Applying Demand Analysis of a Set of Test Problems for Developing Adaptive Courses

Dietrich Albert & Cord Hockemeyer
Department of Psychology, University of Graz, Austria
Universitätsplatz 2/III, A-8010 Graz, Austria
{Dietrich.Albert|Cord.Hockemeyer}@uni-graz.at

Abstract

Knowledge space theory was already applied for building adaptive testing and training systems which contain test and training problems including their prerequisite structure, and which offer explanations and help for solving these problems. Normally, however, lessons prepare students for solving problems.

In this paper, we present a method for systematically structuring an adaptive eLearning course containing test problems as well as lessons. This method is based on knowledge space theory extended by component-wise representation of problems and on applying demand analysis. A course developed with such a method can be fed into an adaptive tutoring system, realized, e.g., within the adaptive tutoring system RATH.

Theoretical Background

This paper is based on an application of the theory of knowledge spaces and its extensions to building an adaptive tutoring system (ATS). An ATS adapts the learning content to the individual learner, e.g. with respect to the learner's current knowledge. The learner state is assessed through a test or questionnaire, and subsequently learning objects are selected or presented by adapting them to the current learner state which itself may be regularly updated during the learning process.

The theory of knowledge spaces [2, 3] is a psychological model for structuring domains of knowledge based on prerequisite relationships. It was developed aiming at the adaptive assessment of knowledge [3, 4]. Later it was also applied to adaptive training in the ALEKS system [3; see also http://www.aleks.com]. However, ALEKS is limited in that it does not offer genuine teaching by presenting lessons but only explanations for training problems.

Albert and Held applied methods of demand analysis to obtain knowledge spaces for given domains [1, 5]. In a first step, they searched for components of test problems in a certain area, and attributes for these components. Held, for example, found for elementary probability theory problems on drawing balls from an urn as one component the *method of drawing* with three attributes from (1) *drawing one ball*, to (3) *drawing multiple balls without replacement* [5].

In a second step, the *demands* (or *skills*) posed on the learners by the different attribute values were investigated. In the aforementioned example, Held identified four demands related to the attributes for the component *way of drawing* from (a) *knowing the Laplace rule for computing probabilities,* to (d) *knowing that drawing without replacement reduces the number of balls in the urn.* For the three attributes and the four demands specified in the example above, Held found the assignments shown in Table 1.

Table 1: Demand assignments for attributes of *way of drawing*

Attribute	Demands
1	a, b
2	a, b, c
3	a, b, c, d

Based on the demand assignment, the attributes for each component were ordered using the *set inclusion* principle. In this case, Held obtained an order relation $1 \leq 2 \leq 3$. If multiple components have been identified, the problems can be characterized through attribute vectors and can be ordered according to a *component-wise ordering* of these attribute vectors [1, 5].

Developing and Structuring a Course Based on Demand Analysis

Developing and Structuring Lessons

The main tasks for developing a knowledge space based tutoring system are (1) to structure the content into lessons and (2) to find a structure between these lessons. The first task was solved by taking each of the demands identified in Held's analysis of elementary probability theory [5] as content of one lesson imparting the respective skill.

Proceedings of the International Conference on Computers in Education (ICCE'02)
0-7695-1509-6/02 $17.00 © 2002 IEEE

The second, major task was to develop a structure between these lessons. Here, we used in principle the same method as Held did in ordering the attributes of problems. In a first step, we identified for each skill the attributes which demanded the respective skill. Based on the demand analysis according to Table 1, this was done by a simple inversion of the demand assignment as is shown in Table 2. Applying the set inclusion principle to these attribute assignments, we obtained an order relation of skills of the form $a, b \leq c \leq d$.

Table 2: Attribute assignments

Skills	Attributes
a	1, 2, 3
b	1, 2, 3
c	2, 3
d	3

Integrating Lesson Structure and Problem Structure into a Course Structure

The final step in developing and structuring a course based on demand analysis was to merge the problem structure and the lesson (and skill or demand) structure into one course structure.

For this integration, a principal ordering between lessons (and their taught skills) and problems was introduced. For a demand d and a problem q we have $d \angle q$ if, for all attributes a_d assigned to d and the respective attributes a_q of the problem, $a_d \leq a_q$ holds. We obtained an order relation on the complete set of problems and lessons by combining this order $\angle$ between lessons and problems with the two orders within the lessons and the problems, respectively.

A Demonstration of the Structuring Principles

The principles for developing and structuring a course based on demand analysis of a set of problems introduced in the previous sections were applied to produce a course on elementary probability theory. Starting from a set of problems analyzed for demands by Held [5], lessons corresponding to these demands were developed. For most of these lessons, some examples were also developed. The structuring process for lessons and problems described above was applied.

Each lesson, example, and problem was implemented as an own HTML file. These HTML files were augmented with metadata information describing prerequisites. Prerequisites that could be inferred from the reflexivity and transitivity axioms of order relations were omitted. The resulting HTML documents were fed into the adaptive WWW tutoring system RATH [6; see also http://wundt.uni-graz.at/rath/] which is capable of interpreting such prerequisite relationship metadata. The RATH system makes use of these information by hiding links to documents for which the learner does not yet fulfill the prerequisites.

Conclusions

In this paper, we have introduced a method for applying the component and demand analysis of a set of problems for constructing and structuring courses based on extended knowledge space theory. Such courses can then be fed into an ATS thus supporting individualized teaching. A major goal in developing this method was to find an algorithmic way for developing and structuring courses. The proposed method reduces the complex task of course structuring to the much simpler tasks of analyzing single problems for demands, creating respective lessons, and ordering problems and lessons.

Acknowledgements

The work reported in this paper was supported by the European Commission through a Marie Curie Fellowship (Grant No. ERBCHBICT941599) to Theo Held and Cord Hockemeyer for working together with Dietrich Albert.

We are grateful to Harry P. Bahrick for commenting a first draft of this paper.

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