Personal Knowledge Management in a Peer-to-Peer Environment

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Abstract. Architectures of knowledge management systems (KMS) have typically been centralized client/server solutions. Shortcomings of centralized KMS include costs, restricted focus, and lack of integration of personal workspaces. The focus of centralized KMS is typically restricted by organizational boundaries, because of organization-specific ontologies and insufficient integration of heterogeneous infrastructures. We propose a peer-to-peer environment for personal knowledge management that can be used to overcome the limitations of centralized KMS. In this paper we discuss networking, integration, publication, and presentation issues of shared personal knowledge management environments.
Keywords: (personal) knowledge management, knowledge management system, knowledge workspace, peer-to-peer

1 Introduction

Knowledge management (KM) has been discussed intensively both from a human-oriented and from a technology-oriented perspective. Knowledge work has to be supported with adequate organizational as well as information and communication technological (ICT) infrastructures. Knowledge management systems (KMS) have been proposed as integrated sets of ICT that support the deployment of KM instruments in organizational KM initiatives. KMS architectures have typically been centralized client/server solutions.

Shortcomings of centralized KMS include costs, restricted focus, and lack of integration of personal workspaces. The design and maintenance of central knowledge bases involves substantial costs, e.g., for the acquisition of KMS software, for building shared ontologies, and for managing user privileges. The focus of centralized KMS is typically restricted by organizational boundaries, because of organization-specific ontologies and insufficient integration of heterogeneous infrastructures. Moreover, a substantial amount of knowledge is stored and managed by individual knowledge workers and lacks integration with centralized KMS.

The peer-to-peer metaphor has been used for various application domains including file sharing, messaging, and collaboration. There are three variants of peer-to-peer architectures, i.e., assisted, pure, and super-peer architectures. We propose a pure peer-to-peer environment for knowledge management that can be used to overcome the limitations of centralized KMS. The newest version of Infotop supports the creation and management of shared-context knowledge workspaces and organizes knowledge resources in a peer-to-peer environment. In this paper we introduce knowledge work and knowledge management systems (Section 2), show the advantages of peer-to-peer architectures (Section 3) and present the newest version of Infotop that implements a peer-to-peer KMS targeting the specifics of knowledge work (Section 4).

2 Knowledge Work and Knowledge Management Systems

Organizations have to create an effective environment for knowledge generation and application and depend on the knowledge and talent they can recruit, develop and retain in order to provide value innovation (Kim 1999). Consequently, organizations need concepts and instruments that help them to establish such an environment. KM promises guidance in this matter and therefore has recently received increasing attention from a variety of fields and disciplines, see e.g. (Maier 2004). Knowledge management is the management function responsible for regular selection, implementation and evaluation of goal-oriented knowledge strategies that aim at improving an organization's way of handling knowledge internal and external to the organization in order to improve organizational performance. The implementation of knowledge strategies comprises all person-oriented, organizational and technological instruments suitable to dynamically optimize the organization-wide level of collective competencies, education and ability to learn (Maier 2004).

Knowledge management systems have been proposed as ICT platforms that combine and integrate many ICT, i.e., a number of functions for the contextualized handling of knowledge in organizations. A KMS promises significantly enhanced functionality through an integrated combination of a substantial portion of the information and communication systems from a KM perspective. It should not be seen as a voluminous centralized database, but rather as large networked collections of contextualized data and documents linked to directories of people, roles and skills. A KMS provides intelligence to analyze these documents, links, employees' interests and behavior, offers support for personalized access to the knowledge base as well as advanced functions for knowledge sharing and collaboration.

There are substantial shortcomings of centralized KMS with respect to costs, restricted focus, and lack of integration of personal workspaces as stated above. Moreover, centralized KMS implementations apply a metaphor that is simply not suited to support the specifics of knowledge work (Hayes 2001, 81f, Maier 2004, 44ff, Schultze 2003, 43). Knowledge work can be characterized by a high degree of variety and exceptions. Knowledge work is creative and comprises the development, acquisition, application and distribution of knowledge. Knowledge work consists of a number of specific practices, e.g., generating new knowledge, interpreting and representing it, producing and reproducing knowledge or, in Schultze's (2003, 50f) terms, practices of informing, such as expressing or extracting knowledge and experiences, monitoring, translating and networking. It requires a high level of skill and expertise provided by substantial training and education. It is decentrally organized with high personal responsibility and requires new organizational metaphors, such as networks and communities. Inputs and outputs of knowledge work can be primarily characterized as data, information or knowledge. Knowledge work is communication-intensive, mobile, distributed and networked and consequently has to be supported by sophisticated KMS infrastructure.

Summing this up, people primarily engaged in knowledge work (whom we call knowledge workers) typically are communicative, highly individual, mobile, self-motivated people who are rarely closely monitored and thus, within limits, can decide when, where, why, from and with whom they acquire, document, share and apply what knowledge and to what extent and how they use information and communication infrastructure to support these tasks. Consequently, there are a number of organizational issues that have to be resolved when implementing a KMS, before one could expect knowledge workers to actively contribute and before the KMS infrastructure can be fully deployed in an organization. Examples are (see also Susarla et al. 2003, 133ff who discuss participation, trust and coordination issues with respect to peer-to-peer systems):

Participation issue
The problem with many collaborative systems has always been that everybody wants to read, but (almost) nobody finds the time to write. There have to be incentives for knowledge workers to let others access their "knowledge hoard" and to actively participate in the knowledge network(s) in order to foster information sharing and avoid the free rider issue.

Trust issue
Security and reliability of a KMS infrastructure have to be believable for the knowledge workers if they should on the one hand submit valuable resources and on the other hand rely on the KMS infrastructure for their personal knowledge work.

Coordination issue
Structuring and quality management of the knowledge contained in a KMS have to be supported in order to manage the quality of the knowledge base and avoid information overload.

Multiple information space issue
Knowledge workers typically access not only the organizational knowledge base(s), but also numerous external sources accessible via the Internet as well as personal knowledge bases, i.e. the files on their personal computers. Knowledge workers are typically highly mobile, not always online and thus require replication functionality for their personal, mobile knowledge spaces.

Personal knowledge management reflects the goal of supporting individual knowledge work rather than establishing an organizational approach.. Personal KM environments are targeted at seamless integration of individual work environments and infrastructures supporting joint creation, distribution, sharing, and application of knowledge.

3 Peer-to-Peer Architectures

Architectures play an important role as blueprints or reference models for corresponding implementations. The term architecture is used in a variety of ways: e.g., application architecture, system architecture, information system architecture and especially software architecture. There are basically three main sources for architectures describing the structure of KMS:

Theory-driven architectures.
The first group of KMS architectures is the result of theoretic investigations which represent a theory-driven decomposition of an organizational knowledge base or organizational memory and derive ideal components of a corresponding ICT system. Zack classifies KM tools and systems into one of the following two segments: KMS with an integrative versus an interactive architecture (Zack 1999).

Vendor-specific architectures.
Vendors of KMS publish white papers in which they describe their perspective on knowledge management and place their tools in a knowledge management architec-

ture that regularly pays attention to the ICT infrastructure already available in the organizations.

Market-driven architectures.
A more pragmatic approach empirically distills the most important components of an organizational KM environment which is integrated with more traditional data and document management systems as well as communication systems. Vendors of standard software tools, platforms and systems to support KM or individual KM environments of organizations are regarded as KM pioneers. These architectures are mostly layer models. The number, naming and inclusion criteria of the layers differ from author to author.

There are several attempts of KM researchers to profit from the promised benefits of a peer-to-peer metaphor for the design of an information sharing and especially of a knowledge management system, e.g., (Parameswaran 2001, Susarla 2003). The peer-to-peer metaphor promises to resolve some of the shortcomings of centralized KMS, i.e., to reduce the substantial costs of the design, implementation and maintenance of centralized KMS, to reduce the barriers of individual knowledge workers to actively participate and share in the benefits of a KMS, and to seamlessly integrate the shared knowledge workspace with an individual knowledge worker's personal knowledge workspace.

A number of organizational and technological issues still have to be resolved before a p2p KM infrastructure can be fully deployed in an organization, i.e., participation, trust, coordination and multiple information space issues (see Section 2). Participation should be no more of a problem than in centralized KMS within organizational boundaries. Moreover, if shared workspaces can be established in a peer-to-peer network, a large number of users might be convinced to participate. In peer-to-peer knowledge networks that cross organizational boundaries, (professional) communities along with personal contacts, contracts, shared goals and interests might act as a kind of social infrastructure that induces social regulations and also trust into the peer-to-peer network.

Personal data and knowledge sources are extracted, transformed and loaded into an integrated Infotop knowledge base. The integrated knowledge base comprises a private, protected and public area. A personal knowledge cache is used to optimize network traffic when shortly accessing the same knowledge elements multiple times. Due to the fact that knowledge workers might still at some time prefer to work offline, this knowledge base has an offline cache keeping those knowledge elements that are often needed on the local storage medium preferred by the knowledge worker. Just as in the centralized case, knowledge and access services build upon this integrated knowledge repository (see the architecture depicted in Figure 1). The main difference is that the knowledge repository now is spread across a number of collaborating peers that have granted access to parts of their knowledge repositories.

4 Infotop

Infotop is a metaphor for a shared-context information workspace that has been developed with KM issues in mind. The term Infotop stresses in analogy to desktop to be "on top of the information" and thus covers the dynamic aspect, i.e., the flow of knowledge, in contrast to desktop. Infotop provides seamless support for access, knowledge, integration and infrastructure services, see Figure 1. Infotop uses the sources file system, personal information and communication system, office systems, as well as Web pages.

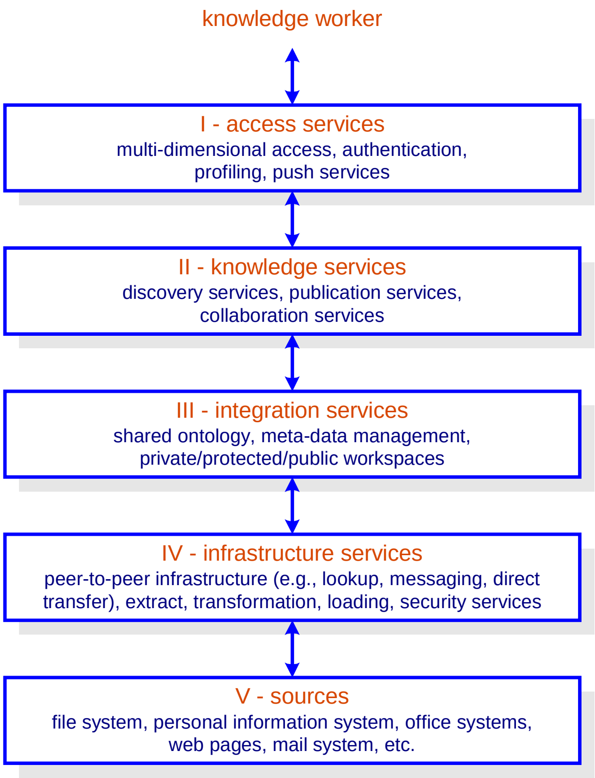

Figure 1. Architecture of a single Infotop peer.

We have implemented a prototype using Microsoft .NET and the programming language C#. First considerations about the implementation were presented in (Maier/Sametinger 2004). In the following, we present details about the actual realization and new ideas that evolved during the implementation. Major contributions have been made by Thomas Keplinger, Klaus Pichler and Michael Retzer. We have now a first version available and have begun with tests. These tests are satisfactory and promising so far. The most important functions that Infotop provides on these levels are presented subsequently. These are (1) networking functions, i.e. establishing peer-to-peer infrastructures for KM, (2) integration functions, i.e. handling meta-data and maintaining a shared multi-dimensional taxonomy, (3) publication functions that address the challenges to motivate users to participate and coordinate them by creating and maintaining knowledge workspaces and (4) presentation functions that are required to conveniently access shared multi-dimensional knowledge workspaces.

4.1 Networking

Users have information on their private computers and can also access public resources, typically on the Internet. Additionally, servers on local area networks provide extra information that is not accessible to the public, but to a restricted number of users only. We use private, protected and public workspaces for users. Private workspaces contain information that is stored locally on our computers and accessible only for the owner of the private workspace. Public workspaces include information that is published via the

Internet and accessible by an undefined group of users. Protected workspaces lie somewhere in between. They contain information that is not accessible for everyone, but for whomever the owner grants explicit access, e.g., digital libraries. Private, protected and public workspaces of an individual can be placed on her computer. A user's protected workspace is not open to the public, but rather allows restricted access only to those individuals that she wishes. Thus, access privileges of a protected workspace have to be configurable in a flexible manner. Typically, public workspaces grant permission to read only, whereas protected workspaces may be open to write.

For a shared-context information workspace, we have private, protected and public workspaces institutionalized on all workplaces. Any information in these workspaces has meta-information attached (see Section 4.2). Assignment to e.g., topics is crucial for workspaces. This allows us to have several virtual workspaces for different topics of interest. Virtual workspaces can overlap, because workspaces and sets of documents can be assigned to more than one topic. Users can select any available workspaces to be included in searches. Thus, whenever knowledge elements are displayed in Infotop, it is possible to include or exclude elements from specific workspaces.

We use .NET remoting for peer-to-peer communication. Workspaces are identified by their IP address and optionally a folder path. The contents of external workspaces are automatically included in a user's environment. Searches are handed over to the appropriate workspaces and done by these. Only the results are returned to the searching peer. Any file sharing between peers is done using the ftp and http protocols. In order to limit network traffic, searches are not broadcasted, but just sent to those workspaces that are manually included in the search.

4.2 Meta-data management

Meta-data are data about data. A knowledge structure contains knowledge elements and the relations between them as well as meta-data which give further information about their content and associations. The two terms taxonomy and ontology are used widely in KM. The term taxonomy denotes the classification of information entities in the form of a hierarchy, according to the presumed relationships of the real-world entities that they represent (Daconta et al. 2003, 146). Ontologies are formal models of an application domain that help to exchange and share knowledge with the help of ICT systems. An ontology is in general an explicit specification of a shared conceptualization or, more specifically, defines the basic terms and relations of a topic area as well as the rules for combining terms and relations (Gruber 1993, 199, see also Maier 2004, 214ff).

To facilitate knowledge sharing, a joint knowledge structure has to be established, in order to create a joint understanding between Infotop peers. Simple hierarchical knowledge structures are not suitable, because different users classify their knowledge elements or documents on the basis of different criteria (e.g., processes, topics) and end up using individual, incompatible taxonomies. Thus, it is difficult to find a structure that meets the needs of all participating Infotop users.

Recently, especially in the course of the Semantic Web initiative (Berners-Lee et al. 2001) and to support the exchange of meta-data in libraries, a number of initiatives have been started to provide comprehensive frameworks for the definition of meta-data, i.e. semantic information about documents exchanged between users. Examples are PRISM, Dublin Core, the Resource Description Framework (RDF), the DARPA Agent Markup Language + Ontology Inference Layer (DAML+OIL), XML Topic Maps (XTM) or the Web Ontology Language (OWL) (see e.g., Daconta et al. 2003 and the Websites of the relevant standardization institutions, i.e., ISO, W3C).

Infotop uses a structure for meta-data which on the one hand is as comprehensive as possible and on the other hand remains simple enough to be usable. Special care was taken to limit the meta-data categories to those that might be identified (semi-) automatically when using Infotop for storing and exchanging contextualized documents. The following categories build on the Dublin Core standard (Dublin Core 2003) and are defined as standard in Infotop, see Table 1.

Table 1: Dublin Core-based elements of Infotop

element	description
title	names the object displayed in Infotop. The file name is the default title.
description	describes the content of the object.
keywords	can be assigned to the object to illustrate the topics it covers.
project	represents the (business) process or project in or for which the object was developed.
location	covers geographical references, e.g., office location of the author (*location.author*), location of development (*location.project*) or location which is described or referenced in the object (*location.description*).
person	covers references to authors (*person.author*), participants of (project) meetings (*person.participant*), sender (*person.from*) or receiver (*person.to, person.cc, person.bcc*)
contact	represents address information for home (*contact.home*) and business addresses (*contact.business*) in the vCard standard. The various fields in the contact information are separated by a corresponding extension, e.g., name (*contact. business.name*) or e-mail address (*contact.business.e-mail*).
date	is represented in the case of files (*date.create, date.update*), in the case of e-mails (*date.sent, date.received*) and appointments (*date.start, date.end*).
relation	assigns links to Web resources (*relation.uri*) or other sources (*relation.other*).
language	represents the language of the object in the form of the country code, e.g., *us*, *uk*, *de*.
rights	addresses e.g., copyright issues, IPR or digital rights (DRMS).
type	means a file's extension, e.g., .pdf, .html, .jpg.
format	is derived from the file extension. Formats covered by the Infotop prototype are (examples in brackets): text (doc), picture (jpg), audio (mp3), video (mpg), presentation (ppt), application (exe), Web content (html), message (olmail.msg), appointment (olappointment.msg), contact (olcontact.msg), compressed (zip), source (java).
size	of the object is measured in MB or numbers of pages alternatively.
status	defines the global access pattern of the object: *private*: only the creator, *protected*: a defined group of users by user name and password and *public*: every Infotop user registered in the workspace.

4.3 Publication

Publication basically means inclusion into the Infotop workspace of a peer. Any information in Infotop has to have meta-data attached, such that powerful knowledge services can be supported: query, filter and navigation mechanisms as well as collaboration on the bases of shared information spaces. Meta-data about the author, time of creation or update and location, type and format can be automatically assigned when the knowledge element is saved to the workspace. If the knowledge element is received as an e-mail attachment, Infotop stores this meta-data together with the message's sender (person.from), receiver (person.to, person.cc), date (time.received, time.sent), subject (title, project) and type of attached file (type, size). Infotop might suggest a topic, project, keywords and language by text mining algorithms that extract a (text) document's title, headings etc. Additionally, users may assign meta-data to knowledge elements that are not used by other individuals that access this information.

While the Dublin Core element assignments will be unchanged in most situations, this flexibility is advantageous when users define new meta-data elements. For example, a user may want to document with which camera she has taken her digital pictures. She can introduce a meta-tag „camera". Whenever a picture has the camera tag assigned, it will be presented in the chosen dimension (see Section 4.4).

Knowledge elements can be stored in the private, protected or public part of an Infotop peer's workspace. A user might share parts of other users' workspaces, see user 3 in Figure 2. The dashed line and the gray boxes indicate her shared-context information workspace, i.e., a virtual workspace that includes her private, protected and public workspace as well as all public and parts of protected workspaces of other users. It is important to note that a user's protected workspace is not open to the public, but rather allows restricted access only to those individuals and those parts of the protected workspace that the user wishes.

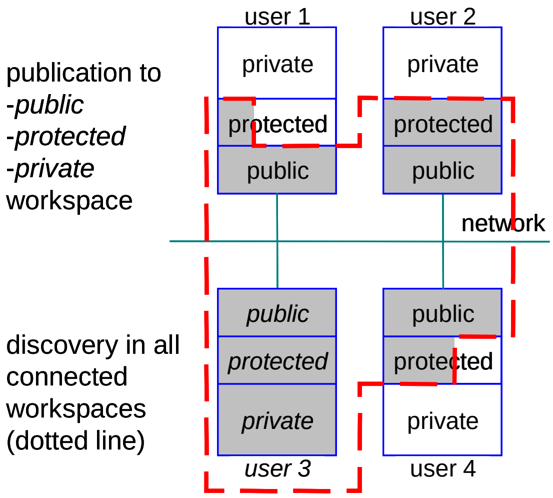

Figure 2: Publication to shared workspaces in Infotop.

Whenever knowledge elements are placed from private workspaces to protected or public ones, these become available to a bigger audience. Say that a number of persons collaborate on a specific project. They typically will set up a protected workspace and place all the documents for their collaboration into this workspace. All members of the team can access the information including meta-information that is being used for search and display. They can also set up various protected workspaces, say one for each member. When working on their project, members will include all workspaces of their team mates that belong to this project and, thus, have all information available on their specific project. Should information be available to the public, then it has to be placed into a public workspace where it can be accessed without any password protection.

4.4 Presentation

The dimensions time (when?), topic (what?), location (where?), person (who?), process (why?) and type (how?) have been identified as being essential for effective categorization, visualization and navigation of collections of contents (Maier/Sametinger 2002). We identify these dimensions as essential for effective categorization, visualization and navigation of collections of contents. The six dimensions are used as the basic structure for accessing Infotop workspaces. Several hierarchies of any of these dimensions can be used for display in addition to well-known visualization techniques like icons, thumbnails or lists. The meta-data in Infotop is attributed to the six dimensions, see Table 2.

Table 2: presentation of dimensions

dimension	meta data types	presentation
when (time)	date (date.created, date.updated, date.sent, date.received, ...)	time-order, document stream
what (topic)	title, description, keywords, relation	multi-dimensional hierarchy, network
where (location)	location	maps
who (person)	person (person.author, person.from, person.to, person.cc, ...), contact (contact.home, contact.business, ...), rights	multi-dimensional hierarchy, thumbnails
why (process)	project	hierarchy
how (type)	type, format, size, status, language	(size of) icons, piles

New categories introduced by individual users can also be assigned to one of the dimensions and will then be used for display in these dimensions. The six dimensions are used as the basic structure for accessing Infotop workspaces. The six dimensions can individually be presented using the visualization techniques shown in Table 2. Information about sets of documents is displayed using these dimensions. Additionally, the numbers of documents are indicated for each displayed category. Views can be restricted to contents with specific attributes in any of these dimensions, e.g., contents of a specific process or of a specific age. Infotop's one-dimensional views are shown in (Maier/Sametinger 2002), however, without considering a shared context.

In Figure 3 we can see how Infotop displays information in the *who* dimension. People are listed on the left side of the window. The user can select one person and Infotop lists all information about that person on the right side. Time is one of the most crucial attributes of documents, e.g., time of creation, time of last modification, time of last read-only access. Typically, only appointments are displayed in calendars, rather than e-mail messages, text documents and other forms of documents, e.g., comments, yellow stickers. It is also useful to display a selection of documents. For example, we may want to

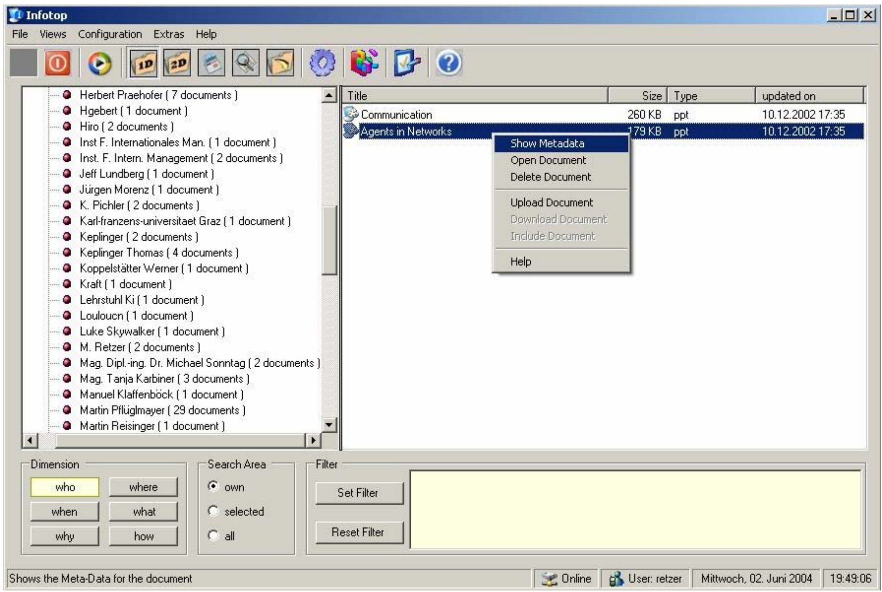

Figure 3. One-dimensional view using the *who* dimension to display documents

see all documents of a project displayed in the calendar, or all documents of a person, i.e., all e-mail messages from and to that person, all files exchanged with that person, all web documents about that person that we have visited, see Figure 4.

In analogy to OLAP (online analytical processing) techniques, Infotop's dimensions can be used for slicing, dicing, drilling down, rolling up, and ranging operations on contents of a personal knowledge environment. Several hierarchies of any of these dimensions can be used for display in addition to well-known visualization techniques like icons, thumbnails or lists. Facts, i.e. the information on sets of contents represented in each

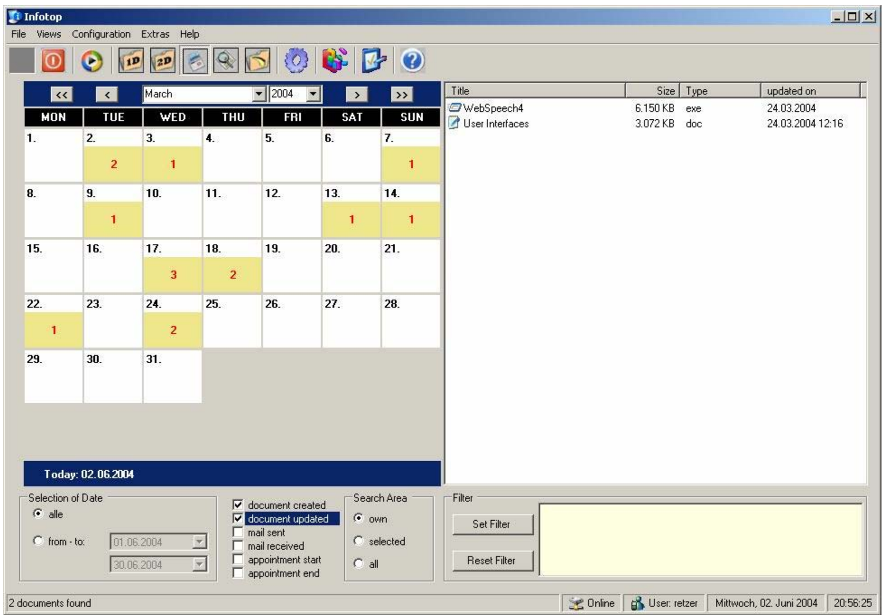

Figure 4. Infotop's calendar view

cell, are the number of elements as displayed in Figure 5. We imagine additional and alternative representations, e.g.,

– the amount of data, e.g., the number of pages or Mbytes,
– the number of contributions of or of questions answered by knowledge providers,
– an aggregate valuation of elements, e.g., the number of accesses to elements, a measure of the skill levels of knowledge providers in a domain,
– any other meta-information stored along with elements, e.g., titles of documents, or
– a comparative measure, e.g., the proximity of competencies between a number of potential knowledge providers in a certain domain.

A two-dimensional view using the *how* and *when* dimensions can be seen in Figure 5. Colors are used to direct the attention to those cells that contain large numbers of documents, see left side of the window. The user can click into a cell and have detailed information on the documents in this cell displayed on the right side of the window. Additionally, other dimensions can be filtered. In this case the *author* tag in the *who* dimension is limited to "Retzer" and the *project* tag in the *why* dimension is limited to "software", see lower right side of the window in Figure 5.

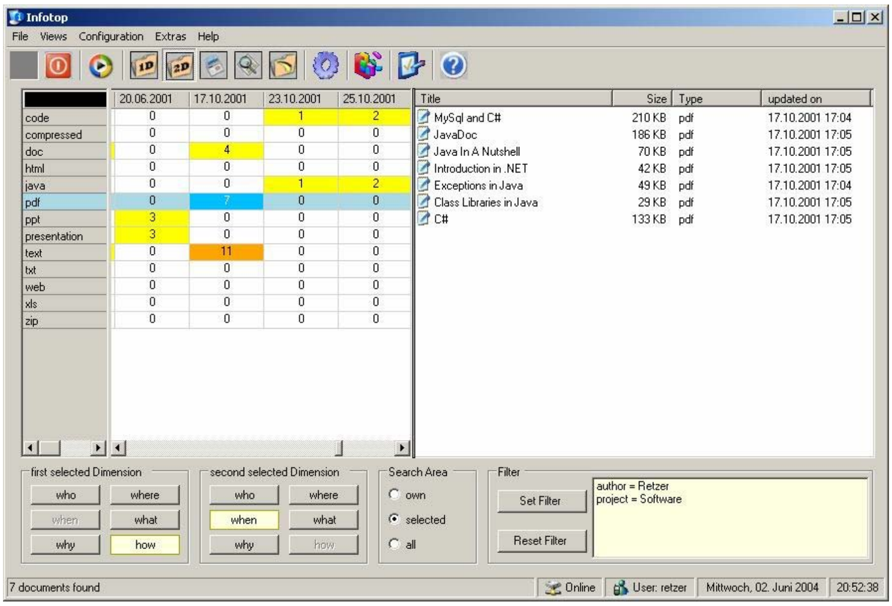

Figure 5. Two-dimensional view

Summing up, Infotop is especially helpful in supporting individuals in knowledge processes that cross organizational boundaries and that involve a number of projects and initiatives with changing partners. As an example, users externalize, submit, acquire, distribute, and apply information in their personal knowledge management environments. Externalization of information is done with regular applications, e.g., a word-processing software, or (co-) authoring tools. This process results in documents that typically are at first stored in the private workspace. It is important to have meta-information attached to these documents. Submission means publication of a new knowledge element and its distribution towards a topic-oriented network, i.e., in a protected or public workspace. Acquisition of information includes the extension of the search domain to include new workspaces, the location of information in any of the accessible workspaces and copying this information or a link to it into one's individual workspace. The distribution process involves moving or copying information from one's private to one's protected or public workspace. The application process involves any usage of information that has been retrieved from an arbitrary source, i.e., from protected and/or public workspaces.

5 Conclusion

We have discussed the differences between traditional work and knowledge work and have analyzed the main requirements for ICT support of knowledge work. The main characteristics of knowledge work have posed four issues for the management of knowledge elements in a KMS, the participation, trust, coordination and multiple information space issues. Consequently, we have argued that a centralized KMS is a limited approach that does not take into account the specifics of knowledge work.

Infotop addresses these issues as the peer-to-peer metaphor much more closely fits the self-image of knowledge workers as individuals who want to be fully in control of their profiles, the knowledge assets they are willing to share and their communication, coordination and collaboration. Infotop contains peer-to-peer information workspaces and proposes fifteen categories for meta-data grouped in six dimensions. Infotop establishes a flexible way to share parts of the organizational knowledge base due to the individual management of access privileges.

We imagine Infotop as the main access point both for personal knowledge management and for ad-hoc collaboration in a shared context. The next steps will be to test the Infotop prototype more thoroughly, to empirically validate Infotop's usefulness to support practices of knowledge work as well as to add further knowledge services on top of the Infotop infrastructure.

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