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Ontology-based Competency Management: the Case Study of the Mihajlo Pupin Institute

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Abstract: Semantic-based technologies have been steadily increasing their relevance in recent years in both the research world and business world. Considering this, the present article discusses the process of design and implementation of a competency management system in information and communication technologies domain utilizing the latest Semantic Web tools and technologies including D2RQ server, *TopBraid Composer*, OWL 2, SPARQL, SPARQL Rules and common human resources related public vocabularies. In particular, the paper discusses the process of building individual and enterprise competence models in a form of ontology database, as well as different ways of meaningful search and retrieval of expertise data on the Semantic Web. The ontological knowledge base aims at storing the extracted and integrated competences from structured, as well as unstructured sources. By using the illustrative case study of deployment of such a system in the Human Resources sector at the Mihajlo Pupin Institute, this paper shows an example of new approaches to data integration and information management. The proposed approach extends the functionalities of existing enterprise information systems and offers possibilities for development of future Internet services. This allows organizations to express their core competences and talents in a standardized, machine processable and understandable format, and hence, facilitates their integration in the European Research Area and beyond.

Keywords: Semantic Web, human resources, competencies, expertise, ICT, case study
Categories: H.4, M.0, M.3, M.4, M.7, M.8

1 Introduction

Human Resources Management (HRM) is the strategic management of the employees, who individually and collectively contribute to the achievement of the strategic objectives of the organization. Many studies discuss the importance of intangibles as sources of competitive advantage, and in particular, the strategic impact of HRM systems on company performance ([Becker, 06], [Ngah, 09]).

Competence management (CM) is an important research subject in the more general area of human resources management and knowledge management. Two different meanings of the concept of "competence" (building blocks of competency models) within the corporate environment could be distinguished:

- *Expert competences* are specific, identifiable, definable, and measurable knowledge, skills, abilities and/or other deployment-related characteristics (e.g. attitude, behaviour, physical ability) which a human resource may possess and which is necessary for, or material to, the performance of an activity within a specific business context. Competence modelling is thus a process of determining the set of competencies that are required for excellent performance in a particular role [Ennis, 08].
- *Organizational core competencies* are aggregates of capabilities, where synergy is created that has sustainable value and broad applicability for an organization [Lahti, 99]. Defining competency models for an organization and performing skills gap analysis which provides essential data for the undertaking of a range of training and development and performance improvement activities is known as *Competency management*.

Competency analysis within an enterprise aims at identifying the knowledge and skills on individual level required to perform the organization's business activities so that they may be developed to fit the requests of work life reality. Depending on the adopted approach to competence management, different individual competence models can be developed, e.g. job, functional, core, or leadership competency models. Core competency models identify the critical skills, knowledge, and abilities that are required for success for all individuals in a particular organization. This creates a common language and an agreed upon standard of performance among employees. Job competency models describe the behaviours, knowledge, and skills required for exceptional performance for any particular job. As a result, individuals and their managers can evaluate performance against an observable standard.

This paper aims at introducing an approach to competence management based on the latest developments (tools and technologies) in the Semantic Web (SW) field, as well as presenting the results of extraction of information and communication technologies (ICT) competences from the existing structured and unstructured sources and their formal representation as OWL models. The approach has been implemented in a real knowledge-intensive establishment i.e. the "Mihajlo Pupin" Institute from Belgrade (MPI), Serbia. The paper is organized as follows. First, Section 2 gives an overview of the research subject and the European Union (EU) policy and introduces a research and engineering methodology to competency management in modern organizations. Next, Sections 3 and Section 4 explain the expertise modelling process in the "Mihajlo Pupin" Institute case study and show how the ontology database has been designed and populated by integrating competences from structured and unstructured sources. Section 5 illustrates several examples of utilizing the implemented system for semantic expertise search and retrieval. Finally, lessons learned are discuses from methodological and implementation viewpoint.

2 Research overview

This Section gives an overview of the research scope, the relevant EU policies, and the overall research and engineering methodology.

2.1 Competency Management Challenges in Modern ICT Organizations

Business processes in modern establishments extend across organizations and national boundaries and invoke challenges such as inter-enterprise cooperation, interoperability and integration, migration and heterogeneity management. Furthermore, resources including enterprise information systems are more often distributed over multiple sites, thus requiring utilization of different technologies and approaches for data/document access and retrieval.

There are certain human resource management issues that are particular for the global enterprise. The key issues involve:

- maintaining flexible organizational structure where human resources are shared by different departments, processes and projects;
- applying different staffing policies e.g. selecting and retaining talented employee, training and development whilst encouraging employees to be innovative and creative;
- improving expertise transparency through introducing standardized competency models and common legal frameworks and qualification systems.

2.2 Overview of EU Policies Relevant for Competency Management in ICT Sector

EU policy including the Bologna Process, the European Research Area initiative and the European Qualifications Framework underlines the importance of the transferability and comparability of competences, skills and qualifications within Europe.

The overarching aim of the Bologna Process http://www.ond.vlaanderen.be/hogeronderwijs/Bologna/) is to create a European Higher Education Area (EHEA, http://ec.europa.eu/research/era/) based on international cooperation and academic exchange that is attractive to European students and staff as well as to students and staff from other parts of the world. The Bologna Process is named after the *Bologna Declaration*, which was signed in the Italian city of Bologna on 19 June 1999 by ministers in charge of higher education from 29 European countries. Today, the Process unites 47 countries - all party to the *European Cultural Convention* and committed to the goals of the European Higher Education Area.

The European Qualifications Framework (EQF) is an important instrument in achieving comparability and transparency within the higher education systems. It acts as a translation device to make national qualifications more readable across Europe, promoting workers' and learners' mobility between countries and facilitating their lifelong learning. Agreed upon by the European institutions in 2008, the EQF is being put in practice across Europe. It encourages countries to relate their national qualifications systems to the EQF so that all new qualifications issued from 2012 carry a reference to an appropriate EQF level. An EQF national coordination point has been designated for this purpose in each country.

The ICT sector is one of the fastest growing industries in many developed countries and, as such, one of the important sectors contributing to the countries' economical growth. Taking this into consideration, the European Commission and the Council of Ministers supported the development of the European e-Competence

Framework (e-CF, http://www.ecompetences.eu/) as a reference framework of 32 ICT competences that can be used and understood by ICT user and supply companies, the public sector, educational and social partners across Europe. The 32 competences are classified according to main ICT business areas and link directly to the European Qualifications Framework. This provides a European basis for internationally efficient personnel planning and development.

2.3 Research and Engineering Methodology

This research aimed at:

- improving the transferability and comparability of competences, skills and qualifications in ICT organizations; and
- expressing the core competences and talents in a standardized, machine processable and understandable format.

	Phase #1	Phase #2
Research	• Study of KM technologies • Study of KM infrastructures • Classical approaches to knowledge integration	• Assessment of SW tools and technologies • Survey of CM related public vocabularies • Study of SW methodologies
Development	• HCM knowledge pool • Document repository	• Establishment of a modular ontological knowledge base • Validation of the ontology model • Validation of the expertise extraction process • Validation of the expertise retrieval process

Table 1: The overall research and engineering methodology

The proposed research and engineering methodology can be chronologically divided into two phases (see Table 1). The first phase is devoted to the study of knowledge management technologies and classical approaches to knowledge integration, as well as to establishment of central human resources knowledge pools in a form of a database and a document repository. The goal of the second phase is to utilize advanced IT tools and technologies for more objectively extraction of skills and competencies and establishment of web repository where qualifications, skills and competences are expressed in a standardized, machine processable and understandable format. Using an illustrative case study of a concrete ICT research-intensive establishment, the Mihajlo Pupin Institute, this paper presents the activities involved in the development stage of the second phase (Phase #2). More information about the overall research can be found in [Janev, 08], [Janev, 09] and [Janev, 10].

2.4 Ontology Engineering

Ontology engineering is a field in information science, which studies the methods and methodologies for building ontologies (formal representations of a set of concepts within a domain and the relationships between those concepts). Ontology engineering provides standards and structures that allow information to be described in a way that captures *what it is*, *what it means* and *what it's related to* - all in a machine-readable form. This enables machines as well as people to understand, share and reason with them at the execution time and offers new possibilities for enterprise systems to be networked in meaningful ways. Ontologies form the backbone of the Semantic Web.

European Union, through its chief instruments for funding research (FP5 - The Fifth, FP6 – The Sixth and FP7 – The Seventh Framework Programs), has financed several projects that focused on ontology-based competence management. As a result of these projects, several prototype systems have been developed [Bizer, 05], [Draganidis, 06] and few ontologies were made publicly available. Schmidt and Kunzmann [Schmidt, 06] developed the Professional Learning Ontology that formalizes competencies as a bridge between human resource development, competence and knowledge management as well as technology-enhanced learning. In [Bizer, 05], Bizer, et all., developed a Human Resources ontology, an e-recruitment prototype and argued that using Semantic Web technologies in the domain of online recruitment could substantially increase market transparency, lower the transaction costs for employers, and change the business models of the intermediaries involved. Furthermore, the research work in the competence management domain in the last decade had a positive impact on several European Public Employment Services [Müller-Riedlhuber, 09]. Some of them have already introduced (e.g. Germany, Norway) or are at the moment working on improvements of their matching (vacancies and job seekers) processes by shifting more emphasis to competences.

3 Expertise Modelling in the Mihajlo Pupin Institute Case Study

The Mihajlo Pupin Institute is a leading Serbian R&D institution in information and communication technologies, as well as the biggest and the oldest ICT R&D Institute in the whole Southeastern Europe. MPI performs applied research with the outcomes directly applicable in industry. In order to achieve better utilization of scientific competence / experience and efficient knowledge transfer from academia to industry, human resources are shared by different departments, processes and projects. Managing human resources in such an R&D environment thus demands planning and tracking professional career of employees and efficient management of knowledge about employees.

Motivated by the need to express the information and communication technologies' competences of the MPI researchers and the MPI organizational units in a machine processable format by using standards and classifications that will allow interoperability of data in the EU research and business space, we adopted an ontology-based approach to expertise profiling and retrieval [Janev, 10].

3.1 Who is an Expert?

There are large differences in the quality of performance of different people on different tasks or in different domains. We can think of this difference as a scale of expertise. Therefore, an expert is someone who is very talented in a specific domain, has a lot of experience, has a very extensive repertoire of knowledge but also knows his or her limits, has good or even excellent skills in his or her domain, delivers quality work and quickly and purposefully finds a solution to a problem or designs and delivers a product that meets the requirements [Boshuizen, 03].

Becoming an expert in any domain requires experience and effort. Expertise development is a process where novices intended to become experts have to learn some knowledge and skill from scratch, need to be developed some skills more highly, learn to apply skills in the right places, and integrate them to the new task. We will refer to the expert's ability to perform within a domain/context at different levels of proficiency as "competence".

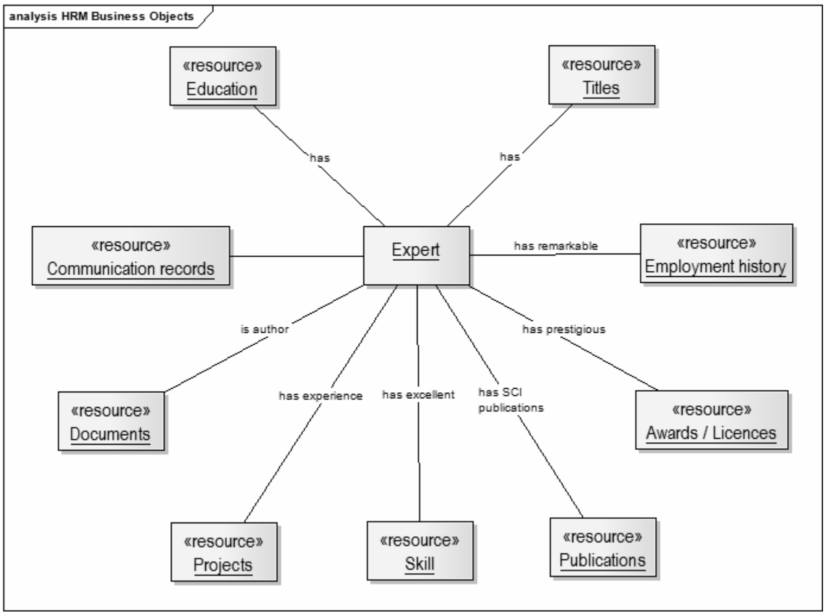

Figure 1: UML analysis model of a business object "Expert"

3.2 Development of Job Competency Models at the Mihajlo Pupin Institute

Using the "Mihajlo Pupin" case study, we can illustrate the career development paths of the higher educated employees as is presented in Figure 2. Nodes represent different employment positions, while the arcs show the possible development paths. Building a competency model means identification of the competencies employees need to develop in order to improve performance in their current job or to prepare for other jobs via promotion or transfer. The model can also be useful in a skill gap analysis, the comparison between available and needed competencies of individuals or organizations. Important variables to be considered during the development of a competency model are the use of skill dictionaries, or the creation of customized ones.

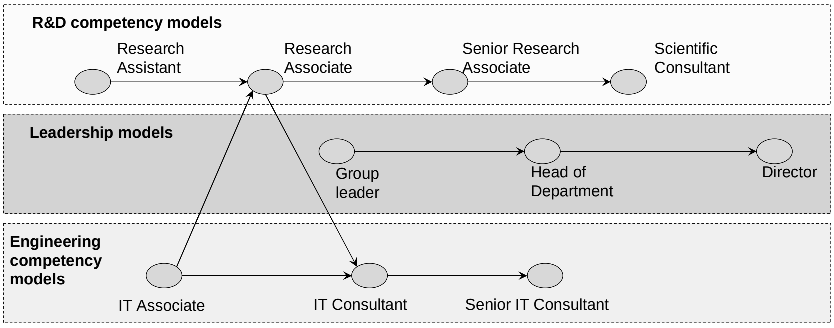

Figure 2: Career development paths

We can distinguish three different job profile types: R&D job profiles, managerial job profiles and engineering job profiles. For example, a competency model for a "Senior Research Associate" might include competencies such as analytical approach to work, excellent problem-solving skills, technical competence and experience, good organizational skills, independence and objectivity, ability to communicate, attention to detail, project-management skills, ability to distinguish between the strategically important and the trivial, negotiation. Non-exhaustive lists of competences for few job positions are presented in Table 2.

3.3 Competency Management in ICT Domain

Information and Communication Technology field includes the following sub-disciplines: computer science, information systems, computer engineering, software engineering and information technology. The Association for Computer Machinery, the world's largest educational and scientific computing society (see http://www.acm.org/) and the IEEE Computer Society, an organizational unit of the Institute of Electrical and Electronics Engineers (see http://www.computer.org/) have taken a leading role in providing support for higher education in ICT in various ways, including the formulation of curriculum guidelines and defining competences i.e. capabilities and knowledge expected for ICT graduate. According to the ACM high-level categorization of Information Systems graduate exit characteristics, for example, the future ICT professionals, scientists, and engineers, should have technology knowledge in the following domains: *Application Development*, *Internet Systems Architecture and Development*, *Database Design and Administration*, *Systems Infrastructure and Integration,* and *IS development* (*Systems Analysis and Design, Business Process Design, Systems Implementation, IS Project Management*). *Internet Systems Architecture and Development*, for example, includes Web page development, Web architecture design and development, design and development of multi-tiered architectures and experience with Web programming languages such as Java, PHP, Pyton, HTML, RDF, etc.

Job profile	Degree	Competences
Research Assistant	B.Sc / B.EE	technical skills, motivation, conducts research under the supervision of a principal investigator, ability to communicate
IT Consultant	B.Sc / B.EE	analytical approach to work, excellent problem-solving skills, interpersonal skills, communication skills, ability to absorb, complex technical information and pass this on clearly, stamina to meet deadlines, ability to work under pressure, project-management skills, detailed technical knowledge, motivation.
Scientific Consultant	PhD	academic excellence in a specific scientific field, technical competence and experience, good deductive skills, good organisational skills, independence and objectivity, excellent communication skills, attention to detail, accountability, project-management skills tact and diplomacy, negotiation and decision-making
General Director	PhD	business and finance skills (knowledge of general business conditions and functions, knowledge of domestic/international trade relations), ability to create and provide strategic/tactical/operational plans, management of human resources from an organizational perspective, excellent communication skills, negotiation and decision-making

Table 2: A subset of identified "competences" for different job profiles in ICT domain

Except technical knowledge ICT professionals, scientists, and engineers should be capable of analytical and critical thinking and have soft skills (*Interpersonal, Communication,* and *Team Skills*). Soft skills, sometimes known as "people skills", are personal attributes that enhance an individual's interactions, job performance and career prospects. Companies value soft skills because research suggests and experience shows that they can be just as important an indicator of job performance as hard skills.

ICT graduates should be also familiar with business fundamentals (*Business Models, Functional Business Areas, Evaluation of Business Performance*). Based on this, ICT professionals develop management skills and leading abilities. Management skills include skills for problem solving, goals setting, organizing, and realization of decisions and enforcement of measures, performing control and evaluating results, costs planning, delegating and constant improvement. Leading abilities are skills for clear mediating of information, interpersonal conversation, notifying, activating energy, creating possibilities, motivational leading, conflicts solving, stimulating co-workers, mutual cooperation, positive treatment with others, and other. In general, we can depict the skills of ICT expert/professional as is presented in Figure 3.

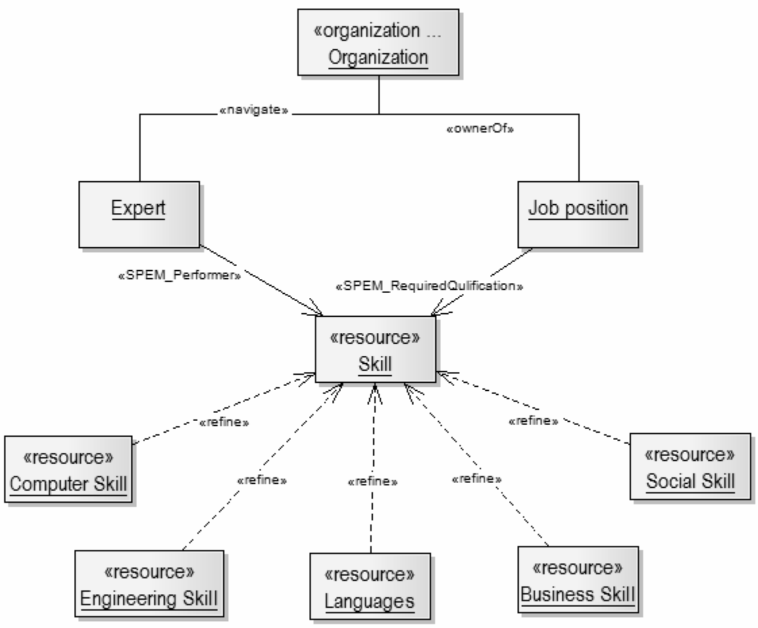

Figure 3: UML representation of competence-related business objects

4 Building Expert Profiles Models in OWL format

This Section describes the process of building an ontological knowledge base for the purpose of establishing a repository of job competency models and storing the expert profiles in a machine processable format.

4.1 Semantic Web Tools and Technologies

SW technologies form the basic building blocks of the SW—that is, the "extension of the current Web in which information is given the well-defined meaning, better enabling computers and people to work in cooperation" [Berners-Lee, 01]. Alternatively, we can say that SW technologies enable explicit, unambiguous, and shared definitions of domain terms and relations (for humans and machines to interpret) as well as a global system for identification and reuse.

The emerging Semantic Web technologies foster new trends in the design and implementation of the enterprise knowledge management systems [Gliozzo, 07]. As a result, contemporary knowledge management systems are based on open standards (JEE, XML, XSLT), as well as on semantic technologies RDF/RDFS, WSDL, OWL, etc.

4.2 The Modular Structure of the MPI Ontological Base

Modularity is an important Software Engineering principle. It is a practical application of the principle of "Separation of Concerns" by dividing a complex system into simpler and more manageable modules e.g. see Figure 4. Modularization can take place in two ways: composition or decomposition. The "Composition" is a bottom-up approach that takes modules and puts them together to form a larger system, while the "Decomposition" is an alternative approach that take a complete system and decompose it into its modules in top-down manner.

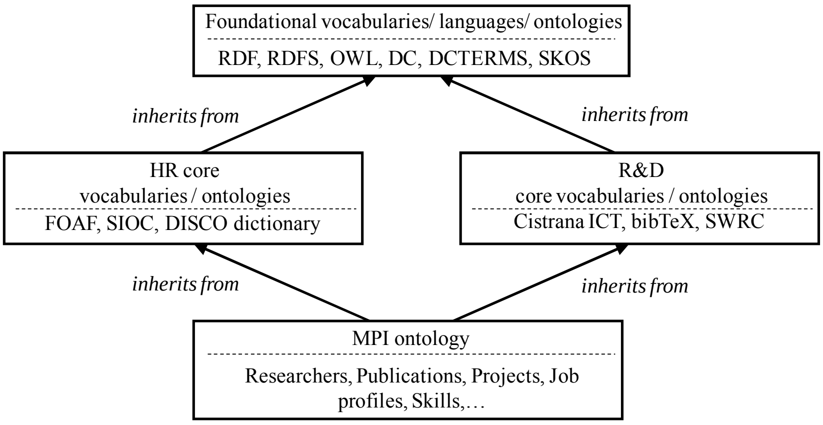

Figure 4: The modular structure of the MPI ontological base

In order to ensure semantic integration and interoperability, one of the basic principles in ontology engineering is to use terms from existing public ontologies and taxonomies (see http://www.w3.org/2001/sw/BestPractices/OEP/SemInt/). Instead of proposing a new ontology for tackling the challenges of the semantic expert finding we rather suggest a framework of the existing vocabularies which shall be fruitfully combined. Table 3 lists the ontologies that are relevant for building an expertise finding system. In this way, the MPI core concepts are related to public vocabularies. Concepts and properties specific to the case study e.g. quantification of the research results in accordance to the standards of the Serbian Ministry of Science and Technological Development [SMSTD, 08], can be modeled with additional vocabularies.

4.3 Reusing Existing Ontologies and Taxonomies for Ontology Design

The main "components" of the MPI ontology, for example, are defined as subclasses of the public concepts (*foaf:Person*, *foaf:Organisation*, *foaf:Document*, *foaf:PersonalProfileDocument*, *doac:Education*, *doac:Skill*, *doac:Experience, bibtex:Entry*), while links/relations between the components are defined as sub-properties of *foaf:interest*, *foaf:made/maker*, *foaf:topic*, *foaf:topic_interest*, *foaf:primaryTopic*, *foaf:homepage*, etc. Additional classes and properties specific to the MPI were defined manually with elements from the RDF Schema (www.w3.org/TR/rdf-schema/) or defined automatically in bottom-up manner via the import facilities of the *TopBraid Composer* engineering environment. As a result, the ontological database is a set of interlinking public ontologies and in-house ontologies in RDF/OWL format. As MPI ontology serves to describe the scientific competences of the MPI employees in different ICT domains, we adopted the CISTRANA Information Society Technologies taxonomy of European Research Areas (IST ERA, http://www.kooperation-international.de/eu/themes/info/detail/data/2962/ ?PHPSESSID=c332).

Prefix:	Namespace URI (http://):	Ontology describes:
foaf	xmlns.com/foaf/0.1/	People and relationships
owl	www.w3.org/2002/07/owl#	The Web Ontology Language
rdfs	www.w3.org/2000/01/rdf-schema#	RDF vocabulary description language
dc	purl.org/dc/elements/1.1/	Dublin Core standard
doac	http://ramonantonio.net/doac/0.1/#	The career of a professional
sioc	rdfs.org/sioc/ns#	Information in online communities
sioct	rdfs.org/sioc/types#	SIOC ontology types
skos	www.w3.org/2004/02/skos/core#	Taxonomies and other vocabularies
bibtex	purl.org/net/nknouf/ns/bibtex# zeitkunst.org/bibtex/0.1/	Bibliographic data

Table 3: Commonly used ontologies

4.4 The Ontology Engineering Environment

The ontological knowledge base was designed and built using the *TopBraid Composer,* an enterprise-class modelling environment for building semantic applications (see the *TopQuadrant*'s Web site at http://www.topquadrant.com/). The tool provides powerful *Input facilities* (see Figure 5) that enables us to integrate diverse knowledge sources (e.g. the HRM system, the enterprise document management system, RDF models of the identified ICT competences from unstructured sources, etc). It supports many inference engines that can run alone or in a sequence. The latest version of *TopBraid Composer* has introduced the SPARQL SPIN rule language (http://spinrdf.org/) that we have used to define constraints and inference rules on Semantic Web models. Using the *TopBraid Suite Export facilities* we have merged, converted and exported the expertise data to RDF graphs and thus prepared the data for exploitation with other client applications e.g. with *OntoWiki* (see http://ontowiki.net/).

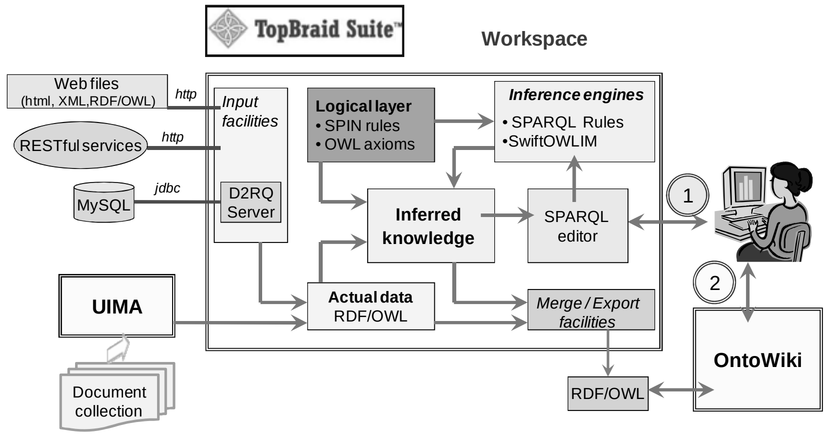

Figure 5: The TopBraid Composer workspace

4.5 The Process of Extracting ICT Competences from Structured and Unstructured Sources

After the ontological knowledge base is designed, the next step is to populate the ontology i.e. import data into the ontology and create instances (see Figure 6). Manually creating of ontologies is a time consuming task. Semantic Web community has delivered many high-quality open-source tools (e.g. the D2RQ server, http://www4.wiwiss.fu-berlin.de/bizer/d2r-server/) that can be used for automatic or semiautomatic ontology population i.e. to convert the facts trapped in the legacy systems or business documents into information understandable both for machines and people. Table 4 summarizes some types of competences that were extracted from structured sources (i.e. from the MPI HRM system) and unstructured sources (i.e. from documents using the MPI Competence Analysis component).

4.6 Ontology Population from Structured Sources (MPI HRM system)

There are two different ways of using data from structured source in semantic web applications. In human resources domain, for example, the personal data that is often static can be extracted from the legacy system and copied into RDF/OWL format using tools such as the *Protégé DataMaster* extension. The RDF/OWL model can be queried with tools such as the *OntoWiki* (see example bellow). Another way is to use declarative languages and tools such as the D2RQ server for creating mapping files between a relational database schemata and an OWL/RDFS ontology. On top of this, SPARQL CONSTRUCT syntax can be used for transforming the legacy data into OWL concepts and properties. Then, a Java application can query and retrieve relational data as it is a RDF source using the SPARQL protocol or the Jena/Sesame API.

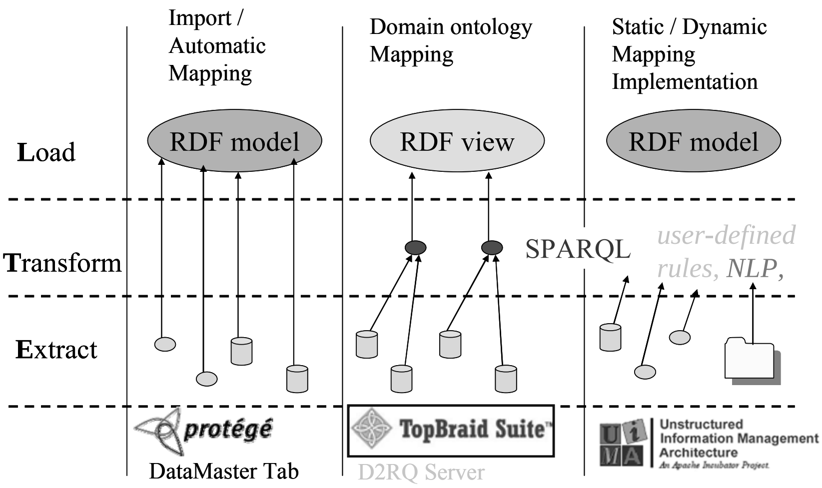

Figure 6: Populating the ontological knowledge base - Mapping sources to RDF/OWL models

4.7 Extracting Expertise Data From Unstructured Sources with MPI CompetenceAnalysis Component

In March 2009, OASIS, the international open standards consortium (see Organization for the Advancement of Structured Information Standards, http://www.oasis-open.org/) approved UIMA (Unstructured Information Management Architecture, http://incubator.apache.org/uima/) as standard technology for creating text-analysis components. UIMA defines interfaces for a small set of core components that users of the framework provide implementations for. Annotators and Analysis Engines are two of the basic building blocks specified by the architecture.

The *MPI CompetenceAnalysis* component was built upon the UIMA *ConceptMapper* Annotator. The *ConceptMapper* Annotator is a high performance dictionary lookup tool that maps entries in a dictionary onto input documents, producing UIMA annotations. The dictionary of *MPI CompetenceAnalysis* component was built using the ICT taxonomy of European Research Areas. The taxonomy structures the ICT technology areas into four main categories: C1 - Electronics, Microsystems, Nanotechnology; C2 - Information Systems, Software and Hardware; C3 - Media and Content, and C4 - Communication Technology, Networks, and Distributed Systems. In addition, the dictionary contains vocabulary of computer skills that is used for extracting expert experience with *Programming languages, Operating systems, Hardware, WEB technology, SW Solutions, Modeling environments, Development Tools,* etc.

Furthermore, the *MPI Collection Reader* was built because the source documents are coming from different parts of an expert's computer and tokens are mapped accordingly to different concepts. The *MPI CAS Consumer* was built because we wanted to customize the processing made by *ConceptMapper* annotator and prepare the output results in an OWL format suitable for integration in existing expertise knowledge base.

Sources	Type of competence	Content
Structured - SAP HRM system stores self declared competences of the experts	ICT main research field	A category from a catalog defined by Serbian Ministry of Science
	ICT subfields	unlimited list of ICT areas
	Key qualifications	Free text in Serbian language
	Key experiences - responsibilities	Free text in Serbian language
	Foreign languages	Items from a catalog of foreign languages
Unstructured - documents in .doc, .pdf, .txt, etc.	Computer skills	7 different competence types are extracted and transformed into structured format
	Project Experience	Major ICT fields of project expertise is identified and transformed into structured format
	Publications	An extensive list of topics of interest is extracted and transformed into structured format

Table 4: Integrating competences from structured and unstructured sources

Currently the *MPI CompetenceAnalysis* component assumes that the input documents belong to a single person and exports an OWL file whose content looks like:

```
<ict:Person rdf:ID="ID_1526">
<Global_ID
rdf:datatype="http://www.w3.org/2001/XMLSchema#integer">1526</Global_ID>
<ict:topic_interest_project
rdf:resource="http://www.institutepupin.com/ict.owl#Semantic_Technologie
s"/>
<ict:topic_interest_reference
rdf:resource="http://www.institutepupin.com/ict.owl#Imaging_Image_Proces
sing_Pattern_Recognition"/>
  …
<ict:useOperatingSystem
rdf:resource="http://www.institutepupin.com/skills.owl#Windows"/>
<ict:useDBMS
rdf:resource="http://www.institutepupin.com/skills.owl#MS_SQL_Server"/>
<ict:useSoftwareSolution
rdf:resource="http://www.institutepupin.com/skills.owl#SAP_ERP"/>
</ict:Person>
```

4.8 Using SPIN Rules for Inferring New Knowledge

The latest version of *TopBraid Composer* has introduced the SPIN rule language (http://spinrdf.org/). SPIN is a collection of RDF vocabularies enabling the use of SPARQL to define constraints and inference rules on Semantic Web models. SPIN also provides meta-modeling capabilities that allow users to define their own SPARQL functions and query templates. These templates are then used to dynamically compute property values even if there are no corresponding triples in the actual model. Indeed, OWL 2 RL rules can be converted into SPIN templates.

Using SPIN, for example, we first defined a class *InferReferenceCategory* as a subclass of the *spin:Templates* class. The aim of this template was to infer the main ICT areas that a person has worked in from evidence of type *Project*. The InferReferenceCategory class has two arguments (predicate and *mpi:hasDomain*) of type *spin:constraint*. Using the defined template, as is presented in Figure 7, we specified a rule of type *spin:rule* for the *mpi:Person* class and gave the rule a name (e.g. *hasExperienceReferenceICT*) that reflected the aim of the template. This rule aggregated the experience of a person in writing papers in specific technical areas (e.g. “Semantic Technologies”, “Knowledge technologies”) and dynamically computed the values of the property i.e. inferred the ICT ERA top categories (e.g. C2).

Figure 7: Extension of the conceptual class and property schema with rules

5 Expert Search with SPARQL and *OntoWiki*

Generally, an ontology knowledge base consists of actual data (facts) in RDF/OWL format and a logical layer that together with an inference engine enables creating new knowledge. Depending on the type of logical constructs (e.g. OWL axioms, SPIN rules, Jena rules, etc.), in *TopBraid Composer*, we configure the inference mechanism as a sequence of inference engines, e.g., using TopSPIN (SPARQL rules) on top of SwiftOWLIM. From many possibilities that exist for querying an ontology knowledge base, we will discuss:

- the on-line use of *TopBraid Composer* SPARQL editor (option 1). For resolving a SPARQL query specified by a user, the system uses a SPARQL engine with built-in TopSPIN inference engine. The TopSPIN inference engine automatically calculates user defined SPIN rules stored in a separate file (see “Logical layer” box in Figure 5).
- the use of *OntoWiki* on top of an RDF/OWL file (option 2). After running the preconfigured inference service, *TopBraid Composer* generates a separate file with the inferred knowledge. If we want to query the knowledge data base with a client application that does not support SPIN rules, we have a possibility to merge the actual data and the inferred knowledge and export the triples as a compound RDF/OWLfile via the Export/Merge/Convert facilities.

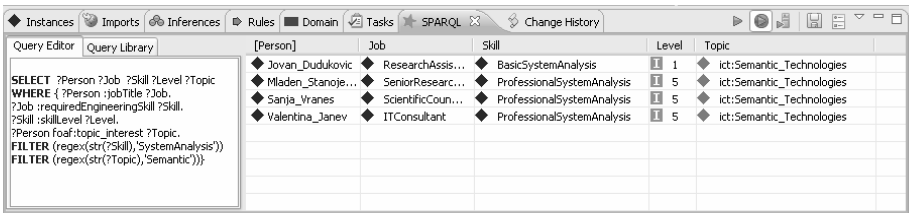

Figure 8: SPARQL sample query against the ontological knowledge base

5.1 Searching Job Competence Models with SPARQL

Operating both in the research sector and in the business sector, the Mihajlo Pupin Institute has separately defined career paths for carrying on scientific career in engineering and engineering career in business sector. Using the job competence models, we can filter the experts that have the required engineering skills (e.g. “SystemAnalysis”) in a specific technical area (e.g. “Semantic” technologies). The SPARQL query is presented on the left and the found experts are listed in the right side of Figure 8. Proficiency levels are expressed with numbers that mean: 1-Basic, 2-Foundational, 3-Intermediate, 4-Advanced, and 5-Expert/Professional.

5.2 Querying Job Competence Models with *OntoWiki*

A far more comfortable way for querying the ontological base is, however, to use free of charge open-source tools, such as the *OntoWiki*, in order to improve the expertise search, analysis and retrieval. The main goal of the *OntoWiki* [Auer, 08] is to rapidly simplify the presentation and acquisition of instance data from and for end users. It provides a generic user interface for arbitrary RDF knowledge bases and uses SPARQL to access the underlying databases. Using the *OntoWiki* tool (see Figure 9), the RDF/OWL expertise data can be full-text searched (see the “Search” panel in the upper left corner), browsed using semantic relations (see the “Classes” panel in the lower left corner) and searched using faceted navigation method (see the “Filter” panel in the right most side).

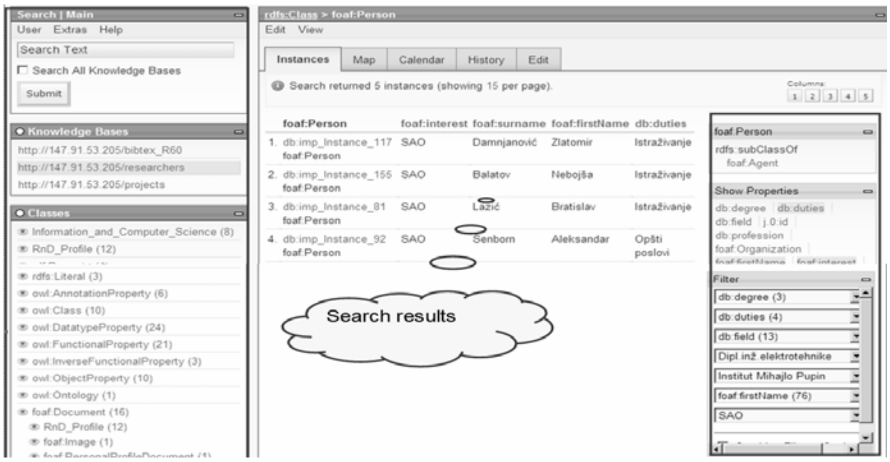

Figure 9: Expertise search with OntoWiki

6 Lessons Learned

The implementation of an integrated knowledge management platform is a large, multifaceted project that is often carried on by turns in a bottom-up and top-down manner. Successful design, implementation and introduction of such a system in practice require several prerequisites such as the involvement and contribution of the senior executive leaders in the project, the adoption of a proven methodology, setting up realistic goals for the planned time scope, ensuring availability of data sources, the involvement of the end users from the beginning of the project, etc.

In this Section, we discuss several lessons learned related to the proposed approach to introducing and using competency management in enterprises.

6.1 Methodology

In classical HRM approaches personal profiles usually rely on the self-declared expertise. Employees keep track of their areas of expertise manually by maintaining a list of keywords or phrases and this list of key qualifications is being stored in the HRM system. This approach is error-prone since users are typically subjective/biased and reluctant to update the file regularly. Also, manually created lists cannot be an exhaustive description of the person's expertise areas. Therefore, we conclude that just self-declared expertise is not suitable for building competence profiles, and that new approach, such as the one presented in this paper should be introduced. The presented MPI *CompetenceAnalysis* component was developed at the "Mihajlo Pupin" Institute with the aim to objectively identify and extract the key expertise of employees and automate the ontology population process.

6.2 Competency Management System

The benefits of upgrading the existing HRM systems with an ontology-based competency management module are as follows:

- increase visibility of know-how and possibility for marketing this outside the organization via existing or emerging Semantic Web;
- identify previously hidden/unknown competencies gives possibilities for new assignments;
- support location of experts, facilitate exchange of employees data via Web;
- support integration of individual expert profiles and staffing of project teams with specific competence demands;
- provide detailed overview of organizational competencies, through competence profiles and statistics for employees, positions and organizational units.

6.3 SW technologies

New technologies are usually subjected to experimentation, refinement, and increasingly realistic and exhaustive testing. Innovative enterprises interested in developing new business models are already introducing Semantic Web technologies to facilitate data integration and interoperability, as well as improve search and content discovery [Janev, 09]. This case study, for example, proves the maturity of these technologies for applications in the human resources domain.

7 Concluding Remarks

Virtually integrated organizations seek to link their individual core competencies through cost-sharing and risk-sharing agreements, so that these organizations can act as a larger, single entity. Competency management and finding expertise (either a person or/and accompanied knowledge items) in such a dynamic and often complex organizational structure, that is supported by an extended information system, is a challenging issue.

This paper discussed the process of building expert profiles in a form of ontology database by integrating competences from structured and unstructured sources. What has been achieved so far is automatic identification and extraction of skills from available structured and unstructured sources and semi-automatic population of the ontology database. Structured sources (SAP HCM knowledge pool) store expertise items that are based on evidences (e.g. certificates) or declared by the experts themselves and entered in the knowledge pool by an officially assigned person. Once the expertises have been extracted from unstructured documents using the MPI *CompetenceAnalysis* component, the results have to be checked by the officially assigned person prior to integration into the ontology database. Automatic analysis has advantages compared to manual analysis because of the objectiveness of results. Our analysis has shown that manually created lists of expertise were not an exhaustive description of the person’s expertise areas. Introducing standard classification of ICT expertise facilitates data integration and interoperability of expertise data within the European Research Area and beyond.

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