From Informing to Remembering: Deploying a Ubiquitous System in an Interactive Science Museum

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Abstract

This paper describes our experiences implementing and testing nomadic computing tools at the Exploratorium, an interactive science museum in San Francisco. This is a challenging environment because it is hands-on, boisterous, and makes navigation and visual identification difficult. Therefore, the Exploratorium user experience differs from test environments (e.g. historic houses) used in much previous research.

We present a classification of possible tool functionalities. We then describe the two specific prototypes we implemented: an electronic guidebook similar to those deployed by previous research groups and a simpler "Rememberer" tool which allows users to bookmark exhibits and take pictures of their experiences at the exhibits. Results are presented from studies of how people use these tools, as well as from a study of museum visitors without extra technology.

Our studies suggest the guidebook is too distracting for many visitors to this environment and that the simpler Rememberer tool better matches their needs. Moreover, our results illustrate the value of early deployment and user testing: our initial experiments with the guidebook led us to the design of Rememberer.

1 Introduction

This paper presents our experiences designing, implementing and deploying applications to enhance visits to an interactive science museum. This work is part of the Cooltown project [11][12], which carries out research into infrastructure and applications for "nomadic computing systems"--ubiquitous systems in which mobile ("nomadic") humans use portable devices to access services and applications that are integrated with the physical world. Our museum study has focused our attention on nomadic computing *tools*: applications that enhance users' interactions with the physical world but whose functionality is sufficiently simple that they are largely transparent.

We carried out this work in collaboration with the Exploratorium in San Francisco [9]. The Exploratorium consists of a large open-plan space populated with hands-on science exhibits. Users of most ages and levels of scientific knowledge roam from exhibit to exhibit, manipulating the apparatuses, reading information mounted on labels, and occasionally consulting "explainers"--museum guides who explain the exhibits' operation and the scientific phenomena behind them.

The Exploratorium is an environment rich in physical artifacts and explored by mobile users, and thus promising but challenging ground for nomadic computing tools. Specifically, the Exploratorium is:

> *Hands-on*. The Exploratorium emphasizes exploration and learning by doing. The exhibits invite physical interaction which may involve, for example, two-handed manipulation of a mechanism or putting one's head inside an echoing tube. Some exhibits contain materials hostile to electronic devices, such as sand and water.

> *Boisterous*-both vigorous and noisy. The Exploratorium is popular with children who can be uninhibited in their urge to race between exhibits and exclaim discoveries to one another. Adults are also known to get excited!
>
> *Hard to navigate and identify*. The exhibits are sometimes clustered by topic but have no obvious order. There are few distinctive areas, landmarks, or backgrounds in the open-plan layout to aid in locating them. The exhibits are hard to identify without close inspection because they tend to be unfamiliar and may be obscured by other visitors and exhibits.

A wide range of nomadic computing tools might be deployed in this environment. However, there seems to be only a small list of basic functionalities to consider:

Informer: Informer provides the user with information related to the exhibits, particularly the exhbit that the user is currently visiting. This information may be more detailed than what is on the physical exhibit labels and/or may be tailored to the user (e.g. their interests).

Suggester: The full functionality of exhibits is not always obvious. Suggester offers ideas for what to try at an exhibit, e.g. " try moving the lever to see the effect on the waveform". This supplements the short list of suggestions on the exhibit's physical label.

Guider: The Exploratorium's open organisation does not indicate any order for visiting the exhibits. For those who would like more structure, Guider suggests exhibits to visit next, along with navigational advice (c.f. the Guide project [3]). Exhibit order might be fixed or adapt to a user's interests and past behavior.

Communicator: There is often a strong social dimension to visiting museums [16][19]. Communicator helps users communicate, in the context of the exhibits. Communication might include electronic bulletin boards for individual exhibits, instant-messaging , and/or beaming information between handheld devices.

Rememberer: Exploratorium visitors are frequently overwhelmed by the vast amount of information presented. Rememberer helps them build a record of their experiences which they can consult during or after their visit. The user deliberately selects the phenomena to record, in contrast to passive recording systems such as Forget-Me-Not [13].

Our main contribution is an analysis of the above functionalities based on our deployment experience and user studies. Based on discussions with staff at the Exploratorium, we began by implementing a hybrid implementation of Informer, Suggester and Rememberer skewed towards real-time information provision (our "electronic guidebook"). Studies of museum visitors and volunteers using the guidebook, however, led us to change our focus to a pure Rememberer tool.

After a review of related work (section 2), this paper will describe our studies of visitors without technology (section 3), and the deployment and testing of the guidebook prototype (sections 4 and 5). Sections 6 and 7 discuss the motivation for switching to Rememberer and present preliminary user study results for it. Section 8 concludes.

2 Related work

Museums, thanks to their enclosed nature and well-defined role, have been a fertile ground for studying visitor behavior [16] and envisioning systems that would enhance visitor experience. Early electronic guidebook tools in the form of acoustic guides have been successfully deployed in museums for some time. Their application, though, is limited by the fact that they rely upon sound to guide a visitor through an exhibit. Audio guides can inform only by describing; they require the user to make his or her own associations with an exhibit with no visual cues to assist them.

With the introduction of inexpensive portable devices that can render multimedia content, several other projects have developed prototype or commercial systems for museum augmentation or navigation with handheld and/or wireless technologies (see projects presented at the Electronic Guidebook Forum [7]). The use of technologies such as PDA's and Pagers has provided a means by which museums can communicate with their visitors in a more personal manner. The San Francisco Museum of Modern Art, for example, uses static and local content on a PDA, including a short video clip of the artist explaining their work, to provide visitors with a different perspective about the exhibits. The Experience Music Project [8] in Seattle uses infrared beacons at which the user points their device to select relevant content.

The Sotto Voce electronic guidebook, which was tested at Filoli mansion [2] [19], also provides content about the exhibits on a handheld device. Users are presented with images of the rooms in the historic house on their PDA's. Users thus orient themselves in the physical and virtual world together as they locate the content relevant to an artifact. Each image shows artifacts against a physical wall of a room. The visitor can select artifacts from the virtual image and find out more about them, principally in the form of audio content. Visitors could share the content in the relatively quiet environment and it was found to play a positive role in social interactions.

In most related projects, the devices have been deployed at museums where there is not much hands-on activity. In fact, in many of those other situations, the visitor is not able or allowed to touch the exhibits. The Exploratorium, as the previous section describes, is a very different environment.

3 A Study of Visitors without Technology

We carried out an informal study of how visitors ordinarily-that is, without any extra technology-behave at exhibits. We observed 30 individuals and groups, randomly selected from the visitors using one of four exhibits, and briefly interviewed them immediately after they had finished. Our goal was to broadly characterising their interactions, both with the exhibit and among themselves, and their use of the exhibit labels.

Exploration

The most common approach to an exhibit is to walk up to it and try to figure out what to do with it. The exhibits support a combination of "play" and "science"; many visitors, especially children, are very creative in the way they use exhibits. For example, two girls invented a sophisticated game involving catching sand, using an exhibit intended to illustrate exponential decay, which had no connection to the "script" on the exhibit label. Such "play" can lead to "science": one adult mentioned that interacting with an exhibit helped him finally understand a scientific concept encountered twenty years before at school.

The role of the labels

The visitor will often read the exhibit label only when they have finished or their attempt to figure out the exhibit fails. The majority of visitors said that the exhibit itself was explicit enough and that the information on the label was a bonus. Some adult visitors spent a fair amount of time reading the labels and discussing the science behind the exhibits. However, a striking observation was that visitors spent more time at the exhibit when they did not read the label. Bypassing the label seemed to correlate with play and exploration.

Social behaviour

When a pair or larger group of people visit an exhibit, often one person will read the instructions while the other "does" the exhibit. People seem to enjoy helping each other out and discussing the exhibits, and this seemed to encourage additional interaction with the exhibits.

A physical experience

When children see an exhibit they like, they often just throw to the ground whatever they are carrying and start to play with the exhibit. This shows why any electronic tools must be robust and also suggests a tendency to react non-verbally to the exhibits. Although adults are often more circumspect (they sometimes walk on the periphery of an exhibit before deciding whether to interact with it), they also seem to react spatial rather than verbally e.g. they refer to exhibits by location("that one over there") rather than by name or description.

4 The "Electronic Guidebook"

In parallel with the no-technology study, we deployed and tested a prototype "electronic guidebook". Our original goals were to discover how to add value for visitors by integrating electronic resources with the

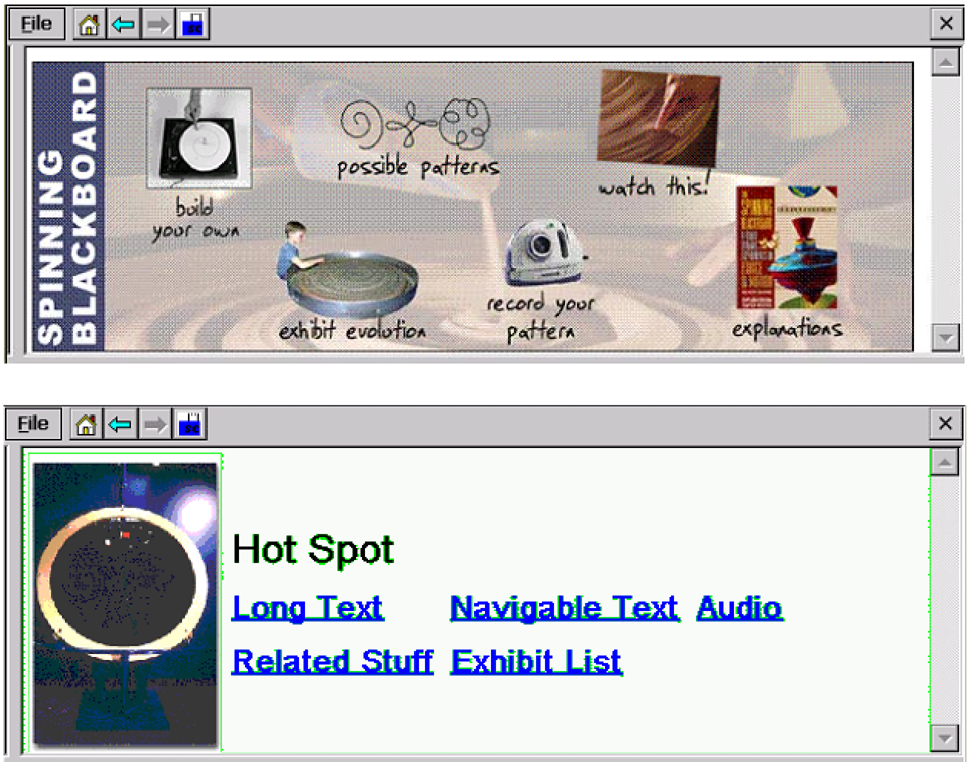

Fig. 1. Examples of content seen by a visitor in modified Web browser on Jornada 690.

physical exhibits, and, in particular, to test technologies developed by the Cooltown project for associating the exhibits with Web resources.

3.1 The prototype

Our guidebook prototype combined the functions of informing, suggesting and remembering (the latter because users sometimes jot marginal notes in conventional guidebooks). The three functions were to be delivered principally in the form of Web pages, accessed on PDA's while at the exhibits, and before and after the visit on any computer.

The guidebook prototype provides content about the exhibits to users as they visit them; it also provides them with a record in the form of a personal "scrapbook" on the Web, for perusal after the visit.

> *Supplementary exhibit content*. The guidebook delivers static Web pages to users' PDAs when they visit exhibits. Each exhibit has a "home page" which contains links to 4-16 pages containing information about the exhibit and the underlying phenomena; and suggestions about what to do with the exhibit. Figure 1 shows the home pages for two exhibits, one with detailed content developed by Exploratorium staff and one with more basic content. Visitors could also access the guidebook home page, which contains a list of exhibits and a map of exhibit locations.

> *A personal scrapbook*. The guidebook also lets users "bookmark" pages. This creates a "personal scrapbook" page, containing links to the selected pages, which can be accessed from anywhere on the web. (Users are assigned pseudonyms to protect privacy.)

Only six exhibits were used due to equipment limitations and the manhours required to develop content for each exhibit. Audio content was developed for several exhibits but it could not be heard without headphones because the Exploratorium is very noisy. We believe that headphones would inhibit social interactions.

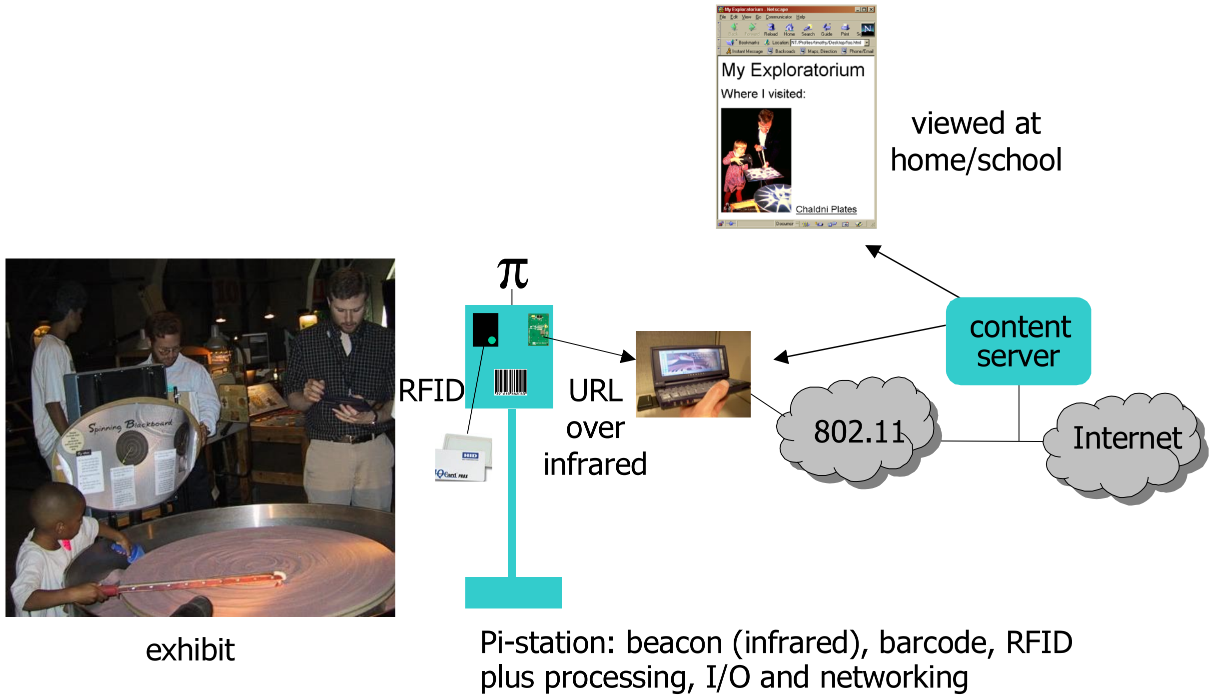

Fig. 2. System overview.

The prototype system (shown in Figure 2) consists of PDAs, pi-stations, and a content server, all connected by an IEEE 802.11 wireless network.

PDA's. Most of our tests used HP Jornada 690's, a clamshell with a colour screen about 6 inches by 2 inches and 640 by 240 pixels, and a keyboard. We also used a Hitachi ePlate--another Windows CE device, without a keyboard but with about twice as large a screen. Visitors interacted with a web browser simplified to have only four control buttons: “forward”, “back”, “home”, and “bookmark”. A stylus was used to press buttons and follow hyperlinks.

Pi-stations-”point of information stations” -at a selection of the exhibits. A pi-station is a conspicuous portable free-standing unit that can be configured for and placed next to any exhibit, housing identification technologies and sometimes cameras and placing them at a convenient height.

Content server. Exhibit content is static, served by a standard Apache web server. Personal information for each user (e.g. “scrapbook” entries) is managed by the Cooltown Web Presence Manager [5]. All requests from the PDAs are sent via a proxy which logs all activity, indexed by the user's pseudonym.

3.2 Physical hyperlinks

One of the key aspects of the design is the mechanism by which users obtain the home page of a given exhibit in front of them. We used the approach that is standard in our Cooltown research, in which the user picks up an identifier by pointing his handheld device at the physical object of interest. This may be implemented by attaching an identifier on or near the object and installing a sensor in the PDA. Alternatively, the identifier token can be given to the user and the sensor attached to the object.

Once the identifier has been picked up, it is converted to a URL (if it isn't one already) using a “resolution service” [10]. The URL is dereferenced and the resulting web resource (the “web presence” of the physical object) is rendered on the PDA's web browser. We call our identification technology “physical hyperlinks” because, from the user's point of view, the process is similar to clicking on a hyperlink in a web document; reading an identifier with a handheld sensor replaces clicking with a mouse.

Alternatively, users could be asked to find the exhibit's web page using conventional web navigation (e.g. a list of exhibits) or manually enter an exhibit number (as in audio guides). However, we believe that these methods would be more awkward for the user than the single, coarse-grained actions of reading a beacon or barcode. The Filoli guidebook [2] uses an interesting interface in which the PDA displays a view of each wall of the room, with artifacts laid out against the wall as the user would see them. The user selects the appropriate wall and clicks on the picture of the appropriate artifact. However, we believe such an interface is not suitable for the Exploratorium because its exhibits are hard to identify visually and its open-plan layout does not offer canonical 2D views.

Within the physical hyperlink paradigm, we wanted to experiment with different options for identification hardware. Therefore, we equipped the pi-stations with three types of identification technology: an infrared "beacon" [4], a barcode, and an RFID reader. URLs transmitted by beacons can be picked up using the infrared ports on our Jornada PDA's, within a cone of a few tens of degrees and up to about 2 meters away. The barcodes can be picked up by a laser scanner on the Hitachi ePlate; a resolution service converts them to URLs. Use of the RFID reader is explained in section 7. Several other types of identification technology exist [18].

In choosing an identification technology, a major issue is scaling up to large numbers of users and exhibits. Barcodes are much cheaper per exhibit than beacons. However, barcode readers for PDAs are still relatively expensive whereas most PDA's have integrated infrared receivers. RFID tags are closer to barcodes than beacons in price but RFID readers are relatively expensive and can be cumbersome (depending on their range).

5 Testing the Electronic Guidebook

We carried out several rounds of informal studies of users with the electronic guidebook, to get a general sense of how users reacted to it and uncover major usability and system issues.

5.1 The Experimental Set-up

To reflect the diversity of Exploratorium visitors, we recruited a variety of users, including users with and without prior computer experience, and users who had or had not visited the Exploratorium before. The 35 users consisted of:

- 16 adult female;
- 9 adult male;
- 8 children (aged 10-13; 1 female).

The adults ranged in age from about 25 to about 50. Twelve of the adults were teachers; most of the others came from backgrounds that involved museums and/or computers. Some users were in small groups (2-3) sharing a PDA, including two family groups each with two children. All users were fluent speakers of English with no major disabilities.

The majority of the tests were done under the Exploratorium's normal conditions: very noisy, with many people milling around. One subject used a Hitachi ePlate; the others used Jornada 690's.

The tests began with a brief demonstration of a pi-station and the workings of the PDA, including how to pick up a beacon (or barcode for the ePlate). They were then directed to the general area of the six instrumented exhibits (i.e. with a pi-station). The instrumented exhibits were in a reasonably well defined section of the Exploratorium, but interleaved with other exhibits. Orange flags were used to make pi stations conspicuous. The users interacted with the instrumented exhibits and sometimes other nearby exhibits.

Each user or small group of users with a PDA was shadowed by a project member, who observed the users' actions and reactions, and helped them recover from major problems. Semi-structured interviews were held afterwards. All web accesses from the PDA's were logged automatically.

5.2 The Findings

Our study yielded the following findings:

Overall positive response

Most users reacted positively to the electronic guidebook overall. Some appreciated the ability to obtain more information about the exhibits. Several tried the suggested exhibit activities and liked having more options than those on the exhibit labels. Several thought the ability to look back on "remembered" exhibits on the personal scrapbook would be useful-especially in the classroom. Overall, users found the prototype stimulating and made suggestions, for example about the ability to input comments into the pages.

Not enough hands

> "? (I have to) hold it and deal with it. (I) want to be free and explore."

> "I'm scared I'm gonna break it."

The PDA's tended to interfere with the hands-on activities at the exhibits. They are too big for a pocket and tended to swing awkwardly on a neck strap. There is nowhere obviously safe to put them down, so some users tried to manipulate the apparatus with one hand while holding the PDA with the other.

Demands on the user's attention

> "What's here is enough" [pointing to the exhibit]

Some of the teachers were keen to explore the content-particularly the suggestions-at the exhibits. But for many of the users overall, the information and suggestions were extraneous and the PDA represented an undesirable demand on their attention.

Lost in hyper-reality

The content for each exhibit contained hyperlinks to other, related exhibits. One user followed such a hyperlink without realizing that she had done so, and ended up trying to follow a suggestion intended for an exhibit which she was not at. Some of the children became more focused on the content (and the PDA itself) than the exhibit, reversing the behavior we saw without the PDA.

The "wow factor"

> "This is so cool! Can I keep it? How much does it cost?"

> "You can add GPS to track you way back and a mini CD to play music and games for kids!"

Part of the overall positive reaction was clearly due to the novelty of the hardware rather than the system's functionality. Controlling for this "wow factor" is a problem in testing most (all?) nomadic computing systems.

Beacons are OK, but...

Most users quickly grasped the notion of receiving a beacon via their PDA's infrared port to view the exhibit's pages and had little difficulty physically managing beacon reception. The one ePlate user with a barcode scanner also seemed to get along well, though this PDA proved uncomfortably heavy.

Users did occasionally pick up beacons accidently, triggering a disruptive change in the page displayed by the browser. The most common case involved accidently reading a beacon soon after reading it deliberately. Therefore, for repeated pickup of the same beacon, we modified our software to ignore the second pickup or query the user before changing pages, depending on the interval between the pickups. Requiring users to press a button when picking up a beacon might help, but our PDA's didn't have an ergonomically suitable button that users could find and press accurately.

Browser interface

Some users unfamiliar with PDA's had trouble manipulating the stylus to click on a hyperlink, e.g. some tried scratching on the link rather than tapping it. Brief hands-on training may be required for such users.

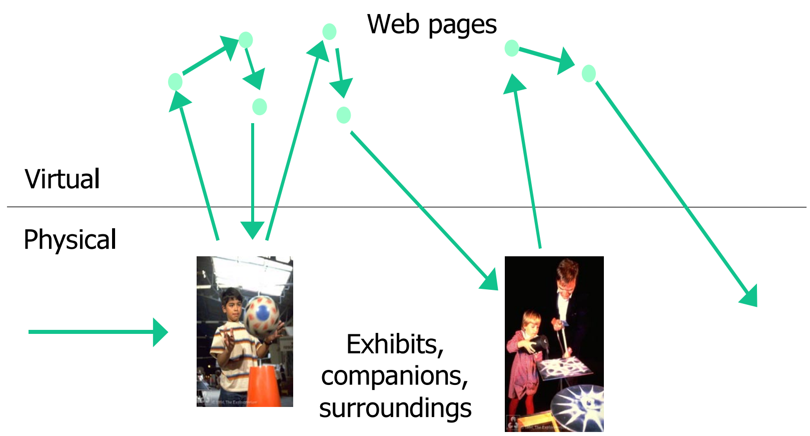

Fig. 3. Transitions of attention between the virtual and physical worlds.

Content design

The style of content varied across the exhibits. Most users correctly recognized underlined text as hyperlinks. However, in heavily graphical content, they seemed to have trouble guessing which items could be clicked on. Explicit marking (e.g. outlining) of graphical hyperlinks might help (cf. [2]), as would consistent content design.

Forgetting to remember

Despite statements of enthusiasm about the potential uses of the personal scrapbook, very few of the users pressed the button on their PDA to add pages to it.

6 Choosing a Tool

The studies of Exploratorium users without technological assistance (Section 3) and with it (Sections 4 and 5) led us to the following conclusions:

Cooltown physical hyperlinks are an effective mechanism for invoking services in a place such as the Exploratorium where navigation and identification are difficult, though some details (e.g. accidental beacon pickup) need improvement.

The hands-on nature of the Exploratorium made informing and suggesting more distracting than useful, except to those users who wanted to explore an already-familiar exhibit more deeply.

The PDA's are too large and fragile to be convenient for users who want to experiment with the exhibits, given the relative boisterousness of the environment.

The combination of several functions (Informer, Suggester and Remember) was too complex, e.g. users were too busy with the first two functionalities to use Rememberer.

We were thus led to design a simpler system, concentrating on one basic tool.

One option would be to implement a pure version of Informer or Suggester, but in a less obtrusive form factor. For example, content could be displayed on screens mounted on or near exhibits (though this might distract in a different way). Or simplified text content could be delivered using a small-screen wearable device.

However, we believe that the critical resource is the user's attention. Consulting the PDA requires the user to repeatedly shift attention between the virtual world of content and the physical world of the exhibit, the user's companions, and the surrounding environment (see Figure 3). The transitions require physical manipulation (e.g. removing the PDA from a belt clip or pouch), shifting visual attention and re-establishing visual context, and cognitive effort.

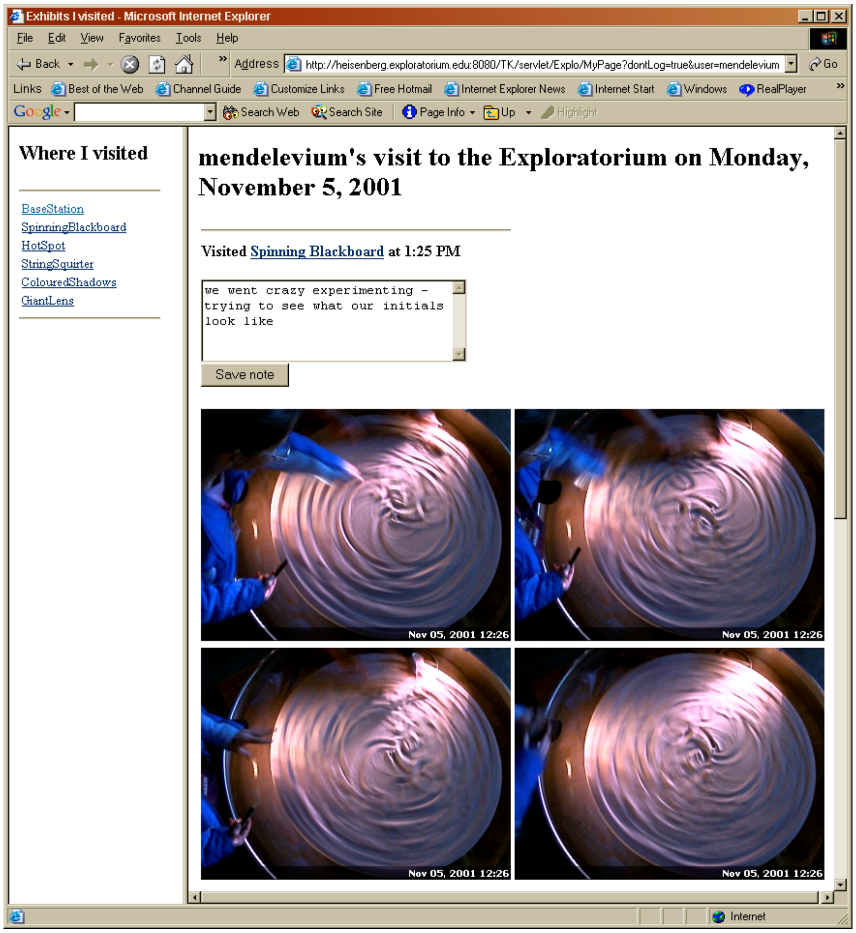

Fig. 4. A Rememberer page showing a user's visit to the "Spinning Blackboard" exhibit.

This analysis would suggest that physical/virtual transitions would be less distracting if they occur less often and/or between exhibits, when users would already be making a transition between different physical objects, a likely usage pattern for Guider and Communicator. Rememberer should dramatically reduce the number of transitions, because the user can maintain their attention on the physical world while visiting exhibits--except when taking actions necessary to record phenomena--and cross to the virtual world when consulting their recorded information at home or at an in-museum kiosk. We chose to concentrate on Rememberer for this reason and because our guidebook users expressed a strong interest in it.

7 On to Rememberer

Rememberer is a tool that helps the user create a personal record of their visit to the Exploratorium, primarily for access after their visit. It is intended to aid personal recall, stimulate discussions and other forms of social interaction, and support the user's research or classroom work. It consists of:

- a "remember-this" technology with which the user selects objects during their visit;
- the visit record, consisting of a set of web pages;
- a physical artifact that reminds the user of the visit and contains a pointer (URL) to the visit record.

Because the remember-this technology performs a very simple task, its handheld unit can be kept correspondingly simple and small. For our initial tests, we used RFID tags (some credit-card shaped and some mounted in watches). Bringing the tag within about 10 cm of the pi station's reader ("swiping") registers the exhibit under the user's pseudonym and causes an LED to light up briefly.

In addition to a list of exhibit names, in order visited, we included pointers to detailed content for each exhibit and a field for users to record comments. Moreover, to make the record more specific to the user's personal experiences of the exhibits, we also equipped the pi-stations with cameras. Figure 4 shows a page created at the “Spinning Blackboard” exhibit.

When the user swiped their ID card, four photographs were taken at 1-second intervals. The cameras were positioned to take a picture of users at the exhibit or (for one exhibit) a phenomenon that the user had created on the exhibit. The pictures were not displayed at the exhibit: users saw them only later when inspecting their visit records.

Before visiting the exhibits, users swipe their tag at a “basestation” to register themselves with the system and get a pseudonym. It also creates and displays the beginning of their visit record, including a picture of the user visiting the basestation. This gives users brief hands-on practice with the system and a mental picture of what artifact the system is generating during their visit.

For our initial tests, we observed and informally interviewed 14 adults, all but one employees or volunteers at the Exploratorium. 6 visited the exhibits alone and 8 were in groups of two to three. One group shared a tag but otherwise all users had their own tag. Users viewed their visit records at the end of the visit. A laptop was also available for viewing their record during the visit, but only some chose to use it; those who chose not to still swiped their tags at the exhibits.

Users reacted very positively to the system overall. They were especially stimulated by the photographs, even though the images were often blurred and of low resolution, and even though the users were not clear about exactly when the pictures would be taken (the only feedback was the RFID reader’s LED which lit at about the time of the first photograph in the sequence of four). Users almost always did swipe their tags at the exhibits, sometimes several times to capture particular phenomena. They did so casually but accurately, with no indication that this disturbed their engagement with the exhibit or their companions.

We gave the users the URLs of their pages and logged visits to their Web pages after they left. Most re-visited the pages, some several weeks after the event. Several of those saved comments within their pages, referring to the photographs. We prototyped personalised fridge magnets and postcards as artefacts that recorded the URLs of the users’ pages.

In summary, we have preliminary evidence that Rememberer has approximately the “right” amount of physical-virtual interaction to add value to a visit to the Exploratorium without distracting from the experience. We are currently doing more extensive studies.

8 Conclusion

The Exploratorium is an interesting environment for nomadic computing design because its physical environment already requires much of the user’s personal resources, e.g. eyes, hands, mental attention. A successful nomadic tool must, therefore, provide a valuable service while making only very small demands on these resources. Rememberer seems the right level of complexity; our initial electronic guidebook was too distracting (except for particular classes of users, such as teachers or explainers, who wanted to go beyond their familiarity with the exhibits).

Nomadic computing applications cover a wide range of environments. Electronic guidebooks have been shown [2][3][6][14] to work well in museums, historic buildings, and historic towns. These environments are often quieter, not hands-on, and/or more clearly organized than the Exploratorium. We expect our findings to generalize to environments which also place high demands on a user (e.g. shopping with children in tow).

Our studies also provide preliminary evidence that mere bookmarking of physical objects, together with basic photographic capability, may be sufficient to provide a valuable service to nomadic users. We are currently running more experiments to investigate this hypothesis.

Finally, this study illustrates the value of incorporating prototype deployment and user testing in the early stages of developing a nomadic computing tool, despite the substantial investment of time required to do so. Demos inside HP labs gave us little preparation for the conditions we found inside the Exploratorium. For our specific application, the change in environments led to a radical change in tool design.

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