Paper

Personal Ontologies for Knowledge Acquisition and Sharing in Collaborative PrOnto Framework

Cezary Chudzian and Jarosław Sobieszek

Abstract—This paper summarizes our preliminary experiences with implementing some of the ideas lying behind the concept of creative environment. Research group at the National Institute of Telecommunications has developed a prototype framework for collaborative knowledge acquisition and sharing, called PrOnto. At the moment the artifacts we organize and share are typical sources of scientific knowledge, namely journal papers and web pages. In PrOnto we introduce two interrelated explicit levels of knowledge representation: keywords and ontological concepts. Each user of the framework maintains his own ontological profile, consisting of concepts and each concept is, in turn, by subjective user's decision, related to a set of weighted keywords that define its meaning. Furthermore, dedicated indexing engine is responsible for objectively establishing correspondence between documents and keywords, or in other words, the measure of representativeness of the keyword to document's content. Developing an appropriate knowledge model is a preliminary step to share it efficiently. We believe that higher level representation facilitates exploration of other people's areas of interest. PrOnto gives an opportunity to browse knowledge artifacts from the conceptual point of view of any user registered in the system. The paper presents the ideas behind the PrOnto framework, gives an outline of its components and finalizes with a number of conclusions and proposals for future enhancements.

Keywords—collaborative knowledge sharing, creativity support, knowledge acquisition, knowledge management, ontologies.

1. Introduction

Willing to support the development of knowledge creating environments, one has to consider common patterns existing in knowledge intensive processes maintained at, not only academic and research institutions, but also growing number of commercial companies, trying to improve their position in contemporary knowledge based economy market, by putting higher stress on knowledge management activities. Instantiations of those patterns differ from institution to institution, depending on the maturity of knowledge management policy development, but still they can be observed at, at least, rudimentary stage.

Models of creative processes have been investigated for many years now. Significant milestone on the pathway of research in this area has been put by Nonaka and Takeuchi in [1]. They introduced SECI[1] spiral as an algorithmic model of organizational knowledge creation. Theory of Nonaka and Takeuchi describes the creation process as reliant on the collaboration of individuals involved and shows the special role of knowledge transfers between implicit, codified representation and tacit, intuitive form. Concepts of Nonaka and Takeuchi have been widespread in and met interest of the knowledge management community. Here, in this paper, we refer to the further augmented theory of creative environment, better suited to creative environments, namely triple helix of normal knowledge creation presented by Wierzbicki and Nakamori in [2]. Triple helix is the combination of three spirals modeling three aspects of knowledge creation: hermeneutic, experimental and intersubjective. All they have a cross-cutting point – enlightenment – a transition in creative space, expressing the creation of the new idea.

The enlightenment-analysis-hermeneutical immersion-reflection (EAIR) spiral, reflects the process of searching through rational heritage of humanity and reflecting on the object of study. It is usually accomplished with a repetitive "search & browse" strategy, usually implemented in the way as follows. First some query against knowledge repository is performed and after browsing over the results, selection of relevant information and drawing new conclusions, refined query is prepared that starts another strategy iteration. More specific form of the strategy is acquiring new knowledge through reading scientific papers. Starting with a very rough idea on the object of study, one looks up for papers with the keywords and titles somehow corresponding with the object. The more papers one reads, the more accurate his query may be and, in turn, more appropriate knowledge resources one can find in subsequent steps of "search & browse" run. Unfortunately, there exists a risk of obtaining the query overfit to what one already knows, making it harder to find any new, but relevant resources. Wider exploration of the research area may be facilitated by looking at the object of study from different individual perspectives, thus extending the "search & browse" paradigm with some collaborative dimension. We shall consider this important issue further on.

The enlightenment-experiment-interpretation-selection (EEIS) spiral models verification and objectification of the ideas through scientific experiments. As we do not provide support for this area of knowledge creation in our developed framework, we only mention here its existence, without going into details, which may be found in [2].

[1] Acronym for the names of transitions present in the model (socialization externalization combination internalization).

Debating on the ideas obtained from other spirals or through any other source of enlightenment is a subject of the enlightenment-debate-immersion-selection (EDIS) spiral. Implementing process modeled with EDIS is crucial for tacit knowledge sharing and encompasses transitions between tacit and explicit levels of knowledge and between group and individuals. The framework we present herein supports EDIS spiral in indirect way. First, it helps to meet people interested in common topics, second it facilitates acquiring and sharing textual materials for the debate.

In the following sections we present work of other teams done in our area of interest, then we provide more formal definition of the knowledge representation we use, present knowledge sharing capabilities of the framework and finally conclude with the steps to be made in the future.

2. Related Work

The problems of knowledge acquisition, organizing and sharing have recently gained much attention. Systematic review of the developed solutions and already finished or still running projects is far out of scope of this paper. Nevertheless, we will try to provide the reader with information on some selected tools and methods, we have examined throughout our research. We were especially interested in software products that organize knowledge around structures more complex than just bag of keywords and leverage cooperation between individuals for effective knowledge acquisition and sharing.

The most common way of performing "search & browse" routine, as mentioned above, is supported by one of general purpose or dedicated search engines and usually is organized as repetitive query refinement on the basis of previous findings. Query is, in fact, a set of keywords. Leading companies on the search market have already noticed that keyword search is getting less effective with the growth of available information amount and new approaches to finding and structuring information are needed. Therefore they started to work on the new products, closer to the idea of semantic search. In June, 2009 Google launched an experimental service, called Squared, which displays search results in a tabular form, with rows representing objects and columns corresponding to their common attributes. One month earlier, Stephen Wolfram[2] released his Wolfram Alpha answering engine, with queries interpreted semantically, before giving the answers drawn from underlying, structured knowledge base.

Growing popularity of social network services creates a new potential for structuring and personalizing knowledge resources. The biggest service of this kind, Facebook, with 200 million users storing their data on Facebook servers, may be perceived as an alternative web [3]. Its power comes from the fact that, in contradiction to the web, it keeps its content organized and personalized from the very beginning, when the piece of information is shared by the user. Much less expanded social networks, like Index Copernicus, BiomedExperts or BioCrowd, have been developed to facilitate knowledge sharing and organizing communities of practice focused on common topics.

The vast majority of web search engines, as well as social networks, assess relevance of a piece of information to the object of interest, on the basis of some keyword-based model. In general there are two basic approaches. One is to define some objective measure of relevance, for instance, the number of occurrences of every keyword found in the text document[3] and rank documents according to its value. On the other pole one finds a subjective model in which person annotates pieces of information with keywords of one's choice - so called tags. Both those models, in classical form, do not organize keywords in any semantic structure, using them as ordinary textual labels.

Combining richer indexing models, specifically ontology-based ones, with social networking, in order to develop novel knowledge management tools has been a subject of investigation in research projects for a couple of years now. Social networking contributes its value – further dimension of the knowledge space – as every piece of information is associated with its contributor. Ontologies, defined as a "*formal, explicit specification of a shared conceptualization*", create semantic backbone, linking resources of parties involved and organizing them around common conceptual structures.

OntoShare [4], a tool for knowledge sharing within communities of practice, is one of the examples. Common ontology of the group is agreed upon and imported into the system. Each community member contributes textual documents he judges as relevant to the interests of the whole group. The semantic proximity between the concepts from ontology and documents is measured on the basis of their profiles. Document's profile and ontological concept's profile are sets of keywords with weights measuring how much given keyword is representative to corresponding document or concept. The weights and keywords are computed by a specialized background algorithm and they are not explicitly exposed to the user. OntoShare user subscribes to existing concepts, thus adding them to his own profile and tags documents with concepts' signatures. The latter indirectly influences the profile of the concept as it is the main input of the computing algorithm. The OntoShare way of building ontological structure is called usage-based evolution of the ontology. The primary usage scenarios are document recommendation and finding users with similar interests to facilitate tacit knowledge sharing. They are both accomplished with the use of the acquired profiles.

PrOnto shares some of the ideas implemented in OntoShare. There are, however, important differences between them in the way the ontology is defined and maintained and how they deal with the keywords and relate them to ontological profiles, not to mention disparate interfaces for human – computer interaction. Moreover OntoShare is no

[2]Known previously as mathematica's author.

[3]It is called term frequency and is well known in the community of text miners.

longer available in the public domain, at least it is not accessible from project dedicated website.
The SWAP[4] project [5], [6] is another example of EU-financed project situated in the area of knowledge management through application of ontological models in networked environments. The network is decentralized in a peer-to-peer manner, which promises greater scalability. The semantic concepts are specific to every node (user) of the network and ontology matching techniques are applied to discover the grade of correspondence. The only known and available instance of SWAP-like system is Bibster, peer-to-peer network for sharing bibliographical information [7].
Recapitulating, there is a lack of publicly available knowledge management tools, organizing knowledge artifacts around structures more expressive and human understandable than simple keywords, facilitating knowledge sharing and leveraging the power of social networking. Therefore to address those issues we have decided to develop PrOnto.

3. Motivation

The main goal we were aiming at was to create a social networking platform for organizing and sharing knowledge resources by leveraging activities of network members to collect and index resources and to accelerate "search & browse" processes, thus supporting hermeneutic EAIR spiral execution. We wished to build up a digital library of documents with a certain level of quality assured. Collected artifacts ought to be accessible by every single user of the platform from his own semantic perspective. Further, formal representation of the perspective maintained by the user should be available to his colleagues as well, in order to facilitate cooperation and to speed up their learning processes in the areas they do not know, but which had been already investigated by their colleagues. The knowledge structure was to be organized in the way that not only let people order existing library items, but also was capable of accumulating new knowledge, fitting new documents to the structure, thus making it possible for the user to discover previously unknown, but relevant resources.
We have started our work on PrOnto framework having in mind some general rules and remarks, coming from previous experience, intuition and common sense. We have been following them then as the development guidelines. Let us discuss them shortly as they have influenced the current shape of the framework.
First observation is that semantically richer indexing schemes, specifically ontologies, enable contextual access to knowledge resources and thus allow their more intuitive exploration and, in turn, support cognitive processes. Still appropriate presentation layer has to be proposed, leveraging ontology-based knowledge representation. Particularly suited for interactive systems, such as PrOnto, is the visual form presentation. Diagramming approaches, like semantic networks [8], mind mapping [9], concept mapping [10], have proven their usefulness in human-oriented modeling of conceptual areas. They facilitate understanding and accelerate learning processes.
It seems reasonable to think that every human being feels more comfortable arranging his knowledge according to his own conceptual structure. Personalized ontological perspective may then serve as a guide to a subdomain of knowledge, recognized and arranged by a person, for other people use, especially when it is presented in a handy visual form. On the other hand, using ontologies as the knowledge representation means to have a common conceptualization of the domain. Therefore, while maintaining individual ontologies, it is essential to provide users with a set of tools facilitating ontology matching.
Semantically overlapping content can be usually retrieved with many different keyword queries. An example may be the concept of uplift modeling, being a predictive modeling technique. According to the information provided by Nicholas Radcliffe [11], one of its inventors, more than eight keyword queries characterize information on the concept. Those are: uplift modeling, differential response analysis, incremental modeling, incremental impact modeling, true response modeling, true lift modeling, proportional hazards modeling, net modeling. Using every one of them as a query in any web search engine results in different set of web pages retrieved, but the content is semantically close. Someone who is not familiar with that domain, which is typical case when he is just about to start exploring it, will have less chance to get relevant and useful information. Sharing queries, not only the artifacts itselves, can therefore support much wider exploration.
The high quality of information is an important factor for the knowledge creating environment. Creating a digital library out of knowledge sources recommended by, to some extent, trusted person might turn the social network into a filtering engine for quality control. Every piece of information becomes a part of the library by a conscious decision of the recommender.

4. Knowledge Representation

Before going into details of knowledge representation model we implemented in PrOnto framework, some attention has to be paid to a concept of hermeneutic horizon. In PrOnto, and further in this paper, we use the word "horizon" when referring to individual ontological profile, being a personalized perspective imposed on some domain of interest. Any user or a group may organize knowledge around their own semantic structure, or in PrOnto terminology, horizon.
But the term hermeneutic horizon has even deeper philosophical implications. Gadamer [12] defined it as: *The totality of all that can be realized or thought about by a person at a given time in history and in a particular culture*.
Alternative definition by modern Polish philosopher Król [13], says *the hermeneutic horizon is a set of intuitive*

[4]Acronym for *semantic web and peer-to-peer*.

assumptions on the object of study. PrOnto's way of understanding the horizon is closer to the meaning developed by Gadamer, as it refers more to explicit level of knowledge, instead of implicit, intuitive one.
Schema of the knowledge structure implemented in PrOnto framework is illustrated in Fig. 1. It consists of three levels of representation: artifacts (documents) D – keywords K – horizons (profiles) H.

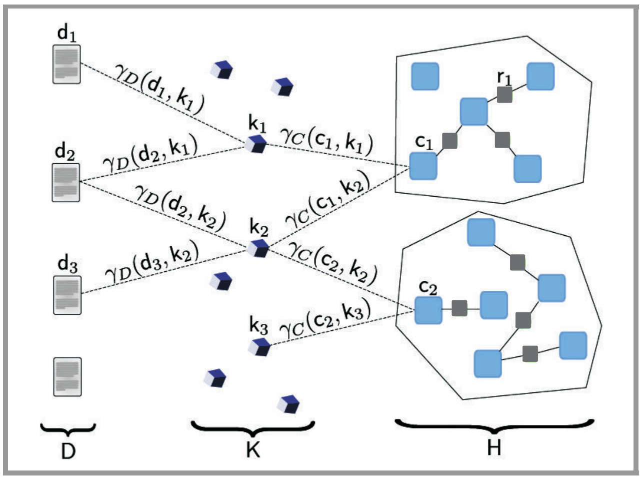

Fig. 1. Knowledge structure in PrOnto.

Definition 1: Knowledge in PrOnto framework is organized around the structure:

$$\mathsf{KR} := (\mathsf{H}, \mathsf{C}, \mathsf{R}, \mathsf{K}, \mathsf{D}, \alpha_{\mathsf{C}}, \alpha_{\mathsf{R}}, \sigma, \gamma_{\mathsf{C}}, \gamma_{\mathsf{D}}), \tag{1}$$

where:

- C is a set of concepts uniquely identified within the framework. In contradiction concepts' names or labels are not required to be unique.
- R is a set of relations. Every relation is unique, but the labels of the relations might repeat.
- $\sigma : \mathsf{R} \mapsto \mathsf{C} \times \mathsf{C}$ is a mapping that specifies concepts for which the relation holds.
- H is a set of horizons. Horizon is an individual perspective superimposed on the knowledge accumulated in the system. Every concept and relation is localized within a single horizon, which is reflected by the following mappings:
  - $\alpha_{\mathsf{C}} : \mathsf{C} \mapsto \mathsf{H}$
  - $\alpha_{\mathsf{R}} : \mathsf{R} \mapsto \mathsf{H}$
- K is a set of keywords. Keyword is an ordered set of words in a fixed grammatical form.
- D is a set of knowledge artifacts. Currently PrOnto framework deals only with textual documents, thus further we will be using term document interchangeably.
- $\gamma_{\mathsf{D}} : \mathsf{D} \times \mathsf{K} \mapsto \Re$ is a function measuring how strongly a keyword $\mathsf{k} \in \mathsf{K}$ represents an artifact $\mathsf{d} \in \mathsf{D}$, given fixed collection D.
- $\gamma_{\mathsf{C}} : \mathsf{C} \times \mathsf{K} \mapsto \Re$ is a function, measuring how much a keyword contributes to the meaning of a concept according to the preferences defined for the horizon $\alpha_{\mathsf{C}}(\mathsf{c})$ within which the concept has been defined. The measure corresponds to the conditional probability $P(c|k)$, $\mathsf{c} \in \mathsf{C}$ and $\mathsf{k} \in \mathsf{K}$.

4.1. Implemented Measures

Although the basic model does not make any assumptions on the formal, mathematical definitions of γ_{D} and γ_{C}, we had to decide on some specific implementation for the purpose of PrOnto development.
γ_{D} is to be an objective measure, reflecting both, strength of relation between k and artifact d and how d is distinguished among other artifacts with respect to k, or in other words how k is representative to d and unrepresentative to $\mathsf{D} \setminus \{\mathsf{d}\}$. As the current version of PrOnto limits artifacts to textual documents, we have adopted TF-IDF measure as γ_{D} function. TF-IDF stands for term frequency – inverse document frequency and is well-known tool in the text mining and information retrieval community for measuring document's relevance to a given query.

$$\text{TF-IDF}(\mathsf{k}, \mathsf{d}) = \frac{\mu(\mathsf{k}, \mathsf{d})}{|\{\mathsf{k}' : \mathsf{k}' \in \mathsf{K} \wedge \mathsf{k}' \in_{\mathsf{k}} \mathsf{d}\}|} \cdot \log \frac{|\mathsf{D}|}{|\{\mathsf{d}' : \mathsf{k} \in_{\mathsf{k}} \mathsf{d}'\}|}, \tag{2}$$

with $\mu(\mathsf{k}', \mathsf{d}')$ being a number of occurrences of k' in d'. Relation $\in_{\mathsf{k}}$ denotes "k occurs in d". See [14] for more information on term weighting approaches in information retrieval.
Relation between ontological concept and keyword is, on the other hand, measured subjectively. The user is equipped with an interactive tool for adjusting the strength of every concept-keyword relation by picking a value from some predefined interval. While PrOnto approach is completely manual and thus subjective, alternative procedures have been also proposed, like those implemented in OntoShare or OntoGen [15] systems. They derive concept profiles as keyword vectors, by analyzing document corpus in a semi-automatic fashion. We consider adding such a procedure as a further extension to our prototype framework, but still leaving the final decision to the user.

4.2. Ranking Method

Given two above measures, γ_{C} and γ_{D}, one can construct ranking procedure, for ordering knowledge artifacts from D according to their relevance to the concept $\mathsf{c} \in \mathsf{C}$. Obviously, any artifact is tied to a concept through a set of common keywords and there are many ways to leverage this indirect association for ranking definition. In the current stage PrOnto ranks documents in concept perspective, utilizing easy to compute in a database, and conceptually simple function ϕ.

Definition 2: Ranking function $\phi : \mathsf{D} \times \mathsf{C} \mapsto \Re$ takes form:

$$\phi(\mathsf{c},\mathsf{d}) = \sum_{\mathsf{k}\in\mathsf{K}} \gamma_{\mathsf{C}}(\mathsf{c},\mathsf{k}) \cdot \gamma_{\mathsf{D}}(\mathsf{d},\mathsf{k}), \ \forall \mathsf{c} \in \mathsf{C}, \ \forall \mathsf{d} \in \mathsf{D}. \qquad (3)$$

Interpretation is rather straightforward. We shall only notice the number of ranking procedures one can adapt here is much bigger, ranging from simple counting of common keywords to complex interactive multicriteria analysis.

5. Knowledge Sharing

PrOnto is based on a client-server architecture with a client-side application running inside a web browser and central server storing all the metadata and the library of collected knowledge resources. Upload of documents is implemented as a firefox browser extension. Client application, developed using flash technology, allows editing concept maps, adding new keywords and linking them with the concepts, searching and browsing the library, receiving alert messages on significant events occurring in the system.
In this section we present in more details how knowledge sharing is realized within PrOnto framework. Our discussion is organized around three main subtopics, corresponding to different levels of knowledge representation. First is exchanging artifacts, second is sharing procedures of locating them and third is about finding someone who is likely to know that procedure.

5.1. Sharing Artifacts

While searching and browsing the web, user may take a conscious decision to share a piece of information with other framework users. Firefox browser extension is used as an entry point for document delivery. At the time decision is being made, the document becomes a part of the repository and then dedicated module takes care of extracting the most relevant keywords, computing γ_{D} measures. From then on it is accessible for any user, by any access method implemented within the framework.
The main view on the conceptual horizon (Fig. 2) is implemented as a concept map-like graph, with concepts as nodes connected with named relations. Given ranking procedure realized with scalarizing function ϕ Eq. (3), there exists ordering of documents for every concept. User's own graph is fully editable, others are accessible in the read-only mode, letting the user to browse knowledge resources from any semantic perspective defined within the framework.

The access to the library through multidimensional "search & browse" view (Fig. 3) is closer to standard search engine approaches, however it enables additional semantic features to be added to search criteria or as browsing dimensions. Exploiting direct or indirect relations between knowledge model components one can analyze, for instance, which concepts are covered by the document content and what keywords are common to both concept and document (see Fig. 2).
In PrOnto, there exists a mechanism, acting like a subscription service. Each time a new knowledge artifact is added

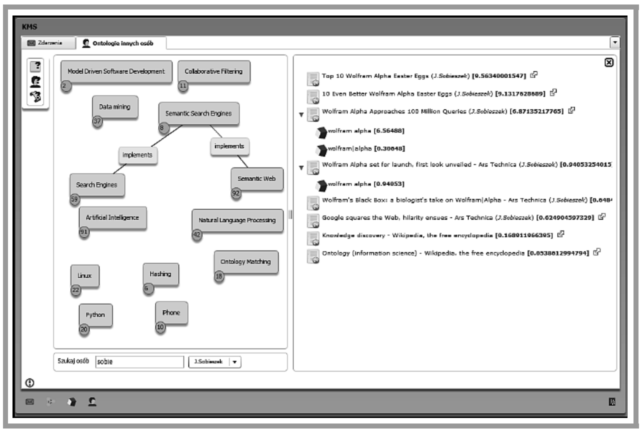

Fig. 2. Concept map view.

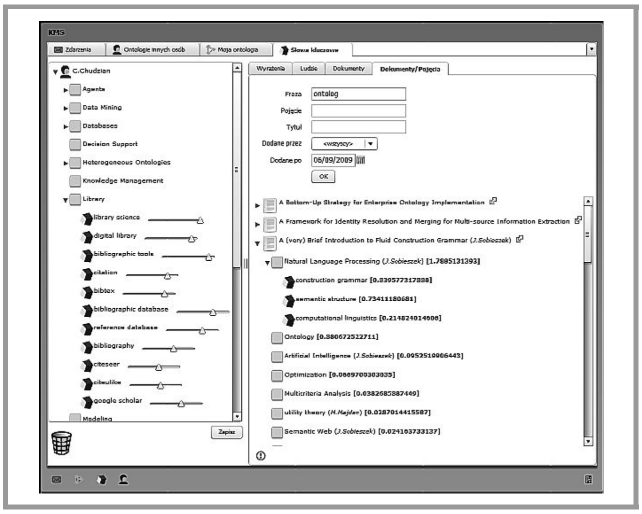

Fig. 3. Multidimensional "search & browse" view.

to the library, users whose profiles contain matching concepts with $\phi > 0$, are alerted with a message sent to their private mailboxes.

5.2. Sharing Queries

As mentioned before, sharing knowledge is not only about creating a common repository of knowledge resources, but also about sharing queries, or in other words, procedures of finding the resources most wanted at the given moment. The basic building block of a query in its classical search engine meaning is a keyword. In PrOnto we keep keywords bound to ontological concepts of individual horizons (see the left pane in Fig. 2). As the horizons are exposed to all members of the PrOnto network, one can discover new keywords, while exploring higher level - ontological description of the domain.
Keywords are initially imported to the framework's database from any external source (e.g., Wikipedia) and then used for indexing documents flowing into the system. Just exactly as in the case of sharing documents, user can share a keyword that becomes a part of a common collec-

tion visible to all PrOnto users. Browsing through a concept map of another user, one can possibly discover new keywords, previously unknown or unrealized, that might be useful in formulation of more accurate queries. Another context that the new keyword might be recognized in, is browsing the artifacts in the framework's library. Keyword gets a high γ_D-score for the document it is relevant to and becomes visible on the list of document's characteristic keywords. So, with the mediation of library item, a keyword is transferred between users and query sharing mechanism is established.
To keep the user on track of what is going on in the system, messaging module alerts the user whenever any new document is shared, or any new concept is created in the system, that is strongly related to the keyword might be interested in.

5.3. Sharing Expertise

Third, conceptually the highest level of knowledge sharing in PrOnto, is about locating domain experts for further debating on the object of study, thus supporting EDIS spiral and creating platform for tacit knowledge exchange. Since PrOnto lets every user to use his own, individual concepts, a tool must be provided for searching for the concepts semantically similar to any given one. This task has been a subject of interest within ontology matching stream of research and methods have been developed to deal with it [16]. PrOnto prototype is as far limited to assessment of the similarity between concepts by exact matching their label names and by the comparison of keywords associated with them. The latter similarity degree is measured with the formula

$$\mathrm{sim}(c_i, c_j) = \sum_{k \in K} \gamma_C(c_i, k) \cdot \gamma_C(c_j, k)\,.$$

Owner of the horizon containing concepts similar, in the sense of one of above definitions, to the ones from user's own horizon is put on the concept map view screen (Fig. 4). The multidimensional "search & browse" view marks concepts and documents with the names of their owners. Here we understand document owner as a user who shared the document uploading it with firefox browser extension.

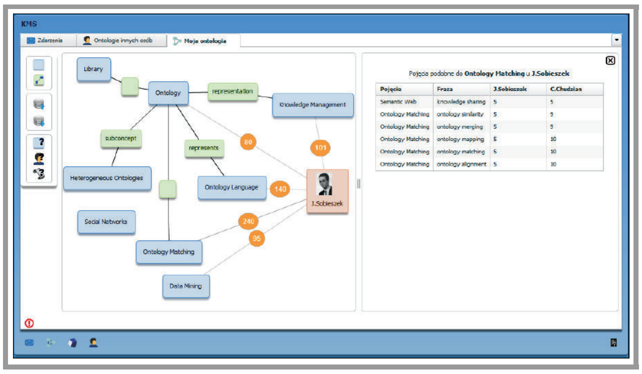

Fig. 4. People sharing concepts.

6. Evaluation

Being the social system and applying subjective preference model for concept definition (γ_C measure), PrOnto needs an evaluation procedure adapted to those characteristics. We plan to ask users to give us a feedback on their perception of the framework. We have not yet started evaluation process. The only thing we have done in the testing area was implementation of contextual notes system. On every screen, there is a button for opening a window in which user may write down a note and categorize it with problem type and priority. The notes system covers the problems of rather technical nature. There is still a need for more formal evaluation and we plan to provide users with a questionnaire letting them to express their opinion being guided with a set of questions on usefulness and usability of the PrOnto framework.

7. Conclusions

The paper introduces PrOnto, the web based framework for acquiring and sharing knowledge artifacts. PrOnto is social networking platform whose main ambition is to support creative processes within community of practice. The knowledge in the framework is to be searched and shared at the higher, conceptual level, aiming beyond keyword based searching and sharing techniques. The user is provided with graphical interface for defining and exploring the knowledge structure.
At the moment of writing this paper PrOnto is at the prototype stage. Below we present some of the ideas for further development.

- Concept map-like structure we have implemented is a semantically weak language for describing hermeneutic horizon. The language shall be semantically strengthened for more formal description of knowledge structure.
- The γ_C measure, for subjectively associating concepts with keywords, is defined in a manual procedure. Incorporating techniques of automatic or semi-automatic estimation of initial values of γ_C on the basis of social network data and library contents would be a helpful hint tool for the users.
- We consider the query sharing task particularly interesting and important for searching the web. Employing the potential of social system for constantly improving the search procedure by making the queries more accurate adds a social dimension to the idea of hermeneutic agent [17]. We wish to explore this research direction particularly.
- The only ranking method for ordering knowledge artifacts in PrOnto is by applying scalarizing function ϕ. The model presented above, however, gives an opportunity for more complex procedures to be used, specifically interactive multicriteria analysis methods. This direction shall be examined, as well.

- The reconstruction of the learning processes performed by other users is another challenge for the future. Having learning path recorded as a sequence of steps leading to the current state of knowledge, with possibility of highlighting milestones and warning about dead ends, may accelerate knowledge acquisition.

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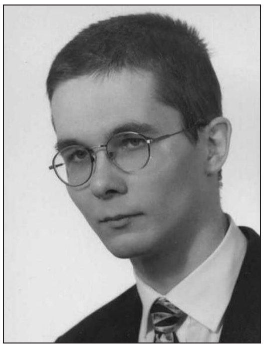

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