Integrating Physical and Digital Interactions

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Integrated user interfaces enable richer forms of collaboration.

Today, physical and electronic media coexist like ships passing in the night: proximate but unaware of each other. Contemporary design studios, offices, and labs are filled with both physical and electronic artifacts, but the two exist separately, and the infrastructure for moving between media representations—scanning and printing—is heavyweight and cumbersome, at odds with the freewheeling, organic nature of creative work.

For the past six years at UC Berkeley and Stanford University, my colleagues and I have conducted research into user interfaces that bind physical and electronic representations of artifacts for integrated interaction: Manipulation in one medium effects a corresponding change in the artifact's dual medium. Based on fieldwork with designers, office workers, scientists, and engineers, we've created and evaluated integrated interfaces ranging from whiteboards to oral history transcripts to field notebooks.

DESIGNERS' OUTPOST

We initially became interested in integrated interaction techniques while studying Web site designers. Mark Newman, James Landay, and I learned that, even in this high-tech industry, users preferred working with sticky notes and marking on walls and whiteboards in a project's early design stages. This observation led us to create the Designers' Outpost (http://hci.stanford.edu/research/outpost).

Interactive whiteboard

With this system, shown in Figure 1, users collaboratively author Web site architectures on a touch-sensitive electronic whiteboard augmented with cameras that capture documents placed on the wall. Designers create new pages by writing with standard pens on sticky notes and organize a Web site by physically moving the notes around on the board.

The Designers' Outpost vision system uses two cameras to provide interactive feedback and near-interactive capture. A 640 × 480 pixel firewire video camera mounted inside the whiteboard offers interactive rate tracking of physical objects placed on the board. A high-resolution digital still camera captures the objects' contents, albeit at a lower frame rate—one frame every few seconds.

Users can link notes by drawing a line with an electronic stylus as well as add ink annotations to a design to convey design rationale. Electronic capture enables replacing physical documents with their electronic images. Users have the same capabilities when content is electronic as when it's physical, thereby retaining physical direct manipulation.

The main timeline is a visually navigable time-ordered set of design thumbnails. The thumbnails aren't just a visualization of the changes in the board—they're also a direct manipulation interface: Users can touch a thumbnail to return the board to the corresponding state.

Dual media representations

With Designers' Outpost, users interact with physical and electronic media in a georeferenced manner—the two representations occupy the same physical space and appear to overlay each another. Users can perform operations on physical objects by tapping on them to invoke an electronic menu.

Documents that are physical in one space are electronic in the other space and vice versa. Thus, a user can place a document on a wall in San Francisco, and colleagues in Seattle can synchronously see the electronic dual of that document. This interface retains the wall-size scale and physicality of the design process, extending it with advantages that electronic capture provides: fluid movement between design tools, design versioning and history, and remote collaboration.

Papier-Mâché toolkit

Developing vision-based interfaces for the Designers' Outpost was difficult and time-consuming, and it required a detailed understanding of the underly-

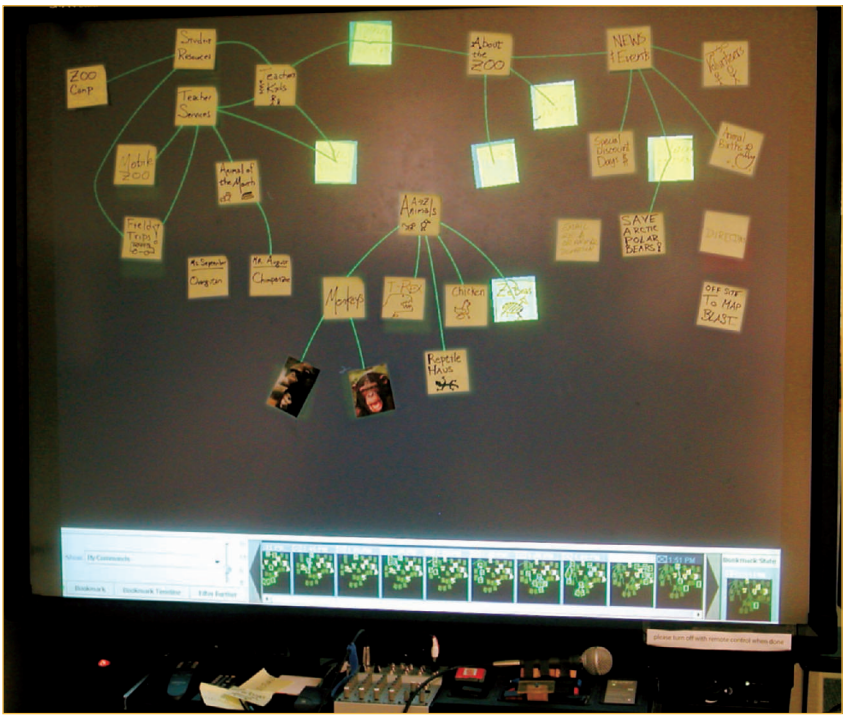

Figure 1. Designers' Outpost system. Users collaboratively author Web site architectures on a touch-sensitive electronic whiteboard augmented with cameras that capture documents placed on the wall.

ing technologies and algorithms. This realization inspired us to create the Papier-Mâché toolkit, which introduced a software architecture for acquiring and abstracting physical input (http://hci.stanford.edu/research/papiermache).

Calm user experience

During the project's three years, iterative evaluation of the Designer's Outpost by 27 professional designers demonstrated substantial merit in a system that is simultaneously tangible and virtual. The integrated interactions that designers found most valuable were

- the fluid transition from artifacts on walls to single-user tools for fleshing out design details;
- lightweight support for design history; and
- richer distributed collaboration.

The evaluations also consistently underscored the importance of a calm user experience. Today's desktop interfaces are largely designed to occupy the user's entire attention. Our experiences show that, as we enter the age of ubiquitous computing, the most successful technologies honor the calm interactions their analog-only predecessors afforded.

BOOKS WITH VOICES

After three years working on the Designers' Outpost, I was curious to explore another domain. Long fascinated by documentary work, I began looking at technology support options for oral history. Through UC Berkeley's Regional Oral History Office (http://bancroft.berkeley.edu/ROHO), the second-oldest and one of the largest oral history offices in the country, I attended a training workshop and conducted two oral history interviews with David Patterson and Carlo Sequin.

Our contextual inquiry into oral historians' practices unearthed a curious incongruity. While oral historians consider interview recordings a central historical artifact, they prefer using the written transcripts of these recordings. We hypothesized that this was because paper books have a superior "interface": Users can read, skim, highlight, photocopy, and share them with far greater ease than audio tapes or MP3 files.

This insight inspired me and my colleagues at Ricoh Innovations to create Books with Voices, which provides barcode-augmented paper transcripts for fast, random access to digital video interviews on a PDA (http://hci.stanford.edu/research/oral-history). In one study, oral historians found that this lightweight, structured access to video recordings offered a level of emotion not available in printed transcripts alone. The video also helped observers clarify the text and observe nonverbal cues.

BUTTERFLYNET

When I arrived at Stanford in 2004, Andreas Paepcke and Hector Garcia-Molina asked me if I would like to collaborate with the university's InfoLab (http://www-db.stanford.edu) on the National Science Foundation-funded BioACT! project (http://www-db.stanford.edu/bioact).

Ron Yeh and I conducted structured interviews with field biologists, which revealed the field notebook to be their research's central organizing artifact. These notebooks contain everything important: narrative writing, tabular data, photographs, pasted-in experimental results, photocopied pages from colleagues' notebooks, even plant specimens. The contents are so valuable that participants would only let us photograph pages from their notebooks in their presence.

Field notebooks are robust, easy to browse, readable outdoors, and easily portable. Electronic tools offer a different set of equally powerful benefits: dynamic organization, textual search, remote sharing, and easy backup. To explore integration of these benefits, we developed ButterflyNet (http://hci.stanford.edu/research/biology).

Electronic field notebook

Field biologists input data in the ButterflyNet system with an Anoto pen that converts their handwriting into digital images. These pens are an order of magnitude cheaper than tablet PCs and offer an order of magnitude greater battery life. Another advantage is that the system reverts to traditional pen and paper when the Anoto pen's battery runs out.

ButterflyNet integrates field researchers' notes with other digital information that they explicitly capture as well as environmental data such as digital camera photographs, sensor network data, and Global Positioning System data. The system timestamps and correlates this heterogeneous field data and then presents it through the browser shown in Figure 2, enabling biologists to "leaf through" their notes along with related media and other contextual information.

Chunyuan Liao and François Guimbretière at the University of Maryland, College Park, collaborated with my group to create pen gesture techniques for users to explicitly designate relationships between notes and photographs.

Just as the Designers' Outpost transfers data from walls to personal design tools for later refinement, ButterflyNet transfers notebook contents to spreadsheets for data processing. It also automatically maintains the data's lineage back to its original form, a key benefit of integrated interaction. In addition, users can share their work with other members of their group.

We're currently evaluating ButterflyNet at the Jasper Ridge Biological Preserve (http://jasper1.stanford.edu). We believe that the system will offer field biologists a greater understanding of their data with minimal overhead and that these benefits will foster even richer collaboration.

Beyond biology

Brian Lee and I have been extending the ButterflyNet infrastructure to enable the electronic capture and sharing of design students' paper "idea logs," photographs, wall-based ideas, and captured information from studio critiques. We're deploying the system in an interaction design course this fall and anticipate that rich, low-overhead capture of design ideas will facilitate students' ability to share their work with teammates and staff as well as to create electronic portfolios after completing a project.

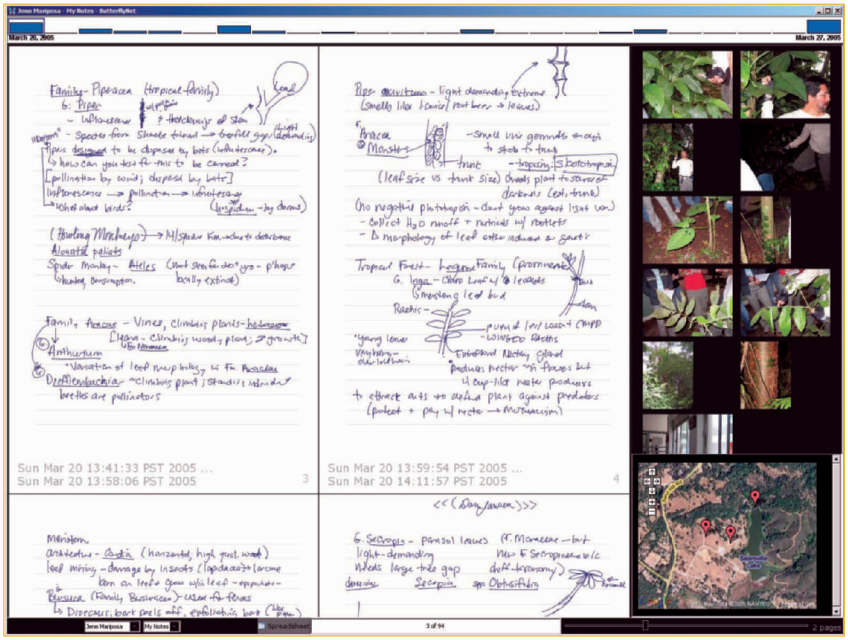

Figure 2. ButterflyNet system. Biologists can "leaf through" their field notes, related media, and other contextual data.

The next decade promises sweeping transformations in how we interact on the move. Looking forward, we're exploring ways to combine an electronic notebook with a flexible, high-resolution, input surface and a smart phone that provides computation, interactivity, and network access. These complementary technologies afford integrated interactions that speak to a model of nearly invisible computing: ready-made for everyday use but capable of conscious manipulation for richer interactions. ■

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