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Collaborative Knowledge Visualisation for Cross-Community Learning

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Abstract. Knowledge exchange between heterogeneous communities of practice has been recognized as the critical source of innovation and creation of new knowledge. This paper considers the problem of enabling such cross community knowledge exchange through knowledge visualization. We discuss the social nature of knowledge construction and describe main requirements for practical solutions to the given problem, as well as existing approaches. Based on this analysis, we propose a model for collaborative elicitation and visualization of community knowledge perspectives based on the construction of personalised learning knowledge maps and shared concept networks that incorporate implicit knowledge and personal views of individual users. We show how this model supports explicit and implicit exchange of knowledge between the members of different communities and present its prototypical realization in the Knowledge Explorer, an interactive tool for collaborative visualization and cross-community sharing of knowledge. Concrete application scenarios and evaluation experiences are discussed on the example of the Internet platform netzspannung.org.

1 Introduction

The concept of knowledge visualization is often interrelated with information visualisation and the problem of organizing and displaying complex information structures with the goal of amplifying cognition of human users (Card et al., 1999). In contrast, Eppler and Burkhard (2004) propose the definition of knowledge visualization as being concerned with the "use of visual representations to improve the *creation* and *transfer* of knowledge between people". Such a definition leads to a fundamental insight – while information visualization typically solves problems of complex *information* structures, knowledge visualization is intrinsically connected to the problem of knowledge transfer in *social structures*. The view that "knowledge visualization aims to improve the transfer and creation of knowledge among people by giving them richer means of expressing what they know" (Eppler & Burkhard, 2004) puts emphasis on the relationship between knowledge and human actors - even when designing

and developing visual knowledge artefacts, which will inevitably be based on some form of visual presentation of information.

In proposing this perspective on the concept of knowledge visualization, this paper starts with the premise that in order to develop effective knowledge visualization, we need to consider a social context. In a concrete approach, we consider the problem of supporting knowledge exchange between heterogeneous communities of practice, which has been recognized as the critical source of innovation and creation of new knowledge in organizations. We discuss the social nature of knowledge construction in such communities and describe the main problems that need to be solved. We then discuss a concrete knowledge visualization model that we have developed as a possible solution, and describe its prototypical realization in the Knowledge Explorer, an interactive tool for collaborative visualization and cross-community sharing of knowledge.

2 Communities and Social Construction of Knowledge

Social theories of learning (such as constructivism and social constructionism) help us understand how people construct meaning out of information, and how this is related to social interaction and communication with other people. For example, Berger and Luckmann (1966) describe how people interacting in a certain historical and social context share information from which they construct social knowledge as a reality, which in turn influences their judgment, behaviour and attitude. Bruner (1990) shows how the construction of meaning can be related to cultural experiences, in a similar way as Vygotsky (1962) has explained how thought and language are connected and framed by a given socio-cultural context of the learner. The studies of Lave and Wenger (1991) emphasise the role of immediate social context for learning a body of implicit and explicit knowledge through a kind of apprenticeship they call „legitimate peripheral participation“.

All these studies demonstrate how the construction of knowledge (learning) is an inherently social process in which the „learner“ actively constructs meaning through a process of information exchange and social interaction with other people. Furthermore, both the personal implicit knowledge of the learner (his previous knowledge, interests, values and beliefs), his current context of intention (e.g. a problem or task at hand) and the social and cultural context in which the learning takes place (e.g. team, workplace, community) fundamentally determine the possible meanings that the learner can/will construct in this process. The principal implication of these findings is the notion of a shared cognitive and social context, which has to be established in order for the members of a social group to negotiate, share meanings, and hence construct collective knowledge.

One of the major models of social structures in which knowledge is generated and exchanged in today’s so-called knowledge society are technologically supported informal social networks. Such social networks are often referred to as virtual communities (Rheingold, 1993), communities of practice (Brown & Duguid, 1991; Wenger, 1998), knowledge communities (Carotenuto et al., 1999) and business communities. They bring together groups of people based on a shared set of interests or

specific concerns (virtual communities, communities of interest), or based on work-related sharing of knowledge and experience (communities of practice). While such social formations have been a major model of knowledge production and dissemination in scientific research even before the Internet, in recent years they have been increasingly acknowledged as major forms of knowledge exchange in professional and work-related settings, both within organisations and across organisational boundaries (Cohen & Prusak, 2001). This class of approaches is based on the social paradigm of knowledge construction: knowledge exists only in a social context and is created by social practices shared by the individual members, e.g. (Wenger, 1998).

Communities are a special form of such a context that has been increasingly used as an important unit of analysis when considering processes of knowledge construction, sharing and collaboration. In contrast to groups and teams that are defined institutionally, participation in communities is voluntary and typically independent of specific projects and formal organizational processes. Rather, the evolvement of such communities is based on spontaneous participation and self-motivated choice, common goals such as shared needs and problems and on a common repertoire (experiences, places and practices) resulting in common sense-making and a common language. According to this view, knowledge is created and reproduced through social relationships and interaction in communities and makes sense only in relation to such communities. Social interaction between community members and information exchange through shared community repositories facilitate the knowledge flows and the conversions between implicit and explicit forms of knowledge (Nonaka & Takeuchi, 1995).

While much research has been devoted to the development of tools and systems for supporting knowledge creation and sharing in teams and within communities, the problem of supporting cross-community exchanges has been relatively under-investigated. At the same time, a critical requirement for modern organizations and knowledge-intensive work has become the need for supporting cooperation and integration of knowledge between different communities, with highly specialized expertise and activities. Different studies have emphasised cross-community interactions as a critical source of new knowledge and innovation (Swan, 2001; Dougherty, 1992; Brown & Duguid, 1991)

A common approach to this problem has been the establishment of shared community platforms and knowledge portals (Internet/Intranet) aiming at providing one central point of encounter and knowledge workspace for different communities. Examples are corporate knowledge portals in commercial organizations and cross-community platforms in research settings such as netzspannung.org or the EU mosaic-network.org. However, appropriate support for such platforms is still missing. They are typically based on a combination of centralized knowledge bases and standard community-tools that have been developed for supporting exchanges in teams and within communities (e.g. shared workspaces, awareness, online communication). In contrast, Dougherty (1992) and Swan (2001) identify special challenges and requirements that need to be considered in such heterogeneous situations. But the development of appropriate systems and tools incorporating these insights is still lagging behind.

3 Requirements for Supporting Cross-Community Sharing and Creation of Knowledge

As observed by a number of authors, each community develops its own social and interpretative context (genres, repertoires, perspectives), which in turn determines its interpretations of the world. Different communities inhabit different "thought worlds" (Dougherty, 1992) which determine how their members interpret the meaning of information, artefacts, procedures, events and experiences. Different thought worlds then have different funds of knowledge and systems of meaning which means they cannot simply "share" ideas since important issues in one world may be viewed as meaningless in the other (Boland & Tenkasi, 1995).

In other words: knowledge artefacts produced by different communities (documents, emails, forum discussions) are not a neutral organization of information, but reflect perspectives of those involved in the sensemaking process. Thus knowledge cannot simply be passed on by exchanging information between members of different communities. In order to make sense out of information and construct knowledge, one needs to contextualise it within one's own existing knowledge and thought world. What is needed is finding ways for enabling the members of different communities to discover how the knowledge reflected in artefacts of one community, relates to their own knowledge and its context within their own community.

Thus, in order to support the sharing of knowledge between different communities we need to provide a way for members of different communities to establish a „shared context of knowing" as a way of "locating one form of knowledge in the context of another" (Boland & Tenkasi, 1995; Swan, 2001). On one hand, this requires that knowledge perspectives underlying individual communities be captured, represented and visualized. On the other hand, the different knowledge perspectives need to be put in relation to each other. But these perspectives are neither immediately visible nor readily available. They are largely implicit and are normally acquired only through extensive participation in community interactions. This is a requirement congenial with processes of knowledge development and sharing within communities, but not applicable between heterogeneous communities since intensive interactions between members are not given.

3.1 Perspective Making and Perspective Taking

The theoretical foundations for dealing with this problem have been provided by the model of perspective making and perspective taking describing the processes of knowledge exchange between different "communities of knowing" (Boland & Tenkasi, 1995). Perspective making refers to intra-community development and refinement of knowledge, whereas perspective taking refers to making the thought worlds of different communities visible and accessible to each other. Boland and Tenkasi (1995) propose that these processes are intrinsically connected: a community develops new knowledge both through social exchanges and knowledge discourses between its members, as well as by taking on perspectives of others. The interplay of

these two processes then provides the ground for allowing knowledge to be exchange between different communities.

This kind of cross-community interaction and integration of knowledge inherently involves two needs. Firstly, the need to share meanings (of information, artefacts, procedures) among a community's members. This occurs through reification of knowledge within physical, mental, and cultural artefacts, that stem from members' participation in the community. Secondly, the need to negotiate and coordinate meanings among different communities, which manage specialized knowledge. Due to local needs, different background, contexts, and artefacts, local knowledge is managed and represented in different ways that are appropriate for different communities' needs. Thus, communities share, convert, negotiate and cooperate only through negotiation of perspectives. These processes are facilitated and mediated by particular artefacts such as boundary objects (Star, 1989) and human knowledge brokers (Wenger, 1998).

3.2 Boundary Objects

In the context of this paper, of particular importance is the proposition that perspective making and perspective taking can be supported technologically by designing systems that allow the construction and discussion of "boundary objects" - such as classification schemes, cognitive maps and narrative structures (Boland&Tenkasi, 1995). The concept of "boundary objects" (Star, 1989) refers to knowledge artefacts that embody different perspectives and can be interpreted in different ways, without the need for prior shared understanding to be established. Thus such boundary objects are seen as essential means for supporting cooperation between different communities in a way, which allows each community to retain local perspectives and yet these perspectives to become interconnected.

3.3 Community Knowledge Repositories and Implicit Knowledge

The exchange of knowledge in communities is commonly reflected in an unstructured repository of knowledge artefacts reflecting community exchanges (e.g. discussion forums, mailing list archives, project repositories.). But, in contrast to formal organizational structures, explicit creation of taxonomies or ontologies to represent local community knowledge is rarely done by informal communities. Moreover, individual communities are by no means homogeneous within themselves. Individual members often have strongly profiled personal views (e.g. communities of experts) and the dynamics of communication constantly shifts between current information need (a problem or opportunity at hand) and long-term information need (interest profiles). Such a decentralised and loosely structured mode of community interaction makes it difficult to express the knowledge contained in the community information space by means of a predefined and unique categorisation.

Furthermore, since in communities knowledge is created and exchanged to a large extent through informal social interactions, the information pool that archives the community exchanges will reflect merely some externalised part of this knowledge.

So, even if cross-connected categorisation structures are created by hand through explicit negotiation, they will not capture the highly personal (implicit) knowledge of individual members (Nonaka & Takeuchi, 1995). Thus, supporting cross-community exchanges through visualizing community knowledge perspectives and relating them to each other poses the following challenges: How can we construct artefacts that elicit and visualize the existing, but not explicitly formulated knowledge of a community? And how can we do so in a way, which makes it usable for discovering relationships between perspectives of different communities and domains of knowledge?

4 Existing Approaches to Knowledge Sharing and Collaborative Knowledge Visualization

Existing approaches to knowledge sharing and collaborative knowledge visualization usually cover some of the following aspects: sharing implicit knowledge, mediating between different conceptualisations, eliciting knowledge automatically and visualizing the derived shared structures.

4.1. Sharing Implicit Knowledge: Internalisation, Socialization and Externalisation

Different authors have emphasized the largely tacit nature of human knowledge (Nonaka & Takeuchi, 1995) and the difficulties of codifying and formalizing socially distributed knowledge in communities. Existing solutions to this problem can be roughly classified into three main approaches: the „internalisation“ model based on individual reflection on the community discourse, the „socialisation“ model based on direct interaction mediated by CMC & CSCW technologies and the „externalisation“ model based on the explicit construction of shared conceptualisations.

The internalisation model is the only model supported by basic community technologies such as mailing lists, bulletin boards and discussion forums. The development of a shared context requires members' extensive and active participation in the community exchange. There is no mode for the shared understanding of the community to be expressed, and the repository of the collective memory is an unstructured space of many interrelated but rather isolated pieces of information. Context is very difficult to establish.

The socialisation model is connected to approaches that aim at supporting the sharing of social knowledge through a shared virtual space (e.g. (Erickson & Kellogg 2001)). This is the so-called awareness and knowledge socialisation approach, which can be related to two basic premises. The first is that by providing mutual awareness of spatially distributed, but contextually related users (e.g. working on same task, or belonging to same community) by means of a shared virtual space, the cognitive distance between them is bridged. The second is that once this cognitive distance is bridged, the conditions are established for the users to enter into conversations through which they exchange otherwise inaccessible personal knowledge. There are several variants of this basic model. Some of them are for example connected to the

constructionist theory of learning (Papert, 1990), others focus on the establishment of identity and the self-organising of social norms (e.g. (Turkle, 1995)).

The externalisation model is addressed by approaches aiming at supporting the explicit formulation of shared conceptualisations in form of knowledge ontologies. Ontologies represent models for formal descriptions of concepts and named relationships between them, that describe how a given individual or a group of people understands a particular domain of knowledge. Ontologies often have to be created explicitly by hand and require a process of explicit community negotiation for achieving a consensus about the shared understanding that is to be expressed. Once created they can be used to access and navigate the community information pool, as well as to visualise the semantic structure of the shared community understanding. An example of existing efforts for building such ontologies in different disciplines but interrelated to each other is the DublinCore initiative (http://www.dublincore.org). The Open Directory Project aims at a collaborative definition of a somewhat simpler taxonomy for manually mapping the content of the whole Web (http://dmoz.org).

The main shortcoming of computer-mediated socialisation approaches is that the sharing of implicit knowledge requires extensive interaction between individual members, and the resulting exchange still resides only in individual users. There is no possibility to visualise the resulting structure of shared understanding. On the other hand, existing approaches to creating externalised representations of a shared conceptual structure require explicit negotiation for achieving consensus between the members. There is no or little support for expressing the personal points of view of individual users and putting them in relation to the shared structure. At the same time, one of the essential mechanisms of knowledge creation is the ability to change perspective and see the world with „different eyes“. Finally, the challenge remains of how to provide insight into the underlying values and beliefs shared by a group of users, as fundamental elements influencing their thinking, judgment and the creation of new knowledge.

4.2 Creating a Shared Structure vs. Mapping Multiple Structures

While the aim of ontologies and other forms of knowledge externalisation usually is to create a formalized common understanding, a radically different approach is to allow different knowledge structures to co-exist and to mediate between them automatically by means of a mapping between different taxonomies, categorization structures or ontology schemes (see (Lacher, 2003) for a survey). These approaches offer the benefits of allowing a decentralized creation and maintenance of knowledge (and thus personal views on a domain) with little explicit coordination. But finding an intentional mapping between conceptualisations is far from being trivial and usually depends on a logical description of concepts. Thus ontology mapping also depends on the assumption that the meaning of concepts and thought worlds of communities can be codified in a formal representation and therefore suffers from the same basic problem as the other knowledge externalisation approaches.

4.3 Knowledge Elicitation and Knowledge Discovery

While explicit externalisation is often costly and unsuitable for capturing tacit and social knowledge, an alternative is to infer the common understanding of groups of users from their interactions. On the one hand, this reduces the amount of work for the users. On the other hand, it is often acknowledged that knowledge is created through interaction. An example is the paradigm of information access (Pirolli & Card, 1995), that emphasizes the need to understand the process of information retrieval as a knowledge acquisition and sense-making process – i.e. a process in which people through their interaction with information develop and internalise new knowledge. While there are several approaches following this paradigm that help individual users to elicit their personal implicit knowledge, such as information interfaces with sensemaking support (e.g. (Baldonado & Winograd, 1997)), the problem of the social context of individual users and the problem of eliciting the common knowledge of a group of people is usually not supported by such systems.

Analysing the interactions of users among each other and the interactions of users with information spaces therefore provides a means of eliciting tacit knowledge of individual users and groups of users in an unobtrusive and intuitive way. On a technical level, many of the approaches that follow this basic idea are based on Data Mining and Knowledge Discovery (Fayyad et al., 1996) techniques. They try to find structures in given sets of interaction data, from which the common understanding of the participants can be inferred (semi-) automatically.

Two approaches that explicitly support elicitation of this kind of knowledge are Cognitive Maps and Collaborative Filtering. Previous experiments on cognitive maps include the use of methods inspired by personal construct psychology (Kelly, 55) such as the repertoire grid elicitation, for extracting conceptual structures of individuals and groups of users (Shaw, 95). For an overview of different methods and applications in the context of knowledge management see also (Huff & Jenkins, 2002).

On the other hand, the approaches of collaborative filtering and recommender systems (Resnick et al. 1994), (Shardanand et al., 1995) provide a way for putting in relation perspectives of different users, based on explicit expression of their judgment and preferences (e.g. ranking) or on implicit statements such as bookmarks or patterns of interaction with information. Typically, they allow the identification of members with similar interests and can recommend items of relevance to a given user based on the fact that they have been highly rated by other users with similar interests.

A special form of automatic knowledge elicitation is text mining. By analysing a corpus of documents that represents parts of the knowledge of a given community (e.g. publications on human genetics), it is possible to derive a common understanding in the corresponding field to the extent to which it is encoded in these documents. Text-mining techniques have been used for constructing semantic overviews of complex information spaces and for computer-supported social network analysis based on statistical and linguistic analysis (Sack, 2001). In scientific communities, a frequently used technique has been the author co-citation analysis (Chen, 1999b). This method extracts patterns of relationships that show how scientists in a particular subject do-

main are intellectually interrelated as perceived by authors in their scientific publications.

4.4. Knowledge Visualization

Typical structures extracted from data by techniques of knowledge discovery or knowledge elicitation include hierarchies, networks and graphs, matrices or multi-dimensional tables and vector spaces (e.g. see Andrews in this volume). In our application context, these structures typically represent connections between documents, topics, concepts and users. They are organized and visualized through knowledge representation models such as ontologies, semantic nets, concept and topic maps, based on different forms of graph-based models, hierarchical trees or concept networks. Here techniques from information visualization are often used to solve the problem of displaying complex and high-dimensional structures. Information visualization techniques attempt to solve this through the use of appropriate visual metaphors, mapping algorithms or special interaction paradigms, which reduce the complexity by allowing the user to manipulate the visualization. Examples of popular information visualization techniques include hierarchical trees and Tree Maps, and focus+context techniques for graph visualizations such as FishEye Views or Hyperbolic trees (see (Card et al., 1999) for an overview). Hence, developing effective models for knowledge visualization intrinsically depends on the combination and integration of techniques from knowledge discovery, knowledge elicitation and information visualization.

5 Our Approach

The main idea of our approach is to develop a model of dynamic knowledge artefacts that support users' access to community information spaces, in a way, which enables the discovery of relationships between knowledge of different communities. The assumption is that by mediating users' access to community repositories through interactive knowledge maps, which enable them to see the information contained in the repository from different semantic perspectives, we can qualitatively enhance the processes of knowledge construction that occurs during information access. This approach is related to the view that understands information access as a process of sensemaking and knowledge acquisition in which people through their interaction with information develop and internalise new knowledge (Pirolli & Card, 1995). Accordingly, incorporating the ability to explore the community repositories not only from a predefined community perspective, but through the perspectives of members of different communities, is a way of supporting the sharing and creation of knowledge that crosses boundaries of individual communities (Boland & Tenkasi, 1995).

5.1 The Knowledge Map Metaphor

In developing this approach we use the knowledge map metaphor as a vehicle for describing the idea of a visual structuring of information in a way, which provides insight into contexts and relationships between semantically related information. The crucial difference to existing approaches from knowledge management and knowledge visualisation is thereby that the point of departure for constructing such maps is the personal, highly implicit knowledge of individuals and communities of users, rather than explicitly predefined taxonomies or ontologies. Since knowledge in communities is highly implicit and socially constructed (Chapter 2) such knowledge maps cannot be static representations which "codify" knowledge. Rather they are conceived as interactive visual artefacts that can be interactively manipulated and discussed by the community members in order to get an understanding of different mental models and interpretative schemas underlying different communities: e.g. by exploring maps of different users, applying them to different situations, comparing personal concept structures to those of others. Hence, such interactive knowledge maps could support the processes of perspective making and perspective taking that have been recognized as critical means of cross-community exchange of knowledge (Chapter 3).

Framing the problem in this way shifts the focus away from the problem of appropriate formal models of knowledge representation addressed by taxonomy and ontology approaches. Rather, the focus becomes the need for constructing models and tools for dynamic knowledge visualization that provide contextualised views of information, showing its relationships to the knowledge perspective of a given community and supporting the discovery of relationships to potentially relevant knowledge perspectives of others. The question is then, how can we construct and visualize such knowledge maps so that they reflect personal, implicit knowledge of individuals and communities of users? How can we design an intuitive interface that enables the users to apply them easily and to interactively manipulate the criteria determining their behaviour? And how can we visualize the resulting new cross-community knowledge structures created through such exchanges?

6 Conceptual Model for Collaborative Elicitation and Exchange of Knowledge

As a practical context we consider the everyday practice of information seeking and access to the community information space as a process of knowledge acquisition and sensemaking (Pirolli & Card, 1995). The users' interaction with information both reflects their interpretation of the meaning of information, their personal knowledge perspectives and their creation of new knowledge structures. Thus, it can be taken as a point of departure for uncovering and visualizing community perspectives in a way which incorporates personal viewpoints of individual users, and hence the shared implicit knowledge. In order to develop a practically feasible solution for capturing and visualizing implicit knowledge structures of human users based on their interaction with information, two basic problems need to be solved:

1. A context for user actions has to be created in order to be able to interpret the meaning of user interaction with information items. The lack of a sufficiently clear interaction context is the main difficulty of general "user-tracking" and interaction mining approaches.
2. A form of visual representation has to be found that communicates to the user both the semantics of the information space in itself (content, structure and relationships) and relates this to the meaning of his actions.

To this end we have developed a model for creating and visualizing personalised learning knowledge maps and shared concept networks based on user interaction with information (Novak et al., 2003). This chapter presents the main elements of this model and the technical foundations for its realization based on the integration of methods from knowledge discovery, information access and knowledge visualization.

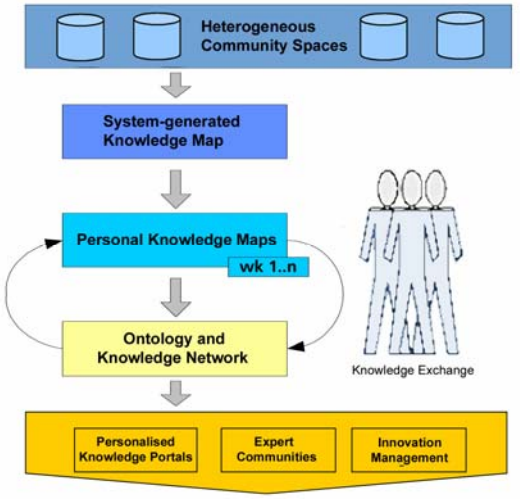

Fig. 1. The Collaborative Knowledge Elicitation and Exchange Model

6.1 Eliciting Individual Points of View through Personalised Learning Knowledge Maps

In our model a knowledge map consists out of two main elements: the Document Map and the Concept Map. The Document Map (Fig 1, left) presents the knowledge artefacts from the community space (e.g. documents, emails, forum postings, project descriptions) structured into clusters of semantically related objects. This provides an overview of topics and relationships in the community information space. The Concept Map (Fig 1, right) displays a network of terms that represents groups of different words used in similar contexts and the relationships between them. It provides insight into criteria determining the structuring of the Document Map and serves as a navigation structure.

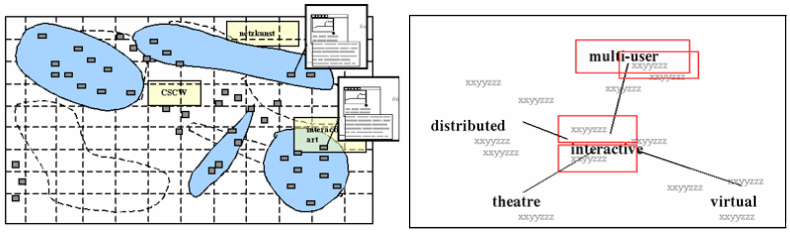

Fig. 2. The Knowledge Map Model

To construct such maps based on a users' personal points of view we combine methods for statistical text-analysis and self-organised clustering with methods for supervised learning of user-induced templates (for details refer to (Novak et al., 2003)) The user is presented with a system-generated structure that provides an initial context for accessing the community information space. In doing so, the user can explore and rearrange the system-generated structuring as part of her normal access to information (moving documents between groups, creating new groups and adding new cluster labels). In this way the user creates personal DocumentMaps that reflect her personal point of view and the insights she discovered and internalised as knowledge. Such personal maps serve as templates that are learned by the system and can be used as personalised semantic filters to automatically classify information into user-defined clusters.

Based on the statistical analysis of the users' personal DocumentMaps, for each user the system also extracts a personal Concept Map, which displays a network of most relevant terms and connections between them, as „seen" from a user's perspective. The most relevant terms for the document clusters from all personal maps of a given user are put in relation to user-defined labels of the clusters in question. In this way a personal knowledge perspective is created. It consists of conceptual structures represented in the personal Concept Map and a series of personal DocumentMaps that present specific contexts of user's knowledge. The documents, which are contextualized and labelled in clusters of the user's personal DocumentMaps, are also connected to corresponding concepts in the personal Concept Map. Hence, they represent concrete instances and examples of concepts defining a user's knowledge perspective.

6.2 Constructing Community Perspectives

In a similar way, an overall structure of relationships between words and concepts based on personal maps of all users is created. The inference of relations between concepts from personal maps is based on the fact that by labelling clusters, the users draw a connection between a term and a set of objects. Two concepts to which related objects are assigned by many users can be considered to be related. Using this kind of relationships, a collaborative Concept Map is created that represents a shared community perspective (Novak et al., 2003).

6.3 Supporting Collaborative Discovery and Sharing of Knowledge

This model provides several ways for collaborative discovery and sharing of knowledge.

6.3.1 Applying personal maps for "seeing with different eyes"

Firstly, a map can be called up explicitly by another user and applied to classify an information space from the viewpoint of the map author. This supports learning by providing a contextualised view on a possibly unfamiliar knowledge domain. Not only can relevant documents be discovered but also relationships between topics, concepts and documents in the resulting map provide a way for developing an understanding of the other user's knowledge. In this way personal maps support "seeing through different eyes" and facilitate knowledge sharing between members of different communities.

6.3.2 Contextualised search and matchmaking

Secondly, the results of users search queries can be automatically contextualised in the personal maps of different users. The idea is that while the query expresses the user's current information need, the long-term information need (interest profile) can be extracted from the maps a given user has created so far. The search results can then contain both the list of retrieved objects based on full-text keyword match, as well as a ranked list of most relevant personal maps of different users. Search result objects can then be, for example, highlighted within thematic groups represented in the most relevant map. Hence, the user can identify related documents, which a normal, match-only search query would not have retrieved. At the same time, based on document-concept relationships, the corresponding concepts can be marked in the appropriate Concept Map. This supports the discovery of unfamiliar concepts that describe related knowledge perspectives. In this way users can enter queries in their own community vocabularies and discover possibly related artefacts, concepts and people (map authors) from other communities and areas beyond one's own expertise.

6.3.3 Navigating through cross-community concept networks

Through the above describe ways, users from different communities can discover relevant objects and concepts from unfamiliar domains of knowledge. By adding the found objects to their own maps and clusters they express relationships between concepts and documents from different communities. Based on such similarity of objects and similarity of concepts a Concept Map emerges that connects concepts from different communities. This structure can then be used as a means of navigation across different domains of knowledge.

6.3.4 Reflective Awareness as a Means of Constructing New Knowledge

Another important aspect is what we call „reflective awareness". The basic idea here is that one of the critical elements influencing the potential for the construction of new knowledge is the existing knowledge of individuals and groups of people. Thus becoming aware of this knowledge is a prerequisite for processes involving the crea-

tion of new knowledge. In other words, one of the critical aspects of learning is the ability to change perspective and discover hidden assumptions and mental models underlying a given point of view. From this aspect the personalised knowledge maps can also be seen as a kind of knowledge artefacts that can be interactively manipulated and discussed by the community members (exploring maps of other users, applying them to different situations, comparing a personal concept structure to other individual and shared concept maps) in order to get an understanding of different mental models and interpretative schemas. The idea is that rather than just through automatic inference of relationships, it is through one's interaction with the maps that one can develop an awareness of and insights into implicit structures - such as mental models, values and beliefs - of one's own or shared by the community. The hypothesis is that by achieving this kind of reflective awareness the processes of communication and sharing of knowledge especially in heterogeneous communities can be qualitatively improved to stimulate the emergence of new knowledge.

7 Visualization Model for Interactive Cross-Community Knowledge Artefacts

The task of the visualization model is to present the elicited knowledge structures to the user, in a way which allows her to discover and learn from relationships between different perspectives on community knowledge. As noted in Chapter 5.1 the constructed knowledge maps cannot be considered as static representations, which "codify" knowledge that merely needs to be "presented". Rather we need to visualise dynamic artefacts that can be interactively manipulated by the community members in order to get an understanding of different perspectives.

To achieve this we have developed an interactive visualization model for representing multiple perspectives and relating them to each other. A particular requirement has been that the visualization model needs to be appropriate for embedding it into an exploratory information interface for access to community knowledge repositories. The developed model enables simultaneous visualization of 1) document-topic relationships that can be inferred from heterogeneous community document collections, 2) personal ontologies representing views of individual members, 3) shared ontologies and concept networks representing a community perspective, and 4) relationships between concepts, topics and artefacts used in different communities.

7.1 The Multiple-Perspectives Visualization Model

We employ a multiple coordinated views concept (similar to (Becks & Seeling, 2004)) for simultaneously providing different visualizations of knowledge structures and information in the community space. Rather than a fixed, predefined semantic structuring of information, the multiple views concept allows us to simultaneously present views of different users and communities in relation to each other.

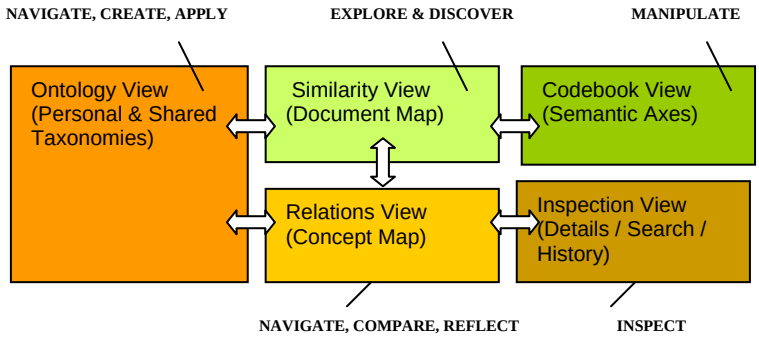

Fig. 3. The Multiple Perspectives Visualization Model

To this end the multiple perspective visualization model (Fig. 3) consists of the following components:

- **Similarity View.** The task of the similarity view is to enable the user to *explore and discover* possible relationships between documents from information spaces of different communities. To achieve this, this view is conceived as a spatial visualization of semantically related document clusters based on inter-document and inter-cluster similarity. Different ways for realizing this view exist, such as methods for clustering textual collections and multidimensional scaling (Card et al., 1999). Such techniques commonly support the construction of visual maps where similar documents and groups of documents are positioned close to each other, and the document groups can be characterized by characteristics concepts that describe their semantics.
- **Codebook View.** This view complements the similarity view, by displaying the main semantic criteria that determined the presented structuring of the document collection. These criteria are represented by a set of principal concepts that best characterize the document collection, such as the most frequent terms in the document pool and the sets of terms that have been used to encode the semantic properties of documents into text vectors used for the mapping. Understanding and manipulating these criteria is a critical requirement for making sense of the visualization and gaining a deeper understanding of implicit knowledge structures contained in the collection. To communicate this to the user we introduce the metaphor of *semantic axes* to describe the "meaning" of the concepts and terms presented in this view.
- **Ontology View.** The ontology view enables the user to *navigate* a document pool based on a predefined semantic structure. This structuring can represent personal views of individual members or shared community views, as well as taxonomies representing formal knowledge domains or organizational structures. As the ontology view represents an explicitely expressed and edited externalisation of a semantic structure (by individuals or groups of users) it provides an insight into explicit knowledge of communities and individual users. But, since the personal ontologies in our model have been created by a method similar to perceptual mapping, they also reflect implicit

knowledge of the individual users. Different techniques for visualising ontological structures, such as hierarchical trees, tree maps or graph networks can be used.

- **Relations View.** This view allows the user to visualize and explore relationships between concepts used by different individuals and communities of users. It presents relationships between concepts and groups of concepts, based on inter-concept relationships. Two concepts are defined as related if they are used by the user (or community) in similar contexts. This view maps the patterns of language use in different communities and relationships between them. In contrast to Ontology View where conceptual structures are created manually by the users themselves, the concept maps of the Relations View are extracted by the system. The system thereby combines the relations extracted from word usage in texts with the relations that can be induced from the comparison and analysis of user's personal and shared ontologies (Novak et al., 2003).
- **Inspection View.** This view accommodates the display of object details, the formulation of search queries and the visualization of the history of user actions (e.g. inspected maps, search queries etc.).

7.2. User Interaction with Visualizations

The main modalities of user interaction with the visualizations are selection, navigation and drag&drop interaction. The user can select individual documents or sets of documents in the Similarity View, as well as topics, concepts or documents in the Ontology View and concepts in the Relations View. Selecting an item in a particular view causes related items in other views to be highlighted. For example, the Similarity View might be presenting a system generated structuring of the document collection from a user's community. In the Ontology View, a user's personal Document Map as well as his personal Concept Map might be open. In the Relations View a collaborative Concept Map that represens the relationships between perspectives of all users might be shown. Selecting a document in the Similarity Map would highlight similar documents in the user's personal Document Map and related concepts in his personal Concept Map (Ontology View). At the same time, related concepts stemming from maps of other users would also be highlighted in the collaborative Concept Map. In this way, by simply selecting a document that spurred his interest, a rich context of relationships to different knowledge perspectives is presented to the user. In a similar way, the user might have selected an unfamiliar but interesting concept in the Relations View and would have discovered example documents in the Similarity View - both those directly highlighted by the system as well as those positioned in the same thematic clusters. The discovered relationships can then be incorporated into the personal or community structure by dragging&dropping the documents or concepts in question into the Ontology View. Finally, selecting a particular personal map in the Ontology View as a dynamic semantic template for a given document collection, causes the relevant documents in the Similarity View to be classified into topics defined by the map in question.

7.3. View Coordination

The different views are coordinated between each other according to the "navigational slaving" principle (Baldonado et al., 2000): effects of user actions in one view are immediately reflected in dependent views. In our case, we have two main couplings of dependent views. Firstly, the Codebook view is directly coupled to the Similarity View. As the user explores the document clusters and relationships presented in the Similarity View, she can select individual clusters or sets of documents from different clusters for closer inspection. The visualisation in the Codebook view is updated accordingly, to present only concepts relevant for the clusters and documents in the user's selection. In this way the user can explore the details of the semantic structure of a document collection representing one or more community repositories. The user can also select a subset of concepts presented in the Codebook View and define them as new semantic axes. As a result, the cluster structure presented in the Similarity View will be recalculated by the system, based on the user-defined concepts. Dragging & dropping an individual document, a set of documents or a whole cluster into the inspection view displays details of the documents in question.

A second coupling connects the Similarity View, the Relations View and the Ontology View with each other. Conceptually, this coupling is represented by associations between documents and clusters, documents and concepts, and between concepts themselves. Technically, the coordination is modelled by the star-schema layout with the Similarity View acting as the coordinating view (see also (Becks & Seelinger, 2004)). Whenever the user performs a selection in one view, the corresponding set of documents is determined and the other views are updated appropriately. This is possible because the data-models underlying all views, associate documents as concrete instances of knowledge resources to corresponding concepts, and vice-versa.

8 Prototypical Realization: The Knowledge Explorer

A prototypical realization of the described model for collaborative elicitation and exchange of knowledge and of the related interactive multi-perspective visualization is presented by a multi-agent system and an interactive interface, the Knowledge Explorer (Fig 4)[1].

8.1. The Multi-Agent System

Our prototypical system consists of two groups of agents that together provide a set of services to the client applications. One group of agents is concerned with responding to user requests (e.g. visualization and interactive tasks). These agents have to work very efficiently, as interactive work requires very short respond times. To achieve this, we use a second group of agents, which asynchronously pre-process data

[1] Developed in the project AWAKE – Networked Awareness for Knowledge Discovery, http://awake.imk.fraunhofer.de.

and store it in intermediate structures. These agents take much of the workload from the first group of agents. Using this strategy we can use sophisticated and costly data and interaction analysis methods and even so have short respond times. Please refer to (Novak et al., 2003) for a more detailed description of the underlying agent system.

8.2. The Knowledge Explorer Interface

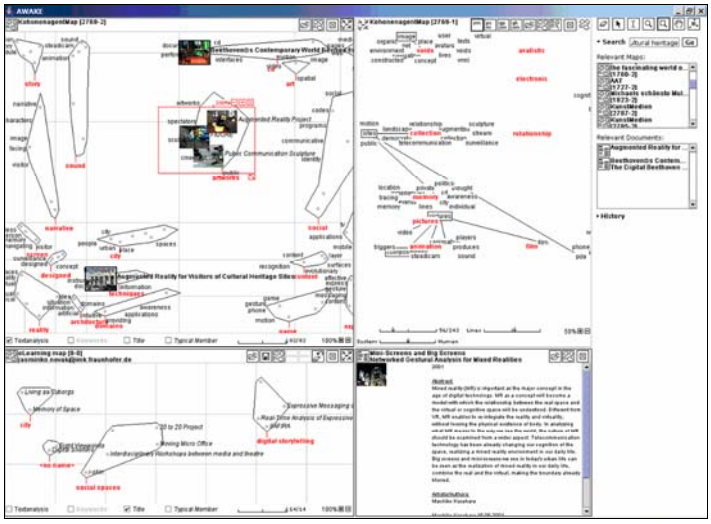

Fig. 4. The Knowledge Explorer Prototype

The principal goal of the Knowledge Explorer prototype is to realize a tool that incorporates the described model of collaborative knowledge elicitation and multiple perspective visualization into an exploratory information interface for cross-community access to knowledge repositories.

In the concrete implementation, the Similarity View has been realized by a clustering and visualization method based on the Kohonen's self-organised network. The resulting Document Map presents clusters of related documents based on inter-document similarity. By displaying the distribution of all documents and their grouping in semantically related clusters, such a Document Map (Fig. 5, top left) presents the user with a quick overview of the topics and relationships in the community document pool. The semantic space of each cluster is described by the most representative keywords. The corresponding Concept Map (Fig 4., top right), realizing the Relations View is displayed to the right of the Document Map.

The current system distinguishes between three different kinds of Concept Maps: 1) the system-generated Concept Map related to the system generated Document Map, 2) the personal Concept Map is based on term usage in personal maps of a given user, and 3) the collaborative Concept Map presents relationships between terms and concepts used by different users and communities. The user can switch between these different visualizations at will by selecting the appropriate interface

icon in the Concept Map window (Fig. 4, top right). Multiple Concept Maps can be visualized by simply dragging the Concept Map icon into another window.

The system-generated Concept Map is realized using a Kohonen self-organized network to determine clusters of words used in similar contexts and their relationships to principal concepts characterizing the document collection. In this way, the system-generated Concept Map also serves as the Codebook View visualization. The main concepts displayed in red (Fig. 4, top right) present the most characteristic concepts that have determined the clustering in the related Document Map. The user can select any set of terms as new semantic axes and invoke the reclustering of the Document Map based on these new criteria. The construction of personal and collaborative ConceptMaps is based on a variant of the "nearest neighbour" collaborative filtering method. The visualization of the resulting graph network uses a spring-based algorithm for two-dimensional layout of graph structures (Chen, 1999a).

The Ontology View is realized in two ways. On one hand the collaborative Concept Map presents the shared structure, although in the current version it cannot be manually edited and is rather complex due to the large number of connections. The latter problem is addressed by interactive sliders that allow the user to adjust the maximum number of nodes and connections displayed. On the other hand, the personal maps represent user-defined ontologies. They are currently visualized as groups of labelled document clusters on a two-dimensional surface (Fig. 5, bottom left). The user can position the documents and the clusters on the 2D surface of the personal map at free will.

The Inspection View has been realized by simply dragging an object into any free window (Fig. 5, bottom right). The search query, the interaction history and search results have been accommodated in the rightmost interface column.

9 Application and Evaluation

The practical test bed and an application context of the described work is the Internet platform netzspannung.org (Fleischmann et al. 2001). netzspannung.org aims at establishing a knowledge portal that provides insight in the intersections between digital art, culture and information technology. Typical netzspannung users are artists, researchers, designers, curators, journalists and interested public. By using the system in the way described in previous chapters, such a heterogeneous user group is enabled not only to construct an information pool in a collaborative way but also to interactively and collaboratively structure this pool, to visualize and explore it by the means of personalized knowledge maps. Furthermore, the user group sets up a shared navigational structure, which combines different points of view on the semantics of the information. This allows them to explore possible relationships between work in different topics or fields of profession (e.g. for finding projects from different disciplines relevant for one's own work). Another scenario is comparing sets of projects against one's own personal point of view and against views of other experts (e.g. for discovering contexts and hidden assumptions). Finally the general public could use the knowledge maps of experts as a guide for navigating the information space of netzspannung.org

Following the methodologies of participatory design an early proof-of-concept prototype has been evaluated in a netzspannung.org workshop with a heterogeneous group of target users: curators, artists, information technology researchers, media designers and representatives from museums, cultural institutions and media industries[2]. The users reacted very well to the exploratory interface for discovering relationships between different thematic fields. In particular the idea of an initial system-generated map serving not only as an overview, but also as a means of inspiration for discovering unexpected relationships between different thematic fields has been appreciated. A very much discussed issue has been the users' need to understand the criteria of the system functioning. This is incorporated in the current model by the system-generated Concept Map that provides insight into the clustering criteria of the Document Map and enables its interactive parameterization by the users. The users also highlighted the importance of the support for expressing personal views and relating them into a shared but multi perspective structure. This was seen as an essential feature for supporting the exchanges between such heterogeneous and loosely connected communities as theirs. Finally, they received enthusiastically the envisioned possibility of publishing and exchanging their personal maps with each other.

The developed system has also been internally deployed as information access interface to the submissions of the cast01 conference and of the competition of student projects digital sparks. This simulates the use scenario in which users can explore possible relations between information usually isolated in separate archives of different communities in the fields of media art, research and technology. The results can be tried out in the guided tour and partially online available interactive demos[3]. An early visualization prototype for browsing system generated maps is still in day-to-day use as a public information interface in netzspannung.org[4].

A usability evaluation of the current prototype of the Knowledge Explorer with 12 test persons has proven good acceptance of the main use cases. In particular the following functions were considered very helpful: applying maps of other users for discovering new knowledge, the contextualization of search results and the topic-based navigation across different fields of profession. At the same time the variety of the available interaction and navigation methods was also perceived as a source of complexity that requires a noticeable learning curve. We are currently addressing this by optimising the navigational ways to optimal paths identified in the trial.

10 Concluding Remarks

In this contribution we have discussed the problem of cross community knowledge sharing and visualization, as well as several requirements to successfully enable it.

We have presented an approach based on the construction of personalised knowledge maps and shared concept networks in a way which is unobtrusively embedded in

[2] This very early proof-of-concept workshop took place in 2001. See http://netzspannung.org/workshops/knowledgemaps.

[3] http://awake.imk.fhg.de/guided_tour.html http://awake.imk.fhg.de/prototypen.html

[4] http://netzspannung.org/cast01/semantic-map

the users everyday activity of access to the community information space. In the described way, a semantic representation of shared understanding of the community can be constructed, which presents the main concepts and relationships describing both the community knowledge and incorporating personal views of individual users. As the collaborative structure is created dynamically based on user interaction with information it will evolve together with the patterns of the community development and interaction. The members of the community can share knowledge through exchanging their personal maps or by navigating the shared concept structure. This is enabled by a multi-perspective knowledge visualization model that has been prototypically realized in the Knowledge Explorer tool. We described how this supports cross-community access to knowledge repositories and outlined the results of an application and evaluation of the prototype to the Internet platform netzspannung.org.

We are aware of several critical issues of the presented model. One is the classical problem of collaborative aggregation methods, which tend to suppress minority views. In consequence only mainstream patterns of relationships might emerge in the shared concept structure, hiding more interesting ones. In an extension to the current model, this problem is addressed explicitly.

Another critical point is also the question of privacy. Since our concrete application context is an interdisciplinary professional community of experts (netzspannung.org), the assumption is that the users will be willing to share their maps, as a motivation for gaining expert reputation within the community. But in other cases this might be a non-trivial problem to consider.

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