Physical-Digital Ensembles for Mobile Interaction

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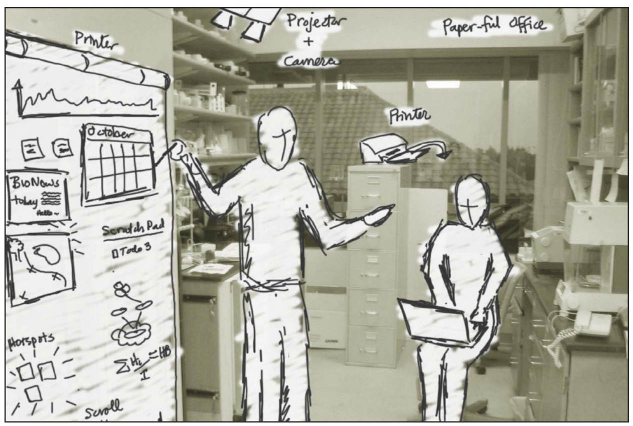

Figure 1. The Interactive Gigapixel Display provides ensemble interactions that will enable users to interact with both digital and calm technologies in tandem.

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Abstract

We describe *ensemble interactions*, which bridge the gap between the physical and digital worlds, enabling users to leverage paper tools and computers in tandem. Our projects (*e.g.,* see Figure 1) serve as test beds for these interactions. This research will inform mobile and tangible computing, where integrated paper-electronic interfaces will have great impact.

Keywords

Informal and Mobile User Interfaces, Augmented Paper.

ACM Classification Keywords

H5.2. User Interfaces: Input devices and strategies.

Introduction

On the train, at the park, and in cafés, we see mobile professionals working with their mobile phones and computers. Yet, despite the prevalence of these digital tools, many still carry a paper notebook. When we consider the advantages of each, we can quickly see why. Computers afford multimedia, interactive computation, digital information management, and electronic communication. Paper notebooks, on the other hand, are robust, turn on instantly, have infinite battery life, and enable fluid ideation. Mobile workers will not give up their paper tools any time soon.

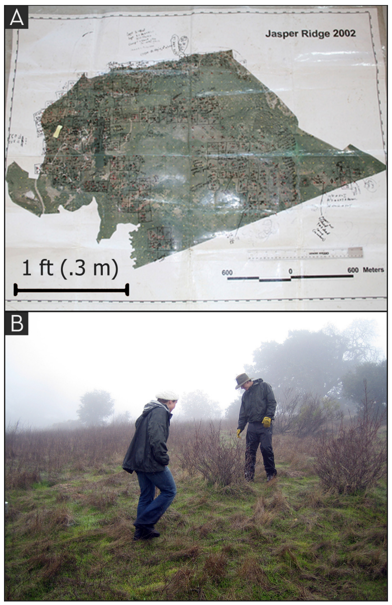

Figure 3. A) One field biologist we interviewed uses a large paper map to coordinate her work, folding it up before hiking out to the field (note the 1 ft. scale). Using a permanent marker, she records data from her experiment onto corresponding areas of the map, implicitly associating that data to that plot's location. B) The laminated paper map can withstand harsh field conditions, such as the wet winter conditions at Jasper Ridge.

Unfortunately, paper tools are frustrating when one needs to search or share data, as paper does not have any modern computing advantages. Mobile handsets can prove equally frustrating, but for opposing reasons. Many devices have clumsy input interfaces, are not robust, and occasionally run out of battery. We address this issue by developing *ensemble interactions*, interactions where a user works with digital and physical tools in tandem, leveraging the complementary advantages of both worlds. Through an ensemble interaction, a user can write "Pizza in San Francisco" on paper, and have his mobile phone perform the search. The paper provides the user a fast, fluid, input interface, while the phone provides the network, search capabilities, computation, and multimedia output.

This device ensemble approach enables technologies to complement paper tools, and is valuable when screen real estate or other resources are intrinsically limited for some tools. Our research will contribute:

- Guidelines for designing mobile device ensembles.
- Open source tools that use ensemble interactions.
- Software libraries for developing new interactions.

Fieldwork

This research is based on approximately 370 hours of talking to, observing, and working with field biologists. Through this process, we have witnessed a number of current practices that have informed our designs.

Our primary observation was that paper notebooks are the central organizing tool in field biology research (see Figure 2). Everything goes into paper notebooks: observations, procedures, measurements, and results. And while paper offers amazing benefits, it also comes with serious shortcomings. Paper notebooks do not provide text search, flexible organization, or multimedia output. Moreover, notebooks have limited data storage.

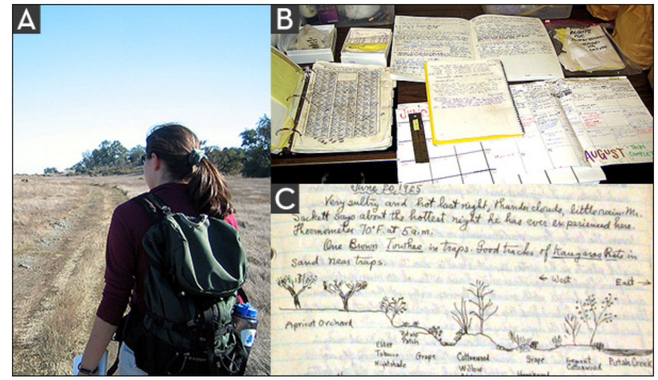

Figure 2. A) Field biologists choose paper notebooks because they are portable, robust, readable outdoors, and have infinite "battery life." Paper notebooks come in B) many form-factors, and C) support flexible input, one drawback of mobile devices.

In addition to notebooks, biologists also make use of large paper artifacts. One biologist we interviewed uses a 12 ft^2 (~1.1 m^2) laminated paper map to organize her research (see Figure 3), folding the map before going out to the field. This map enables her to tag data with location information, which she will later import into her ArcGIS software. From our other observations, we have seen hand-made calendars that facilitate collaboration, and also colorful, wall-sized research posters that populate field stations.

Though these tools are impressive in what they can do, they also prove problematic. For example, organizing, transcribing, and sharing data from paper artifacts is currently a labor intensive and error prone process. Ensemble interactions are designed to fix this problem.

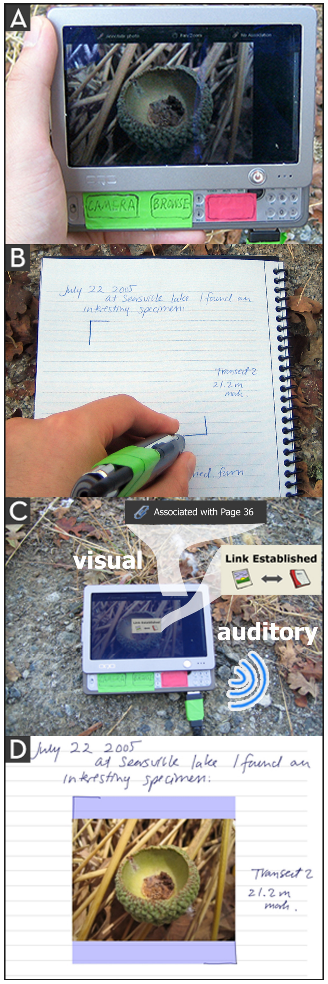

Figure 4. A biologist A) captures or browses to a photo and draws B) a hotspot gesture. C) The camera confirms the link with real-time audio-visual feedback. The browser renders the photo D) inline with the digitized notes.

Designs

We now describe ensemble interactions that we have designed for our three projects: ButterflyNet, the Interactive Gigapixel Display, and the Super Notebook. Our interactions marry the benefits of mobile technology with the affordances of paper by utilizing Anoto digital pens [1] with Bluetooth, which enables real-time communication with mobile computers.

ButterflyNet [7], a capture and access system for field research, includes several ensemble interactions. One technique, called hotspot association (see Figure 4), illustrates a *Link* interaction. Hotspots enable a biologist to paste a photo into a region of her digitized notebook. She captures (or browses to) a photo using her camera and then draws a frame for the photo in her paper notebook. In the browser, the biologist sees that the photo has been pasted into her notes. Generically, the *Link, Combine,* and *Stitch* techniques enable people to connect artifacts. For example, one can tap pages in sequence to indicate that they are semantically linked.

A second interaction technique enables a biologist to use her physical notebook to *Navigate* digital media. To retrieve photos associated with page 53, the biologist flips to that physical page and taps it with her digital pen. The browser detects the request and displays all associated photos in a context panel. *Navigate, Drag,* and *Flick* interactions leverage the physical interface to manipulate the digital world.

A biologist can also use her physical notebook to *Constrain* operations. She can draw crop marks on her physical notebook to copy notes to a spreadsheet for transcription. The S*elect* and *Constrain* interactions enable users to specify parameters for computer actions. For example, to send notes to a collaborator, a user might tap a page, and then pick the recipient using the mobile device. Specifying parameters through physical interactions is more efficient in this case.

A second project, the **Interactive Gigapixel Display** (see Figure 1), is motivated by our observations of biologists using large paper artifacts. This project augments large paper printouts with benefits from the digital world, including search, multimedia output, and digital data storage. It utilizes: 1) wide-format printing to provide high spatial, low temporal resolution output, 2) projectors and mobile handsets to provide low spatial, high temporal resolution (*i.e.,* interactive) output, and 3) Anoto pens to provide real-time input. Though it has an extremely low refresh rate, it provides an extremely large display, affording collaboration around walls or tables. From a distance, users can get an overview of the data. Up close, the fine detail of the printed output surpasses today's digital displays.

This system provides several ensemble interactions. First, it enables users to *Retrieve* data. A user can visually skim photos printed on a wall-sized paper blog. With a tap of her pen, she can send the image to her mobile computer. *Retrieve* and *Send* enable people to transport digital data through physical interactions.

This system also provides *Freeform* capture. Architects can discuss their designs over a large floor plan, while a computer captures paths drawn on the plan and displays real-time 3D walkthroughs of the building. The computer can save edits, while updating an on-screen model. *Freeform* and *Informal* interactions enable users to work naturally on a physical input surface, while a computer processes the input in real-time.

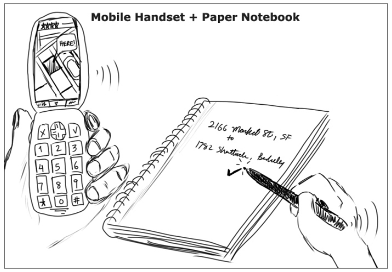

Figure 5. The Super Notebook enables mobile workers to interact with information tools in concert.

Figure 6. Left) A couple browses a map and guide book. Right) A man dials a number on a mobile phone.

Finally, our **Super Notebook** (see Figure 5) enables a mobile professional to use his handset and paper notebook in tandem. A user can leverage the flexible input surface of paper to *Send* information to his smart phone. One can write a query, such as a street address, and have the phone perform the search and display results in real time. This interaction, leveraging tools that people are already familiar with (Figure 6), allows users to avoid the phone's cumbersome input interface.

Related Work

Two augmented notebooks inspired our early work. Mackay's a-book [5] provides laboratory biologists a paper notebook with a PDA "interaction lens," which helps users create a table of contents, links between pages, and links to external sources. A-book showed how interactions on a mobile device can enhance interactions with a paper notebook. The second system, Audio Notebook [6], introduced a paper notebook where tapping parts of a page retrieves audio recorded at the time those notes were written. The elegance of imbuing paper with query capabilities was one of our main inspirations. Our designs improve upon these two by introducing techniques beyond linking and retrieval.

Other paper-centric systems, such as Paper PDA [3] and PADD [2], demonstrated techniques for managing documents in either digital or physical form. PADD enabled documents to "move" between the digital and physical worlds. Instead of moving between worlds, we contribute novel techniques to operate on the physical and digital worlds in tandem. With our techniques, a user can compose on paper while receiving real-time output on his computer. Another paper-centric system, Books with Voices [4], comprised a PDA and notebook ensemble that introduced paper transcripts as an input device for browsing video. We extend this by offering real-time output (printing) in the physical world as well.

Evaluation and Current Work

We are currently deploying ButterflyNet to biologists and anthropologists for long term evaluations. We also plan to deploy the Interactive Gigapixel Display and Super Notebook at Jasper Ridge, to see if the tools can help biologists coordinate their work more effectively.

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References

[1] Anoto AB, Anoto Technology. http://www.anoto.com

[2] Guimbretière, F. Paper augmented digital documents. UIST: ACM Symposium on User Interface Software and Technology. pp. 51-60, 2003.

[3] Heiner, J. M., S. E. Hudson, and K. Tanaka. Linking and Messaging from Real Paper in the Paper PDA. UIST: ACM Symposium on User Interface Software and Technology. pp. 179–86, 1999.

[4] Klemmer, S. R., J. Graham, G. J. Wolff, and J. A. Landay. Books with Voices: Paper Transcripts as a Tangible Interface to Oral Histories. CHI: ACM Conference on Human Factors in Computing Systems. pp. 89–96, 2003.

[5] Mackay, W. E., *et al*. The Missing Link: Augmenting Biology Laboratory Notebooks. UIST: ACM Symposium on User Interface Software and Technology. pp. 41-50, 2002.

[6] Stifelman, L., B. Arons, and C. Schmandt. The Audio Notebook: Paper and Pen Interaction with Structured Speech. CHI: ACM Conference on Human Factors in Computing Systems. pp. 182–89, 2001.

[7] Yeh, R. B., C. Liao, S. R. Klemmer, F. Guimbretière, *et al*. ButterflyNet: A Mobile Capture and Access System for Field Biology Research. CHI: ACM Conference on Human Factors in Computing Systems, 2006.