A Virtual Reality Environment for Prospective Memory Training

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Abstract. Prospective Memory (PM), or remembering to perform tasks in the future, is of crucial importance for everyday life. Stroke survivors often have impaired prospective memory, which can interfere with their independent living. In 2011, we started working on computer-based training for improving prospective memory in stroke patients. The primary goal of our project is to develop an effective PM treatment that could be used without the input of clinicians. Our approach combines the use of visual imagery with practice in a Virtual Reality (VR) environment. In this paper, we present the VR environment and the user modelling approach implemented.

Keywords: prospective memory training, virtual reality environment, constraint-based modeling,

1 Introduction

People with brain injury (including stroke) have severely impaired prospective memory in comparison to healthy people [1, 2]. Prospective memory, or remembering to perform actions in the future, is of crucial importance for everyday life [3]. Prospective memory failure can interfere with independent living, as it can result in forgetting to take medication, switch off the stove or missing doctor's appointments. It is a complex cognitive ability, which requires coordination of multiple cognitive abilities: spatial navigation, retrospective memory, attention and executive functioning [4].

There are two critical aspects of PM: it is closely related to retrospective memory (remembering what was learnt and experienced previously), as it is necessary to know what the task is in order to actually perform the task. The other aspect is the retrieval of the intention at the time appropriate for the action. There is a distinction between event- and time-based prospective tasks. In the case of a time-based task, a certain action needs to be performed at a certain time (e.g. having a doctor's appointment at 4pm). In event-based tasks, an action needs to be performed when a certain event happens (like asking a friend a question when we see them next time).

Prospective memory is very difficult to assess using neuropsychological tests as conventional tests consist of simple, abstracted activities that are very different from real-world tasks. In the last decade, many research projects have used Virtual Reality

(VR) in neuroscience research and therapy [5], ranging from the use of VR for assessing cognitive abilities, over neuro- and motor rehabilitation to psychotherapy, such as treatment of phobias. VR environments are computer-generated environments that simulate real-life situations and allow users to interact with them. They provide rich, multisensory simulations with a high degree of control and rich interaction modalities. They can also have a high level of ecological validity. VR has been used for assessment of prospective memory in patients with traumatic brain injury (TBI) [4] and stroke patients [2]. VR is suited for prospective memory as it supports complex, dynamic environments that require coordination of many cognitive abilities.

Although there has been some research done on how to assess PM, there is very little available on rehabilitation strategies for PM. Yip and Man [6] involved 37 participants in 12 sessions of prospective memory training using non-immersive VR. The participants were asked to perform a set of event- and time-based PM tasks in parallel with an ongoing task. The PM training was based on remedial and process approaches. The remedial approach provides repetitive exercise within the VR environment. The process approach, on the other hand, aims to support multiple facets of PM, and supports encoding of intention, retention and performance interval and recognition of cues. Participants were given a list of four shopping items they needed to memorize, and their recall was tested before entering the VR environment, where they needed to perform the tasks. The VR training showed significant improvement in participants' immediate recall of PM tasks, performance on both time- and event-based tasks as well as ongoing tasks, and also a significant improvement in self-efficacy.

In our previous work, we have developed many successful Intelligent Tutoring Systems (ITSs) using Constraint-Based Modeling (CBM) [7, 8]. In this paper, we present the VR environment we developed for PM training, and describe how we utilize CBM for tracking the user's PM skills in this environment. The participant will first be administered a set of psychological tests, followed by a set of sessions in which he/she will be trained on using visual imagery to remember PM tasks. After the training, the participant will practice in the VR environment, presented in Section 2. We have recently started an evaluation study, the goal of which is to determine the effectiveness of the developed PM treatment.

2 VR environment

We have used the Unity[1] game engine to develop a VR environment, which represents a house with common household objects, and a garden. Figure 1 shows two scenes from the environment. The user is given a problem, which consists of several PM tasks he/she needs to visualize first, and then perform in the VR environment. The user can perform various actions on objects in the VR environment, such as turning the TV set on or off. To perform an action, the user first selects the object, and then specifies the desired action from a menu. The user can view a clock whenever they choose, which is necessary for time-based tasks. The tasks vary in complexity: the ones in early sessions consist of a cue and a single action, such as *Turn on the*

[1] https://unity3d.com/unity

radio at 3pm. In later sessions, the user will be given more complex tasks, such as *When the oven timer beeps, take the roast out of the oven and put it on the dining table.* Some tasks, such as taking the roast out of the oven, involve other objects, which are added to the inventory. Other tasks require inventory items to be collected beforehand. Consider the task *Take the red shirt from the bedroom and put it into the washing machine*. The first step involves collecting the inventory item *red shirt*, while the second step involves operating the washing machine. The user can view the inventory at any time. The problems range in complexity: the initial ones contain only three simple tasks, and they become more complex as the user practices in the environment.

Fig. 1. Two scenes from the VR environment

The system maintains the list of active tasks. Tasks should only be attempted from a point known as 'cue discovery'. Time-based tasks become active several minutes before the stated time. For example, if the task is *Turn on the radio at 3pm*, the user can start to move towards the radio a few minutes earlier in preparation. Event-based cues only begin when the stated event occurs. Consider the task: *When the courier truck arrives, take the parcel and leave it in the study*. For this task, the user has no way of knowing when the courier will arrive, and so he/she cannot perform the action before the cue is discovered.

For every task, there is a finite amount of time for which the task can be completed before it becomes obsolete or impossible. However, this alone is not the only factor in determining which tasks are more important. Some tasks, such as turning off the stove, have worse outcomes for failing to complete than other tasks do, such as turning on the radio. Each task therefore has a priority level, which is an integer from 0 (lowest) to 5 (highest). Tasks with a level 5 priority are tasks with a very real chance of injury or household damage if they are not completed on time. A typical priority 5 task is *When the timer beeps, turn off the stove top*. By contrast, a priority 0 task may be: *When you are finished all other tasks, watch television.* From cue discovery, the user has a fixed time to complete the task before it becomes obsolete.

3 Using CBM for PM Training

We have defined a set of constraints that enable us to evaluate the participant's actions and provide feedback. As originally proposed by Ohlsson (1992), each constraint has two components: a relevance condition and a satisfaction condition. The relevance condition specifies features of situations for which the constraint is relevant, while the satisfaction condition details what must be true for the constraint to be satisfied. A constraint can be described as: *If <relevance condition> is true, then <satisfaction condition> had better also be true, otherwise something has gone wrong*. If a constraint is violated, the user needs some means of knowing that he/she has made a mistake, and they need to know what needs to be done differently next time. This is the role of feedback: it informs the user on what tasks need to be performed, and what objects need to be interacted with.

We have developed 15 constraints that deal with navigation, prioritization of tasks, selection of objects to perform actions on, remembering/selecting actions to be performed and general skills of interacting with VR (such as selecting objects, selecting items from the menu or crouching). In order to be able to specify relevance and satisfaction conditions, we have defined a set of functions and predicates. For example, the *OnRouteTo* predicate takes the current position of the user (i.e. the room the user is currently in), the target position needed in order to perform the current task, and returns *True* if the current position is on a path to the target position.

A constraint contains three feedback messages. When a constraint is violated for the first time, the user will be given a general message, in order to remind them that they have missed something. For example, if the user is going in the opposite direction from the target destination, he/she will be given feedback "*You're going the wrong way*!" If the user continues down the wrong path, the feedback for the second violation of the same constraint becomes more specific: "*Perhaps you should be going to the [goalRoom]*" (*[goalRoom]* is a function which returns the position for the current task). This culminates on their third violation of the constraint with "*You should be going to the [goalRoom] and use the [goalObjects]*". This is the bottom-out feedback which instructs the user what to do.

Three constraints check whether the user is working on the correct task. Tasks with only one minute left should be done before tasks with more than one minute left, even if that task with more than one minute left is of higher priority. In this way the user can still complete all the tasks. It is also important to bear in mind that higher priority tasks will reach the point of only having one minute left a lot sooner than a lower priority task. If there are multiple tasks with less than one minute left, the user should choose the highest priority one. The next threshold is at five minutes. Users must do tasks with less than five minutes left before they attempt tasks with more than five minutes left. As discussed in the previous section, tasks are first stratified according to time left into less than one minute, less than five minutes, more than five minutes. From there they are ranked according to priority. If any tasks have equal time strata and priority, they can be done in any order, otherwise the user must pick the top one.

Figure 2 illustrates a situation when the user is interacting with the wood burner, but there is another task that is about to expire (*Once it starts raining, bring in washing*). The constraint relevant to that situation is:

If the user is interacting with Object X and there is a task with less than 1 min left,
Then Object X should be related to that task.

The feedback from the violated constraint shown in Figure 2 informs the user that there is a more pressing task. If the user cannot recall the other task, the next feedback message will be more specific, and will provide a hint to the user about the object he/she needs to interact with. In the case of the third violation of the same constraint, the user will be told which task needs to be performed.

Fig. 2. Feedback from a violated constraint

In addition to receiving feedback, the user can also press the H key for more help. If the user has received feedback in the last 30 seconds, the same feedback is displayed again as a reminder. Otherwise the default message is displayed. If there are no tasks left to do, the default feedback informs them of this. Otherwise it gives them increasingly specific hints as to what they should be doing.

In our previous work with ITSs, constraints are evaluated when the student submits the solution, therefore explicitly requiring feedback from the system. The timing of constraint evaluation in the VR environment differs, as the system needs to be able to evaluate constraints when appropriate. The constraints that deal with task prioritization are evaluated at intervals of 0.5s. Other constraints are evaluated in the appropriate contexts: for example, navigation constraints are evaluated every time the user changes room, while constraints that deal with objects are evaluated when the user selects an object or an action.

We have conducted a case study with a stroke survivor, who used the VR environment for 30 minutes. The case study identified a few usability issues and further improvements to the timing and duration of feedback. We then had a domain expert interact with the system. The domain expert was able to compare the feedback generated by constraints with the feedback they expected from the system. All constraints were satisfied or violated as expected. At some points, the feedback actually led to the domain expert making more errors. In such situations, the user was alerted that they should be doing one of several tasks, and told all the tasks currently available. When the user completed the lowest priority of these tasks, they violated the constraint that they should be doing the most high priority tasks. This led to the recommendation that feedback messages should only suggest the single most important task at the current time. The findings were then used to improve the constraint set and the system.

4 Conclusions

In our previous research, we have shown that constraint-based modeling is an effective student modeling approach applicable in a wide range of instructional domains. In this paper, we describe how we use CBM to track the user's prospective memory. We present a VR environment in which stroke survivors can improve their memorization skills. The contribution of this research is in extending CBM from modeling cognitive skills to modeling PM skills. We have developed a constraint set that allows us to track the user's behavior in the VR environment. The constraints identify whether the user is prioritizing tasks correctly, whether there are any problems with navigation, identifying cues (time or event ones), interacting with objects and specifying actions. The pilot study performed with one stroke survivor was promising. We also had a domain expert evaluate the feedback from the VR environment, which resulted in further improvements made. We are currently conducting an evaluation study with stroke patients.

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