied discipline and showing the domain's conceptual structure (Kinchin, De-Leij, Hay, 2005). This structure is frequently represented by a so-called "ontology".

From a philosophical viewpoint, "ontology" is the branch of philosophy which deals with the nature and organization of reality. Ontologies aim at capturing domain knowledge in a generic way and providing a commonly agreed understanding of a domain, which may be reused and shared across applications and groups (Chandrasekaran, Josephson, Benjamins, 1999). Neches and colleagues (Neches et al., 1991) gave the classical definition as follows "An ontology defines the basic terms and relations comprising the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary".

The visual approach to presenting ontologies is not only compact but also comprehensive. It makes ontology a powerful mind tool (Jonassen, 1998; Gavrilova, Voinov, 1996). Ontologies are also widely and effectively used in education, and many learning ontologies have been developed for a number of disciplines (Barros et al., 2002; Gaeta, Orciuoli, Ritrovato, 2009; Gavrilova, Leshcheva, Bolotnikova, 2012).

However, the ontology-based approach to knowledge representation in research and pedagogy is a relatively new development. There are numerous definitions of this milestone term (Neches et al., 1991; Gruber, 1993; Guarino, Giaretta, 1998; Gómez-Pérez, Fernández-López, Corcho, 2004). Many researchers and practitioners have argued about the distinctions between ontology and a conceptual model. We propose that ontology corresponds to the analyst's view of the conceptual model, but is not de facto the formal model itself. There are more than a hundred techniques and notations that help to define and visualize conceptual models. Ontologies are now considered as the most universal

Ontologies are useful structuring tools, in that they provide an organizing axis along which every researcher (or student) can mentally mark his/her vision in the information hyper-space of domain knowledge. Frequently, it is impossible to express all the information as a single ontology. Accordingly, subject knowledge storage consists of a set of related ontologies.

Of course, the ontologies are inevitably subjective to a certain extent, as knowledge by definition includes a component of personal subjective perception; however, using the ontologies developed by others is a convenient and compact means of acquiring new knowledge. At the same time, collective ontology development experience allows the participants in the process to gain the fullest possible understanding of the subject area.

Meta-ontology provides a more general description dealing with higher-level abstractions. Figure 1 illustrates different ontology classifications in the form of the mind map. This representation may be called the knowledge map. Such maps are graphical tools for organizing and representing knowledge. Later in this paper and in our study we will use two particularly appropriate forms of knowledge maps: mind maps (Buzan, 2005) and concept maps (Novak, 1998; Novak & Canas, 2006).

Knowledge maps are now widely used for visualizing ontologies at the design stage, while ontology editors (like Protégé) facilitate the development stage. Research on knowledge mapping in the last 12 years has produced a number of consistent findings (O'Donnell, Dansereau, Hall, 2002). People recall more central ideas when they learn from a concept map than when they learn from

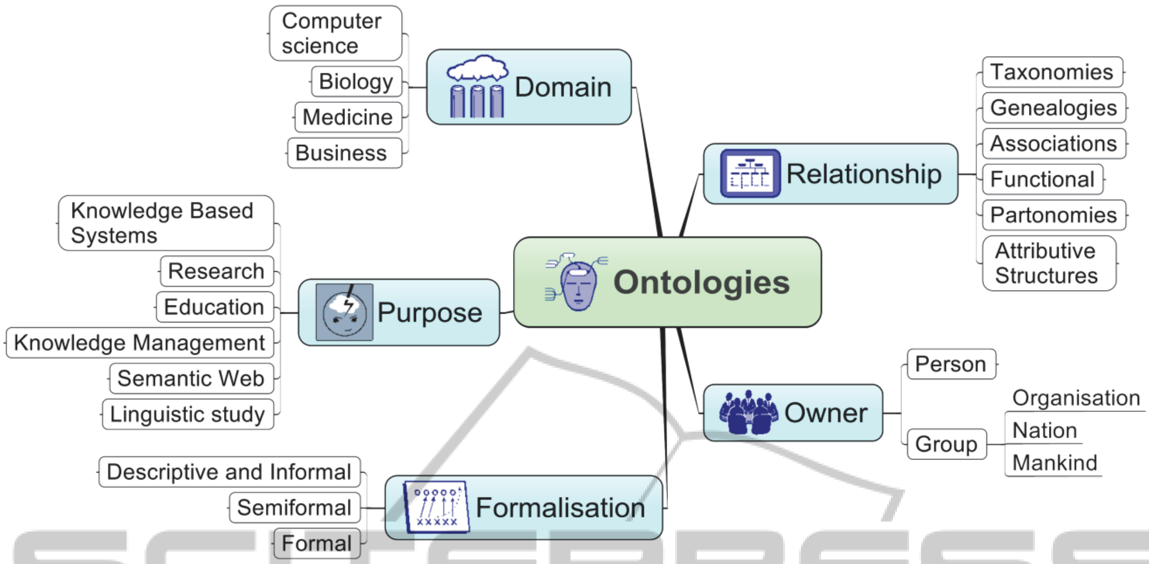

Figure 1: Summarizing the ontology classifications in a mind-map.

text, and those with low verbal ability or low prior knowledge often benefit the most. It seems that knowledge maps reduce cognitive load.

3 COGNITIVE STYLES FEATURES

The cognitive-styles view has acquired great influence within the education field, and is frequently encountered at levels ranging from kindergarten to graduate school. There is a thriving industry devoted to publishing cognitive-style tests and guidebooks for teachers and educationalists (Peterson, Rayner, Armstrong, 2009).

However, we will use the concept of cognitive style only for the predefined aim. As the aim of the KOMET project was to develop a paradigm of structuring data and knowledge with regard to individual cognitive styles, we had to choose the appropriate features of cognitive style.

The cognitive styles explain and describe how an individual acquires knowledge and processes information. The cognitive styles are related to problem solving, and generally to the way that information is acquired, structured and used.

Among the main features of cognitive style (Hayes, Allinson, 1998) we can name:

- field dependence versus field independence
- impulsivity versus reflection
- narrowness versus width of the categories
- rigidity versus flexibility
- levelling versus sharpening
- scope of cognitive equivalence
- visual/audio/kinesthetic preferences.

Three characteristics have been chosen from the plethora of cognitive style characteristics described in the literature (Kholodnaya, 2004): field dependence/field independence (FD/FID), impulsivity/reflection, and narrowness/width of the category.

According to the definition by Witkin (Witkin et al., 1977), FD/FID is "a structuring ability of perception". The field-independent style is defined by a tendency to separate details from the surrounding context. It can be compared to the field-dependent style, which is defined as a relative inability to distinguish detail from other information around it. The FD/FID characteristic can be interpreted as a proxy of the structuring capability of an individual mind. The characteristic of this style does influence the structuring process as a whole (e.g. ontology development "from scratch"), and even more it affects the restructuring process (the merging of individual ontologies). FD/FID exerts considerable influence on the collective problem-solving process. In dyads where members have cognitive styles differentiated by the FD/FID characteristic, the final solution is usually closer to the variant suggested by the FID participant. The FID dyads experience difficulty in developing common decisions on arguable points, while the FD dyads are more successful in coming to agreement in collective problem solving.

Psychologists in our research group were used to working with on-line text based on the popular modification of Witkin's method of "embedded figures" which is aimed at the search for a simple figure hidden within the complicated one (Witkin, 1971).

The impulsivity/reflection characteristic considers the amount of information collected prior to making a decision: impulsive individuals are able to make decisions on a considerably bounded information basis, while the reflective individuals are more inclined to make decisions considering completely full information on the respective situation. For assessing the respondents' impulsivity/reflection features, the "similar pictures comparison" (Kagan, 1966) method has been used.

As for the narrowness/width of the category, the main difference between the extreme poles of this characteristic is that narrowly categorizing individuals are inclined to restrict the area of application of a certain category, while the broad categorizers are, conversely, inclined to include a plethora of more-or-less related examples into a single category. The psychologists that help us with the experimental part advised us to use a modification by Pettigrew (1958) and Fillenbaum (1959): their method of so-called "average judgment". The procedure is based on respondents' opinion on the minimum, average and maximum evaluations of a concept or category. It is advisable to keep all the given values.

4 METHODOLOGY

The research into an expert's individual cognitive style and ontology development objective was divided into four consecutive phases:

1. Identifying the significant individual cognitive style characteristics on the basis of the on-line testing results, using the software ONTOmaster-TECOS (http://ontomaster.ru) developed in PHP and Java Script by Elena Kotova and Andrew Pisarev (Kotova, 2013).
2. Creating the "informatics" research domain ontologies using the Protégé tool (Protégé).
3. Informal assessment and formal automatic estimating the ontology metrics using the COAT software environment (Gavrilova, Bolotnikova, Gorovoy, 2012).
4. Performing statistical analysis in order to find out significant relationships between the young researchers' (experts') individual cognitive style characteristics and the ontology metrics.

The second phase of the research was performed using the same test sample of students and included ontology development in/with the use of the Protégé tool. All the tested students were given the task of developing an ontology for the informatics domain. They did it by using visual mapping approach.

The quality of the developed ontologies was assessed by two methods:

- An expert method, where the ontology analyst and domain experts (both professors in computer science) assessed the quality by such criteria as simplicity, completeness, imbalance, relevance and some other.
- A formalized method, where any ontology was assessed by a set of quantitative metrics using COAT software.

The formalized method was preferable as it was free from experts' and analysts' subjective interpretations and had the potential to be automated.

5 COGNITIVE ERGONOMIC METRICS

In our research the developed ontologies were assessed by an augmented set of metrics (e.g. minimal depth, absolute width, etc.) suggested in Bolotnikova, Gavrilova and Gorovoy (2011). In evaluating the quality of the designed ontologies, the following two aspects are most important: (1) correctness and depth of reflection of the subject domain, and (2) ergonomic aspect of the ontology representation from the point of view of quality and human speed of perception.

The notation used to describe the metrics is the following:

"g", a graph representing an ontology; the concepts (classes and exemplars) of the ontology are the graph nodes, the relationships between the concepts are the graph edges;

"G", a set of all the nodes g;

"E", a set of all the edges g.

A minimal depth:

$$m = N_{j\in P}\ ,\quad \forall i(N_{j\in P} \leq N_{i\in P}) \qquad (1)$$

where $N_{j\in P}$ and $N_{i\in P}$ are the path lengths j and i from the set of paths P of the graph g.

90% line depth:

$$m = P_{90}(N_{j\in P}) \qquad (2)$$

where $P_{90}(N_{j\in P})$ is a 90% percentile of the graph depth (possible value of the graph path length, not exceeding the length of 90% of the graph paths).

An absolute width:

$$m = \sum_{j}^{L} N_{j \in L} \tag{3}$$

where $N_{j \in L}$ is a number of nodes of degree j from the set of nodes L of the graph g.

Complexity metric:

A number of nodes with multiple inheritance to the set of all the graph nodes:

$$m = \frac{N_{v \in MI}}{n_G} \tag{4}$$

where $MI = \{v \in G | \exists a_1, a_2 (isa(v, a_1) \wedge isa(v, a_2)\}$ is a set of all the graph nodes with more than one "is-a" relationship arc, $N_{v \in MI}$ is a number of all the elements of this set, n_G is a number of the graph nodes.

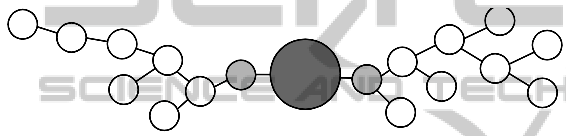

Figure 2: Example of narrow and deep ontology structure.

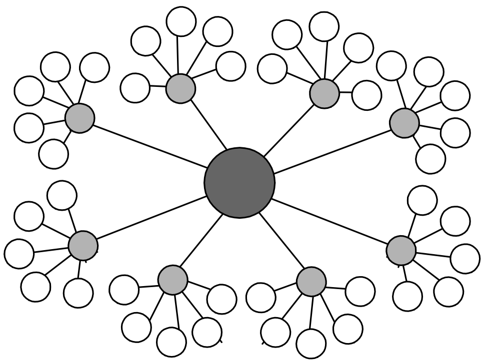

Figure 3: Example of wide ontology structure.

Many aspects affect the quality of ontology from the cognitive point of view. The COAT software environment provides calculation of more than 20 metrics. Metrics of this kind were first proposed by the research group of Aldo Gangemi (Gangemi et al., 2006). The ontology evaluation based on these metrics is formal but it helps to assess the ontology quality. The complete list of metrics was presented in detail in two works (Bolotnikova, Gavrilova, Gorovoy, 2011; Gavrilova, Bolotnikova, Gorovoy, 2012).

These metrics can help to understand what should be corrected in the description of the subject domain in order to improve it from the point of view of cognitive ergonomics or better perception. Thus it is supposed that each next version of the ontology will be better and it can be perceived faster by users.

The metrics can also be used in evaluating ontologies of the same subject domain produced by different people/teams. The calculated metrics help to estimate which of them is better from the point of view of cognitive ergonomics and to choose the best of them if the evaluations of other important criteria differ insignificantly. Figures 2 and 3 show different types of ontology structures from described perspective point of view.

6 MAIN HYPOTHESES

As mentioned in the introduction, the research sample consisted of 79 students, enrolled in the intelligent systems development course. All the tested students were given the task of developing an ontology for the informatics research domain. Due to the professional specificity of the sample, a bias toward narrow, reflective and field-independent test persons was found in the sample. However, a statistically significant Spearman's negative correlation between the FID score and the time of the first answer in the Kagan was calculated, showing that the sample was dominated by the fast FID and slow FD respondents.

On the basis of the literature review and the practical ontology development experience, the following hypotheses are suggested:

Hypothesis 1. Individuals belonging to the FID extreme point of the FD/FID cognitive style characteristic tend to have highly developed cognitive structuring capabilities; thus, the quality of ontologies developed by the FID individuals would be higher.

Hypothesis 2. Impulsive individuals tend to develop superficial ontologies lacking sufficient categorization in the upper level, while the reflective individuals tend to develop deeper ontologies.

Hypothesis 3. Ontologies developed by the individuals described as "imprecise" in the Kagan impulsivity/reflectivity test results tend to be more complex.

Hypothesis 4. The "narrowness/ width of the category" cognitive style characteristic exerts significant influence on the ontology width: the "wide categorizers" tend to develop broader ontologies.

Table 1 presents a part of the two series of testing results. It describes the correlation coefficients for several metrics and main parameters of cognitive style:

- I/R — impulsiveness/reflexivity and
- NC/WC — narrowness/width of category.

The correlation between the cognitive style and ontology metrics values was assessed by Spearman's coefficient (rank correlation). The significant correlation between the metrics and such features as field dependence/ field independence was not found, that is why it is not presented in the table. Empty cells in the table mean that no correlation was found.

Hypothesis 1 was not confirmed, as no significant correlation between the FD/FID metric and the quality of the ontologies was found; this result gave rise to optimistic feelings about the whole project, as it shows that it is possible to teach any individual to develop ontologies of a high quality.

Hypothesis 2 was partially confirmed: the "90% line depth" metric demonstrated significant positive correlations with the time of the first answer in the Kagan test, thus showing that reflective test persons tend to develop deeper ontologies; however, no significant negative correlation between the time of the first answer and the ontology width was found.

Hypothesis 3 was confirmed, as the number of mistakes in the Kagan test demonstrated a significant positive correlation with the values of the "Average number of parents of a graph node" metric that characterizes the ontology complexity.

Furthermore, the number of mistakes in the Kagan test demonstrated significant positive correlations with the metrics of the "Minimal depth of the ontology" and the "Families branching coefficient" and significant negative correlation with the weighted leaves branching coefficient.

Hypothesis 4 was fully supported: the broad categorizers developed bigger ontologies in terms of the number of concepts, achieved mainly by the greater number of "children" of each parent concept.

Respectively, the results of the "Average judgments" test demonstrated significant correlations with such metrics as the "Average ontology width", "Number of leaves", "Absolute cardinality of families". These results also demonstrated significant correlation with the root-mean-square deviation of the average ontology width. This result shows that the number of concepts belonging to the neighbouring levels and to different branches is significantly different, indicating imbalance in the ontologies developed by the wide categorizers.

Despite the objectivity of the quantitative metrics-based method of ontology assessment, this method has the significant drawback of being too formalized and lacking semantic analysis elements.

Having augmented the quantitative metrics-based analysis by a semantic analysis performed manually, we found that the ontologies developed by the field-independent test persons tend to have simpler and clearer structure. However, this simplicity and clarity tends to be achieved by truncating the concepts that do not fit into the developed ontology, thus sacrificing the ontology's completeness and integrity for formal logical consistency.

So, the following relationships between the respondent' individual cognitive styles and the peculiarities of respondents' subject domain ontology development have been identified as a result of the research:

Table 1: Correlation matrix illustrating the correspondence between ontology metrics and the cognitive styles' indices.

Metrics	**Test results**		
	I/R		**NC/WC**
	The time of the first answer	**The number of mistakes**	**The size of the category**
Number of classes			0,44
Number of leaves			0,46
Absolute depth			0,39
Minimum depth		0,54	
90th percentile depth	0,34		
The average width			0,48
The standard deviation of the relative width			0,48
Average number of parents of a graph node		0,47	
The absolute cardinality of families			0,44
Branching factor		0,50	
The absolute cardinality of leaves			0,46
The weighting factor branching leaves		-0,39	

- Considering the “impulsivity/reflection” scale, the reflective individuals tend to develop deeper ontologies;
- The ontologies developed by the imprecise individuals (as defined in the Kagan test) tend to be more complex;
- The “narrowness/ width of the category” cognitive style affects the ontology branching coefficient, i.e. the ontology width.

7 CONCLUSIONS

This study deals with the conceptual limitations of traditional research communication and proposes using a visual metaphor for illustration and presentation of the research state-of-the art and main findings.

Using visual inspection of the ontology it is possible to detect gaps and misunderstandings in the state-of-the-art knowledge level and cognitive model of the domain knowledge. However, there is as yet little consensus on the useful design and orchestration of such structures. Furthermore, in many cases it is not known what the structure of socially legitimate knowledge patterns looks like, or how a particular instance of a knowledge model deviates from that “ideal” state (e.g. guru’s view) (Cross et al., 2001). However, researchers are individuals, and they may disagree among themselves.

The authors made only a first step in the interdisciplinary research field dedicated to the inquiry into the affect of the expert’s individual cognitive style parameters on the group structuring design activity. Our results are therefore of a preliminary nature.

Our work presents a novel perspective on ontology development from the psychological point of view. Using recent advances in knowledge engineering and a human factors approach, we aim at creating new consistent knowledge bases for various areas of science and education.

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