LIVEBOARD: A LARGE INTERACTIVE DISPLAY SUPPORTING GROUP MEETINGS, PRESENTATIONS AND REMOTE COLLABORATION

Scott Elrod, Richard Bruce, Rich Gold, David Goldberg, Frank Halasz, William Janssen, David Lee, Kim McCall, Elin Pedersen, Ken Pier, John Tang and Brent Welch*

Xerox Palo Alto Research Center
3333 Coyote Hill Road
Palo Alto, CA 94304
elrod@parc.xerox.com, (415)812-4224

ABSTRACT

This paper describes the Liveboard, a large interactive display system. With nearly one million pixels and an accurate, multi-state, cordless pen, the Liveboard provides a basis for research on user interfaces for group meetings, presentations and remote collaboration. We describe the underlying hardware and software of the Liveboard, along with several software applications that have been developed. In describing the system, we point out the design rationale that was used to make various choices. We present the results of an informal survey of Liveboard users, and describe some of the improvements that have been made in response to user feedback. We conclude with several general observations about the use of large public interactive displays.

KEYWORDS: interactive display, large-area display, cordless stylus, collaboration, group work, gestural interface.

INTRODUCTION

An integral part of most meetings is a central display or drawing surface which serves as a medium for presenting and capturing ideas. Examples include slides and viewgraphs projected onto a screen, whiteboards and flip-charts.

Recent work on computer-supported meeting environments [6,4,2] has recognized the importance of a central display surface. Meeting rooms such as Colab [6], Capture Lab [4] and Project Nick [2] all utilize one or more large displays as a major focus of the group work. For the most part, however, these displays function primarily to present information. Drawing and recording ideas is usually accomplished with a keyboard and a mouse at a workstation adjacent to the large display. Although this configuration supports the interactive presentation and discussion of ideas, it still lacks the dynamic, direct interactivity of a whiteboard or flip-chart.

Recent work has explored the use of more directly interactive display surfaces. For example, VideoWhiteboard[7] used audio-video links to create a large-area interactive drawing surface that could be shared between remote locations. Commune [5] examined the use of a stylus-based computational sketchpad to support shared drawing at a distance. Although the drawing surfaces in these systems are more directly interactive, the technologies are not suitable as the central display in a fully networked computer-supported meeting room.

The Liveboard system described in this paper is an attempt to build a directly interactive, stylus-based, large-area display for use in computer-supported meetings. While still falling short of the ultimate wall-sized, flat-panel, high-resolution display, prototype Liveboards have enabled us to begin to develop and evaluate user interfaces for group meetings, presentations and remote collaboration.

The Liveboard project fits into the broader scheme of ubiquitous computing for the workplace of the future [9]. Liveboards complement other personal computing devices (i.e. office workstations and portable sketchpads) by providing a shared workspace around which groups can collaborate.

*Current address of John Tang is: Sun Microsystems Laboratories, Inc, 2550 Garcia Avenue, Mountain View, CA 94043, Tang@eng.sun.com, (415) 336-1636.

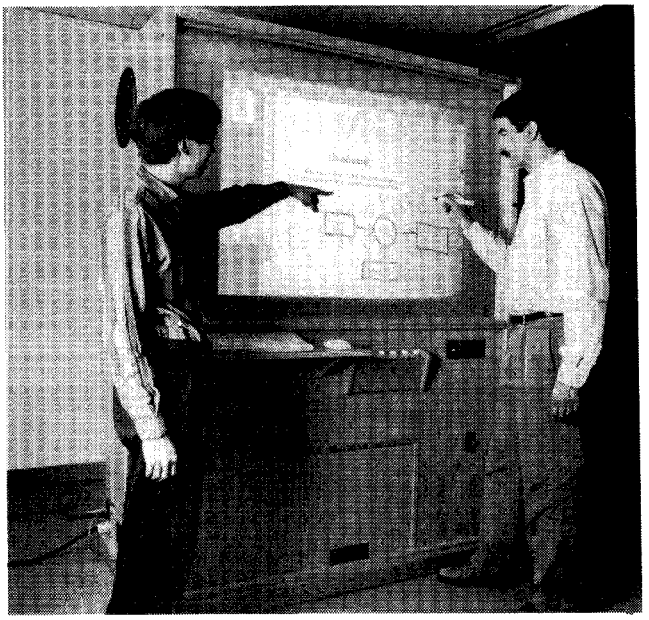

Figure 1: The Liveboard in use.

As can be seen in Fig. 1, the current Liveboard is a large display housed in a wooden cabinet. The display surface (46 x 32 inches) is approximately the size of an office whiteboard and has nearly 1 million pixels. Two features of the system allow the display to be viewed comfortably at very close distances. First, the Liveboard image is projected from a digitally addressed liquid crystal display. As a result, the image does not exhibit any of the jittering and wavering often found in CRT-based projection systems. Second, the Liveboard incorporates a rear-projection screen which widely disperses the image and can be easily seen at oblique angles. The result is a crisp, stable image which can be viewed comfortably by a group of people standing around the Liveboard.

The Liveboard incorporates an accurate cordless pen, a feature which is particularly important for group meetings. Allowing participants to interact directly with the display provides a natural point of focus for meetings. By contrast, it is difficult to maintain the focus of a meeting when interaction with the central display is mediated by an adjacent keyboard. In addition, the cordless pen is easy to pass among participants. For these reasons, the pen is a particularly appropriate technology for group interaction around a large display surface.

The pen has four distinct states which are controlled by buttons on its body, and by a pressure-sensitive tip switch. Under software control, these states are used for drawing, to pop up menus, or to provide other means of input control.

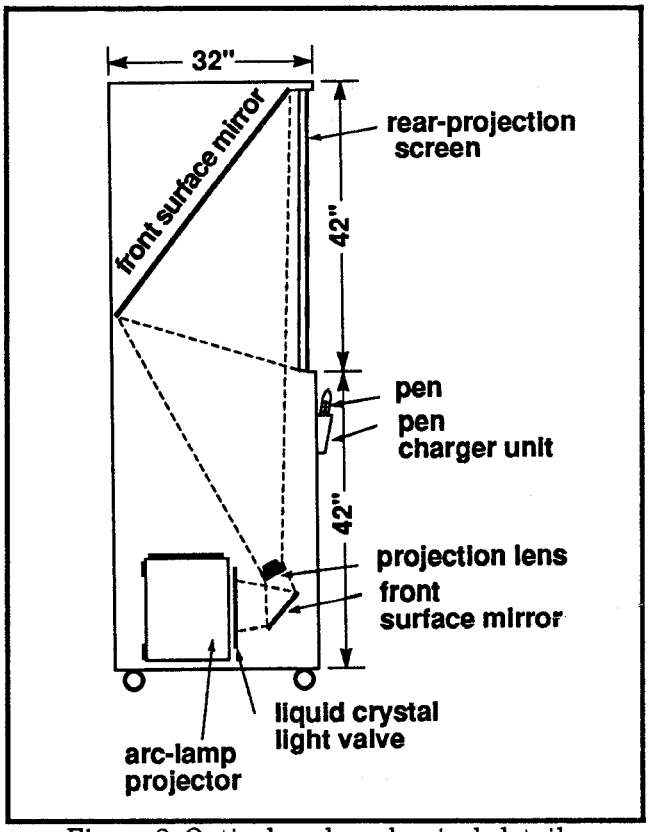

Figure 2: Optical and mechanical details.

The Liveboard is controlled by a high-performance workstation (Sun SPARCstation-2) and can run a large collection of UNIX-based software. Liveboards are fully networked, and can be used in a shared mode between remote locations.

SYSTEM HARDWARE: Display

The Liveboard image is produced by projecting a liquid crystal display (LCD) onto a rear-projection screen, as shown in the side view of Fig 2. The LCD's 1120 x 780 monochrome pixels are magnified to give an image that measures 46 x 32 inches and has a resolution of 25 lines per inch. The Liveboard optics can accommodate projected images with resolutions up to 50 lines per inch. In order to minimize the depth of the cabinet, the optical path is folded twice, as shown in Fig. 2. We found it necessary to exclusively use front surface mirrors in order to eliminate secondary reflection images. In order to make the image sufficiently bright, we chose a 600W arc-lamp overhead projector for the light source. This results in images which are bright enough (25-50 foot-lamberts) for use in a typical office or conference room.

Cordless Pen

The design of the Liveboard pens was driven by several requirements. They were to be cordless for ease of use and especially to avoid tangling when several pens were used simultaneously. They were to provide input at some distance from the board to allow for remote pointing and gestural input. Also, they were to provide the functionality of a three-button mouse so that they could be used with existing software. Human factors considerations dictated that the pens be as small and light as possible, and that the batteries be placed so that the weight was properly balanced.

Shown in Fig. 3 are functional details of the Liveboard pen. The pen emits a beam of optical radiation which is imaged onto a detector module located behind the screen near the LCD. After

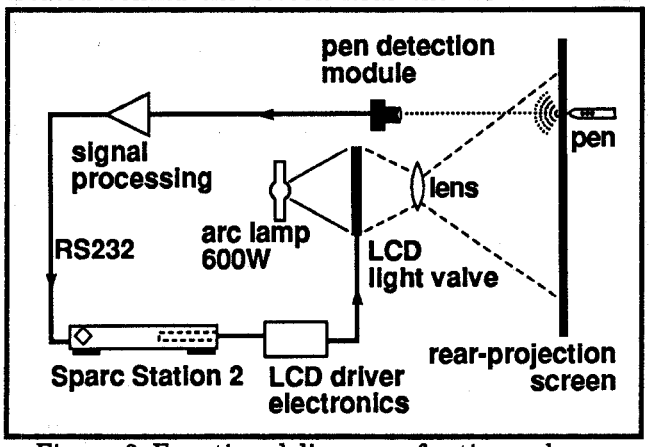

Figure 3: Functional diagram of optics and pen.

some signal-processing, the digitized pen position readings are sent through a serial port to the computer. The pen is capable of a marking accuracy of better than 1 mm, and produces 90 X-Y coordinate pairs per second.

Circuitry inside the pen allows for operation in four distinct states, one for cursor tracking and three that are controlled by the buttons on the body of the pen and by the pressure-sensitive tip switch. The front, middle and rear buttons on the pen body are configured to emulate the left, middle and right buttons of the standard mouse. The tip switch is redundantly mapped to the left mouse button.

In Fig. 4, a person is using the pen to pop up a menu by touching the tip to the screen. The pen can be used at distances of up to several feet from the screen, as can be seen in Fig. 5, where the user has depressed the front button to pop up a menu. The pen has rechargeable batteries, and charging

Figure 4: Popping up a menu by pressing the pen tip against the screen.

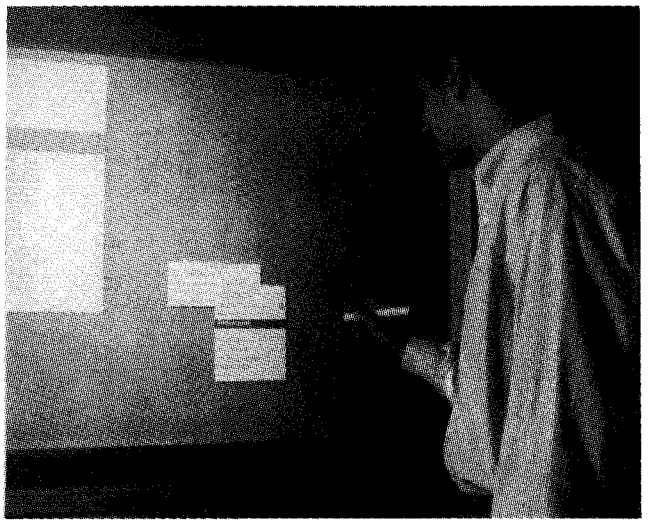

Figure 5: Operating the pen remotely to pop up a menu.

sockets are provided on the front of the Liveboard cabinet.

SYSTEM SOFTWARE: Pen Device Driver

In order to give the pen the widest possible applicability, we developed a custom software device driver. The driver serves to map readings from the pen detection electronics to genuine X-Y screen coordinates, and packages them in a form that can be readily integrated with window systems. With this device driver, the pen can be used as the pointing device in X windows (MIT X11R4 or XNeWS) or in SunView.

Walk-Up User Interface

The Liveboard is intended to be an information appliance with wide usage, rather than merely a large computer display. As such, it requires an

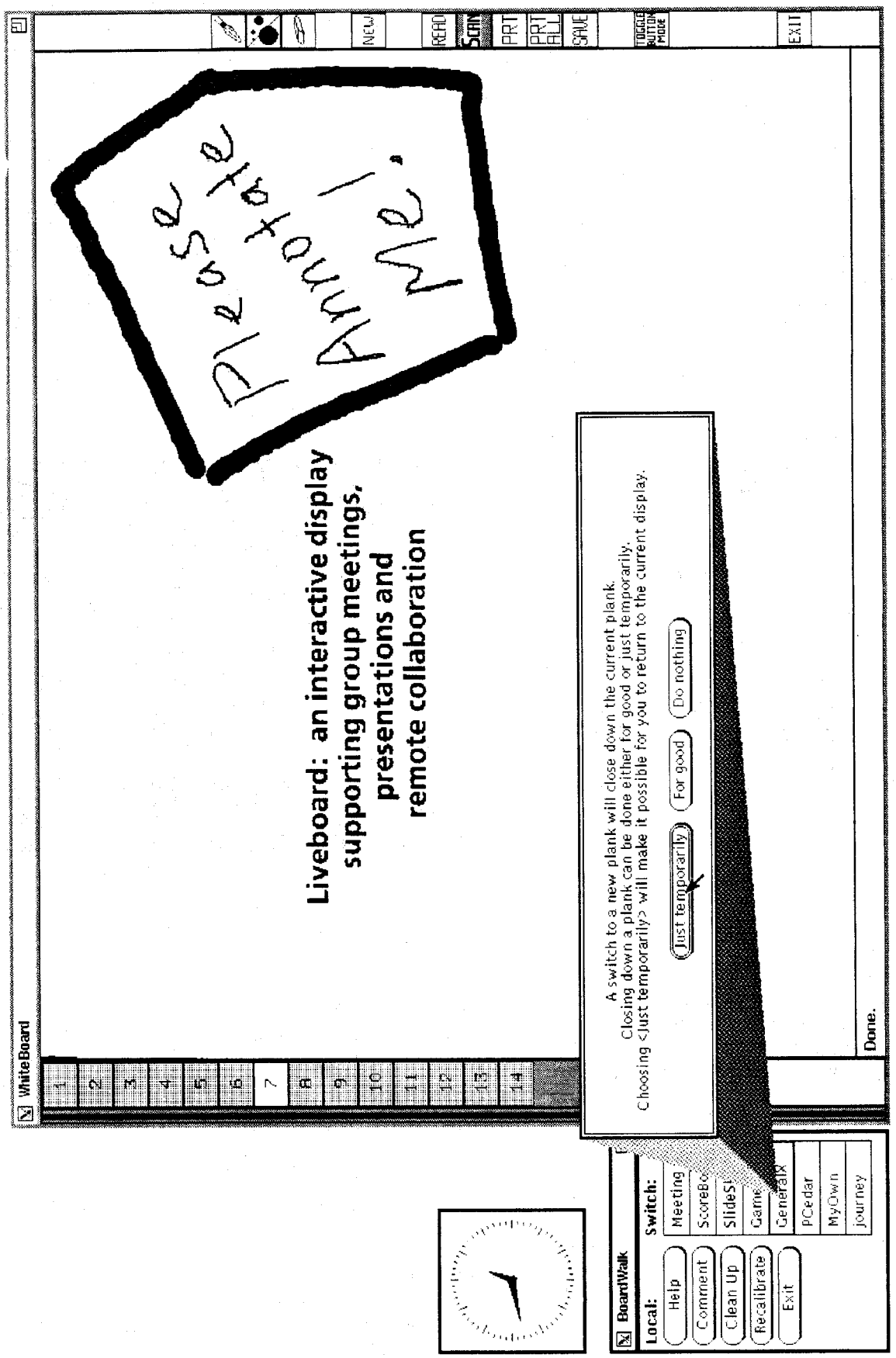

Fig. 6: The Whiteboard application, with a pre-loaded document and annotations made using the pen. The user has just initiated a change to another plank.

interface which the average meeting participant can use without knowing the intricacies of UNIX. Our solution to this requirement is a custom *walk-up* interface called the *BoardWalk*.

BoardWalk is implemented as a simple extension of the TWM window manager. It makes use of the basic mechanisms of the window manager, but hides the details with a layer of tailored environments, called *planks*. We chose not to use the well-known Rooms system [3] for this purpose because we believed that it was too powerful for novice users.

The BoardWalk control panel is shown in the lower left corner of Fig. 6. The control panel contains a list of planks that the user can choose among. The standard planks are:

1) *Meeting*--meeting tools, including a Whiteboard application, a text editor and a clock.
2) *Scoreboard*--a dynamic electronic bulletin board (under development [8].)
3) *SlideShow*--an application for versatile display of prepared slides.
4) *Games* ---what to do when the boss is away.
5) *General X*--a plain and unrestricted X/Unix environment.
5) *PCedar*--for applications written in PARC's PCedar [1] programming environment.

Choosing a plank automatically opens a set of applications. A dialogue box, shown in Fig. 6, asks whether the user wants to leave the current plank *for good*, or only *temporarily*. When the user logs in as *liveboard*, the Meeting plank comes up as the default environment.

In addition to the planks, there are utility functions like *Help*, *Comment*, *Clean up*, *Recalibrate* and *Exit*.

SOFTWARE APPLICATIONS: Whiteboard

One of the uses imagined for the Liveboard is as a meeting support tool, at which people can write down ideas and retrieve documents. Shown in Fig. 6 is *Whiteboard*, an application designed to support this use. The application provides whiteboard-like functionality, with an added flip-chart capability to handle multiple *sheets* that can be printed or saved for later use.

Whiteboard is a simple X11-based bitmap painting program. Features include a variable brush size and an eraser that can wipe out pixels. New sheets can be readily created by touching an icon with the pen. All sheets are remembered, and any sheet can be easily recalled. The sheets can be printed, or can be stored in a file and retrieved at a later time.

The Whiteboard program has been used both for taking notes at informal meetings, and for presentations. For meetings, two important features differentiate the Whiteboard program from conventional copy-boards. First, the meeting record can be stored and subsequently retrieved on any Liveboard. Having such a record has been found to be very useful in returning the collective attention of work groups to previous discussions. The Whiteboard has multiple sheets that can be rapidly switched, providing almost unlimited drawing space.

For presentations, people usually pre-load the Whiteboard with text or scanned images. With the Whiteboard, material is much more available than with conventional slides. One can circle important concepts while they are being discussed, draw connections between related ideas, and illustrate ideas as they are being explained. The final annotated version of the slides can be printed.

SlideShow

Another BoardWalk plank is for the SlideShow presentation tool, which combines the features of a slide projector and an overhead transparency projector. SlideShow presents a multi-page image file, encoded in a page description language such as PostScript, as a set of slides. The presenter, standing a few feet from the Liveboard, gestures with the pen at the SlideShow window. A sweeping gesture to the right is used to bring up the next slide, while vertical gestures are used for direct-manipulation scrolling. SlideShow also provides random access to slides via a gauge at the top of the window. Buttons can be tapped with the pen to adjust the scale of the displayed images. In Fig. 7, the user has chosen the *Fill* option (i.e. fill the SlideShow window) for the current slide, and has just gestured with the pen to bring up the next slide.

SlideShow uses a display graphics package with device-independent imaging, so scrolling, scaling and filling the screen are easily accomplished. Unlike conventional slides or overhead transparencies, each SlideShow slide may be individually scrolled and scaled for optimum viewing, or a common viewing transformation may be applied to all slides in a set. Finally, the presenter may use the pen to write directly on the slides.

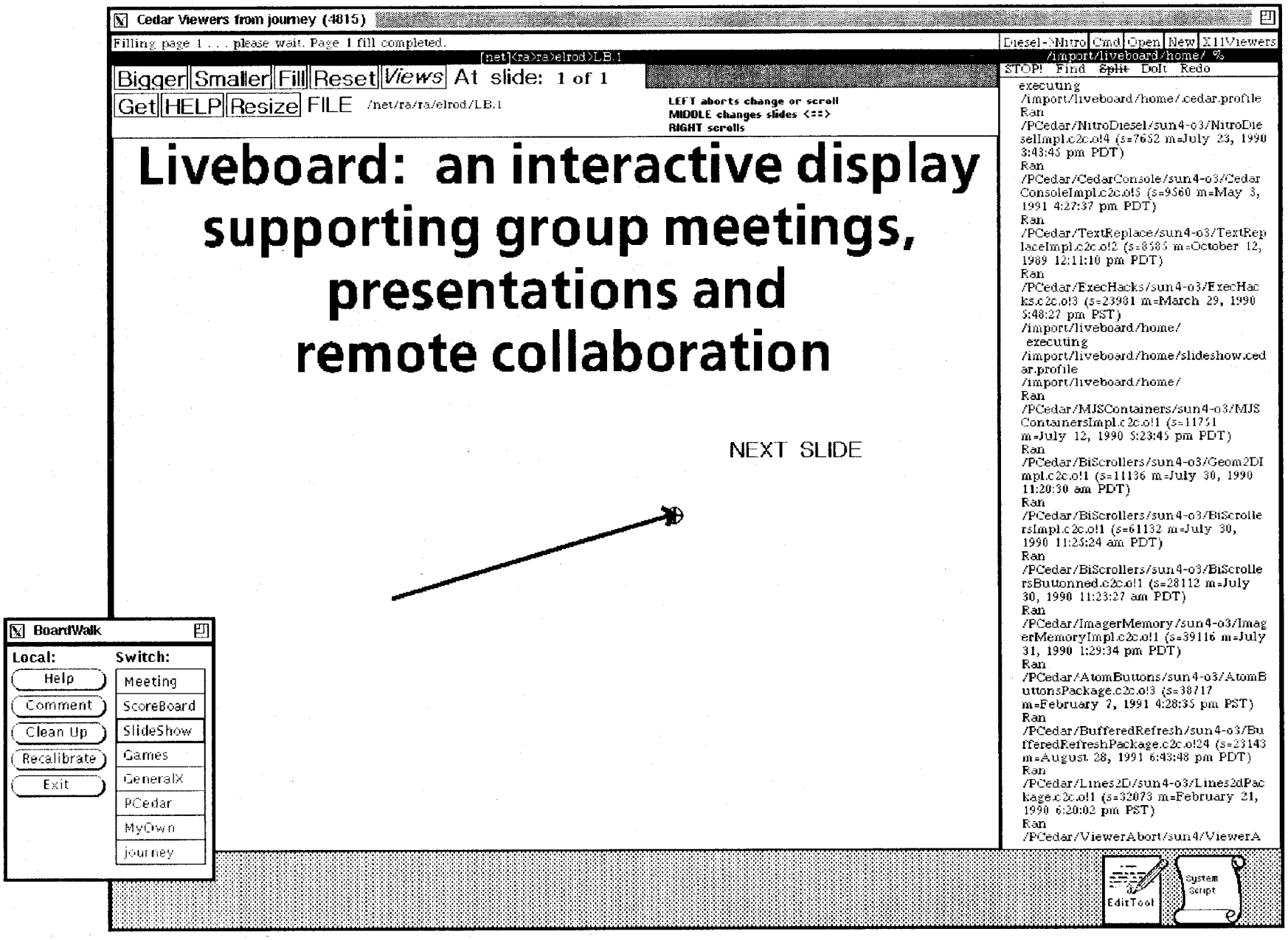

Fig. 7: The SlideShow presentation tool. The user has just made a sweeping gesture to the right to bring up the next slide.

SlideShow is motivated by the observation that default font sizes displayed on the Liveboard are generally too small to be easily viewed in meeting rooms. In addition, most editors do not provide bidirectional scrolling or scaling for presentation purposes. The SlideShow user interface is deliberately simple in an attempt to make it immediately available to novice users. After a few tries, people generally remember and use the gestures naturally.

LIVEBOARD USE: Informal Survey Results

Of the twelve prototype Liveboards that have been built, ten have been placed in conference rooms and open areas within PARC, while two have been sent to Xerox facilities overseas. During the year since they were installed, Liveboards have been used by diverse people for wide-ranging purposes: hardware researchers for meeting facilitation, managers for presentations, designers for remote collaboration, authors for collaborative writing of papers, and software developers for code reviews.

In order to better understand the situations in which Liveboards have been used, we conducted an informal survey of the PARC community. The survey consisted of an e-mail questionnaire sent out to everyone at PARC (250 researchers, managers and support personnel). The 60 respondents were self-selected, and while the survey was not conducted in a scientific manner, we believe that it raises important issues about the design of large, public, interactive display systems.

Table I summarizes the results of the survey. Perhaps most striking is the fact that while most respondents have used the Liveboard at least once, a significant number of those who have used it (34%) do not know how to turn it on. (This is despite the prominent display of an "ON" button on the front panel.) Users have reported general feelings of discomfort at the idea of walking up and just trying things. Some are intimidated by the size of the Liveboard, while others express fear of making a mistake and damaging it. Still others feel limited by their lack of UNIX knowledge.

Not surprisingly, the Liveboard is most often used for meeting facilitation (50% of respondents.) Of the different software applications that can be run on the Liveboard, the Whiteboard meeting tool is the oldest and most well publicized in the PARC community. In fact, it has had the favored status of being the default tool that comes up whenever the BoardWalk is started. Other common uses are casual drawing and explaining ideas to others.

Total number of respondents who:	Yes	No
1) know how to turn it on	32	16
2) have ever used one	46	3

Purposes for which respondents have used a Liveboard:	%Yes
1) in a meeting	50%
2) to randomly walk up and draw	48%
3) to show something to a friend	36%
4) to explain an idea	30%
5) in a presentation	26%
6) to write or look at code	18%
7) to write a paper	8%
8) to write a paper collaboratively	8%
9) for remote communication	8%

Items needing improvement, ordered from most to least as indicated by respondents:
1) image quality
2) accuracy of pen
3) size of cabinet
4) feel of pen
5) shape of cabinet
6) color of image (i.e. add color)
7) add printer
8) add scanner

Table I: Results of informal survey taken one year after Liveboards were installed. (60 respondents)

Above all else, people would like to have better image quality on the Liveboard. While the number of pixels is high (1 million), there are still perceptible jaggies that degrade the appearance of handwriting. Next in importance to users is the accuracy of the pen. People are troubled by positional inaccuracies of the pen that can result from optical parallax in the screen and from long-term drift in the detection electronics. People are also concerned about the way the pen feels. They

are concerned both about its size and shape, but also about having a tip which feels "right" as it moves across the screen surface (i.e. uniform friction of the proper amount.)

RESPONSE TO SURVEY FEEDBACK

We have begun to take steps to address the concerns raised by Liveboard users. First, we have attempted to reduce the barrier that users feel in getting started at the Liveboard. The PARC security staff now turns on all Liveboards before people arrive at work in the morning. A software script has been implemented which automatically starts up the BoardWalk whenever the Liveboard is rebooted. The script includes a loop which automatically restores the machine to the Meeting plank of the BoardWalk whenever the Liveboard is not being actively used. The result is that the Liveboards are more reliably in a state of readiness, where they look like a clean whiteboard.

Steps have also been taken to reduce the parallax of the Liveboard pen, and to improve the feel of the pen tip on the surface of the screen. In addition, a simple four-point pen recalibration has been implemented which allows users to correct for long-term drift in pen accuracy.

GENERAL OBSERVATIONS: Input to a Large Screen

Only by observing the Liveboards in use have we realized the extent to which stylus input on a large screen is different from a mouse at a workstation. Before building the current Liveboard pen, we constructed several prototypes in an effort to understand the optimal size, shape and placement of buttons. Despite these efforts, we have observed that while people readily use the pen for drawing, they find the buttons awkward and tend to avoid using them.

Clearly, a usable multi-state stylus will require semantics that are more intuitive than the current Liveboard pen. On the other hand, our early experience suggests that with more carefully designed user interfaces, most functions could be implemented using only two states (i.e. tracking and screen contact.)

Another important difference between the pen and a mouse is that the act of putting the pen down frequently causes the cursor to move across the screen. This makes it difficult for the user to define an input focus and then move to the keyboard. We have partially alleviated this problem by using a click-to-type mode in our window manager. A more satisfactory solution might be to separate the tracking feedback and focus point functions that are commonly combined in mouse-based software. The tracking cursor would still follow the pen, but explicit action would be required to specify a new focus point.

The fact that the Liveboard pen is cordless, operates from a distance and interacts directly with the screen allows for types of input that make no sense with a mouse. As an example, we have found ways to use natural gestures (i.e. sweeping motions up or down) to accomplish various functions in a slide presentation (i.e scrolling).

Large Interactive Displays vs Workstations

Unlike workstations, Liveboards are frequently used by a group, often with one person standing at the screen and a larger number of people seated in the room. For the person working at the Liveboard screen, the user interfaces of most workstations and notebook computers are inadequate. The Liveboard is large enough that fixed buttons can be difficult to locate, and awkward to reach. We believe that either gestural input, or some type of floating or movable menus or buttons will be required for such large screens. For those people seated in the room, the default font size is often too small for comfortable viewing. Arbitrary scaling and scrolling will be needed to accommodate groups of different sizes.

While users may tolerate the intricacies of UNIX in the privacy of their offices, we have found that in group settings, people are much less willing to take the time to solve software mysteries. Typically, they will give up on using the Liveboard, and revert to a conventional whiteboard if they encounter problems with the software. To be accepted in group settings, systems like the Liveboard must have robust, easy-to-use software.

On the other hand, one of the virtues of Liveboards is that they are fully networked and, like workstations, can draw on a rich and complex set of applications and document formats. Finding the compromise between these two requirements (having both ease of use and the full power of networked workstations) will be central focus of much of our future work.

ACKNOWLEDGEMENTS

Many people have made valuable contributions to the Liveboard project. On the hardware side, we would like to thank R. Bell, T. Fisli, J. Gasbarro, W.

Jackson, E. Richley, G. Sander, D. Steinmetz and F. Vest. For their software contributions, we are indebted to N. Adams, R. Allen, P. Dourish, D. MacDonald, D. Nichols, M. Theimer, M. Toho and P. Wellner. For their contributions to early use studies, we are grateful to S. Bly, S. Harrison, S. Irwin and S. Minneman. Finally, we would like to thank a number of others for their creative suggestions and support of the project: R. Bauer, R. Beach, E. Bier, D. Bobrow, W. Buxton, R. Flegal, R. Gold, A. Henderson, C. Kent, S. Kojima, M. Krueger, J. Mackinlay, C. Marshall, M. Molloy, T. Moran, G. Robertson, Z. Smith, M. Stefik, and M. Weiser.

REFERENCES

1. Atkinson, R., Demers, A., Hauser, C., Jacobi, C., Kessler, P., and Weiser, M., Experiences creating a portable Cedar. In Proceedings of the 1989 ACM SIGPLAN Conference on Programming Language Design and Implementation, Portland, OR (June 1989), SIGPLAN Notices 24, 7 (July 1989), 322-329.

2. Cook, P., Ellis, C., Graf, M., Rein, G., and Smith, T. Project Nick: Meetings Augmentation and Analysis. ACM Transactions on Office Information Systems 5, 2 (April 1987), 132-146.

3. Henderson, D. A. Jr., and Card, S. K. Rooms: The Use of Multiple Virtual Workspaces to Reduce Space Contention in a Window-Based Graphical User Interface. ACM Trans. on Graphics, 5, 3 (July 1986) 211-243.

4. Mantei, M., Capturing the Capture Lab Concepts: A Case Study in the Design of Computer Supported Meeting Environments. Proceedings of the Conference on Computer-Supported Cooperative Work (Portland, OR, September 1988), 257-270.

5. Minneman, S. L., and Bly, S. A. Managing a trois: a study of a multi-user drawing tool in distributed design work. Proceedings of the Conference on Computer Human Interaction (CHI), New Orleans, LA (April 1991), 217-224.

6. Stefik, M., Foster, G., Bobrow, D., Kahn, K., Lanning, S., and Suchman, L. Beyond the chalkboard: Computer support for collaboration and problem solving in meetings. Communications of the ACM 30, 1 (Jan. 1987), 32-47.

7. Tang, J. C., and Minneman, S. L. VideoWhiteboard: Video Shadows to Support Remote Collaboration. Proceedings of the Conference on Computer Human Interaction (CHI), New Orleans, LA (April 1991), 315-322.

8. Theimer, M., and Nichols, D. Private Communication.

9. Weiser, M. The Computer for the 21st Century. Sci. Amer. 265, 3 (Sept. 1991), 94-104.