Everyday-use Wearable Computers

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Abstract

Since 1993, members of the MIT Wearable Computing Project have been engaged in a "living experiment," incorporating wearable computing into their everyday lives. Such immediate access to computation power enables a unique lifestyle and has many social implications. Through the use of anecdotes, this paper will attempt to relate our observations on the perception and adoption of new technology, interface issues, collaboration, and privacy as related to the intimate use of wearable computing.

1 Background

The social and cultural implications of a given technology are rarely clear at the technology's introduction. In fact, many decades may pass before a technology is deployed fully and its effects studied [8, 9]. However, when faced with a promising socially significant technology, scientists have a responsibility to examine its potential paths of development and use. Wearable computing has the potential to have the greatest effect of any portable consumer electronics technology to date on society. Thus, initial examinations of its functionality, usefulness, and social effects are appropriate.

One of the most straightforward ways to experiment with the use of a new technology is to encourage an early community of users by lowering the technology's entry cost, both in effort and money. Once established, such a community lessens the individual's maintenance burden, creates an environment for rapid prototyping and the free exchange of ideas, and allows for preliminary observation of the impact of the technology. In many senses, this approach leverages a form Metcalfe's law of networks, which states that the value of a network is roughly proportional to the square of the number of users, to the new technology. The MIT Wearable Computing Project at the Media Laboratory was developed with this principle in mind [1].

While there have been other such "living experiments" using pagers, palmtops, cell phones, instrumented environments, and cameras [3, 13, 19, 14, 1, 6], the MIT Wearable Computing Project is unique in its approach to applying computation to common, almost mundane, situations in a user's life. The project was started and maintained by students intent on developing tools for the intimate use of and everyday life with wearable computers. Emphasis was placed on augmenting the mind and senses of the user. While the first everyday-use wearable computer was brought to the Media Laboratory by Thad Starner in 1993, the project was not named as a distinct entity until a group of students began to have weekly meetings on the topic in 1995. Starting with the availability of funds in early 1996, any Media Laboratory faculty, graduate, or undergraduate with a good idea could obtain the parts for a machine and manufacture one, up to the limits of the resources available. Volunteers came from wildly diverse groups in the laboratory, each with a different agenda. Figure 1 shows some of the participants in the project. Each wearable computer user manufactured his or her own system from a common set of directions [16]. This principle gives each participant the ability and confidence to modify and improve his machine, and, indeed, no two machines are identical. The project conveys a sense of ownership to everyday users so that they would both care for their machines and contribute to the pool of knowledge and expertise. In addition, one of the re-

[1]This research performed at the MIT Media Laboratory with the support of BT and the Things That Think consortium

quirements of "ownership" is assisting a new user in the manufacture of his machine.

Figure 1: The "Wearfolk" at the MIT Media Laboratory.

Figure 2: A safety glasses mounting of the Private Eye.

Figure 3: The Private Eye mounted on a hat's brim.

1.1 The Lizzy wearable computer

A particularly unique aspect of the community is the characteristic form of the users' hardware. In general, users wear some variant of a head-up display, type using a Twiddler one-handed keyboard, and carry a PC/104-based computer in a shoulder satchel, backpack, waist-pack, or vest. Most often, Reflection Technology's Private Eye display (720x280 bitmapped pixels) is used, mounted in either a pair of safety glasses as in Figure 2 or on the brim of a hat as in Figure 3. More recently, displays built into normal-looking eyeglasses manufactured by MicroOptical are beginning to enter the project (see Figure 4). The base computer design is named the "Lizzy" and its parts list, suppliers, and assembly instructions were released to the public in early 1997 [16].

While Starner's earlier system used lower-end 80286-based PC/104 boards and hard drives, in 1996, when members of the project first began to assemble additional PC/104 systems [6], most systems used a 50MHz 80486 and a 815 megabyte hard drive. Later, these systems were upgraded to at least a 100MHz 80486 and up to a 4 gigabyte hard drive. Due to the practical issues of device drivers creation, development, and maintenance, variants of the Linux operating system, Gnu tools, and X Windows were used as the software basis. Emacs is the most commonly used application.

1.2 What will be covered

Much practical knowledge in design, human factors, psychophyics, and ergonomics was gained in supporting a community of wearable users over the course of several years. In addition, many specific experiments were enabled by the project (see [17] for an early survey). However, space does not permit an exploration of these observations or experiments here. Instead, this paper will attempt to convey the lifestyle experienced by an everyday user in the experiment. Due the early nature of the equipment, the wearable computing lifestyle includes constant interactions with the public as well as new types of social interactions among the wearable computer users themselves.

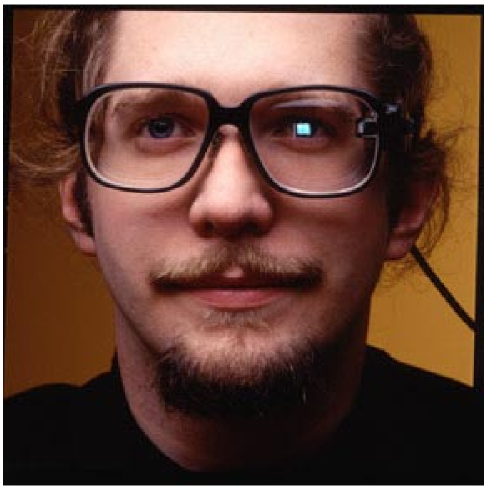

Figure 4: A pair of prescription MicroOptical display eyeglasses (quarter VGA resolution).

The first sections of this paper detail our observations of interactions with bystanders and unadorned colleagues. While we've observed that typical desktop applications such as e-mail and web browsing become increasingly useful as they become mobile and near-instantaneous to access, space limits our coverage of these details. Instead, later sections of the paper detail everyday uses that are more limited to wearable computers as opposed to laptops, palmtops, or pentops.

1.3 The cast

In outlining this paper, we determined it would be nearly impossible to write a traditional academic paper on this subject. The anecdotes and observations below are provided in the spirit of Fred Brooks's sentiments that "any data is better than none" when pursuing a new direction of research [2]. However, in order to provide a grounding for the information, short biographies of each author are provided, relating their experience to wearable computing.

1. Alex Pentland: Academic Head of Media Laboratory, Professor Pentland heads the Perceptual Computing Group from which the Wearable Computing Project is based. Himself an occasional user of one of the smallest systems made in the project and a continual advocate of the creation of less obtrusive and fashionable machines, Professor Pentland is a long-time observer of everyday users and researches how a wearable computer can be used for perceiving user actions.

2. Bradley Rhodes: A member the Autonomous Agents group and a graduate student with Professor Pattie Maes, Brad became one of the earliest everyday users of the Lizzy design in mid-1996. Brad is responsible for creating a practical Remembrance Agent and zephyr system for the MIT wearables community (see below). In addition, Brad has explored creating more socially graceful hardware and software wearable computer interfaces.

3. Thad Starner: Probably best representative of the "24 hour/7 days a week" user [2], Thad has been wearing his computer since the summer of 1993 and switched to doing most of his work on his wearable as opposed to a desktop at the end of 1996. Professor Starner is a former doctoral student of Alex Pentland in the Perceptual Computing Group. Thad created the Lizzy design and managed the hardware for the Wearable Computing Project before taking a professorship at Georgia Tech in 1999.

4. Joshua Weaver: The youngest of the current everyday users, Josh brings a unique perspective to the project, having used a wearable computer as part of his undergraduate studies since early 1997. Josh manages the standard software distribution for the project and works on the American Sign Language to English wearable computer translator exploration in the Perceptual Computing Group [18].

The stories and observations below are a conglomerate of the experiences of the authors. Upon completion of his wearable computer, each user is requested to maintain two files: one on the technical issues of the interface and one on the social issues. In some cases the notes that make up the anecdotes below where typed in as they occurred. In other cases, the situations were reconstructed or merged for literary convenience.

2 Public perception

> I [Bradley Rhodes] just got asked again for the zillionth time if this [wearable computer] was a camera. After explaining the system, I asked him why he thought it was camera, since it doesn't really look like one.

[2] In actuality, everyday users only sleep and shower with their equipment by accident!

He said that since I was looking into it and it was mobile, he figured it was helping me move around in some way, *e.g.* helping with low vision. He added that if I were sitting down, he would have guessed it was a display instead.

Such interactions have been common for everyday users of wearable computing, even prior to popular press accounts of head-mounted cameras such as Steve Mann's WebCam [6]. Casual observers tend to try to relate the wearable computer to familiar equipment, and the most common association is with a camcorder's eyepiece. In fact, sometimes it is difficult to correct bystanders' preconceptions of the equipment's function after they have already classified it in their own minds. While wearable computing hardware is becoming significantly less obtrusive due to efforts by industry, the reactions to current hardware reveal much about the public's perception of technology.

Since the safety glasses that hold my display broke, I decided to paint my Private Eye black, to be less obtrusive and to match my clothing. Wearing the newly painted display, I was surprised when stopped by another Media Lab student who exclaimed, "Hey Thad, I see you got a new display! I bet this one is much better, with it being smaller and looking nicer."

We have discovered that the color of the equipment (especially the eyepiece) often affects how the public perceives a wearable. The Private Eye appears white or beige by default, which seems associated with medical applications. Before painting his HMD, people told Rhodes that they were embarrassed to ask about the wearable because they thought it was to help his vision or check insulin levels. Deep grey seems to be associated with industrial applications. However, when painted black or a brighter color the equipment is associated with consumer electronics. A quick look at the equipment produced for these respective fields demonstrates this societal color code for electronics.

Current fashion and style also seem to effect the public's views on wearable computing. During a 1995 trip to Zurich with everyday users, Pentland observed that, as a class, punks seemed to take wearable computing as a fashion statement that was acceptable to their culture. More recently, Pentland has noted with some amazement that Parade Magazine, when reporting on the pointedly flamboyant fashion show hosted by the Media Laboratory after ISWC'97, called wearables one of the ten best ideas of the year. In fact, style seems to be becoming a larger determinant in the acceptability of the technology as it matures and approaches established norms. The most common disparaging comment Pentland and Starner receive on their MicroOptical display eyeglasses [15] is the choice of frame, while the much more primitive Private Eye mount goes without comment.

Another interesting observation is that preconceptions and associations with wearable computers have changed slowly but significantly. In the earliest years of the project, as documented by Starner's personal notes, the wearable computer was commonly mistaken for a seeing aid. Beginning in 1994 or 1995, the most common association became the camcorder. As the Gameboy, Newton, and Palm Pilot have developed the popular concept of small, mobile computers, wearable computer users have begun to be accosted by small children wanting to see the video game and information technology professionals who want to know where they can purchase a system. This suggests that current products in the consumer-grade electronics market can affect the public's views and readiness for wearable computers. Still, in order for wearable computers to be successful in horizontal markets, mental models of how wearable computers are used must form in the public's collective consciousness, following the path of the telephone, pager, PDA, laptop, and cellular phone.

3 Developing mental models of use

"Excuse me, what time is it?" asked a fellow pedestrian.

Making eye contact while continuing to walk, Starner glanced at the clock on his word processor and replied "6:23."

The pedestrian suddenly looked puzzled, since Starner had not looked at his wrist but had provided a specific answer. "Uh, if you don't mind my asking, how do you know?" he queried.

"My clock says so. This is my computer display." Starner replied, touching my eyeglasses.

This simple exchange summarizes one of the major issues with new technologies: no one has yet formed a mental model of its use. In some cases, this can cause social awkwardness for early users, as in the instance above. Normally, such interactions follow a certain "script" [12]. Someone asks the time. The queried individual rotates her wrist, raises her arm, looks at her clock, and after a pause, speaks the time. With a head-up display, it takes a fraction of a second to attend a clock displayed in a known position, and often the conversational partner will not even notice the eye movement. Thus, it can appear as if the user has invented a time just to be rid of the query. This was the thought of the pedestrian in the above anecdote given his tone of questioning.

> Often, conversations between Rhodes and Starner go something like this:
>
> "Do you have any anecdotes on using the wearable for communications, for the ISWC paper?"
>
> [Rhodes pauses to type on his wearable, Starner waits]
>
> "Yeah, here's one about a time I was going to a restaurant..."
>
> [Starner starts to take notes, Rhodes pauses while he types]

As wearable computers become more commonplace, some social rules will naturally develop. For example, when Starner and Rhodes talk and one starts to take notes, the other naturally waits for him to finish. This is a natural interaction, since both understand what the other is doing and understand the social cues involved with their wearables. It is similar to the interaction between a class lecturer and her students, where the speaker pauses when students start to scribble down notes. These pauses are seen as entirely natural, because both the students and the lecturer have a strong mental model of how a classroom operates and of what note-taking looks like in a classroom. However, when Starner or Rhodes are talking with people less familiar with the wearables they usually go out of their way to type quickly or take notes without drawing attention. Rhodes will actually cross his arms or type with the keyboard in his pocket to keep from being obvious. He will also wait for a person to pause before looking up information, since otherwise the speaker is likely to stop completely, thinking he is more distracted than he actually is.

> While giving a guest lecture for a class, Starner and Rhodes met with a fairly hostile audience. When pressed for why they were so upset about the technology, one of the students offered:
>
> "We can't tell if you're talking about us behind our backs!"

Although in some cases the scripts of social interaction can be changed, wearable computers provide a bit of a conundrum for industrial designers. Due to their general functionality, the various functions of a wearable computer can be opaque to bystanders and can lead to many misconceptions. In the past, the "affordances" [7, 4] of portable devices help constrain their perceived use. For example, even before the Sony Walkman became a cultural icon, its headphones, buttons, and shape helped to convey its use for playing audio tapes. However, unlike the Walkman which has a specific function that is immediately identifiable in our culture, wearable computers may be used to combine the functionality of many different devices, such as the wristwatch, cellular phone, fax machine, palmtop, compact disk player, camera, camcorder, health monitor, *etc.* Thus, even when an onlooker properly identifies the wearable computer, he may still have no idea as to how the device is being used at the time and whether or not the user is interruptible. [3]

The anecdote given above shows one effect of that problem. At the time the lecturers were not secretly sending each other notes, but they could have been. They could also have been reading email, taking notes on the class, playing tetris, or doing nothing at all with the wearable. The fact that all these applications are possible make it very difficult for designers to present this complex internal state to other people in a socially accessable form.

3.1 Convenience, security, privacy, and ergonomics

At one point or another, almost all traditional desktop applications have been run on a Lizzy: spreadsheets, video games, text formatters, compilers, debuggers, graphical web browsers, graphical calendar programs, music and movie players, etc. In fact, almost all of Starner's PhD dissertation was written on a Lizzy, and much of the data analysis for the thesis was performed on one as well. However, why would Lizzy users desire to run desktop applications on their wearables when desktops can provide significantly more processing power? A simple answer is convenience. Once full computing capabilities are possible in a highly mobile apparatus, users discover many situations where they can take advantage of them. Some such situations include looking up phone numbers with one hand while dialing them with the other, recording readings while running a physics experiment, and referring to on-line maps. Another convenience is having all your resources contained in one physical device. In

[3] Ironically, as the first author writes these words over dinner, he has been interrupted twice by waiters curious about the interface.

this manner, the user has to remember only one item as opposed to choosing between one or more devices or books depending on his day's goals. In addition, this concentration of resources allows the user to adapt rapidly to unexpected occurrences during the day.

An advantage of the Lizzy is an inherent sense of security and privacy for everyday users. Since the user's data is stored on his body, the user has an innate sense of possession and control of the data. While this security may be illusory depending on if the user maintains an active, unsecured network connection, it still encourages a "diary-like" feel to the machine. Thus, users tend to retain more private thoughts on their wearables than on desktops. In fact, when upgrading disk drives, everyday users are particularly careful about their old repositories of data. Thus, manufacturers of wearables designed for personal use should take precautions not to violate this sense of trust.

Another advantage remarked upon with the Lizzy is the different ergonomics afforded by the hardware. The user can work just as effectively sitting, walking, or lying down. The head-mounted display and one-handed keyboard allow the user to work in many different positions, reducing the effects of certain repetitive stress injuries. In addition, the variable focus depth, contrast, and sharpness of the display reduces eye strain compared to normal computer monitors.

4 Information capture

The head-up display and one-handed keyboard design of the Lizzy allows rapid note-taking in virtually any situation. In some cases, the wearable provides a more efficient or less obtrusive method of typing information than is possible with traditional means.

4.1 Student note-taking

One of the reasons Starner began prototyping wearable computers was due to his perception of a failure of standard classroom techniques. Often students can either attend to and understand the lecture or copy the blackboard verbatim, but not both. Unfortunately, if the students concentrate on the former, their understanding disappears in as little as a couple of hours. If students concentrate on the latter, they can't reconstruct the concepts or, as in the first author's case, understand their own handwriting upon review. Using a laptop computer can help but still may not be sufficient. While a student might type faster than he can write, the continual movement of his head and refocusing of his eyes between the screen and the blackboard takes considerable effort. With the Lizzy, the user can focus the display at the same distance as the blackboard. In addition to eliminating head motion and eye strain, the system allows the student to maintain a peripheral awareness of his typing while concentrating on the subject of the lecture. With the Twiddler, the student can hide his hand under my table or chair, making the key clicks virtually unnoticeable in a normal classroom. Thus, the Lizzy enables an unobtrusive method for taking good notes while still understanding a lecture.

Weaver remarks that he takes all his class notes on his wearable, with the exception of highly technical math and engineering classes where circuit diagrams and math expressions make notes difficult. While Starner was not taking classes that required circuit diagrams when he first assembled his wearable, he defined many Twiddler chords for Latex expressions for taking mathematical notes. In this manner, Starner found that he could keep pace with blackboard writers and, as a result, maintained all his classroom notes on his wearable. He still refers to some of these classroom-presented equations while teaching his own classes at Georgia Tech.

An unexpected effect of using a wearable computer for annotating lectures is an significant increase in user concentration and memory. This effect has been remarked upon by other wearable computer users at various workshops. A possible cause is the repetition in the student's mind that is necessary to create good lecture notes. The student must first parse what the lecturer is stating both in speech and on the blackboard, determine a way to phrase the desired entry into his computer, type the entry, and then see the entry on his head-up screen. While no formal experiments have been performed, an interesting study for the future would compare comprehension rates between experienced wearable computer users taking notes on their machines versus taking notes on paper.

4.2 Conversations

> "When you wear your display, how can I tell if you are paying attention to me or reading your e-mail?" a colleague asked.
>
> "Simple: watch my eyes. If they scan back and forth, I'm reading e-mail. Otherwise, I'm looking at you," Starner answered.
>
> "Then why do you wear your computer when talking with people?"
>
> "I find that the most interesting conversations occur spontaneously, just when you are the most unlikely to have the ability to

remember the parts that you want. With my wearable I find I can enter the most salient portions of the conversation without interrupting the flow of it. In fact, while at BBN I found that people soon grew so accustomed to the hardware when talking to me that they could not tell you after the fact whether or not I was wearing the display for the conversation."

"I doubt that, but why not just use pen and paper?"

"Because writing with pen and paper is very obvious and attention grabbing for the person who is talking. The process of remembering the conversation interrupts the conversation itself. With the keyboard at my side and my maintaining eye contact you probably did not notice that I've been taking notes on this conversation."

"Actually, no I didn't!"

Interestingly, once colleagues understand that a wearable is used in a conversation to type in particularly technical, salient, or important information, their objections to the use of the machine evaporate. In fact, some long-time colleagues have noted that it has become a point of pride when they see wearables users type during a personal conversation. However, a common game played by new acquaintances, once they understand the machine's purpose, is to guess when the machine is being accessed in a conversation. Generally, unless the observers specifically watch the user's hands, they often confuse the eye motions that occur in natural discourse with glances at the display. This confusion is probably due to the novice observer's misconception that the wearable user must look at his screen to type.

Surprisingly, the confusion occurs even when the display is positioned to give appropriate social cues to its use. Rhodes's display is mounted up and to the right of his right eye. In this manner, Rhodes can maintain eye contact with both eyes. When referring to his computer during a conversation, Rhodes will say "Hold on, let me look that up," followed by his eyes looking up and right to his display. In this manner, Rhodes has adopted a social etiquette which makes display use explicit.

The notes taken during a conversation are often terse, using just enough words for the note taker to reconstruct the concepts later. Where appropriate, a direct quote may be included. For such instances, Starner has found he has a natural five word "typing buffer" in that he can remember five words and type them with very little cognitive load while still attending to the conversation.

One technique both Starner and Rhodes use is to have a scratch buffer that works as a short-term memory. Without the wearable, if a person comes up with an important point while someone else is speaking they have to remember the point for later. Often the person either forgets the point they wanted to make, or wind up being distracted from the conversation at hand because they're too busy remembering their own point. With the wearable, new ideas are quickly added to a buffer where they can be reread several seconds to a minute later in the conversation. As an extra benifit, after the conversation is over these notes can be expanded for permanent storage.

5 Information retrieval

"What did we say was the importance of deixis?" asked the lecturer. With the end of the term approaching, the class was reviewing their study of discourse analysis.

Volunteering, Starner said, "We said the importance of deixis is ... uh ... uh ... humph, whoops! Uh, I'll get back to you on that."

The class, most of whom were Media Laboratory graduate students familiar with wearable computing, began to laugh. Starner had not known the precise wording of the answer and had tried to retrieve his class notes on the topic. Having done this routinely in the past, Starner had expected to have the information in time to complete his sentence. Due to a complex series of mistaken keystrokes, he had failed so badly that he could not cover his error, much to everyone's amusement.

One of the members of the class leaned over and said, "You actually do that sort of thing successfully all the time, don't you? Now I'm impressed."

Often it is only because of a dramatic failure that colleagues realize that wearables are used for information retrieval on a day to day basis. In addition, many are surprised that the interface can be used in such a time critical manner.

With the ease of capturing information enabled by a wearable computer, users tend to type volumes of notes on all aspects of life. This large amount of text creates the corresponding problem of timely retrieval. How can the user keep track of everything? One method is to use a system of directories that distinguish between classes of notes: conferences, meetings, classes, wearable computing issues, ideas, and everyday, practical information. With careful maintenance, the users can locate the appropriate file on a given topic within a couple of key strokes, as mentioned above. However, this direct approach assumes that the user knows he has information on a given topic. This assumption quickly becomes invalid as the wearable computer user gains experience. Thus, an early question that formed from the use of a wearable computer was how could the computer aid in the discovery and use of these "memories?"

5.1 Serendipitous interfaces

Most computer interfaces are designed for explicit control by the user. In many respects, this is an artifact of the current physical design of the desktop "workstation." When the user wants to perform a task on a computer, he walks to his desk and turns on a machine. Computational assistance is associated with a particular location and device that requires a lengthy starting process before it becomes useful. In many senses, the "affordances" of computers constrain their perceived use [7, 4]. What happens when these affordances are changed to suggest interactions where the manipulation of the computer interface is not the primary task of the user? For example, what if the computer performs secondary information assistance tasks augmenting the user's capabilities in reaching a primary goal?

The first interface that we prototyped in this vein is the Remembrance Agent (RA). The idea is simple. While the user types with his word processor, the Remembrance Agent continuously searches the user's disk for files or e-mail that contain similar terms to what the user is typing. The top three files that match in this manner are displayed with one line summaries describing their content in the bottom of the user's window. While the user types, the RA updates its "hits" every ten seconds. The user mostly ignores this unobtrusive, automatic service but occasionally glances down and sees a description that cues his own memories of something important to his work [11, 17, 10]. While the user might not have recalled the piece of information on his own, he recognizes the significance (or lack of significance) of the one-line summary and can request the RA to bring up the associated file or e-mail for further inspection. This sort of interface "increases serendipity" for the user. While the continuous presentation of information requires little user attention, much of the effectiveness of the interface depends on "chance" encounters of useful information. Thus, the Remembrance Agent creates a symbiosis between the highly associative memory of the user with the perfect recall and tireless nature of the computer. Figure 5 shows an early example session with the Remembrance Agent.

Figure 5: A screen-shot of the wearable Remembrance Agent. The main screen shows notes just starting to be taken during a wearables group meeting. The mode line shows the current context, namely the date, the room number, and the person speaking, with a bias to the location. The bottom lines show the RA's suggestions. The top suggestion was from another weekly group meeting, and so matches on room location, time of day, and day of week.

As an interesting application, both Rhodes and Starner used the Remembrance Agent during their doctoral oral exams to help them remember key references. While the RA performed well, finding appropriate information unbidden except by the students' notes to themselves during examination, both students were exceedingly familiar with their readings at that point and rarely required the RA's help. The RA is most useful in providing assistance when information is nearly forgotten.

5.2 Sharing knowledge and experience

If a user can store his textbooks and memories on the wearable's hard disk and use the Remembrance Agent to help index these memories, why not download the Library of Congress as well? Unfortunately, such an application breaks the familiarity conditions necessary for the RA to be effective. The user must have enough personal knowledge of the RA's database to recognize the importance of a file or e-mail based on its one-line summary. Without this intimate knowledge, the RA's suggestions are relatively useless. In other words, the Remembrance Agent can't implant random memories into its users.

However, the notes of a close collaborator, who shares the same vocabulary and some of the same experiences, might prove useful to an RA user. As an informal experiment, three wearable computer users combined their notes. We've found that the RA suggestions from a colleague's database can be quite eerie. The user recognizes the significance of the suggestion and can almost claim the memory as his own due to the similarity with his own experiences, but he knows that it isn't his entry. These "shadow memories" create an asynchronous form of collaboration, one of the most dramatic instances of which is related below.

> One of the duties of a Media Laboratory graduate student is demonstrating his projects to sponsors. Over time, wearable computer demonstrations became popular. Fortunately, with several wearable computer users in the laboratory, each with his own specialty, demonstrations can be distributed so as not to put an undo burden on any particular individual. For Starner's demonstrations, he maintains a file that details his primary talking points. Not only does this improve his short presentations, but it also reinforces the use of the machine to the visitor when trying the display. To provide further aid, Starner keeps a list of answers to common questions that are asked during demonstrations.
>
> A few days before the merge of RA databases, Starner was asked a new question by a sponsor. Knowing that he speaks better if he has a detailed response at hand, Starner used his notes from the conversation to write a few sentences addressing that question immediately after the demonstration.
>
> At the end of that week Starner was working in a different group's laboratory, when he heard Rhodes begin a wearables demonstration. Hidden from view, Starner kept working. However, at the end of the demo, he heard the same, new question asked by this different sponsor. Surprised, Starner finished writing the sentence he was working on and rose to introduce myself when Rhodes replied with the exact answer he had written just a few days before!

From this experience, the utility of sharing up-to-date "notes" became apparent, for Starner had not spoken, written, or otherwise articulated this new information to Rhodes except through the massive merging of databases. However, Rhodes was still able to find and use the information appropriately at the time it was needed. Such "just-in-time" information support provided by the wearable computer was striking. However, in addition to such asynchronous collaboration, wearable computers can enable synchronous collaboration as well, as will be shown in the next section.

6 Connectivity and collaboration

> Recently, Weaver subscribed to a course where Rhodes was a teaching assistant. The class met over a two hour time period. During a particular meeting, many of the students were acting tired and needed a break. A message appeared on Rhodes's screen: "Think we can take a break?"
>
> Such short messages are common to zephyr, a simple messaging and alert system used by MIT students. Zephyr allows simple messages to be sent to an individual or collections of individuals subscribed to a group. While not interactive *per se*, zephyr is used for eliciting more immediate responses than e-mail. In addition, a user can choose to reveal their presence and location on the network when they log in or log out. Conversations over zephyr tend to be terse and may have frequent pauses as the user performs other tasks.
>
> Reading the message and seeing that it was from Weaver, Rhodes responded, "I'll ask." Being a student, Weaver felt awkward about requesting a break from the lecture and so forwarded his request to Rhodes. When the lecturer began to switch topics, Rhodes interjected, reminding the lecturer that he had promised a break between the two hours of the weekly class.

The combination of computer messaging tools, wireless connectivity, and a head-up display make such situations possible. In fact, members of the MIT wearable computing community and their colleagues take such an ability for granted. This informal networking can be used to organize social gatherings for dinner, make quick informational requests, ask someone to perform a physical act (*e.g. "Can you check the lab soldering iron on the way out?"*), or coordinate professional activities. In our experience, the informality and ease-of-use of wearable communication means it will get used more often than would a pager or cell phone. On occasion, while speaking as a group to visitors, Lizzy users will send messages back and forth, dynamically arranging the visitors' schedule for that day depending on their expressed interest. These messages are also sometimes used to shape the conversation during meetings. This behavior demonstrates a form of "intellectual collective" where a group of people combine knowledge and ability. Indeed, when possible, Starner makes a habit of using zephyr while speaking on conference panels. However, one of the most striking examples of an "intellectual collective" is related below.

> "Ask me a question, any question," Starner commanded a reporter who wanted an example of an intellectual collective.
>
> "What is the population of London?" she asked.
>
> "Now, let me tell you what I'm doing. I've just hit a chord on my keyboard corresponding to 'zwrite -i help' and typed in your question. This command allows me to send your question to a collection of computer users across MIT's campus who are subscribed to the 'help instance.' The help instance exists as a general, informal resource to the community. Users subscribe to the group while doing homework or playing games to help others in their spare time and to learn from the questions and answers that get sent over the group."
>
> "What are they saying?" the reporter asked.
>
> "Actually, it's embarrassing. Since the World Wide Web took off a year or so ago, easy research questions like this one are not tolerated as much. The initial responses have been to the effect of 'Go do a web search!' I've replied that this is actually a demo for CNN and could someone please provide the answer. I've gotten a few 'Hi Mom's' in response to that! They think we're filming."
>
> "All this while we're riding in the elevator?"
>
> "Aha! Here a former Londoner has replied that the population, including the neighboring suburbs, is approximately 7 million."
>
> "And why do these people normally respond to questions?"
>
> "Some of it is reciprocity. Many of these people have used the help instance as neophytes. Some of it is the status of being deemed knowledgeable on a topic by others. However, much of it is that these people have short periods of excess time when their code is compiling or when a partner in an on-line game makes his move. Why not help out someone else when it takes so little effort?"

The task of editing a paper provides an example of how the wearable computer may enable more personal collaborations. Weaver and Starner needed to outline a paper for publication, using pieces of text already written. Weaver happened to have his wearable connected to the high speed laboratory network, but Starner had the current copy of the document on his wearable. Deciding to experiment with a feature in emacs, "make-frame-on-display," Starner used his wireless CDPD connection to establish a co-editable buffer shared between the wearables. In this manner, each author controlled independent cursors in the same emacs buffer and could include text from their own machines. While this feature is certainly useful, the collaboration itself seemed very interesting as it progressed. Since both participants were using Twiddlers and Private Eyes, they could hold something akin to a normal face-to-face conversation while jointly editing the document. Instead of both facing a computer monitor and taking turns at the keyboard, the authors could watch their partner's hand and facial gestures as they discussed different aspects of wording (this effect was also found by Ishii in his Clearboard experiments [5]). In addition, the users could work in parallel, pointing to different sections of the document with their cursors. In this manner, they could engage many different conversational modalities and not be inconvenienced by needing to share a desktop interface designed for one person. While simple, this computer supported collaboration was surprisingly compelling.

7 Lessons of the project

While we are still formulating how to convey the lessons of the project, there are a few points that stand out.

1. Mental models of use: One of the most important goals for gaining user and social acceptance is communicating the purposes for which wearable computers are used as well as their abilities. Due to their general purpose nature, wearables

pose a particularly difficult problem in communicating their function at a given time to onlookers. Many of the objections to the daily use of a wearable computer disappear when the community views the machine as a personal aid as opposed to a spying device. [4] However, just as new telephone headsets have a little light indicating when the user is on the phone, wearables need to make pieces of their internal state available to the people around it.

2. The wearable computer is not just for work, it's for living: The maximum benefit from a wearable computer comes when it is personal and used for both private and professional life.

3. Fashion and design matter: Color and form help communicate a machine's purpose and help frame the socially accepted uses of a given tool.

4. Quick access increases use tremendously: An informal rule developed within the project is that every function intended for everyday use must take under two seconds to access. Any longer "set-up" or "tear-down" time for the interaction poses a significant barrier to useage. This follows Zipf's principle of least effort [20], which states that people choose a strategy for action that ensures that the minimum effort is required to reach a desired result. A wearable interface has to be at least as convenient and simple as not using the system. Otherwise, people will simply rely on their own memory or do without, even if the wearable is more accurate or helps them more in the long term.

5. Attention is the greatest commodity: Wearable computers are often used while performing another, more primary task, such as walking, conversing, attending lecture, or manipulating a physical artifact. Thus, the interface must not distract from this task and use as little human resources as possible, preferably in a different modality than the primary task. While possessing a full bitmapped screen, Lizzy users rarely run graphically or mouse intensive applications. While this observation may be an artifact of the particular hardware used, we predict that the future interface challenge will be to design interfaces and operating systems to optimally utilize the user's limited attention.

6. Breaking away from a sense of place without loosing a sense of community: Wearable computing offers the current extreme in mobility. Members of the MIT community routinely communicate and collaborate over significant distances. In fact, these words, hosted on a wearable, are being edited by three of the authors concurrently in different locations. A challenge to such situations is finding serendipitous communication means, such as zephyr and the Remembrance Agent, to maintain a sense of community and cohesiveness while not requiring a sense of place or possibly even synchronicity.

[4] Correspondingly, almost no one objects to a Lizzy user typing notes. Some express concern over video recording. Audio recording is almost never permitted without specific safeguards on the release of the data.

8 Conclusion: a killer lifestyle

Using a piece of technology as a basic part of your everyday life is fundamentally different from using it for specialized purposes. The constraints and possibilities change significantly. In addition, the value of such technologies increases significantly as more users adopt it. Through supporting a community of everyday wearable computer users, we've learned much more about the social aspects and use of wearable computing than any one user could have discovered on his own. As the technology improves, becoming more widespread and less obtrusive, the ongoing explorations in the use of wearable computers will continue, expanding to include a broader base of users. Through a discussion of the use of mostly traditional applications, this paper has conveyed a feeling of living in such a community. It is an exciting time. Recently some of the anecdotes above were related in a short talk, and the speaker was asked what the "killer application" of wearable computing would be. A new colleague, upon hearing the presentation for the first time, provided the best response:

> "It's not about a killer application with wearables; it's about a killer existence!"
> *Gregory Abowd*

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