IT-supported Visualization of Knowledge Community Structures

Matthias Trier
Faculty of Computing Sciences and Electrical Engineering,
Technical University Berlin,
Franklinstr.28/29, 10587 Berlin, Germany, trier@sysedv.cs.tu-berlin.de

Abstract

In the first part of this article, Communities of Practice are conceptually positioned as a very important and successful element of corporate Knowledge Management. By utilizing IT platforms they enable a direct connection of knowledge workers and the transfer and reuse of tacit expertise to geographically remote business problems. Although current Community Software provides its members with many sophisticated features, facilitators or moderators still lack functionalities to monitor, evaluate and communicate the development of their expert networks. After discussing the requirements of this special target group, this contribution concentrates on electronic discussions and proposes a software system for automatically analyzing the structure and value of Knowledge Communities by extracting available electronic data about their communication network. This includes the entities employee, topic, and document and their many relationships. Insightful structural visualizations based on theories of Network Analysis are introduced. They can be accessed and manipulated in a Management Cockpit to improve the transparency in communities.

1. Introduction

Knowledge work is happening in the physical and value-creating business processes. It requires information processing, which in turn requires information procurement processes. Practice shows, that instead of analyzing a set of related documents, employees prefer to directly contact reference persons or experts in their problem domain to gather relevant information. Over time, they construct a relationship network consisting of dynamic and living communication processes, thereby forming an informal and topic-oriented organizational structure between people. Very interactive and dense clusters within this organizational structure are called Communities of Practice. This is also emphasized by Wenger, who describes a Community of Practice (CoP) as different from a network in the sense that it is "about" something; it is not just a set of relationships [1].

In order to establish the position and communicate the role of CoPs within the broader area of Knowledge Management (KM), a systematic KM Entity Model has been developed in practical KM projects (Figure 1). It assembles all relevant concepts together with their interrelationships on a very aggregated level. The respective entities are Process/Activity, Document, Employee, and Topic. Connecting these four main entities automatically directs the focus to very relevant relationships between the concepts. For example, an author is connected with other authors, with topics, his documents and of course with the processes or activities he is responsible for.

The model can now help to understand the main task of Knowledge Management and position the instrument 'Community of Practice'. The first objective for KM is to create transparency about this model's entities and their connections by capturing the structure of topics, documents and employees. This helps to derive useful insights like who is responsible for which process and what documents are needed to carry out which activity. Using this structure, it can also be traced who created which documents in which topic and for which processes.

Once elicited, the structure can also be used to manage the creation of knowledge in the enterprise, including the documentation or the qualification of employees in certain topics or for new processes. It can also help with the development of expertise about topics of a special activity.

Looking at the entities, the approach of business process modeling can be identified to be of importance for Knowledge Management, because it models the process (as a sequence of activities), the attached responsible person and the documents necessary for the transactions. Only recently, this approach has been extended to consider the area of knowledge intense business processes. A main innovation of these new modeling approaches has been the introduction of topic elements into process models [2].

But the KM entity model contains more relations than process models represent. For example to enable a better transparency about the enterprise, it is important to know about the relations between the various instances of one

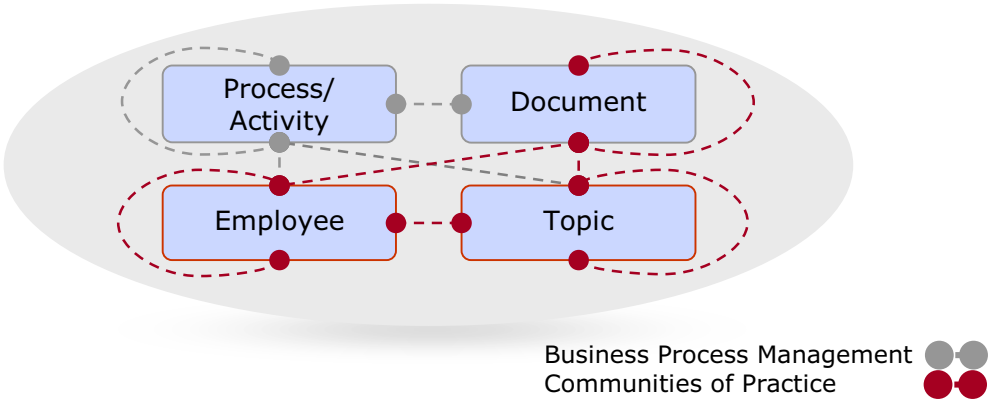

Figure 1. KM Entity Model

entity: e.g. which employees are related or which documents are related.

Here, the network-oriented approach of communities constitutes a valuable KM instrument [3,4,5]. They actually contain networks of people which are gravitating around topics [1]. The people create documents and are working in business processes.

With this focus, CoPs comprise a second content-, people-, and network-oriented perspective next to the transactional and process-oriented perspective. In this way, CoPs are a valuable and complementing instrument for Knowledge Management in corporations [4].

This raises important research questions: How can CoPs be systematically employed for KM? How should members and the central role of a Community Moderator be supported and how can tools and the available data about the communication network be utilized?

2. Research Objective and Methodology

Looking from the network perspective of Knowledge Management, this paper introduces a generic and component based software system which generates visual insights into structures of existing virtual Knowledge Communities [42].

Utilizing the available electronic data of virtual communication networks, the objective of this research is to apply Information Systems to discover active or inactive areas of networking and discussion. This helps moderators and researchers to better analyze and intervene into community structures. The design focus is on simple and automatic data import from a variety of sources, insightful visualization forms and general ease of use. In section 6 of this paper, four of the visualization features are demonstrated and discussed using a sample dataset of the public NNTP-based Newsgroup php.xml.dev.

The research methodology includes extensive literature review to derive preliminary requirements for moderators, exploratory interviews with moderators, and prototypical software engineering to translate the identified requirements into preliminary visualizations and functionality. Currently, the project is in the stage of field testing using virtual community networks to refine and enrich the technical approaches.

The developed system aims to provide an external addition to current community systems, which are often lacking features for monitoring and employing their extensive electronic data archives (see section 4).

To substantiate the developed set of visualizations and functionality, the next section discusses the tasks and requirements of moderators in virtual communication networks using material on European and American case studies and literature on the respective sociological theories.

3. Identifying Moderator Requirements

A CoP is a flexible knowledge network that overcomes existing rigid organizational communication structures as it allows for virtually unlimited configurations [6]. The hosting organization becomes a stakeholder by allocating necessary time or financial budgets. This commits the CoP to transparently communicate its value and progress [7]. A recent survey of the American Productivity and Quality Centre substantiates that measurement of effectiveness and 'health' is a major issue for a Knowledge Community. Results should be measured and compared to objectives using a monitoring approach [8].

In such a professional application with increased responsibility, a general Community Management role is often established: e.g. Shell employs 'Hub-coordinators' for facilitating large groups of more than 1000 people and Siemens establishes CoP Managers [4,9,11]. These persons can be identified as an important target group for user-oriented design of monitoring functionality for Communities of Practice.

The emergence and value of such coordination roles has been widely discussed in the literature. For example,

McDermott [12] proposed five leadership roles including a community leader, Fontaine [13] identified a leader or facilitator, and Kim [14] developed a seven role model including the three roles host, event coordinator and greeter. Finally, Wenger [15] identifies seven leadership roles including an institutional leader who links the CoP to the organizational structures, an interpersonal leader, who cares for social networking, and a day-to-day leadership, organizing activities. All these approaches together constitute a more general role, referred to as 'Community Manager'. Such a community manager is not only a coordinator of internal interactions within the community but is operating on the surface of the community to integrate interests of members and external stakeholders. This person is responsible for internal tasks like organizing events, hosting the platform, or managing and developing topic and member portfolios.

Here, Oliver and Herrington state that the content of asynchronous discussion can become poor and superficial without coaching and scaffolding [10].

Further, there are external tasks like acquiring external resources, communicate results, or connecting to other communities.

The name of the role implies that communities are manageable. Nevertheless, this management is very special, because communities are based on the principle of voluntarism. Members work on a topic only if they feel the need to do it and they dislike to be instructed. This renders management more a facilitating context management to enable members to work on their ideas [13]. In practice, these managers often emerge from the group and are provided with expert legitimation to strategically and tactically influence the community development.

This is also discussed by Johnson [16] who analyses the constructivist properties of Communities of Practice. This involves ill-structured problems, learning in a context of real-world-problems, shared goals, and the use of cognitive tools to organize knowledge. Ill-structured problems can not be solved by any individual alone and hence the instructor is developing towards a facilitating coach for guiding the learning and helping the team develop. This moves the control away from the instructors to the group and a network of people emerges.

For enabling a Community Manager to analyze his group of people and its value, a system of captured data, measurement ratios, and visualizations helps to generate network overviews that are interpreted to guide management activities and to justify outputs to stakeholders. Before such detailed and user-oriented measurement requirements of a moderator can be derived, in a preparatory step his business tasks and objectives have to be analyzed.

When analyzing the tasks of Community Management it has to be differentiated between Face-to-Face Communities and Virtual Communities. The first group mostly has just a small number of participants and management is thus focused on people. In bigger Virtual Communities the management tasks are less bound to direct personal contact and a content-related field of work emerges. Typical and additional work domains for such communities are the transformation of unstructured information, e.g. by analyzing written interactions, to quickly identify emerging information and connect this to create structured knowledge. Further, the diffusion of community knowledge, using means like newsletters or e-mail, the provision of relevant content from external sources, the establishment of ergonomic user interfaces, the adaptation and improvement of interaction and problem-solving structures, the generation of content for multiple reuse, the socialization of users, e.g. with membership programs, the measurement of interaction, the identification of established social relationships ('strong ties') and key persons, the connection of related persons and groups, the creation of necessary incentives, the execution of events like off-site meetings of new members with CoP-Experts, and membership management.

Next to these content-related and transactional tasks, the literature discusses various indicators for the dominance of social motives of a Community Moderator. This includes tasks like fostering and maintaining participation with valuable feedback [17], communicating purpose, objectives, and progress [17,18,19], analyzing specialization and roles of individuals to form role architectures that increase group stability [20], balancing group autonomy versus openness [21], creating relationship networks with tight connections and transparent visibility of members within the network [18,19], establishing an environment of obligation, mutual trust, and commitment and weaken detrimental factors like concurrence and unsupportive personal profiling [19,22], foster and communicate homogeneity and similarity in groups [23], or influencing orientation and objectives (polarization versus diversity) [24]. These suggestions can be extended by tasks like balancing solution exchange and solution development, creating a group identity, integrating isolated participants to improve inefficient parts of the network, monitoring the quality of interactions, sharing best practices, understanding existing informal CoP structures in order to be able to formalize a group, increasing the informal learning activities, fostering innovations, creating a familiarity between persons, or analyzing interaction and interactivity.

Summarizing, internally the manager has to generate value in the domains people, content, and networks. In the latter, he has to develop Social Capital by influencing the social identity, social structure and social processes, as most internal community processes and platform participation is based on internal and self-organizing

group dynamics and social mechanisms. To external stakeholders he has to communicate and report a measurable and comprehensible value of his community.

Within this complex system of operational tasks and soft management issues, IT-supported and automatically created measurements from the actual knowledge exchange processes in the actor network are now conceptualized to support the manager in the development and communication of value in his virtual Knowledge Community.

The analysis will concentrate on Virtual Communities with a considerable part of interaction based on computer-mediated communication. Their special and for research purposes very helpful property is that their networks are partially visible and analyzable.

A further research restriction has to be imposed to deal with the multiple communication channels utilized by expert groups. They together comprise the communication network and include personal communication, phone, e-mail, instant messages, and discussion groups.

The channel discussion group is especially interesting, as it still insufficiently recognized, although it allows for a central and topic-oriented storage of messages between experts. Whereas e-mail is a decentralized peer-to-peer communication concept, where it is very likely to not oversee the overall content of an e-mail network, discussion groups provide a consistent and complete access to the insights stored in it. It is mainly stored in topic threads and most importantly does not cause a privacy problem, because the information contained in it is meant to be public to the members of the group. This renders discussion groups a focal channel for our research on exchanging and analyzing expert knowledge in problem-domains.

4. Gaps in current CoP Software

Although communities do not necessarily require an IT platform, it is widely recognized nowadays, that IT can play a major role in efficiently supporting large groups of geographically separated experts [18]. This is especially important for international enterprises, where regularly similar functions are spread across different divisions, e.g. local sales departments or distributed product development departments. The most value of IT platforms is added by the opportunity for one-to-many and many-to-many communication over a central virtual location. This implies fundamental challenges for a CoP Manager when migrating from decentralized communities to centralized and transparent IT platforms (see the preceding section for the additional tasks in this scenario).

For the support of large and geographically separated groups, Community Software usually offers a compilation of features. Traditional features are discussion boards, urgent request facilities, blackboards, e-mail listservers, or membership directories. Advanced Applications may additionally offer synchronous communication spaces like chats (text or video-based), document storage, evaluation systems, buddylists, alert agents, mailcenters, and calendars [25].

Interestingly, nearly all these features are only focusing members and their various communication channels. Although some vendors provide simple logging facilities, the user group of coordinators and managers is still insufficiently recognized. Thus, the software is not yet very supportive for the implementation of IT-based communities in enterprises, as it is not designed to create and manage a transparent structure and communicate the progress to different stakeholders. On the other hand, most data like logins, contributions, and references are hidden in the software and could be extracted and stored in databases for further analysis. Relevant components are interaction analysis (including contents, durations, interaction patterns, clusters, traffic patterns, etc.) and the visualization and analysis of social structures (including concentration of expertise, role formation, integration of isolated members, and elimination of gaps in the knowledge network). Thus, IT can help coordinating interventions by developing sophisticated methods and frameworks for analyzing and visualizing community structures and processes.

In practice until now, companies often conduct survey-based audits to assess their communities, not utilizing the rich data they could derive from their platforms [26].

Summarizing, a demand for augmenting Community Software with features for monitoring community activities, social structures and outputs can be recognized.

The value of visual components next to text-based communication is also being substantiated in the literature, e.g. Oliver et al. find that interactive materials are essential in a virtual environment, as opposed to pure text-based scaffolding [27]. Further, Johnson frames the question: Can Communities of Practice in their true definition be set up, maintained, and supported using current web-based applications, which are mainly text-based environments [16]?

5. Establishing a Framework for a moderator-oriented Software System

In order to systematically design the support of a Community Moderator, the following framework consisting of the domains Business Objectives, Data Sources, Analysis, and Visualization has been defined for the research project. It helps to focus the work on different

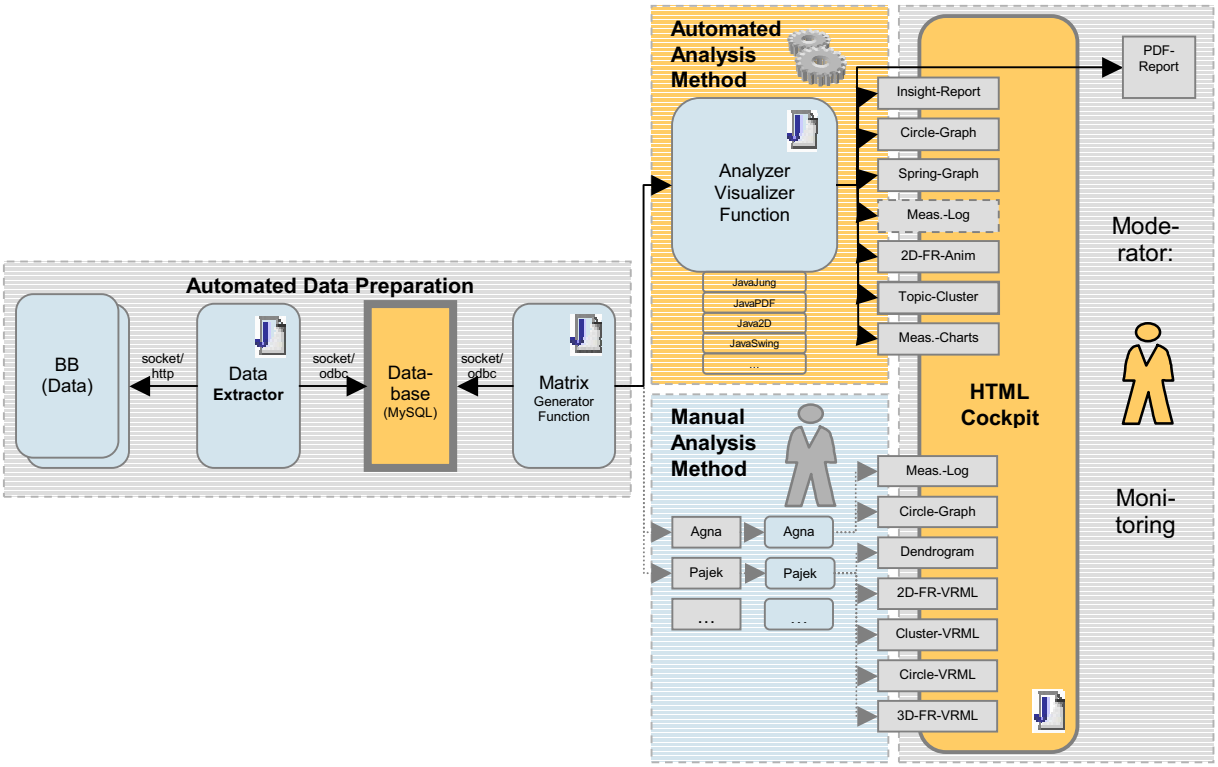

Figure 2. The Technical Components of the Community Monitoring Cockpit

aspects of a solution, which in the end can support community moderation.

The first work domain assembles and examines relevant Business Objectives and the respective tasks of moderators to produce a list of user requirements (compare previous section). Using this information the second area (Data Layer) identifies and assesses the relevant source data of selected platforms of Virtual Communities. These data sets can then be automatically processed using the measurement methods as developed for the Analysis Layer. Here, data about author properties, thread properties, topic structures and network properties is processed.

The identified interaction patterns around actual topics allow insights about the concentration of expertise, the formation of network roles, or about gaps in the network. This triggers actions like integrating isolated members (i.e. no replies and no comments to other contributions) and shows the relation of answers to requests. Further, it can provide visual insights about influential and supportive members in a topic field (i.e. most comments to others, most active, most referred, best ratings, etc.) and about the acceptance of new topics. In order to provide an easy to understand monitoring cockpit for the target group of Community Managers, a fourth work area is established: The Visualization Layer transforms the statistical results into intuitive and interpretable visualizations, which are presented in a web-enabled environment. They can be manipulated and printed by the moderator in order to achieve and communicate his insights about the development of his community. With such functionality, a management cycle of observation, measurement, interpretation and corrective action can be created for the facilitation of a community network.

Figure 2 summarizes how the work domains translate into the technical concept of the software. The first part is the Data Preparation Component, responsible for connecting various community communication platforms using special Data Extraction Connectors. They elicit useful data about the information exchange. Currently, the solution concentrates on the analysis of virtual discussions and therefore connects to sources like Usenet Newsgroups, PHP Bulletin Board Software, and Lotus Notes Discussion Databases. However, the component based architecture utilizes a special MySQL Database, where every extracted data is transformed into a standardized dataset. This keeps the Analysis and Visualization Component independent from the varying formats of the data sources and allows for easily adding several connectors, like for proprietary community platforms used in an enterprise. Typical elements of the database's structure are author names, posting contents and - in order to derive the communication structure - the referenced addressee of the content. Further, the database stores a time stamp of every communication to provide for

longitudinal analyses. For the development of topic-oriented analysis of member networks, a keyword extraction algorithm has been incorporated in the Data Extraction Connectors. It stores the most important keywords from each communication relation in the database. In the next section, this feature is applied for investigating a method of integrating people network and topic analysis into a useful visualization.

After having captured the data in the database, the Analysis and Visualization Component is executed. Figure 2 indicates two alternative methods. The main objective is an automated generation of various graphs that provide insight into the people networks of the community. This component is based on Java-Technologies and generates the visualizations and measurements. Examples are clustered views on the discussion network, circle representations showing important authors and connections, insight-reports containing relevant ratios for the moderator's network properties, and topic cluster visualizations.

In order to enable further representation of the knowledge network, a second manual analysis method is supported. Here, an experienced network analyst can utilize several third-party tools to experiment with the elicited data structure and to create useful representations that can be added to the set of automatically generated views on the net. They can then be seamlessly incorporated into the Visualization Cockpit for a homogeneous presentation to the Community Moderator. This second mode enriches the available set of useful views on the complex knowledge network of the community.

The last big component is the final Cockpit provided to the user. It has a web-enabled interface that allows easy access by community moderators. All rendered visualizations are presented in a systematical way together with relevant measurements and automated report elements. The moderator can manipulate the visualizations and the textual elements and can manually add his own written interpretations to the graphs. Then, he generates a printable report document, containing pages with graphs, textual analysis sections and manual comments in order to communicate the community development.

6. Deriving Visualization Methods

Recapitulating the objectives of the moderator, the Analysis and Visualization Component has to deal with the available data about topic structures, author properties, thread properties and especially network properties to care for the content-oriented and socially motivated tasks.

Here, it is very important to select and implement various network measurements and visualizations into an Analyzer Component, which combines these aspects.

To guide the development of this component, the rapid and regular advance in social networks research provides a vast body of measurements and methodologies [28], which can be applied to increase the transparency of people networks in Communities of Practice. The sociological approach of sociomatrices yielded in the suggestion of various measurements, which emphasize the most important properties using a very simple set of data about the network stored in a matrix. Examples are network density, centrality of authors, prominence, and activity proxies for authors derived from network data [28]. The related analytical approaches concentrating on network graphs enable a more visual analysis of large people networks. This visualization approach actually originates in the works of Moreno in 1932 [29]. He introduced points which represent actors and edges which indicate the link between actors. From this time on, there where several stages of development, like the introduction of computational procedures in the 1950's [30,31], first screen-oriented graphs in the 1970's [32] or the event of social network analysis tools in the 1990's [33] (For a good introduction, refer to [34]).

All these tools deal with the analysis and visualization of network graphs. They necessitate an experienced analyst, who is either uploading a dataset or generating it with the tool. Then by manipulating the data with various statistical configurations he can finally render the required network graph and analyze its properties. Unfortunately, these tools do not lend themselves to an automated analysis of continuously updated networks and require much skill in interpreting the results.

Next to graphs that originate from the domain of social network analysis other related visualization approaches have been employed for increasing the transparency of computer mediated communication.

One example is the Babble-Timeline developed by the IBM T.J. Watson Research Center in order to visualize discussion histories [35].

Users are placed on various parallel horizontal timelines. Gray parts of every user's line indicate a participant who is logged on but not viewing the current discussion, gaps represent periods, where the user was logged off. Colored parts imply that the user looked at the discussion currently examined. Vertical marks indicate the user's postings, gray marks stand for postings in other discussions, and colored marks are contributions to the actual discussion.

A second example is the interface of Coterie, created at the MIT Media Labs [36]. It is representing users as ovals, their color brightens if they are active, they form clusters around topics, active conversants move to the center, inactive listeners (called 'lurkers') get located at the sidelines. Despite providing insights in the current movements, the solution lacks a statistical perspective for ex-post analysis of social processes or structures.

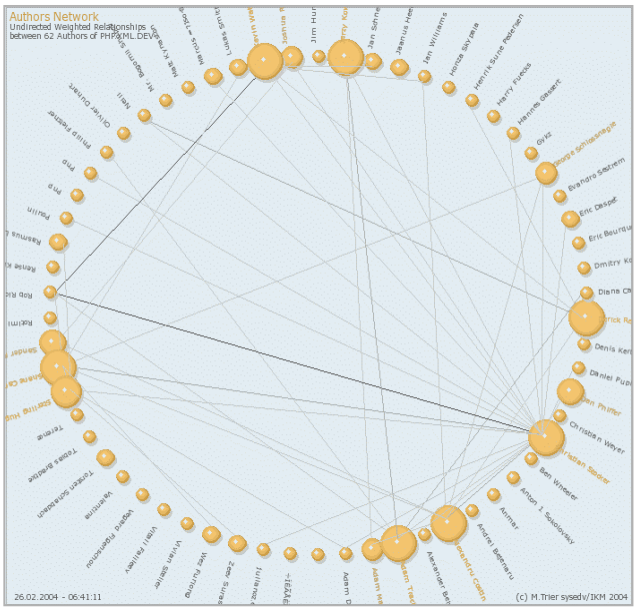

Figure 3. Circle Graph of a Community Network

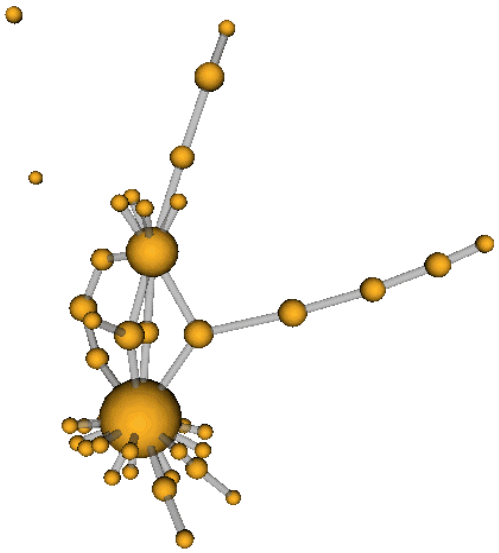

Figure 4. 3D-Representation of a Discussion Group

Further research projects are working on related representations [37,38] or apply aspects of social network mapping to online communication [39].

Summarizing, the various approaches can be categorized into a group, which draws its inspiration from social network theory and a group, which is experimenting with multiple ways of visually illustrating the body of data contained in the platforms.

Using all these available representations, a set of graphs can be selected for implementation into the Community Cockpit Module. Nevertheless, the modular and open approach of the Cockpit Module allows for continuously adding further useful network representations. Examples are longitudinal time-frame analysis, author activity timelines etc.

A first, very easy and yet insightful sample visualization produced in the project was the Circle Graph shown in Figure 3. It positions all actors of a communication network on a circle and shows the relations between them as lines. This allows an intuitive estimate about the density of communication, the strength of relations and the set of active actors in the group under consideration. Further, very active authors have bigger nodes to allow for quickly spotting the most important members. On the other hand, passive members without any connections are identified easily. Another central feature of the software system is based on the Spring Embedder Algorithm [40]. Using this algorithm a people network can be presented in meaningful clusters. Actors that are shown close together have stronger links than actors which are very distant. At the moment, the according visualization classes implement the available Java Jung Libraries [41].

The impression of a network can even be improved, if a 3D Model is produced. In Figure 4, a discussion group working on debugging the programming language PHP and extending it to include XML has been analyzed and exported by the software into a web-enabled three-dimensional graph using Virtual Reality Modeling Language (VRML). This visualization gives insights about the structure of the group and represents it similar to a chemical molecule. By rotating this model, one can easily spot the two centers of communication and the various important network positions. The two important actors are identified by their node's size. There are four members, which act as cut-points. If they would not form a bridge between the two subnets the whole network would break into two parts.

The keyword extraction feature embedded in the Data Extraction classes of the software has already been introduced. It extracts the most important concepts from the contributions of the various authors. The component furthermore identifies the addressee. In the end, all communication acts between any two authors can be analyzed and the most important topics are identified. By this form of analyzing the topics of the communication network, pure people network analysis is augmented with content analysis. The approach developed for the software system is shown in Figure 5. The concepts Fopen and HTTP have been automatically identified as the most important keywords in the communication relations between the three authors Y, H, and S. If the contributions share this property, then obviously they are central concepts talked about in this communication relation. If the concepts appear in just one posting then they are located near its author. This gives insights about the actual

topics domains of each member and provides a new view on the network. The moderator can now find and observe authors and subnets of selected topics and hence select topical parts of a complex network for further development. He can easily see which people talk in their subnets about which topic. This perspective is now much closer to the real impression of a discussion than it is originally being found in hierarchically structured listings of texts and authors distributed across the whole discussion board.

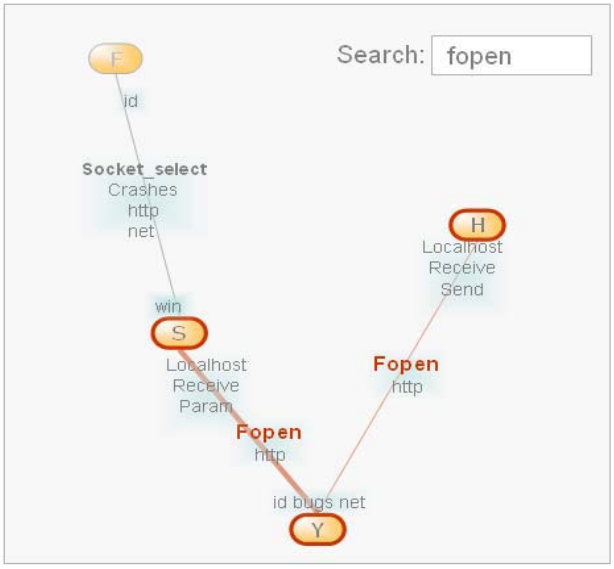

Figure 5. People Network with Content Keywords

7. Conclusion

One objective of Knowledge Management is to improve the transparency of networks of people and their relations to topics, documents, and activities. Communities of Practice are a complementing KM instrument, which focuses such expert groups. They often employ IT platforms to support large groups of geographically separated experts and their network connections. Moderators are established to guide such a community as a facilitator of learning processes. They are responsible for a variety of content-oriented and socially motivated tasks. Here, visualizing network structures and processes in virtual Communities of Practice improves the transparency of the group and hence enables a better Knowledge Management in content-oriented people networks. To examine this issue, virtual discussion boards have been selected as a communication channel, as they provide a public, central, and consistent structure of network-oriented expert communication.

To create moderator-oriented software functionality, the adopted design methodology first assembles moderator requirements, derived from a task analysis. These business objectives determine the selection of captured source data of common discussion boards, the selection of measurement and analysis domains, and of course the design of intuitive visualizations, which model the expert network using different views. Especially the combination of topic analysis and people network visualization is considered to provide insights about the actual discussion structure. Finally, all visualizations are accessible through a web-enabled Management Cockpit. In addition to the introduced graphs, various measures of network analysis are automatically generated by the software. The moderator can access these textual results and can add individual comments, like planned tasks or the documentation of special observed phenomena in the group. By selecting, configuring and storing the network graphs and the according measurements, a detailed report can be generated, which helps the moderator to communicate the growth and value of his community to his stakeholders.

Future research will focus on practical applications of the Commetrix System [42] to analyze existing virtual networks and further exploration and development of innovative visualization forms, including topic-people networks, time-based networks, and three-dimensional graphs.

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