Considering Human Memory Aspects to Adapting in Educational Hypermedia*

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Abstract. In this paper we target the limited capacity of the human memory while developing adaptive educational hypermedia systems. We discuss implications of remembering and forgetting for the adaptive hypermedia systems development. The forgetting is characterized as a consequence of time passed between two learning events. Knowledge from psychology is used for stating implications of the human memory properties for an improvement of the adaptive learning systems. An experimental implementation of the model of remembering and forgetting is described.

1 Introduction

Current adaptive educational hypermedia (AH) systems recognize several aspects of an individual user such as user's goals/tasks, knowledge, background, preferences, interests, or user's individual traits [4]. Important aspect considered in educational AH systems is undoubtedly a level of the user's knowledge related to the learned topic (in the IEEE Personal and Private Information [8] learner profile denoted as the learning performance). The user model reflects current state of the user knowledge related to the presented information as it is comprehended by the AH system. The user's characteristics change (evolve) in the course of learning in accordance with changes of current state of his knowledge (as evaluated by the AH system).

Most current AH 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 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.

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Considering mentioned characteristics of the learning process is important during the learning [10]. We presume that a utilization of the human memory aspects while developing an educational AH system would also improve the effectiveness of the AH system 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 event – 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 AH system (which does not consider the remembering and forgetting in an adaptation of the educational material to the individual) and the actual state of the user's knowledge. As a result, we will likely observe incorrect recommendation of the educational AH system.

Described situation occurs due to not considering specific characteristics of the human memory. In this paper we describe some issues related to the human memory and implications for adaptive hypermedia. We consider the human memory as a new aspect of the user's background modelled in the AH system user model. We give several suggestions for increasing effectiveness of the AH system, especially educational AH systems. In the paper we presume some "minimal amount of knowledge" delivered to the user via the AH system because the effect of the knowledge forgetting process becomes significant with only relatively large knowledge spaces.

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. In the next section, we discuss implications of the human memory characteristics for adaptive hypermedia and propose a model, which considers the human memory characteristics. Finally, conclusions and further directions of our research are stated in the Conclusions.

2 Background of human memory models

The human mind can be viewed as an information processing system. Its architecture is thought to consist of three basic components: sensory memory, working memory and long-term memory [2]. 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 (to be able to find information later again). This view provides a useful basis for considering the human memory characteristics during the learning process [10].

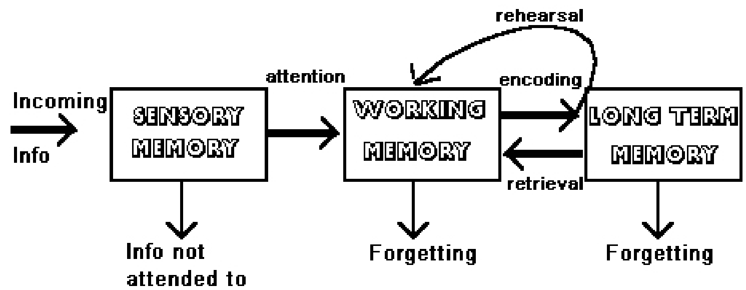

Fig. 1. Model of human information processing system [2].

Information stored in the working memory can be looked up much faster than in the long-term memory. The working memory is essential for reading comprehension. Frequently, the read sentence is related to the previous sentences, so the new sentences are considered along previous according their sense. It is believed that this process is accomplished in the working memory (as a consequence people with higher capacity of working memory are able faster understand a text).

One of the most interesting and significant characteristics related to the human mind is the very small capacity of the working memory known as the magical number "seven plus or minus two" [9]. The limited storage capacity of the working memory is accompanied also by a relatively brief duration (estimates range from 12 to 30 seconds without a rehearsal), which results in the information loss.

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.

The information loss can be prevented by means of repeating. Here the elaborative rehearsal which in contrast to maintenance rehearsal involves deep semantic processing of a to-be-remembered information item[1] is more effective [6]. The maintenance rehearsal involves only simple rote repetition aiming at lengthening periods of time the information item is maintained in the working memory. The elaborative rehearsal can be supported by guidelines.

Accessing an information item can be influenced by several factors. Time of searching the information item can be cut down with a good guideline. But the effect of a guideline degrades with the rising number of information items bound with the guideline. Expectant reason is that the system of guidelines brings a hierarchical organization of the information items. The benefit is that the search is performed on the smaller file of information items. However, every new related information item enlarges the file and aggravates the hierarchy.

[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.

Mentioned factors imply the forgetting. 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. It was showed that an individual lost most of the learned information items in first hours (after 8 hours was on average remembered less than 40% information items). After this time is the oblivion less intensive (in average still more than 30% after 24 hours and a bit lesser than 30% after month). Ebbinghaus also 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.

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 Some implications for adaptive hypermedia

While designing an educational adaptive hypermedia system we can take an advantage of knowing characteristics of both working and long-time memories. Considering the human memory along other aspects of the student's background brings several assets:

- more accurate information about the state of the user's (student's) knowledge,
- better aid for remembering the knowledge and automatic repetition of lost knowledge,
- more effective (adaptive) assistance for students with memory-problems, or in opposite, assistance for students with more-than-average memory abilities.

First two items are related to the effectiveness of delivery of the educational material by the AH system in general. The last item enables to accommodate individual differences in the human memory capacity for personalization.

To achieve mentioned assets several techniques can be used. The most important are:

- hierarchical organization of the learned material – improves the information access and enables the effective usage of limited capacity of the working memory,
- guidelines for effective information searching – helps to overcome an interference between the information items,

- forming linkages between the concepts (natural or artificial) – results in a possibility of elaborative rehearsal and better structuring of the knowledge space,
- measuring understanding the sense of knowledge (or measure the usage of the knowledge) – helps in planning of the repeating,
- considering a context of the environment – helps to decrease the amount of information items considered at the time by giving contextual cues.

Some of the techniques are already used in designing educational adaptive hypermedia systems or authoring their content [5].

Following discussion is based on our experiments with the adaptive book on computer architecture where we applied knowledge on the human memory characteristics [1]. Our proposals can be easily incorporated to various adaptive hypermedia educational systems.

3.1 Modeling the process of remembering and forgetting

The simplest method of modeling the remembering and forgetting information items in the student's memory is an application of the forgetting curve [7]. 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. However, we cannot recognize whether specific information item in a given point of time *is remembered* or has been *lost*.

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).

We have proposed a simple model which reflects the forgetting. It extends every concept's traditional performance value from the user model [8] with data about how much is the knowledge remembered. We call it *knowledge activity in the memory*. Every knowledge (represented by a concept in the domain model) has defined the knowledge activity in the memory represented by a real number. It's value must be upon given bound B, otherwise the knowledge represented in the concept is considered as being *lost* (from the user's memory). After a successful learning the corresponding concept is set as "learned" and the knowledge activity in the memory is set to a value greater than B. Moreover, after every new user's session with the AH system, the user model reflects the forgetting curve by decreasing the knowledge activity for every concept not being used in the session.

Described approach ensures that the repeated knowledge or knowledge more used are being lost more slowly. The knowledge-remembering model can be supplemented by including hierarchical binds between the knowledge items in a domain.

3.2 Remembering and repeating

Knowledge is remembered better if we work more with it. It is not enough if the information item representing a knowledge only appears many times on a page presented to the student. A measure of remembering depends on how much is the knowledge substantial (e.g., whether it is a prerequisite for understanding another knowledge presented on the page, or whether it is necessary for finding-out results of exercises) and on the appearance (layout) of the corresponding information item.

It is advisable to distinguish at least three levels of the rate at which a user has worked with particular knowledge represented by the information item:

- *normal level:* the user has worked with the knowledge in such a way that after the end of the session he has remembered it and can correctly reproduce it;
- *low level:* the user has worked with the knowledge less than in the normal level (e.g., the information item has been mentioned just a few times among many other information items) and
- *high level:* the user has worked with the knowledge more than in the normal level (e.g., the user has intensively and repetitive worked with the information item and successfully passed several exercises related to the knowledge).

While in the first case the *speed of losing* can be computed according to the standard forgetting curve, in the second case the oblivion is faster and in the last case slower. Of course, there is no linear relationship: very high measure of the user's work with a knowledge does not substantially increase its measure of the remembering. The measure of remembering of a knowledge item depends on a "measure of working" with it. However, the raising is very slow from a certain level. The reason lays in the memory limits. It is possible to remember more than at the normal level (e.g., frequently used knowledge, important knowledge) but not substantially more. On the other hand, if the measure of working has been low (e.g., the information item has been put down only once) the probability of remembering the knowledge is very low.

The same is true not only for *learned knowledge*, but also for the *repetition*. After a knowledge has been learned, its activity in the memory in time decreases. By repeating and using the knowledge, its activity in the memory increases. For example, if a user studies a page where the knowledge item K is referenced or repeated, or should be used for understanding other assertions, all these activities increase the knowledge activity in the memory. Of course, there is also important measure of the user's work. For example, if a knowledge was noticed only (in a text, comment, footnote) or announced, then increasing the knowledge activity in the memory is futile.

The open issue is the determination of a list of the knowledge items considered during the inference related to remembering and repeating. It seems that it is not possible particularize the list automatically. We can count up automatically the frequency of textual representation of a given knowledge in the given text but this does not reflect its "importance". It may happen that the knowledge has no textual occurrence in the presented page, however, for understanding the content of the page the user should work with the knowledge intensively (so it is repeated many times). On the other hand, another knowledge item may occur frequently in the text but it is not much important for the comprehension (and therefore not repeated so much). Information on the mapping of knowledge items to the content should be provided by he author of the educational material.

3.3 Repetition

Information items the user read on a page are inserted into his working memory. Because of limited capacity of the working memory the information items are either moved to the long-term memory or they are lost. To support the process of moving the information items into the long-term memory (i.e., to enforce the remembering) it is effective to repeat them.

One possibility is a *periodical repetition*. After the user has learned given "amount" of the knowledge, the AH system provides the repetition of the knowledge learned from the previous repetition. The repetition can take several faces. In our adaptive book it is automatically observed how many new knowledge items the user has learned. Providing the summation of the occupied items is greater than the predefined capacity limit the AH system invokes a repetition. The system generates a page with the resume of learned knowledge (occurrence of the knowledge items in the information fragments is tagged by the author). The complexity of the knowledge item is also considered. Described approach does not give exact results, but it ensures a repetition in time closed to the point where the user has learned certain amount of the knowledge.

Other techniques of the repetition realized in our adaptive book are:

- repeat at the end of a lesson the knowledge learned in the lesson (*final 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*).

The same can be applied to sessions or various parts of the book content.

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

Selection can be made on several criterions, for example: random selection, selection based on time of the acquisition a knowledge (priority is given to the knowledge acquired longer time ago), selection based on a measure of remembering, i.e. the activity in the memory characteristic is used (priority is given to the knowledge item with lower activity in the memory), selection based on prerequisite-dependencies (priority is given to the knowledge item which is supposed to be in the need of the user in the next study time).

3.4 Knowledge space organization

Knowledge space is formed by the concepts (with corresponding information fragments). The concepts are connected by relations. The currently most used approaches to structuring the knowledge space are the hierarchical approach and the network approach [5]. The structure of the hyperspace can aid the repeating in such a way that the repeating one knowledge item may cause the need of repeating (in part or in whole) another knowledge item. The same holds for the forgetting.

For example, if a student is able to compute the volume of a cylinder, he must be able to compute the square of a number. In opposite, if he has forgotten how to compute the square of a number, he will not able to compute the volume of a cylinder. But it is not true that if the student has forgotten to compute the volume of a cylinder, he also has forgotten how to compute the square of a number or that if he remembers how to compute the square of a number he also remembers (and knows) how to compute the volume of a cylinder.

The prerequisite relation is well known relation in adaptive educational hypermedia [3]. Considering the human memory characteristics it is useful to distinguish between *domain prerequisites* and *pedagogical prerequisites*. Let A be a prerequisite of B. If A is a domain prerequisite, the student is constrained in understanding B with requirement to understand A. If A is a pedagogical prerequisite the constraint is weaker and it is possible to comprehend B without knowing A. As an example, let us present expressions in C programming language course. If the adaptive book explains this part using commonalities and differences between C and Pascal languages, then the knowledge about Pascal are denoted as pedagogical prerequisites. The student needs a knowledge of Pascal to understand this part of the content. But, when a repetition process is evoked on the "expressions in C" knowledge item, the Pascal knowledge item is not necessary to be repeated.

There can be an objection that the above is not fully true. We may repeat some topics of Pascal when we repeat C language. For example, some things may be the same (or similar) and the user may have remembered data like "in C it is the same like in Pascal". The user may also remember the page itself, text or/and its graphical layout on the page. It is also possible that when he would hear about some topics of C language, he will bring back some information about Pascal. In all these cases the user will repeat with some knowledge about C language also some knowledge about Pascal. This may happen. But after some amount of time the intensity of repeating related knowledge items will decrease and the user will repeat only already repeated knowledge and its domain-depended prerequisites.

4 Conclusions

The research discussed in this paper addresses the possibility of improving effectiveness of learning using adaptive educational hypermedia 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 hypermedia systems. Our research is supported by experimental adaptive web-based book. Known adaptation techniques (annotations of links and conditional inclusion of fragments) are supplemented by an inference based on a model of the remembering and the forgetting which leads to the repeating. The base for modelling the remembering is the forgetting curve. The forgetting curve can be tuned individually for each user which results in more effective repeating by utilization of individual differences.

We still work on experimental evaluation of issues elaborated in this paper. Our future work will concentrate on using experiments for proving effectiveness of the proposed approach. Naturally, we expect that the proposed models should be tuned for particular usage and differences of the individuals.

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