Semantic-enabled Efficient and Scalable Retrieval of Experts

Witold Abramowicz, Elżbieta Bukowska, Monika Kaczmarek, Monika Starzecka
Department of Information Systems, Faculty of Informatics and Electronic Commerce, Poznan University of Economics, Poznań, Poland
{w.abramowicz; e.bukowska; m.kaczmarek; m.starzecka}@kie.ue.poznan.pl

***Abstract*—Nowadays, efficient utilization of knowledge became a key to the success of an organization. The need to identify experts within or outside an organization has been for a long time inspiration for various initiatives undertaken by academia and industry. The eXtraSpec system developed in Poland is an example of such initiatives. In order to realize its tasks, the eXtraSpec system needs not only to be able to acquire and extract information from various sources, but also requires an appropriate information representation supporting reasoning over person characteristics. The considered mechanism should allow for precise identification of required data, but simultaneously, be efficient and scalable. The main goal of this paper is to present the reasoning scenario we applied within the eXtraSpec project and discuss the underlying motivation, which led to the development of pre-reasoning mechanism. The system architecture and developed ontology together with implementation details are also discussed.**

Keywords - Expert finding system; knowledge representation; expert characteristic

I. Introduction

Efficient utilization of knowledge is a key to the success of an organization. Knowing the skills and expertise of employees as well as a proper recruitment are of major importance. More and more often organizations take advantage of data available on the Internet to locate experts they require. As the data available is very dispersed and of distributed nature, a need appears to support the human resources management process using IT-based solutions, e.g., information extraction and retrieval systems.

Within an information retrieval (IR) process a single query is executed on a set of resources to identify the relevant data [1]. In general, a typical retrieval system encompasses three components: a module responsible for collecting data and creating its representation in the form of an index; an interface allowing formulating queries consisting of a set of keywords and finally, a mechanism matching a query to the created indexes.

These components affect the quality of the retrieval process i.e., values of the precision and recall metrics.

The traditional expert retrieval systems face well known IR problems caused by application of different keywords and various levels of abstraction by users while formulating queries or by using different words and phrases while creating a description of a phenomenon, based on which indexes are created. Thus, to ensure that in a response to a query an expert retrieval system returns documents, which do not contain words included in the query, but are still relevant, very often semantics is applied.

There are many research and commercial initiatives aiming at development of expert retrieval systems supported by semantics. They are to provide interested parties with detailed information on people's experience and skills. One of such initiatives is the on-going Polish project eXtraSpec [23]. Its main goal is to combine company's internal electronic documents and information sources available on the Internet to provide an effective way of searching experts with competencies in the given field. The system is to support three main scenarios: finding experts with desired characteristic, defining teams of experts and verifying data on a person in question. In order to support these scenarios, the eXtraSpec system needs not only to be able to acquire and extract information from various sources, but also requires an appropriate information representation supporting reasoning over person's characteristics. In addition, the mechanism should allow on the one hand for precise identification of required data and, on the other hand, be efficient and scalable.

The main goal of this paper is to present the reasoning approach we followed within the eXtraSpec project and discuss the underlying motivation, which led to the development of a semantic-based mechanism to retrieve experts in its current state. In addition, the ontology developed to describe expert characteristics is presented.

In order to fulfill the mentioned goals, the paper is structured as follows. First, the related work in the area of expert finding systems is discussed. Next, the ontology developed for the needs of the eXtraSpec project to support retrieval of experts is presented. Then, the short description of the considered scenarios regarding the application of the reasoning infrastructure follows. Finally, the system architecture as well as implementation details are given. The paper concludes with final remarks.

II. Related Work

The need to find expertise within an organization has been for a long time inspiration for initiatives aiming at development of a class of search engines called expert finders [2]. There are several aspects connected with expert finding, for instance, following McDonald and Ackerman

 ISBN: 978-1-61208-121-2

[3] those may be: expertise identification aiming at answering a question: 'who is an expert on a given topic' and expertise selection aiming at answering a question 'what does X know'? Within our research, we focus on the first aspect i.e., identifying a relevant person given a concrete need.

First systems focusing on expertise identification relied on a database like structure containing a description of experts' skills (e.g., [4]). However, such systems faced many problems, e.g., how to ensure precise results given a generic description of expertise and fine-grained and specific queries [5] or how to guarantee the accuracy and validity of stored information given the static nature of a database. To address these problems other systems were proposed focusing on automated discovery of up-to-date information from specific sources such as e.g., email communication [6]. In addition, instead of focusing only on specific document types, systems that index and mine published intranet documents were proposed [7]. An example may be the Spree project [8] aiming at providing automatic expert finding facility, able to answer a given question. The system automatically builds qualification profiles from documents and uses communities and social software in order to provide efficient searching capabilities. In addition, currently the Web itself offers many other possibilities to find information on experts, as there are a number of contact management portals or social portals where users can look for experts, potential employees or publish their curricula in order to be found by future employers (some examples may be [24] [25], [26]).

When it comes to the algorithms applied to assess whether a given person is suitable to a given task, at first, standard IR techniques to locate an expert on a given topic were applied [9][10]. Usually, expertise of a person was represented in a form of a term vector and a query result was represented as a list of relevant persons. If matching a query to a document relies on a simple mechanism checking whether a document contains the given keywords, then the well-known IR problems occur: (1) low precision of returned results (there is a word, but not in this context); (2) low value of recall (relevant documents described with another set of keywords are not identified); (3) a large number of documents returned by the system (especially in response to a general query) the processing of which is impossible (e.g., due to the time limit). Therefore, few years ago, the Enterprise Track at the Text Retrieval Conference (TREC) was started in order to study the expert-finding topic. It resulted in further advancements of the expert finding techniques and application of numerous methods such as probabilistic techniques or language analysis techniques to improve the quality of finding systems (e.g., [11] [12] [13] [14]).

As the Semantic Web technology is getting more and more popular, it is not surprising that it has been used to enrich descriptions within expert finding systems. The introduction of semantics into search systems may take two forms: the use of semantics in order to analyze indexed documents or queries (query expansion), or operating on semantically described resources (e.g., RDF files) with use of reasoners.

Within the expert finding systems, both approaches have been applied and a number of ontologies to represent competencies and skills was developed. For instance, a Single European Employment Market-Place project [15] aiming at providing interoperable architecture for e-Employment services. used an ontology in order to create a semantic description of job offers and CV. The ontology is called "Reference Ontology" and it consists of thirteen sub-ontologies: Competence, Compensation, Driving License, Economic Activity, Education, Geography, Job Offer, Job Seeker, Labour Regulatory, Language, Occupation, Skill and Time. It was built based on the commonly used standards, e.g., ISO 4217 [27], ISCO-88 (COM[28]), ONET [29], DAML ontology [30].

In turn, in [16], authors describe requirements and a process of ontology creation for the needs of HR management. They developed an ontology used by a meta-search engine searching jobs in job portals [17] and by a university competence management system [18]. The ontology was created in the OWL formalism. It consists of sub-ontologies for competencies, occupations and learning objects. Another example is an ExpertFinder [19] framework enabling application of existing vocabularies in semantically supported systems. It provides terms and best practices for describing web pages, persons, institutions, events, areas of expertise or educational aspects. It uses such vocabularies as: FOAF [31], SIOC [32], vCard [33] or Dublin Core [34].

In addition, numerous ontologies, taxonomies and classifications have been created in the HR management area, e.g., the Standard Occupational Classification (SOC) [35] of the US Federal statistical agencies or taxonomy of skills in the KOWIEN project [20].

The system discussed in this paper relates to the semantic-based expert finding. However, our setup is a bit different. The eXtraSpec system acquires information from outside and assumes that one can build an expert profile based on the gathered information. The system gathers information on a large set of experts. More experts imply bigger topic coverage and increased probability of a question being answered. However, it also causes problems connected with the heterogeneity of information as well as precision and recall of the system. The application of semantics may help to normalize the gathered data and ensure appropriate level of precision and recall; however, it generates problems with scalability and efficiency of the designed mechanisms. In addition, the ontology itself developed for the needs of the eXtraSpec system differs from other projects: (1) it is not limited to hierarchical relations; (2) it has been developed for the Polish language and relate to Polish standards; (3) it has been built in accordance to the Simple Knowledge Organization System (SKOS) [36] standard.

 ISBN: 978-1-61208-121-2

III. Ontologies in the Extraspec Project

One of the most important functionalities of the eXtraSpec system is the identification of persons having the desired expertise. As already discussed, in order to ensure the quality of returned results, the decision to apply Semantic Web technologies to retrieve and describe profiles was taken. The eXtraSpec system acquires automatically data from dedicated sources, both company external and internal ones. The extracted content is saved as an extracted profile (PE), which is an XML file compliant with the defined structure of an expert profile (Figure 2) based on the European Curriculum Vitae Standard [37]. Vocabulary in the extracted content is then processed and normalized using the developed ontology. The result of the normalization process is a normalized profile (PN). Every normalized profile provides information on one person, but one person may be described by a number of normalized profiles (e.g., information on a given person at different points in time or information acquired from different sources). Thus, normalized profiles are analysed and then aggregated, in order to create an aggregated profile (PA) of a person. Finally, the reasoning mechanism is fed with the created aggregated profiles and answers user queries on experts.

The above-mentioned steps impose requirements on the ontology. It should enable semantic annotation of all elements of profiles as well as support the normalization and discovery process. The basic element of the eXtraSpec system is an already mentioned profile of an expert. Each expert is described with series of information, e.g., first and last name, history of education, career history, hobby, skills, obtained certificates. To make the reasoning possible, the following attributes from the profile of an expert should be linked to ontology instances:

- Educational organization – name of organization awarding the particular level of education or educational title;
- Certifying organization – name of an organization that issued particular certificate;
- Client, employer and role – those three attributes are used to describe history of an employment. A single step in the employment history is described as a business relation. Each relation consists of three basic elements: client – employer and a role (i.e., profession) that an expert played in this relation;
- Scope of education – the domain of education (for example: IT, construction, transportation);
- Topic of education – for a higher education description, it will be a name of the specialization, for trainings or courses etc. – their topic;
- Result of education – the obtained title;
- Skill – an ability to do an activity or job well, especially because someone has practiced it;
- Name of a certificate;
- Degree of a skill.

Performed analysis of the requirements imposed on the ontology for the needs of reasoning, concluded with the definition of a set of relations that should be defined:

- *subConceptOf* – to represent hierarchical relations between concepts,
- *isPartOf* – for representation of composition of elements, for example: ability of using MSWord is a part of ability of using MSOffice (however, knowing MSWord does not imply that a person knows the entire MSOffice suit),
- *isRequired* – connection between two concepts, for example: to have a role – doctor, one must have graduated from some medical school.
- *implies* – from one fact, or set of facts, another fact can be concluded. For example, if one has skills A and B, then he also has skill C.

As the result of the conducted analysis of different formalisms and data models, the decision was taken to use the OWL language as the underlying formalisms and the SKOS model as a data model. The criteria that influenced our choice were as follows: (1) relatively easy translation into other formalisms; (2) simplicity of representation; (3) expressiveness of used ontology language; (4) efficiency of the reasoning mechanism. Many knowledge representations, such as thesauri, taxonomies and classifications share some structure elements and are used in similar applications. SKOS gathers most of those similarities and explicitly enables data and technology exchange between different applications. The SKOS data model enables low cost migration that will allow making a connection between existing SKOS and the semantic Internet. Ontologies developed in accordance to the SKOS model can be expressed in any known ontology language. Because of the strong software support and a wide usage of OWL, we decided to use that formalism within our work.

As a result of the conducted work, the data structure was designed having one SKOS ontology with eight concept schemas for each area of interest: Organizations (for organizational organizations, certifying organizations, Employer and Client), SkillName, SkillDegree, Certificate, Role, EducationScope, EducationTopic and EducationResult. While building the ontology for the needs of the eXtraSpec system, a wide range of taxonomies and classifications has been analyzed in order to indentify best practices and effective solutions. As the eXtraSpec system is a solution designed for the Polish market, so is the developed ontology. For instance, during the development of Concept Schemas for Organizations information provided by the Polish Ministry of Science and Higher Education [38] was used while for Role organization the official Polish Classification of Occupations [39] published by the Polish Ministry of Labor and Social Policy was utilised.

IV. Considered Searching Scenarios

One of the most important functionalities of the eXtraSpec system is the identification of persons having the desired expertise. The application of Semantic Web

 ISBN: 978-1-61208-121-2

technologies in order to ensure the quality of returned results implies application of a reasoning mechanism to answer user queries. In addition, the strict requirement towards the performance and scalability of the developed system was formulated. Therefore, a design decision needed to be taken on how to apply semantics and at the same time ensure the required quality of the system during the discovery process.

Given the above criteria (precision and recall on the one hand, and efficiency and scalability on the other), three possible scenarios were considered. The *first* scenario involves using the fully-fledged semantics by expressing all expert profiles as instances of an ontology, formulating queries using the defined ontology, and then, executing a query using the reasoning mechanism. This approach involves the need to load all ontologies into the reasoning engine and representing all individual profiles as ontology instances. Performed experiments showed that querying the reasoning infrastructure, even while using only a small set of gathered profiles, is resource (large memory consumption) and time consuming task (up to a few minutes). Therefore, although having a high precision and recall, it has poor performance and scalability.

The *second* scenario relies on query expansion using ontology, i.e., adding keywords to the query by using an ontology to narrow or broaden the meaning of the original query. It allows to get answers faster than the previous scenario, however, it could not take into account additional relations expressed in the ontology, and therefore, did not always allow for increased precision. In addition, each user query needs to be normalized and then expanded using ontology, therefore, application of a reasoner was necessary. The experiments showed that it affected the values of system performance and scalability.

The *third* scenario called pre-reasoning involves two independent processes: creation of enriched profiles (indexes), to which additional information reasoned from the ontology is added and saved within the repository as syntactic data; formulating query with the help of the appropriate GUI using the defined ontology serving as a controlled vocabulary. Then, the query is executed directly on a set of profiles using the traditional mechanisms of IR. There is no need to use the reasoning engine while executing a query. This approach allows circumventing the drawbacks associated with the first approach, shifting the burden of an operation on the stage of indexing using ontologies.

Summarizing, our experiments proved that applying fully-fledged semantics is a precise but neither efficient nor scalable solution. Query expansion provides increased precision of the results (in comparison to traditional IR mechanisms) and has better scalability and efficiency than the fully-fledged semantics, however, does not allow to take full advantage of the developed ontologies and existing relations between concepts. Only application of the third considered scenario allows taking advantage of the mature IR mechanisms while increasing the accuracy and completeness of the returned results by: introducing a preliminary stage called pre-reasoning in order to create enriched indexes and the minimum use of the reasoning engine during the search.

The short overview of the constituents of the proposed mechanism follows.

V. Semantic-enabled Retrieval of Experts

The eXtraSpec system consists of a number of modules specialized for different tasks. Its architecture is described in [22], here we focus on the REA component (REAsoning) presented in Figure 1. It consists of indexing mechanism (indexer), searching mechanism (searcher), composition mechanism (composer) and a reasoning engine with set of ontologies loaded.

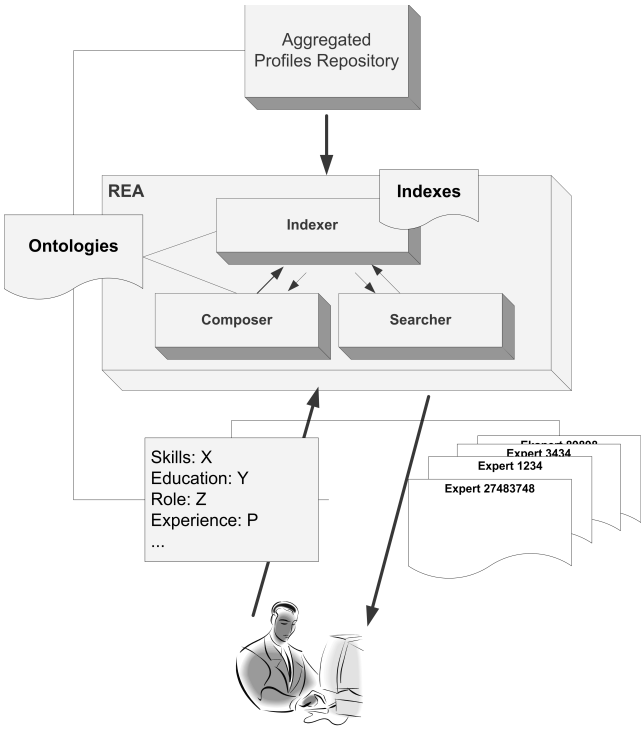

Figure 1. REA overview

The selected scenario requires the support of two independent processes. First, creating profiles' indexes optimized for search, i.e., structured so as to enable a fast search based on criteria preset by a user, and enriched with additional information using an ontology (pre-reasoning).

The second process that needs to be supported is defining the query matching mechanism on the enriched indexes - this process is initiated by a user formulating queries using a graphical interface.

To perform the IR side of the mechanism, the open-source java library Lucene [40], supported by the Apache Software Foundation, was selected. Fields in the Lucene documents cannot be grouped together nor stored as hierarchical structures. However, within an aggregated profile (PA), which is a base profile for searching, some hierarchies and groups might be found. Since explicit mapping from PA to the Lucene document is not possible, during the indexing process profiles are divided into a

 ISBN: 978-1-61208-121-2

number of separate documents as shown in Figure 2. Concurrently with the indexing process, pre-reasoning takes place, in order to complete profile with implied facts. Documents contain fields generated directly from PA (marked with +) as well as the additional fields (marked with #). In the simplest case, the reasoning engine returns a list of all superconcepts for the given element to the indexing module. The hierarchy of superconcepts is preserved. Superconcepts are indexed as additional values for the given document field: these values are saved as next array elements and it is assumed that the higher array index number, the smaller weight the concept has. The assigned weight affects the ranking procedure. If returned superconcepts do not correspond with PA elements conceptually, additional fields are added to the document being indexed. For example, PA element „address" might be divided into data that are more detailed, i.e., zip code, city, street, etc. Based on the zip code it is possible to specify county and province and search for experts using the spatial criteria. Since PA does not contain such elements, we add fields to the personal data document during the indexing process. In turn, documents that contain information about education history have been expanded by field „catOfEduOrganization". Hierarchy of superconcepts for each education organization is acquired from ontology and indexed. This enables, e.g., searching people who graduated from a desired type of educational organization, e.g., any technical university. In the document that contains data about skills, the field „skillName" was expanded in order to contain all superconcepts from the ontology for a given skill. The same expansion was made in the document about history of employment, were the field „role" was expanded using the hierarchy of superconcepts for occupied positions.

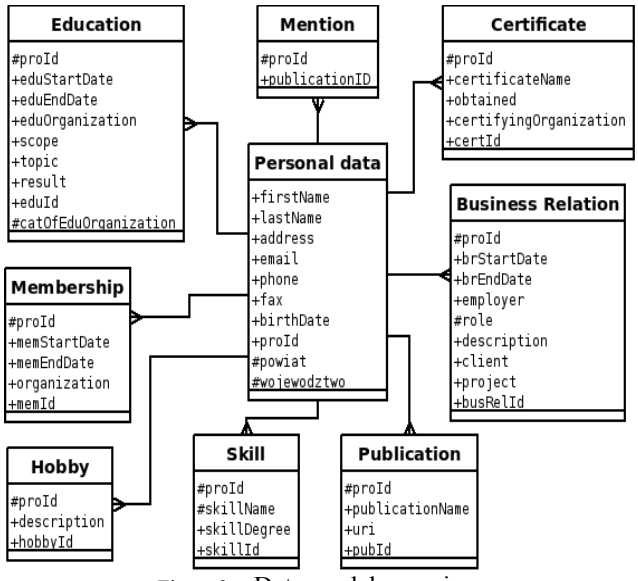

Figure 2. Data model overview

Lucene provides a very flexible but simple query structure. Therefore, in the eXtraSpec system it had to be extended in order to correspond to the PA structure and searching scenarios. In order to execute more sophisticated queries encompassing several criteria from various documents, a QueryObject structure needed to be defined. It stores information on fields' names, required values as well as logical operator that should be fulfilled.

The performed tests have shown that the system fulfils the defined requirements. Application of semantics in the form of a pre-reasoning phase allowed to achieve precise results, simultaneously allowing to take advantage of the matured IR mechanisms guaranteeing scalability and good performance of the system.

VI. Conclusions and Future Works

The main goal of the eXtraSpec project is to develop a system supporting analysis of company documents and selected Internet sources for the needs of searching for experts from a given field or with specific competencies. The provided system focuses on processing texts written in the Polish language. The obtained information is stored in the system in the form of experts' profiles and may be consolidated when needed. The system aims to offer a user friendly interface to perform queries that allow to find persons with specific characteristics. Realisation of this goal requires interconnection between developed interface and underlying ontologies. Within this paper, we have discussed the concept and considered scenarios regarding the implementation of the reasoning mechanism for the needs of the eXtraSpec system. We argue that by introducing the pre-reasoning phase, the application of semantics may be used to achieve precise results when searching for experts and at the same time, ensure the proper performance and scalability.

The set of developed ontologies discussed within this paper was designed specially for the Polish language, however, the main structure and model as well as defined relations may be reused also for other languages. As mentioned, the ontology in question is still under development, however, in the current state of affairs the reasoning about competencies in order to complete person's profile with additional data on education, work experience is successfully performed by the REA component described within this paper. Our future work focuses on the implementation of the second scenario supported by the eXtraSpec system i.e., composition of teams of experts using the developed ontology.

Acknowledgment

The work published in this article was supported by the project titled: "Advanced data extraction methods for the needs of expert search"financed under the Innovative Economy Framework and partially supported by European Union in the European Regional Development Fund programme (contract no. UDA-POIG.01.03.01-30-150/08-01).

 ISBN: 978-1-61208-121-2

References

[1] van Rijsbergen, C. J.; "Information Retrieval and Information Reasoning". Computer Science Today 1995,pages 549-559

[2] Yimam, D.; "Expert finding systems for organizations: Domain analysis and the demoir approach" in: ECSCW 999 Workshop: Beyond KNowledge Management: Managing Expertise, pages 276–283, New York, NY, USA, 1996. ACM Press

[3] McDonald, D. W. and Ackerman, M. S.; "Expertise recommender: a flexible recommendation system and architecture" in: CSCW '00: Proceedings of the 2000 ACM conference on Computer supported cooperative work, pages 231–240. ACM Press, 2000.

[4] Yimam-Seid, D. and Kobsa, A. "Expert finding systems for organizations: Problem and domain analysis and the demoir approach". Journal of Organizational Computing and Electronic Commerce, 13(1):1–24, 2003

[5] Kautz, H., Selman, B., and Milewski, A.; "Agent amplified communication" in: Proceedings of the Thirteenth National Conference on Artificial Intelligence (AAAI-96), pages 3–9, 1996

[6] Campbell, C. S., Maglio, P. P., Cozzi, A., and Dom, B.; "Expertise identification using email communications" in: CIKM '03: Proceedings of the twelfth international conference on Information and knowledge management, pages 528–531. ACM Press, 2003

[7] Hawking, D.; "Challenges in enterprise search" in: Proceedings Fifteenth Australasian Database Conference, 2004

[8] Metze, F., Bauckhage, Ch., and Alpcan, T., "The "Spree" Expert Finding System" in: Proceedings of the First IEEE International Conference on Semantic Computing (ICSC 2007), September 17-19, 2007, Irvine, California, USA, pp. 551--558

[9] Ackerman, M.S., Wulf, V. and Pipek, V.; "Sharing Expertise: Beyond Knowledge Man-agement"; MIT press, (2002).

[10] Krulwich, B. and Burkey, C.; "ContactFinder agent: answering bulletin board questions with referrals" in: Proceedings of the National Conference on Artificial Intelligence, pages 10-15, 1996

[11] Balog, K., Azzopardi L. and De. Rijke, M.; "Formal models for expert finding in enterprise corpora" in: Proceedings of the ACM SIGIR, pages. 43-50, 2006.

[12] Fang, H. and Zhai, C.; "Probabilistic models for expert finding" in: Proceedingsof the ECIR, pages 418-430, 2007

[13] Petkova, D. and Croft, W.; "Hierarchical language models for expert finding in enterprise corpora" in: Proceedings of the 18th IEEE International Conference on Tools with Artificial Intelligence, pages 599-608, 2006

[14] Serdyukov, P. and Hiemstra, D.; "Modeling documents as mixtures of persons for expert finding" in: Proceedings of the ECIR, pages 309-320, 2008.

[15] Gómez-Pérez, A., Ramírez, J., and Villazón-Terrazas, B., "An Ontology for Modelling Human Resources Management Based on Standards" in: B. Apolloni et al. (Eds.): KES 2007/WIRN 2007, Part I, LNAI 4692, pp. 534–541, 2007

[16] Dorn, J., Naz, T., and Pichlmair, M., "Ontology Development for Human Resource Management" in: "Proceedings of 4rd International Conference on Knowledge Management", Ch. Stary, F. Barachini, and S. Hawamdeh (Hrg.); Series on Information&Knowledge Management, 6 (2007), ISBN: 978-981-277-058-5; pp. 109 - 120.

[17] Dorn, J. and Naz, T.; "Meta-search in Human Resource Development", in: Proceedings of 4th Int. Conference on Knowledge Systems, Bangkok, Thailand, 2007

[18] Dorn, J. and Pichlmair, M.; "A Competence Management System for Universities", in: European Conference on Information Systems, St. Gallen, 2007, pp.759 - 770

[19] Aleman-Meza, B., Bojars, U., Boley, H., Breslin, J.G., Mochol, M., Nixon, L.JB., Polleres, A., and Zhdanova, A.V., "Combining RDF Vocabularies for Expert Finding". In: Proceedings of the 4th European conference on The Semantic Web: Research and Applications ESWC '07, 2007, pp. 235--250

[20] Dittmann, L.;"Towards Ontology-based Skill Management, Projektbericht zum Verbundprojekt KOWIEN", Universität Duisburg-Essen, 2003.

[21] Abramowicz, W., Wieloch, K.; "Raport podsumowujący wyniki prac przeprowadzonych w ramach zadań Z1.1, Z1.2 oraz Z2.1", Technical report of the eXtraSpec project, Department of Information Systems, Poznan University of Economics, 2009

[22] Abramowicz, W., Kaczmarek, T., Stolarski, P., Węcel, K., and Wieloch, K.; "Architektura systemu wyszukiwania ekspertów eXtraSpec", in: Proceedings of "Technologie Wiedzy w Zarządzaniu Publicznym", Hucisko, 19-21 September 2010

[23] http://extraspec.kie.ue.poznan.pl/, last access date: 3.12.2010

[24] http://www.bizwiz.com, last access date:3.12.2010

[25] http://www.xing.com, last access date: 3.12.2010

[26] http://linkedin.com. last access date: 3.12.2010

[27] http://www.iso.org/iso/en/prods-services/popstds/currencycodeslist.html, last access date: 3.12.2010

[28] http://ec.europa.eu/eurostat/ramon/index.cfm?TargetUrl=DSP_PUB_WELC, last access date: 3.12.2010

[29] http://online.onetcenter.org/, last access date: 3.12.2010

[30] http://cs.yale.edu/homes/dvm/daml/time-page.html, last access date: 3.12.2010

[31] http://www.foaf-project.org/, last access date: 3.12.2010

[32] http://sioc-project.org/, last access date: 3.12.2010

[33] http://www.imc.org/pdi/, last access date: 3.12.2010

[34] http://dublincore.org/, last access date: 3.12.2010

[35] http://www.bls.gov/soc, last access date: 3.12.2010

[36] http://www.w3.org/TR/swbp-skos-core-spec, last access date: 3.12.2010

[37] http://www.europa-pages.com/jobs/europass.html, last access date: 3.12.2010

[38] http://www.nauka.gov.pl/szkolnictwo-wyzsze/system-szkolnictwa-wyzszego/uczelnie/, last access date: 3.12.2010

[39] http://www.praca.gov.pl/pages/klasyfikacja_zawodow2.php, last access date: 3.12.2010

[40] http://lucene.apache.org, last access date: 3.12.2010

 ISBN: 978-1-61208-121-2