The Design of a Human Memory Prosthesis

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Memory is the forgotten problem of office systems research. We believe that a new class of applications, which we call 'memory prostheses', are needed when memory problems arise. We expect these systems to provide help with a range of everyday memory problems, including: finding files, papers and notes (in whatever medium they are expressed), recalling names of people and places, procedures and lists, remembering to perform tasks. A memory prosthesis will be sensitive to its environment and able to record data automatically about its user's activities. These data can later be retrieved to help users remember things they have forgotten, especially things they did not know they would need to remember. This sensitivity to the environment will also enable the memory prosthesis to issue context-sensitive reminders of things that the user intended to do. In this paper we present guidelines for the design of memory prostheses, drawing on studies that have been carried out on the psychological basis of memory problems in the workplace and on technological possibilities for dealing with these problems. These guidelines define this new class of application, provide the basis for our continuing work in support of the problems of everyday office life and offer a new challenge for computer systems research.

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1. THE PROBLEM

If you observe yourself in action, you will probably see that the everyday procedures you employ to get your work done often involve some process designed to compensate for your fallible memory. You organize files to make them easier to find, you keep lists, you set traps for yourself to remember to do things. Look around you: you design your environment to make remembering easier—file cabinets, notice boards, alarm clocks. How much of your life is spent memorizing and remembering small things that are nevertheless important? How much is spent failing to remember and then finding another way to get the job done? How much time is spent organizing information to make it easier to find or to ensure it does not get forgotten? Our studies show that these are common concerns: memory problems impose a hidden tax on work.

We believe that a new and distinctive class of applications, called 'memory prostheses' is needed to tackle this memory tax. We expect these systems to provide help with a range of everyday memory problems, including: finding files, papers and notes, in whatever medium they are expressed, recalling names of people and places, procedures and lists, remembering to perform tasks. The differences between these problems mean that there will be many different applications but there are still certain features that will be important for all memory prostheses.

We envisage memory prostheses as personal systems, extending the user's ability to recall things that are specific to his or her life. Such systems were foreshadowed by the Memex envisaged by Vannevar Bush (1945), a device that would collect all of a user's books, notes, comments, sketches etc. into a personal database for future use. A recent system called MEMOIRS (Lansdale and Edmonds, 1992) treats a personal filing system as a history of events and allows retrieval of filed documents on the basis of memorable characteristics of these events. The Memex was described as a desk-sized electromechanical device and MEMOIRS runs on a Macintosh II, but current advances in technology will allow us to fulfil many similar functions in a small portable package.

Electronic organizers and more recent variants such as personal digital assistants purport to address these problems, but they are little more than high technology versions of conventional diaries and note books, perhaps also with the capability of an alarm clock. We are considering something more radical: a device that will be sensitive to your environment and will be able to support you in a much more proactive manner. This device will help you remember things that you did not know you were going to need to remember at the time you encountered them and, by being sensitive to your surroundings, will remind you in appropriate ways of things you had planned to do, whether in a particular context or at a particular time.

A memory prosthesis should become an unobtrusive companion in everyday life, automatically capturing data that may be of use later. It will not require data to be explicitly recorded or categorized, but on the other hand, it will allow you to make notes or annotate the data if you wish. Given the large amounts of data that are captured, it will provide mechanisms that help you to focus on relevant information and to search flexibly

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for what you need. In order to be a useful companion it will be easy to use, reliable and available everywhere. It will be integrated with a wide variety of computer applications to enable you to use them more effectively. It will also be respectful of privacy, only recording the kinds of things that you wish to have recorded and making it clear what is being captured at any time.

These requirements have emerged from work that has been done in both computer science and psychology. In this paper we present this groundwork and then, from this, develop our guidelines for the design of memory prostheses. First we consider psychological studies into the nature of human memory and present the results of two studies into memory problems at work. Secondly, we summarize some recent technological developments that open up new possibilities for experiments with memory aids. Thirdly, we describe some initial experiments with applying technology to memory problems. Finally we present in detail the guidelines we have developed for memory prostheses.

Our interest is in supporting healthy people in their everyday work. We are not considering the problems resulting from traumatic brain injury or devising physical implants of any form, although our work may have implications in these areas.

2. PSYCHOLOGICAL BACKGROUND

Understanding the processes underlying human memory is important if we hope to design effective technological support for memory in the workplace. Although there has been a great deal of psychological research on memory, little attention has been paid to memory processes in the workplace. We need to understand what kinds of memory problems people have at work, how frequently they occur and how troublesome they are when they occur.

2.1. Memory problems at work

Two studies were carried out to document the kinds of memory problems people experience at work (Eldridge *et al.*, 1992). The first was a diary study in which people were asked to note down the memory problems they experienced during the course of their daily work. The second was a questionnaire study based on the results of the diary study.

2.2.1. The diary study

The main purpose of the diary study was to understand the range of memory problems that occur at work. People at two research organizations in Cambridge (RX EuroPARC and the MRC Applied Psychology Unit) were asked to write down their memory problems as they occurred. A total of 182 problems were collected, and these were divided into three broad categories:

- Retrospective problems: problems with recalling past events or information acquired in the past.
- Prospective problems: problems in remembering to carry out planned actions.
- Action slips: problems arising from losing one's train of thought in the middle of some action.

About half of the problems reported were retrospective memory problems, either involving difficulty in recalling information, or in recalling some aspect of a specific event. Some examples from the data collected are:

- We spent an awfully long time looking for the name of someone whose first name is John, who works in the EEC—and I cannot remember for the life of me what his second name is. So we're looking to see if we can find it.
- I've just forgotten the word for 'taking a responsibility'.
- Confusion about whether I had given Mary something (some documents). Had no recollection of the event, let alone what happened.
- Lost expenses claim form I was supposed to fill in. Hunted high and low. Then picked up a file I had to start work on and found it there.
- Forgot how to e-mail John in California.

About a third of the problems reported were prospective memory problems. Some examples from the data collected are:

- Had to phone my doctor. Had intended to do this last week but never remembered. At last remembered, but number was engaged. Forgot to try again.
- I forgot that I was supposed to ask John Smith about a meeting.

The remaining problems reported were action slips. These are somewhat different in nature from the previous two categories in that they are short-term and immediate. Most are the result of inattention, either due to externally generated distracting events, or due to general 'absentmindedness'. Examples from the data collected are:

- Wrote a letter saying I would enclose a program for a meeting, and then sealed up the envelope, omitting the program.
- When I left the building, someone opened the door for me. I quickly walked out. The next morning I saw my 'name switch' said 'IN'.
- Off to fax room with letter to be faxed–forgot to take the fax number (again!).

Action slips do not involve deliberate attempts to remember, as is the case with prospective memory problems. Thus, it is not likely that a person would be likely to use a memory aid for these temporary and often quite unpredictable lapses. For this reason, action slips are not addressed in the general design of the memory prostheses.

Although this diary study was carried out in research organizations, other diary studies of memory problems in everyday life (e.g. Crovitz and Daniel, 1984; Terry, 1988) have found similar ranges of problems. To our knowledge, no other diary studies of memory problems in the workplace have been carried out.

2.2.2. The questionnaire study

To better understand the relative frequencies and severities of the different kinds of memory problems, a memory lapse questionnaire was designed. The questionnaire consisted of 21 questions, covering the three broad categories of problems identified in the Diary Study. The frequency of occurrence was rated for each question on a five-point scale, ranging from 'daily' to 'never'. The questionnaire was distributed to approximately 300 people at a Rank Xerox engineering site and 118 completed questionnaires were returned.

The results of this study showed that the most frequently occurring retrospective memory problems were: forgetting a person's name, forgetting the location of a paper document and forgetting a word or phrase. As a general class, prospective memory problems (forgetting planned actions) were also rated among the most frequent, as well as being rated as fairly severe when they occurred.

2.3. Retrospective memory

The first class of memory problems reported in the diary study, retrospective memory problems, is by far the most thoroughly studied class in the psychological literature on human memory. Many distinctions have been made within the area of retrospective memory, one of the most well-known being Tulving's (1983) distinction between *episodic* and *semantic* memory. Episodic memory (or 'autobiographical memory') is a person's memory for unique personal experiences and semantic memory is a person's knowledge of the world that is shared by others. Although some memory prosthesis applications may support processes of semantic memory (i.e. memory for facts), our primary focus is on the processes of episodic memory. One part of our goal is to provide support for remembering past activities, even those activities you think you will never need to remember.

There are three characteristics of episodic memory which are of particular importance. First, the basic unit of information in episodic memory is an *episode*. The dictionary defines an episode as an "event that is distinct and separate although part of a larger series". Thus, as Tulving (1986) points out, one can think of a person's life as being a series of successive episodes.

Second, although people are notoriously poor at remembering the precise date of an episode (Wagenaar, 1986), they are often very good at remembering temporal relationships between episodes (e.g. Loftus and Marburger, 1983; Saywitz *et al.*, 1992). For example, if you were trying to remember when you posted a letter to a friend, you might not be able to remember exactly when you had posted it, but you might well remember that you posted it just before you went on your summer holiday and just after you had a phone call from that person.

Third, presenting partial information about an episode can help people remember more information about that episode (Cohen and Faulkner, 1986; Linton, 1986; Wagenaar, 1986; Brewer, 1988). For example, if you were trying to remember the name of someone you met at a meeting last week, you might be more likely to remember the person's name if someone re-created the meeting for you by telling you who else was there, where the meeting took place and so on.

We aim to capitalize on these three characteristics of episodic memory in our design of technological support for human memory. For example, consider the problem of trying to find a recently-filed letter from your manager about your performance appraisal. The relevant episode is 'filing the letter', but you do not remember where you filed it. However, you do remember that you filed it before you attended a seminar by someone from the University of Dundee. You also remember that you received the letter just after your appraisal, and that appraisals occur in August. Now imagine that your memory prosthesis has stored information about when these other episodes ('attending the seminar' and 'having your appraisal') occurred, thus allowing you to pinpoint when the letter was filed. Imagine also that your memory prosthesis has stored information about every document you filed for this period of time, along with many pieces of information about each document (e.g. who wrote it, what it was about, where it was filed, etc.). By telling your prosthesis what you do remember about the letter, it can now tell you where you filed it.

In summary, then, a memory prosthesis should provide: information in a form which allows people to retrieve past episodes; information about many different episodes and the temporal relationships among them; and information about many different characteristics of episodes. With a memory prosthesis designed following these principles, you may never have to 'remember' the information yourself—the memory prosthesis will remember it for you.

2.4. Prospective memory

The second class of memory problems reported in the diary study, those involving prospective memory, is an almost unexplored area of research within the study of human memory (for review, see Kvavilashvili, 1992). However, both the diary and the questionnaire studies highlight its importance as a class of problems which needs technological support. These studies confirm that remembering one's intentions at some point in the future, without the use of memory aids such as lists, appointment diaries, and alarm clocks, is a very difficult task. The most difficult part of the remembering task is 'remembering to remember' at an appropriate point in time. Once one 'knows' that one needs to remember something, recalling exactly what that was is not usually a problem.

The diary study also illustrates that there are different kinds of prospective memory problems. Some are 'time-based' in that things have to be remembered either at some specific point in time in the future (such as an appointment or meeting) or within a time window (such as remembering to post a birthday card). Other problems may be called 'event-based' in that the thing to be remembered is contingent on the occurrence of some event. For example, trying to remember to pass on a telephone message to a colleague is contingent on encountering that particular person. Remembering to make a phone call when you get back to your office is a case where remembering is dependent on entering a specific place (i.e. the office). Thus people, places and activities form the cues that should trigger event-based remembering. Unfortunately, such cues are often ineffective in everyday life.

A memory prosthesis for prospective memory needs to be sensitive, therefore, not only to intentions which must be triggered at particular times, but also to intentions which depend on the occurrence of particular events. Because plans and intentions can occur to us anywhere, at any time, we should be able to set reminders for ourselves when they occur, before we forget them.

2.5. Implications for the design of technology

The results of both the diary and questionnaire studies emphasize the wide range of problems that are reported as both frequent and troublesome. One of the main implications of these studies for the design of technology is that different memory problems will require very different kinds of memory aids. Problems occur in a variety of situations and a range of retrieval cues may be useful depending on the problem. A memory aid developed to help people remember proper names may have features which are quite distinct from one designed to support the location of paper documents. Applications required to support prospective memory problems will again be fundamentally different from those required to support retrospective memory problems. Although these applications need to be tailored to fit the problem, there are nonetheless some requirements for technological support of memory which are more general, and which are outlined in the following sections.

3. TECHNOLOGICAL BASIS

As we have seen, for a memory prosthesis to be useful to us it must know a lot of things about us, such as where we are, what we are doing, who we are with. This will enable it to provide us with reminders of things we intended to do in this context, and, by recording such information, it will later be able to help us to recall details of events that would otherwise be forgotten. The more personal information it knows the more potential it has to be of help to us. We call this kind of device an 'Intimate Computer'. Ideally an intimate computer would be one that goes with us everywhere and is able to sense and record things about our environment that may be of use to us later. Fortunately, computer technology is about to undergo yet another major revolution that opens up exciting possibilities for such devices.

Using cellular radio and infrared technology computers are able to communicate with each other without wires. Until recently, radio transceivers were large and power hungry, so much so that the machines to which the transceivers were attached were also fairly large. Credit card sized radio transceivers are now available as commercial products (NCR, 1993) and we only have to look a short while into the future to see mobile computers that will be small enough to be *worn* rather than carried—perhaps resembling a watch or piece of jewellery. People will not have to remember to take their computer with them, they will wear it and take it everywhere.

Such systems will have several fundamental capabilities not previously available on such a wide scale. They will communicate, not only with each other, but with office equipment, domestic appliances and the plethora of electronic equipment that already contain one or more single-chip microprocessors. We are comfortable in this assumption because inexpensive communication facilities will inevitably become just another standard part of tomorrow's single-chip microprocessor.

The wireless communication technology used by these systems will be cellular, perhaps based upon the new digital cellular telephone standards. The requirement for low power usage and the need to handle many transceivers in a small area means that the cells will be small, each cell being connected by wire or higher-powered radio to its neighbours. The consequence of this is simple yet profound. Computers will know where they are. To find out their location they simply ask the nearest non-mobile object, for example, the base station connecting the local wireless cell to the building's conventional wire-net.

So, to summarize the anticipated developments in technology:

- Computers will be small enough to wear and take everywhere.
- They will be embedded in domestic appliances, office and consumer equipment.
- They will talk to each other using cellular wireless communications.
- They will know where they are.

3.1. Commercial products

A number of computer and electronic equipment manufacturers have recently announced products that nearly meet these specifications. One of the first plausible products on the market is the PenPad from Amstrad in the UK; but, unfortunately, it has no built-in wireless communications and can only take a Release 1.0

PCMCIA card (credit-card sized peripheral), precluding the use of plug-in communications. The EO 440 and 880 support radio communications, but use conventional cellular telephone technology which means that their cells are too large for fine-grain location. More interesting are the Casio/Tandy Zoomer and Apple/Sharp Newton MessagePad devices, which support infrared wireless communications, but which are only just becoming available.

Moreover, these are all significantly bulkier than we would like. We have therefore become involved with colleagues in the Computer Science Laboratory of Xerox PARC in the development of suitable portable computers as an interim solution.

3.2. The PARC Tab

The resulting device is known as the PARC Tab (see Figure 1) developed by Want and others (Adams *et al.*, 1993b). It is small (100 mm × 75 mm × 25 mm) and light (225 g) and can be worn either clipped to the user's belt or hung from a pocket. It has a bitmapped, touch-sensitive screen with a resolution of 128 × 64 pixels. In addition there are three buttons and two-way infrared communications. The user can interact with the Tab by pressing the buttons or by pointing with a finger or stylus on the screen. Power is supplied by rechargeable batteries that give a full working day's use from an overnight charging.

Each Tab has a beacon that is used to indicate its location in much the same way as an Olivetti infrared active badge (Want *et al.*, 1992), and a more sophisticated protocol maintains a link using infrared, serial line and Ethernet communications between each Tab and a home computer associated with its owner (Adams *et al.*, 1993a). A suite of library software presents the Tab to application programs as a simple bitmap terminal.

We believe that the Tab provides a feasible vehicle for implementing a memory prosthesis, both by building up the autobiographical data used by the system and by providing a user interface to it.

4. INITIAL EXPERIMENTS

Exploratory work on applications to support both retrospective and prospective memory has been carried out. Our experience with these applications, along with the psychological studies, provides the basis for the guidelines that we develop in the next section.

4.1. Systems to support retrospective memory

The Activity-based Information Retrieval (AIR) project (Lamming and Newman, 1992) was the beginning of many of the ideas related to the memory prosthesis. The goal of the AIR project was to improve the ability of the user to retrieve information and recall past events in the workplace. The basic idea was first to collect information about activities automatically and to timestamp each activity as it occurred; and, second, to translate these data into descriptions that correspond to the way users would themselves describe their activities. Thus a person could use easily remembered information about events to help recall other less memorable information.

The AIR project led to a number of pieces of work, summarized here, to test the feasibility of some of these ideas. These explorations were inspired both by technological possibilities and the psychological findings discussed earlier.

FIGURE 1. The PARC Tab.

4.1.1. Pepys

A paper by Newman et al. (1991) describes an early project to use automatically time-stamped data about peoples' movements around our laboratory. The Olivetti infrared active badge network (Want et al., 1992) at EuroPARC senses the locations of badges around the building and these data can be gathered to give a log of the locations of people wearing badges. The raw badge data are very detailed, e.g. walking from an office to the common room to meet a visitor will generate events at a whole series of sensors along the way.

In the Pepys project techniques were developed for extracting significant episodes from the raw badge data. These included periods spent mostly alone, gatherings of two or more users (e.g. meetings) and travel by users between locations. Part of a typical diary generated in this way can be seen in Figure 2. Discounting those episodes in which errors occurred due to people not wearing badges, at least 90% of episodes are correctly identified. This has been good enough to encourage people to make use of Pepys for such things as reminding them of the need to follow-up activities from the previous day. Visitors to EuroPARC have used Pepys to help in writing trip reports.

On the other hand, the episodes recognized by Pepys are purely location based and often lack sufficient detail to make them distinct. For example, 'In Office [2hr 20m]' does not give much information about what activities were actually being done in the office. Several other experiments were carried out with other recording methods in order to provide further detail to the Pepys diary.

14:14 In office [50 mins]
15:04 In and out of event in Nathan's office; with W. Nathan, R. Hatton [45 mins]
15:50 In office [10 mins]
16:00 In Conference room [4 mins]
16:05 Attended part of event in Commons; with B. Andrews, M. Morton, R. Hatton [7 mins]
16:13 Mostly in office [44 mins]
16:57 Attended event in Wright's office; with P. Wright [7 mins]
17:04 Looked in on event in Morton's office; with I. David, M. Morton [1 min]
17:05 Mostly in office [2h 3m]
17:05 In office [5 mins]
17:11 In event in office; with P. Wright, I. David [1h 2 mins]
18:13 In office [36 mins]
18:50 Meeting in office; with W. Nathan [13 mins]
19:03 In office [5 mins]
19:09 In 2nd floor rear area [2 mins]
19:11 Last seen

FIGURE 2. A typical Pepys diary.

4.1.2. Video diary

The Video diary provides a way of augmenting the Pepys diary with video snapshots (Eldridge et al., 1991). The video network around the building (Buxton and Moran, 1990), directed by the active badge network, enables the recording station to switch to the camera nearest a particular person as they move around the building. Any significant change in the image being received triggers the recording of a frame. The study by Eldridge et al., (1991) tested the ability of the video diary to aid recall. Considerably more activities were recalled when users viewed their video diaries than when a Pepys diary was used, especially when a month or more had elapsed since the original activities.

4.1.3. NoTime

Although Pepys can inform its user that a meeting occurred, it can provide little useful data on the content. Hence other methods are needed to capture this information. NoTime (Lamming, 1991) is a system that electronically captures the hand-written notes normally made by a person attending a meeting. The electronic notepad links each note to the appropriate part of an audio and video recording that is made of the meeting. Each stroke is given a time-stamp and this is used as the link to the recordings. Later, when the user sees 'In conference room with Mik and Peter 1hr 45m' she can go back to these notes and find out more about the content of the meeting. Because each stroke in the notes is time-stamped she can listen to selected parts of the meeting relating to points in the notes, for example if the notes are incomplete or unclear. Other projects have successfully used the prototype to gather and analyse annotated video data.

4.1.4. Monitoring paperwork

Long periods spent alone in the office also provide little detail for Pepys, and the video diary presents only a view of the office and no detail of paper documents. A system that recognizes and tracks paper documents could contribute details of paper-based activities during these periods.

A prototype system, called Marcel (Newman and Wellner, 1992), is able to recognize activities involving paperwork by using a video camera mounted over the user's desk. Images of documents are digitized, processed and then compared with a database of known documents. Recognition is sufficiently fast and reliable to make this a plausible approach for logging the arrival and departure of documents on the desk top.

4.1.5. Monitoring workstation activities

Monitoring workstation activities is another way to provide further useful details of activities in the office. For example, recording which electronic files were touched could aid in the retrieval of documents relating to particular activities. Similarly, recording sequences of workstation commands could help the user recall complicated procedures performed earlier.

Experiments have been carried out to gather various kinds of workstation activity data, such as what the user types, which files are open, and the creation and destruction of processes on the machine. There were various technical difficulties to be overcome, but a large quantity of potentially useful information was gathered. The major problem is in processing the raw data into higher level episodes that match the user's recollections. The records were very detailed and extensive, and although it is possible for a skilled user to recognize what they were doing it takes considerable effort. We anticipate more success by directly instrumenting applications to generate more meaningful data.

4.2. A system to support prospective memory

Prospective memory either involves delaying an action until some future pre-specified time or until some pre-specified event, such as entering a room, meeting a person or performing an activity. This suggested a reminding system which allows reminders to be set not only on the basis of time, but also on the basis of place, people and activity. Since intentions can spring to mind any time, any place, another requirement of the system is that it be portable, allowing users to set reminders wherever they are.

A prospective memory experimental prototype was built to explore ways of providing reminders about intentions (Sellen *et al.*, 1992). This system used the existing Khronika system (Lövstrand, 1991) in conjunction with active badges. The system was limited in that it relied on the audio-video network (Buxton and Moran, 1990) to play audio reminders, required that reminders be set from a workstation and could not effectively deliver the content of a reminder (i.e. what the user wanted to be reminded about). However, this prototype was useful in showing how reminders based on time, place and people could be implemented.

The system is now being implemented on PARC Tabs. Tabs are ideal for this kind of application in that audio reminders can be generated by the Tab itself, reminders can be set any time and in any place within range of Tab sensors, and the contents of the reminder can be displayed on the Tab screen as not much screen area is required for a typical reminding message.

Future plans include incorporating 'smart' reminders so that the delivery of reminder cues will be sensitive to certain aspects of the environment. For example, one does not want a series of bleeps going off during a seminar, and so in this situation audio cues might be replaced by visual ones. Notification might also be sensitive to whether the user is on the telephone or is in a meeting. Another feature of this system is that it might monitor the user to see whether planned actions are actually carried out. For example, after playing a reminder to attend a meeting, the system could monitor the movements of the user to see whether that person went to the meeting. If not, the system could replay the reminder. Both the basic functionality of the reminding system, as well as the utility of features such as those described above, will be tested and refined by studies of use within an actual workplace.

5. THE DESIGN OF A MEMORY PROSTHESIS

Memory problems are a serious challenge in office automation. Our workplace studies have revealed a range of problems, particularly retrospective memory problems concerned with recall for past events and prospective memory problems concerned with remembering to carry out intended actions. Psychological studies have shown the value of partial information about past events in aiding recall of further details. Information about the location, the people present and the kinds of activities they were involved in are of special value. In the case of prospective memory, actions are often intended to be carried out in a particular location or when meeting a particular person but frequently the person forgets the action when they actually encounter that context. These kinds of problems have led us to define a new class of applications, called 'memory prostheses', that provide support when these problems arise. The nature of human memory problems makes memory prostheses distinctly different from any current office information system.

The central feature of these applications is the ability to sense aspects of their user's environment and make records which can then be used later to enable the user to recall things they did not know they were going to need to remember. This sensing of the environment also enables the issuing of context-sensitive reminders, an important feature of support for prospective memory. The various experiments reported above demonstrated the feasibility and utility of making records of a person's environment and activities. However, analysing and presenting the data in a form that makes sense to users and does not overwhelm them with a mass of detail was found to be a challenge. On the other hand, the data relate to a person's own experiences and thus provide a framework for interpretation and triggering recall of what they need to know, even if that information is not present in the data.

We are now in a position to present our current design guidelines for memory prostheses and to lay out the challenges that these present for computer systems research. The first four guidelines are specific to the functionality provided by a memory prosthesis:

1. Sensing of the environment.
2. Automatic data capture.
3. Manual data capture, note taking, annotation.
4. Focussing on relevant information for retrieval.

The remaining guidelines are normal requirements for any interactive system but have a particular interpretation in the context of a memory prosthesis:

5. Easy to use.
6. Available where needed.
7. Integrated with other applications.
8. Reliable and fail-safe.
9. Respectful of privacy.

In what follows we elaborate on each of these guidelines.

5.1. The guidelines in detail

5.1.1. Sensing of the environment

A memory prosthesis must be able to sense its external environment if it is to be of help to its user. Experiments with Pepys and the video diary have shown that the more information a system can gather about the user's activities then the more help it can be when information needs to be recalled later. This sensing of the environment is also important in providing support for prospective memory. Many intentions are related to particular people or places, such as remembering to hand over a message to someone when you next meet them or remembering to phone someone when you return to your office. A memory prosthesis that is sensitive to where you are and who you are with can provide reminders at an appropriate time. This sensitivity to the context also enables reminders to be delivered in a manner appropriate to current activities. For example, a visual rather than audio reminder would be issued in the middle of a seminar.

A wide range of aspects of the environment can be sensed. We have already experimented with information from an audio-video network, from an active badge network (yielding people's locations) and from software that recognizes documents from video images of desks. Many other things can also be sensed, such as whether a door is open or closed or whether someone is using the telephone or some other electronic device.

5.1.2. Automatic data capture

A memory prosthesis is intended to have records of information that will be of help in an unspecified future situation when something is forgotten. The problem with many current information systems is the need to recognize that information is going to be important and should be stored. The user also needs to decide how to categorize what is recorded so that it can be retrieved later. It is often not possible to recognize what will be needed in future or in what way it will need to be retrieved, and as a result the information may be irretrievably lost. A memory prosthesis that relied on explicit recording and on-the-spot categorization would be less useful. Hence it should automatically capture as much data as possible, with no intervention from the user. Minimal structure should be imposed at the time of recording so that a variety of categorizations can be applied later.

Automatic capture should potentially cover the whole range of what can be sensed by the memory prosthesis. In addition to the immediate aspects of a person's activities that we have already mentioned, there are many other things that can provide powerful cues for remembering, e.g. the weather and the news headlines. Services exist to provide such data on-line and so these too can be captured into the records. Instrumented software is another potential source of useful data.

Certain aspects of support for prospective memory might also be handled automatically. For example, centrally-organised events could be entered through an events database such as Khronika (Lövstrand, 1991). The user can set up daemons that detect particular kinds of events in the central database and then carry out some action, which could include entering it into their personal records.

5.1.3. Manual data capture, note taking, annotation

There will be situations in which the user wishes to make some explicit record, such as a note or sketch. This should be simple to do and the record should then become part of the on-going collection of information about the user's activities. The device should also support the annotation of existing records, whether automatically or manually generated. The kind of functionality provided by NoTime, described earlier, is a step towards this. It demonstrates note taking at the time of recording and similar technology could be envisaged for annotation of video records after the event. A fully functional memory prosthesis would allow annotation of any kind of record.

The system for supporting prospective memory is one important aspect of a memory prosthesis that cannot rely entirely on automatically recorded data. The user will need to enter many future events manually and will also want to set up various kinds of reminders associated with future events. Such reminders can be seen as a special kind of annotation associated with the event.

5.1.4. Focussing on relevant information for retrieval

The automatic recording will generate large quantities of data to be searched. A memory prosthesis should provide simple ways for the user to constrain the search to relevant parts of the archive.

Different memory problems require different strategies for solving them and so memory prostheses should provide for a range of strategies. The user may be able to remember enough to specify accurate retrieval of an item, or at the other extreme they may only remember a little and therefore will want to browse around guided by what cues they do recall. The user should be able to switch freely between constrained pattern-matching and free-range browsing.

This is a case of a guideline where the particular nature of the data being searched or browsed simplifies the requirements. Getting lost is a serious and well-known problem when people browse large quantities of data (Nielsen, 1990). An advantage of the memory prosthesis is that the data is all related to events in a person's life. Although the user may have forgotten many of the details, their memories, along with the natural temporal organization of the data, will help to orient them (Loftus and Marburger, 1983; Saywitz *et al.*, 1992). This should make it much easier for them to navigate than would be the case with completely new and unfamiliar data.

The kinds of cues remembered will vary and so the search could be started with any of a number of kinds of information. For example, we may remember that we last had the lost document when we were with a particular person in a certain room and so wish to start from person and location information. On the other hand, we may remember that it was on the day when we had a very hot and sticky office meeting, and so we start from the office calendar and the weather records.

The information we wish to retrieve will vary, too. If we have lost a document, we may wish to follow our movements from the time we last remember having it, to see if we are then reminded of the place we might have left it. However, if we simply remained in our office for a long period, then snap shots from a video diary or information from a document recognizer watching our desk would be more helpful.

This approach to retrieval provides a new approach to the management of electronic documents in general. Currently such documents must be explicitly named and stored in an appropriate location. The name and location must then be remembered in order to retrieve the document. This is particularly a disincentive to producing small electronic notes about miscellaneous things that arise as the overhead involved in ever finding them again is too great. A memory prosthesis should associate a rich variety of retrieval cues with any electronic note such that we can still retrieve it even if we never got around to naming or categorising it.

5.1.5. *Easy to use*

Quantifying 'ease of use' is hard. However, for a memory prosthesis we know that it must be easier to use than other means of recalling something that has been forgotten. This means that it must have a user interface that readily reveals how it should be used and how the system records, stores and retrieves information.

A memory prosthesis has to capture a variety of different types of information and allow it to be browsed using a single user interface, whatever the type of data. The system should also convey the status of the information that is presented to the user, ranging from its technical reliability (e.g. was the system unavailable for a time because of maintenance work), through conveying in-built limitations (e.g. moving out of range of the wireless communication system) to user-imposed privacy constraints.

For the users to feel in control of their personal data it is important that they can see clearly what information is being revealed to others and how they can control this. An unclear and complex system makes it unlikely that users will be able to take this control.

The information retrieved should be presented in a human-recognizable form. For example, in the Pepys experiments raw location data were processed into chunks such as 'meetings' that approximated more closely to the user's experience. Such processing will always be an approximation, but it makes the data more manageable and recognizable.

5.1.6. *Available where needed*

A traditional diary is available wherever the person carries it and a memory prosthesis should be similarly available for both capture and retrieval, provided it is within range of the network. Events of interest happen in both the 'physical' and 'electronic' worlds, and so this device should record activities in both. Obviously there will be limits to this, both in physical extent and in the kinds of data recorded. The system must make it apparent where these limits are so that the user knows when and what it can be relied on to record. Similarly when information is being retrieved, it should be clear what the limits of the information are.

One way to achieve ubiquitous availability is with a small, portable device such as the PARC Tab, combined with a network. Ideally the device should be sufficiently small and unobtrusive that it can be carried at all times. Another form of ubiquity is to have non-portable devices available in any location where they might be needed. In fact, portable and non-portable devices can play complementary roles in an integrated system. Small devices are ideal in situations such as meetings where a workstation would be obtrusive and inappropriate. Brief notes could fairly easily be made on the small screen. On the other hand, the small screen is highly constraining, for instance if you wished to browse quantities of previous notes. In such a situation it may be more appropriate to find a nearby workstation with a large screen. Memory prosthesis applications should move gracefully between devices in such a mixed environment.

5.1.7. *Integrated with other applications*

We expect a memory prosthesis to frequently be used during the use of other computer applications, e.g. to retrieve mail addresses, find files, refer to notes and so on. It should provide an integrated set of facilities that can be accessed by the designers of other applications so that memory prosthesis functionality can be made available wherever it is needed. It could be thought of in a similar way to file-browser 'widgets' in that it will provide a consistent way to browse through the memory prosthesis records, whatever those records will eventually be used for.

Another essential form of integration is the collecting of records from other applications, such as the creation of files in a document processing system or the sending of electronic mail to particular people. All such data could be useful as cues for remembering.

A successful memory prosthesis will integrate seamlessly into the user's normal everyday activities and be available to provide help when needed.

5.1.8. Reliable and fail-safe

If a user is to depend on this system for remembering things, it should be very reliable and fail in safe ways. It should always be obvious when it is not working correctly and it should be clear to the user what strategies should be adopted to deal with this.

An analogy with the telephone network might be helpful here. If your own telephone is not working then the next thing you try to do is use a neighbour's telephone to report the problem and request that it be fixed. If all your neighbours' telephones are not working then it must be a much larger, central problem and so there is nothing more you can do. An interesting problem with current telephones is that a non-working telephone is not apparent until you try to make an outgoing call. You might happily sit waiting for a call on a non-working telephone without knowing this. We would wish a memory prosthesis to make it much more obvious that it is not working correctly.

System failures should also be apparent in the records when they are browsed later. For example, it should be possible to see whether your absence from the record was because you were away that day, because your active badge was not working or because the whole network had failed.

5.1.9. Respectful of privacy

People treat traditional paper diaries as personal and usually confidential. The memory prosthesis should similarly allow its user to maintain his or her desired level of privacy. An important underlying requirement here is that the memory prosthesis convey a clear and coherent model of its behaviour to its user. The user should be presented with no difficulties in understanding what is being recorded, what is being revealed to others and how all this can be controlled. Different people may have different boundaries between what they consider acceptable behaviour and what they consider to be intrusion. In addition, the same person may have different boundaries in different contexts. Hence the system must be easily tailorable at any time.

Interesting questions arise about the recording and reuse of publicly available information about a person. A record of my location at a particular time will appear in the records of other people who meet me. There may also be an audio recording of our conversation which also becomes part of both my records and those of the other person. It is unclear what are appropriate policies, and no doubt these will vary between people and work organizations. What we can say is that a memory prosthesis should allow for a variety of policies and a high level of personal control. Further issues arise about how and whether a user is informed of the preferences of another person, as revealing these could itself be considered an intrusion.

6. CONCLUSION

We have defined a new class of applications to support human memory that we call memory prostheses. The guidelines we have developed for the design of these applications derive from psychological studies of memory in the work place as well as from technological considerations. A person's memory for details of past events can be triggered by providing partial information. It has been demonstrated that sensing and recording a variety of information about a person's activities, such as location and other people present, can be a useful aid to remembering. We have also shown the feasibility of providing people with context-sensitive reminders to carry out intended actions. This class of applications will be sensitive to their environment, able to record what they sense and able to present the recorded data in a comprehensible and useful form. Many of the guidelines are similar to those for more general information capture and retrieval but the particular nature of human memory problems provides its own difficulties and opportunities.

The guidelines for memory prostheses that we have developed in this paper pose many interesting research questions. We are now working on a prototype model which tries to meet some of the challenges of data capture and retrieval by a user carrying a portable device. There are also interesting (and sometimes disturbing) issues of privacy—issues never contemplated when current privacy and data protection legislation was conceived—and we are addressing these too.

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