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Applying Competence Prerequisite Structures for eLearning and Skill Management

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Abstract: Several approaches for formalising prerequisite structures on skills or competencies based on the psychological theory of knowledge space have been suggested and applied for adaptive eLearning. In this paper, we will discuss how these structures may be applied in skill management in a broader sense. After introducing some formal structures for prerequisite relationships between competencies, we will briefly present an example of an adaptive eLearning system based on this approach (APeLS). Several other aspects of the system which promise to be useful for advanced skill management are discussed. In the final part of this paper, we will discuss such broader applications of the model with respect to personal as well as to organisational skill management.

Keywords: Skill management, eLearning, Personalised hypermedia
Categories: J.4, K.4.3, H.5.4

1 Introduction

Several approaches for structuring a domain of knowledge through prerequisites between skills (or competencies) within this domain have been developed on the basis of the theory of knowledge spaces [Doignon and Falmagne (1985)], [Doignon and Falmagne (1999)], [Albert and Lukas (1999)]. While the original aim of these approaches lay in testing knowledge, the focus has changed in recent years to applying these structures for teaching knowledge in personalised hypertext systems [Albert and Hockemeyer (1997)], [Conlan et al. (2002a)].

These (and other) personalised eLearning systems based on knowledge space theory share two limitations: (i) personalisation is limited in these systems to personalisation toward the learner's current knowledge and (ii) the support in learning and personal knowledge management is limited to singular learning processes neglecting the need to update previously learned knowledge to the current state of the art as well as neglecting the support for repeating the previously learned contents in order to achieve a life–long retention. The latter point includes a shift in the interpretation of “life–long learning” from “learning throughout the whole life” towards “learning for the whole life”.

In the sequel, we will first briefly introduce a formal model for competence prerequisite structures and present an example for an personalised eLearning system based on this model. Afterwards we will discuss how this model can be applied for skill management on a personal as well as on a company level.

2 Competence prerequisite structures

2.1 Knowledge space theory

The model for competence prerequisite structures we use in our work is based on the theory of knowledge spaces [Doignon and Falmagne (1985)], [Doignon and Falmagne (1999)]. This theory models the response behaviour for knowledge tests on a behavioural level, i.e. on the basis of prerequisite relationships between the items in a test.

A basic notion in knowledge space theory is the *surmise relation*. Two test items a and b are in a surmise relation ($a \leq b$) if, whenever a person has solved item b correctly, we can surmise that this person is also able to solve item a correctly. From a mathematical point of view, such a surmise relation is a quasi–order on the set of test items.

If we regard, on the other hand, a person’s *knowledge state* as the subset of test items this person is able to solve, we see that the set of possible knowledge states is limited through the surmise relation. The set of all knowledge states conforming to a surmise relation is called (quasi–ordinal) *knowledge space*. A knowledge space conforming to a surmise relation contains the empty set (i.e. knowing nothing) and the complete set of test items (i.e. knowing all items) as knowledge states. Furthermore, for any knowledge states K and K', their union and their intersection are also knowledge states (called closure under union and under intersection, respectively).

In practice, we often find test items which can be solved in different ways. Doignon and Falmagne have defined a certain mapping, the *surmise system* as a means to model this. A surmise system assigns to each test item a family of subsets of items called *clauses*. Each clause is a subset of prerequisite items corresponding to some way of solving the test item. Knowledge spaces conforming to a surmise system are sill closed under union but the are not necessarily closed under intersection.

This behavioural model for prerequisite structures has been applied for eLearning, e.g., in the ALEKS (http://www.aleks.com) system.

2.2 Competence performance approach

Over the last decade, there have been a number of approaches to enrich the theory of knowledge spaces by modelling not only the observable behaviour but also the underlying latent skills or competencies [Albert and Lukas (1999)]. Throughout this paper, we will focus on the competence performance approach [Korossy (1997)], [Korossy (1999)].

Korossy models a domain of knowledge through performances (i.e. test items) and the underlying latent competencies. He derives a performance structure from three sources: an *interpretation function* mapping each item to the subset of competencies required for solving this item. A correct solution to an item is interpreted in such a way that the person's *competence state* contains at least all those competencies assigned to this item. On the other side, a *representation function* assigns to each subset of competencies the subset of items solvable by a person who has these (and only these) competencies. This function denotes how the unobservable competencies are represented visibly through item solving behaviour. Furthermore, there may also be defined a prerequisite structure on the set of competencies.

From these three entities (interpretation function, representation function, and optional competence structure), a structure on the set of performances, the *performance space* can be derived. Thus, we obtain an item structure based on theoretically analysing the items in the regarded field of knowledge.

A similar approach was applied to eLearning in the RATH system [Hockemeyer et al. (1998)]. RATH uses a knowledge space which was, however, developed through a demand analysis of test items [Albert and Hockemeyer (2002)].

3 Personalised eLearning based on competence structures

Based on an extension of Korossy's competence performance approach, an eLearning application based on APeLS (Adaptive Personalised eLearning Service) [Conlan et al. (2002b)] was developed as a first step towards metadata based reuse of adaptive eLearning resources, [EASEL (2000)]. We will first describe the *competence learning structures* forming the psychological basis of APeLS and then the system itself.

3.1 Competence learning structures

The original intention behind Korossy's competence performance approach was to develop a solid basis for knowledge structures obtained through theoretical analysis of the respective domain of knowledge. Applying this approach to personalised eLearning with an additional attitude towards reusability of adaptive resources through standardised metadata led to an extension of Korossy's model.

A domain of knowledge be described through a set of learning objects (e.g. lessons) and a set of competencies. We define two mappings t and r which assign to each learning object the subsets of competencies taught within the learning object or required to be able to understand the learning object, respectively [Hockemeyer (2003a)]. From these mappings, we can also derive a third function l assigning to each subset of competencies (i.e. competence state) the subset of learning objects which can be understood by a person having exactly that competence state.

From the mappings t and r, we can also derive a surmise system on the set of competencies and, thus, also a competence space. Similarly, also a prerequisite structure on the set of learning objects can be derived.

This approach works fine for lessons and other learning objects oriented towards teaching (see Section 3.2). In the case of test items, however, this approach is not able to model different ways of solution although the prerequisite relationships are described through a surmise system as the mapping *r* defines *one* set of required competencies for each object. The surmise system in the original knowledge space theory, however, models alternative sets of prerequisites for a certain test item (i.e. learning object).

For this reason, the more general concept of *competence testing structures* was developed [Hockemeyer (2003b)]. First of all, in the case of test items, the distinction between taught and required competencies is replaced by a distinction between competencies to be actually (intended to be) tested with the test item and other required competencies. A test item about dividing two fractions, e.g., might intend to actually test the knowledge that the quotient of two fractions can be computed as the product of the nominator and the reciprocal value of the denominator. However, solving the item would furthermore require the knowledge how to multiply two fractions. This would then be a required but not actually tested competence. The shift from taught to actually tested competencies, however, is only a shift in the interpretation of the model.

In order to model also different ways of solving an item (which might involve different sets of prerequisites), one needs also an extension of the competence learning space approach: Each solution path may involve different subsets of required and of actually tested competencies. In the *competence testing structure* approach, each object is, therefore, mapped to a set of pairs of such subsets of required and of actually tested competencies. From such a mapping, again a surmise system on the set of competencies can be derived.

3.2 Adaptive Personalised eLearning Service (APeLS)

APeLS (http://wundt.uni-graz.at/demos/apels/) applies the competence learning space approach for personalised eLearning in the context of metadata based reuse of adaptive eLearning resources [EASEL (2000)]. This approach is achieved in APeLS by the following three steps which are explored further in this section.

- Developing a mechanism to model the learner, both in terms of capturing their prior knowledge and in capturing the knowledge they acquire through using the personalized course
- Creating an appropriate narrative [Conlan et al. (2002b)] that generically describes how the theory of knowledge space may be implemented
- Creating appropriate metadata describing the candidate eLearning resources. Specifically this involves creating metadata describing the conceptual relationships between candidate content groups and the eLearning resources within them [Dagger et al. (2003)]

3.2.1 Modelling the Learner

The modelling of the learner occurs in two stages in the eLearning application developed – (i) Initial modelling of the learner's prior knowledge. (ii) Continuous monitoring and updating of their knowledge as they use the personalised courseware. By adopting the first approach of initial modelling, the competencies of learners can be assessed before they approach the learning material enabling the learners of different abilities to start at different stages of the eLearning material. This initial learner model forms the basis upon which the first personalised offering is created. With respect to the theory of knowledge spaces the competencies that exist as learner prior knowledge may be considered as prerequisites for any material that may be presented.

The second, continuous, stage of learner modelling through monitoring involves keeping track of the pages that learners access. More specifically, it involves keeping track of the competencies taught by the learning resources on these pages. If the learner has been successful in their learning then these competencies taught become competencies the learner has acquired.

In order to ensure the learner had control of their learning experience, new competencies learned did not immediately impact upon the personalised course, i.e. the navigation structure of the course did not shift as the learner browsed from page to page. Instead the learner was given the ability to initiate a *re-personalisation* of the course, i.e. an adaptation of the course contents based on the current learner model. This re-personalisation involved interpreting the narrative based on the most current competencies the learner had learned.

3.2.2 Narrative

The approach taken to providing personalised eLearning solutions in APeLS revolves around reusing not only the eLearning resources through metadata, but also reusing, where possible, the adaptive narratives that describe how the personalization occurs. In the case of the personalised eLearning applications based on the theory of knowledge spaces the role of the narrative was to embody the principles of this theory. Narratives in APeLS are capable of accessing metadata and modelled information and reasoning upon it. In this instance the narrative can access the competencies the learner has learned and the competencies required to understand a given concept. The narrative also determines the structure in which concepts will be presented.

The narrative does not, however, refer directly to the eLearning resources to be taught. Rather it refers to them abstractly through a candidacy architecture [Dagger et al. (2003)]. This enables reuse of the narrative as it is not tied directly to the resources used to teach the material. A use of this may be in applying the theory of knowledge spaces to material in different languages while reusing the narrative and the teaching approach embodied in it.

3.2.3 Metadata

One of the fundamental components to the approach to adaptivity and personalisation taken in APeLS is appropriate metadata. In the case of the eLearning application based on the theory of knowledge spaces described here the metadata described the competencies required to understand an eLearning resource and the competencies the learner would gain upon learning the resource [see Albert et al. (2001)]. In developing this metadata a conceptual structure must exist that details how learning concepts in the domain being taught are related, in particular the prerequisite relationships. This structure is used to place the learning resources (abstracted through candidacy [Dagger et al. (2003)]) into a knowledge space. The domain structure is not used directly in the adaptation process, but is inferred through the descriptive metadata. As such, the individual learning resources remain reusable and independent from the eLearning application, as they are not tied directly to the implementation of that application.

This section has briefly described APeLS and an eLearning application based upon it highlighting the importance of appropriate learner modelling, narrative and metadata. For further details on APeLS and the multi-model, metadata driven approach please refer to [Conlan et al. (2002b)].

4 Applying competence models for skill management

In the previous section, we have shown the applicability of competence models and competence structures for personalised eLearning. In this section, we will take a broader and more programmatic view on the application of competence models for skill management in general [see Ley & Albert (2003)].

In the sequel, we look at applying competence modelling for skill management first on a personal and afterwards on an organisational level. Finally, we will also look at other elements of the APeLS system ant their applicability to skill management.

4.1 Applying competence modelling for personal skill management

A central issue in research as well as in strategic planning on eLearning is the concept of life–long learning. Traditionally, this term denotes supporting learning throughout a person's life. Especially with respect to the professional life, it is nowadays not any more sufficient to learn in school and university before starting to work. Instead, we have to acquire new knowledge in parallel to our work. Taking a view of personal skill management here means that everybody takes over responsibility for themselves to acquire new knowledge whenever it is needed.

We propose to extend the idea of personal skill management to cover not only *life–long learning* but also *life–long retention*, i.e. it is not sufficient to learn any new things coming up but, at the same time, it is also important to keep active what we have learned before. Ecological memory research [see Bahrick (2000)] has investigated models and methods for this purpose. However, so far this work has been focused on basic research and has not yet found its way into applications, e.g. in eLearning.

For a true personal skill management, however, it is important not to regard life–long learning and life–long retention as isolated goals. Instead, we have to connect these two sides, e.g. distinguishing between previously learned knowledge that should be repeated to support long–term retention and previously learned knowledge that is obsolete and needs an update due to new developments, for example in technical areas. The competence model in such an integrated system could then help identifying (i) deprecated competencies that should be replaced or updated, (ii) seldom needed but nevertheless important competencies that need a refresh, and (iii) often used competencies that are already implicitly refreshed regularly by daily work. The latter two aspects need, of course, also a strong integration to organisational skill management, e.g. by assigning competencies to work tasks within a company [see Stefanutti & Albert (2002)].

4.2 Applying competence structures for organisational skill management

A central area for skill management is still given on the organisational level, i.e. companies etc. need an identification of needed as well as of available competencies within their staff. A central issue organisational skill management here is the identification of competencies required for certain tasks as well as the identification of competencies available within the staff in general but also within each single staff member [Stefanutti & Albert (2002)].

The results of such a competence modelling are an important information basis for building project teams based on the competence demands of the tasks and the competencies available among the staff [see Hoppe (1995)]. On the other side, the results of such an analysis are an important basis for demand–oriented further education of staff members, in an integration with the aims of personal skill management mentioned above.

4.3 A system for the support of skill management based on the ideas underlying the APeLS system

In the description of the APeLS system, we have mentioned three important aspects, learner modelling, narratives, and metadata. While we have discussed the application of the learner modelling mechanism, i.e. the competence modelling, in the previous subsections, we will now focus on the other two aspects.

4.3.1 Narratives

The narratives of the APeLS system can be regarded more generally as strategies to teaching. Transferring this to skill management, it means that the system clearly separates the content and domain related issues from general, transferable issues. A skill management support system based on the ideas underlying APeLS would support the transfer of successful skill management strategies between different departments of an organisation or between different organisation sin general. Since these strategies are contained in one system, its users could switch between different strategies at any time.

4.3.2 Metadata

Metadata usage in APeLS goes beyond the normal usage as a means to describe objects. In APeLS, metadata connect the concrete objects to abstract concepts (in this case competencies) and, thus, serve as a means for realising adaptivity. An important point is here the usage of fixed vocabularies in order to avoid ambiguities [see Albert et al. (2001)].

In a skill management support system, metadata would be used to describe the skills and competencies of the organisation’s members. In order to integrate skill management and eLearning, such metadata should be oriented towards existing learner metadata schemas [see IMS (2003)]. From these metadata, information about the competencies of groups, departments and whole organisations could be derived. However, also groups to be built could be described using the same schemas as for existing groups. Competence metadata here would describe the competencies the group should have, e.g. in order to be able to solve a certain task. Afterwards, the aforementioned general strategies could be applied to find the appropriate persons for the to–be–built group.

5 Conclusions

We have introduced structures for modelling prerequisite relationships between competencies within a certain domain of knowledge. Such prerequisite structures have been used to provide personalised eLearning in an efficient and flexible way.

Approaches to broaden these ideas for skill management in general have been discussed. The methods use in the APeLS system promise to be similarly efficient and effective in this broader application as they have proven in eLearning. However, further research and development is necessary to find out how various existing methods for skill management could be incorporated, e.g. as strategies, into such a system and, thus, lead to an integration of different methods.

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