MIE 1404

Mobile Computing and Memory Prosthetics

Third Draft

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Abstract

This chapter examines the design of mobile memory prosthetics, devices used to augment memory. First, I review the different forms of memory. Then, I look at how people augment their memories currently: list-making, reminders, and the like. I follow that with a discussion of research that has been done on memory prostheses, and look at early mobile memory prosthetics. Finally, I finish with a set of guidelines for designing effective memory prostheses in the future.

Introduction

Human memory is notoriously faulty. We constantly forget important dates, meetings, names, and (let us not forget) the proverbial car keys. It is probably safe to predict that this situation is only going to get worse — the world is becoming more complicated and information-driven, and our memories are not improving any. In fact, they are probably becoming worse because of the overload.

The costs of memory failure are often very high. Think of the embarrassment, frustration and wasted time behind missed meetings, showing up late because of unforeseen scheduling conflicts, forgetting the names of people you meet, and so on. For companies, these memory failures often result in financial loss as well. For example, a lost meeting can result in a lost client. Anything that can minimize these problems will be a relief of frustration, embarrassment, and frustrations, and could make our lives less complicated.

Fortunately, people have found clever ways to augment their memory. We make lists, reminders, and to-do lists; we use calendars and other people to keep track of things we aren't able or willing to keep inside our heads. Recently, we have used technology to augment our memories as well. PDAs and time-management software have become hot-selling items.

This article looks at how to effectively design memory prosthetics. I will look at how people remember things now, review what research has told us about the workings of memory, and will suggest design guidelines for memory prostheses. Finally, I will conclude with suggestions for future research in this area.

How we Remember

If we are to design a device to augment our faulty memories, we should have an understanding of how memory works. Otherwise, we will have no idea of what it is we are trying to augment. Therefore, we will first establish a clear understanding of how memory works, and the different types of memory within the human brain. Memory can be divided into many sorts of memory, all of which will be presented here. The types of memory that concern us most with memory prosthetics are episodic, prospective memory, semantic memory. However, a clear understanding of all of the forms of memory will be helpful for effective designs.

Several Kinds of Memory

For this section, I am heavily indebted to Squire, et. al's overview of memory, in the Annual Review of Psychology (1993).

Short-term Memory

While designing a memory prosthesis, short-term memory will probably not be the focus, because we're looking at the type of information that the person is not thinking about at the moment. However, because short-term memory does have some implication on design, and also because we do want to have a general understanding of how memory as a whole works, I will give a brief overview of short-term memory.

Short-term memory (STM) is where we store information such as phone numbers that we're about to dial, or a shopping list of items to buy: "STM has come to be viewed as a diverse collection of temporary capacities that are distributed across multiple, separate processing modules" (Squire 1993, p. 456). STM is distinct from long-term memory, and although there is a little disagreement on this issue, researchers generally support the notion that items from short-term memory flow into long-term memory in a serial fashion (i.e. they must flow into short-term memory before they can enter long-term memory.

Short-term memory can be further subdivided into two types of short-term memory, "primary memory" and "working memory" (Craik XXXX, p. 80-81). Briefly, the difference is that primary memory deals with situations in which information is held for a short period of time (usually just a few seconds) right before it is to be used. An example of this type of short-term memory is remembering a phone number right before using it. Working memory, on the other hand, deals with situations in which the information is transformed actively while it is being dealt with. Craik gives the following example of a working memory task:

> The subject faced a row of lights, one of which was illuminated at a time; under each light was a corresponding response key, and the subject's task was simply to press the key under the illuminated light. This was the "0-back" condition. In the "1-back" condition, the task was to work one back in the series; that is, to press the key corresponding to the previously illuminated lamp. There was also a "2-back" condition in which subjects responded to the light illuminated two stimuli previously. (Craik XXXX, p. 82.)

An example of this might be simultaneous translation. It requires that the person not only be remembering what is heard, but also dealing actively with the information that is already there. Aside (something to take out later): it seems to me that the major difference in these two types of tasks is the amount of noise present, but that may be my ignorance.

Long-term Memory — Declarative Memory

A major division in long term memory is between declarative and non-declarative memory. With declarative memory, the person is conscious of the fact that they are accessing memory, which is why it is refereed to as conscious memory, and with non-declarative memory, the person is not conscious of the attempt to access memory:

> The major distinction is between conscious memory for facts and events and various forms of nonconscious memory, including skill and habit learning, simple classical conditioning, the phenomenon of priming, and other instances where memory is expressed through performance rather than by recollection (Squire 1993, page 457).

Declarative memory, sometimes also called explicit or relational memory, contains memory of places, people, and events (episodic memory) and memories of meaning (semantic memory). Declarative memory is fast, not very reliable, and flexible, while non-declarative memory (discussed later) is slow, reliable, and inflexible. There are some problems in trying to divide memory into declarative and non-declarative memory (in particular, how do you apply these terms to animals?) but they are working terms that are used currently.

Long-term memory can be further subdivided into several forms of memory, as explained below:

Episodic Memory

This form of memory is the type we think of most when we think of memory. Episodic memory is memory of events or episodes that have happened to us — they are autobiographical memories located in time and place. To remember these past events, we can use three different cues: who was involved, what objects were involved, and what places were involved.

One important issue with episodic memory is the debate over whether recall and recognition are separate forms of memory. Whether or not they are biologically, in practical terms, there are some very significant differences between them, so it is useful to look at them separately. Generally, it is well known that recognition tasks are easier than recall tasks, likely because the visual cues provide more triggers for the memory to be recalled. Older adults tend to do poorly on recall tasks, but about the same on recognition tasks (Craik XXXX, p. 82-83).

For more information on episodic memory, see Tulving (1983) or Loftus (1983).

Semantic Memory

This form of memory is memory involving general knowledge about the world. This includes vocabulary, verbal ability, and information that we pick up about our environment. It can include stories, myths, and general common sense. This type of memory does not degrade very much with old age.

Additional Issues

Several other divisions of declarative memory have been proposed, but they are still controversial. Research has not yet determined whether there are separate areas of the brain that handle these functions yet, but they are sometimes useful to see other forms of memory.

The first of these is spatial memory, our memory of where things were. For example, when I read a book, I often remember on what section on the page the information I read was on. If the information was on the upper right-hand corner of the page, I will often remember that, and when I want to refer back to that page, I am able to scan through the book rapidly, searching only the upper right-hand corner.

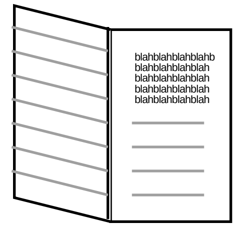

FIGURE 1: Spatial memory of location in a book

Long-term Memory — Non-Declarative Memory

Although slower than declarative memory, non-declarative memory is much less error-prone (albeit less flexible). Thus, a clever designer may be able to use non-declarative memory to help augment declarative memory. For this reason, this section may be of interest to designers.

Squire (1993) says this about non-declarative memory: "Although it is too early to develop a classification scheme for all the nondeclarative forms of memory, one can tentatively distinguish among skills and habits, some forms of conditioning, and the phenomena of priming."

Skills and Habits

Most skill and habit learning is done both with declarative memory and non-declarative memory (i.e. the person is aware that they are learning a skill, and may be even consciously trying to develop it). However, Milner showed in 1962 that it was possible for a severely amnesiac patient to learn without even remembering that he had learned the task (Squire 1993, p. 472).

Bill Buxton once talked about this during an informal talk (1998), although he wasn't specifically talking about non-declarative memory. He called it the "bicycle-lock principle" — at the end of the winter, when you open up your garage and take out your bicycle, you can't consciously recite the combination, but your fingers will often remember the combination for you.

One example of a technology that has taken advantage of this type of memory is marking menus. Traditionally, the view of interfaces has been that beginners require very simple interfaces, and that designers should add in separate sets of functionality for expert users so that they can accelerate their activities once they learn the basics (such as command keys). Marking menus are exceptional because they take advantage of non-declarative memory so that beginning users use the same motions that expert users do. Thus, the beginner is trained every time they use a command on what the expert command is. The only difference between an expert command and a beginning command is that an expert command is done without hesitation, so that a menu doesn't pop up. Kurtenbach found that marking menus were about 3.5 times faster than conventional menus (1994), and it is also an example of a learning technique with a short learning curve, because it takes advantage of both declarative and non-declarative memory.

Priming

Another form of non-declarative memory is the phenomena known as priming: "Priming refers to an improved facility for detecting or identifying perceptual stimuli based on recent experience with them." (Squire 1993, p. 478). This type of memory is non-declarative, because it can be demonstrated in severe amnesiac patients. Squire described a typical priming experiment as follows:

> Subjects see lists of words, pictures of objects, or nonverbal materials such as novel objects or line drawings. Subsequently, subjects are tested with both old and new items and asked to name words or objects, to produce items from fragments, or to make rapid decisions about new and old items. The finding is that performance is better for old than for new items. (Squire 1993, p. 478-479)

What is amazing about this form of memory is not that it is distinct from declarative memory, but that it is often very long lasting. Sloman, in 1988, showed priming effects even after 16 months (Squire 1993, p. 479).

The implications of priming on memory prostheses is difficult to imagine at this point, but the fact that the brain processes stimuli quicker if it has been perceived before might have some implications on future designs.

Prospective Memory

Prospective memory is remembering something at a future time. For example, if I have to remember to make a phone call at 1:00 tomorrow afternoon, this requires my prospective memory. In other words, prospective memory is remembering to remember or do something in the future.

This is a relatively new field of research for psychologists, so a lot of the conclusions they have come to should probably be considered preliminary. Because it is so new, a lot of areas are still being worked out. For example, there is a lot of disagreement over the effect of age on prospective memory. Many studies have shown that there is no difference between elderly adults and younger adults, and other studies have shown just the opposite. In 1990, Einstein and McDaniel introduced a further subdivision of prospective memory to deal with these contradictory results (Mäntylä 1994, p. 276). This difference can be described as event-based versus time-based prospective memory:

> An event-based task is one in which action is to be performed when a certain external event occurs (e.g., remembering to give someone a message), whereas in a time-based task an action is to be performed at a certain time or after a specified time interval (e.g. remembering an appointment at 9 a.m..). A major difference between these two types of tasks is that an event-based task is assumed to have some form of external event that cues retrieval. (Mäntylä 1994, p. 276)

These two types of prospective memory tasks are very important for the design of any device that relies on remembering something in the future. In general, event-based tasks require much less self-initiated action, and are thus much easier, especially for older adults. Context is probably very important, then, in the design of such devices. Mäntylä gives the example of remembering to buy a loaf of bread on the way home from work. There are conceivably many places a person can buy bread (for example, a bakery or a grocery store). It is presumed to be easier for people to remember to buy bread if they go to a bakery than a grocery store, because the memories will be triggered by a specific event (Mäntylä 1994, p. 277).

Mäntylä also states, “remembering *when* to perform a future action is a necessary, but not sufficient, characteristic of optimal [prospective memory]. Although prospective remembering typically has a low information content, most tasks require not only remembering *when* but also what should be remembered” (Mäntylä 1994, p. 277). This would explain why event-based tasks are easier than time-based events. Event-based tasks relieve part of the cognitive load of information that needs to be remembered, allowing the person to concentrate on what to remember.

Most of the research into memory prostheses has been on retrospective memory devices (e.g. Newman 1991, Eldridge 1992, Lamming 1992, Lamming 1994, Lamming 1994b, and Lamming 1994c). A lot of this research is focused on augmenting episodic memory by automatically storing information about the context that information is remembered or stored. Currently, very little research has been done into memory prostheses that take advantage or concentrate on prospective memory. The research that has been done has been fairly limited (see Sellen et. al. 1992 referred to in Lamming 1994b).

Summary

The types of memory that will be most important for the development of a memory prosthesis are going to be episodic, semantic, and prospective memory. These are the areas that memory failure exact their greatest toll.

Memory Tasks

In designing a memory prosthetic, it is useful to look at how people currently augment their memory, both with technology and from communication. This section is mostly derived from first-hand observation.

Episodic, semantic, and prospective memories are notoriously fallible and inaccurate. Some myths in our culture relate memory to a process like a computer: our brain records all memories perfectly, but it’s just a matter of retrieving them. Unfortunately, memory is not encoded like that, so we often use tools and tricks to help remember both past events and future things to do.

List-making

List-making has probably been around for as long as literacy and paper. It is certainly characteristic of present-day society. Grocery lists, shopping lists, and to-do lists are ubiquitous in modern society.

When making these lists, we may employ several different methods, but a common method is to brainstorm. Lists can be prioritized, sorted, categorized, or left completely unsorted. For example, while writing out a shopping list, a person will list all of the items they think they need. If necessary, they may then go back and prioritize or order the list. Of course, there are other methods of developing a list. For example, my father has prepared a list of typical items he buys at a grocery store, arranged by the row in the grocery story. Before he visits the grocery store, he will print out a copy of this list, circle all of the items he needs to buy, and then as he walks through the store, he will always know the next item he is looking for.

List-making is useful in two respects. First of all, it gives us an artifact that we can use in the future. Second, it also helps organize our thinking so that it is easier to remember what we wanted to remember, even if we no longer have access to the list (Burack 1996).

Note that for to-do lists, the items have different priorities. Some items have absolute deadlines, some are flexible, and some are just items the person would like to do at some point in the future.

Collaboration

Collaboration can aid in both episodic and prospective memory tasks. Using the grocery store example again, when two people are going to the grocery store, one person may ask the other person, "please remind me to buy avocados," or "please remind me to turn off my headlights when we arrive at the grocery store." Although this is not a technological solution, it is a method very often employed in memory tasks, and one that we see in our everyday lives. Indeed, "two heads are better than one", presumably because if there is a 15% chance of forgetting something, the odds of both people forgetting is much less likely.

Bower (1997) found that "when allowed to collaborate, elderly couples who have been married for 40 years or more remember what they read better than young married couples or individuals." This would imply that it is also a skill that people develop over time. This may be significant for memory prosthetic design, because a device that is collaborative with the human user may be effective in augmenting memories. Further research could be done into how people collaborate in order to augment their memories.

Reminders

Another way people remember things is by using reminders. This is a fairly broad category, but generally, they are intended to trigger our memories in the future. For example, we put sticky notes on our computers, we tape notices on our doors so that we'll see them when we leave the house, and we can wear watches on the opposite hand to remind us to remember something(!). Often, if I have something I definitely want to remember, I will place it in the middle of the floor so that it literally prevents me from going anywhere unless I remember and notice it. These are all tactics that are used in our daily lives.

With technology, we have developed several methods of reminding ourselves of things to do. For example, alarm clocks are a form of a reminder — it is a way of intentionally placing an event in the future to remind us to wake ourselves up. Other examples of reminders are cooking timers (interestingly, these reminders also give audio feedback).

Computers have traditionally been very poor at dealing with anything other than the present. One person at Apple during the early days of the graphic interface commented that computers were very similar to pidgin languages. INSERT

SOURCE HERE. They contain only the present tense and a simple subject/verb/direct-object structure, and the challenge is to give them history and future tenses as well, as well as richer grammatical structures.

Schedules

Schedules are a combination of a list and a reminder. A schedule is chronologically ordered, and the person using it typically will look at it periodically to see if there are any events that they need to be aware of.

Schedules have the benefit of organizing the day in the person's head as well. The act of scheduling a day, and fitting activities into time-slots, helps organize the structure of their day. I find that sometimes I don't need to look at my schedule-book because the act of writing it down makes it unnecessary.

The weakness of schedules is that they typically rely on time-based prospective memory. As noted earlier, this is not generally as effective as event-based prospective memory tasks. However, it may be possible that the act of repeatedly looking at the schedule throughout the day has the effect of reinforcing what has to be done throughout the day. Another possibility is that people will look at their schedule when they complete a task to see what is next. If that were the case, the ending of one task would be the event that would have the person look at their schedule, and would negate the advantage of an event-based prospective memory task. In either case, this is an often-used method of remembering meetings and activities to do in the future.

Designing Memory Prostheses

Research on Memory Prostheses

What unites the research into memory prosthetics is that they are attempting to give the computers a greater sense of context, so that data can be joined with context. The reason for this is that they imagine that adding context to data and events the computer is aware of will help to trigger memories for the user.

Eldridge studied the value of adding video to aid in memory recall of work activities (1992). They found video to be helpful to remember the context of memories, but this might be less effective with older adults due to Luszcz's finding that picture memory decreased with age (1997). Because location is also an important cue for episodic memory, Harper's research on active badge systems, which give location information (1992), could be useful for the design on memory aids. For example, a system that tracked a person's movement through their house could help a person locate their car keys. In some ways, they are reminiscent of Star Trek's uniform emblems.

Newman's PEPYS system automatically created information on where a person went and the person they met, and aimed to see if their memories could be improved by doing so (1991). The results were somewhat mixed.

FIGURE 2: Xerox's Forget-Me-Not

Mik Lamming and Mike Flynn developed a system called "Forget-Me-Not" which was designed with how episodic memory works in mind. This mobile computing device was supposed to help with common memory problems (Lamming 1994).

A very useful paper on memory prostheses is Mik Lamming (1994) "The Design of a Human Memory Prosthesis." In this article, Lamming describes how technology could augment human memory, and offers some design guidelines for the development of these devices. He concentrates on episodic memory devices, but mentions prospective memory devices as well. However, the only paper he mentions on it is not published (I wrote to him, and he said that the article had never been published).

Some interesting questions that arise from this are the following:

- How important is it for the computer to understand the context it is in? Ideally, we would like the computer to understand the context it is in as much as possible, because it could use this information to help cue the user's memories in episodic memory tasks. There are some simple subsets of context as well. For example, a mobile device can know its global location, or it can know if it is being held or not. Or it can keep track of when it was active and not. It may be able to keep track of phone calls made on an attached cellular phone, etc… However, is there a way to trigger memory without giving the computer so much context? This would be similar to the problem mentioned in the chapter on input and output. Concentrating on recognition is often missing the point. The focus should be on the results the human wants, not on the computer understanding what context it is in. However valuable that may be, while computers are still context-blind, solutions that take advantage of not having to utilize context may be more effective for the end-user.

Early Memory Prostheses

Current PDAs may be viewed as early forays into memory prostheses. They have taken common and well-understood behavior, such as to-do lists, schedule books, and address books, and put them into a mobile format. As pointed out in the chapter on process control, these effects have been basically just transferring the tasks that were previously done on paper to computer devices.

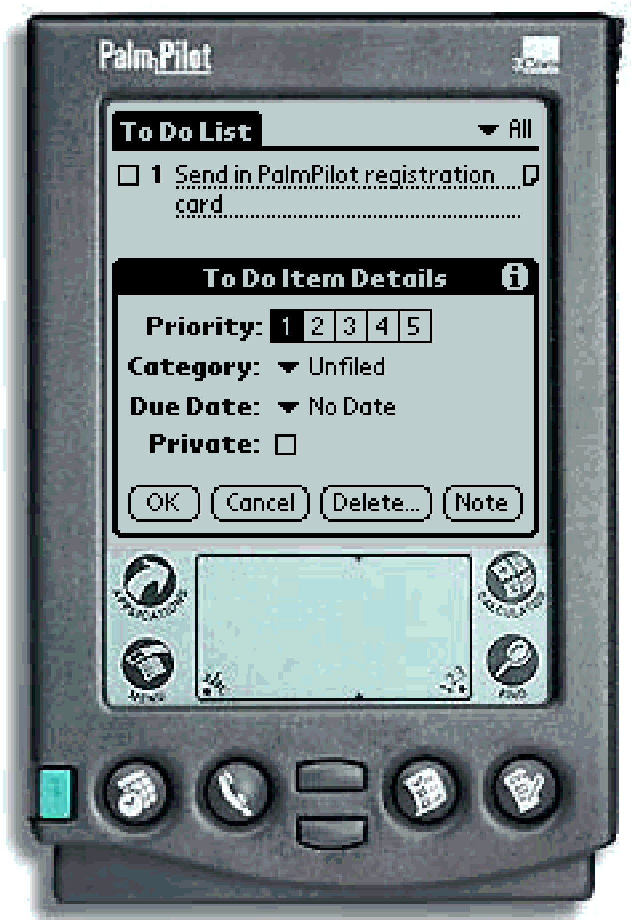

FIGURE 3: The PalmPilot To Do List

This has been remarkably successful, however. The reason for that is probably because they chose a task that was well-defined and understood, and then tried to transfer that task as naturally as possible to a mobile computer. In addition, they made some small improvements that computers can provide. One example of this is recurring appointments. If you're doing schedules on paper, you can't automatically have a weekly meeting put in automatically — you must write it over and over until you have it everywhere.

Talk more about what has been successful and what hasn't?

These PDAs have typically focused on data-management, and a small subdomain of memory — addresses, phone numbers, and the like.

Conclusion

Design Guidelines for Memory Prostheses

Given what we've discovered about memory, how people make up for faulty memory, and our look at research into memory prostheses, what guidelines can we draw up for the design of future memory prostheses?

First of all, determine the scope of the problem you're attempting to solve. Is the memory prostheses designed to handle only autobiographical information (episodic memory) or is it intended to help users remember things to do in the future (prospective memory)? Is it intended to help them keep track of their general knowledge of the world, and organize the information that they meet with in their day to day lives? Perhaps some combination of these?

Episodic memory prosthetics will need to concentrate on richness of context, and the problems they will need to solve will be how to give as much context as possible so that users will have a wide variety of cues to trigger memories. Specifically, designers will want to concentrate on location, object, and personal information (who they met, where they were, what was there, and when it happened). Designers will need to choose whether their device is intended to store information for the person, or help to trigger memories in the person. Technologically, the second is a much simpler problem, but also one that requires extremely good design, and an excellent understanding of how memory works.

Maybe talk more about the difference between these two?

If you're designing a prospective memory prosthetic, the problem is "how do I trigger the user's memory in the future." There are two solutions to this problem, which depend on the nature of the task being performed. If the device is similar to a schedule book, and your analysis of the user group has found that they will use the device periodically throughout the day, then it may be sufficient to use time-based prospective memory tasks (i.e., it may not be necessary to interrupt them with events). Otherwise, the best solution is probably to interrupt them with some sort of event — a beep, a vibration, a light, a hum, or the like. It may be feasible to use interruptions for more important events, and for less important events, to rely on time-based prospective memory. The problem then become an issue of richness of feedback, and how to differentiate between levels of importance of different tasks. To help in this, I have developed a matrix which describes the characteristics of basic tasks (see Figure 4).

How Flexible \ How Critical	less	more
less	Events	Deadlines
more	To-Do Items	Milestones In-progress work

FIGURE 4: Rubick's Prospective Memory Task Matrix

There are a wide variety of different interactions possible for interrupting the user or calling their attention to a future task. The question then becomes, "which one should I use". The answer is not going to be a simple one. However, there are a few guidelines that may be helpful.

First of all, sound is effective because of input/output issues. Sound is hands-free, so it doesn't interrupt mobility, conveys the information without interrupting the task that the user is doing, and is flexible in the amount of information that it can portray. Thus, depending on what is appropriate, subtle sounds can be used for less important interruptions, or they can be used in the same way a kitchen timer is used — the sound is a background sound, it is not obnoxious or distracting, it conveys the state of the system, and when it's really important to do so, it RINGS. Voice is one possibility, because it can convey such a broad range of information. If intonation and a range of urgency were added, that would be even more valuable.

For simpler applications, however, looking at technology such as pagers and cellular phone may be insightful. Social considerations are important (e.g. the cell phone should be silenced during a movie), and similar considerations should be made with mobile computing devices. This may require some flexibility in the output. For more information on the output, look at the chapter on input and output. One thing to note, however, is that there may be some prospective memory tasks that should only interrupt enough to make the user conscious of them, while others should require confirmation from the user when they are able to.

User testing is going to be crucial in any of these devices, if they are to be practical. The design issues are likely to be much more important than any technological issues (if you're not convinced of this, read the chapter on input and output). If you're not familiar with user testing principles, I suggest studying Human Computer Interaction and Human Factors literature.

Suggestions for Future Research

This topic isn't really that interesting, so all research in this area should be halted immediately.

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