Ontologies for Knowledge Management

Andreas Abecker and Ludger van Elst

German Research Center for Artificial Intelligence
– Knowledge Management Department –
67655 Kaiserslautern, Germany
(aabecker,elst)@dfki.uni-kl.de

'People can't share knowledge, if they don't speak a common language.'
(Tom Davenport)

Since the term *ontologies* in AI was coined within the *Knowledge Sharing and Reuse Effort* [68] for engineering of knowledge–based systems ([40, 41]), it is not surprising that it heavily entered Knowledge Management ([21, 25], KM) research: *Sharing* and *reuse*—in this case of organizational knowledge—are among the core knowledge processes tackled within every KM endeavor. In this chapter we briefly introduce the main ideas of KM and the role and requirements for information technology (IT) in KM. We then discuss the potential of ontologies as main elements in IT solutions for KM. We characterize their current role in research and practice, derive a working focus for the near future, and conclude with an outlook on possible future trends in KM software and their implications on ontologies.

1 Information Technology for Knowledge Management

Knowledge Management (KM) is a young interdisciplinary science with roots in Business Sciences, Information Technology, Pedagogics, Psychology, and Organizational Theory (cp. [21, 47]). According to Eppler [32] we can define **Knowledge Management** as a:

- *systematic approach* (with a background in information technology, human resources, strategy, and organizational behavior)
- that views *implicit and explicit knowledge* as a key strategic resource, and
- aims at improving the handling of knowledge *at the individual, team, organization, and inter-organizational level*
- *in order to improve* innovation, quality, cost-effectiveness and time-to-market.

From the very beginning of the KM endeavor two streams of research and applications could be identified which we called the *Process-centered* and the *Product-centered view on KM* (see [54]), which was called the *Personalization versus Codification Strategy* by [45], *the Organic versus the Mechanistic* approach by [99], or the *Community Model versus Cognitive Model* view by [97], and which could be identified as two basic dimensions of KM activities in consulting practice as well (cp. [63]):

1. The *process-centered view* mainly understands KM as a social communication process. It is based on the observations that the most important knowledge source in an organization are its employees, and that solving *wicked problems* [20] is merely a process of achieving social commitment than one of problem solving. Hence knowledge exists, is created, and is further developed in the interaction among people and tasks such that the focus of IT should be to enable, facilitate, and support communication and collaboration.
   Technical solutions in this area comprise, e.g., yellow page and expert finder systems for determining the right communication partner, Computer-Supported Collaborative Work (CSCW) systems for effective collaboration between geographically separated people, or Skill Management systems for the systematic and planned acquisition and development of human skills and competencies, etc.
   In this view, organizational measures such as installation of expert networks, training courses, virtual teams, and all kinds of cultural KM support play a particularly important role.
2. The *product-centered view* focuses on knowledge documents, their creation, storage, and reuse in computer-based *organizational memories* (OMs). It is based on the idea of explicating, documenting, and formalizing knowledge to have it as a tangible resource, and on the idea of supporting the user's individual knowledge development and usage by presenting the right information sources at the appropriate time. Hence the main assumption is that knowledge can exist outside of people and can be treated as an object dealt with in IT systems.
   Of course, the transition from intangible (implicit and tacit) to tangible (explicit) knowledge in the form of standardized processes and templates, FAQs, lessons learned and best practices, etc., allows a company to enhance its structural capital, maybe at the price of loosing creativity and flexibility. Basic techniques for this approach come from Document Management Systems, Knowledge-Based Systems and Information Systems.
   In this view, organizational measures aim at fostering the use and improving the value of information systems by bonus systems, or by installing organizational roles and editing processes for high-quality knowledge content management.

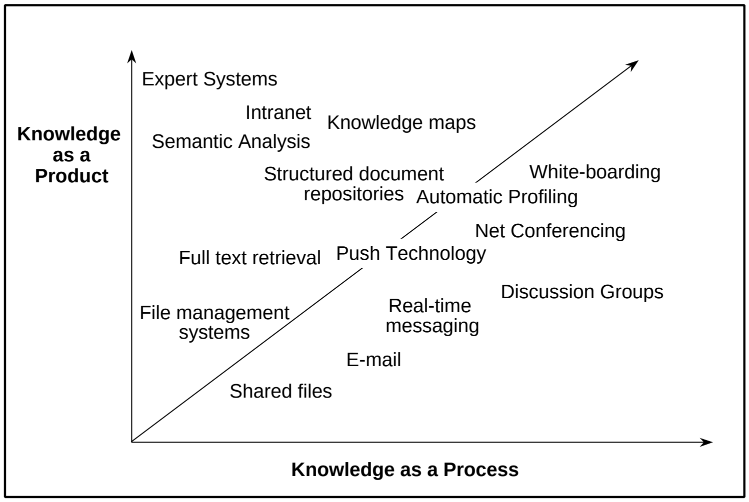

Fig. 1. Software Support for the Product and the Process Approach to KM

Figure 1 gives an idea of typical software support for both dimensions. Analyzing the history of IT support for KM one may identify the following types of KM applications:

Type 1 Applications: Conventional Software Basis.

Type 1a Applications: Standard Software Applications. As, e.g., [24] show, especially the early success stories of KM were—although IT-enabled and heavily IT-dependent—not building upon any new IT solutions, but used conventional technology like databases or discussion boards. This area should not be underestimated in practice. However, it is not interesting in the context of this book.

Type 1b Applications: Integrated Standard Software. The first specific KM solutions are characterized by the explicit approach to combine manifold aspects of KM support in one integrated software suite, hence incorporating both the product and the process aspects of KM. Typical representatives are the big KM tool suites still successful in the market, like, e.g.:

- Coming from the knowledge process side, e.g., Livelink or Lotus Notes-based solutions, which combine comprehensive groupware and process management support, many types of synchronous and asynchronous communication, with standard document management functionalities.
- Coming from the knowledge product side, e.g., Verity's or Inxight's product suites which attach many individual and organization-wide information management functions (push and pull services, content management

support, Intranet portal functionalities etc.) around advanced information classification and retrieval technology.

Figure 2 gives an idea of the elements of a somehow ideal KM toolbox which incorporates data and information from manifold sources, organizes them according to a common corporate knowledge map, provides collaboration and discovery services working upon these organizational knowledge sources (such reflecting the process and the product view, respectively), and finally feeds these services via a common knowledge portal into operational and knowledge-level meta business processes. Although Type 1 applications normally do not maintain a knowledge-rich, explicit ontological basis, nevertheless indicates the box 'Knowledge Map' in the middle of the picture the central role of a shared language to connect people to people, people to information, and information to information in the company. This is the target for more 'heavy-weight' knowledge-based approaches for improving KM systems and services by ontological power.

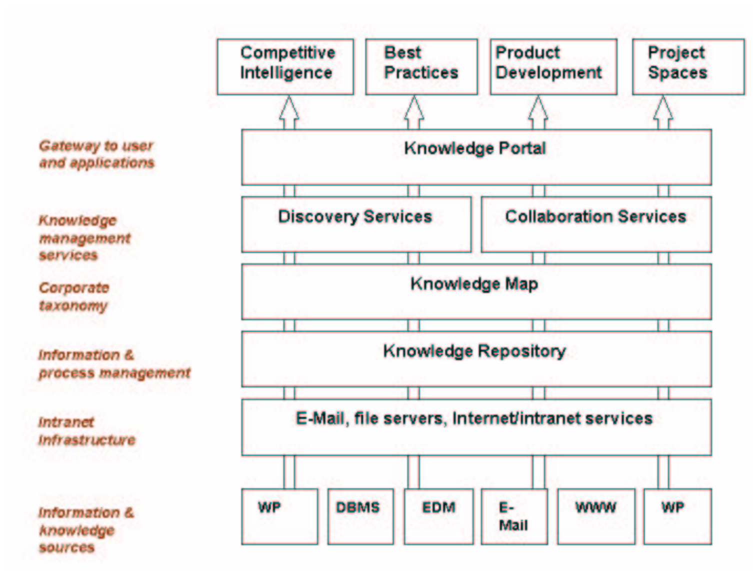

Fig. 2. Abstract KM System architecture, adapted from OVUM

Type 2 Applications: Intelligent Software Basis.

Type 2a Applications: Intelligence-Enhanced Solutions. While Type 1 applications are based on 'traditional' IT approaches, we here subsume applications based on Artificial Intelligence (AI) methods, including ontologies as a core enabler. Figure 3—adapted from [110]—gives some examples arranged according to their role in different KM core processes. While Type 1 Applications represent the current state of practice in industry and administrations, Type 2 applications represent mostly the status of mature prototypes with some industrial showcases.[1] Type 2a applications are today's most important field of application for ontologies in KM, in particular for creating Semantic Community Web Portals, for supporting Intelligent Search and Retrieval algorithms in Intranet and Internet, and for providing a target data structure for Information Gathering, Information Extraction and Information Integration techniques. We will discuss these fields in more detail below in Section 3.

	Share knowledge	Distribute knowledge	Capture & codify knowledge	Create knowledge
Traditional systems	E-Mail, Group Collaboration, Discussion Groups, P2P technology, Intranet Portals	Word processing, DTP, Document Management	*All systems that codify knowledge are knowledge-based*	Brainstorming software, mindmapping, statistical analysis
Knowledge -based systems	Ontology-based portals	Expert Systems, Lessons-Learned + Best Practice Systems	Knowledge acquisition and coding tools	Knowledge discovery and data mining systems, Creativity systems

Fig. 3. Traditional vs. Knowledge-Based KM Technology (i.e. Type 1 vs. Type 2 Applications), from [110]

Type 2b Applications: Enhanced Solutions Integrated. It is both a challenge and a chance of well-understood approaches to KM software design that they always should try to capture 'the whole picture', i.e. integrate the product and the process view and cover the whole architecture sketched in Fig. 2. Certainly, Type 1b applications are the first software artifacts which deserve to bear the dedicated name 'KM software'. Since KM is by definition *boundary spanning*, bridging the gaps between departments and organizations, between people and information, and between different kind of software services, the interesting question for Type 2 applications is the hardly ever posed question how different knowledge-based functions in a comprehensive KM application can exploit synergies. We will sketch some ideas in a section below in Section 4.

[1] Of course, for concrete software products it is sometimes difficult to make a clear distinction between Type 1 and Type 2 applications. However, for the purpose of this book it is sufficient to clarify whether an application is based on explicit, formal ontologies, or not.

While the first generation KM success stories were typical type 1a, or, seldom type 2a applications—like a Lessons Learned database, an Expert System, or a Yellow Page system—the big commercial KM toolboxes are comprehensive type 1b approaches trying to integrate manifold complementary functionalities. Seen from the IT—or, AI point of view, the interesting questions are to which extent 1a services can be improved towards ontology-based 2a approaches, and what possibilities arise when thinking about integrated type 2b applications. Before we come to these questions, we will shortly discuss some general requirements for KM software and their implications for the use of ontologies.

2 Requirements for KM Software and Ontologies

Several authors analyzed barriers for the introduction of KM solutions as well as success criteria and requirements for IT-enabled KM (see, e.g., [54]). We discuss three major requirements and their implications for the ontology topic:

R1: Minimalization of upfront knowledge engineering

Since KM is considered an additional organizational task orthogonal to the 'productive' work, expensive start-up activities may be a big barrier for a successful KM introduction. On the other hand, it seems clear that no ontology-based approach can be introduced without an explicit commitment of all people involved and without their contributions to creating the shared ontological space. Hence, all topics dealing with a smooth and cost-efficient introduction of ontology-based applications turned out to be particularly important for ontology-based KM solutions:

- **Ontology Learning.** At least the 'first cut' ontologies to start ontology engineering in an organization should avoid the typical 'cold start' problems by building as much as possible upon structures already explicit in the organization (e.g. Intranet organization, DB schemata [84], department structures, etc.) or hidden in organizational text documents (technical reports and documentation, web pages, etc). The use of machine learning and text analysis algorithms for ontology structuring and population is discussed in this book in [59] and [69].
- **Ontology Reuse.** Though having been a main motivation for introducing ontologies in the area of Knowledge-Based Systems, it is still more research and development than daily practice that companies reuse substantial parts of externally created ontologies for their internal use. Besides technical and methodological provisions to be made to this end (cp. [91] and [70] in this book), it is mainly a 'political' challenge to bring together a significant number of companies—naturally being competitors—to invest in a joint effort for creating a shareable ontology of their application domain. So, the major areas where such endeavors were already successful

are driven by public efforts and research scientists; here, the most important example are medicine and—to some extent—biology and genetics [38]. Other areas with good reuse chances concern broadly shared concepts in product and business modelling required for e-commerce and product data sharing [33]. Other promising areas for the future are dominated by few global players which are powerful enough to push broad standardization efforts which may lead to shared ontologies in the future; an example might be the insurance sector (see http://www.acord.org). In such sectors, ontologies are already useful for data exchange and resource integration, but all of them can profit even more from comprehensive KM approaches.

- **Methodology-Embedded Ontology Engineering.** There are several far-developed ontology modelling and management tools like Protégé (http://protege.stanford.edu), KAON (http://kaon.semanticweb.org), WebODE (http://delicias.dia.fi.upm.es/webODE/) and others [28]. In the KM environment we identify the highest demands on such a framework. The ontology shall often be built and maintained for a community-spanning use, seen from different perspectives, in an evolving domain, by non-Knowledge Engineers. Hence we expect in the ideal case not only incorporation of legacy structures and text analysis results, as mentioned above, plus technical solutions for the distributed creation and use of an ontology, but also a convincing methodological approach built into the ontology tool suite to guide and support the user. This concerns community concepts like distributed discussion support, versioning concepts etc. (see Tadzebao [31] and WebODE [11]), help for managing the informal-formal transition in a group discussion process for ontology building (cp. [62]), and, in the ultimate solution, an integrated support for all steps of a business-oriented KM methodology—which is not necessarily the same as a research-oriented KM methodology. For instance, in the DECOR project about Business-Process Oriented Knowledge Management (BPOKM, [7]), an amalgamation of the CommonKADS approach for top-level business-process analysis and the IDEF5 for ontology creation is proposed [75]; in the PROMOTE project, the Business Process Management Systems (BPMS) Paradigm is extended by Knowledge Management Process and Organizational Memory Modelling which includes the description of ontological structures with Topic Maps [52]; in the SPEDE project, Business Process Improvement is supported by knowledge captured with traditional knowledge acquisition (KA) tools in a KA process guided and assisted in a business-process oriented manner with the help of: a representation ontology for process knowledge; a high level process ontology; and process modules for modularization of complex processes [22, 23].

R2: Integration of KM support with everyday work procedures

In order to achieve a good user acceptance and to realize a maximum effect on knowledge workers' task performance, it is useful to integrate KM software as seamlessly as possible with the tools already in use for daily work. Several research prototypes [3, 6, 89] as well as industrial case studies [76, 52] can be found which address this goal by coupling knowledge storage and retrieval processes with workflow enactment which controls the operational business process. Here, the ontology is the 'glue' between operative and KM tasks on one hand, describing task-specific knowledge needs expressed in terms of an application domain ontology, and the Organizational Memory archive system on the other hand, providing ontology-based annotated knowledge resources.

[49] go a step further: they propose an ontological foundation of all business modelling based upon (i) a static ontology (the things in the world their attributes and relationships); (ii) a dynamic ontology (states, state transitions, and processes); (iii) a social ontology (agents, positions, roles, organization forms); and (iv) an intentional ontology (believes, goals, etc. of agents). Such a comprehensive semantics-based business model could be the basis for powerful KM services and systems.

The EULE system presented by [80] formally represents and enacts even more task knowledge: process aspects (temporal and causal relationships), normative aspects (deontic knowledge), and terminological aspects (concepts and their relationships) are modelled in an insurance application, in order to realize partially automatic problem-solving and far-reaching inferences for information retrieval. Of course, from an ontological point of view, such 'heavy-weight' approaches are much more interesting than simple IR applications. However, they have still to demonstrate their feasibility in practice. Maybe, domains which are heavily regulated by law, norms, and regulations, are well-suited for such an approach since, there, a deep level of formalization can be achieved, as well as deep inferences, and capture of legal regulations can be done economically, since bigger parts of the relevant ontologies can be reused in a wide range of applications (cp. [16, 105]). An application field with similar characteristics, not only regulated by law, but nevertheless highly controlled, is the area of medical guidelines and standards: there, ontological foundations for KM are (i) useful because of their high importance, and (ii) possible because of the broad range of potential applicants (cp., e.g., [78]).

R3: Integration of heterogeneous information

If one tries to find a *practical* definition of 'knowledge' (in contrast to data and information), it seems important that knowledge is always somehow oriented towards *action*—this aspect is already treated with the paragraph above; other aspects concern the fact that knowledge is normally strongly related to *context* and that it has a *network* character—showing how pieces belong together. Technically, this leads to the requirement that KM applications often have to process data, information, and information sources created to capture knowledge (like lessons learned entries or best practice documents) in a highly integrated manner (cp. [54]). As a solution approach, such knowledge documents are annotated with metadata which can be processed automatically and set into relation with application data. Hence, a KM application should be built upon an ***Information Ontology*** [3] which defines:

- which types of documents occur;
- what metadata attributes they have and which ontologies determine the value ranges of these attributes, where:
  - this may differ from document type to document type: a lesson learned may have a pointer to the project it was created in and the question how successful this project was, whereas a technical report may have an attribute for the location of the hardcopy of the document in the library, or links to experts for the technology described)
  - this can also be application specific; e.g. in an *e-Learning* application (which can be seen as a specific KM task) it might be important to specify how difficult to understand a document is and which prior knowledge is required, while in a *Knowledge Trading* scenario [10] attributes for pricing models, IPR issues and contract models might be required
- what relationships between documents are represented; linking logically related documents is a powerful mechanism for representing context; for example, in the EULE system knowledge with different degree of formalization is linked together (e.g. formal inference rules and textual explanations) [79]; discourse representation and group decision support systems implement in a somehow 'hardwired' manner an information ontology by providing different kinds of message types (e.g., issues, arguments, questions) and relationships (e.g., explains, corroborates, contradicts) for documenting argumentation structures in meetings or discussion processes (see [67] for some applications); in an e-learning system specific relations may describe that some lessons require other lessons as (mandatory or useful) prior knowledge, or that an example illustrates some definition.

Although the issue of Information Ontology is not yet tackled very deeply, we consider this an interesting point of application for putting more semantics into KM applications.

One area where this happened already is *Experience Management for software development* processes, where sophisticated domain-specific information ontologies have been developed in order to identify the facets of a development experience, which are important to assess its later reusability in another situation [108, 98]. Other areas which employ case-based reasoning approaches for reuse of, e.g, technical designs, go into similar directions (cp. [82]).

Of course, real-world KM applications (and their ontology aspects) must not only meet the requirements described above, but also hold a *rigorous cost-benefit analysis*. A detailed analysis of an expected ontology life cycle can be a powerful guide to achieve an optimal level of formalization in terms of costs and benefits. Likewise an explicit handling of an ontology's sharing scope helps minimizing negotiation costs as well as the complexity of revision processes in case of ontology evolution (cf. [103]).

After these fundamental design considerations, we show some practical examples in the following sections.

3 Ontologies in Intelligence-Enhanced Applications

O'Leary characterizes the role of IT in KM—and in particular the role of Artificial Intelligence (AI) technology in KM—as 'converting and connecting' [72]. In detail, he lists the following KM functions to be supported by IT (cp. [74]): conversion of data and text into knowledge, conversion of individual and group's knowledge into accessible knowledge, connection of people and knowledge to other people and other knowledge, communication of information between users, collaboration between different groups, and creation of new knowledge that would be useful to the organization. Typical ontology-based KM applications to support these functions are:

(1) Knowledge Portals for Communities of Practice. Following [8, 71], a *Community of Practice* (CoP) is a, typically, informal, self-organizing group of individuals with an interest in a particular practice, for example the group of people in a company who do the same (or partially overlapping) jobs. The CoP might be contained within an organization, or spread across several. The CoP members have in common a desire to develop their competence, either for pleasure or pride in their ability, or for improving their work efficiency. CoP members typically exchange 'war stories', insights or advice on specific problems, or tasks connected with their common practice. A CoP can act as a part of the organizational memory, transfer best practice, provide mechanisms for situated learning, and act as a focus for innovation.
Knowledge Portals, or, Community Portals act as an information intermediary who structures all aspects relevant to a given, specific topic, in order to allow a community of users to flexibly and easily access a huge amount of information in different formats (today, usually text documents) related to this topic, to exchange information and communicate about the topic in quest, and to maintain and extend the content base accessed via this Internet (or, Intranet) portal (cp., e.g. [88, 87]). Normally, such a portal comprises browsing and searching mechanisms for documents, as well as community services such as online forums, mailing lists and news articles. Examples comprise the OntoWeb Semantic Web community portal [86], the KM portal `http://www.brint.com`, or the RiboWeb portal for molecular biology [9].

(2) Organizational Memories. An Organizational Memory Information System OMIS, or, for short, Organizational Memory OM [3, 29]—or, as a specialization, a Project Memory [35, 39]—is a computer system within an organization which continuously gathers and actualizes knowledge and information (from within and from outside the organization) and provides it to the end user in a context-dependent and task-specific, manner, thus giving proactive

assistance to a knowledge worker working on knowledge-intensive tasks. It integrates manifold types of information, such as, e.g., best practice and lessons learned documents, continuous news articles, document templates, company regulations and manuals, CAD drawings, minutes of meetings, etc. Typical functionalities comprise integration of knowledge with different degree of formalization [79], intelligent problem-solving assistance by automatic generation of partial problem solutions [80, 54], and context-aware, task-specific retrieval of information [6, 89].

(3) Lessons Learned Archives. A Lesson Learned is a piece of knowledge gained through experience, which if shared, would benefit the work of others.[2]. It is typically generated from a customer project in a debriefing step, or created by an innovation or adverse experience which lead to some shareable insight to promote repeated application, or avoid reoccurrence, respectively.
Lessons Learned (LL) systems are typically used in Consulting firms [73], large technology companies, or in big government institutions, like military. Technologically, the challenge in LL systems lies in finding (and filling) an appropriate metadata schema (or, information ontology) which allows to precisely assess the potential value of a given LL as a reuse candidate in a new situation [106, 109]. As a related problem, the question of matchmaking arises (compare stored LL metadata with characteristics of the current situation to estimate whether the application of the LL will be useful) which is today often addressed by methods from the CBR (Case-Based Reasoning) and textual CBR area. [106] distinguishes four types of LL systems according to the way the systems capture their input *(passive versus (semi-)automatic)* and according to the way the Lessons Learned are published to the users *(push versus pull)*.

(4) Expert Finder and Skill Management Systems. Since it is generally agreed upon that tacit and not (yet) explicated knowledge is at least as important in KM as explicit, documented knowledge, the 'classical' means for connecting people to people—yellow page systems, simple expert directories, and personal web pages—belong to the typical 'quick win' applications for KM (cp. [12, 13]).
More advanced approaches for expert finders (e.g. for project team configuration, specific technical questions, or strategic knowledge development plans in the organization) try to avoid the manual creation and continuous maintenance of skill profiles by exploiting and analyzing existing explicit information like documents created by a person, documented trainings and formal qualifications, project membership, collaboration or co-authorship relations, information flows, etc., in order to acquire and evolve such competency maps automatically [112, 111]. Further improvements comprise sophisticated faceted descriptions of competencies and elaborated matching functions for retrieval purposes [14, 94]. In the ideal case such functionalities are combined with and integrated into the personal and organizational skill and Human Resource

[2] See http://www.aic.nrl.navy.mil/ aha/lessons/, cp. [109]

management functions for planning, monitoring, staffing, etc. Further extensions comprise additional value-adding services like automatic scheduling of appointments for knowledge exchange between users, provision of extra information during interactions, negotiation support for knowledge exchange planning etc. [107].
Ontologies are normally used to structure the area of competencies, sometimes also to structure the environemnt in which competencies were acquired, used and further developed, i.e. projects, publications etc. (in order to allow for further inferences for skill assessment and retrieval). Requirements for comfortable expert finder systems include (cp. [111]): (i) incremental and interactive visualization / browsing and query mechanisms; (ii) support for expertise analysis (e.g. seeing different relationships between experts, having dynamic ranking mechanisms etc); (iii) more intelligent concept-expert relationships taking into account in which document context (CV paragraph, self-assessment, title of Ph.D. thesis, footnote in workshop paper, ...) a keyword indicating a concept occurs.
Examples for ontology-based skill management include the SwissLife case study from a big insurance company [57], and the OntoProper case deployed in a large IT department [94].

Use of Ontologies

In the above mentioned, major knowledge-based KM applications, ontologies are typically used for the following three general purposes:

O1: Ontologies support knowledge visualization

Different aspects of visualization for information search have been discussed in the literature on Human-Computer Interaction (HCI) and in the Digital Library community (see, e.g., [55]). With the advent of the Internet society, such methods gain growing interest (cp. [19]) for surveying and analyzing big amounts of information and complex interconnections. Recently, [46] gave a survey about applicable visualization methods, such as (i) basic *graph layout approaches* (like H-tree layouts, balloon views, radial views, tree-maps, cone trees, hyperbolic views, etc.); (ii) *navigation and interaction* techniques (such as zoom-and-pan, focus+context techniques like fisheye distortion, and approaches to incremental exploration); and (iii) *clustering* for grouping data based on a chosen semantics and reducing the number of shown nodes or the complexity of the created view by methods like ghosting, hiding, or grouping.

Such methods can be used for inspecting the metadata and content descriptions of knowledge stocks in order to create new knowledge by analysis and recombination of existing knowledge. In such cases visualization may help to illustrate structure (e.g. content density) and distribution of content in a document corpus, as well as relationships between specific metadata attributes (like time or geographic relationships regarding document content or document creation, or co-authorship relations between people). Visualization of content structures in order to get a rough overview of topics discussed, their textual manifestation, and their interrelationships, or in order to have a quick topics-based access to document parts can even be used for intra-document analysis when dealing with long documents (like government reports, classical literature, socio-economic almanacs, etc). Visualization is also valuable for finding useful knowledge items in very vaguely specified search situations where (partially) exploring the information space is a part of problem-solving and helps clarifying the problem specification and/or its solution space.

With the success of the IEEE Topic Map standard, visualization for topic-oriented document access went into commercial practice. For instance, USU AG (http://www.usu.com) provides knowledge networks as an interface to document corpora (see Fig. 4); other interesting visualization tools are offered, e.g., by AIdministrator [93] or intelligent views GmbH (http://www.i-views.de/).

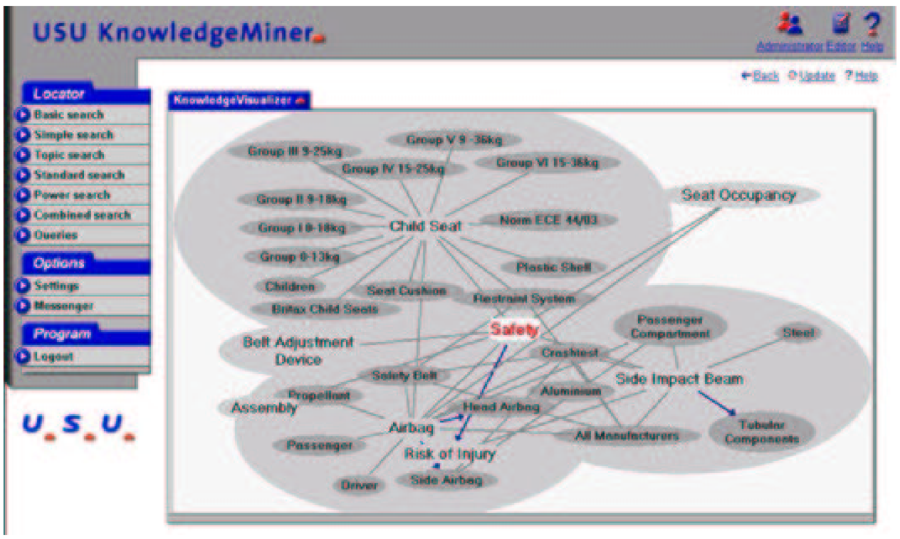

Fig. 4. Knowledge Visualization in the USU Knowledge Miner.

Independent from the question which visualization is used for knowledge access (even in the case of a simple tree-structured browsing interface), the fact that KM usually deals with sharing complex knowledge content between people with quite different background and interests normally leads to the requirement that *multiple views* onto the same knowledge base should be provided. Although this is to some extent contradicting to the goal of creating a widely shared ontology to enable real communication between people, this requirement cannot be neglected in practice, in particular regarding the future trends of even more distributed KM scenarios introduced in Section 5. In [84] we made some preliminary considerations about the technical support for such scenarios, based upon the idea that specific, user-oriented GUI views can be created from special presentation ontologies created by selection and transformation operations from one (or more) core ontologies.

O2: Ontologies support knowledge search, retrieval, and personalization

The most important application of ontologies in KM—besides organization of browsing interfaces (with or without sophisticated visualization methods) in Knowledge Portals—is certainly to improve search and retrieval of documents by exploitation of ontological background knowledge about the application domain.

In [60] the basic ideas of using taxonomic relationships for increasing information retrieval (IR) recall for browsing and querying are described. Normally, in the case of an empty or small answer set, taxonomic knowledge is used for extending the query by subconcepts or superconcepts. The more specific a domain is modelled and the better understood typical queries and query situations are, the better can similar ideas be applied to other, non-taxonomic relationships. For instance, in the Electronic Fault Recording system for structured documentation and retrieval of maintenance experiences (fault events, maintenance measures, repair actions, etc.) for a complex and large mechanical device [15], the retrieval of potentially useful documented experience is not only supported by a detailed machine model in terms of is-a and has-part relations; similarity of potentially useful situations can also be assessed using modelled links describing hydraulic and electrical connections between machine parts, as well as analogy relationships because of similar construction plans. [58] propose an easy, declarative specification formalism for search heuristics for an ontology-based skill management approach: potentially useful information is inferred via graph-traversal activities following domain-specific links in the knowledge-base, e.g. about project team membership etc. A similar idea is realized in [94] using declarative rules about relationship instantiations for skill inferencing ('If a programmer X worked in a software project P which used the programming language L, then we can assume the X is knowledgeable in L').

Of course, in general, the more specific a domain is described, the more powerful inferences for query expansion and reformulation are possible; however, detailed models are expensive to acquire and maintain, such that here we have the typical KM trade-off asking for economic rationality when deciding between 'high-tech' and 'low-tech' approaches.

While the above approaches usually increase recall of IR, precision is not so often treated very explicitly. One example is the KonArc prototype [84] for sophisticated storage and retrieval of experiences in a database for software solution designs, which used also domain-specific information about incompatibilities of search constraints (e.g. between operating systems and specific software packages) for early detecting empty answers sets (and also explaining the contradictions to the user). [43] show for the example case of yellow pages and product catalogues—both important application areas in enterprise KM—that an ontology coupled with a linguistic knowledge-base can increase both recall and precision because it supports query disambiguation in the case of polysemous query terms.

Compared to the already discussed approaches which describe information *pull* situations, ontologies are, of course, often used to provide the vocabulary for expressing personal interest profiles for information *push services* which automatically deliver knowledge and information for categories a user is interested in. For instance, the myPlanet system realizes a personalized news service with the help of an ontology-based user profile [50].

O3: Ontologies serve as the basis for information gathering and integration

As mentioned above, KM deals with knowledge resources of different degree of formality, often informal text documents. On the other hand, the more formally represented information we have, the more formal inferences for query answering and passage retrieval, for derivation of new knowledge, and for comparing and integrating facts and documents from different sources, are possible. This allows, e.g., to partially automate problem solving and to integrate information retrieval results into operative business applications. The basis for such inferences are the information ontology structuring the metadata of informal knowledge sources, and domain ontologies structuring the content area of documents and providing background knowledge for inferences. This background knowledge may comprise information *search knowledge* as well as domain-specific *application knowledge*. *Information Extraction* (IE) algorithms [69] for (semi-)automatically annotating metadata to documents and *Text Categorization* techniques [83] for finding semantic content indexes map informal sources to formal metadata attribute values.

For realizing Business Intelligence applications in a KM context, domain ontologies provide the target data structures for gathering information from different sources in the Internet or a corporate Intranet. For example, [72] describes a Price Waterhouse Coopers application filling information frames about management changes in companies by analyzing a stream of business news articles. Similar applications are reported for filtering specific events out of news articles about economy or politics, for analyses in the military sector, and for fact extraction from personal web pages or publication web pages (see [56] for a technology survey). [53] describe an ontology-based application which creates narrative biographical sketches of artists based upon information automatically gathered, extracted and integrated from Web pages.

The Ontobroker project [27] showed how formal inferences can support information retrieval and analysis in the WWW in the case of a-priori ontologically annotated web pages. The CREAM suite represents a comprehensive set of software tools for starting and using such a solution [44].

Since Type 2A applications more or less represent the state-of-the-art in using ontologies for KM, we summarize here some challenges which we see for the near future of research and technology transfer in this area:

Evaluation: It is already an indispensable need for KM applications to show their economic benefits to the project sponsors—which is not easy. In order to be successful, we should define *success criteria* and develop *metrics* to assess success with respect to these criteria, to demonstrate that ontology-based applications are more useful than solutions with 'low tech' approaches. Although there exist already first comprehensive methodologies for ontology-based KM projects [95], the aspect of benchmarking or quantitative performance metrics is rarely tackled.

Evolution: Since we are talking about long-living systems in dynamic environments, also ontological structures must be evolved cost-effectively to avoid decreasing system performance. Recently a maintenance methodology for Case-Based Reasoning systems has been proposed [81] which could probably be transferred to the KM case. What would be required are *quantitative quality and performance indicators* for the KM system. [92] gave a well-structured analysis of the field of change discovery for ontologies distinguishing between structure-driven (obvious structural deficiencies of the ontology), data (instance) driven, and usage-driven change indications.

Inference: As already argued, exploiting the power of inferences would show the usefulness of knowledge-rich ontological system approaches in contrast to, e.g., taxonomy-based ones. We should search for domains requiring powerful reasoning mechanisms and expressive domain descriptions in KM. This may include aspects not yet fully adopted in ontology-based KM systems, such as the use of manifold link types [101], the representation of uncertainty and vagueness in domain modelling, and the definition of similarity on top of ontologies as required in CBR systems.

4 Ontologies towards Enhanced Integrated Solutions

We mentioned already that exploitation of synergy effects between different applications in the complex KM scenario are an interesting source of innovation for both new services and improved effectiveness of existing services. Although this area—especially with respect to ontologies—is not yet explored very well, we give some examples for work into this direction:

- [4] report on performance improvements for document analysis (DA) and information extraction from paper documents by using expectations generated taking into account open workflow instances. The link between workflow system and DA is established by process, domain and DA ontologies and their mutual mappings. Similarly, task-specific IR is realized by coupling IR needs to workflow tasks.

- The ONTOCOPI system [8] is a tool for identifying potential members of a (hidden) Community of Practice by uncovering informal relationships between people trough traversal of instantiations of ontologically described formal relationships, like *is-coauthor-of*. Recommender systems learn about user preferences over time for realizing precise information push [66]. [65] describe how both systems can mutually benefit using the same ontological basis as the link between them.
- Typical software systems for supporting the process-view on KM comprise groupware (CSCW) and workflow systems. If, on the other hand, personal interest and skills are described formally on an ontological basis, groupware and CSCW support can be improved using this information. Examples for more intelligent CSCW support are more knowledgeable task assignment to employees in a workflow application, more knowledgeable project staffing when configuring a new team, or better informed briefing of participants before a virtual meeting.

5 Future Trends

Though the sections above show that ontologies in KM applications still provide chances and challenges enough, we would nevertheless like to give an idea of possible future trends. Comprehensive KM frameworks emphasize that Knowledge Management can take place at the individual, the group, organizational, and interorganizational level (e.g., [63]). The software functionalities discussed in Sections 3 and 4 are mostly used to support effectivity at the group and organizational level. Focussing on at the personal and the interorganizational level are logical next steps (cp. [100]). Economically, the transition to interorganizational KM is driven by the movements towards the *Extended Enterprise* which tries to integrate logistics and production processes along the whole production chain (cp. [77]), and towards the *Virtual Enterprise* which is configured ad-hoc for specific projects from normally independent small units, in order to dynamically establish a temporary value-creation chain. One can easily see that suitable KM approaches are even more important in such scenarios than in traditional enterprises, and that such scenarios also provide big chances to enhance effectiveness by appropriate KM measures.

Technically, the concepts of *Distributed Organizational Memory* (DOM) [103] and *Agent-Mediated Knowledge Management* [30, 104] have been introduced recently in order to deal with such highly dynamic and highly distributed environments. Projects dealing with aspects of this area comprise:

- The NAUTICUS system [85] envisions a collaboration between role agents and knowledge agents for achieving both just-in-time knowledge support (put task-specific best practice at empolyees' fingertips) and just-in-place knowledge management (ensure that shared knowledge is deployed and changed locally by its stakeholders).

- Jasper II [64] shall provide collaborating agents for knowledge capture, retrieval, summarization, and user profile refinement in a virtual community of users.
- The COMMA project [37, 36] identified the following sub-societies for an agent-based OM systen and demonstrated its feasibility using existing RDF and Semantic Web technologies: (i) the annotation-dedicated sub-society; (ii) the ontology and model sub-society; (iii) the user-dedicated sub-society; and (iv) the matchmaker sub-society.
- The FRODO project [5] added workflow task and role agents to this list and thus improved the notion of task-specific context-sensitivity.
- The KDE project [48] used already a CommonKADS extension for analyzing task specific knowledge needs in a knowledge-intensive workflow and realizing a knowledge-worker desktop using ontologies and agent technology.
- The EDAMOK project also elaborated on the notion of context in OM systems [17].

Today it is nearby to think about Peer-to-Peer technology as an appropriate means for realizing such functionalities as mentioned above (cp. [34, 96, 100]). From the projects above, only few address this technology explicitly, and even fewer tackle the problem of ontologies in DOM and P2P-KM scenarios in detail. Among those are **EDAMOK** [17] which explicitly suggests to engineer social order into P2P-KM agent systems for coordinating agents' activities related to contextualized knowledge search and retrieval as well as meaning negotiation [2, 102, 51] and **FRODO** which proposed to manage ontological issues in a DOM scenario by installing a society of ontology management and usage agents which are structured by social mechanisms (rights and obligations, [103]). In general, the basic problem to be dealt with is how to balance efficiently private issues and organizational issues in a complex and dynamic scenario. This area provides manifold challenging technical questions and is nevertheless highly relevant for industrial practice.

References

1. *13th International Workshop on Database and Expert Systems Applications (DEXA 2002), 2-6 September 2002, Aix-en-Provence, France.* IEEE Computer Society, 2002.
2. Bouquet P (2002) Meaning Negotiation – Papers from the AAAI Workshop. Technical Report WS-02-09. AAAI Press
3. Abecker A, Bernardi A, Hinkelmann K, Kühn O, Sintek M (1998) Toward a technology for organizational memories. IEEE Intelligent Systems 13(3):40–48
4. Abecker A, Bernardi A, Maus H, Sintek M, Wenzel C (2000) Information supply for business processes – coupling workflow with document analysis and information retrieval. Knowledge-Based Systems 13(5):271–284

5. Abecker A, Bernardi A, van Elst L (2003) Agent technology for distributed organizational memories. In: Proceedings ICEIS-03, 5th International Conference on Enterprise Information Systems
6. Abecker A, Decker S, Maurer F (2000) Special Issue on Knowledge Management and Organizational Memory. Int Journal on Information Systems Frontiers (ISF) 2(3/4)
7. Abecker A, Hinkelmann K, Maus H, Müller H-J (eds) (2002) Geschäftsprozessorientiertes Wissensmanagement. xpert Press Springer, Berlin Heidelberg
8. Alani H, O'Hara K, Shadbolt N (2002) ONTOCOPI: methods and tools for identifying communities of practice. In: Intelligent Information Processing Conference, IFIP World Computer Congress (WCC), Montreal Canada
9. Altmann R, Bada M, Chai X, Carillo MW, Chen R, Abernethy N (1999) RiboWeb: an ontology-based system for collaborative molecular biology. IEEE Intelligent Systems 14(5):68–76
10. Apostolou D, Mentzas G, Abecker A, Eickhoff W-C, Georgolios P, Kafentzis K (2002) Challenges and directions in knowledge asset trading. In: Karagiannis D, Reimer U (eds) PAKM2002 - Fourth Int Conf on Practical Aspects of Knowledge Management. Springer, Berlin Heidelberg
11. Arpírez JC, Corcho O, Fernández-López M, Gómez-Pérez A (2001) WebODE: a workbench for ontological engineering. In: First Int Conference on Knowledge Capture (K-CAP 2001)
12. Becerra-Fernandez (2000) The role of artificial intelligence technologies in the implementation of people-finder knowledge management systems. In: Staab S, Tsui E, Garner B (eds) Proc AAAI Spring Symposium Bringing Knowledge to Business Processes
13. Becerra-Fernandez I (2001) Locating expertise at NASA. Knowledge Management Review 4(4):33–37
14. Benjamins VR, Cobo JML, Contreras J, Casillas J, Blasco J, de Otto B, García J, Blázquez M, Dodero JM (2002) Skills management in knowledge-intensive organizations. In: Gómez-Pérez A, Benjamins VR (eds) Knowledge Engineering and Knowledge Management. Ontologies and the Semantic Web – 13th Int Conf (EKAW 2002). Springer, Berlin Heidelberg
15. Bernardi A (1997) Electronic fault recording: A corporate memory for maintenance support of complex machines. In: Barthès JP (ed) Proc Int Symposium on the Management of Industrial and Corporate Knowledge
16. Boer A, Hoekstra R, Winkels R (2001) The CLIME ontology. In: Proc Second Int Workshop on Legal Ontologies, University of Amsterdam
17. Bonifacio M, Bouquet P, Mameli G, Nori M (2002) KEx: A peer-to-peer solution for distributed knowledge management. In: Karagiannis D, Reimer U (eds) PAKM2002 - Fourth Int Conference on Practical Aspects of Knowledge Management, Springer, Berlin Heidelberg
18. Borghoff UM, Pareschi R (1998) Information Technology for Knowledge Management. Springer, Berlin Heidelberg
19. Börner K, Chen C (eds) (2001) Visual Interfaces to Digital Libraries - Its Past, Present, and Future / Workshop at the The First ACM+IEEE Joint Conference on Digital Libraries JCDL-2001, URL http://vw.indiana.edu/visual01/
20. Conklin E, Weil W (1997) Wicked problems: Naming the pain in organizations. White Paper of Group Decision Support Systems Inc

21. Cortada JW, Woods JA (eds) (2000) The Knowledge Management Yearbook (1999-2000). Butterworth-Heinemann
22. Cottam H (1999) Ontologies to assist process oriented knowledge acquisition. Technical Report SP142, SPEDE Project, University of Nottingham
23. Cottam H (1999) Process knowledge editor – user guide. Technical Report SP143, SPEDE Project, University of Nottingham
24. Davenport T, Jarvenpaa S, Beers M (1996) Improving knowledge work processes. Sloan Management Review 37(4):53–65
25. Davenport T, Prusak L (1997) Working Knowledge: How Organizations Manage What They Know. Harvard Business School Press
26. Davies J, Fensel D, van Harmelen F (eds) (2002) Towards the Semantic Web: Ontology-Driven Knowledge Management. John Wiley and Sons, London
27. Decker S, Erdmann M, Fensel D, Studer R (1999) Ontobroker: Ontology based access to distributed and semi-structured information. In: [61]
28. Denny M (2002) Ontology building: A survey of editing tools. URL: http://xml.coverpages.org/Denny-OntologyEditorSurveyText20021111.html
29. Dieng-Kuntz R, Matta N (eds) (2002) Knowledge Management and Organizational Memories. Kluwer Academic Publishers, Dordrecht
30. Dignum V (2002) An overview of agents in knowledge management. URL: http://www.cs.uu.nl/people/virginia/amkm.pdf
31. Domingue J (1998) Tadzebao and webonto: Discussing, browsing, and editing ontologies on the web. In: 11th Knowledge Acquisition for Knowledge-Based Systems Workshop
32. Eppler M (2002) Definition of knowledge management in the NetAcademy glossary. Available via URL: http://www.knowledgemedia.org
33. Fensel D (2003) Ontologies and e-business. In: [90]
34. Fensel D, Staab S, Studer R, van Harmelen F (2002) Peer-2-peer enabled semantic web for modern knowledge management. In: [26]
35. Frank U, Fraunholz B, Schauer H (2001) A multi layer architecture for integrated project memory and management systems. In: Khoshrow-Pour M (ed) Managing Information Technology in a Global Economy: Proc of the 2001 Information Resources Management Association Int Conf. Idea Group Publishing.
36. Gandon F (2002) Distributed Artificial Intelligence and Knowledge Management: ontologies and multi-agent systems for a corporate semantic web. PhD thesis, INRIA and University of Nice - Sophia Antipolis
37. Gandon F, Poggi A, Rimassa G, Turci P (2002) Multi-agent corporate memory management system. Journal of Appl Artificial Intelligence 16(9–10):699–720
38. Goble C, Stevens R, Ng G, Bechhofer S, Paton N, Baker P, Peim M, Brass A (2001) Transparent Access to Multiple Bioinformatics Information Sources. IBM Systems Journal Special issue on deep computing for the life sciences, 40(2):532 – 552
39. Golebiowska J, Dieng-Kuntz R, Corby O, Mousseau D (2001) Building and exploiting ontologies for an automobile project memory. In: Gómez-Pérez A, Gruninger M, Stuckenschmidt H, Uschold M (eds) IJCAI-01 Workshop on Ontologies and Information Sharing, CEUR-Proceedings 47, URL: http://sunsite.informatik.rwth-aachen.de/Publications/CEUR-WS/Vol-47/
40. Gruber T (1991) The role of common ontology in achieving sharable, reusable knowledge bases. In: Allen J, Fikes R, Sandewall E (eds) Proc of the 2nd

Int Conf on Principles of Knowledge Representation and Reasoning, Morgan Kaufmann Publishers
41. Gruber T (1995) Toward principles for the design of ontologies used for knowledge sharing. Int Journal of Human-Computer Studies, 43(5,6):907–928
42. Guarino N (ed) (1998) Formal Ontology in Information Systems – Proceedings of FOIS'98. IOS Press
43. Guarino N, Masolo C, Vetere G (1999) Ontoseek: Content-based access to the web. IEEE Intelligent Systems, 14(3):70–80
44. Handschuh S, Staab S, Maedche A (2001). CREAM - Creating relational metadata with a componentbased, ontology driven annotation framework. In: First Int Conf on Knowledge Capture (K-CAP 2001)
45. Hansen M, Nohria N, Tierney T (1999) What's your strategy for managing knowledge? Harvard Business Review, reprint 990206
46. Herman I, Melancon G, Marshal MS (2000) Graph visualization and navigation in information visualization: A survey. IEEE Transactions on Visualization and Computer Graphics 6(1):24–43
47. Holsapple C (ed) (2002) Handbook on Knowledge Management. International Handbooks on Information Systems. Springer, Berlin Heidelberg
48. Jansweijer W, van de Stadt E, van Lieshout J, Breuker J (2000) Knowledgeable information brokering. In: Stanford-Smith B, Kidd P (eds) E-business: Key Issues, Applications and Technologies. IOS Press
49. Jurisica I, Mylopoulos J, Yu E (1999) Using ontologies for knowledge management: An information systems perspective. In: Proc 62nd Annual Meeting of the American Society for Information Science (ASIS99)
50. Kalfoglou Y, Domingue J, Motta E, Vargas-Vera M, Buckingham-Shum S (2001) MyPlanet: an ontology-driven web-based personalised news service. In: Gmez-Prez A, Gruninger M, Stuckenschmidt H, Uschold M (eds) IJCAI-01 Workshop on Ontologies and Information Sharing. CEUR-Proceedings 47 URL: http://sunsite.informatik.rwth-aachen.de/Publications/CEUR-WS/Vol-47/
51. Kalfoglou Y, Schorlemmer M (2002) Information-flow-based ontology mapping. Informatics Research Report EDI-INF-RR-0135 University of Edinburgh
52. Karagiannis D, Woitsch R (2002) The PROMOTE Prototype: A Meta2Model Based Process Oriented KMS. In: [1]
53. Kim S, Alani H, Hall W, Lewis P, Millard D, Shadbolt N, Weal M (2002) Artequakt: Generating tailored biographies from automatically annotated fragments from the web. In: Workshop on Semantic Authoring, Annotation & Knowledge Markup (SAAKM02) at the 15th European Conf on Artificial Intelligence, (ECAI02)
54. Kühn O, Abecker A (1998) Corporate memories for knowledge management in industrial practice: Prospects and challenges. In: [18]
55. Kumar V, Furuta R, Allen RB (1997) Metadata visualization for digital libraries: interactive timeline editing and review. In: Proc Third ACM Conf on Digital Libraries
56. Laender A, Ribeiro-Neto B, da Silva A, Teixeira J (2002) A brief survey of web data extraction tools. ACM SIGMOD Record 31(2)
57. Lau T, Sure Y (2002) Introducing ontology-based skills management at a large insurance company. In: Modellierung 2002, Modellierung in der Praxis - Modellierung für die Praxis

58. Liao M, Hinkelmann K, Abecker A, Sintek M (1999) A competence knowledge base system for the organizational memory. In: Puppe F (ed) XPS-99 / 5. Deutsche Tagung Wissensbasierte Systeme. Springer, Berlin Heidelberg
59. Maedche A, Staab S (2003) Ontology learning. In: [90]
60. McGuiness D (1998) Ontological issues for knowledge-enhanced search. In: [42]
61. Meersman R, Tari Z, Stevens SM (eds) Database Semantics - Semantic Issues in Multimedia Systems, IFIP TC2/WG2.6 Eighth Working Conference on Database Semantics (DS-8). IFIP Conference Proceedings 138. Kluwer
62. Meier D, Tautz C, Traphöner R, Wissen M, Ziegler J (2001) Building ontologies for knowledge management applications in group sessions. In: K-CAP 2001 Workshop on Interactive Tools for Knowledge Capture
63. Mentzas G, Apostolou D, Young R, Abecker A (2002) Knowledge Asset Networking. Advanced Information and Knowledge Processing. Springer London
64. Merali Y, Davies J (2001) Knowledge capture and utilization in virtual communities. In: First Int Conf on Knowledge Capture (K-CAP 2001)
65. Middleton S, Alani H, Shadbolt N, Roure DD (2002) Exploiting synergy between ontologies and recommender systems. In: Eleventh Int World Wide Web Conference (WWW2002), Semantic Web Workshop
66. Middleton S, Roure DD, Shadbolt N (2003) Ontology-based recommender systems. In: [90]
67. Mulholland P, Zdrahal Z, Domingue J, Hatala M (2000) Integrating working and learning: a document enrichment approach. Journal of Behaviour and Information Technology 19(3):171–180
68. Neches R, Fikes R, Finin T, Gruber T, Patil R, Senator T, Swartout W (1991) Enabling technology for knowledge sharing. AI Magazine, 12(3):36–56
69. Nedellec C, Nazarenko A (2003) Ontologies and information extraction. In: [90]
70. Noy N (2003) Tools for mapping and merging ontologies. In: [90]
71. O'Hara K, Alani H, Shadbolt N (2002) Identifying communities of practice – analysing ontologies as networks to support community recognition. In: Intelligent Information Processing Conference, IFIP World Computer Congress (WCC)
72. O'Leary D (1998) Knowledge management systems: Converting and connecting. IEEE Intelligent Systems 13(3)
73. O'Leary D (1998) Using AI in knowledge management: Knowledge bases and ontologies. IEEE Intelligent Systems 13(3)
74. O'Leary D (1999) Reengineering and knowledge management. In: Fensel D, Studer R (eds) Knowledge Acquisition, Modeling and Management – 11th European Workshop, EKAW '99. Springer, Berlin Heidelberg
75. Papavassiliou G, Mentzas G, Abecker A (2002) Integrating knowledge modelling in business process management. In: The Xth European Conference on Information Systems (ECIS-2002)
76. Papavassiliou G, Ntioudis S, Mentzas G, Abecker A (2002) Managing knowledge in weakly-structured administrative processes. In: Online Proceedings Third European Conference on Organizational Knowledge, Learning, and Capabilities (OKLC-2002)
77. Pedersen MK, Larsen MH (2000) Inter-organizational systems and distributed knowledge management in electronic commerce. In: Svensson L, Snis U,

Sorensen C, Fägerlind H, Lindroth T, Magnusson M, Östlund C (eds) Proceedings IRIS 23 URL: http://iris23.htu.se/proceedings/
78. Pisanelli DM, Gangemi A, Steve G (2000) The role of ontologies for an effective and unambiguous dissemination of clinical guidelines. In: Dieng R, Corby O (eds) Knowledge Engineering and Knowledge Management. Methods, Models, and Tools – 12th International Conference (EKAW 2000). Springer, Berlin Heidelberg
79. Reimer U (1999) Knowledge integration for building organisational memories. In: 11th Banff Knowledge Acquisition for Knowledge-Based Systems Workshop
80. Reimer U, Margelisch A, Staudt M (2000) EULE: A Knowledge-Based System to Support Business Processes. Knowledge Based Systems, 13(5):261–269
81. Roth-Berghofer T (2002) Knowledge maintenance of case-based reasoning systems. The SIAM methodology. PhD thesis, University of Kaiserslautern
82. Schaaf M, Maximini R, Bergmann R, Tautz C, Traphöner R (2002) Supporting Electronic Design Reuse by Integrating Quality-Criteria into CBR-Based IP Selection. In: Proc 6th European Conf on Case Based Reasoning
83. Sebastiani F (2002) Machine learning in automated text categorization. ACM Computing Surveys, 34(1):1–47
84. Sintek M, Tschaitschian B, Abecker A, Bernardi A, Müller H-J (2000) Using ontologies for advanced information access. In: Domingue J (ed) PAKeM 2000, The Third Int Conf and Exhibition on The Practical Application of Knowledge Management
85. Sorli A, Coll GJ, Dehli E, Tangen K (2002) Knowledge sharing in distributed organizations. In: [29]
86. Spyns P, Oberle D, Volz R, Zheng J, Jarra M, Sure Y, Studer R, Meersman R (2002) Ontoweb - a semantic web community portal. In: Fourth Int Conf on Practical Aspects of Knowledge Management (PAKM-2002)
87. Staab S, Angele J, Decker S, Erdmann M, Hotho A, Mdche A, Schnurr H-P, Studer R, Sure Y (2000) Semantic community web portals. WWW9 / Computer Networks (Special Issue: WWW9 - Proc 9th Int World Wide Web Conference), 33(1–6):473–491
88. Staab S, Maedche A (2000) Knowledge portals: Ontologies at work. The AI Magazine, 22(2):63–75
89. Staab S, Schnurr H-P (2000) Smart task support through proactive access to organizational memory. Knowledge-based Systems 13(5):251–260
90. Staab S, Studer R (eds) (2003) Handbook on Ontologies in Information Systems. International Handbooks on Information Systems, Springer
91. Staab S, Studer R, Sure Y (2003) Ontology engineering methodology. In: [90]
92. Stojanovic L, Stojanovic N, Maedche A (2002) Change discovery in ontology-based knowledge management systems. In: Second Int Workshop on Evolution and Change in Data Management (ECDM 2002)
93. Stuckenschmidt H, van Harmelen F (2001) Knowledge-based validation, aggregation and visualization of meta-data: Analyzing a web-based information system. In: Zhong N, Yao Y, Ohsuga S (eds) Web Intelligence: Research and Development – Proc First Asia-Pacific Conference on Web Intelligence (WI'2001). Springer, Berlin Heidelberg
94. Sure Y, Maedche A, Staab S (2000) Leveraging Corporate Skill Knowledge - From ProPer to OntoProPer. In: Mahling D, Reimer U (eds) Proc Third Int Conference on Practical Aspects of Knowledge Management (PAKM-2000)

95. Sure Y, Staab S, Studer R (2002) Methodology for development and employment of ontology based knowledge management applications. ACM SIGMOD Record 31(4)
96. Susarla A, Liu D, Whinston A (2002) Peer-to-peer knowledge management. In: [47]
97. Swan J, Newell S, Scarbrough H, Hislop D (1999) Knowledge management and innovation: Networks and networking. Journal of Knowledge Management 3(3):262–275
98. Tautz C (2000) Customizing Software Engineering Experience Management Systems to Organizational Needs. PhD thesis, Universität Kaiserslautern
99. Trittmann R (2001) The organic and the mechanistic form of managing knowledge in software development. In: Althoff K-D, Feldmann R, Müller W (eds) Advances in Learning Software Organizations. Springer, Berlin Heidelberg
100. Tsui E (2001) Technologies for personal and peer-to-peer knowledge management.
101. Tudhope D, Alani H, Jones C (2001) Augmenting thesaurus relationships: possibilities for retrieval. The Journal of Digital Information 1(8)
102. van Elst L, Abecker A (2002) Negotiating domain ontologies in distributed organizational memories. In: [2]
103. van Elst L, Abecker A (2002) Ontologies for information management: Balancing formality, stability, and sharing scope. Expert Systems with Applications 23(4):357–366
104. van Elst L, Dignum V, Abecker A (eds) (2003) Agent-Mediated Knowledge Management - Papers from 2003 AAAI Spring Symposium. Technical Report SS-03-01, AAAI Press.
105. van Engers TM, Kordelaar PJ, den Hartog J, Glassée E (2002) POWER: Programme for an ontology based working environment for modelling and use of regulations and legislation. In: DEXA-2002 Electronic Government Workshop
106. van Heijst G, van der Spek R, Kruizinga E (1998) lessons learned cycle. In: [18]
107. Vivacqua A (1999) Agents for expertise location. In: Proc 1999 AAAI Spring Symposium Workshop on Intelligent Agents in Cyberspace
108. Gresse von Wangenheim C (2002) Operationalizing Reuse of Software Measurement Planning Knowledge. infix, Berlin
109. Weber R, Aha D, Becerra-Fernandez I (2001) Intelligent lessons learned systems. International Journal of Expert Systems Research & Applications 20(1):17–34
110. Weber R, Kaplan R (2002) Knowledge-based knowledge management. In: Faucher C, Jain L, Ichalkaranje N (eds) Innovations in Knowledge Engineering. Physica, Heidelberg
111. Yimam D (2000) Expert finding systems for organizations: Domain analysis and the DEMOIR approach. In: Ackerman M, Cohen A, Pipek V, Wulf V (eds) Beyond Knowledge Management: Sharing Expertise. MIT Press
112. Yimam D, Kobsa A (2000) DEMOIR: a hybrid architecture for expertise modeling and recommender systems. In: Proc 9th IEEE Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises