Expert Systems
The Journal of Knowledge Engineering

Article

DOI: 10.1111/j.1468-0394.2008.00470.x

Soft ontologies, spatial representations and multi-perspective explorability

Mauri Kaipainen, Peeter Normak, Katrin Niglas, Jaagup Kippar and Mart Laanpere
KERG Knowledge Environments Research Group, Tallinn University, Estonia
E-mail: mauri.kaipainen@tlu.ee

Abstract: *It is against the dynamically evolving nature of many contemporary media applications to be analysed in terms of conventional rigid ontologies that rely on expertise-based fixed categories and hierarchical structure. Many of these rely on sharing 'folksonomies', personal descriptions of information and objects for one's own retrieval. Such applications involve many feedback mechanisms via the community, and have been shown to have emergent properties of complex dynamic systems. We propose that such dynamically evolving information domains can be more usefully described by means of a soft ontology, a dynamically flexible and inherently spatial metadata approach for ill-defined domains. Our contribution is (1) the elaboration of the so far intuitive concept of soft ontology in a way that supports conceptualizing dynamically evolving domains. Further, our approach proposes (2) a whole new mode of interaction with information domains by means of recurring exploration of an information domain from multiple perspectives in search of more comprehensive understanding of it, i.e. multi-perspective exploration. We demonstrate this concept with an example of collaborative tagging in an educational context.*

Keywords: folksonomies, tagging, exploration, multidimensional scaling, soft ontologies, ontospaces, interactive media, multi-perspective exploration

1. Introduction

It is against the dynamically evolving nature of many contemporary media applications to be analysed in terms of conventional rigid ontologies that rely on expertise-based fixed categories and hierarchical structure. In particular, applications of the second-generation Internet, popularly referred to as Web 2.0, are typically characterized by user-contributed content and metadata. Many of these, e.g. user content sites like *Flickr* and *YouTube* and shared bookmarking applications like *Del.icio.us*, rely on 'folksonomies', i.e. the result of personal free tagging of information and objects for one's own retrieval in a social environment (Vander Wal, 2004). Such applications involve many feedback mechanisms via the community, and have been shown to have emergent properties of complex dynamic systems (e.g. Golder & Huberman, 2005; Halpin & Shepard, 2006).

We propose that such dynamically evolving information domains can be more usefully described by means of a *soft ontology* (SO) (Aviles Collao *et al*., 2003), a dynamically flexible and inherently spatial metadata approach for ill-defined domains. Our contribution to the SO discussion is (1) the elaboration of the so far intuitive concept in a way that supports conceptualizing dynamically evolving domains. Further, our approach proposes (2) a whole new mode of interaction with information domains by means of recurring *exploration* of an information domain from *multiple perspectives* (multi-perspective exploration, MPX) in search of more comprehensive understanding of it, and thereby suggests new potential for interactive media and online communities. We demonstrate this concept with an example of collaborative tagging in an educational context.

2. Soft ontologies

Soft ontologies (SOs) are flexible sets of metadata that describe a domain of information by means of spatially conceptualized properties, *ontodimensions*, that jointly define the *ontological space* (ontospaces) in which an information domain 'is' or exists. We interpret that an SO is commensurate on a general level with Gruber's (1993) definition of an ontology as 'a specification of conceptualization'.

Individual items of a domain are characterized by values representing the degree of salience of each ontodimension (Aviles Collao *et al.*, 2003). SOs are *open-ended* in the sense that they allow the creation of new ontodimensions, as well as the deletion of existing ones. Further, they are *flat*, i.e. not structured *a priori* by multilevel hierarchies. Instead, such a specification of an information domain can be interpreted as a priority order of organizing criteria, which in this sense corresponds to a hierarchical conceptualization of a conventional ontology. The difference is that the implied hierarchy is malleable and interactively explorable instead of being rigidly fixed *a priori*.

Because of these characteristics, we suggest that SOs are better suited to modelling dynamically evolving information domains, such as those of *collaborative tagging* practices described by, for example, Vander Wal (2004) and Mathes (2004), than conventional rigid hierarchical ontologies. Relying on this conceptualization, we propose (1) a formal definition of SO, which in turn supports (2) exploration of multiple perspectives to such domains by allowing each property to be taken into account to a degree chosen by the user.

Formally, an SO is an open-ended coordinate system $O = [x_1, x_2, \ldots, x_m]$ that defines shared m-dimensional ontospace A, i.e. the shared and expanding vocabulary of describing a domain D. Each item i of domain D can be represented by an m-tuple $\boldsymbol{A}_i = [a_{i1}, a_{i2}, \ldots, a_{im}]$, were a_{ij} stands for the salience of property x_j with respect to item i, spatially interpreted as the position of item i with respect to *ontodimension* x_j. In collaborative tagging applications, a_{ij} may represent the strength of tag j for item i calculated, say, by scaling the frequency of tag j for item i between 1 and 0.

From a more general semantic point of view, a_{ij} allows a range of reading options depending on the nature of that property, e.g. *presence*, *proximity*, *probability*, *strength-of-relation* or *agreement* of item i with x_j. As another interpretation, following Zadeh (1965), a_{ij} can be seen to stand for the *degree of membership* of item i in one-dimensional fuzzy set x_j.

3. Reduction of dimensionality as a model of sense-making

Several fields of research suggest quite consensually that organizing items to spatially laid-out clusters by their mutual similarity relations is the most natural strategy for making sense of the environment's complexity. On the neural level, adaptive cortical maps, such as *tonotopies* (e.g. Hood, 1977; Wessinger *et al.*, 1996), *somatotopies* (e.g. Merzenich *et al.*, 1988; Wall, 1988) and spatial representations (Olton *et al.*, 1977), altogether suggest that mapping from multidimensional experiential space onto the cortical surface, i.e. *dimensionality-reducing neural processes*, is the physiological means of managing sense of the environment.

As to language, Lakoff and Johnson have elaborated a theory according to which the very core elements of language and cognition are spatial metaphors (e.g. Lakoff & Johnson, 1980, 1999; Lakoff, 1986) originating from bodily–motor–spatial experiences, such as the expressions '*under-stand*', '*get-around*' or '*up-load*'. Further, in his *geometrical approach* to thought, Gärdenfors (2000, p. 258) proposes that spatial representations can model both dimensionality-reducing neural processes, such as discussed above, and a range of symbolic conceptualizations, and can thereby serve as an explanatory bridge between the neural and symbolic domains. Kohonen's self-organizing map algorithm (1982), in turn, must be credited for the particular epistemological value of demonstrating how two-dimensional or three-dimensional representations, which are reminiscent of cortical projections on one hand and the result of order-preserving statistical algorithms on the other, can be approximated with an extremely simple computational abstraction of adaptive neuronal activity.

Based on the above, our approach relies on the general assumption that a representation of complex information on a low-dimensional space can be considered a rather universal model of sense-making, to be referred to as the assumption of *dimensionality reduction*. Various algorithms exist for the purpose of revealing the structure of a multidimensional data set by producing approximating similarity-preserving representations of lower dimensionality. The most generic and well-known algorithms of these fall into the family of multidimensional scaling (MDS) (e.g. Kruskal & Wish, 1978; Kotz & Johnson, 1985). MDS algorithms represent items characterized by points on a low-dimensional (usually two-dimensional) Euclidean space so that the proximity of points reflects their mutual similarity. In our treatment we generally refer to MDS even though other algorithms can also be accommodated with this formalization.

Spatial representation of a finite set of items $\sigma = \{i_1, i_2, \ldots, i_n\}$ of a domain D by points in a lower-dimensional space B can be considered as a mapping R_σ: $\{A_{i_1}, A_{i_2}, \ldots, A_{i_n}\} \rightarrow B$. In order to satisfy the conceptualization of an SO it is necessary to introduce means that allow each property to be taken into account to the degree chosen by the user. For this purpose we define weights $\boldsymbol{P} = [p_1, p_2, \ldots, p_m]$, $0 \leq p_j \leq 1$, for corresponding ontological dimensions x_j of A. P is conceived of as an *ontological perspective*, defining transformation P of A as $P[x_1, x_2, \ldots, x_m] = [p_1 x_1, p_2 x_2, \ldots, p_m x_m]$.

It should be emphasized that in our conceptualization A itself is always a result from some *a priori* choice of perspective, i.e. a choice of a particular set of salience weights out of the multitude of possible sets. We argue that some ontological perspective P is always present, at least implicitly, typically due to the choice of the dimensions, or by means of statistical preprocessing, scaling, standardization or weighting. Therefore P should not be considered as an additional factor but rather as an intrinsic term. In our approach it is made explicit, accessible and negotiable by the user, instead of accepting it as given by the expert (author, designer, editor, owner etc.) of the domain. We claim that in this way our formalization reflects new ownership relations of Web 2.0 media.

Thus, a spatial representation $R_{P,\sigma}$ of a finite set of items $\sigma = \{i_1, i_2, \ldots, i_n\}$ of a domain D consists of the transformation P: $A \rightarrow A$ followed by application of an algorithm that preserves similarity patterns from an m-dimensional domain A to some q-dimensional domain B, $q \leq m$. In our application, P is used as the means of determining the desired degree to which each ontological dimension should be prioritized by a spatial representation. For the user-chosen values $0 \leq p_j \leq 1$, the extremes can be interpreted as follows:

$p_j = 1$ reflects the desire to maximize the preservation of the variance along dimension x_j and thereby prioritize the dimension over dimensions with lower values of p, while

$p_j = 0$ reflects the decision to totally ignore the variance along the dimension.

Thus, it should be noted that transformation P will not preserve the distributions of all dimensions equally, but distorts some more than others.

The potential of expressing the priority order of ontological dimensions in terms of ontological perspective P is an additional benefit with regard to searches from typical 'folksonomies', in which one either takes any particular tag (ontological dimension) into account or does not.

4. Multi-perspective exploration

To distinguish our approach from standard applications in statistics (e.g. from MDS), we hold that a single representation corresponding to a particular perspective should not be re-

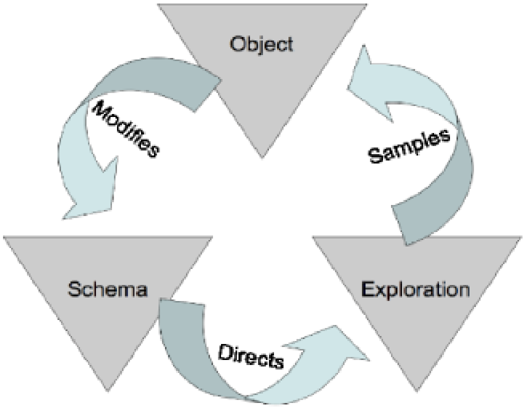

Figure 1: *Neisser's perceptual cycle (adapted from Neisser, 1976).*

garded as more than a *transient* and *partially revealing view of* multidimensionally complex information. We argue that a more profound comprehension emerges in the course of an iterative process of exploring the data from alternative ontological perspectives. As a metaphor that helps to clarify this idea, one can consider a typical architectural design that cannot be fully comprehended just with a two-dimensional visualization, but for any better understanding it is instrumental to see the object from different perspectives using three-dimensional miniatures, computer-aided design visualizations or virtual reality models.

This implies the assumption of some kind of cognitive system that binds together subsequent perceptions. An explanatory framework for what binds subsequent mappings together in the mind is the recursively iterative perceptual cycle of Neisser (1976, pp. 112–113) (Figure 1), in which perceptual *exploration* samples available *information in an object*, of which the perception *modifies the orienting schema*, which again *directs exploration*, then feeding back to exploration, *ad infinitum*.

Reflecting our approach against this conceptualization we propose that the accumulating outcome of the explorative activity is like an *orienting schema* that keeps integrating subsequent representations into increasingly encompassing syntheses of a domain. If this kind of conceptualization is accepted, it is not meaningful in this framework to discuss MPX of SO spaces as an operation or algorithm with a predefined or fixed end condition. It is assumed that the activity of exploration is driven by the purpose of discovering new insights and qualities of the domain, or interdependences of the ontological dimensions. Given that aim, it is then the point of interpretive saturation, i.e. the point when new perspectives will not add anything of substantial importance to the understanding of the domain, when the user may decide to end the process of exploration. However, this end point should be taken only as 'local'.

5. Demonstration

In order to demonstrate the idea of MPX we have developed a prototype application,[1] in which the interface provides a set of sliders for the user to adjust and change perspectives P. The MDS representation $R_{P,\sigma}\colon \{A_{i_1}, A_{i_2}, \ldots, A_{i_n}\} \to B$ is performed and visualized as a real-time response to every interaction the user has with the interface. In the activity of exploration, a dimension to be taken fully into account, i.e. to be given priority as an organization criterion, is assigned the weight 1 (slider to the right) while a dimension the user wants to ignore totally remains with the weight 0 (slider on the left).

In our example we use data[2] from a junior high school students' class work assignment in which they were asked to tag learning materials of a project management course with their own descriptive keywords, creating a kind of 'folksonomy', with the purpose of facilitating knowledge building of the domain of information and to help to identify right materials for reference. For the purposes of the present demonstration, every tag is represented as an ontological dimension, and a learning material document as an item. Correspondingly, the domain is described as a matrix of tag frequencies for every learning material.

We consider two main strategies of exploration that contribute to more profound compre-

[1]*Online demonstration at http://kerg.tlu.ee/demos/multi-perspective-exploration.*

[2]*Data accessible at http://www.tlu.ee/imke/data/ProJuht_EN.txt.*

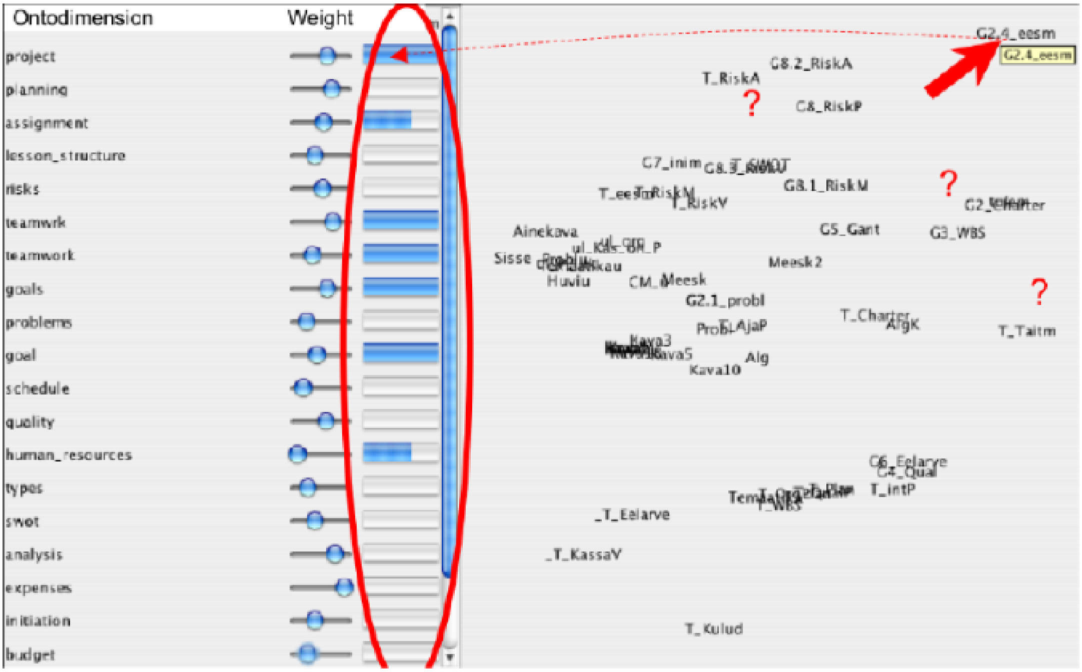

Figure 2: *A high-dimensional representation of the ontospace in the initial stage of a reductive exploration. The values (relative tagging frequencies) of the item pointed to by the cursor are circled. Items that are similar with respect to the chosen perspective are positioned near each other to form similarity clusters. For the search interpretation, the best match is pointed to by the cursor, and near-best hits to be explored are indicated with question marks.*

hension of the domain, i.e. *reductive* and *inductive* strategies. Within both, the observer may either pay attention to the *overall clustering* of the domain, or use the representation as a visualization of a *search result* where the perspective is regarded as a multi-term search key allowing the user to adjust the weight for every particular search key according to its relative importance. In all cases, the user can *promote* or *demote* dimensions at will in the course of iterative exploration, i.e. either increase or decrease their weights relative to other dimensions.

6. Reductive strategies

Reductive strategies start with some given high-dimensional ontospace (Figure 2) that will be scrutinized in order to identify perspectives that are defined by fewer dimensions than the total dimensionality of the ontospace, and from which the domain appears ordered in a way that matches with the orienting schemas, i.e. existing knowledge. This, according to our *dimensionality reduction* assumption discussed above, contributes to better comprehension of the domain.

Involved in reductive exploration, the observer explores ontological dimensions one by one, looking for those whose weights can be demoted without causing additional ambiguity, i.e. overlapping item labels in the overall spatial representation. As a result of every change, a two-dimensional visualization of the similarity cluster representation computed by means of an MDS algorithm appears. The point of saturation is reached when a low-dimensional perspective is identified that results in a sufficiently disambiguated representation.

In the case of the *search interpretation*, the chosen perspective can be regarded as a search key representing the priority order of search

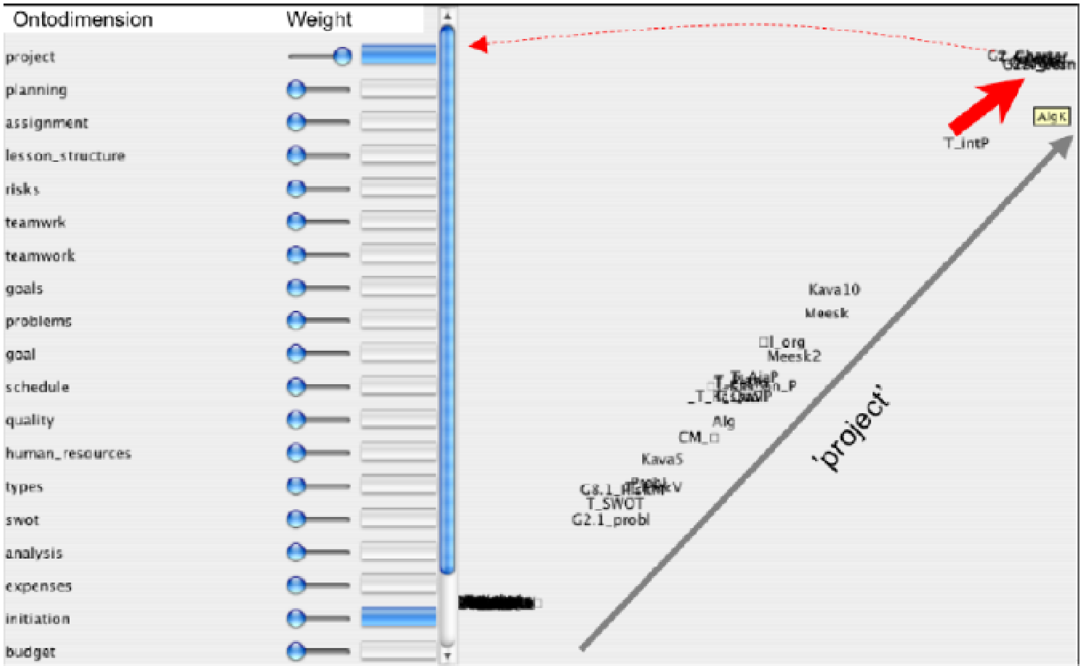

Figure 3: *One-dimensional search as the initial setting of inductive exploration. Full weight is given to the dimension 'project' using the slider interface, and the corresponding value of the item under the cursor is indicated by the horizontal bars. Items with highest values on the dimension 'project' (highest tagging frequency) are piled on top of each other at the top-right corner.*

terms, leaving the overall spatial order as the secondary concern. For this interpretation, the best matching item is displayed at the top-right corner, a design feature of the demonstration software to comply with the convention of reading two-dimensional plottings in statistics. Search results visualized in this way are essentially more informative than standard one-dimensional lists of search outcomes, because the spatial layout supports immediate consideration of the position of the best hit with respect to the next-best ones (indicated by question marks in Figure 2), and allows its superiority over the next-best hits to be estimated as perspectives change in the course of exploration.

7. Inductive strategies

Inductive strategies of exploration are suited for making sense of ill-defined domains with weak or non-existent ontologies, i.e. for building ontologies from scratch. The goal is to identify sets of dimensions, i.e. perspectives, that cluster the domain items in some meaningful and coherent manner with respect to existing knowledge of the domain (schema). The saturation point of this activity is when a compact set of perspectives is recognized that allows making sense of the domain as a whole, while keeping the dimensionality spatially comprehensible.

Starting from no order at all, the activity proceeds by experimenting with dimensions one at a time, and observing the effect of each on the spatial representation using the slider controls to promote or demote dimensions. In them, the data are first clustered with respect to one dimension (Figure 3), and gradually to more dimensions. Initially the visual representation displays clusters of more or less superimposed labels. Additional dimensions may or may not contribute to revealing items obscured by others or by breaking tight clusters into sub-clusters.

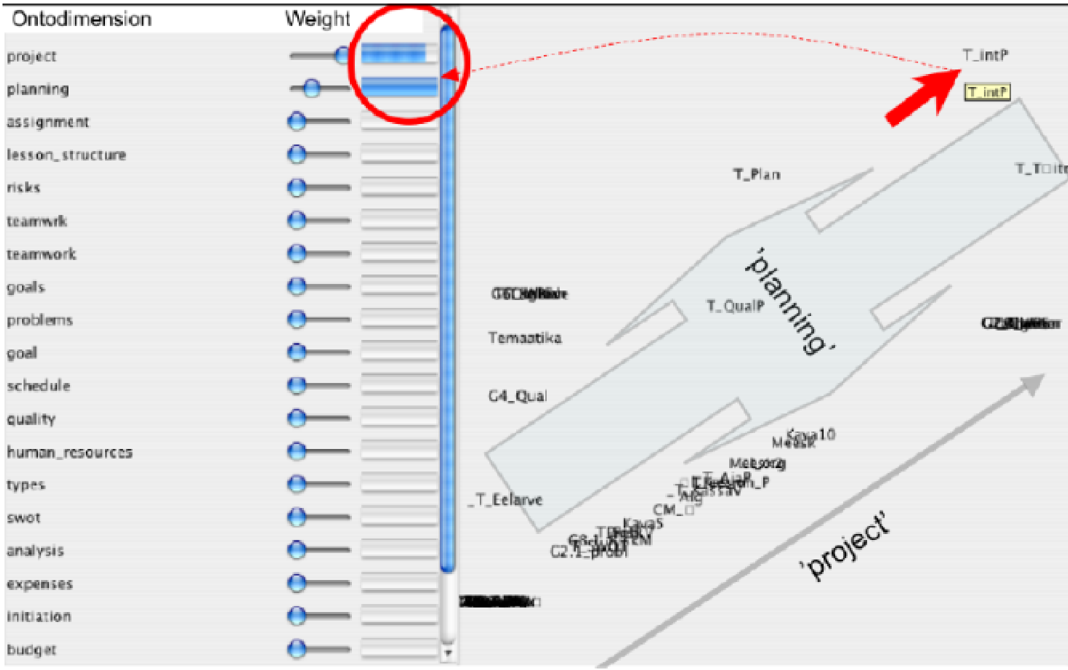

Figure 4: *Additional ontodimension 'planning' is taken into account in addition to 'project', splitting the clusters of Figure 3 (double-ended arrow). The arrow points to the best matching item for the perspective, and the circled bar indicator indicates the respective data, as in Figure 3.*

The visual effect of each added dimension is perceptually self-explanatory, reminiscent of perspective change in the physical world.

As with the reductive exploration strategy, in addition to being an *overall visualization* of the similarity clustering of the domain, a perspective can be interpreted as a *search* for the best-matching item (Figure 4, item pointed at by the cursor).

8. Adding ontological dimensions

Adding new tags, treated in this framework as ontodimensions, at will is the defining characteristic of collaborative tagging practices. Adding dimensions is to be seen as another inductive strategy of making sense of complex information domains in the dimensionality-increasing direction. In this case, an added ontodimension constitutes a request for the community to apply the new tag, or in other words to evaluate content items with respect to the added ontological dimension and thereby provide additional data, which allow the domain to be explored from new perspectives.

In collaborative tagging practices it is a well-recognized problem that contributors often add new tags without checking whether there already exist tags with nearly the same meaning, which eventually leads to the accumulation of synonymous tags. This problem occurs because at present the environments and interfaces typically do not allow easy exploration of the ontospace (tag space). Our approach can be regarded as a suggestion of how the quality of collaborative tagging applications can be improved by supporting the awareness of the community members of the ontospace.

9. Conclusions and implications

The present approach implies new kinds of interactive media, i.e. in which the user interacts directly with the ontology instead of taking for granted an implicit ontology predetermined by somebody else, e.g. the designer or owner of the medium. We have argued that conventional fixed ontologies with hierarchical structure are not optimally suited for the analysis of dynamically evolving domains of information, e.g. those which involve non-constrained collaborative tagging, and we have claimed SOs to be more appropriate for that purpose. In addition to the flexibility of SOs with respect to the dynamically evolving dimensionality, we propose that the inherent spatial representation is their major advantage. On one hand, the latter allows dimensionality-reducing representations, such as those suggested by a range of research results across disciplinary boundaries, which we propose to serve as a universal model of sense-making. On the other hand, it allows dimensionality induction necessary in the case of ill-defined domains.

We have demonstrated two main strategies of exploiting such explorability in a purpose-driven manner: (1) the reductive approach, i.e. identifying a range of perspectives that make sense of the ontospace as selective subsets of its dimensions, and (2) the inductive approach, i.e. iteratively promoting ontological dimensions to construct a comprehensive ontospace, yet with enough dimensions to distinguish domain items in a meaningful way. We argue that it is reasonable to compare the resulting knowledge to the comprehension of concrete artifacts, such as buildings or statues, which are hardly collapsible to any single perspective.

With respect to both strategies, the final outcome is not necessarily a single perspective but rather a range of perspectives that together contribute to overall comprehension of the domain. Beyond the present treatment, different exploration strategies under the two main directions are conceivable.

The concept of MPX is more than just applying one-time spatial visualization to complex content. We claim that the MPX concept supports a new kind of self-directed interactive relationship between the user and abstract content, comparable to navigation in computer-aided design or virtual reality environments. We suggest that the explorative activities addressed above involve construction of mental schemas, i.e. understanding not only the data *prima facie* but also their underlying conceptual ontology via recursive action, in the manner of the Neisserian perceptual cycle, so that the immediate visualization of the exploration facilitates and encourages this dynamic activity.

There is a good reason to assume that making ontologies of abstract information domains interactively explorable allows going 'beyond the information given' in the sense of Bruner (1973). We argue that this type of exploration is comparable to hands-on learning, say in science education, generally considered superior to top-down-dictated teaching, and we propose that the suggested kind of activity will contribute to knowledge building in line with constructivist and sociocultural learning theories, where social negotiation of meaning is considered one of the key mechanisms in human learning. Furthermore, when the ontospace is shared by the members of an online community, as in the case of shared tagging applications, then it is conceivable that MPX will contribute to joint sense-making (Golder & Huberman, 2005, p. 3) and social knowledge building. Bereiter and Scardamalia (2003) have defined knowledge building as a collaborative activity aimed at creation or modification of public knowledge. We argue that combining MPX with the use of discursive knowledge building tools will enhance the quality and efficiency of the collaborative knowledge construction process thanks to spatial visualization of the SO, and also because it facilitates scaffolding (Bruner, 1975) both reductive and inductive strategies of exploration.

The potential application field of MPX beyond collaborative tagging is as broad as the need to facilitate understanding of complex information domains in general. Elsewhere we have introduced MPX as a *research tool* in the context of mixed methods, i.e. hybrids of quantitative and qualitative research (Niglas *et al.*, 2008). As another type of potential application domain, one may consider that any corpus of text documents has an enormous number of hidden ontological dimensions, with respect to which each document is positioned in terms of frequencies of words. Such dimensions can be revealed at request, assuming search functionalities that return counts of word frequencies from the corpus, scaled and normalized in some reasonable way. Given this potential, the user could define his/her private and shareable domain ontologies 'softly' at will and explore them with the method suggested in this paper.

Furthermore, more generally multi-perspective explorability of ontospaces relates to new ownership and intellectual property relations of the 'democratized' web media in terms of explicating the omnipresence of an ontological perspective and making it interactively negotiable rather than taking the media owner's perspective for granted.

Acknowledgements

The work has been funded by European Social Funds, priority 1.1, and by Estonian Science Foundation grants 6148 and 7663. We thank Martin Sillaots for example data and Kaido Kikkas for comments.

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The authors

Mauri Kaipainen

Mauri Kaipainen is Professor of New Media at Tallinn University and Guest Professor of Media Technology at Södertörn University College. He studied education, musicology and cognitive science at the University of Helsinki and earned his PhD in 1994. He has worked with a number of media projects involving topics of learning and cognition, narrative spaces and logics, e-participation and cultural heritage. He has developed the approach of modelling interactive media in terms of knowledge ecologies that involve continuous exchange of conceptual artefacts with dynamically flexible spatially defined ontologies. Following this line, his present research activity is focused on defining the concept of interactively explorable multi-perspective media, particularly suited for the analysis and design of applications for online communities, collaboration and content sharing.

Peeter Normak

Peeter Normak is Professor of Informatics at Tallinn University. He studied mathematics at the University of Tartu and earned his PhD in 1982 from the M.V. Lomonossov Moscow State University. He is studying representations of semi-groups (algebraic automata), problems that belong both to algebra and to theoretical computer science. He has also coordinated a number of research and development projects in mathematical modelling, e-learning and curriculum development.

Katrin Niglas

Katrin Niglas is associate professor of data analysis at Tallinn University. She has taken part in various research projects in the fields of education, social sciences and humanities as an expert in methodology and data analysis and has successful experience in leading several research and development projects. Her main field of scientific interest as well as teaching is research methods and data analysis. After receiving a teacher training diploma and MA degree in Tallinn, Katrin Niglas studied at the University of Cambridge and obtained an MPhil degree in educational research. In her PhD dissertation, defended in 2004 at Tallinn University, she focused on the combined use of qualitative and quantitative methods in educational research. Her continuous work on elaborating mixed methods theory and practice is internationally recognized. She is a member of the editorial board of the *International Journal of Multiple Research Approaches* and a reviewer for Sage Publishers and for *Journal of Mixed Methods Research*. She also holds the post of an international correspondent of IASE (International Association for Statistical Education).

Jaagup Kippar

Jaagup Kippar is a programming lecturer and programmer at Tallinn University. He studied in Tallinn Pedagogical University and graduated with a BSc in natural sciences in 2000, and an MSc in didactics of informatics in 2002. He teaches different web technologies and has significant experience in Java.

Mart Laanpere

Mart Laanpere is head of the Centre for Educational Technology in the Institute of Informatics, Tallinn University. He received his MSc in educational and training systems design from the University of Twente, The Netherlands. He has also studied in the Educational Sciences PhD programme at Tallinn University. He has participated in a number of international R&D projects as a researcher specializing in conceptual design of virtual learning environments and didactics of e-learning.