SIMILARITY MEASURES FOR SKILL-PROFILE MATCHING IN ENTERPRISE KNOWLEDGE MANAGEMENT

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Abstract: At DaimlerChrysler's truck plant in Wörth, we are currently implementing a comprehensive IT solution for integrated and synergistic processes in personnel development. In this paper, we sketch some ontology-based software modules – as well as their interdependencies and synergies – which support streamlined and integrated, comprehensive personnel-development processes. A central element in the software architecture is ontology-based similarity assessment for skill-profile matching which is exemplarily discussed for software-supported project staffing.

1 MOTIVATION

In the coming 10 years, Human Resource Management (HRM) departments in large companies in Germany and most parts of Europe will face radically new challenges and tasks. Already today, demographic studies and prognoses show clearly, that in the long-term, the number of young people will significantly decrease (Federal Statistical Office Germany, 2003). Even with a realistically estimated amount of immigration, the share of citizen under 20 years will reduce from 20% (2001) to 16% (2050) of the overall population while the share of people above 60 years increases from about 25% to about 33%. Consequently, the working population will run through a continuous aging process (in the average), and from ca. 2015 on, the number of persons available for employment will more and more run short. Under such conditions, a coordinated, long-term personnel development strategy gains increasing importance. Such a strategic personnel development must be part of a comprehensive HRM strategy which should in turn be embedded into an overall, holistic Knowledge Management (KM) approach (Biesalski; Abecker, 2005).

From the IT point of view, HRM departments mainly use IT applications for the management of personnel data (standing data, performance reviews), for junior employee development, or for training planning, seldom also for assessment of training needs. Real-world system landscapes are often characterized by manifold heterogeneous systems, evolved over time, showing pretty non-uniform features – which hinders interoperability of those applications. Further problems come from massively redundant data storage, as well as complex interfaces between systems. Since such system landscapes are typically a combination of standard software and proprietary developments of the HR software department, they seldom support an integrated personnel development approach, i.e., a coordinated behaviour of different applications. Modern views on knowledge and skills of employees are normally not realized. The purpose of such systems is to manage the single employee, not to model and manage an integrated view on employee, tasks and organizational context.

At DaimlerChrysler's truck plant in Wörth, we are currently developing such an integrated system and process landscape. In Section 2, we sketch the respective software architecture. In Section 3, we focus on one module of the system, designed for supporting project staffing. At the hand of this example, we discuss in more detail the ontology-based matching of skill profiles – which is a central functionality also for the other modules. Finally, in

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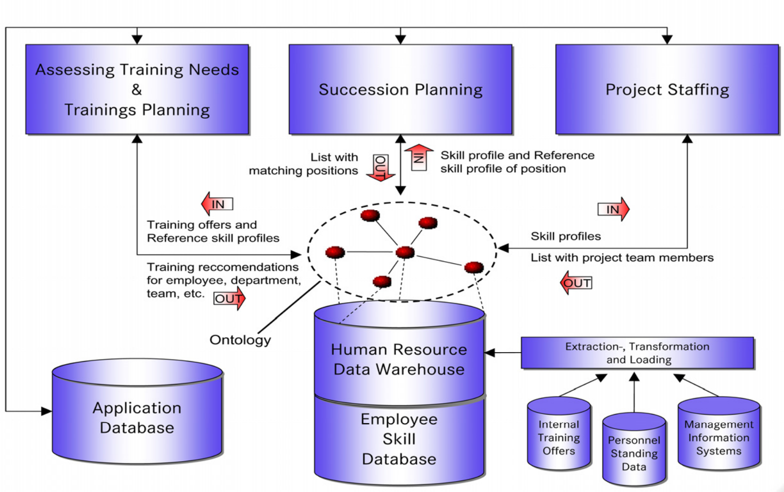

Figure 1: Overall Perspective - Personnel Development Software Framework.

Section 4, we briefly summarize, sketch some related work and report on the current implementation status of the system.

2 AN APPLICATION FRAME-WORK FOR PERSONNEL DEVELOPMENT

We propose an integrated software and process framework for personnel development (PD Framework) as depicted in Figure 1. It contains business processes for personnel development (Biesalski; Abecker, 2005a), a Human Resource Data Warehouse (HR DWh) which integrates data from different legacy systems, an ontology-based employee-skill database, as well as different new application modules.

In this article, we focus on the application module for project staffing. A core idea of this and all the other modules is the ontology-based modelling of employees' skill profiles. This is based upon an ontology which formalizes the former skill catalogue that describes all different personal skills occurring or required in the company (cp. Figure 2). Each software module employs an ontology-based matching procedure which is able to compare skill profiles (i.e. bundles of skills which characterize an employees' knowledge, skills, and qualifications, or, the competences required for a specific job, respectively). For the **"Succession Planning"** module, this means to compare the to-be skill profile of an open position with the as-is profiles of a number of employees – in order to find out the most suited candidate. To this end, we compare bundles of ontology instances, as indicated in Figure 3.

In the same manner, in the module **"Detection of training needs / Training planning"**, we compare competence profile of jobs with the as-is profile of employee in order to identify qualification gaps. Such a comparison can also regard strategic directions, e.g. of the department, thus leading to a training planning and behaviour which is closer to the company's overall strategic needs. When having identified strategic training gaps, they can be compared with training offers, and suggestions for filling gaps can be made, also regarding time restrictions of employees, budget restrictions, etc. Such suggestions can then be offered by the department manager to the employees. In the module **"Project and job staffing"**, the matching procedure searches best available employees for vacancies in project teams, based upon matching between to-be (project / job requirements) and as-is (personal profile) comparisons.

3 THE MODULE: PROJECT STAFFING

In industrial practice, open jobs are seldom staffed along a structured procedure. Personal networks and preferences often play the major role. Of course, this guarantees neither a fast nor an optimized result, in particular when staffing a large project team with a number of heterogeneous required skills and competencies. Since large enterprise usually have electronic data about the competences and experience of their employees, a (partial) automation seems feasible and desirable.

In order to support project staffing, we need on one hand position skill requirements and on the other hand employees' skill profiles. We want to find – with a minimum staffing effort – the best

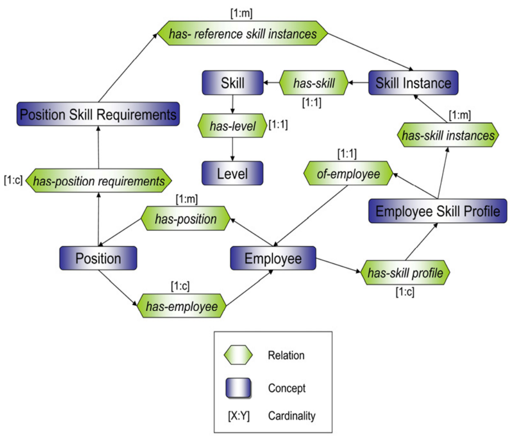

Figure 2: Top-Level Structure of Skill Ontology (simplified).

suited employees who fulfil the position skill requirements as well as other constraints, such as availability. For integrating project staffing into a comprehensive HRM approach, we particularly need the standardized skill catalogue which allows for a unified semantic description of position skill requirements and employee skill profiles, and a skill-matching procedure. For addressing these issues, we adopted the approach of (Hefke; Stojanović, 2004), introduced a comprehensive ontology-based skill catalogue at DaimlerChrysler plant Wörth / Rhine, as well as ontology-based similarity measures for profile matching.

Table 1: Some Central Concepts of the Skill Ontology.

Concept	Description
Skill	The ability to produce solutions in some problem domain. In Enterprise Skill Management, the identified, named, trainable competence of some employee, often required to perform a specific organizational task (well), to fill a position, or to enact an organizational role.
Weight	Achieved or required level of expertise which indicates to which extent the given competence is or shall be mastered.
Skill instance	A skill together with a level of expertise (e.g., “expert in C++ programming”, “beginner in English”). As a unit of reference only needed for internal technical reasons.
Skill Profile	A list of skill instances. As an *employee skill profile* describing as-is situation regarding an individual’s personal qualifications, as *position skill requirements* describing necessary qualifications to do a job successfully.

3.1 Ontology Based Skill Modelling

In general, a *skill catalogue* contains skills relevant for the company. In a *structured skill catalogue,* the skills can be equipped with a weight, describing the achieved level of expertise. In the DaimlerChrysler Wörth case, about 700 single skills have been modeled. For an employee, a personal *skill profile* lists his or her actual skills, together with weights for the achieved level of expertise. A profile for *position skill requirements* is a list of weighted skills which are important for successfully doing the required tasks in a given position (here the weight expresses the relevance of having achieved the specified level of expertise). Both profiles refer to the same, unified vocabulary specified in the skill catalogue (cp. Figure 2 and Table 1).

3.2 Project Staffing with Ontology Based Similarity Measures

As an efficient and expressive data structure for processing skill profiles, we use an ontology-based approach (Staab; Studer, 2004) which stores, manages, and compares profiles with the help of the KAON (Mädche; Motik; Stojanović, 2003) ontology management framework. For supporting the selection of qualified employees, our „project staffing“ module is a web-based tool which allows to define project-specific position skill requirements and – based upon those – gives dedicated project staffing advice. To this end, decision-supporting information is taken into account from sources such as employee-skill profiles, job catalog, time recording system, etc. Since a multitude of perspectives must be fed into the complex employee selection process, the matching procedure which compares job profiles and potential candidates’ profiles should be capable of semantically assessing the similarity of ontology instances. For realizing such a candidate selection procedure, we employed the similarity framework introduced in (Ehrig; Haase; Stojanović; Hefke, 2004). However, while (Ehrig; Haase; Stojanović; Hefke, 2004) focus on text-dominated application areas (comparison of vocabularies and terminologies), the comparison of skill profiles requires more advanced combination and expression means for similarity measures. So, we extended the framework such that the user can be provided with different metrics for assessing a candidates’ suitability for a given job profile. Our requirements analysis and analysis of existing HRM systems showed that different similarity metrics for profile comparison should be used to express different aspects relevant for different tasks. For project staffing, an aggregated metric is used which combines the following four aspects:

- **Direct skill comparison:** we require an *exact match* of as-is and to-be. So we can specify *K.O. criteria* for the central requirements, especially in strategically important jobs.
- **Proportional similarity:** we identify also *partially fulfilled requirements*. This is also important if we can plan for additional teaching and qualification measures or for "training on the project".
- **Compensatory similarity:** we identify not only partially fulfilled requirements, but also *overqualifications*; so, additional expertise on one hand may compensate deficiencies on the other hand. If several employees fulfil the K.O. criteria, this can be useful to find the most suited one.
- **Taxonomic similarity:** the taxonomic structure of the skill ontology is taken into account to find "close matches" in the case that no employee has exactly the required qualifications. Also usable for deciding between several candidates, and for refining profile specifications.

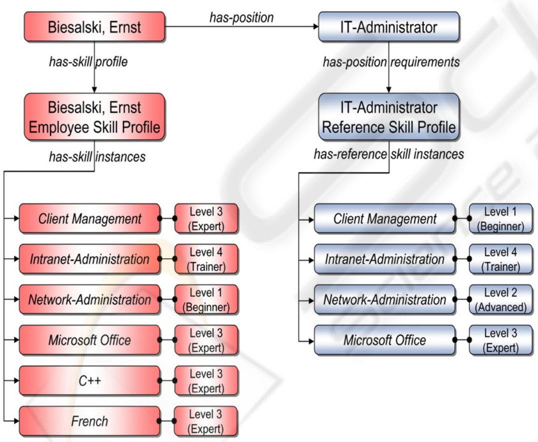

Figure 3: Example: Part of Ontology-based Employee-Competence Database.

Let us now discuss these similarity measures in some more detail.

3.3 Similarity Measures for Skill Profiles

The basis of our skill-profile matching is the mapping of all competence metrics to a four-level scale (beginner, advanced, expert, teacher). Comparison of skill profiles is reduced to the comparison of skill instances. Let:

- R be a profile for some position-skill requirements consisting of a non-empty list of skill instances r with skill name rs and expertise level rl, and
- E be an employee-skill profile consisting of a list of skill instances e with skill name es and expertise level el

$$sim_{\text{skill name}}(r,e) := \begin{cases} 1, \text{ if rs} = \text{es} \\ 0, \text{else} \end{cases} \qquad sim_{\text{skill level}}(r,e) := \begin{cases} 1, \text{ if rl} = \text{el} \\ 0, \text{else} \end{cases}$$

3.3.1 Direct Skill Comparison

Often we want to specify special skill instances as K.O. criteria. This requires an extension of our skill modelling. Then we can define the direct skill comparison metrics for a position skill requirements profile R and an employee skill profile E as follows:

$$sim_{\text{direct comparison}}(R,E) := \frac{\sum_{r\in R, e\in E} weight(r) * sim_{skilllevel}(r,e) * sim_{skillname}(r,e)}{\sum_{r\in R} weight(r)}$$

3.3.2 Proportional Similarity

The idea of direct comparison leads to the effect that each underfulfillment of a skill requirement finally results in a complete disqualification of the respective employee. It does not allow to assess the possibly differing extent to which the requirements where not fulfilled (only marginal deficiencies versus complete misqualification). In reality, project leaders need a metrics which is suited to assess partial fulfillment of requirements in an appropriate manner. To this end, we define the proportional similarity:

$$sim_{\text{proportional-similarity}}(R,E) := \frac{\sum_{r\in R, e\in E} weight(r) * sim_{proportional-level}(r,e) * sim_{\text{skill name}}(r,e)}{\sum_{r\in R} weight(r)}$$

with:

$$sim_{\text{proportional-level}}(r,e) := \begin{cases} 1 \text{ if rl} \le \text{el} \\ 1 - (\text{rl} - \text{el}) * \frac{1}{4}, \text{ else} \end{cases}$$

3.3.3 Compensatory Similarity

Proportional similarity is an extension of the compensatory similarity which addresses not only under-, but also overqualifications. These can be especially valuable when several candidates have fully satisfied the requirements of the other similarity measures and cannot yet further be distinguished.

$$sim_{\text{compensatory-similarity}}(R,E) := \frac{\sum_{r\in R, e\in E} weight(r) * sim_{compensatory-level}(r,e) * sim_{\text{skill name}}(r,e)}{\sum_{s\in S} weight(s)}$$

with:

$$sim_{\text{compensatory-level}}(r,e) := 1 - (\text{rl} - \text{el}) * \frac{1}{4}$$

This metrics must be interpreted differently from the other two presented before. In contrast to the situation with an exact match or a proportional similarity, a "1" is here not anymore an indicator that all requirements are fulfilled completely. Instead, overqualifications in some skill-profile facets may compensate for underqualifications in other facets.

3.3.4 Taxonomic Similarity

It is often difficult to find employees which fit relatively exact into a given profile specification.

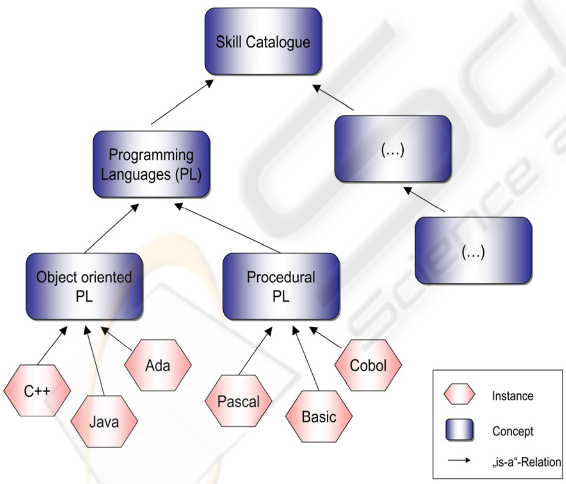

Figure 4: Example Taxonomic Similarity.

This comes also from the fact that it is not always trivial to specify the expected requirements unequivocally if there are different possible opinions how to characterize the required profile in terms of a complex skill catalogue which might provide many, slightly different, but related skills in a certain competence area. For instance, knowledge about „Spreadsheet software" might also be proven by a certificate about using „Microsoft Excel". Depending on the perspective, profile models may differ, both when employees describe themselves, and when project leaders define a required skill profile.

Taxonomic similarity can be derived from semantic cotopy of two ontology instances. Figure 4 gives an example as a small excerpt from a hypothetical skill catalogue: the skills „Object oriented programming" and „Procedural programming" are closely related since the have the same parent concept. While "Java programming" and "C++ programming" are very similar, "Pascal programming" is still related, but far more loosely. Such sophisticated comparisons of profiles based on the taxonomic skill catalogue as background knowledge, allows far-reaching detailed assessments of whole project team staffs, if required. In particular, they allow for fine-granular ranking of candidates. Due to space limitations, we don't go into details about the computation of taxonomic similarity, here. For more information, see, e.g. (Ehrig; Haase; Stojanović; Hefke, 2004).

4 SUMMARY AND CONCLUSION

The idea of detailed ontology-based modelling of personal skills is not new (Stader, Macintosh, 1999; Liao; Hinkelmann; Abecker; Sintek, 1999), but has found just recently more practical interest. Our own work within DaimlerChrysler, but also for instance (Hefke; Stojanović, 2004; Lau; Sure, 2002; Dittmann, 2003; Hiermann; Höfferer, 2005) show that such an approach – if appropriately supported by organizational processes – can lead to more efficient and more effective project staffing in real-world, large-scale industrial application scenarios. As sketched in Section 2, even more impact can be achieved by designing a comprehensive ontology-based skill-management infrastructure, joining up existing systems, adding new functionalities, and designing suitable support processes. The focus of this paper was the use of ontology-based similarity measures for skill-profile matching. Many academic approaches for using *advanced reasoning* for skill matching (like: Colucci; Di Noia; Di Sciascio; Donini; Mongiello; Mottola, 2003) apparently have not yet been applied in large-scale real-world scenarios. *Similarity-based approaches* seem not yet very widespread in this area, but they have proven their practical usefulness in a vast amount of Case-Based Reasoning (CBR) applications (see, e.g., Watson, 1997). CBR tools have also been successfully applied in Expert Finder systems which can be seen as a very specific partial instance of a skill management system (Vivacqua; Lieberman, 2000). The specific contribution of the work presented in this paper is to settle the CBR ideas upon a state-of-the art ontology infrastructure – thus combining the advantages of similarity based search (good retrieval results in vaguely specified query situations and complex domains) with those of ontology-based systems (clear semantics, good application potential for integration of different legacy systems).

When writing this paper, the software framework is fully specified, the HR Data Warehouse and the employee-skill database are already implemented, and the three application modules are under implementation.

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