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Ontology design and individual cognitive peculiarities: A pilot study

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ABSTRACT

The paper presents the main results of the KOMET (Knowledge and cOntent structuring via METhods of collaborative ontology design) project, which aims to develop a novel paradigm for knowledge structuring based on the interplay between cognitive psychology and ontology engineering. By the knowledge structure (a conceptual model) we define the main domain concepts and relations between them in the form of a graph, map or diagram. This approach considers individual cognitive styles and uses recent advances in knowledge engineering and conceptual structuring; it aims to create new, consistent and structurally holistic knowledge bases for various areas of science and technology. Two stages of research have been completed: research into correlations between the expert's individual cognitive style and the peculiarities of the expert's subject domain ontology development; and research into correlations between the expert's individual cognitive style and the group ontology design (including design accomplished by groups of experts with either similar or different cognitive styles). The results of these research stages can be applied to organizing collaborative ontology design (especially for research and learning purposes), data structuring and other group analytical work. Implications for practice are briefly delineated.

1. Introduction

One of the main objectives of research and learning processes 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 visual thinking used 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 is working as a cognitive tool that facilitates communication both in teacher/learner interaction and within research communities.

Special interest in such graphical 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.

Mutual understanding and mentalization in research is of special interest in collective study or discovery. One of the most productive methods of research and learning collaboration promises to be group ontology design. An ontology is a set of definitions we make in understanding and viewing the world (Gruber, 1993). The specific problem being addressed in this work deals with the problem of improving the quality of group or collective ontologies. We are also interested in filling the gaps in understanding the group ontology design process specifics, such as the causes of differentiation between the form and the content of individual ontologies.

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 modeled domain, might serve various purposes such as better understanding, knowledge creation, knowledge sharing and reusing, collaborative learning, problem solving, seeking advice, or developing competences by learning from peers (Chu, Lee, & Tsai, 2011; Jung, 2012). Recently, the ontological engineering perspective has gained interest in many research domains, such as medicine, business and computer science (Brochhausen et al., 2011; Oltramari & Ferrario, 2009; Pfister & Eppler, 2012; Schnotz & Kurschner, 2008).

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, 2003; Mizoguchi & Bourdeau, 2000). The largest number of knowledge engineering research articles has been generated around the theme of descriptive logics and formal foundations of ontology design (Baader, Horrocks, & Sattler, 2005; Kuznetsov, Obiedkov, & Roth, 2007). Our work, however, emphasizes the informal approach

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based on human-centred ontology design processes, an aspect neglected by most of the existing approaches. Several attempts have been made to bridge this gap and ease the overall ontology development process, such as HCOME – Human-Centered Ontology Engineering MEthodology, by Kotis and Vouros (2006); and human-centred ontology design, by Iqbal, Murad, Mustapha, and Sharef (2013).

The tools and techniques developed in the domain of ontology engineering can be applied fruitfully in the field of knowledge structuring and design (Dicheva & Aroyo, 2004; Dicheva, 2008; Knight, Gašević, & Richards, 2006; Schreiber, 2000) and semantic web applications (Davies, van Harmelen, & Fensel, 2002). The idea of using ontologies and visual structuring in research description and introduction has been discussed in many works (Fonesca, Davis, & Camara, 2003; Sherlock, 2000; Tansley & Tolle, 2009; Yudelson, Gavrilova, & Brusilovsky 2005) and is now being implemented in several research projects and software tools (Bard & Rhee, 2004; Hevner, 2007).

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 that use group visual ontology design in educational purposes, with regard to the respondents' individual cognitive styles. The group ontology design was tested in the medical domain by a smaller group (Gavrilova, Ravodin, Bolotnikova, & Kotko, 2012) and computer science (informatics) domain by a larger group of participants (Gavrilova, Leshcheva, Bolotnikova, Blagov, & Yanson, 2013). In the larger group of 79 respondents, all the participants were graduate students of the School of Computer Science of Saint Petersburg Polytechnic University. Almost all had 1–2 years' experience of research in computer science, and were in their fifth year of study, on the Masters programme. The domain "computer science" was chosen as all the students are young professionals in this area. We use the term synonymously with "informatics".

The paper is organized as follows. First, it describes the concept of ontology, with an emphasis on the visual approach to ontology design. Section 2 concentrates on the theoretical background, with sub-Section 2.1 describing ergonomic metrics and their purpose and sub-Section 2.2 providing an overview of cognitive styles and the tests used to assess them. Section 3 presents our human-centred research paradigm and framework, and Section 4 the results obtained in the study of the relationship between cognitive styles and the peculiarities of individual development of ontologies. Section 5 introduces the main results of collective ontology development, taking into account the cognitive styles of participants. Finally, some conclusions are drawn and future work is outlined.

2. Theoretical background of ontology engineering: visual bias

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 (Conlon, 1997; Grosslight, Unger, Jay, & Smith, 1991; Jonassen, 1998; Sowa, 1984) has been used to compile maps and mental models that support the process of knowledge sharing.

Many scholars, especially those who teach science 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".

There are numerous other definitions of this milestone term (Gruber, 1993; Guarino & Giaretta, 1998; Gómez-Pérez, Fernández-López, & Corcho, 2004). Together, these definitions clarify the ontological approach to knowledge structuring while giving sufficient freedom for open-ended, creative thinking. Many researchers and practitioners have argued about the differences 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.

The visual approach to presenting ontologies is not only compact but also comprehensive. It makes ontology a powerful mind tool (Jonassen, 1998).

By definition, ontology is a declarative representation of a certain precise domain specification, including the glossary of the domain terms and the logical expressions describing the meanings and the relationships of these terms, thus allowing structured sharing of knowledge related to the domain (Gruber, 1993). The relationships between the concepts in ontologies can be of different types, e.g. "is", "has part", "has a property of", etc. The concepts and relationships are universal for a certain class of objects in a subject area. Conceptual model visualization methods such as ontologies are also widely and effectively used in education, and many learning ontologies have been developed for a number of disciplines (Barros, Verdejo, Read, & Mizoguchi, 2002; Chi, 2009; Dall'Alba and Barnacle, 2007; Fonesca et al., 2003; Gaeta, Loia, Mangione, Miranda, & Orciuoli, 2014; Gaeta, Loia, Orciuoli, & Ritrovato, 2015).

However, the ontology-based approach to conceptual knowledge representation in research and pedagogy is a relatively new development. Ontologies are now considered as the most universal and shareable forms of such representation and modeling. There are more than a hundred techniques and notations that help to define and visualize conceptual models.

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. Some problems may occur when moving from one ontological space to another, but constructing group meta-ontologies may help to resolve these problems.

For both formative and summative assessment purposes, creation of ontologies and explanation of the processes involved can clearly indicate the extent and nature of the knowledge and understanding. Knowledge entities that represent the static knowledge of the domain are stored in hierarchical order in the knowledge repository and can be reused by others. At the same time, those knowledge entities can be reused in descriptions of the properties or a methodological approach as applied in the context of another related knowledge entity.

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 (mind maps (Buzan, 2005) and concept maps (Novak, 1998; Novak & Cañas, 2006)). Fig. 1 (Gavrilova & Kudryavtsev, 2011) illustrates different ontology classifications in