A Knowledge-Engine Architecture for a Competence Management Information System

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Abstract

This paper describes the ongoing project to develop a knowledge-engine architecture that is being specified and developed by a Portuguese software development company called Shortcut. The primary goal of this work is create an architecture suitable for use, initially, in a Competence Management System (CMS) but also scalable for later use in more generic forms of Knowledge Management Systems (KMS). In general, Knowledge Management (KM) initiatives promote the management, i.e. the creation, storage and sharing, of knowledge assets within an organization. The practical focus of our work is to support the management of employees' competencies through using a KM approach to create a web based CMS based on a structured content management infrastructure. The system is designed using an ontology-driven framework that incorporates expert annotations which integrate aspects of less tangible knowledge, such as contextual information with more structured knowledge such as that stored in databases, procedures, manuals, books and reports. The theoretical focus of the work is on the representation of competence-based knowledge resources, such as human capital, skills, heuristics acquired during project development, best practices and lessons-learned. This work should contribute for improving the understanding and analysis of the collective knowledge, skills and competencies that are created through problem solving in day-to-day activities and could act as a meeting point for issues around problem solving in complex organizations and context-based information retrieval.

Keywords: Competence Management, Knowledge Engineering, Knowledge Management, Knowledge-Engine, Ontology Design, Organizational Knowledge

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1.0 Introduction

The resource-based view of the firm that began to emerge in the 1980s (Wernerfelt 1984) views the firm as a bundle of resources and capabilities. In this context resources can be anything that be thought of as a strength or weakness of a firm which can include any tangible or intangible assets that are tied to the firm such as in-house knowledge of technology, the skills of personnel, trade contacts, etc (Wernerfelt, 1984). In general, this view of the firm argues that those resources that are valuable, rare, difficult to imitate and non-substitutable can lead to a long-term competitive advantage.

During the 1990s the importance of unique and inimitable assets such as tacit knowledge and competencies (Prahalad and Hamel, 1990) came to be seen as the core competencies for firms that wished to compete in the new 'knowledge based economy' (Hessani and Moore, 2007). As Lindgren et al (2004) argue, with its focus on organizational knowledge as the key strategic resource, the resource-based view in general and the core competencies perspective in particular, is especially relevant to the knowledge-intensive organizations that form the heart of this sector.

With the upsurge of interest in Knowledge Management (KM) and the recognition of the value of tacit knowledge that took place at the same time, there was renewed interest in trying to develop Knowledge Management Systems (KMS) in general and Competence Management Systems (CMS) in particular (Abdullah et al, 2006). However, despite various attempts, the creation of reliable descriptions of competencies that can be used as a consensual model for such systems remains an organizational and a design challenge Lindgren et al (2004).

The approach taken in this work is focused on supporting the management of employees' competencies in an efficient and structured way. It uses a KM approach to define a CMS using a structured web based content management infrastructure. The CMS is seen as a step towards a larger KMS. This knowledge layer of this system, termed a knowledge-engine, is designed using an ontology-driven framework that incorporates annotations by domain to provide additional semantic elements missing in many other forms of KMS.

The use of annotations to capture aspects of tacit knowledge for use in KMS is not particularly new (e.g. see Stein & Zwass, 1995) however, the distinctive contribution of this work does is to relate the annotation directly to the competence taxonomy. Treated in this way, annotations can be viewed an instance of expert knowledge that has been externalised and recorded in a specific context (Vasconcelos & Kimble, 2007). Thus, expert annotations can be used to enable the capture of individual and group knowledge that is embedded in ordinary day-to-day workgroup activities and to preserve that knowledge for future reuse.

2.0 Knowledge Intensive Organizations, Knowledge Management, Competencies and Competence Management

As we indicated in the introduction, Knowledge Intensive Organizations (KIOs) rely on making the most effective use of the knowledge that is available to them in order to compete and survive. By definition, knowledge based tasks such as recognising patterns in organizational behaviour and dealing with abstraction, ambiguity and uncertainty, form a large part of their corporate activity. In practice, much of this work is done through exploiting a constantly changing and evolving network of relationships between people, sources of information and organizational needs. Organizational groups in such organizations need to create mechanisms to elicit innovation, find sources of information, manage skills efficiently and gather ideas and suggestions in order to do their work. In other words, to work effectively in a KIO, groups need to be able to work collaboratively.

KM focuses on techniques to manage a common base of organizational knowledge that allows heterogeneous organizational groups, functions and communities to coordinate their efforts and share knowledge across time, function, discipline and task specific boundaries (D'Adderio, 2003). Developing versatile employees and leveraging their competencies in order to cope with different corporate needs is a matter of pivotal importance (Michellone & Zollo 2000) as employees' competencies in the form of technical and cognitive capabilities directly affect the company's knowledge creation abilities.

Competence management is concerned with the better usage of human skills and knowledge, however, the term competence is used in different ways in the management, organizational and information research literature. In this work, our aim is to model the individual, group and organizational competencies in such a way that they could form part of a corporate knowledge base. As we explain in detail in section 4.1.2, we do this by defining for individuals, a taxonomy of primitive (domain independent) competencies and a taxonomy of competencies related to domains specific areas of expertise, and for the organization, a taxonomy of competencies related to tasks performed.

In KIOs, most of the daily tasks require the exercise of professional judgement and the management of a large body of technical knowledge. In such settings, competence management requires qualitative and quantitative methods for identifying and recording organizational competencies (Zulch & Becker 2007). It also requires processes such as competence identification, competence assessment, competence acquisition and competence usage (Berio & Harzallah 2007). The software architecture we propose aims to assist this by focusing on the identification and representation, measurement and assessment of organizational competencies.

The next section of the paper will briefly outline the elements of an ontological design approach in general and of ontology driven methodologies in particular. It will then provide a brief description of the project and the work so far broken down in terms of the stages of the ontology lifecycle.

3.0 An Ontology Engineering Approach to Competence Management

3.1 Ontological design approach

The term "ontology" has its origins in metaphysics and philosophical sciences. In its most general meaning, an ontology is used to explain the nature of the reality. There are at least a dozen of definitions of ontologies in the computer science literature, but the most widely cited is that provided by Gruber (1993). For Gruber an ontology is a high-level formal specification of knowledge domain: it is a *formal and explicit specification of a shared conceptualisation*.

Firstly, a *conceptualisation* is an abstract view of particular real-world entities, events and the relationships between them. *Formal* refers to the fact that an ontology is a form of knowledge representation and has a formal software specification to represent such conceptualisations, for example, an ontology has to be machine-readable. *Explicit* means that all types of primitives, concepts and constraints used in the ontology specification must be explicitly defined. Finally, *shared* means that the knowledge embedded in ontologies is a form of consensual knowledge, that is, it is not related to an individual, but accepted by a group.

3.2 Ontology driven methodology

It is widely accepted that ontology design and construction can improve knowledge and competence management practices within the organizations (Sicilia & Lytras, 2005). However, ontology design and development can be approached from several different perspectives (Holsaple & Joshi 2002): inspirational, inductive, deductive, synthetic and collaborative. In recent years, there has been a move towards the integration of these different styles (Edgington et al. 2004). This particular project builds on previous work by the authors (Vasconcelos & Kimble 2007) and uses an ontology-driven methodology to define and build a knowledge-engine. The underlying ontology-driven software design method also attempts to integrate of these different styles by focusing on a collaborative approach, and building on existing ontology research, such as the Enterprise Ontology (Uschold et al. 1997), and ontology design (Swartout & Tate 1999).

4.0 The project

The project is based in a Portuguese software development company called *Shortcut*. *Shortcut* was formed in January 2001 and has a strong commitment to research and development activities. The principal focus of the company is customised software for telecommunications systems, interactive voice response services and messaging services. However, recently it has begun to develop interests in the provision of services for e-government and in KMS.

This project is partially founded by a Portuguese research funding programme (NITEC from the Innovation Agency ADI), which aims to develop and promote research and development centres within the companies. Consequently, part of this project has involved the creation of a research and development centre within *Shortcut* to facilitate knowledge and technology transfer between the company and universities and other research institutions.

4.1.1 Creation, discovery, elicitation and acquisition

An important step towards a KM project is the characterisation of a knowledge asset. Domain knowledge includes business processes, decision-making procedures, corporate competencies, declarative and procedural knowledge, heuristics and informal knowledge such as assumptions, insights and justifications. To do this, a requirements gathering and analysis process was carried out in *Shortcut*.

The requirement gathering and analysis was done through interviewing project managers and executives, investigating business tasks, and analysing and annotating business use cases. A problem statement and the project scope were also defined at this stage, which necessitated the identification of the principal stakeholders, future users, strategic goals, resources, an effective schedule for the work.

Before undertaking the modelling step, the organization, business partners and stakeholders gathered, categorised and classified the different types of knowledge they used. A literature review research on KM, Competence Management, Knowledge Engineering and Ontology design were also used to supplement this process. When applying the ontologies, the target knowledge assets were initially structured using a taxonomy of concepts and their related terminologies.

4.1.2 Modelling, formalisation and representation

An ontology is a basic structure around which a knowledge base can be built (Swartout & Tate 1999). However, ontology itself is not a formal programmatic representation. Our approach includes a hierarchy (taxonomy) of concepts based on graph theory and semantic networks in order to represent more complex relationships and domain constraints. At this stage, the control vocabulary should be extracted and defined in order to create the first conceptual model. Other domain ontologies can then be reused and incorporated as appropriate.

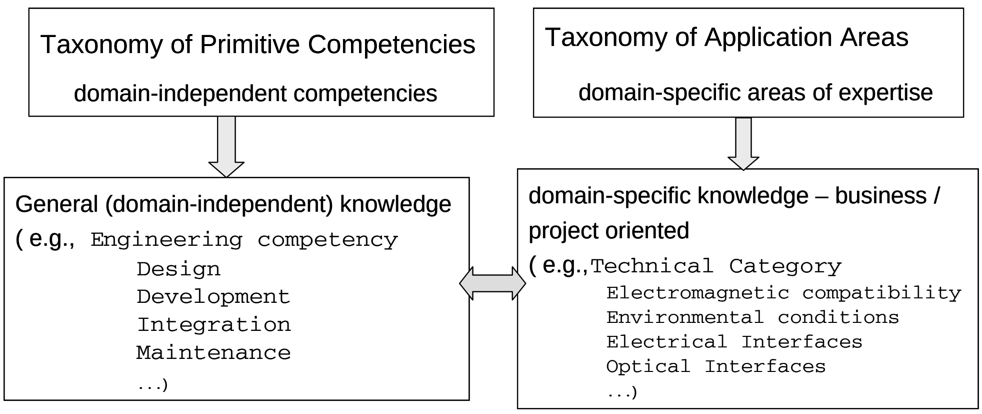

Figure 1 Dimensions (an example of) of an organizational competency

The generic model to represent competencies includes the following aspects:

- A taxonomy for primitive (general, technical, and behavioural) competencies
- A taxonomy for application areas

- Entity (individual, group or organization) profile representation
- Project management model and related competencies

Examples of primitive (or generic) competencies might be cognitive (understanding, reasoning, and creativity) and technical (modelling and analysis) competencies. Examples of application areas are domains (or organizations) that are reasonably well defined, such as a software development company, a university, an insurance company or a pharmaceutical company.

Organizational competencies (see Figure 2) refer to capabilities, skills, proficiencies, expertise and experience achieved during daily work. There are two types of competencies: technical and non-technical. The initial focus for this work was a software development company and the related technical and non-technical competencies. These competencies are often referred as professional skills. Nevertheless, the non-technical competencies (or primitive competencies) should be considered as part of the proposed competence model.

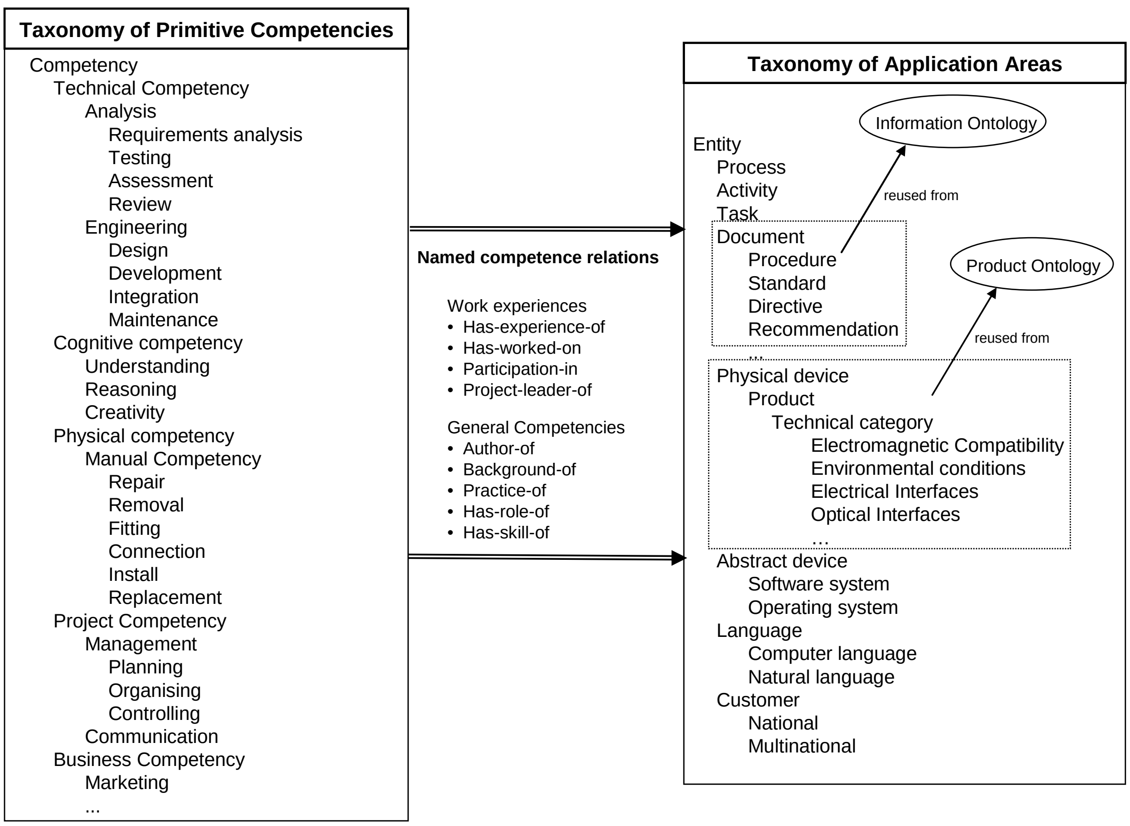

Figure 2 Example of a Competence Taxonomy

This conceptual model is an example base structure for the ontology-skill architecture (next section) that was conceived to support the knowledge ontology and related engine for our k-now approach and KM solution. The following figure illustrates a practical application of the previous competence framework using the K-NOW software prototype.

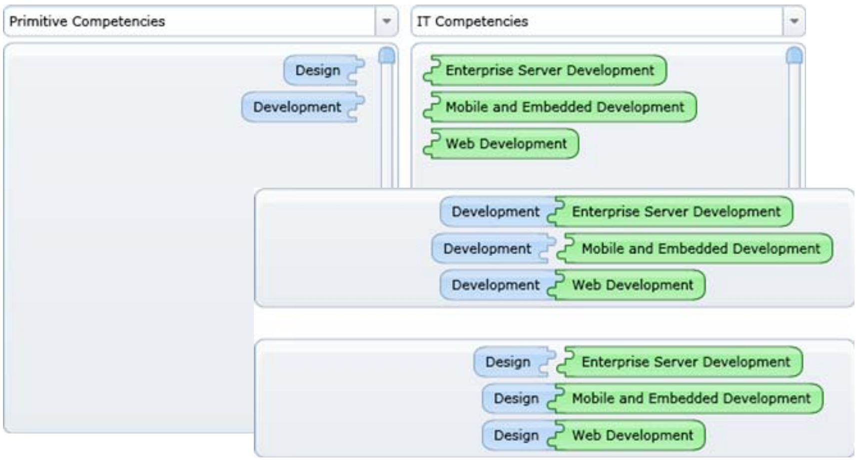

Figure 3 Competence Taxonomy application using K-NOW prototype

4.1.3 Capture, encoding, storage and security

The aforementioned ontological conceptual model represents the metadata for the key concepts and their relationships. Attributes characterises the concepts and things in the knowledge ontology that we designated as ontology-skill architecture.

The ontological meta-level knowledge representation needs a formal and effective software representation in order to produce an ontology-driven KM solution. For this purpose, based on the domain (software engineering area) taxonomies, algorithms for graph / taxonomy traverse were specified and implemented using the C# programming language. The resulting software interface and the related web deployment are based on the recent *MS Silverlight* programming infrastructure.

Figure 4 illustrates an object-oriented (OO) implementation of the ontology-skill approach further detailed in the following section. This OO implementation represents the ontology-skill architecture, and represents the conceptual layer for the web-based KM application for managing (organizational) competency assets.

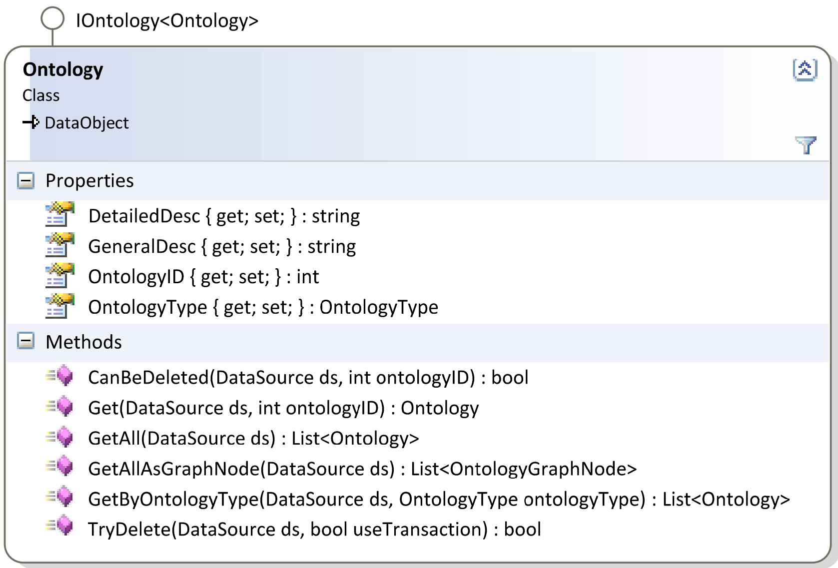

Figure 4 Object-oriented design representation of the Ontology-skill approach

4.1.4 Retrieval, dissemination and application

Knowledge application is performed during the creation and closing of project tasks, between related email procedures, during meeting registration tasks and follow-ups, as well design rational actions and decision-making statements.

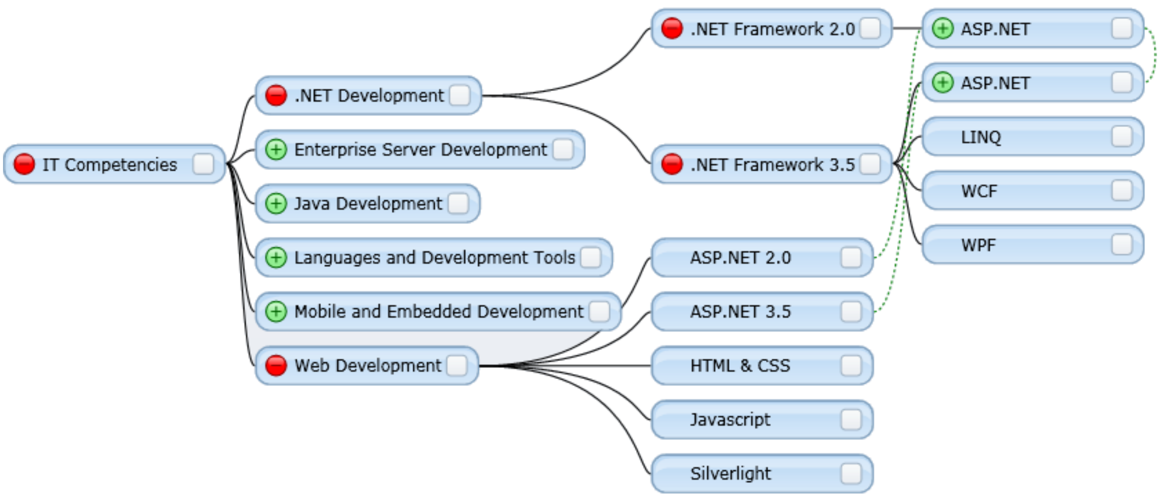

Figure 5 web Information visualisation (sample of a taxonomy from k-engine)

Advanced information visualisation mechanisms to manipulate the knowledge taxonomy were then applied. These mechanisms assist effective (web) taxonomy management, categorisation and classification.

4.1.5 Review and improvement

This stage has not been reached yet.

4.1.6 Adaptation and re-deployment

This stage has not been reached yet but, it is planned to apply k-now approach and the related k-engine infrastructure to other business domains, and consequently, several domain adjustments will need to take place.

4.1.7 Release and/or disposal

Not yet planned

5.0 Knowledge Architecture and System Design

5.1 Ontology-skill architecture

The ontology-based knowledge architecture aims to create mechanisms capable of supporting knowledge engineering (creation, representation, elicitation and acquisition), features of abstract elements and entities and additionally the performance logic and inference operations between them.

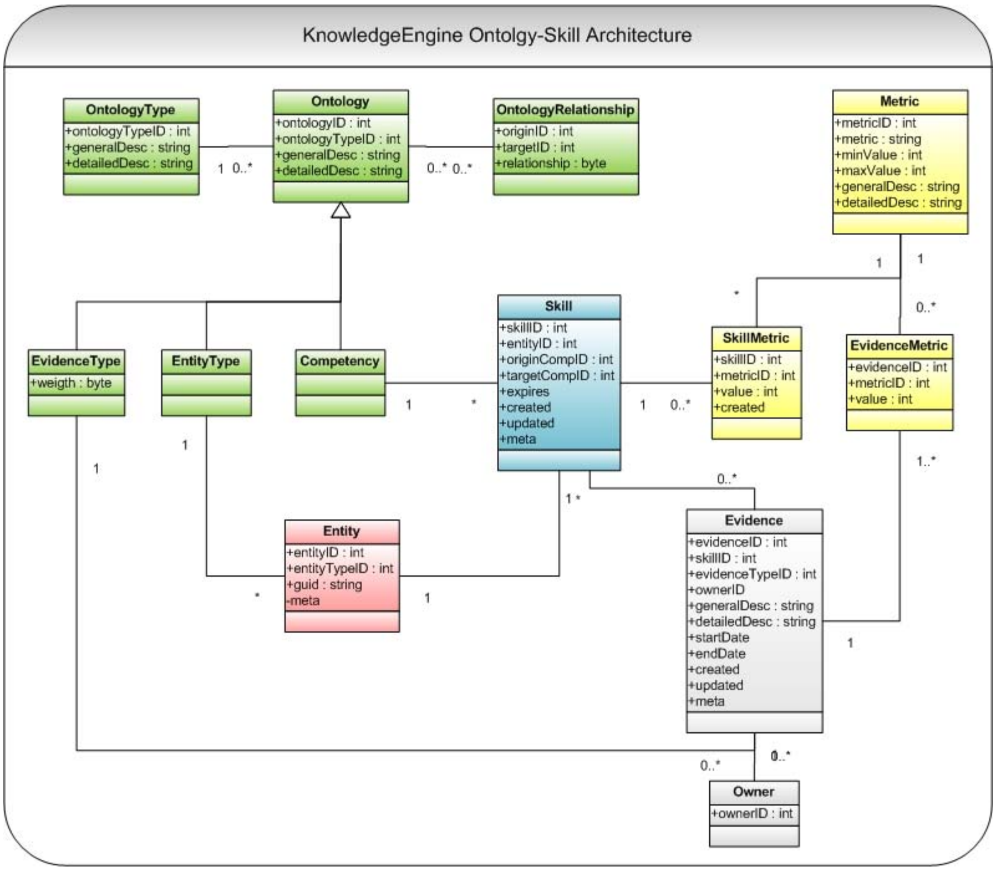

Figure 6 Ontology-skill architecture

This architecture aims the creation of an infrastructure for a generic model to represent and manipulate graph structures or semantic networks of data. An ontology is considered an abstract element that describes and represents to itself, using a structured set of ontological terms.

5.2 Ontological terminology

The ontology-skill approach and related knowledge-engine incorporate a set of ontological terms (Figure 6) and associated semantics as described (in brief) below.

- *Competency* - describes an ontology instantiation from the type "competency", defined specifically to represent domain (business) competencies.
- *Entity* - knowledge representation abstract element.
- *Entity type* - instance of an ontology from type "*entity type*" used to categorise entities.
- Evidence - element that assigns the reliability of a skill.
- Evidence metric - application of a given metric to a specific evidence.

- Evidence type - instance of an ontology from type “evidence type” for the categorisation of evidence.
- Metric - generic metrics (evaluation measures) to classify.
- *Ontology* - the basic elements for the representation of entities and their semantic relationships.
- *Ontology relationship* - represents a relationship between two ontologies.
- *Ontology type* - a logic group of ontologies with similar characteristics.
- Owner - entities that certify and/or belong to a given piece of evidence.
- *Skill* - represents the relationship between two competencies from different types and its application to a specific entity.
- Skill metric - the application of a given metric to a specific skill.

5.3 Knowledge-engine and skill quantification

The K-Engine also aims to quantify knowledge in a process called Skill Quantification. The skill quantification process applies rules to skill metrics and evidence in order to quantify the knowledge represented by a single skill. The goal here is to produce a suitable uniform metric for quantifying skills.

Knowledge quantification aims to answer the following questions:

- How much does someone knowledgeable about a specific area of knowledge?
- How sure are we that they effectively know this?
- How do we measure and assess that knowledge?

The answers lie in evidence in the same way as a driver’s license is an evidence of qualification to drive a certain category of vehicle. The use of quantified evidence brings a certain level of reliability to the evaluation of expertise, although different forms of evidence have different degrees of reliability and different types of metrics are used to express this expertise.

The quantification of knowledge is described using two different values:

- Quantification value (how much is known)
- Reliability value (how sure are we about it)

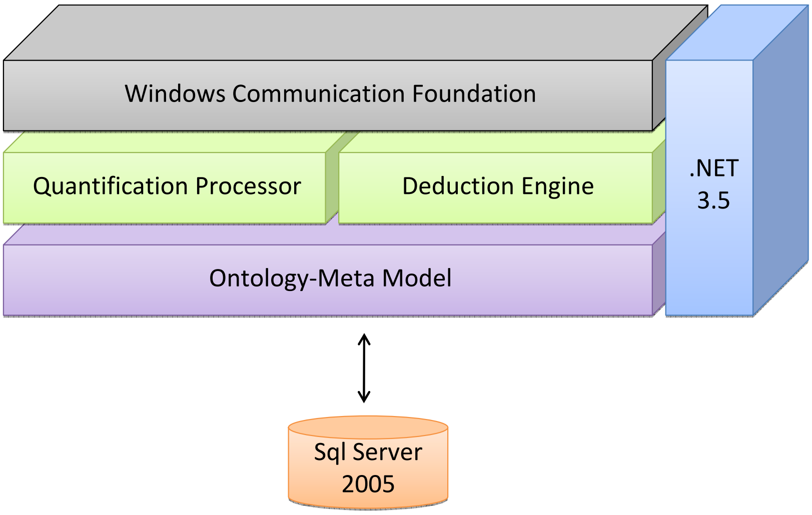

Figure 7 K-Engine architecture

There are two types of rules, quantification rules and quality assessment rules, both are expressed as mathematical expressions in which the metrics and evidence can be manipulated numerically. A quantification rule seeks to aggregate metrics into a single numerical value, a quantification rule may use all of the available metrics and evidence or focus on particular types of either one; different weights or modifiers may also be applied. A quality assessment rule seeks to express the quality of the metrics and evidence used by the quantification rule, this includes the total number of elements available, how many were used and their reliability. Thus, the quality rating value does not modify the quantification value, but complements it.

5.4 Knowledge-engine and competence-based practices

An important ability of K-Engine is to provide a tool to perform skill based queries with external systems.

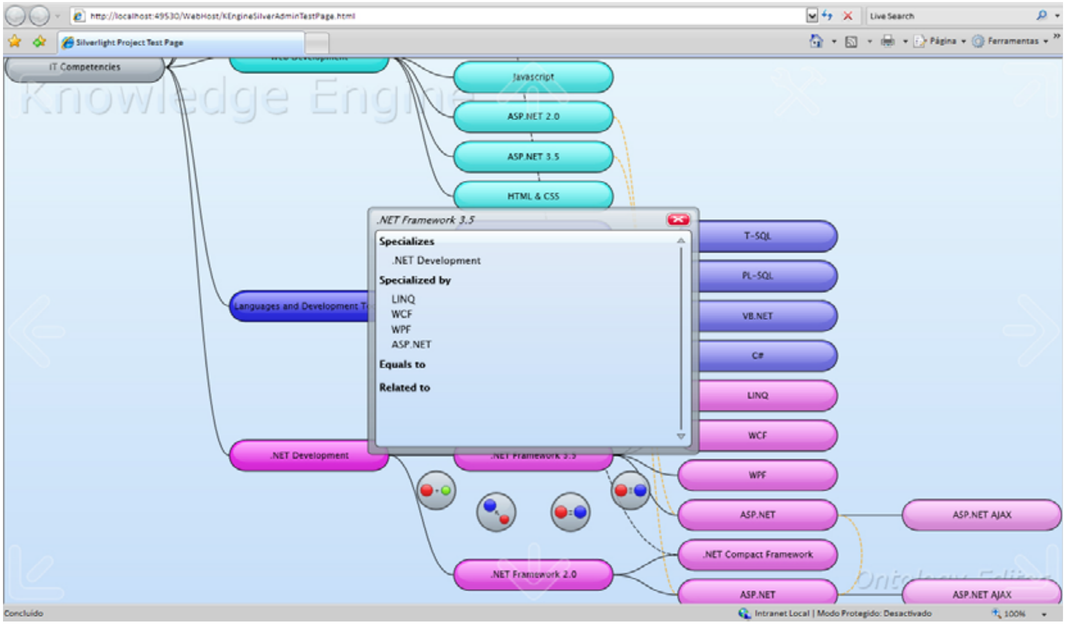

Figure 8 K-Engine prototype tool

A skill based query answers questions like “who knows what" and "how much do they know”. A skill-based query relies heavily on deductive inferences that can be restricted to narrow or broad the results. A Search Quantification rule is then applied to the quantified skills deduced from a set of weighted skills. The main factor in this rule is the “distance” between the given skills and the set of deduced skills. The query result consists of a set of quantified entities, which includes a “match rating”, quantification rating and quality rating.

K-Engine application domains are semantically rich networks of competencies related to a specific knowledge area. Skills are composite competencies and represent the relation between competencies of different domains. This allows for artificial intelligence deduction in decision support tools. Rules allow the retrieval of meaningful information from evidence in a way that better fits our purpose. The quantity and reliability of knowledge is not a static value, it depends on how we interpret it, and on which rules we define and apply.

5.5 K-Now software architecture

K-Now is a web solution that brings the K-Engine functionalities to the *MS Sharepoint Portal* and MS Project server technologies in order for them to be available to a range of clients (organizations) using application service provider (ASP) services (Figure 9).

For this reason, the client only needs a simple web browser to configure and operate with the k-now system.

For specific medium and large organizations that require for additional performance and security measures, a targeted k-now system infrastructure could be installed and deployed in a specific organization.

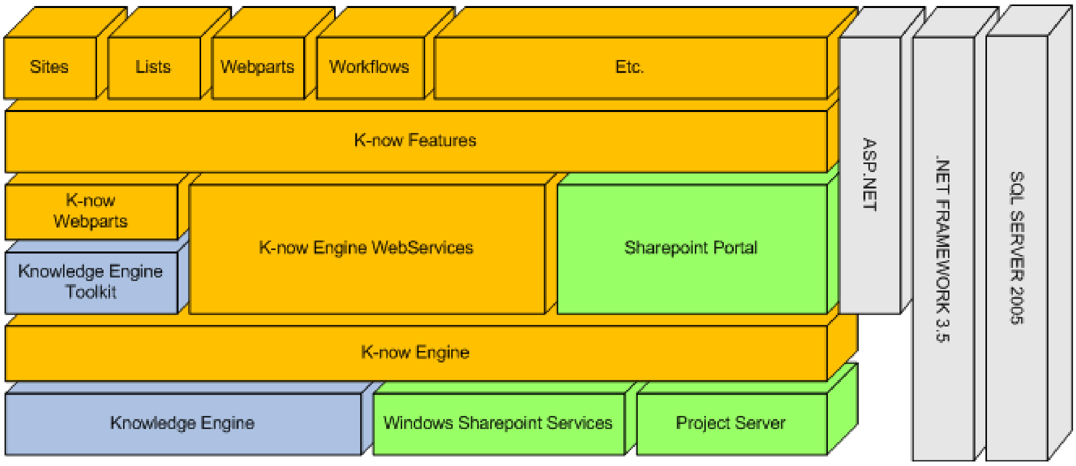

Figure 9 K-Now software architecture

The main K-NOW objectives and functionalities are:

- Make competency-based KM workable in decision support activities in large knowledge intensive organizations
- Provide a innovative solution for corporate competence modelling and representation
- Empower competence assessment and performance management with an flexible software system
- Improve organizational learning and compensation management
- Knowledge gap analysis

6.0 Conclusions and Future Work

As we indicated at the start of this paper, this is an ongoing project to develop a knowledge-engine architecture that has been specified and is being developed by a Portuguese software development company; consequently, this paper is very much a report of 'work in progress'. Having said that, our long-term goal and our main motivation for pursing this work is to develop a scalable architecture that would be suitable for use both in a Competence Management Systems and in other forms of Knowledge Management System. We will comment on these two aspects of the work separately.

Firstly, concerning the project with *Shortcut*, the aim is to create a web based CMS to support the management of employees' competencies. This work is progressing and is currently at the stage of being able to produce prototypes based on actual data that can be used in visualisation exercises. The next stage of reviewing the findings from these exercises (section 4.1.5 in the paper) has yet to start.

In terms of our longer-term goal, our broad approach of designing a system using an ontology-driven framework that uses expert annotations as a method of integrating aspects of both tangible and less tangible knowledge has been broadly successful and has now been applied in two different domains (see Vasconcelos, Gouveia and Kimble, 2002). The approach of treating annotations as an instance of expert knowledge that has been externalised and recorded in a specific context also appears to be a viable way to represent and render manageable some less tangible knowledge assets such as competencies and skills, heuristics or instances of best practice.

Practical considerations are also fundamental to the acceptance and integration K-Now in an organization. As we have indicated before (Abdullah et al, 2006), previous KM initiatives have floundered through a neglect of these considerations. Thus, equivalent efforts must be made to secure a sense of knowledge ownership: too much knowledge closure obstructs efforts of knowledge sharing, however the absence of security and preservation mechanisms could lead to loss or corruption of knowledge assets. The K-Now approach aims to balance these two perspectives by managing and capitalising knowledge and competencies within the organization and across its boundaries.

Although much progress has been made, much work remains to be done. To be able to develop this approach further, the K-Now solution needs to be applied and refined in a number of different organizations and knowledge domains. It must be capable of addressing the particular constraints of each based on their unique objectives, processes, human resources and intellectual capital. Testing times lie ahead!

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