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Making Sharing Pervasive: Ubiquitous Computing for Shared Note Taking

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Making sharing pervasive: Ubiquitous computing for shared note taking

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As a variety of low-cost note-taking devices becomes pervasive, shared notes can help work groups better communicate ideas and information. To explore this idea further, we carried out three related case studies of how members of a large research group shared meeting notes. The group found value in combining personal notes and presentation slides with a single, unifying document, such as regular meeting minutes. The minutes provided structure when there were too many sources of notes. We used this insight in our design of NotePals, a note-sharing system with a lightweight process, an interface, and hardware that distinguish it from previous systems. We have developed note-taking applications that run on inexpensive personal digital assistants and other ink-based capture devices, such as the paper-based CrossPad™. Experience with using NotePals has shown that shared notes can add value to meeting, conference, and class records.

Communication of ideas and experiences is critical to the success of a work group. Individuals spend much of their time alerting colleagues to new information, explaining ideas to them, or searching for a person who has needed information. NotePals, a system that captures and provides access to personal notes, presentation slides, and documents of interest to a work group, attempts to give group members more direct access to their colleagues' thoughts and experiences by automatically capturing notes taken in any context and making those notes accessible to an entire work group via the Web. Group members can share notes with one another by synchronizing with a shared note repository that they can then view using a desktop-based Web browser. This allows group members to benefit more easily from their collective experience.

Shared notes from meetings can capture group members' detailed thoughts and differing perspectives. If one person in the meeting creates an important diagram or list of ideas in his or her personal notes, all group members have easy access to that information. Likewise, shared notes that one group member takes during a conference session can benefit other members who did not attend that session. When the group reviews the conference, its members can retrieve the notes taken during each presentation and discuss them in detail. These notes can be useful long after the meeting, because the notes can be combined with on-line proceedings to create an augmented record of the conference. We have also found that group members often take better notes, in terms of both legibility and content, because they know that other group members will want to share them.

Although previous systems have investigated the use of shared notes created on workstations (e.g., Free-

Style[1]), we have found no other systems that explicitly support the sharing of personal meeting notes, nor have we found studies of shared note taking using more common technologies, such as pen and paper. This paper gives a detailed description of the NotePals system and shows how group members can share notes, as in the above examples. In the first part of this paper, we describe three case studies of group note taking that helped us to better focus our early ideas and led to better applications for shared notes in later prototypes. In the second part we begin with a review of the related work. We then describe the NotePals system, focusing on the note-taking interfaces and Web-based note browsers. Next, we describe usage experiences that have shown the positive value of shared notes. We finish with future plans and conclusions.

PART I: CASE STUDIES OF EXPLORATORY GROUP MEETINGS

Our vision for a shared note-taking system was to allow individuals to take personal notes in meetings as they do now, and to use those notes to automatically generate meeting minutes. There are problems with existing approaches to creating minutes. In particular, there is a lack of shared understanding inherent in personal notes, and there are several drawbacks to using a meeting scribe. For example, if scribes are not part of the teams that are meeting, they may lack the background to take good notes. In contrast, if scribes are team members, they will not be able to participate fully in the meetings. Finally, there is some anecdotal evidence that in large meetings involving several groups, the group that controls the scribe controls the perceived outcome of the meeting.

We hypothesized that if group members only wrote what they thought was important, it would make the creation of minutes easier and have the benefit of providing multiple perspectives on what occurred in the meeting. With this idea in mind, we conducted three related case studies in which we explored several possibilities for shared note-taking systems. Here we describe the general approach, participants, and environment, and then present the method, detailed results, and conclusions for each of the case studies in turn.

General approach

We carried out these case studies over the course of three meetings. They were structured as a group exploration in which both experimenters and participants contributed to the final solution. A "Wizard-of-Oz" prototype[2,3] of a shared note-taking system was introduced into an existing group's meeting environment. Participants took notes with pen and paper, and one participant, the *assembler*, helped the experimenter merge these notes into a shared document after each meeting. This simulated the production of an automatically generated document, given best-case technology assumptions. The assembler would not be necessary in the envisioned electronic system. This technique helped us evaluate whether such functionality would be useful to a work group. A designated scribe at each meeting also took minutes to allow for comparison with the "automatically" assembled minutes.

The participants viewed the assembled notes after each meeting, both as typed text and in their original handwriting. Handwritten notes, we thought, would be sufficient and perhaps preferable to ASCII text for groups that may create drawings during meetings. To compare the two styles, we asked the assembler to transcribe the notes manually.[4] After assembly, we asked for reactions from group members.

Participants and environment

The group we studied was a computer systems research group composed of professors, graduate students, and staff. There were 16 group members, of which 12 participated in the studies. The group had been taking minutes at meetings for over a year, selecting a different scribe each week. Most group members took meeting minutes on paper and transcribed them into a computer after the meeting. A few group members typed minutes directly into a small computer during the meeting. Most group members said they needed between 15 and 45 minutes to prepare the minutes after the meeting, but some took as little as five minutes or as much as two hours.

The minutes served three main purposes. Of eight participants who answered a prestudy questionnaire, four said that they used the minutes as an archive of meeting details, whereas the other four said that they used the minutes as a summary to catch up on missed meetings. Five respondents added that they used the minutes to track personal action items. Six of the respondents also took personal notes in meetings, often in dedicated notebooks.

Though the group members were generally satisfied with their current process for taking minutes, there were complaints. Five group members said that they could not participate fully in meetings while taking minutes. Two members noted that the quality of the minutes varied too much from week to week, and one said that it was difficult to write about unfamiliar topics.

The meetings took place in the group's regular meeting room. A large table in the center of the room accommodated 12–14 group members, and the remaining members sat outside the inner circle. The experimenter was in the room during the meetings and occasionally moved around the room.

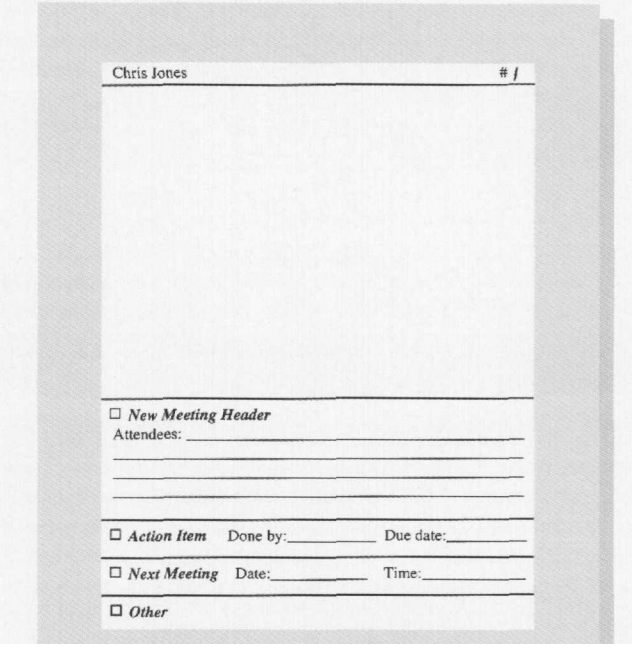
First case study—Making shared records

The goal of the first case study was to make shared records that were better and easier to create than meeting minutes. We asked the group to begin by taking notes that they thought the group should see, and to assume that no one was taking regular minutes.

Method. At the beginning of the meeting, group members were each given a small pad of paper and asked to write their notes on this pad, keeping in mind that they would share their notes. In addition to these personal notes, one group member took minutes as usual. The note pads were one fourth the size of an 8½ × 11-inch piece of paper and contained the participant's name and blanks for entering various types of note attributes, as shown in Figure 1. We chose this size to emulate a personal digital assistant (PDA), one of the note-taking devices we were planning to use in our shared note-taking system.

After the meeting, the notes were collected, assembled into a meeting record, and transcribed into ASCII text. All three records, consisting of the regular minutes; the handwritten, assembled record; and the transcribed, assembled record, were made available for review on the Web. We asked group members to read and compare these three records and answer a questionnaire after the meeting. Questions focused on the content and clarity of the notes, and also asked group members to say which set they would rather use, which set they thought was easier to create (assuming assembly was automatic), and what they would change about any of the records. We analyzed the answers and used them to guide the subsequent case studies.

Figure 1 The note pad used in the group note-taking case studies

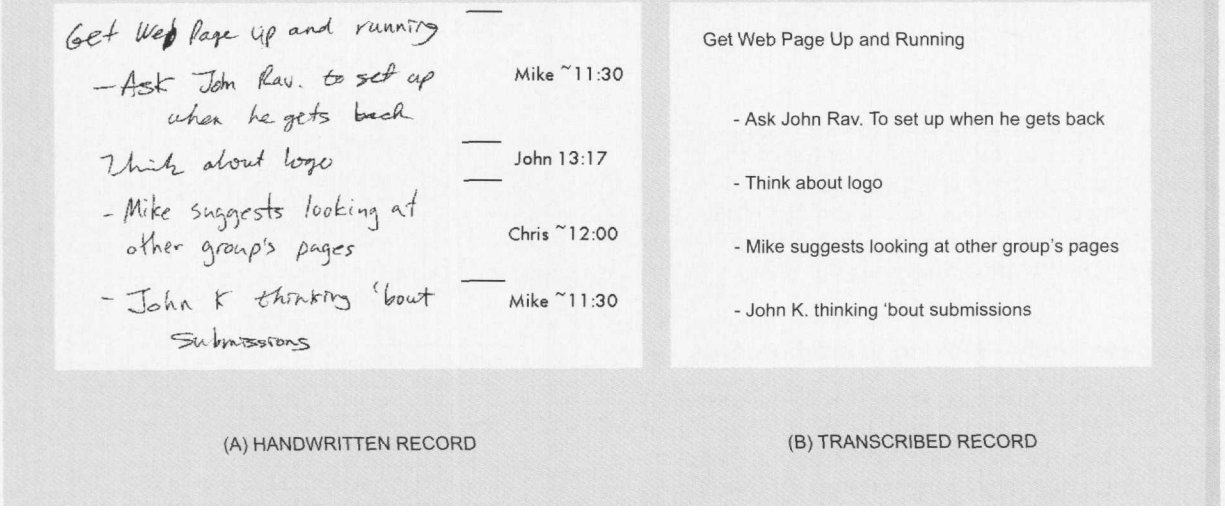


Results and discussion. This was a tense meeting, during which the group discussed a project that was to be completed in the following three days. At the start of the meeting, several participants asked where they should take their personal notes. Since the notes were to be merged into a shared record, we suggested they write private notes in a separate place. The meeting lasted approximately 60 minutes, and the group took 20 pages of "group" notes during this time. Two participants took eight pages each, and two others collectively took the remaining four.

After the meeting, one participant was given free reign to turn the notes into any kind of record he desired. He cut the notes into tiny pieces and assembled them into something that resembled minutes, as simulated[5] in Figure 2A. He probably used this organization because it was the most familiar and conformed closely to what he expected to get out of a meeting record. The assembler then transcribed the notes, as simulated in Figure 2B.

When asked to rank the meeting records by preference, all participants put handwritten notes at the

Figure 2 A simulation of the meeting documents generated after the first meeting



bottom, and most put the regular minutes at the top. Though few noted any difference between the scribed minutes and the assembled notes, some commented that the assembled notes were slightly less coherent. Both, however, had the "feel" of minutes, and each captured points that the other missed, making neither obviously superior to the other. All participants agreed that they did not like the handwritten notes, which some called "useless" without further explanation. The main complaint was that a combination of different handwritten text blocks lost the coherent structure that made minutes easy to read.

When asked whether they would rather rotate the scribe responsibility or have their notes automatically assembled after meetings, all participants said they would rather be scribes. The two participants who took most of the notes said that they *felt* as if they were taking minutes. They said they could not rely on others to take the notes that they wanted to see in the group record.

Conclusions. We came away with three main conclusions from this first case study.

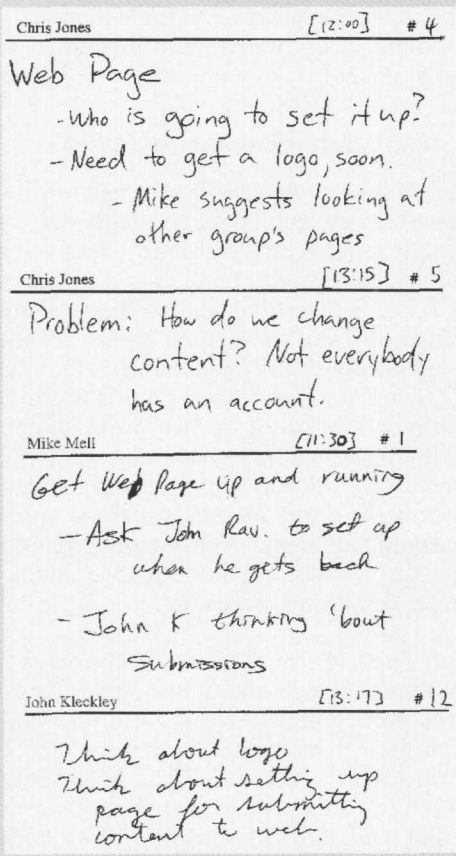
First, there were no complaints about taking notes using pen and paper, indicating that this technique was acceptable to this group as a way of creating notes. Second, frequent changes in the handwriting and wording styles seemed to lead to the reported lack of coherency in the assembled minutes. Third, the incoherence of shared notes was not balanced by any improvements in ease of creating meeting records, as evidenced by the large number of notes taken by two participants.

Second case study—Making shared notes more coherent

The goal for the second case study was to make the shared notes more coherent and easier to create. We tried to reduce the number of times handwriting and wording changed in the meeting records. In addition, by asking the participants to focus on what they needed for their own notes, we thought they would find the process of taking and sharing notes more natural.

Method. The same method was followed as in the previous meeting, with the following three changes. First, while a volunteer was asked to assemble the notes into something useful after the meeting, this time the volunteer was instructed to insert or cut notes *only if absolutely necessary*. Second, the group

Figure 3 A simulation of the meeting documents generated after the second meeting



(A) HANDWRITTEN RECORD

(* Chris Jones 12:00 *)

Web Page

- Who is going to set it up?
- Need to get a logo soon.
  - Mike suggests looking at other group's pages

(* Chris Jones 13:15 *)

Problem: How do we change content? Not everybody has an acct.

(* Mike Mell 11:30 *)

Get Web Page up and running

- Ask John Rav. To set up when he gets back
- John K. thinking 'bout submissions

(* John Kleckley 13:17 *)

Think about logo

Think about setting up page for submitting content to web

(B) TRANSCRIBED RECORD

members were told to ignore the final record and to take notes for their own benefit, still assuming that no scribe was taking minutes. Third, since several participants asked about taking private notes in the previous case study, this time the participants were told that their notes would be copied and returned to them. We asked them to add a "Private" attribute to any notes they did not want to appear in the group record.

Results and discussion. The second meeting had a more varied format than the first. It included several project updates and planning for a retreat and a company visit. It lasted about 95 minutes, and the group took 52 pages of notes. Two participants wrote 25 pages of notes, and eight others collectively wrote 27. Although handwriting size varied, these numbers indicate that note taking was much more evenly spread across participants than in the first meeting.

The assembler grouped notes into topics, with each group containing a sequence of perspectives, as simulated in Figure 3. The assembler did not cut out

repeated points, and there was no clear indication of where one topic ended and another began.

The response to these records was more varied than before. Half the respondents said that the assembled minutes had more detail, and half said that they had about the same content as the scribed minutes. Most participants agreed that the structure of the assembled notes was hard to follow. The lack of clear section headings made it difficult to know when one topic ended and another began. Others pointed out that they did not like reading repeated information and preferred the organized format of minutes. Even so, two group members felt that the assembled notes were preferable to regular minutes because they were easier to create and were acceptable as meeting records. They said they would rather share notes this way than take minutes. Most of the participants, however, still felt that taking shared notes was not as simple as taking personal notes.

The response to the handwritten, assembled notes did not improve after the second meeting. One group member commented that he thought handwritten notes were especially bad for meeting archives or summaries, because handwriting is hard to visually scan and search.

Conclusions. The results of this second case study were encouraging, but it was clear there were still several problems with the idea of shared note taking.

First, two participants continued to believe that they had to take complete minutes on their own. The system appeared to exhibit one of the classic problems leading to the rejection of groupware.[6] Shared notes could benefit the scribe, who was no longer responsible for minutes, at the expense of other group members. The uncertainty about what would make it into the notes shifted the note-taking load to those who cared enough to take detailed notes every week, undermining the load balancing provided by the scribe.

Second, the negative reaction to handwritten minutes signaled that this group would never *prefer* handwritten meeting records to typed meeting records, although handwritten records might be organized in a way that made them *satisfactory* as meeting records, if the scanning and searching problems could be overcome.

Third, limiting the number of times the handwriting and wording style changed did seem to improve the structure and coherence of the shared notes. Still, most group members preferred the organized format of minutes. Members of this group visually scan meeting minutes for important points if they miss a meeting or if they need to retrieve a critical piece of information. For these tasks, it is essential to have a concise, coherent, and well-structured record.

Third case study—Enhancing minutes

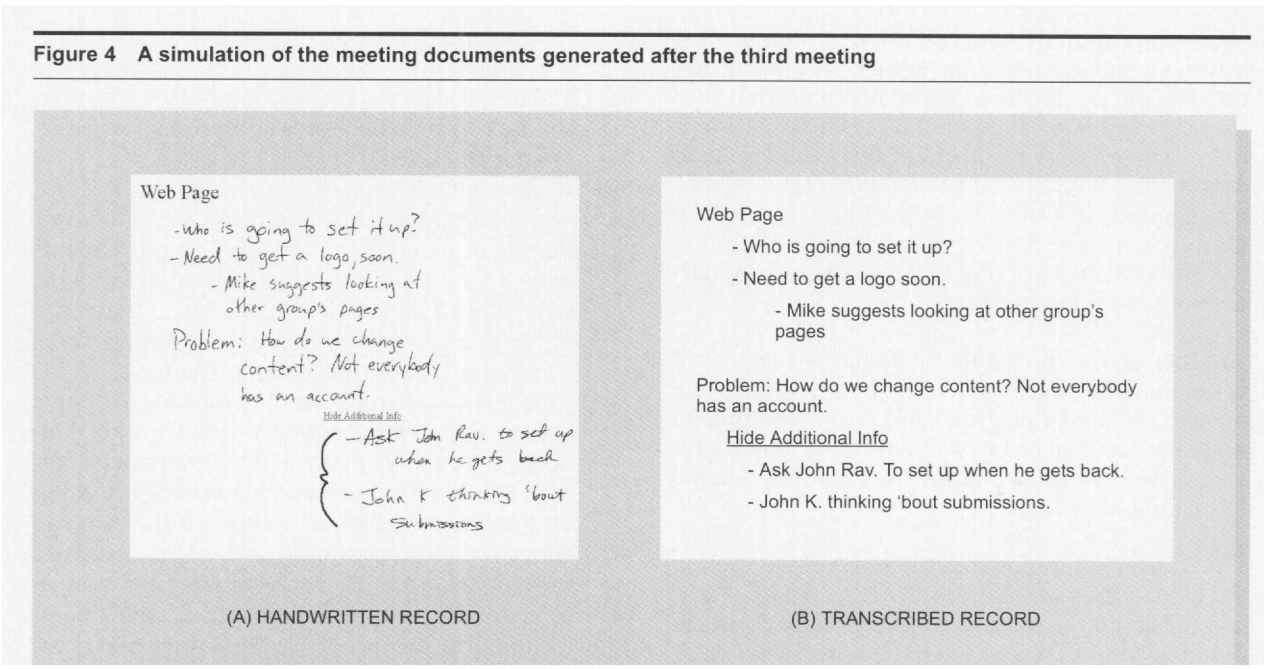
Because of the problems with the structure and coherence of the assembled meeting records, and because many group members found assembled meeting records harder to create, we decided not to pursue the idea of automatically generated minutes in the final case study. The third case study focused on automatically *enhancing* minutes, rather than replacing them. The goal for this session was to create a better meeting record by incorporating personal notes into the regular minutes, using the minutes as the structure by which to organize the personal notes. By assuring the group members that the appointed scribe would still create their meeting minutes, we felt that they would feel more at ease taking their own notes only when necessary.

Method. The same method was followed as in the previous meeting with the following three changes. First, the participants were asked to take personal notes on their pads, assuming that a scribe would take their minutes as usual. Second, the scribe was also asked to use a pad, so that the minutes could be used in the handwritten record. Third, although a volunteer was asked to assemble the notes into something useful after the meeting, this time the experimenter worked more closely with the assembler to try to make the best meeting record possible from the notes.

Results and discussion. In the third and final meeting, many of the students presented updates on their projects. The meeting went on for approximately 110 minutes. Note taking was fairly balanced across group members. Of 25 pages of notes, the scribe created only six. Eight other participants took two to three pages of notes each. In addition to notes, the experimenter collected a set of slides presented during the meeting.

After the meeting, the assembler first divided all of the notes by topic. Next, he laid out the minutes in separate topics with large headings for easy scanning. He then selected a few notes written by other participants that contained new information. He put

Figure 4 A simulation of the meeting documents generated after the third meeting



those in a separate "Additional Info" area. We then put the minutes on the Web and added hyperlinks to show or hide the additional information, as illustrated in Figure 4. A table of contents was also added at the top of the minutes with links to the various sections, as was a link to the presentation slides.[7]

The response to these assembled notes was much more positive. Over half the group *preferred* the typed, assembled minutes to the regular minutes taken by their scribe. All cited the *additional information* provided by the assembled minutes, both the personal notes and the presentation slides. They also liked the fact that they could hide or reveal this additional information as necessary using hyperlinks, thereby making the minutes more readable and coherent.

The few who did not prefer the assembled minutes said that there was not enough additional content to justify the distraction of added hyperlinks and section headings to the minutes. In addition, the added structure did not make the handwritten, assembled notes acceptable. Nearly all group members said that they would prefer the notes to be presented as ASCII text.

Conclusions. The positive response to the note-taking methodology of the third case study produced several important insights into how a shared note-taking system might work for large groups.

First, if a group is accustomed to having scribed notes, keeping that practice will allow the group members to be at ease during meetings and take their own notes only when necessary. This practice is illustrated by the balanced note taking exhibited in the third case study.

Second, scribed minutes can serve as an organizing structure around which to display the personal notes of the meeting participants. Most of the members of this group found this valuable and preferred this scheme to meeting minutes alone.

Third, handwritten minutes with no search capability are undesirable for a group that is accustomed to typed minutes and uses the minutes to scan for important points, or to search for critical pieces of information.

Other observations

We made other observations during the course of these case studies that are worth noting. First, privacy did not appear to be a big issue with this group. When given the option of marking notes "private," participants did so on less than four percent of the

notes. Only one participant mentioned, after the first meeting, that she was uncomfortable having her notes made public. She added, however, that putting personal notes in a separate place would solve the problem. Most members of this group seemed comfortable with the idea of shared notes, and others adapted to it quickly. Indeed, the group took more notes after the first meeting, indicating that the group visibility of notes did not discourage participants from taking them.

Another observation is that no diagrams appeared in the shared notes taken during the study. Only one member created a diagram, and it was on a private note. Perhaps the group would have been more receptive to handwritten notes if its minutes needed to include diagrams.

It is worth mentioning that the style of pad used in the case studies was not problematic. No one complained about the small size of the note pads. In addition, attributes were used to add properties (e.g., the note type) to nearly 25 percent of the pages created during the meetings.

Summary of case study conclusions

The case studies illustrated that the hypothesized advantages of automatic creation of meeting minutes are hard to achieve. In this section, we summarize the lessons learned during this series of case studies as well as their implications for the design of shared note-taking systems.

1. *Providing access to shared notes with alternative perspectives and to other meeting artifacts is the essential advantage of shared note-taking systems.* We found that shared meeting notes could add valuable alternative perspectives to meeting documents. We also found that the ability to link to other meeting artifacts, such as presentation slides, enhanced meeting records. A majority of the participants in the third case study preferred the hypertext document to their scribed minutes alone. They cited the alternative perspectives and linked artifacts as the reasons for this preference. A shared note-taking system can provide both of these functions.
2. *Shared documents can be made more coherent by using a single document to organize and provide links to other documents.* The presence of multiple threads of thought in a single document has the potential to be confusing. We dealt with this problem by structuring shared notes around a single document, the meeting minutes, and by preserving the flow of thought in that document as much as possible. Shared note-taking systems should organize the notes around such structuring documents.
3. *While handwriting interfaces may be acceptable for note taking, handwritten notes are undesirable for sharing in many environments.* The participants were open to unrecognized ink as a note-taking style, though they desired some way to transcribe those notes later into ASCII text. Handwritten meeting notes were ineffective in this series of case studies because group members needed to be able to scan and search meeting minutes quickly. Difficulty in reading others' handwriting slowed this process. A shared note-taking system could use off-line handwriting recognition of the notes to alleviate the transcription and search problems to some extent. For groups in less formal environments that are unaccustomed to typed meeting minutes, and for groups that draw diagrams, handwritten shared notes may still be appropriate, as we discuss later.
4. *Individuals may be comfortable sharing their notes with the rest of their group if there is a mechanism to protect their private notes.* The number of notes taken and the relative absence of complaints indicate that this group did not feel that sharing notes violated their privacy. A number of participants were concerned with how to ensure the privacy of certain notes. Such concern implies that any electronic system for sharing notes should make it easy for users to make notes private.
5. *In large groups, sharing notes may not remove the need for a scribe.* Though assembled minutes were sufficient for some group members, others did not approve of how shared notes shifted the responsibility for creating minutes to all group members. Supplementing the scribe's minutes with the group's personal notes may better support large groups. This may make scribing less tedious, permitting the scribe to participate more fully in meetings. Other groups may deal with this shifting of responsibility differently, however. Our experience with smaller groups of three to five participants, which we describe in more detail later, does not exhibit this problem since these groups do not generally use a scribe. Shared notes work well in these groups because only one or two people are taking notes at any one time, avoiding the frequent switch in perspectives that was problematic in our large-group study.

Table 1 This table compares NotePals to other collaboration and note-taking systems.

	NotePals	Computerized Meeting Room Systems					Personal Note-Taking Systems		
		EMS	WeMet	Tivoli	C2000	Dolphin	Freestyle	Filochat	Dynomite
Ink-based UI	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Combines work of individuals	Yes	Yes	Yes	No	No	Yes	No	No	No
Links notes to (nonaudio) documents	Yes	N/A	No	No	Yes	Yes	Yes	No	No
Automatic organization	Yes	No	No	Yes	Yes	No	No	No	No
Easy sharing of artifacts	Yes	No	No	No	Yes	No	Yes	No	No
Does not require synchronous communications	Yes	No	No	N/A	No	No	Yes	N/A	N/A
Portable hardware	Yes	No	No	No	No	Yes	No	Yes	Yes
Inexpensive hardware	Yes	No	No	No	No	No	No	No	No

PART II: THE NOTEPALS SHARED NOTE-TAKING SYSTEM

The lessons learned from the group note-taking case studies helped us focus our work on an electronic system for taking and managing shared notes. This system, called NotePals, makes individuals' notes more valuable by automatically combining them together in a shared repository. The NotePals user interface is described in Reference 8. This part of the paper starts with a review of the related research. Next we describe the NotePals note-taking and browsing user interfaces in more detail and indicate how the group case studies informed the design of these interfaces. We then describe our usage experience with the system and our plans for future research.

Related work

Although our research was inspired by much of the previous work, it differs in several significant ways. Table 1 summarizes the similarities and differences between NotePals and other collaboration and note-taking systems. The essential difference is the focus on lightweight organization and sharing of freeform ink notes taken on inexpensive, portable, pen-based devices. Here we compare and contrast our work with similar research in two main areas: computerized meeting room systems and personal ink-based note-taking systems.

Computerized meeting room systems. Some meeting room systems seek to improve specific kinds of meetings by structuring meeting activities. The Electronic Meeting System (EMS), for example, leads a group through brainstorming, idea organization, voting, and comment phases.[9] It operates on lists of textual items and requires a room of networked workstations or PCs. The EMS can improve the quality and number of ideas generated by a group, but it is not designed to work for other styles of meetings. NotePals was specifically designed to allow a meeting to take on the structure deemed best by the participants.

Other meeting room systems do not attempt to structure meetings but instead give participants new means to communicate and record meeting activities. These systems often give participants access to traditional applications that have been group-enabled.[10–12] Some of these systems have been shown to help groups create documents, such as outlines, that better reflect a group's ideas and decisions.

These meeting room systems share some problems: They require expensive meeting rooms. They may also shift the focus of a meeting to document creation, redirect some of the group's attention to complex computer interfaces, or require participants to type during meetings, which can be disruptive.

Another class of meeting room systems tries to enhance "natural interaction styles" or record-keeping methods, without shifting the meeting focus or process. By natural interaction styles, we are referring to less structured interfaces that are often pen-based and that try to simulate or improve on the capabilities of the whiteboards found in most conference rooms. WeMet,[13] for example, provides access to a shared drawing space running on multiple workstations. Tivoli[14] allows users to manipulate handwritten text in structured ways on a large electronic whiteboard (the Xerox LiveBoard**[15]). Tivoli notes and meeting audio can be captured together, allowing participants to access the audio from the

notes after the meeting.[16] Similarly, the Classroom 2000 system[17,18] records classroom audio, presentation slides, and the professor's LiveBoard notes, and provides ways to browse through them after class.

These informal, pen-based systems have been influential in our work with NotePals. We have implemented many of these ideas, such as natural input and synchronization with other media, in less expensive, more portable systems than the traditional computerized meeting room. Unlike these systems, our work also focuses on the *sharing* of personal notes and information between group members.

DOLPHIN is another well-known collaboration system.[19] It allows co-located and remote groups to link personal notes and documents in shared spaces. Much of the sharing and linking of notes and documents in DOLPHIN is done manually, whereas NotePals tries to make these links automatically when possible. In many ways, DOLPHIN appears similar to NotePals, but in actuality, they are far different in their usage model. DOLPHIN is oriented toward computerized meeting rooms, whereas NotePals is intended for use in any environment.

Personal freehand note-taking systems. Since typing can interfere with many situations we wish to support, we have also taken inspiration from research in informal, personal note-taking systems. Freestyle allows personal, handwritten notes and annotated documents to be shared using electronic mail.[1] These documents can then be read and manually arranged on the desktop computer of the recipient. NotePals also takes advantage of the simplicity of informal, personal note taking, but has more automated sharing and supports note taking *away* from the desktop.

There has also been research in portable, handwritten note-taking and audio recording systems, such as Filochat[20] and Dynomite.[21] Filochat and Dynomite run on tablet-based computers. These systems also record the audio track of a meeting or lecture and automatically create an index to the audio from the electronic ink. Thus, handwritten notes can be used to access portions of the associated audio track. The simplicity of these note-taking interfaces and the automatic recording of audio context make these systems very similar, in spirit, to NotePals. NotePals, however, allows groups to share personal notes and uses less expensive, more portable hardware. Shared note-taking systems will only be useful if they are commonly found in meeting environments.

Informal, personal note taking was also a minor part of the Classroom 2000 project. An early prototype system merged handwritten notes taken on Apple Newton** PDAs with lecture slides.[17,18] Like Classroom 2000, NotePals merges handwritten notes created on small devices with other meeting documents. Unlike Classroom 2000, we do not assume classroom settings, and we focus on the sharing of notes among meeting participants.

NotePals user interface

NotePals is "lightweight," fitting easily into groups' existing processes. Note taking is a natural activity in which many people engage to record their ideas and experiences. NotePals captures this activity with informal ink-based user interfaces[22] running on PDAs and paper-based electronic tablets. NotePals captures group members' notes and some information that places those notes in context, such as the author, the topic, and the time the author wrote the note. These notes are then uploaded to a shared note repository that all group members can access through Web-based note "browsers," which allow the retrieval of notes taken in a given context. NotePals includes two distinct interfaces for taking notes and several Web browser-based interfaces for viewing notes. Each type of interface had its own requirements and challenges, and we discuss them here separately.

Note-taking interfaces. We wanted the note-taking interface to run on a device that was as inexpensive as possible, portable, usable in almost any environment, and capable of uploading notes to a central repository with little effort. We chose to use an electronic ink-based note-taking interface instead of recognition-based or conventional typing interfaces for several reasons. Users have reported that one reason they do not take notes on their PDAs is the poor handwriting recognition accuracy.[23] Recognition systems also encourage users to correct recognition errors, whereas ink-based interfaces let users focus on taking notes. Typing-based interfaces have a similar drawback. Their precise nature encourages users to correct their work as they go, rather than pay attention to the task at hand. In addition, typing is often considered disruptive and socially unacceptable in meetings. Finally, typing-based interfaces are not well-suited to drawings and diagrams.

Unfortunately, the case studies showed that many participants had difficulty reading one another's handwriting, especially in records that changed hand-

writing styles every few lines. These legibility problems led to the separation of individuals' notes into distinct, nonoverlapping regions in NotePals and the addition of off-line handwriting recognition to the system design. Since some users have trouble writing on today's pen-based computers, we chose to use both a PDA-based solution and a paper-based solution. We present these different note-taking user interfaces in turn.

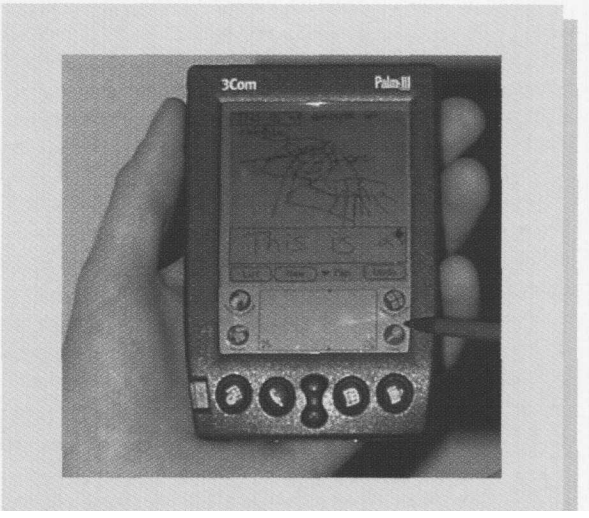
PDA user interface. For the PDA-based solution we chose the 3Com Palm III** and IBM WorkPad* (a relabeled Palm) pen-based PDAs. Over two million people already use them for personal information management,[24] and they currently sell for under $300 (see Figure 5). In addition, the Palm has a simple mechanism for exchanging information with other computers. Placing the Palm in a docking cradle connected to a desktop PC and pressing the HotSync button causes an application-specific data exchange program, or "conduit," to run. The NotePals conduit uploads an individual's notes to the group's Web repository. This platform enabled us to create an informal, electronic, ink-based note-taking system that allows users to share notes with little effort.

The size of the Palm makes it easy to carry but difficult to draw on. An unrecognized, ink-based interface is hard to design for the two-inch square screen of the Palm. Users' hands can obstruct their view of words on the screen. The digitizer and screen resolution are also problematic. Even if users can write words in a very small size, the 160 × 160 pixel resolution makes them hard to read.

The interface we created to deal with these problems is shown in Figure 6A. Users write in their own handwriting directly on the page at the top of the screen (the "overview area") or in the box at the bottom of the screen (the "focus area"). Words drawn in the focus area appear in the overview area inside the "focus cursor," shrunk to 40 percent of their original size. Once the user has filled the focus area with text, a quick right-to-left swipe of the pen moves the focus cursor forward, clearing space for the next word. The user can also drag the focus cursor with the pen to a new position. This interface allows many words to fit on one page, despite the small screen.

To give extra context, users can assign each page of notes a "type" that indicates what kind of information it contains, as illustrated in Figure 6B. The supported types include action item, new meeting header, next meeting, or generic note. Other contextual information, such as the author's name and the time the author created the note, are recorded automatically.

Figure 5 The 3Com Palm III

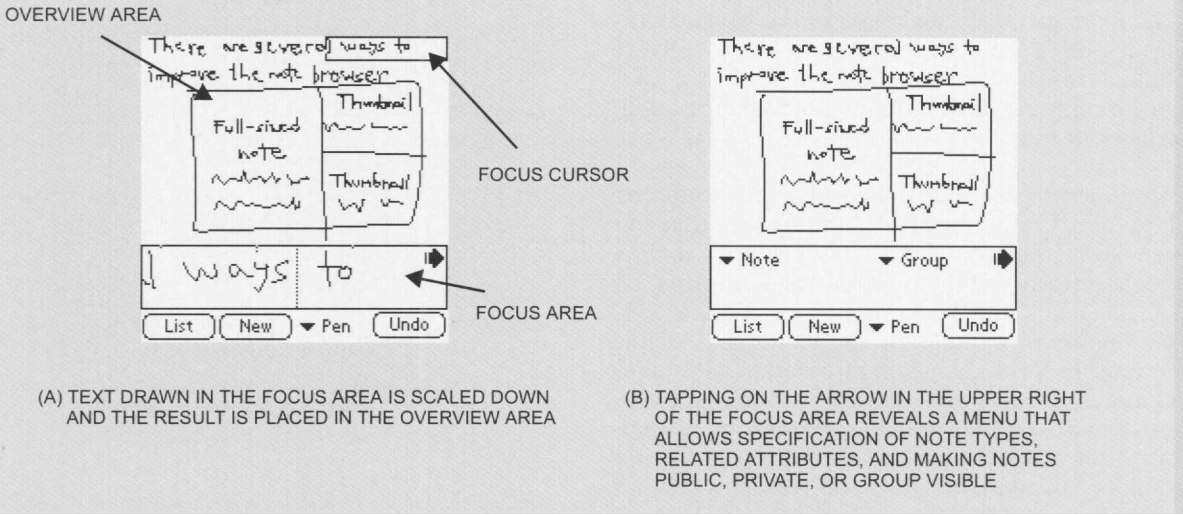


Users can also control who has access to their notes, as illustrated in Figure 6B. By default, notes are visible only to the author's work group, but they can either be marked "private" so that only the author can view them, or they can be marked "public," which makes the notes visible to the world. This design decision was supported by the desire of participants in the group note-taking case studies who wished to take private notes during the meetings.

Each page of notes in NotePals is created within a "project." Projects are organized in a hierarchical set of folders, as in Figure 7, which gives users a way to group notes into topics. New project names are entered using Graffiti (the text shorthand of the Palm) rather than using digital ink, but it is also possible to preload a hierarchical list of project names.

Paper user interface. For some users, the Palm is simply too small and can be uncomfortable for ink-based note taking. Pen and paper is the method that many individuals naturally use for taking notes in meetings. To take advantage of this method, we have implemented support for the paper-based CrossPad**.[25] This portable device uses a special ink-based

Figure 6 The NotePals Palm note-taking interface



pen and an electronic tablet that digitizes ink as it is drawn on standard paper pads (see Figure 8).

The CrossPad can be used just like the Palm for taking shared notes. A user uploads notes to the shared notes repository first by connecting the CrossPad to a desktop PC and then using the built-in ink transfer mechanism. Each page of digitized notes is uploaded to the note repository with a creation time stamp and the author's name. Since there is no easy mechanism for specifying project names on the CrossPad, the system displays a dialog box at synchronization time that allows the user to specify the project with which each set of notes should be associated.

Uploading notes. As notes are uploaded to the note repository, they are processed to make note browsing easier. First, the stroke-based notes are converted to a bitmap format (GIF) in two different sizes: full size and a smaller thumbnail size. Next, the strokes are passed to ParaGraph's CalliGrapher** handwriting recognition engine,[26] which returns an ASCII representation of each note. Finally, the system enters the note attributes, recognized ASCII text, and the file names of the bitmaps and stroke files into a database.

Browsing interfaces. Shared notes are accessed through conventional Web browsers, allowing notes to be viewed at group members' desks or in meeting rooms. We have built several task-specific note browsers, including one for meeting notes. The case studies showed that large groups might find the jumble of personal perspectives in merged notes incoherent. The key insight from these studies was that a single, unifying document can also provide organizational structure when there are many notes. Guided by these findings, we later combined shared notes with other documents, allowing access to notes through these documents. These combinations resulted in two new browsers. The first is specific to the task of finding shared notes from on-line conference proceedings, and the second to finding shared notes in the context of presentation slides.

Browsing meeting notes. When group members wish to review meeting notes, they point a Web browser to the group's Web repository.[27] After entering their names and passwords, they can view a subset of notes by choosing from a list of note properties: project, author, date, type, or keyword (see Figure 9). Users can sort notes by their properties, such as author or type, and change the subset of notes viewed by selecting a new set of properties. As shown in Figure 9, by default the notes are sorted according to the time they were created, with notes from different authors interleaved. Individual notes can also be viewed at full size, as shown in Figure 10. Clicking on thumb-

nails in the notes browser shows notes at full size (top in figure). The recognized text can be used if the handwriting is hard to scan quickly, or if the user wishes to paste the text into another application (middle of figure). Follow-ups can be made to the notes (bottom of figure).

The ASCII output of the handwriting recognizer is used for filtering notes by keyword and for displaying the recognized text as shown in Figure 10 (middle). This recognizer is not always accurate enough to provide a transcript, but it recognizes enough keywords to make searching for text faster than browsing through the notes.

Browsing notes and conference papers. The Conference Notes Browser is a task-specific note browser intended to make conference notes useful both for immediate and future review. If available, electronic versions of the conference program and proceedings can be used to structure these notes both before and after the conference. Before the conference, the title of each talk can be downloaded to the PDAs of all group members. At the beginning of a new talk, the user can simply select the title of the talk from a list and begin taking notes. After the conference, the group members' notes can be combined with the on-line conference proceedings to create the interface shown in Figure 11.[28] Clicking on the arrow icons allows the user to navigate through the notes taken during the presentation of the displayed paper, and clicking on the Aa icon displays the recognized version of the notes. The notes taken during a specific talk are displayed on top of the corresponding conference paper.[29,30]

When browsing these proceedings, other group members can easily see their colleagues' ideas and opinions. As we found in the group note-taking case studies, the confusion that could result from having so many perspectives in one document is avoided by using the proceedings themselves as a unifying document. The proceedings also serve as the context that may be necessary for the group members to recall the subject of their own notes. Because conference notes can be linked automatically to conference papers, we believe this interface can make group members aware of others' impressions of a presentation long after the presentation has taken place.

Browsing notes and presentation slides. Notes can also be structured around presentation slides. The Presentation Notes Browser combines notes with presentation slides, again making shared notes accessible from contextually related documents.

Figure 7 The NotePals Palm interface for creating and selecting project names

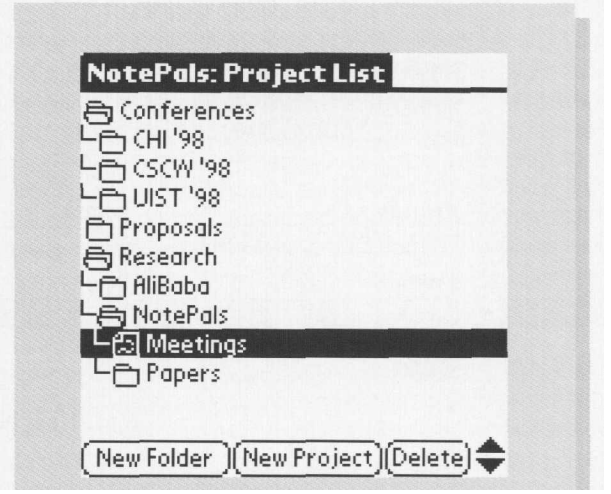


Figure 8 The paper-based CrossPad can also be used to take shared notes.

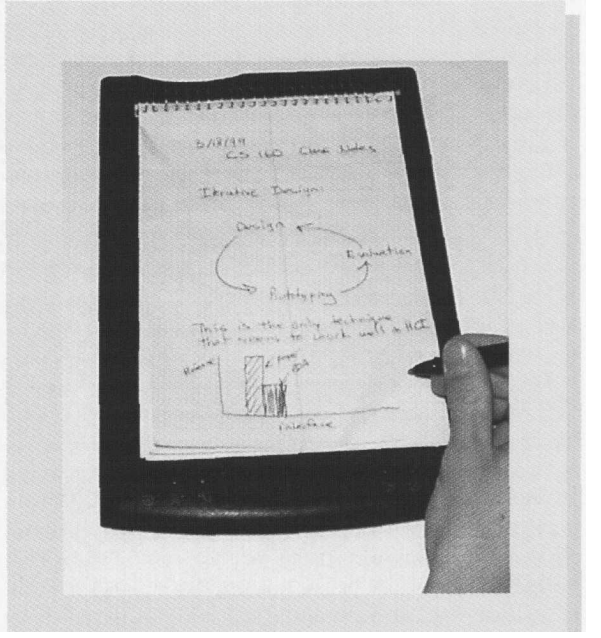
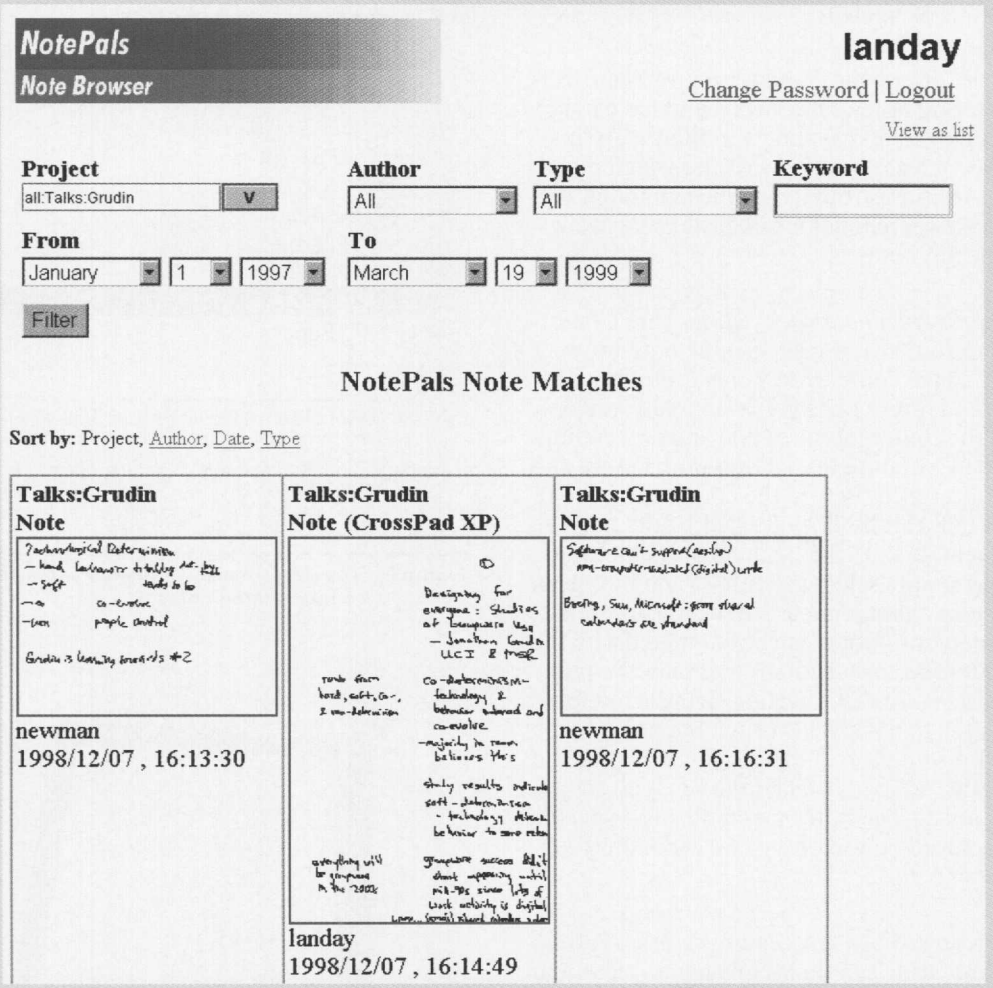


Figure 9 Web-based NotePals meeting notes browser



In this system, presenters start their PowerPoint** presentations with a program that logs when each slide is visible, while the audience takes notes with NotePals. After the presentation, the slides, the slide transition log, and personal notes are uploaded to the system. The browsing interface, shown in Figure 12, allows users to see the notes of up to five people synchronized with the presentation slides. When a user cycles through slides or notes, all other views are changed to keep them in sync. Again, use of a unifying document, in this case the slides, controls the complexity of numerous alternative threads of thought.

Both the conference notes and presentation notes browsers are fairly new, and we have had little usage experience with which to evaluate their effectiveness. We have had considerable experience with the standard meeting notes browser, and we describe those experiences in the following section.

NotePals usage experience

The NotePals system has made it possible for our research group of about 10 people to take shared notes regularly. This group, University of California, Berkeley's Group for User Interface Research, designs, builds, and evaluates novel user interfaces. This section shows how our group uses NotePals. A subset of the group includes the authors of this paper and other developers of the NotePals system. The group has used NotePals for 18 months and has taken over 3200 pages of notes in that period. The ability to share notes has proven quite useful at conferences, in meetings, and in the classroom. Many in the group also find NotePals useful for private notes, which indicates that the system can fit easily into existing note-taking practices. Here we describe the collaborative usage patterns in detail.

Note taking at conferences. The group began to see the value in shared notes at the UIST '97 conference.[31] The authors took a combined 128 pages of notes during talks at this conference. Several weeks later, at a conference review meeting, the entire group viewed the shared notes through a Web browser projected onto a large screen. Previously, there was no direct connection between multiple group members' notes and the conference program, making it hard to coordinate the use of this information. In contrast, NotePals made these connections explicit, and the resulting accessibility of the notes enabled a detailed review of the conference. Group members asked questions about things written in their colleagues' projected notes, and the authors used their own notes to recall further details. Key to this experience were the facts that everyone could see the notes at once and that authors' notes were synchronized so that they could be retrieved at the appropriate times in the discussion.

Inspired by this experience, the group prepared for a greater challenge, the CHI '98 conference.[32] Since this conference has multiple, simultaneous tracks, it was not possible to determine which notes went with which talk by time alone. Therefore, the conference program was preloaded into NotePals. Six members of the research group took over 350 pages of notes at the conference.

After the conference, the group had an even more detailed review that extended over three group meetings. Notes were displayed on a large screen, as before, and each talk was discussed in detail. This review was important for those who were unable to attend the conference and for those who attended but could not be in every session of interest.

Figure 10 Full-size individual notes

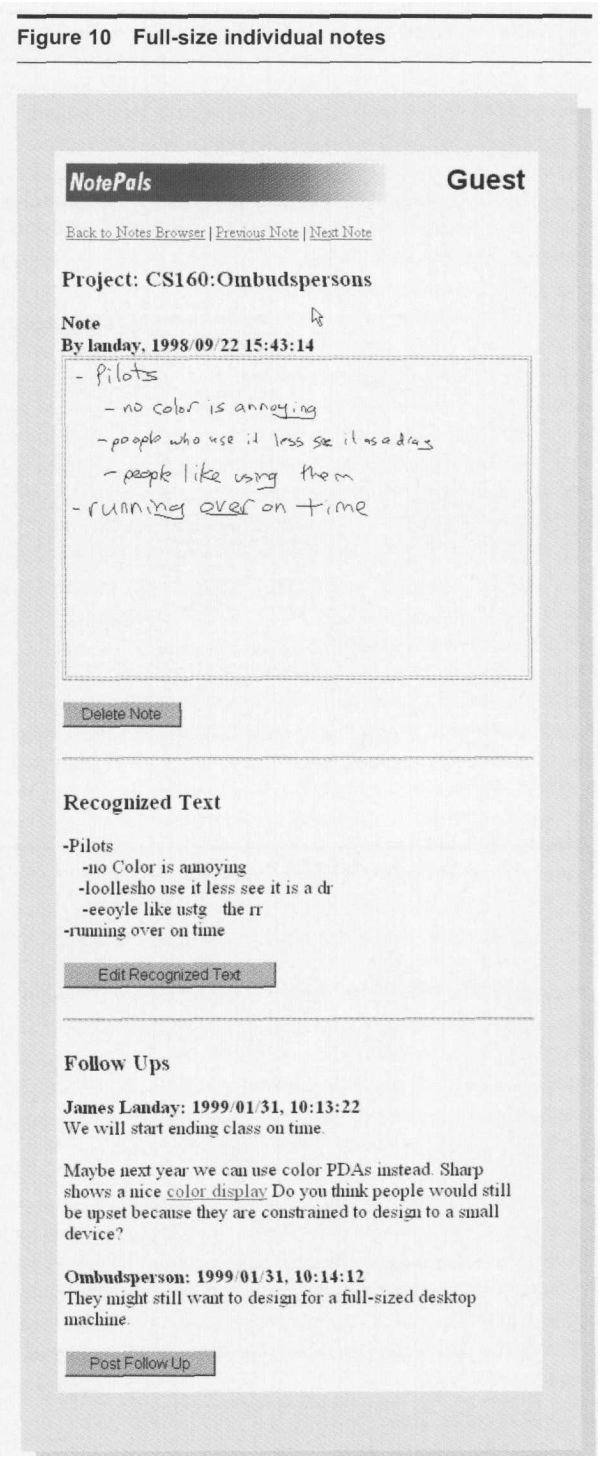


Figure 11 An interface for viewing notes taken during conference presentations

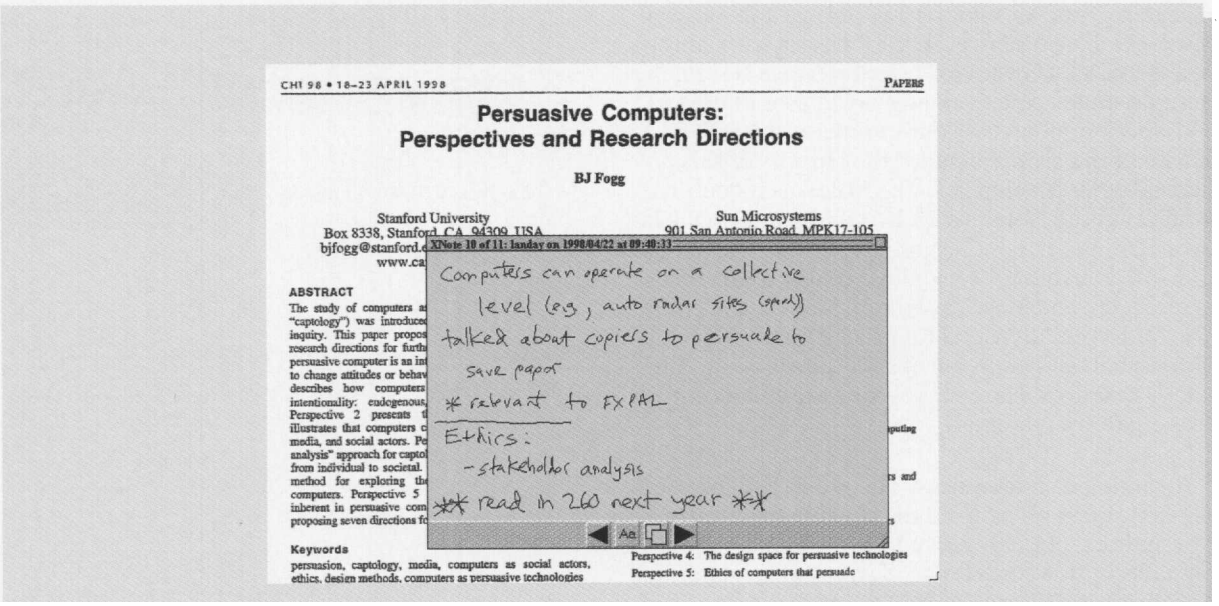
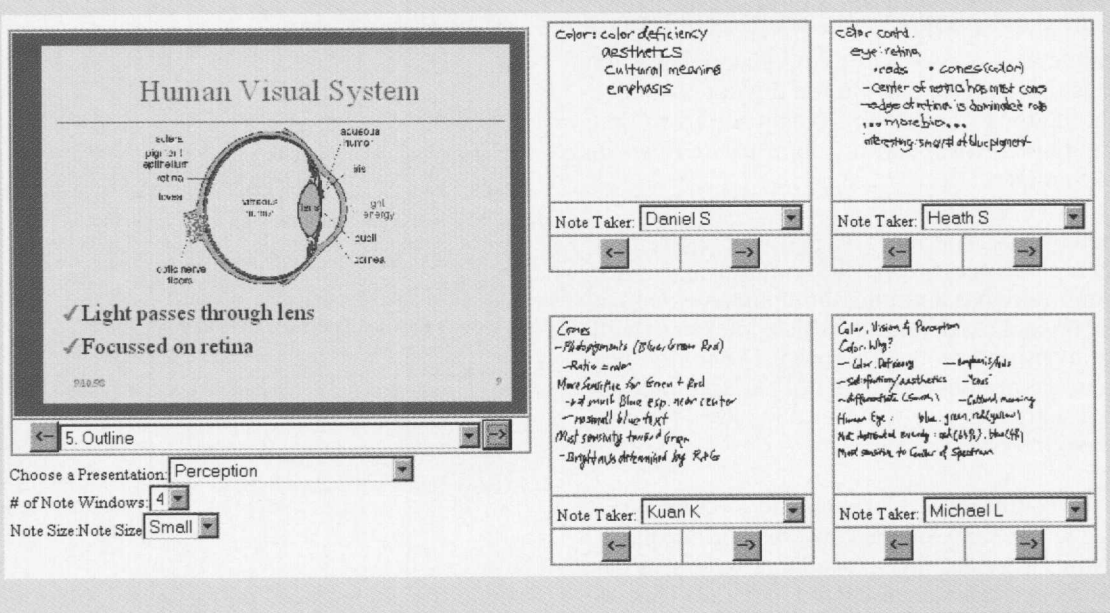


Figure 12 A Web interface for browsing presentation slides along with multiple users' notes



For group members not present at the review, their notes served as their "voice" in the meeting. Group members who were present used their own notes to jog their memories (as before). Other group members asked them questions about the content of their notes, which would be hard to do without NotePals. Note-based communications between team members was one interesting outcome of the knowledge that the notes would be shared. For example, several notes had markings such as "Joe should read this paper." During the review, the intended party was made aware of the communication by seeing the note.

Many of those present said that they had a better understanding of what happened at the conference than they would have had without the shared notes. This benefit appears to be because the notes were displayed in the same place at the same time, and partially because the notes were visible to all group members. Since the conference review, we have found new value in these shared notes. Individuals who may not have attended certain talks can easily access other group members' impressions by using the Conference Notes Browser described above.

Note taking in class. Three group members (one of them a member of the NotePals project team) found shared notes useful in their graduate operating systems course. This course is extremely conducive to taking notes, since the instructor does not lecture from slides, and the classes take the form of a combination of lecture and discussion. The instructor also writes and draws diagrams on a whiteboard frequently, so there is much ephemeral material that is desirable to capture in notes.

These students say that more information was presented in class than they could have recorded alone. They did their best to record the important points, but they relied on one another and NotePals to improve their coverage of the topics. Just before the midterm, they met for a study session in a multimedia-enabled classroom and projected a computer screen displaying the notes in the NotePals project associated with the class.

These students found the NotePals study session to be productive and an effective way to study as a group. Many times during their discussion, the notes helped them recall information they had forgotten. This recall probably could have been accomplished with private, paper-based notes as well, but the public recall of the content indicated by the note would also spark discussion. Presentation of a particular note would often lead to questions and discussion to clarify a concept. Sometimes it would lead the students to look at other information, such as the assigned research papers themselves, the on-line paper summaries, or the instructor's published lecture notes.

Many diagrams were mixed in with their writing (see Figure 13), so it would have been hard to take these notes with other computer-based tools. Paper would have allowed them to take these notes easily, but it would have been harder to share the notes during the review session.

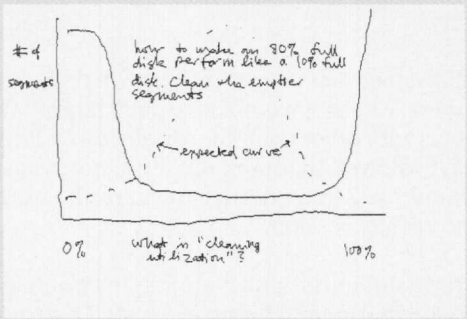
These students found NotePals to be valuable in this class environment because they felt a strong need to recall as many important ideas as possible from class discussions. The students continued to use NotePals for the rest of the semester and reported it was helpful. Two of these students have teamed up with another student this semester to use NotePals for taking notes in a graduate theory course.

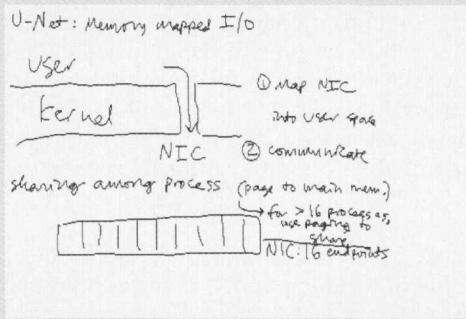
Future work

We are still trying to improve the ease of taking and using shared notes. Thus, we are evaluating solutions based on scanning-in handwritten notes, and we continue to improve our current PDA interface. We are experimenting with new methods for creating ink-based notes on the small screen of the Palm. For example, one method uses a time-out mechanism combined with word wrapping to automatically shrink the text and move the cursor. We are also adding Graffiti support to the Palm note-taking client, so that Palm experts can add ASCII text to their notes by using this recognized shorthand alphabet. In addition, we are currently designing a typing-based note-taking interface for environments where taking notes using a keyboard is acceptable. These notes should integrate seamlessly with the ink-based notes described here. We are also working on improving the output of the off-line handwriting recognition engine to allow automatic transcription of notes. These last three developments could help overcome many of the handwriting legibility problems we have encountered.

Another long-term goal is to add inexpensive systems that capture audio and whiteboard notes so that NotePals can better support meeting environments without expensive equipment, such as the LiveBoard. We will continue to look for useful ways to share per-

Figure 13 Examples of the notes taken by students using NotePals in a graduate operating systems course





sonal notes and to explore methods for linking these notes with related documents and captured information.

Finally, we will continue to evaluate how sharing can be beneficial to workgroups and how sharing changes note-taking behavior. For example, do individuals always improve their notes when they know they will be shared? Do they add different kinds of markings to their notes? What types of information are *removed* from shared notes? Do individuals using shared note-taking tools concentrate more on taking notes and thus less on the task at hand? A future study will directly compare private handwritten notes with those taken with NotePals.

Conclusions

NotePals is a lightweight note-sharing system that gives members of a group easy access to one another's experience through their personal notes. A series of group note-taking case studies found that augmenting traditional meeting documents—such as personal notes, minutes, or slides—with related information that was not previously accessible, was a key benefit of shared note-taking systems. These studies also indicated that the complexity of multiple threads of thought could be managed by finding one document to unify and provide access points to the other documents. The design of NotePals was guided by these case studies.

NotePals captures notes and related documents of interest to a work group and provides a central repository for this information. This information is retrieved through task-specific browsing interfaces that group related pieces of information and make them accessible from one another. We have developed browsers for grouping notes with conference papers, presentation slides, and other notes. NotePals fits easily into a work group's regular practices and uses portable, inexpensive hardware that many groups already own. We have implemented note-taking interfaces running on the Palm PDA and the CrossPad, a paper-based note-taking device. As a variety of low-cost note-taking devices become more pervasive, shared note taking may become a useful way for members of groups to communicate and work more productively. Usage experience with NotePals has shown that shared notes can add value to meeting, conference, and class records.

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**Trademark or registered trademark of Xerox Corporation, Apple Computer, Inc., 3Com Corporation, A. T. Cross Company, ParaGraph, Inc., or Microsoft Corporation.

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