Ability Assessment based on CAT in Adaptive Learning System

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***Abstract*—Ability level of learner is the important dimension of adaptation in adaptive learning system. There are great differences in the capacity dimensions between different learners. Even for each specific learner, his ability level changes in the learning process. In order to more effectively evaluate the learner's ability level and to support the personalized learning, we integrate the Computerized Adaptive Testing (CAT) module into adaptive learning system in this paper. We put forward the architecture of integrating computerized adaptive testing module into adaptive learning system, and analyze the algorithms of adaptive testing based on Item Response Theory and three parameters logistic (3PL) model. Via CAT, the test result updates the learner's ability level in Student Model. So based on the new ability level of learner, adaptive learning system can support the personalized learning with the adaptive content and the adaptive navigation.**

Keywords-computerized adaptive testing; adaptive learning system; ability evaluation; algorithms

I. INTRODUCTION

With the rapid development of e-learning and web2.0, people pay more and more attention to personalized learning. Being intelligent or adaptive is the trend of e-learning platform. [1] Adaptive learning system, in essence, is a kind of online learning environment that supports the personalized learning. And Student Model is the key component of adaptive learning system, which records the learning goal, preference, learning style and the ability level of learner. When learner interacts with the system, adaptive learning system can dynamically support adaptive content based on the Student Model, and meets the needs of individual learning. So ability level of learner is a very important dimension of adaptation in adaptive learning system. However, there are great differences in the ability dimensions between different learners. Even for each specific learner, his ability level changes in the learning process. In general, most e-learning systems use the traditional computer-based testing (CBT), which is the linear testing with the fixed test items in the specified order during a testing session. The linear testing includes a full range of easy and difficult test items. All learners do the same test items. That approach imitates the paper-and-pencil test in digital format and pays no attention to the ability of each learner. In order to more effectively evaluate the learner's ability level and supports the personalized learning, we integrate the Computerized Adaptive Testing (CAT) module into adaptive learning system and analyzed the adaptive testing algorithms based on the Item Response Theory in this paper.

II. COMPUTERIZED ADAPTIVE TESTING

Computerized adaptive testing is based on item response theory (IRT), which is a robust theory in education assessment. Computerized adaptive testing was formally proposed by Lord in 1980. [2] Computerized adaptive testing select the most appropriate test items for learner based on the learner's ability. [3] After the learner answers the test item, the learner's ability is dynamically assessed based on the learner's answer. In more precise terms, computerized adaptive testing is an iterative algorithm that starts with an initial estimation of the learner's ability level and has the following steps [4]:

(1) All the questions in the test item bank are examined to determine which will be the best to ask next according to the current estimation of the learner's ability level.

(2) The question is asked, and the learner responds.

(3) According to the answer, a new estimation of the ability level of learner is computed.

(4) Steps (1) to (3) are repeated until the termination condition defined is met.

The CAT not only can efficiently shorten the testing time and the number of testing items, but also can improve the precision of testing.

III. INTEGRATING CAT MODULE INTO ADAPTIVE LEARNING SYSTEM

In general, adaptive learning system is composed of domain model, instruction model, adaptive model, student model and the user interface. In order to more effectively evaluate the learner's ability level and supports the personalized learning, we integrate the computerized adaptive testing (CAT) module into adaptive learning system. The novel architechture of CAT in adaptive learning system is illustated in figure 1. The computerized adaptive testing (CAT) module includes the test item bank, item generation module (IGM), adaptive testing interface, test record

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database. The basic principles of system are described as follows: First of all, according to the domain model, teachers set up the test item bank and determine the item parameters. Secondly, given a default value of the learner's ability level, item generation module determines which test item will be the best to ask next according to the current estimation of the learner's ability level. After the learner answers the test item, item generation module calculates the new ability vaule according to the learner's response. Then item generation module chooses the next test item based on the new ability value. The process of adaptive testing loops untill the termination conditions defined are met. The test data is saved in the test record database. Thirdly, adaptive learning system updates the Student Model according the result of adaptive testing, and provides the adaptive content and the adaptive navigation suppport according to the new ability level of learner in student model.

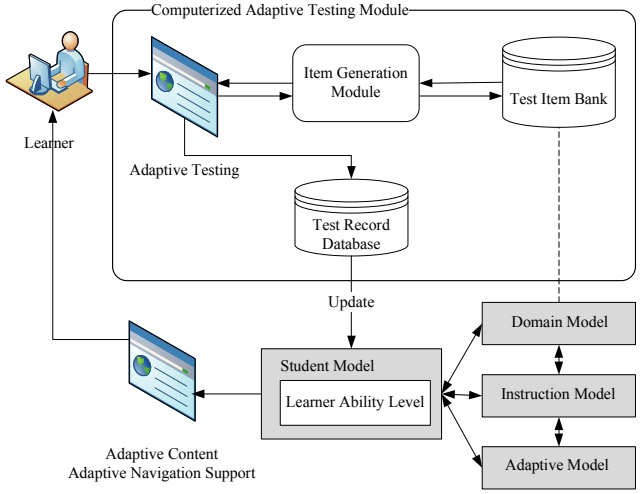

Figure 1. Architechture of CAT in adaptive learning system

A. Item response model

Item response model is a mathematics model, which is used to express the item characteristic curve. Among the existing item response model, the three parameter logistic (3PL) model is one of the most commonly used models. The 3PL model equation is shown below:

$$p_i(\theta) = p_i(u_i = 1 \mid \theta) = c_i + (1 - c_i)\frac{1}{1 + e^{-1.7a_i(\theta - b_i)}} \qquad (1)$$

Where $u_i = 1$ indicates that a test item i is answered correctly by a learner, $p_i(\theta)$ is the conditional probabilities of a correct response to test item i, θ is the ability of the learner, a_i is the item discrimination, b_i is the item difficulty, c_i is the guessing parameter.

B. Test item bank

Test item bank is the important component of CAT module, which is a collection of test items. Each test item includes the content, difficulty parameter, discrimination parameter, and guessing parameter and so on. In order to improve the effect of CAT, test item bank should meet two basic conditions: (1) test item bank must have sufficient test items to supply informative test items during a test session, and (2) the item bank must provide adequate test items covering different topics and difficulty levels.

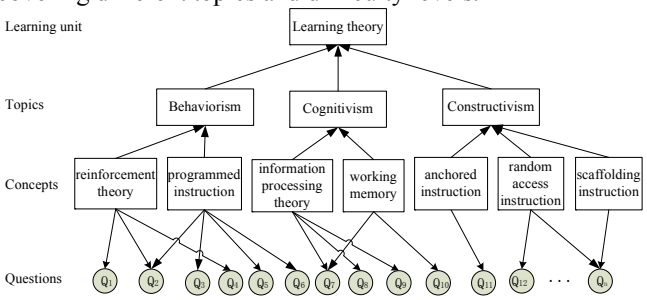

Figure 2. Test items generation by knowledge tree

The test items are established based on the domain knowledge tree, which is illustrated in figure 2. First of all, domain knowledge is divided into the three levels, including learning unit, topic and concept, which are organized as a knowledge tree. Then the test items are generated according to the internal relations and weight of concepts in the knowledge tree. For every test item, the test item bank includes the item's content, correct answer, difficulty, discrimination, and the guessing parameter. In our test items bank, the difficulty is divided into five levels, including the very easy, easy, medium, difficult and very difficult, the corresponding value in the range of -2 to +2.

C. Item generation

Item information function (IIF) is considered as an important value in the process of item selection based on item response theory. IIF shows the amount of information about the test item conditioned on the ability of leaner. Before selecting a question appropriate to the learner, IIF for all the questions in the assessment should be calculated and the question with highest value of IIF is presented to the learner. The Item Information Function is shown as follow [5]:

$$I_i(\theta) = \frac{[P_i'(\theta)]^2}{P_i(\theta)Q_i(\theta)}, \quad i = 1,2,3,\ldots,n \qquad (2)$$

Where $I_i(\theta)$ is the information function of the test item i conditioned on the ability (θ), and $P_i'(\theta)$ is the first derivative of $P_i(\theta)$, and $Q_i(\theta) = 1 - P_i(\theta)$. We take the 3PL model into the IIF, and the IIF of 3PL model after simplification is shown as follow:

$$I_i(\theta) = \frac{1.7^2 a_i^2 (1 - c_i)}{[c_i + \exp(1.7a_i(\theta - b_i))][1 + \exp(-1.7a_i(\theta - b_i))]^2} \qquad (3)$$

D. Ability estimation

Once a test item is answered by the learner, CAT module will automatically evaluate the ability of learner.

What the most commonly used to evaluate ability is Maximum Likelihood Estimation (MLE). Under the local conditions independence assumption, we first assume that a learner responds to a set of n test items with response matrix $U=[u_1,u_2,u_3,\ldots,u_n]$, if $L(u_i \mid \theta)$ represents the conditional probability of response u_i on test item i conditioned on the ability θ, then Likelihood function is shown as follow: [6]

$$L(u_1,u_2,\ldots,u_n \mid \theta)=\prod_{i=1}^{n} P_i(\theta)^{u_i}(1-P_i(\theta))^{(1-u_i)} \quad (4)$$

Where $u_i=1$ represent the correct response, and $u_i=0$ represent the wrong response.

Given a default value of ability, the estimation calculation approach is the modification of the Newton-Raphson iterative method outlined by Lord. The estimation equation is illustrated as follows:

$$\theta_{n+1}=\theta_n+\frac{\sum_{i=1}^{n} S_i(\theta_n)}{\sum_{i=1}^{n} I_i(\theta_n)} \quad (5)$$

Where

$$S_i(\theta)=[u_i-P_i(\theta)]\frac{P_i'(\theta)}{P_i(\theta)[1-P_i(\theta)]} \quad (6)$$

Where θ_{n+1} represents the ability level value after the learner answered n test items.

E. Termination condition

In general, termination condition is the precision of measurement, the test time, and the number of test item or a combination of them. The precision of measurement is represented by the standard error which is given by the equation:

$$SE(\theta)=\frac{1}{\sqrt{TI(\theta)}} \quad (7)$$

Where

$$TI(\theta)=\sum_{i=1}^{n} I_i(\theta) \quad (8)$$

Where $TI(\theta)$ is the test information function that is the sum of the value of IIF. Commonly, when the standard error of CAT is about 0.33 or smaller, the test will be terminated.

IV. System Implementation

The CAT prototype system Met-CATS is developed based on ASP.NET and Visual C#.NET according to the three-tier architecture. The test item bank is a database in Microsoft SQL Server 2000.

In Met-CATS, the learner ability is ranged from -3 to 3, and the default value is 0. According to the default value, system randomly selects a test item which is the medium difficulty from -0.5 to 0.5. If the standard error of this CAT experiment is 0.45 or smaller, the test will be terminated. The process of ability evaluation in a random test experiment is illustrated in figure 3. With the number increase of test items, the ability value of learner becomes gradually convergence, and the standard error gradually reduce. After finished 9 test items, the standard error is smaller than 0.45, so the test ends. And the result of ability of this learner is 1.241.

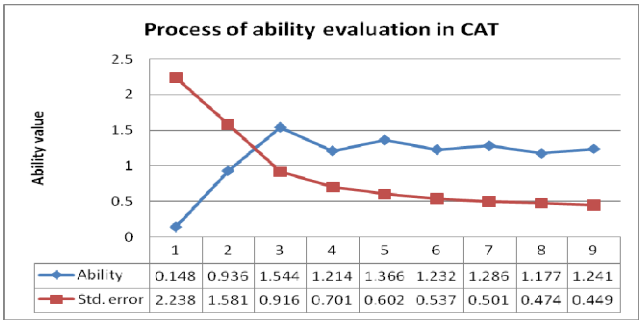

Figure 3. Process of ability evaluation in CAT

The CAT module is very useful in adaptive learning system. After finished the learning unit, learner can evaluate his ability level via CAT. The test result updates the student model in adaptive learning system. And system can understand the overall master degree on the specified learning unit, as well as analyze the grasp situation on each concept that the current topic includes.

V. Conclusion

Adaptive learning system is an online learning environment that supports personalized learning. Ability level of learner is the most important dimension of adaptation in adaptive learning system. In this paper, we regard computerized adaptive testing as a new ability evaluation method for e-learning. We put forward a novel architecture of CAT in adaptive learning system, which integrate the computerized adaptive testing module into adaptive learning system, and then analyze the establishing method of test items bank based on the domain knowledge tree. And discuss the adaptive testing algorithms, including the item generation, ability evaluation, and termination conditions. The Met-CATS is prototype systems embed the computerized adaptive testing module. Experiment shows the CAT module in adaptive learning system run soundly. In future work, we will research the adaptive mechanism in adaptive learning system according to the ability level of learner.

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