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Developing Curricula for Tutoring Systems Based on Prerequisite Relationships

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In adaptive tutoring systems, prerequisite relationships between learning objects within a course have been applied for the selection of new objects to be presented to the student. If large collections of learning objects are available, these prerequisite relationships can also be applied for developing and restructuring curricula, i. e. for selecting smaller subsets of learning objects, or for restructuring existing courses. This paper presents first ideas and concepts for such a (re-) structuring and improvement of courses and curricula. The approach presented requires provision of appropriate meta–information for learning objects by the course authors.

Keywords: Curricula development, course structure, prerequisite relationships, content analysis

1 Introduction

The theory of knowledge spaces developed by Doignon and Falmagne [6, 7] — one of the most influential knowledge structures at all [1, 3] — provides a mathematical framework for the specification of prerequisite relationships between different *items* (i. e. learning objects) within a domain of knowledge. One possibility of representing such prerequisite relationships is the *surmise relation*. Two items *a* and *b* are in a surmise relation if from a student mastering item *b*, we can surmise that this student also masters item *a*. In terms of prerequisite relationships, item *a* is considered a prerquisite for item *b*. From a mathematical point of view, a surmise relation is a partial order on the set of items.

The original aim of this theory was the adaptive assessment of students' knowledge [6]. More recently, the focus shifted from assessing knowledge to training and teaching students. This led to the development of adaptive tutoring systems like ADASTRA [8], ALEKS[1] [7], and RATH[2] [12].

More recent developments extend the behavioural theory of knowledge spaces by taking latent skills, processes, or competencies into consideration [3]. Albert and Schrepp [4] and Korossy [13] suggest designs of tutoring systems applying such extensions of knowledge space theory.

A number of procedures for obtaining knowledge spaces have been suggested. They can roughly be grouped into three classes: analysis of (mass) data, querying experts, and analysis

[1] See http://www.aleks.uci.edu/
[2] See http://wundt.kfunigraz.ac.at/rath/

of underlying demands, cognitive skills, and processes. An overview has been given by Held et al. [9] (see also [7, 3]).

2 Surmise relations between courses

Albert et al. [2, 5] transferred the concept of surmise relations from the level of items to that of tests, i. e. to surmise relations between subsets of items. In a general approach, two tests A and B are in surmise relation if there exists at least one pair of items $a \in A$ and $b \in B$ such that a and b are in surmise relation. Stricter approaches are *left–covering* (for all $a \in A$ there exists a $b \in B$ such that a and b are in surmise relation) and *right–covering* (for all $b \in B$ there exists an $a \in A$ such that a and b are in surmise relation) surmise relations between tests. Both variants have the advantage that the surmise relations are transitive and, therefore, closer related to order relations. These structures on tests can be useful e. g. for identifying parallel and redundant tests, for newly structuring large sets of items into tests, or for validating theories in developmental psychology.

As Hockemeyer, Albert, and Brandt [11] have suggested, the concept of surmise relations between tests (or subsets of items) can also be applied to and re–interpreted in the field of tutoring. In this interpretation, the items correspond to learning objects (e. g. lessons, examples, and test and training problems), and the subsets of items correspond to courses. Thus, the structures can be applied for improving existing or constructing new courses, or for restructuring complete curricula. The new interpretation also involves different desired properties of the subdivision of items into subsets: while test items should be subdivided into disjoint subsets (i. e. building partitions in a mathematical sense) avoiding redundance, for a subdivision of learning contents into courses there should be overlapping to support learning and memory through repetition. Here, the term *learning contents* refers to different types of learning objects like examples, test and training problems, and lessons.

Regarding special properties of surmise relations between courses, two courses A and B are in a left–covering surmise relation if mastery of all contents of A is needed to be able to learn the contents of B. If any content of A is not performed correctly, at least one content of B cannot be learned and mastered. From mastering the whole course B it can be surmised that all contents of A can be performed. Two courses A and B are in a right–covering surmise relation, if for all contents in B at least some contents of A are prerequisites. Not having attended/visited course A means that nothing from course B can be learned. Of course, two courses A and B can be in a right– and left–covering relation at the same time.

Another important property of surmise relations between courses is the *completeness*: A course A is complete if, for any contents a, b, c with (a, b) and (b, c) being elements of the surmise relation between contents and $a, c \in A$, the condition $b \in A$ holds, i. e. if the upper and lower end of a prerequisite chain are contained in a course, then the whole chain is contained.

This formalization facilitates examining courses for certain criteria, e. g. to find out circular prerequisite relationships between courses, and to restructure the courses. This might involve eleminating single contents, moving contents from one course to another, or splitting or joining courses. The goal of such restructuring would be to obtain a set of courses holding criteria like completeness or a certain amount of overlapping, or a left–covering surmise relation.

Even a single course can be improved by applying these formal concepts in order to improve its importance for other courses, to increase its internal coherence by completeness, to specify prerequisites of the course, etc.

Additionally, the development of the RATH system [12] has proven that the formal approach towards tutoring systems through knowledge space theory and its extensions supports easy connection of different types of learning objects (e. g. lessons, examples, test and training problems) within one mathematical structure.

3 Meta–Information

The usage of meta–information evolved in the context of reusing learning objects. An example can be found in the RATH system where preerequisite relationships are specified through HTML `<link>` tags with a REVerse relationship entry having a *Prerequisite* value [10]. The standardization of such meta–information becomes even more important with the semi–automatic grouping and structuring single objects into larger entities (i. e. grouping documents into lessons, courses, and curricula). Determining knowledge structures directly [9, 7] will not always be possible because of the high costs and efforts involved. Instead, surmise relations will have to be extracted indirectly from meta–information attached to the learning objects. Therefore, we need standardized descriptions of single learning objects that allow to apply certain principles for deriving the structure of sets of learning objects. Psychological and pedagogical methods for analyzing learning objects with respect to their demands and to the necessary skills and processes for their mastery have to be used [3]. After obtaining descriptions through these methods, certain relations, e. g. an inclusion relation, between sets of demands, skills, or processes are computed in order to obtain the relation between learning objects. On the basis of this relation, the surmise relation between courses can be computed [5], and the structure of single courses as well as of whole curricula can be improved.

Currently, standards for the specification of such meta–information are developed in the European ARIADNE project[3] and in the IEEE Learning Technology Standards Committee (LTSC)[4]. For example, the components Prerequisite and EducationalObjective of the EducationalUse sub schema defined in the LOM (Learning Object Metadata) document (version 2.5, [14]) could be used to specify prerequisite relationships in a machine readable way. It may, however, become necessary to distinguish between prerequisite test items and prerequisite teaching items and to include process descriptions. This would require an extension of the schema as provided in the LOM document.

4 Conclusions

Prerequisite relationships between learning contents may be applied for (re-) structuring courses and curricula. Knowledge space theory and its extensions (skill and competency approach; surmise relations between tests) provide an appropriate theoretical framework for this task.

First ideas and concepts for applying surmise relations between courses to the (re-) structuring of curricula have been outlined to foster discussion in an early stage of development. In a next step, procedures for the structuring tasks will be elaborated in more detail, implemented, and integrated into a tutoring system.

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[3]See `http://ariadne.unil.ch`.

[4]See `http://grouper.ieee.org/groups/ltsc/wg-12.htm`.

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