Considering Human Memory Aspects for Adaptation and Its Implementation in AHA!*

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Abstract. Existing adaptive learning systems use various user characteristics for preparing personalized presentation of educational material for each user (a student). In the process of learning limited capacity of the human memory plays important role. The student often forgets part of knowledge acquired during the learning. In this paper we discuss implications of remembering and forgetting for the adaptive learning systems. We present a proposal of modeling forgetting process in adaptive learning systems that enables including knowledge repetition into an educational course. We implemented proposed model within the web-based adaptive system AHA! and demonstrate its viability on domain of learning English-Slovak vocabulary. This includes also a technique for inserting concepts for knowledge repeating into a running direct guided course. Using this technique it is possible to dynamically adapt the sequence of presented concepts to the actual state of the user model.

1 Introduction

Adaptive learning systems constitute one of the main areas where adaptive web technologies are used [1]. Their aim is to adapt the presentation of knowledge or navigation within the educational information space to serve effective learning. Current adaptive learning systems recognize several aspects of a user – user characteristics – used during the adaptation, such as user's goals/tasks, level of knowledge, background, preferences, interests, or user's individual traits [2]. Important aspect considered in adaptive learning systems is undoubtedly a level of the user's knowledge related to the learned topic (in the IEEE Personal and Private Information [3] learner profile denoted as the learning performance).

The user's characteristics are represented in a user model. The user model reflects current state of user knowledge related to the presented information as it is comprehended by the adaptive learning system. The user's characteristics

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change (evolve) in the course of learning in accordance with changes of current state of his knowledge (as evaluated by the adaptive learning system). However, most current adaptive learning systems assume that the amount of user knowledge only grows. But increasing knowledge (as a consequence of the remembering) is not the only process. The user can also *lose* (e.g., forget) some of already acquired knowledge. The remembered knowledge is not stored in the human memory forever but in the course of time the knowledge can (and some of them will) drop out from the memory.

Considering remembering and forgetting is important for effective learning process [4]. We presume that a utilization of the human memory aspects while developing an adaptive learning system would also improve the effectiveness of its usage through an improvement of the learning process. Assume for example the following situation: the adaptive book "presumes" that a user possesses adequate knowledge (prerequisites) for understanding a concept just explained. In spite of truly learned concept some time ago, now – after some time passed from this learning session – the user forgot some of the previously acquired knowledge (because of long time without any repeating). The knowledge forgetting causes inconsistencies between the user model as represented in the adaptive learning system (which does not consider the remembering and forgetting in user modeling) and the actual state of the user's knowledge. As a result, we will likely observe incorrect recommendation to the user.

Considering specific characteristics of the human memory can prevent described situation and improve support of learning process by a learning system. In this paper we discuss some issues related to the human memory and implications for adaptive learning systems. We consider the human memory as an aspect of the user's background modeled in the user model. We present a proposal for modeling the forgetting process using current adaptive web-based systems technology together with its implementation for the AHA! system.

The rest of the paper is organized as follows. In the Section 2, we briefly present known facts from psychology about the human memory and the processes of remembering and forgetting. Next, in the Section 3, we give proposal for modeling the forgetting process in adaptive learning systems. Section 4, presents approaches to knowledge repetition. We present a method for dynamic adaptation of the sequence of presented concepts according to findings related to knowledge repetition. Implementation of proposed model within the web-based adaptive system AHA! and demonstration its viability on the domain of learning English-Slovak vocabulary is presented in the Section 5. Finally, we give conclusions and directions for future research.

2 Human Memory and Its Characteristics

The human mind can be viewed as an information processing system. Its architecture is thought to consist of three basic components according the Atkinson-Shiffrin model [5]: sensory memory, working memory and long-term memory. These components roughly correspond to the input (the human mind perceives information from the outside through the senses), processing (information from the sensory memory is processed in the working memory) and storage (processed information is stored in the long-term memory) (see Fig. 1). Naturally, information stored in the long-term memory can be accessed, or activated to help with the processing in the working memory. Accessing information is perceived as the remembering that can be viewed as a usage of the system (ability to find information later again, i.e., to perform information retrieval). Every time we use information from the long term memory this information is repeated. This process is called rehearsal. Described view provides a useful basis for considering the human memory characteristics during the learning [4].

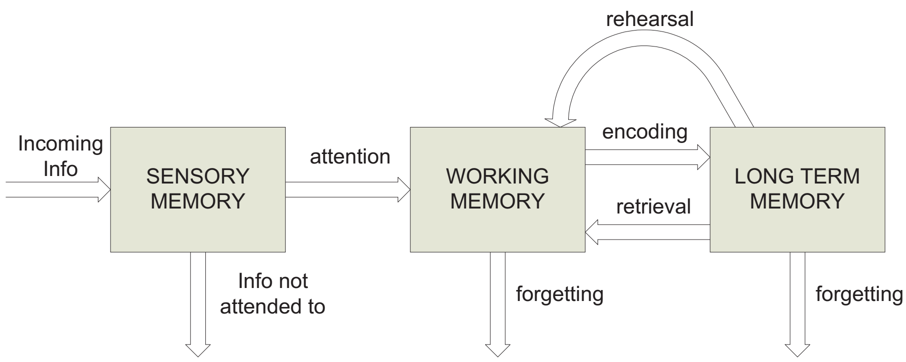

Fig. 1. Human memory model.

In order to use the human memory aspects for improving the effectiveness of learning through adaptive learning system it is important to know its characteristics. One of the most important characteristics of the human memory is the capacity of the working memory. Its size is well known as the "magical number seven plus or minus two" [6] describing the number of distinct items Miller thought humans could hold in the working memory at any time. In addition, information stored in the working memory can be looked up much faster than in the long-term memory. However, the working memory is characterized also by a relatively brief duration (estimates range from 12 to 30 seconds without a rehearsal), which results in the information loss known as forgetting.

The forgetting is viewed primarily as a consequence of:

- fading (trace decay) over time,
- interference (overlaying new information over the old) or
- lack of retrieval cues.

Function of the volume of remembered information depends on time and has a character of falling an exponential curve. So called the *forgetting curve* was first described by Ebbinghaus in 1885 [7]. To test the retention, Ebbinghaus practiced a list of information items until he was able to repeat the items correctly two times in a row. He then waited varying lengths of time before testing himself again. The forgetting turned out to occur most rapidly soon after the end of practice, but the rate of forgetting slowed as time went on and fewer items could be recalled.

Figure 2 displays typical graph of the forgetting curve. It shows that an individual loses most of the learned information items in first hours (after 9 hours was on average remembered less than 36% information items). After this time is the oblivion less intensive (in average still more than 33% after 24 hours and a bit lesser than 20% after month).

The forgetting can be roughly described with

$$R = e^{-t/S}$$

where R is memory retention, S is relative strength of the human memory and t is time.

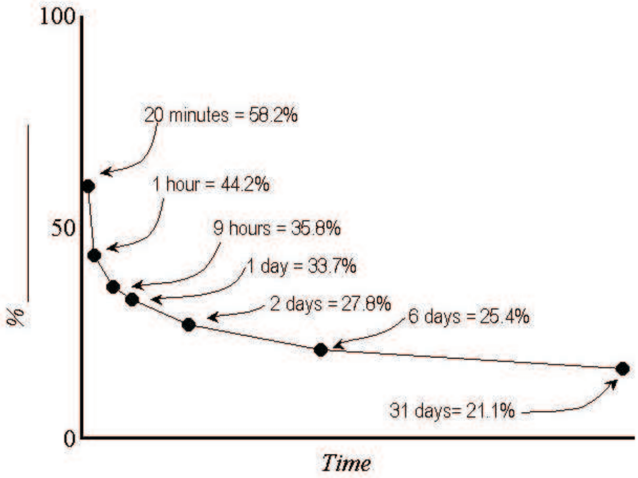

Fig. 2. Forgetting curve.

Graph on Figure 2 is typical, i.e. related to a human without health problems affecting his memory. Otherwise the curve should be adjusted to the human memory characteristics of such a person. The adjusting process is rather difficult and can be done only experimentally (by an analysis of user behavior). Moreover, the forgetting rate differs little between individuals generally. We believe that this issue is not critical for adaptive learning systems as individual differences can be modeled by setting several levels of the rate at which a user has worked with particular knowledge. Important issue is already considering the forgetting and defining means for estimating the probability that the user have not forgotten an information represented by particular concept.

For the integrity, let us notice that the information items loss can also have biological reasons. It is possible that some biological processes necessary for encoding, storing or searching are disrupted. For example, in a process of embedding knowledge in the memory some structures of brain including hipocamp and amygdala are active. Their mutilation has a negative influence on the process of remembering.

3 Forgetting Modeling in Adaptive Learning Systems

We model the forgetting of information items in the user's memory as an application of the forgetting curve. However, using only the forgetting curve directly is insufficient because we can only infer how much per cent from the original grist of the information items has been remembered in some point of time and we cannot recognize whether specific information item in a given point of time *is remembered* or has been *lost*. In this case we can say only that the information item (learned at time t and not repeated) is remembered with high probability (if according to data about the user's memory-losing at time t is remembered more than K% of learned information items, e.g. more than 90%) or lost with high probability (likewise).

Our proposal is to augment the overlay user model of an adaptive learning system in order to reflect the forgetting by extending every concept's traditional performance value from the user model (e.g., *knowledge* attribute in AHA!) with the retention value (expressing how much is the knowledge remembered). We call it *activity_in_memory*. So every knowledge (represented by a concept in the domain model) has defined for each user a pair of values:

- performance value (from original model) and
- activity in the memory (newly added).

The *activity_in_memory* value is represented by an integer number from a specified range (e. g. $< 0; 100 >$). The greater is the value of *activity_in_memory* there is higher probability that the user's performance value related to the concept corresponds to the value presented within particular concept. Its value must be upon given bound AM, otherwise the knowledge represented in the concept is considered as being *forgotten* by the user. After a successful learning (e.g., concept is visited or a test is passed successfully) the corresponding concept is set as "learned" (performance value is set using standard adaptation rules of the adaptive learning system accordingly) and the *activity_in_memory* attribute is raised. On the other hand, according time passed from the learning of the concept the *activity_in_memory* attribute value decreases according forgetting curve.

In order to reflect the forgetting curve accurately we use the *access_time* attribute for each concept in the user model. This attribute stores the date and time of the last visit of the concept. Worthy results can be achieved also by reflecting the forgetting curve simply by decreasing the *activity_in_memory* attribute value after every new user's session for every concept not being used in the session [8] (i.e., without considering real time passed).

Modeling the forgetting process is performed by the adaptation engine using mentioned attributes defined for each concept for each user in the user model. With every visit to a concept the *activity_in_memory* attribute is raised and the *access_time* attribute is set to the actual date and time. We simulate the forgetting by decreasing the value of the *activity_in_memory* attribute after every user login to the adaptive learning system (at the beginning a session).

For every concept in the user model three steps are performed:

1. Calculation of the time t elapsed from the last access to the concept:
$$t = current\_time - access\_time$$
2. Calculation of the $forgetting\_factor$, which represents an output value of the function expressing the forgetting curve (R):
$$forgetting\_factor = R(t)$$
The $forgetting\_factor$ is a value from the range $< 0; 1 >$ representing probability that the information is remembered after the time t passed from the learning of the information item.
3. Modification the *activity_in_memory* attribute:
$$activity\_in\_memory = activity\_in\_memory * forgetting\_factor$$

The *activity_in_memory* attribute value is calculated for each concept and then it is used for more accurate adaptation that considers possible losing information according time passed. One specific usage is including a repetition in the process of learning.

4 Knowledge Repetition

The speed of forgetting depends on a number of factors such as the difficulty of the learned material (e.g., how meaningful for particular user it is), its representation and physiological factors such as stress. Failing to remember something does not mean the information is gone forever though. Sometimes the information is in the human memory but for various reasons we cannot access it. In this case a repetition can help in regenerating forgotten knowledge. Already Ebbinghaus discovered that distributing learning trials over time is more effective in memorizing than massing practice into a single session; and he noted that continuing to practice material after the learning criterion has been reached enhances retention.

Repeating using the elaborative rehearsal which in contrast to maintenance rehearsal involves deep semantic processing of a to-be-remembered information item[1] is more effective [9]. The maintenance rehearsal involves only simple rote

[1] For example, if an individual is presented with a list of digits for later recall (4968214), grouping the digits together to form a phone number transforms the stimuli from a meaningless string of digits to something that has a meaning.

repetition aiming at lengthening periods of time the information item is maintained in the working memory. The elaborative rehearsal can be supported by guidelines.

We have proposed several techniques of repetition for adaptive learning systems using the forgetting model presented in previous section:

- repeat when there is an evidence of certain amount of the knowledge considered as forgotten (*periodical repetition*),
- repeat at the beginning of a new lesson the knowledge learned in the previous lesson (*overall introductory repetition*),
- repeat at the beginning of a new lesson the knowledge (assumed) necessary in this lesson (*necessary introductory repetition*),
- repeat at the end of a lesson the knowledge learned in the lesson (*final repetition*).

Selection of particular technique can be supported by adaptive learning system based mostly on evaluation of student's performance. Leaving an option to select the repetition technique for a user is also useful, mainly due to impossibility of precise modeling of particular user.

Often it is not practical or possible to repeat all of the knowledge items marked as forgotten. The adaptive learning system should select a set of knowledge items for the repetition. Certain number of the concepts representing the knowledge items is selected and only these concepts are repeated at the beginning of a new lesson. If there is large number of the lost knowledge the adaptive book offers a repetition-lesson, aimed for the repetition only.

Concepts for repetition are sequenced using the following steps:

1. select the concepts according the type of repetition used[2]:
   - set of concepts from the previous session (overall introductory repetition),
   - set of concepts from current session (final repetition),
   - set of prerequisites for the concepts in the current session (necessary introductory repetition),
2. filter the concepts they have the *activity_in_memory* value lower than the value of given bound AM,
3. sort the filtered concepts respecting the relations between concepts defined in the domain model (e.g., prerequisite relation),
4. generate the sequence of presented concepts.

Sequencing concepts for repetition can be based on several criterions, for example: random sequencing, sequencing based on time of the acquisition an information item (priority is given to the information item acquired longer time ago), sequencing based on a measure of remembering, i.e., the *activity_in_memory* value is used (priority is given to the information item with lower activity in

[2] The set of concepts considered for periodical repetition can vary from all concepts, concepts included in particular part of the knowledge space as the point is to invoke the repetition when the amount of forgotten knowledge exceeds predefined bound.

the memory), sequencing based on prerequisite-dependencies (priority is given to the information item which is supposed to be in the need of the user in the next study time).

A repetition can be combined effectively with local guidance adaptation technique to support adaptive navigation. 'Forward' links (realized for example using the "Next" button) determined by standard adaptation mechanisms are dynamically completed by links to the concept with low *activity_in_memory* attribute value.

5 Implementing the Human Memory Considerations in AHA!

In order to evaluate proposed approach for modeling of the forgetting process in adaptive learning systems we decided to use the an open source general-purpose adaptive system AHA! developed and maintained at the Eindhoven University of Technology [10]. We enhanced it in such a way that adaptation according the forgetting curve supplements existing adaptation techniques used in the AHA!.

We looked for an application where we can presume some "minimal amount of knowledge" delivered to the user via the adaptive learning system because the effect of the knowledge forgetting process becomes significant with only relatively large knowledge spaces. Suitable application domain in this sense is the domain of learning foreign language vocabulary. Here we have possibly large amount of concepts (each word is considered as a concept) with possibility of exercising various approaches to knowledge repetition.

5.1 Domain model

Domain model consists of concepts and their relationships. Our English-Slovak vocabulary course is structured into lessons, one lesson is divided into several parts in such a way that every part includes at most fifteen words. For individual access to the words each word is represented by one concept in the domain model. That enables us to simulate the forgetting of each word individually. Figure 3 depicts a screen of Graphical Editor tool for AHA! with a part of the domain model.

The AHA! system uses templates for determination which attributes the concept has, and whether it must have a resource associated with it or not [11]. For our course we created a concept template representing one word from the vocabulary with the attributes according the model of forgetting presented in the Section 3.

In AHA! the concept attribute type can be only boolean, integer or string. For our needs it is important to work with date and time in the case of the *access_time* attribute. We decided here for the purposes of evaluation of proposed approach to modeling the forgetting to store the *access_time* attribute as a string value. The data conversion is performed at the source code level. The

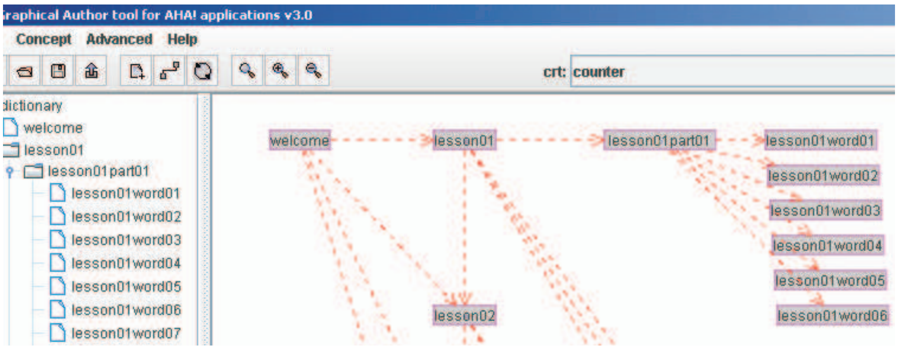

Fig. 3. Concepts of English-Slovak vocabulary domain.

activity_in_memory attribute has a type of integer and it acquires in our prototype application values from a range $< 0; 1\,000 >$ for accurate calculations (the range is optional). The bound value AM for determining a level of information item activity in the memory considered as forgotten has a type of integer.

Repetition is best provided using local guidance technique. The user is provided by a sequence of concepts that are advised to be repeated. In order to realize this technique in the AHA! system, we added into the domain model new attribute named *next_concept* of type string. This attribute is used to represent the name of the concept to be presented next in the dynamically created sequence. After the user selects type of repetition the adaptive learning system generates the sequence of concepts for this user. The system filters the concepts intended for repeating. This set of concepts is then included in the generated sequence according to the type of repetition.

Bellow we show part of the word template.

```
<?xml version="1.0"?>

<!DOCTYPE template SYSTEM 'template.dtd'>
<template>
<name>word page concept template</name>
<attributes>
  ...
  <attribute>
     <name>access_time</name>
     <description>time of last visiting the concept</description>
     <default>NA</default>
     <type>string</type>
     <isPersistent>true</isPersistent>
     <isSystem>false</isSystem>
     <isChangeable>false</isChangeable>
  </attribute>
  <attribute>
     <name>activity_in_memory</name>
```

```
    <description>activity in the human memory</description>
    <default>0</default>
    <type>int</type>
    <isPersistent>true</isPersistent>
    <isSystem>false</isSystem>
    <isChangeable>false</isChangeable>
  </attribute>
  <attribute>
    <name>next_concept</name>
    <description>name of next concept in generated sequence</description>
    <default></default>
    <type>string</type>
    <isPersistent>true</isPersistent>
    <isSystem>false</isSystem>
    <isChangeable>false</isChangeable>
  </attribute>
</attributes>
 ...
</template>
```

5.2 User model

AHA! uses an overlay user model, i.e. every concept from the domain model is defined also in the user model. The value of each attribute for particular user is stored in the user model. To consider the human memory aspect it is inevitable to maintain values of the *activity_in_memory* and *access_time* attributes for each concept from the domain model and each user.

5.3 Adaptation process

In modeling the forgetting process in an adaptive learning system it is crucial to define the process of updating values of *activity_in_memory* attribute. On the beginning of a new session the *activity_in_memory* attribute of all words (each represented as a concept) in the user model (for the currently logged in user) are modified. In AHA! the user model of a single user is stored in an XML formatted file. So the modifications are done in this file. After the user has logged in the java servlet `Get`, the system executes the user model update for this user before the first concept (welcome page) is presented to him. The update process follows the steps of calculating *activity_in_memory* attribute value presented in the Section 3.

We added java servlet `GenCourseSequence` that generates the sequence of presented words (concepts) according selected type of the repeating. This process follows the steps presented in the Section 4. The `GenCourseSequence` servlet redirects the control to the `Get` servlet with the name of first word from the generated sequence as parameter. The sequence diagram presenting main communication performed during the process of the user model update and a sequence of concepts generation is presented in Figure 4.

AHA! allows a user to navigate through the vocabulary using a tree-view over the course structure. We used the link annotation adaptation technique of AHA! to indicate a word considered forgotten. The name of already practiced (i.e., visited) word is displayed using violet color. The value of the *visited* attribute for all words considered forgotten is changed to false during the generating the sequence of concepts for presentation. Annotations of such words are changed in the tree-view to blue color.

During the session after every concept visit (presenting a word to the user) the *activity_in_memory* attribute of this word is increased by a constant value. Also the *access_time* attribute of this word is set to the current date and time.

For presenting a word from the vocabulary we use XHTML files with a form tag to allow processing the data from the page later on. For example, we allow the user to rate his knowledge about the word. This value is then used to evaluate his knowledge level of the English/Slovak word in the vocabulary. The action attribute of the form tag contains a concept name or a string constant value *this.next_concept*. In the first case, the form will be submitted to the listed concept. In the latter case, the destination concept is obtained from the *next_concept* attribute of the currently presented concept. This option is used for the dynamically generating sequence of concepts.

6 Conclusions

The research presented in this paper addresses the possibility of improving effectiveness of learning using adaptive learning system by considering the human memory characteristics. Important aspect is limited capacity of the working memory. We discussed impacts of the human mind nature to the adaptive learning systems. We proposed an approach for modeling the forgetting process together with its usage in adaptation and we realized it in the AHA! system. The base for modeling is the forgetting curve. The forgetting curve can be tuned individually for each user which can result in more effective repeating by utilization of individual differences. At the moment we provide one forgetting curve for all users. Our application of English-Slovak vocabulary teacher proved that in most cases this approach is for such application domain sufficient.

Proposed approach ensures that the repeated knowledge or knowledge more used are being lost more slowly. The knowledge-forgetting model can be supplemented by including hierarchical binds between the knowledge items in a domain. Hierarchical organization of the learned material together with properly defined the prerequisite relation can improve the information access and enables the effective usage of limited capacity of the human working memory. This can be reflected by propagation the *activity_in_memory* attribute value considering the information space structure. We plan to experiment with this issue in our learning course for programming languages [12].

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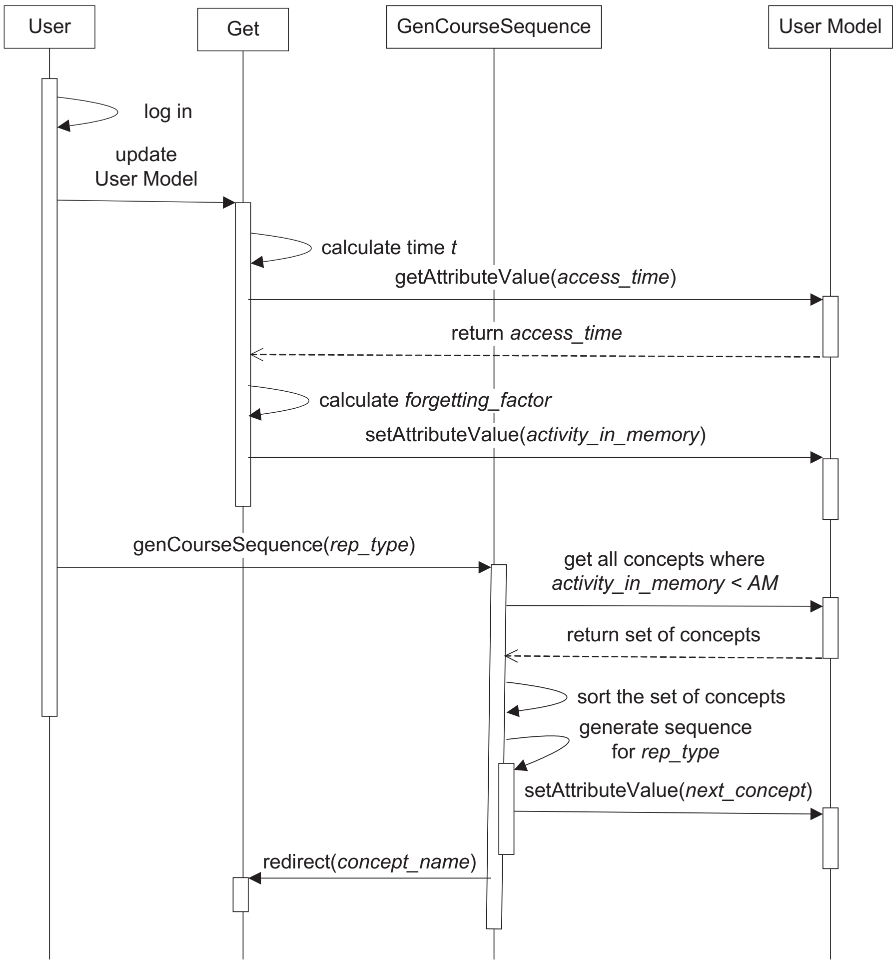

Fig. 4. AHA! servlets operations.