OntoShare:
Using Ontologies for Knowledge Sharing

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ABSTRACT
An ontology-based knowledge sharing system OntoShare is described. RDF(S) and RDF are used to specify and populate an ontology, based on information shared between users in virtual communities. We begin by discussing the advantages that use of Semantic Web technology afford in the area of knowledge management tools. The way in which OntoShare supports WWW-based communities of practice is described. Usage of OntoShare semi-automatically builds an RDF-annotated information resource for the community (an potentially for others also). Observing that in practice the meanings of and relationships between concepts evolve over time, OntoShare supports a degree of ontology evolution based on usage of the system – that is, based on the kinds of information users are sharing and the concepts (ontological classes) to which they assign this information. We conclude by describing some avenues of ongoing and future research and a planned evaluation exercise.

1. INTRODUCTION
There are now more than two billion documents in the WWW, which are used by more than 300 million users globally, and millions more pages on corporate intranets. The continued rapid growth in information volume makes it increasingly difficult to find, organise, access and maintain the information required by users. Tim Berners-Lee and others [1] have proposed a semantic web that provides enhanced information access based on the exploitation of machine-processable metadata. We are particularly interested in the new possibilities afforded by semantic web technology in the area of knowledge management and we discuss this below before moving on in the rest of the paper to describe OntoShare, a system for supporting Semantic Web-based communities of practice.

Central to the vision of the Semantic Web are ontologies. Ontologies are seen as facilitating knowledge sharing and re-use between agents, be they human or artificial [2]. They offer this capability by providing a consensual and formal conceptualisation of a given domain. As such, the use of ontologies and supporting tools offer an opportunity to significantly improve knowledge management capabilities in large organisations and it is their use in this particular area that is the subject of this paper. In OntoShare, an ontology specifies a hierarchy of concepts (ontological classes) to which users can assign information. In this process, important metadata is extracted and associated with the community information resource using RDF annotations.

1.1 The Semantic Web and Knowledge Management
Due to a number of factors, including globalisation and the impact of the Internet, many organisations are increasingly geographically dispersed and organised around virtual teams. As noted in, for example, [3], such organisations need knowledge management and organisational memory tools that encourage users to understand each other's changing contextual knowledge and foster collaboration while capturing, representing and interpreting the knowledge resources of their organisations.

Important information is often scattered across Web and/or intranet resources. Traditional search engines return ranked retrieval lists that offer little or no information on the semantic relationships among documents. Knowledge workers spend a substantial amount of their time browsing and reading to find out how documents are related to one another and where each falls into the overall structure of the problem domain. Yet only when knowledge workers begin to locate the similarities and differences among pieces of information do they move into an essential part of their work: building relationships to create new knowledge.

So information retrieval traditionally focuses on the relationship between a given query (or user profile) and the information store. On the other hand, exploitation of interrelationships between selected pieces of information (which can be facilitated by the use of ontologies) can put otherwise isolated information into a meaningful context. The implicit structures so revealed help users use and manage information more efficiently [4].

Knowledge management tools are needed that integrate the resources dispersed across web resources into a coherent corpus of interrelated information. Previous research in information integration (see for example [5]) has largely focused on integrating heterogeneous databases and knowledge bases, which represent information in a highly structured way, often by means

of formal languages. In contrast, the Web consists to a large extent of unstructured or semi-structured natural language texts.

Ontologies offer an alternative way to cope with heterogeneous representations of Web resources. The domain model implicit in an ontology can be taken as a unifying structure for giving information a common representation and semantics.

1.2 Communities of Practice & the Semantic Web

The notion of *communities of practice* [6] has attracted much attention in the field of knowledge management. Communities of practice are groups within (or sometimes across) organisations who share a common set of information needs or problems. They are typically not a formal organisational unit but an informal network, each sharing in part a common agenda and shared interests or issues. In one example it was found that a lot of knowledge sharing among copier engineers took place through informal exchanges, often around a water cooler. As well as local, geographically based communities, trends towards flexible working and globalisation has led to interest in supporting dispersed communities using Internet technology [7]. The challenge for organisations is to support such communities and make them effective. Provided with an ontology meeting the needs of a particular community of practice, knowledge management tools can arrange knowledge assets into the predefined conceptual classes of the ontology, allowing more natural and intuitive access to knowledge.

Knowledge management tools must give users the ability to organize information into a controllable asset. Building an intranet-based store of information is not sufficient for knowledge management; the relationships within the stored information are vital. These relationships cover such diverse issues as relative importance, context, sequence, significance, causality and association. The potential for knowledge management tools is vast; not only can they make better use of the raw information already available, but they can sift, abstract and help to share new information, and present it to users in new and compelling ways

In this paper, we describe the OntoShare system which facilitates and encourages the sharing of information between communities of practice within (or perhaps across) organizations and which encourages people – who may not previously have known of each other's existence in a large organization – to make contact where there are mutual concerns or interests. As users contribute information to the community, a knowledge resource annotated with metadata is created. Ontologies are defined using RDF Schema (RDFS) and populated using the Resource Description Framework (RDF). (RDF [20] is a W3C recommendation for the formulation of metadata for WWW resources. RDF(S) [21] extends this standard with the means to specify domain vocabulary and object structures – that is, concepts and the relationships that hold between them).

In the next section, we describe in detail the way in which OntoShare can be used to share and retrieve knowledge and how that knowledge is represented in an RDF-based ontology. We then proceed to discuss in Section 3 how the ontologies in OntoShare evolve over time based on user interaction with the system and motivate our approach to user-based creation of RDF-annotated information resources.

2. SHARING AND RETRIEVING KNOWLEDGE IN ONTOSHARE

OntoShare is an ontology-based WWW knowledge sharing environment for a community of practice that models the interests of each user in the form of a user profile. In OntoShare, user profiles are a set of topics or ontological concepts (classes declared in RDFS) in which the user has expressed an interest. OntoShare has the capability to summarize and extract key words from WWW pages and other sources of information shared by a user and it then shares this information with other users in the community of practice whose profiles predict interest in the information.

OntoShare is used to store, retrieve, summarize and inform other users about information considered in some sense valuable by an OntoShare user. This information may be from a number of sources: it can be a note typed by the user him/herself; it can be an intra/Internet page; or it can be copied from another application on the user's computer.

As we will see below, OntoShare also modifies a user's profile based on their usage of the system, seeking to refine the profile to better model the user's interests.

2.1 Sharing Knowledge in OntoShare

When a user finds information of sufficient interest to be shared with their community of practice, a 'share' request is sent to OntoShare via the Java client that forms the interface to the system. OntoShare then invites the user to supply an annotation to be stored with the information. Typically, this might be the reason the information was shared or a comment on the information and can be very useful for other users in deciding which information retrieved from the OntoShare store to access. At this point, the system will also match the content being shared against the concepts (ontological classes) in the community's ontology. Each ontological class is characterized by a set of terms (keywords and phrases) and the shared information is matched against each concept using the vector cosine ranking algorithm [11]. The system then suggests to the sharer a set of concepts to which the information could be assigned. The user is then able to accept the system recommendation or to modify it by suggesting alternative or additional concepts to which the document should be assigned.

When information is shared in this way, OntoShare performs four tasks:

i. an abridgement of the information is created, to be held on the user's local OntoShare server. This summary is created using the ViewSum text summarization tool. The summarizer extracts key theme sentences from the document. It is based on the frequency of words and phrases within a

document, using a technique based on lexical cohesion analysis [22]. Access to this locally held summary enables a user to quickly assess the content of a page from a local store before deciding whether to retrieve the (larger amount of) remote information.

ii. the content of the page is analyzed and matched against every user's profile in the community of practice. As when recommending concepts to the user, the vector cosine ranking model is used: here, however, the shared information is matched against the set of terms (words and phrases) created from the union of all terms associated with the concepts to which has user has subscribed (i.e. the concepts which make up the user profile). If the profile and document match strongly enough, OntoShare emails the user, informing him or her of the page that has been shared, by whom and any annotation added by the sharer.

iii. the information is also matched against the sharer's own profile in the same way. If the profile does not match the information being shared, the system will suggest one or more concepts which strongly match the shared information that the user can then add to their profile. Thus OntoShare has the capability to adaptively learn users' interests by observing user behaviour.

iv. for each document shared, an instance of the class *Document* is created, with properties holding meatadata including keywords, an abridgement of the document, document title, user annotation, universal resource locator (URL), the sharer's name and date of storage. (The ontological structure of the OntoShare store is described in detail in the next section)

In this way, a shared and enhanced information resource is built up in the OntoShare store based on user contributions. Given that users must make a conscious decision to store information, the quality of the information in the OntoShare store is high - it is effectively pre-filtered by OntoShare users. Thus each user leverages the assessment of the information made by all the other users.

2.2 Ontological Representation

We said above that each piece of shared information leads to the creation of a new entry in the OntoShare store and that this store is effectively an ontology represented in RDF(S) and RDF. We now set this out in more detail. RDFS is used to specify the classes in the ontology and their properties. RDF is then used to populate this ontology with instances as information is shared. Figure 1 shows a slightly simplified version of the ontology for a community sharing information about the Semantic Web, along with an example of a single shared document ("Document_1").

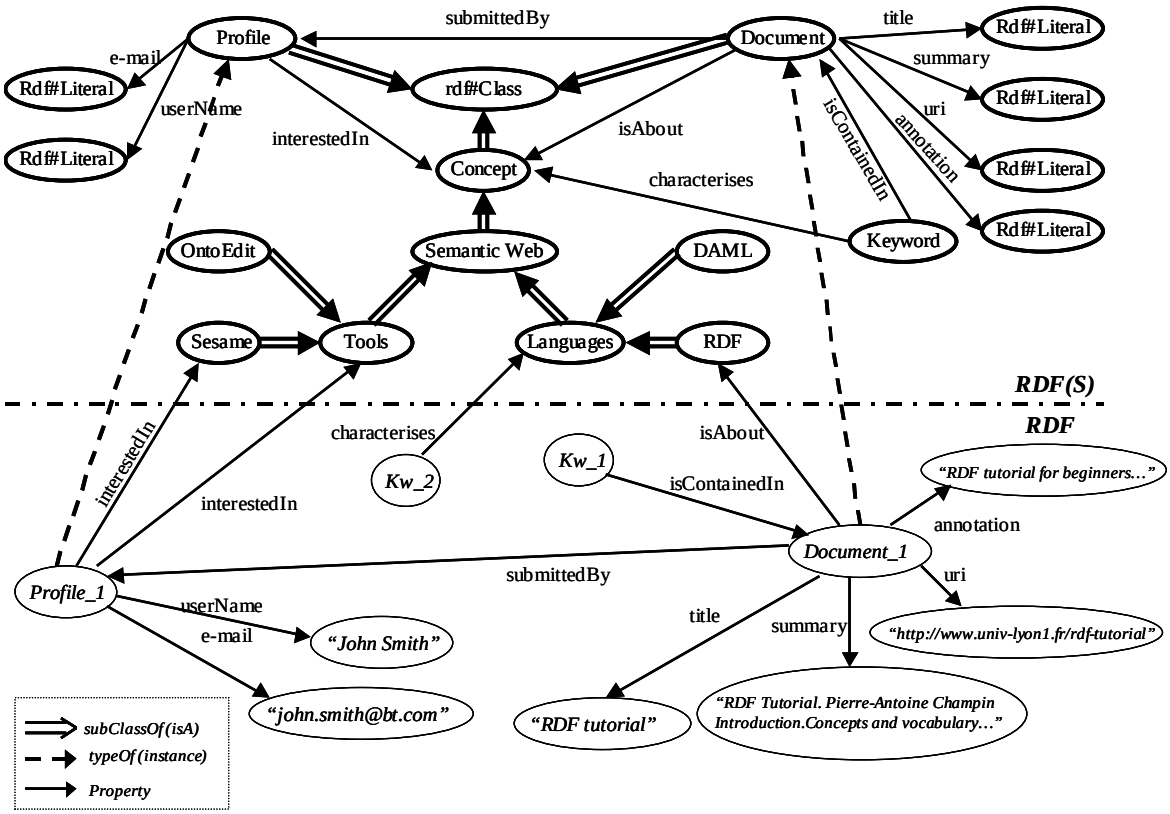

Figure 1**. Ontological Structure in OntoShare**

It is nor our intention to describe each class and property and their function here but we will mention a few key aspects. Firstly, notice *Concept* and its subclasses: this is the set of concepts which the community of practice at hand is interested in. Note that in the current version of OntoShare, the concept structure is limited to a strict hierarchy. Another key class is *Document*, which is the class used to represent shared information: each document shared generates an instance of *Document* with the set of properties shown. *Document_1*, for example, was stored by John Smith into the concept *RDF* with the annotation "RDF tutorial for beginners…" with the summary and URI as shown in Figure 1. It also has a set of keywords associated with it. (For simplicity, note that here we show only one keyword *Kw_1*, which is an instance of the class *Keyword*, as is *Kw_2* and furthermore that the instance (typeOf) relation is not shown for these keywords, nor is the fact that Keyword is a subclass of rdfs#Resource). The third central class is *Profile*, instances of which represent user information, including the concepts in which they are interested, their names and email addresses. *Profile_1*, for example, is the profile of a user with name "John Smith". Finally, note that keyword Kw_2 is one of (possibly many) terms (words and phrases) which characterize the concept *Language*.

Below we include excerpts from the RDFS and RDF (in XML notation) used to represent the ontology depicted above. We see the declarations of the classes *Document*, *Profile* and *Keyword* in RDF(S), followed by the descriptions of *Document_1* and the user profile of John Smith in RDF.

```
<?xml version="1.0" encoding="UTF-8" ?>
<rdf:RDF
 xmlns:rdf=
  "http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
xmlns:ontoshare="http://www.bt.com/ontoshare#">


<!--*************RDFS SCHEMA ************* -->
    <rdfs:Class rdf:ID="Document" />
    <rdfs:Class rdf:ID="Profile" />
    <rdfs:Class rdf:ID="Keyword" />

<!--  Document properties -->
<rdf:Property rdf:ID="submitted_by">
<rdfs:domain rdf:resource="#Document" />
<rdfs:range rdf:resource="#Profile" />
</rdf:Property>
        ..............
        ..............



<!--  ************ RDF DATA ************  -->

<!--  DOCUMENTS -->
<Document rdf:ID="Document_1">
<title>RDF Tutorial</title>
<uri>http://www710.univ-lyon1.fr/champin/rdf-
tutorial</uri>
<submitted_by>#Profile_1</submitted_by>
<summary>doc summary goes here</summary>
```

```
<isAbout rdf:resource="#RDF" ontoshare:ID="7" />
<annotation>RDF tutorial for
beginners...</annotation>
</Document>

<!--  PROFILES -->
<Profile rdf:ID="Profile_1">
<user_name>John Smith</user_name>
<email>john.smith@bt.com</email>
<interestedIn rdf:resource="#Sesame"
ontoshare:ID="5" />
<interestedIn rdf:resource="#Tools"
ontoshare:ID="2" />
    </Profile>
        ……
        ……
```

2.3 Retrieving *explicit* knowledge in OntoShare

In this section, we discuss the ways in which OntoShare facilitates access to and the automatic sharing of the information shared by users.

- **Email notification**

As described above, when information is shared in OntoShare, the system checks the profiles of other users in the community of which the user is a member. If the information matches a user's profile sufficiently strongly, an email message is automatically generated and sent to the user concerned, informing the user of the discovery of the information. Thus in cases where a user's profile indicates that they would have a strong interest in information shared, they are immediately and proactively informed about the appearance of the information.

- **Searching the community store – accessing information and people**

Via button on their OntoShare home page, a user can supply a query in the form of a set of key words and phrases in the way familiar from WWW search engines. OntoShare then retrieves the most closely matching pages held in the OntoShare store, using a vector space matching and scoring algorithm [11].

The system then displays a ranked list of links to the pages retrieved and their abridgements, along with the scores of each retrieved page and any annotation made by the original sharer is also shown. Importantly, the user can elect to simultaneously search for other users by selecting the appropriate check box. We will have more to say about this capability to identify other *users* as well as *information* in section 4 when we look at accessing *tacit* knowledge via other users using OntoShare.

- **Personalised Information**

A user can also ask OntoShare to display "Documents for me" as shown in the top right pane of Figure 2 below. The system then interrogates the OntoShare store and retrieves the most recently stored information. It determines which of these pages best match the user's profile. The user is then presented with a list of links to the most recently shared information, along with a summary, annotations where provided, date of storage, the sharer and an indication of how well the information matches the user's profile (the thermometer-style icon in Figure 2 below).

In addition, 2 buttons are provided (on the button bar at the bottom of the screen in Figure 2) so that the user can indicate interest or disinterest in a particular piece of information – this feedback will be used to modify the user's profile. At this point, the system will match the content of the current document against each concept (ontological class) in the community's ontology. As described above, each ontological class is characterized by a set of terms (keywords and phrases) and the shared information is matched against he term set of each concept using the vector cosine ranking algorithm [8]. The system then identifies the set of zero or more concepts that match the information above a given ranking threshold and suggests to the sharer that this set of concepts be added to or removed from their profile in the cases of user interest or disinterest respectively. The user is then free to accept the system recommendation or to modify it by selecting from the set of suggested concepts.

Two further operations are possible on documents presented to the user. These operations are selected from the "Documents" menu. Firstly, a user can add their own annotation to information stored by another user. Secondly, a user can request that OntoShare identifies other users with an interest in the information under consideration.

This "Documents for me" information is in fact displayed on the user's OntoShare home page, so that whenever they access the system, they are shown the latest information. Figure 2 is a typical OntoShare home page.

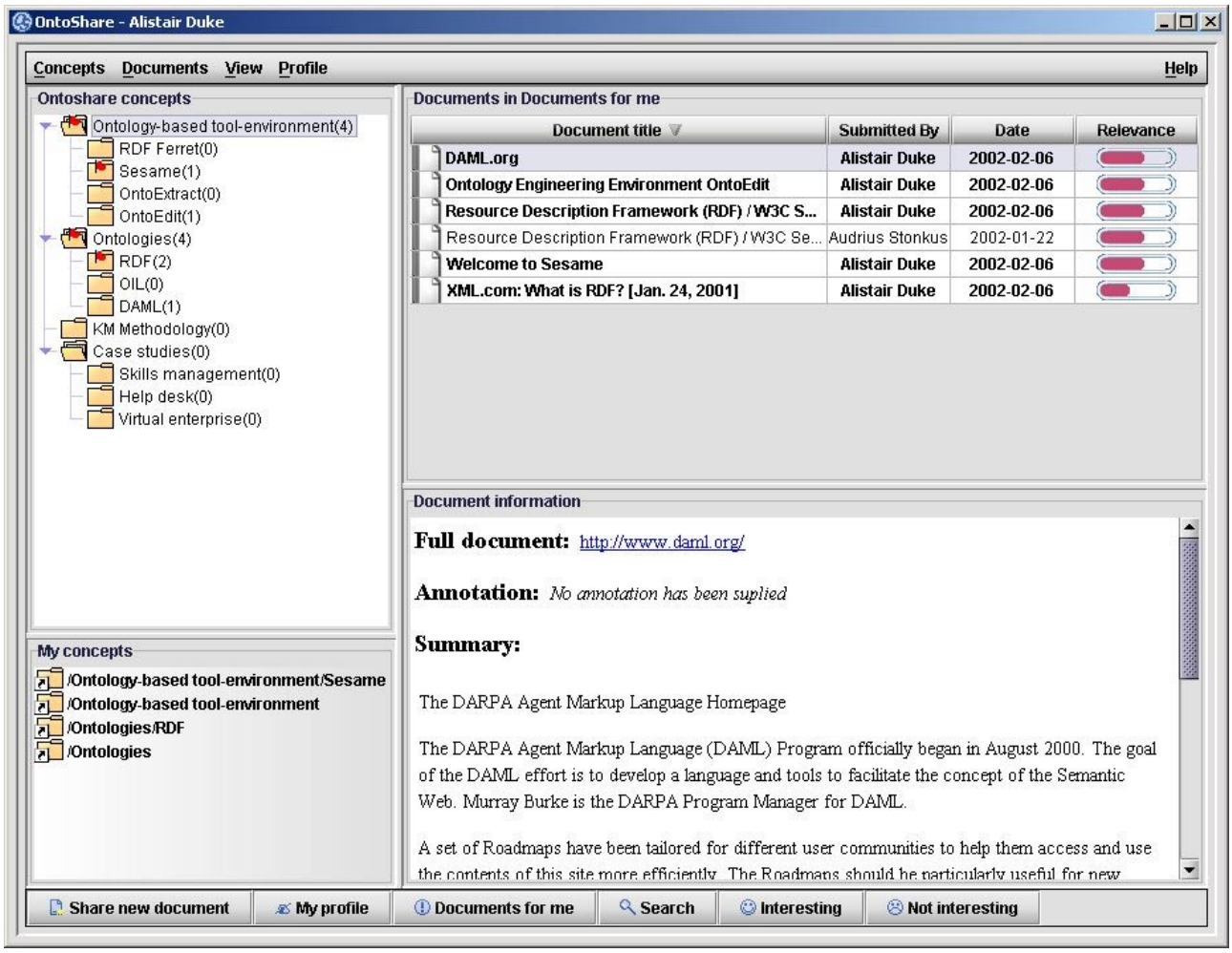

Figure 2**. Typical OntoShare Home Page**

3. CREATING EVOLVING ONTOLOGIES

In section 2, we described how, when a user shares some information, the system will match the content being shared against each concept (class) in the community's ontology. Recall that each ontological class is characterized by a set of terms (keywords and phrases) and that following the matching process, the system suggests to the sharer a set of concepts to which the information could be assigned. The user is then able to accept the system recommendation or to modify it by suggesting alternative concept(s) to which the document should be assigned. It is at this point that an opportunity for ontology evolution arises.

Should the user indeed override the system's recommended classification of the information being shared, the system will attempt to modify the ontology to better reflect the user's conceptualisation, as follows. The system will extract the keywords and keyphrases from the information using the ViewSum system mentioned above. The set of such words and phrases are then presented to the user as candidate terms to represent the class to which the user has assigned the information. The user is free to select zero or more terms from this list and/or type in words and phrases of his own. The set of terms so identified is then added to the set of terms associated with the given concept, thus modifying its characterization.

We call this approach usage-based ontology evolution and in this way the characterization of a given concept evolves over time, this evolution being based on input from the community of users. We believe that this ability to change as users' own conceptualization of the given domain changes is a powerful feature which allows the system to better model the consensual ontology of the community. Clearly, this level of evolution is limited to changing the semantic characterization of ontological

classes and does not support, for example, the automatic suggestion of new classes to be added to the ontology. More advanced ontology evolution is the subject of ongoing research and is described briefly in Section 5. It is also worh noting that we have not concerned ourselves with ontology versioning (tracking and managing changes to an ontology) here. This is an important issue with regard to ontology evolution and the reader is referred to, for example, [26], [27] for details of work in this area.

As well as usage-based evolution, we have seen above how users also indirectly annotate the information as a side-effect of sharing it with the community and we discuss and motivate this approach below.

Pragmatically speaking, it is the case at the time of writing that only a very small proportion of WWW- and intranet-based information resources are annotated with RDF (meta)data. It is therefore beneficial to provide a system wherein such annotation effectively occurs as a side-effect of normal usage.

Another important observation is that it is in the general case impossible to cover the content of a document exhaustively by an RDF description. In practice, RDF descriptions can never replace the original document's content: any given RDF description of a set of resources will inevitably give one particular perspective on the information described. Essentially, a metadata description can never be complete since all possible uses for or perspectives on data can never enumerated in advance.

Our approach accommodates this observation however in the sense that each community will create its own set of metadata according to its own interest in and perception of information that is added to its store. It is very possible that the same information could be shared in two separate communities and emerge with different metadata annotations in each.

4. EXPERTISE LOCATION AND TACIT KNOWLEDGE

In section 2, we focused on the *technical* aspects of OntoShare and on the sharing and storing of explicit knowledge. Explicit knowledge we take to be that knowledge which has been codified in some way. This codification can take place in many different media (paper, WWW page, audio, video, and so on). In the context of OntoShare, by explicit knowledge, we mean the information shared in OntoShare, along with the meta-information associated with it such as the sharer, the annotations attached to it, and so forth. We now turn to the *social* aspects of the system and tacit knowledge.

A large amount of the knowledge within an organization may of course not be codified: it may be personal, context-specific and difficult to write down, and may be better transmitted through a master-apprentice "learning by watching and copying" arrangement. Such knowledge is referred to as *tacit* knowledge [9]. When tacit knowledge is difficult to make explicit (codify), we need to find new ways of transmitting the knowledge through an organization. Failure to do so can lead to loss of expertise when people leave, failure to benefit from the experience of others, needless duplication of a learning process, and so on.

One way in which a system such as OntoShare can encourage the sharing of tacit knowledge is by using its knowledge of the users within a community of practice to put people who would benefit from sharing their (tacit) knowledge in touch with one another automatically.

One important way we gain new insights into problems is through 'weak ties', or informal contacts with other people [10, 11]. Everyone is connected to other people in social networks, made up of stronger or weaker ties. Stronger ties occur between close friends or parts of an organization where contact is maintained constantly. Weak ties are those contacts typified by a 'friend of a friend' contact, where a relationship is far more casual. Studies have shown that valuable knowledge is gathered through these weak ties, even over an anonymous medium such as electronic mail and that weak ties are crucial to the flow of knowledge through large organizations. People and projects connected to others through weak ties are more likely to succeed than those not [12, 13].

User profiles can be used by the OntoShare system to enable people to find other users with similar interests. The user can request OntoShare to show them a list of people with similar interests to themselves. OntoShare then compares their profile with that of every user in the store and a list of names of users whose interests closely match their own. Each name is represented as a hypertext link which when clicked initiates an email message to the named user. Recall that profiles in OntoShare are a set of phrases and thus the vector space model can be used to measure the similarity between two users. A threshold can then be used to determine which users are of sufficient similarity to be deemed to 'match'.

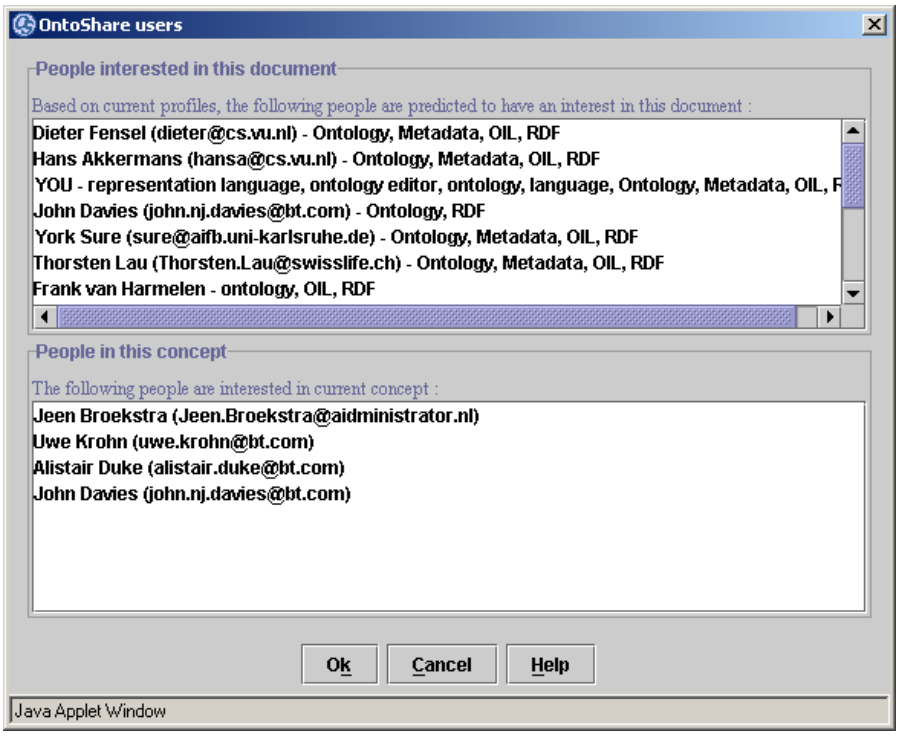

Figure 3. Identifying expertise on OntoShare.

This notion is extended to allow a user to view a set of users who are interested in a given document. OntoShare determines which members of the community 'match' the relevant document above a predetermined threshold figure and presents back to the user a list of user names. As before, these names are presented as hypertext links, allowing the user to initiate an email message to any or all of the users who match the document. Figure 3 shows typical output from this process.

In addition, as already mentioned in section 2.3, a user can carry out a keyword search on other users and thus identify users with an interest in a particular subject.

In this way, OntoShare, while not claiming to actually capture tacit knowledge, provides an environment which actively encourages the sharing of tacit knowledge, perhaps by people who previously would not otherwise have been aware of each other's existence.

5. EVALUATION

OntoShare is a recently developed system and no formal evaluations have yet taken place. We briefly describe here an evaluation due to start in April 2002. The user group for the study will consist of approximately 30 researchers, developers and technical marketing professionals from the research and development arm of a large telecommunications firm. The interests of the users fall into 3 main groupings: conferencing, knowledge and information management and personalization technologies. It is felt that three separate yet overlapping topic areas will constitute an interesting mix of interests for the purposes of the trial.

The case study will commence with a workshop involving the practitioners in order to develop an ontology that encompasses the research fields with particular emphasis upon the overlap between them. OntoEdit [17] will be used to create the ontology for the research areas. This will then be uploaded to SESAME [18], allowing it to be viewed used as the ontology in OntoShare (which contains a module for reading ontological information from SESAME) and provide access to the ontology for other ontology tools with a similar capability. The ontology will automatically evolve and extend over the course of the study as documents are added to OntoShare. The effectiveness of this evolutionary process will be considered in the evaluation exercise. Qualitative and quantitative measures of the trial are being devised. The main evaluation criterion is to what degree the application of tools and methodology can ensure that knowledge discovered by individuals can be transferred to the most appropriate members of the user group. An interesting secondary outcome we wish to look at is the extent to which the ontology built up by the community is useful to other users in other contexts. In this regard, we plan to offer a searching and browsing facility over the community's information using the QuizRDF system [23] for other users outside the community.

6. FURTHER & RELATED WORK

Research and development of OntoShare is ongoing. A particular area of focus currently is the ontological structure: a strict hierarchy (taxonomy) of concepts about which the communities wants to represent and reason may prove ultimately limiting and various possibilities for allowing a more expressive concept map are under consideration. One such is that OntoShare will be developed beyond the subclass/superclass concept hierarchy with *IsRelatedTo* properties, allowing "horizontal" links between concepts. The exploitation of this additional information is again matter for further research. One proposal is that when seeking to match users to other users, the system can use some notion of tree-matching, taking into account the concepts in the users' profiles as well as not only the *IsA* (*subClassOf*) links but also the *IsRelatedTo* links. These richer ontologies may be better represented in a more expressive language such as OWL, the upcoming standard from the W3C Web Ontology working group [25].

A further research area is the automatic identification and incorporation of *new* concepts as they emerge in the community. Work on this is however at a very early stage and is beyond the scope of this paper.

Turning to related work, Staab et al. [28] describe a system for building and maintaining community web portals. As with OntoShare, a ontology-based is taken and an ontology is used to structure and access information, using F-Logic as its underlying language for ontology representation and querying. Relatively sophisticated querying is supported, offering a degree of inferencing in the query engine not offered in OntoShare. Semi-structured information provision is supported by the use of wrappers. User profiling and automatic alerting are not supported, neither is the ability to change the semantic characterization of a class as in OntoShare.

RiboWeb [29] is another example of an ontology-based community portal RiboWeb holds information about ribosome data and computational models for the processing thereof. Most data are scientific papers manually linked to the appropriate ontological categories. Knowledge engineers maintain the data and metadata, rather than the data being provided by the community itself as in OntoShare.

7. CONCLUDING REMARKS

We have described OntoShare, an ontology-based system for sharing information among users in a virtual community of practice. We motivated the use of Semantic Web technology for KM tools and described how ontologies in OntoShare are defined in RDFS. Communities are able to automatically share information and create RDF-annotated information resources as a side-effect of this activity. Furthermore, these information resources are then of course available to other RDF-based tools for processing: the community semi-automatically creates an ontology-based annotated information resource for use by itself and others.

Importantly, the ontology used by a given community in OntoShare can change over time based on the concepts represented and the information that users choose to associate with particular concepts. This is a significant advantage over a community attempting to reach consensus on a set of concepts and how they relate to another at the outset that is then difficult or impossible to change. Much remains to be done in this area however, particularly with regard to the introduction of new concepts. In addition, users have personal profiles according to the concepts in which they have declared an interest and these profiles also evolve automatically, seeking to match more closely a user's information needs and interests based on the usage they make of the system.

We indicated some further directions of research and briefly discussed an ongoing evaluation of the system. OntoShare exemplifies the much-improved knowledge management tools that the advent of the Semantic Web and its support for ontologies makes possible.

8. ACKNOWLEDGEMENTS

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