Prototypes and Paratypes: Designing Mobile and Ubiquitous Computing Applications

Combining physical, contextual, and functional prototyping techniques to generate compound prototypes and situated experience prototypes, or paratypes, can be particularly useful for mobile and ubiquitous computing applications.

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Conducting user-centered design is a primary challenge in ubiquitous computing.[1] Ubiquitous computing applications are exploratory by nature, and often users are unfamiliar with their interaction paradigms and features. Furthermore, these technologies can disrupt existing social practices, potentially weakening or invalidating evaluation results. So, when designing these applications, realistic testing environments are essential. However, high development costs and users' unfamiliarity with the technology make it costly to apply quantitative analytic methods, such as controlled performance measurements, or qualitative techniques, such as iterative field testing.

Over the past several years, members of our research group have been designing and evaluating several mobile and ubiquitous computing applications including memory aids, messaging applications, and technologies that help educate children with special needs. To tackle the unique design and evaluation challenges of these applications, we've refined design and prototyping techniques to be more appropriate for the ubiquitous computing domain.

Prototyping techniques have traditionally supported artifact design, and developers typically view prototypes as a physical prop of an intended design. However, prototypes more generally can replicate various aspects of an artifact before the final product is built by reproducing the physical, computational, or experiential properties of its design.[2] Two kinds of prototyping techniques can be particularly effective for developing mobile and ubiquitous computing applications: *compound prototypes* and *situated experience prototypes*. Compound prototypes combine the final product's user interface (UI) with a computational implementation that runs on a separate system without the resource constraints of the target device. This model lets researchers and designers evaluate a new application's physicality and aesthetics as well as its functionality. Situated experience prototypes, or *paratypes*, include experimental protocols that attempt to reproduce user interaction with the system in real situations, and can optionally use common prototyping instruments such as paper mock-ups or physical props.

Using our Personal Audio Loop (PAL) project as a case study, we discuss how you can fruitfully employ compound prototypes and paratypes when designing and developing mobile and ubiquitous computing applications.

PAL: Personal Audio Loop

PAL is a portable audio memory aid motivated by the everyday experience of conversational breakdowns, as people try to remember some-

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Figure 1. The Personal Audio Loop, which can be attached to a belt clip (inset), has three buttons that control navigation within the recording and record/playback mode. A timeline indicates the current mode and relative place in the buffer.

thing they recently said or heard.[3] Examples include the topic of a conversation before an interruption, or a name or number briefly heard in situations of high cognitive load like a party or conference. The initial concept was to let someone replay easily, at any moment in time, sounds heard in the recent past up to a defined maximum time span (for example, up to one hour). Figure 1 shows an implementation concept of PAL on a cell phone.

PAL's design process shows how we used compound prototypes and paratypes for a novel application that would have been difficult to design with more traditional user-centered practices. Most people haven't experienced an automatic, audio-based memory aid, so they would have little context to leverage in understanding its design. Therefore, to answer questions about PAL, user study participants had to understand its capabilities and be able to refer to concrete moments when they could have used it. The questions covered three important issues:

- *Usability:* How should the application deliver functionality to maximize its effectiveness and minimize its distraction?
- *Usefulness:* How often and in what situations do people recognize a need for near-term, audio-memory aid and think they would actually use the tool?
- *Acceptance:* What social and legal concerns might prevent the successful deployment of an application that continuously records?

When we started analyzing these questions, we had developed PAL prototypes on PCs and PDAs, but we didn't have a robust enough prototype on the form factor we had chosen, a mobile phone, to give to users. At the same time, we didn't want to commit additional development resources before gaining further insight into these issues—a common concern when developing mobile and ubiquitous computing applications. Thus, to study these issues without a robust implementation, we used compound prototypes and paratypes.

Compound prototypes

Compound prototypes are representative artifacts that combine a design's physical and computational nature by providing a realistic UI that controls a faithful implementation of the application on another computing system. Compound prototypes have helped IT product development—for example, developers working on a digital camera for Kodak attached a physical prop of the camera, which provided the UI, to a PC, which provided the application's computing capabilities.[4] Similarly, in the 1970s, HCI research on desktop systems greatly benefited from having access to machines that were five to 10 years more advanced than what was widely available. When the technology became commercially viable, the desktop interface was ready for rapid adoption. Compound prototypes let designers test sophisticated applications on real, sometimes limited, devices while avoiding development risks and commitments to lengthy debugging and optimization on these platforms.

The PAL usability study

To understand whether we could use a mobile phone as the PAL interface, we built a compound prototype using the phone as the interface to the application core running on a PC. This let us conduct a controlled usability study prior to developing a fully functioning version of PAL on a mobile phone.

The limited performance and interface of the selected platform (the Motorola iDEN i730, a clamshell, Java-enabled phone) raised concerns about PAL's usability. When closed, the phone offers only three buttons for input, a 150×10 pixel graphical monochrome display, and an LED that lights to one of three colors (green, red, and blue). The compound prototype we used for this study consisted of a phone connected via serial cable to a laptop (see figure 2). A Java program on the phone transmitted button presses to the PC and provided display feedback. Software on the PC implemented the application core, including audio capture, recording, and playback.

PAL's intended use involves replaying conversations during which the user was present. We used the compound proto-

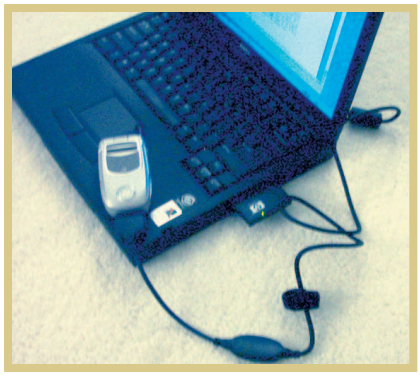


Figure 2. The compound prototype used in the usability study. The phone provides the user interface, while the core application runs on the laptop.

type in a controlled study designed to mimic this scenario and based on a scripted dialog of approximately five minutes. In this script, the participant asked the researcher predetermined questions, and the researcher replied with scripted answers. Answers purposely involved numerous details to increase the likelihood that participants couldn't recall everything from memory. After completing the script, the researcher asked the participant about the scripted replies, inviting the participant to use PAL if he or she didn't recall the answer. The researchers encouraged subjects to think aloud while using the prototype.

Eighteen students and faculty from our institution (five female and 13 male, ranging in age from 18 to 50) participated in the study. Being HCI practitioners, they provided expert feedback on common design heuristics. All participants navigated the audio well enough to complete all tasks. They commented that the device was easy to use with one hand and small enough to carry at all times. They also could clearly understand the audio even in its highly compressed form. The study results confirmed the interface's effectiveness for its intended purpose and provided several insights that we incorporated into the new design. Significantly, some issues dealt with functionality, such as participants expressing the desire for bookmarks in the recording, and some focused on physical interaction with the device, such as mapping forward and reverse buttons to functions.

Compound prototypes in practice

By using a fully functional and physically realistic prototype, designers can probe the application's look and feel (physical prototype) and functionality (computational prototype) and exclude some elements of interface usability as potential causes for failure in subsequent field trials. While studying technologies with potentially complex social ramifications, like PAL, it's especially important to clearly understand and attribute potential adoption patterns. Thus, by evaluating usability and functionality aspects, we were able to target the application's more experiential aspects in real-world settings in subsequent studies.

Our experience with PAL suggests that compound prototypes are quite useful in prototyping and evaluating ubiquitous computing applications designed for platforms with limited resources. Compound prototypes have been used in engineering and industrial design for years, and we find them particularly appropriate for user-centered development on mobile phones—an important platform for ubiquitous computing. Compelling reasons exist for making the compound prototyping of phone-based applications more viable. For example, researchers could create prototyping toolkits to facilitate development, testing, and porting of compound prototypes to a range of different devices. These toolkits would not only facilitate usability testing but also enable the comparison of alternative form factors and UI paradigms with the same application core.

Paratypes

Marion Buchenau and Jane Fulton Suri show, with their concept of *experience prototypes*, that designers can use a prototype for gathering feedback on the experience involved in using a certain design—role-playing a train journey, for example.[4] Extending this concept, *situated experience prototypes* let researchers and designers observe user experiences by simulating a technology's potential use in real-life situations—not in a lab or in role-playing. In this sense, we define situated experience prototypes as *paratypes*: models ("-types") of interaction experiences that happen alongside ("para-") real, experienced situations.

Paratypes are different from typical experience prototypes in that the latter creates exemplary experiences, and the former leverages real life to test a design concept—only the instance of the technology's use is simulated or imagined. By creating an instance of use embedded in real life, you can gather more authentic reactions from participants. These procedures can yield more accurate conclusions than designers can reach using participative storyboards or scenarios, which investigate participants' thoughts about a technology exemplified in a narrative account.

We used paratypes for two PAL user studies: a diary study and a proxy study.

The PAL diary study

To probe PAL's potential usefulness, the diary study aimed to understand, where, why, and how often participants would use the application. After participants interacted with a fully working version of PAL to understand its functions, we used diaries as a paratype—that is, a reporting tool for potential PAL uses.

Paratypes are especially useful when you can't or don't want to use the actual application for field testing. In this study, we used the diary because the PAL prototype wasn't robust enough to withstand user deployment. We didn't want to commit additional resources to product hardening and deployment maintenance (for example, replacing defective phones and responding to emergent problems) before having a strong argument in favor of PAL's utility and acceptability.

Developers have used diary studies as inquiry tools in the mobile technology design process—for example, allowing

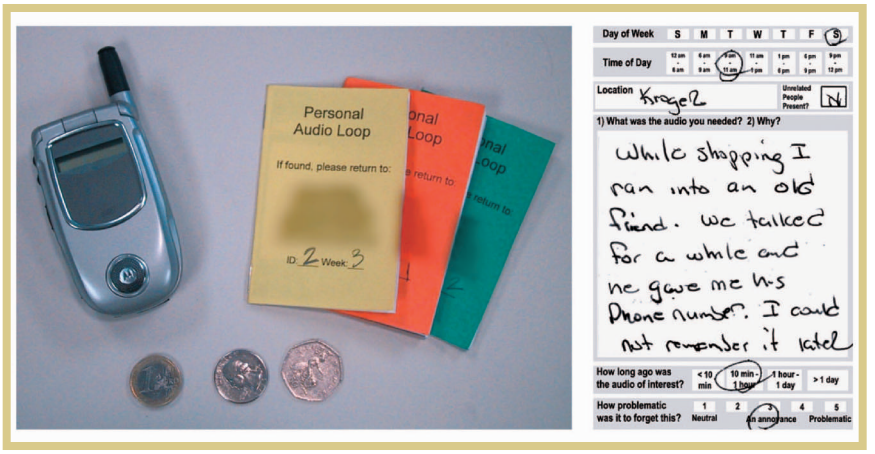


Figure 3. Participants kept personal diaries roughly the size of the phone and recorded an entry each time they would have used the PAL application.

participants to take notes about their daily activities.[5] Diaries can function well as paratypes as a documentation tool for recording the reflections of participants in simulated interaction. In this case, the diary exercise's focus is documenting imagined uses of technology, not participants' activities. Again, it's important to balance the ecological validity of gathering user data in situ against the interruption of everyday activity flow that recording personal observations causes.

This use of paratypes is somewhat similar to *experience sampling method* tools, in which a digital device interrupts the participant, prompting him or her to respond to questions or partake in simulated interaction.[6] However, with paratypes, use is initiated by the participants, not the artifact, and thus can be more salient. Of course, this means there must be a reasonable expectation that the participants will be sufficiently motivated to initiate the survey at appropriate times.

In our case study, diaries let us probe questions about application usefulness in a situated setting. PAL is characterized by isolated and intentional interaction. Hence, the PAL diary entries focused on events, discrete instances of imagined use that participants can recall during in-depth interviews even at a distance of a few days.

Twelve experienced mobile phone users (five female, seven male, ages 22 to 60) participated in the study. We intentionally included these users to gain opinions from people representative of medium-to-advanced cell-phone users in the US market. Participants included a psychologist, finance manager, realtor, car dealer, consultant, professor, and homemaker.

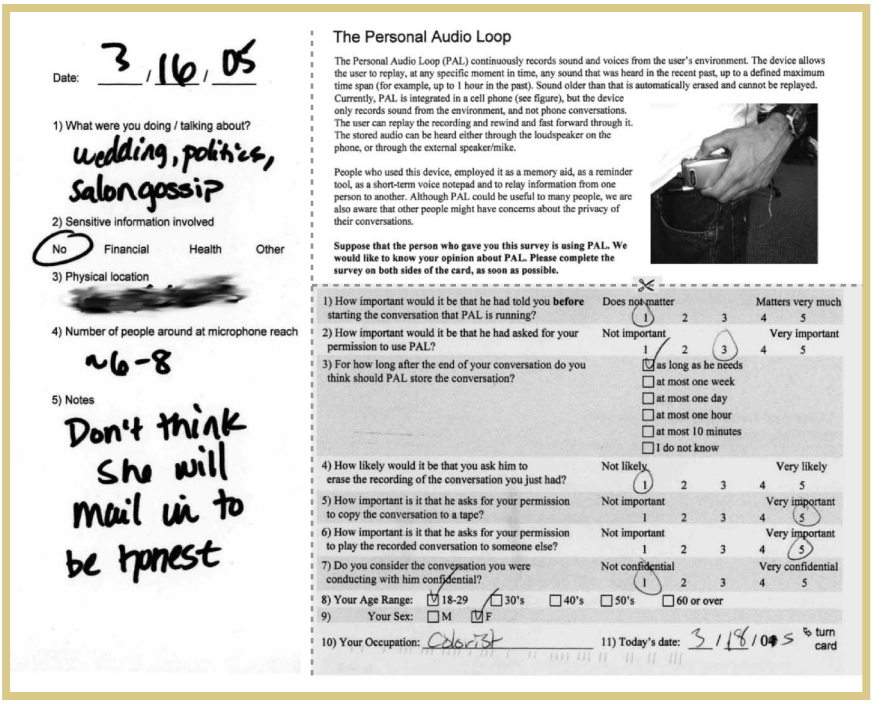
To ensure that participants understood PAL's functionality, we demonstrated a fully working version of the device and let them use it until they were comfortable with it. Then, we asked participants to carry pocket-sized diaries (sized similarly to the phones) and to record one entry for each time they would have needed or liked to use the PAL application. Each diary page contained a form about each potential use instance (see figure 3). Participants described the content of the audio to retrieve, when and where the event occurred, and whether any people unrelated to the conversation were nearby. Participants also estimated how far in the past the salient audio content was and rated how problematic it was to forget that information. The diaries helped us understand the potential uses as well as the difficulties encountered by carrying this pocket-sized device at all times and interacting with it when needed.

The participants in the PAL diary study carried the diaries for up to three weeks. At the end of each week, we collected the diaries and conducted semi-structured interviews to examine in detail some of the diary entries. We inquired about their perceptions of the social appropriateness of using the application in terms of the specific context, privacy, and the disruption inherent in interacting with the device in front of others. We then gave a fresh diary to each participant who chose to continue.

We collected data on more than 100 events. We gathered both quantitative and qualitative data by following up on 83 of those events during the interviews. Quantitative data included statistics such as the average number of reported events per week and how long in the past the audio mentioned the event that was referred to. The diaries let us transition from quantitative inquiry to subjective, qualitative questions without sacrificing firm experiential grounding. For example, after the second and third weeks of use, we asked participants subjective questions about their reactions to hypothetical situations in which a conversation partner objects to their use of the application. In most cases, participants stated that such an objection would "not [be] likely" and indicated that they would not have complied with the objection, had there been one, in roughly two-thirds of the queried events. (This data is hypothetical in nature and should be considered with caution.)

At this point, we were able to ask questions that required a good understanding of how, when, and where people would use the application. For example, we asked how far away they would like PAL to record (67 percent chose "within a small room"). These data led us to the third acceptance study to understand how conversation partners would feel about PAL.

Participants' comments in the diary study left open the question of how their conversation partners might react, knowing that PAL was being used in their presence. A long-term deployment might have provided answers to these questions. So, we started testing the final



Date: 3/16/05

1) What were you doing / talking about?
wedding, politics, salon gossip

2) Sensitive information involved
No Financial Health Other

3) Physical location
[redacted]

4) Number of people around at microphone reach
~6-8

5) Notes
Don't think she will mail in to be honest

The Personal Audio Loop

The Personal Audio Loop (PAL) continuously records sound and voices from the user's environment. The device allows the user to replay, at any specific moment in time, any sound that was heard in the recent past, up to a defined maximum time span (for example, up to 1 hour in the past). Sound older than that is automatically erased and cannot be replayed. Currently, PAL is integrated in a cell phone (see figure), but the device only records sound from the environment, and not phone conversations. The user can replay the recording and rewind and fast forward through it. The stored audio can be heard either through the loudspeaker on the phone, or through the external speaker/mike.

People who used this device, employed it as a memory aid, as a reminder tool, as a short-term voice notepad and to relay information from one person to another. Although PAL could be useful to many people, we are also aware that other people might have concerns about the privacy of their conversations.

Suppose that the person who gave you this survey is using PAL. We would like to know your opinion about PAL. Please complete the survey on both sides of the card, as soon as possible.

1) How important would it be that he had told you **before** starting the conversation that PAL is running? Does not matter (1) 2 3 4 5 Matters very much

2) How important would it be that he had asked for your permission to use PAL? Not important 1 2 (3) 4 5 Very important

3) For how long after the end of your conversation do you think should PAL store the conversation?
- ☑ as long as he needs
- ☐ at most one week
- ☐ at most one day
- ☐ at most one hour
- ☐ at most 10 minutes
- ☐ I do not know

4) How likely would it be that you ask him to erase the recording of the conversation you just had? Not likely (1) 2 3 4 5 Very likely

5) How important is it that he asks for your permission to copy the conversation to a tape? Not important 1 2 3 4 (5) Very important

6) How important is it that he asks for your permission to play the recorded conversation to someone else? Not important 1 2 3 4 (5) Very important

7) Do you consider the conversation you were conducting with him confidential? Not confidential (1) 2 3 4 5 Very confidential

8) Your Age Range: ☑ 18-29 ☐ 30's ☐ 40's ☐ 50's ☐ 60 or over

9) Your Sex: ☐ M ☑ F

10) Your Occupation: Colorist

11) Today's date: 3/18/05

turn card

Figure 4. The proxy survey comprised two parts: one the proxy filled out (left) and the other the participant filled out.

product in a small deployment. Eventually, most participants stopped using PAL, regularly reporting that robustness problems (mainly phone OS crashes, due in part to the high processor load that PAL caused) and availability issues (fast drain on the battery, that, again, PAL caused) generated more discomfort than the application was worth. Unable to directly examine PAL's social issues, we designed a new study to understand the acceptance issues PAL engendered without the need of a deployment.

The PAL human proxy study

In the second study, the human proxy study, we tackled acceptance questions related to the burden imposed on conversation partners' privacy and the social appropriateness of using the application, both from a relational viewpoint and with regards to disrupting interpersonal interaction. We surveyed the PAL user's conversation partners, asking:

- Do you object to people using a device that could potentially record you? If so, why? Do your objections depend on location, topic, and perceived confidentiality? (These questions were relevant in the light of context-sensing technologies that could be implemented on the phone.)
- What parameters, such as retention time, should change to compromise between your interests and those of your conversation partners?

This study relied on human proxies—that is, individuals who introduced a simulated PAL in real-life situations and then probed their conversation partners' reactions by using a simple survey administered on the fly on the researchers' behalf. This experimental design, as opposed to a traditional survey, let us address the common phenomenon in which people's stated opinions and preferences on privacy are often different from their everyday social behavior.[7] We chose not to have proxies actually use PAL on ethical grounds and to avoid potentially contentious situations, even if the application was at the time fit for use by a small group of researchers who could have coped with occasional malfunctions. Using a paratype rather than a fully functioning device let us capture participants' reactions in real social situations, without the potentially disruptive effects of introducing the actual device.

In this study, human proxies simulated the application's use with the people they would encounter during their normal daily activities and collected their reactions on the researchers' behalf. As the proxies conducted their activities, they asked adults they encountered (acquaintances as well as unknowns), with whom they would have a conversation, to read a description of PAL and fill out a survey about the application. The survey asked participants to suppose that the proxy had been using PAL and to provide their opinions about it. The proxies carried a working PAL prototype that wasn't active at the time but could be activated to show participants its functionality.

In this sense, the survey instrument and the human proxy constitute a paratype: Together they create a simulated use of PAL in real-life situations without the need of an actual device. The paratype in this case again provides imminent reference to the situation. In the survey, we probed the situation's salient elements, including its place, the people who took part in it, and the activity the conversation was achieving, as determinant elements of the person's behavior (similar to the characterization of *situation* proposed by social scientists like Erving Goffman[8]).

The survey was anonymous and comprised two parts linked by a unique number (see figure 4). The proxy filled out the left part with information about the conversation's place, topic, and environment. The participant received the right part, which was designed to be self-explanatory and consisted of a description of PAL and the survey on a return-addressed postcard. We coded the back of both parts with numbers that later let us associate the returned postcard to the proxy's portion of the survey.

When possible, the proxy explained the survey to the participant and showed

the working PAL application on request. The proxy asked the participant to fill out the survey, preferably immediately, to preserve recall accuracy. Otherwise, the participant could mail back the survey card at his or her convenience. To control recall accuracy, we asked participants to indicate the date they completed the survey; the proxy also recorded when the survey was distributed.

Administering this kind of survey was relatively unproblematic for the proxies. The cards were portable, preaddressed, and perforated. Of 45 distributed surveys, we received 41 responses. Most surveys were completed on the spot, and nine were mailed back to us. Only one individual refused to accept a survey from us. The high response rate, both from acquaintances of the proxies and from people whom they had just met, suggests that the social relationship originating through a conversation, however brief, was sufficient to encourage most participants to complete and return the surveys. An essential feature of this survey was its brevity, to minimize its impact on conversational routines. The survey focused on a single interaction instance involving the device, thus preserving situational validity and participant understanding of the usage context and social environment.

Paratypes in practice

A fundamental requirement for a successful paratype is that participants understand the application's functionality. In the diary study, we achieved this by demonstrating the working prototype to participants to help them gain immediate and tangible understanding of how the application worked, ensuring that the diary responses would be relevant. Additionally, it communicated to the participants that the application was feasible. Participants reported that after the demonstration, they were more interested in the project, which we believe increased diary response rate and quality.

In the proxy study, the survey was self-contained, which allowed the proxy to give it to the participant with little explanation if the situation didn't allow for a more prolonged interaction, such as at a supermarket check-out. The description and picture on the survey provided sufficient information about the application (we conducted a preparatory study to verify this). In fact, one-third of the participants provided comments and opinions on the backs of the cards, suggesting that the application concept and the paratype's immediacy engaged them.

Because paratypes are administered alongside everyday situations, it's essential that they be fit for use in the participant's social and physical environment. Paratypes must be

- *Unobtrusive.* Researchers must minimize time dealing with any survey tool by gathering only essential information and perhaps using Likert scales or check boxes instead of free-form questions.
- *Compatible with the participant's expected cognitive load in the use situation.* You can achieve this by using plain language and a simple sentence structure and offering clear, step-by-step instructions on using the paratype.
- *Compatible with the physical environment.* For example, if some users can't fill out a questionnaire, let them defer it to a more convenient time and place. You should provide any additional material needed to use the paratype (for example, writing implements and demonstrative objects).

Gathering participants' consent can be the largest hurdle. First, in a rushed situation, participants might not be able to fully understand or consent to participating. Second, recording that consent can be complicated in the context of the experience. Researchers might need to find ways to minimize their impact if study participants can't be enrolled before using the paratype. In our study, when researchers couldn't obtain verbal consent, they gave the consent form to the participant along with the survey to be mailed back to the researchers.

Paratypes can't easily integrate with Wizard of Oz prototyping schemes, which try to capture the experience of using an artifact by intelligently simulating its behavior. However, Wizard of Oz techniques are often more amenable to laboratory-produced or, if in the field, fabricated situations. For example, Yang Li and his colleagues report on Li's Topiary system for producing Wizard of Oz prototypes of location-enhanced applications tested in the field.[9] Their evaluation employs tasks created for the test. Instead, paratypes share the concept of "situatedness" with cultural probes.[10] They study interaction instances that refer to the everyday life situations the participants experience (similar to how cultural probes help reflect on everyday use artifacts). In this way, designers expectedly gain more accurate and relevant feedback.

Experience with compound prototypes and paratypes not only has let us revise and develop new versions of PAL but also has provided us insight into social and privacy aspects of this applications class. Future research into and applications of these techniques will focus on settings in which other techniques might be too intrusive or might not yield useful results, such as healthcare and home environments. Applying these techniques successfully will require careful prototype design with an emphasis on creating close approximations to the technologies in situ with minimal intrusion on the user. P

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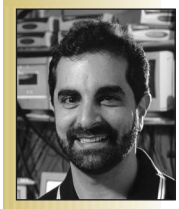

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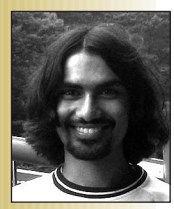

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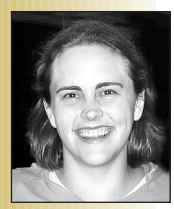

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