

The Missing Link: Integrating Paper and Electronic Documents

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ABSTRACT

Despite the ubiquity of computers and on-line documents, paper persists. As physical objects, paper documents are easy to use, flexible, portable and are difficult to replace. Even though many professionals use computers, engineers also hand annotate large paper engineering drawings, video producers still sketch and rearrange paper storyboards, air traffic controllers still plan traffic flows with paper flight strips and biologists still record experiments and organise data in paper notebooks. In this article, I argue that we should seriously reconsider the urge to replace paper documents with on-line versions that are accessible only with a mouse and keyboard and viewable only a screen. Instead, we should begin to think about "interactive paper", which maintains the ease-of-use of physical paper, while enabling us to benefit from the full spectrum of interactive computing. The goal is to create the missing link between physical and electronic documents.

KEYWORDS: Augmented Reality, Mixed Reality, Interactive Paper, Participatory Design

RESUME

Malgré l'omniprésence des ordinateurs et des documents numériques, le papier persiste dans nos usages quotidiens. En tant qu'objets physiques, les documents papier sont faciles à utiliser, flexibles, portables, et s'avèrent extrêmement difficiles à remplacer. Bien qu'ils utilisent des ordinateurs, les ingénieurs utilisent de grands plans en papier, les producteurs de vidéo créent et organisent des storyboards en papier, les contrôleurs du trafic aérien organisent encore les vols des avions avec des "strips" papier, et les biologistes enregistrent encore leurs expérimentations et leurs données multimédia dans des cahiers de laboratoire en papier. Dans cet article, je défend l'idée qu'il faut sérieusement remettre en cause notre empressement à remplacer tous les documents papier par des versions numériques uniquement accessibles avec un souris, un clavier et un écran. A la place, je présente le concept de "papier interactif", qui conserve la simplicité d'usage du papier physique tout en permettant de bénéficier de toutes les capacités d'interaction propres au document numérique.

MOTS-CLÉS: Réalité augmentée, Réalité mixte, Papier interactif, Conception participative

INTRODUCTION

In this keynote address, I have been asked to talk about *interactive paper*: how to create documents that maintain the benefits of physical paper while benefiting from the properties of a computer. Physical paper is extremely versatile as an object, used for many purposes in a variety of different ways. Yet, once written on or printed, the information on paper is essentially static. The user can erase pencil marks and make new annotations with a pen, but printed information stays the same. If we want to modify information via the computer, we must return to the computer screen, make the changes, and print a new, modified copy, without the hand-written annotations.

The result is that many computer users keep two parallel filing systems, one for their electronic documents and another for their paper documents. The two are often related, but rarely identical, and it is easy for them to get out of sync. Many software application designers understand this problem and have tried to replace paper altogether, usually by providing electronic versions of paper forms. While this works in some situations, for many others, users end up juggling both paper and electronic versions of the same information. An alternative approach is to continue to work with paper, but also augment it with on-line information. The user can continue to take advantage of the flexibility of paper and, at the same time, manipulate information and communicate via a computer network.

A brief history

I did not start out thinking about interactive paper. In the early part of my career, I concentrated on multimedia systems, seeking new ways to integrate text, graphics and video in a distributed computer environment. However, in 1991, as a recent employee of Xerox, I attended a 'top-secret' internal seminar that fundamentally changed the direction of my research. Nick Sheridan presented a new technology, digital paper, in which each "pixel" embedded in a sheet of paper was actually a tiny ball, black on one side, white on the other. These balls were stable, unless explicitly flipped over by a simple device. The result: a sheet of paper that can act as a computer display, while maintaining all the characteristics of ordinary paper. His work sparked a new way of thinking about the future of interactive computing. Suddenly, a paper document was no longer the static output of a printer, but an interactive object in its own right.

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At our lab Xerox EuroPARC, we began to work on what it might mean to actually use interactive paper. Pierre Wellner developed the Digital Desk [23] which simulated future technologies. A video camera captured information from printed documents and a video projector displayed information from the computer onto the paper. The user could point, drag and drop with a finger and use "paper buttons" to provide simple commands. My group continued with this work, exploring different technologies for capturing information (sound, cameras, graphics tablets), displaying it (project, embedded screens in the desk) and linking physical and on-line information. An essential component of the research was to include users with real requirements for handling a mixture of paper and electronic documents.

In early July, 1993, I ran a workshop at MIT on "computer augmented environments" and, together with Wellner and Rich Gold from Xerox PARC, I edited a special issue of the *Communications of the ACM*, with the same name [24]. We included articles about the Digital Desk and interactive paper [17], as well as other innovative augmented reality and mixed reality applications from Columbia, University of Paris-Sud [1] and University of Toronto. ACM received the 1993 American Publisher's award for the best special issue of a journal in any scientific discipline and this special issue effectively launched a new field. Shortly thereafter, Joe Jacobson developed the concept of electronic ink (similar to Sheridan's electronic paper, but with the dynamic pixels located in the ink substrate, not the paper), Hiroshi Ishii began to work on "tangible interfaces" [7] and Mike Hawley [5] created the MIT lab called "Things that Think". Researchers who had moved from Virtual Reality to Augmented Reality, such as Steve Feiner [4], at Columbia, became active in exploring ways in which we can mix real and virtual images.

Since then, the fields of augmented reality, mixed reality, and tangible computing have exploded, as well as the related fields of wearable and ubiquitous computing [22]. The technology continues to improve. We have new and better methods for identifying objects, including Xerox's glylypns [6], Sony's cybercode [21], RFID tags and smart chips. Vision researchers have become increasingly skilled at developing software that identifies objects and registers their location. Some interactive paper technologies have been commercialised, including display devices (Gyricon's¹ "SmartPaper" and E-ink's² electronic ink) and input devices (Anoto's³ pen with a tiny camera and special paper to capture the user's gestures).

So, slightly more than a decade later, it is perhaps time to reflect on what we've accomplished and what the future holds. From the perspective of the technology, we are in the very early stages of commercialisation. We are still a long way from what we prototyped in the lab, but progress is rapid and it is simply a question of time. From the perspective of the user, I have more concerns. Most of the research effort I see is targeted at improving the technology or how to use it in a mixed reality context, e.g. how to ensure that the physical and virtual

versions of an object are truly synchronised. What is significantly less common is research that seeks to understand these technologies from the perspective of the user. In which contexts is it relevant? How can we prevent confusion? How do we ensure that we do not lose the simplicity, predictability and directness offered by physical objects when we make them interactive?

This article describes four research projects which explore the creation of effective interactive paper applications in real settings. In each case, we begin with computer literate professionals who use a combination of physical and electronic documents as a critical element of their work. These users have not clung to paper documents because of fear of computers, but rather have made a conscious choice based on a practical understanding of the advantages and disadvantages of documents in each of their forms.

We use a participatory design approach [8,12] that involves users throughout all phases of the design process. We interview them and observe them as they juggle different forms of documents. We run interactive workshops with them to brainstorm ideas and to video prototype new technologies, and they actively participate in evaluation, from initial ideas to testing working prototypes. The goal of each research project has been to iteratively develop a novel kind of interactive paper document that does not require the user to give up the advantages of physical paper, but still enables him or her to gain the advantages of an on-line document.

This approach has provided us with not only novel designs for interactive paper, but also a deeper understanding of how people use and interact with documents over time. Understanding the latter allows us to re-invent familiar documents to provide radically new functionality, without risking the loss of prior benefits. The next sections will briefly describe each of these four interactive paper projects, including a summary of what we learned in the process. I will conclude with a brief assessment of the future of interactive documents and the new research avenues open to interactive document designers.

Video Mosaic: Interactive paper storyboards

During the 1980s, I worked closely with film makers and video producers at MIT and Digital Equipment. We created a variety of interactive video systems [18] and I learned many of their techniques. One of the most important documents is a paper storyboard, which organizes and illustrates the flow of a movie or video. Storyboards usually consist of a series of "shots", each containing a "best frame" or sketch of a representative image from a motion sequence, the corresponding dialog or voice-over, and notes about the shots or scene.

Although on-line video-editing systems have been available for over a decade, most people continue to use paper storyboards: they are portable as well as easy to read, annotate and exchange with others. On-line video systems make it easy to search for text strings and see the action; but suffer from limited screen real estate and are not very portable. (Even with lap-top computers, it is still easier to read storyboards on paper.)

Video Mosaic [14] explored ways of linking paper storyboards to an on-line video editing system that I

¹ <http://www2.parc.com/dhl/projects/gyricon/>

² <http://www.eink.com/technology/>

³ <http://www.anotofunctionality.com/navigate.asp>

originally developed at MIT, called EVA. We created storyboards that consist of a series of elements, each with a video clip, subtitles and commentary about the shot. The printed version of a storyboard element includes an identification code, an image of the "best" frame, the text of the subtitles and a snapshot of any relevant handwritten notes. The user can manipulate the individual segments of a paper storyboard, reordering, editing and annotating them as desired. The user maintains the flexibility of the paper storyboard, while gaining access to on-line editing facilities for creating new versions of the video. Figure 1 illustrates the basic layout of Video Mosaic, with a close-up camera (or handheld scanner) for detecting precise information, a wide-angle camera for detecting the position of individual storyboard elements (via a light pen or barcode reader) and a projector (or embedded monitor) for displaying information to the user.

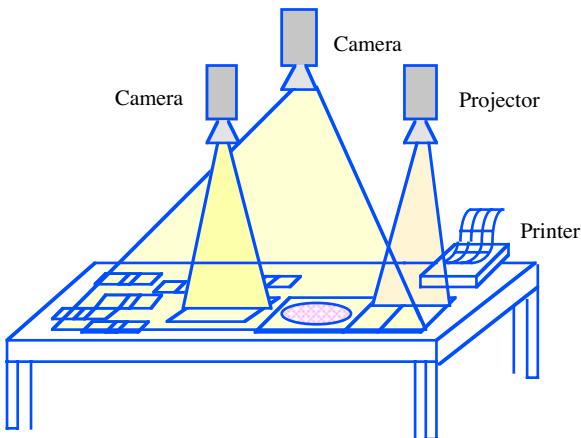


Figure 1: Diagram of Video Mosaic layout

We developed Unix and a Macintosh prototypes to explore different user interface styles. The Unix version (figure 2) uses optical character recognition to identify the storyboard element and the user commands (via "paper buttons"). For example, a user might decide to edit together three particular video clips. She picks up the relevant storyboard elements, places them one at a time under the video camera, tapping once to tell the system to identify that element. She then places a paper button with the word "play" on it and taps. The corresponding video sequence plays in a video monitor embedded in the desk.



Figure 2: Unix version of Video Mosaic

Figure 3 shows a close-up of a storyboard element from the Macintosh version of Video Mosaic. This version is significantly easier use: each storyboard element has a barcode printed in the corner and a menu of possible commands is projected onto the desktop. The user passes the barcode over the desired storyboard and points to the desired command. A video camera detects the red light emitted from the bar code pen and performs the relevant command on the selected video elements. The same projector projects the corresponding video onto the desktop. User annotations can be recorded either with the overhead camera or with a small, hand-held scanner. Note the use of subtitles: Video Mosaic allows the user to search and view video clips by browsing through text subtitles, summarized in the center section and viewed as a banner stream below, with a moving time indicator.

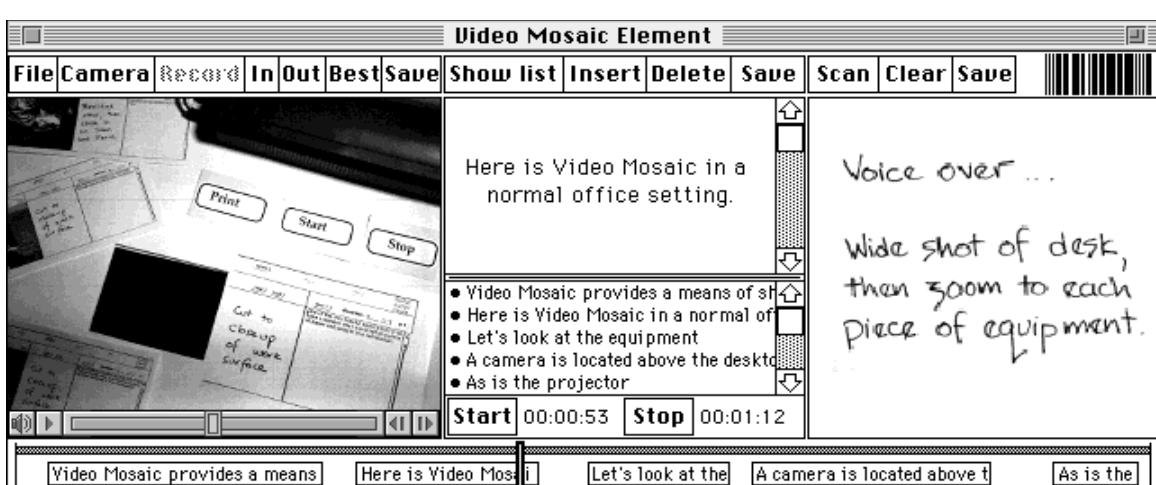


Figure 3: Macintosh storyboard element.



Figure 4: Macintosh version of Video Mosaic.

Figure 4 shows a users interacting with Video Mosaic. The left hand is holding a paper storyboard element and the right is pointing to a live storyboard element that is projected onto the desktop.

The techniques we developed for Video Mosaic proved useful for reading lengthy reports containing video clips. Normally, we prefer to read text on paper. But if the text contains video clips, it is necessary to read the document on-line. Video Mosaic allowed us to print a paper version of the document in which each still image has an identification number (or barcode). When activated, the related video clip plays on the monitor next to the desk. Video Mosaic illustrates how to merge paper storyboards or documents containing video with a variety of on-line video editing functions, taking advantage of the best elements of each.

Ariel: Blueprints that talk to the net

We studied construction supervisors working on the Storebaelt bridge in Denmark (then the world's longest suspension bridge). Our original goal was to provide a sophisticated multimedia communication system that would let them talk to one another and share information. After numerous visits to the bridge and construction sites, we shifted our focus. We discovered that although these supervisors must deal with thousands of engineering design drawings, in any given week they only use four or five drawings. Although all have computers in their offices, they rarely use them, except for occasional email and writing of reports. Normally, they spend their time traveling from their offices to the bridge pylons and from the pre-fabrication sites to administrative offices on shore.

The supervisors much prefer the convenience of paper drawings, especially since they can easily make informal notes and sketch ideas for design changes. These informal changes are extremely important: as many as 30% of their changes are never transferred to the on-line system. Thus the paper drawings are the most accurate record of the final implemented design of the bridge.

We were interested in giving supervisors improved access to critical information as well as to each other. Rather than designing yet another unused program for the supervisor's desktop computer, we decided to use a mixed reality approach. Ariel [10, 19] turns engineering drawings into the interface to the computer. We developed a series of prototypes in collaboration with the engineers,



Figure 5: Ariel prototype: an A0 graphics tablet captures annotations and commands, information is projected onto the tablet.

to explore different interfaces and functionality. Figure 5 shows the first prototype, developed in Unix.

When the supervisor wants to connect the drawing to Ariel, she places it onto the desktop. Ariel identifies the drawing via a bar-code (figure 6). A tiny video camera captures the position of a light pen and a hand-held scanner captures hand-written notes. We experimented with various mechanisms for registering the exact location of the drawing with respect to the graphics tablet. The most successful version involved asking the user to point to each of the four corners of the drawing (after identifying it so Ariel would know the correct size). Ariel then adjusts the electronic image of the drawing to correspond to the actual size of the paper drawing.

Ariel uses a portable video projection panel to display computer images and interactive menus onto the drawing. Figure 7 shows the MacIntosh interface, in which the user can make hypermedia annotations, indicated by "hotspots" to add audio, video or text notes, in addition to the ones written in pencil. Projection of computer images onto the paper drawing can occasionally be confusing. One solution is to place a piece of plain white paper over areas of the drawing, to make it easier to see the projected information. By placing a small led in the corner of the paper, we create a "real" as opposed to a "virtual" window that Ariel can track as it is moved around the drawing.

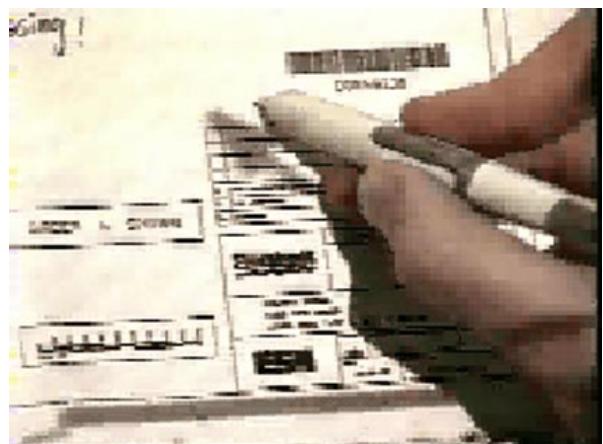


Figure 6: Identifying a drawing via a barcode reader.

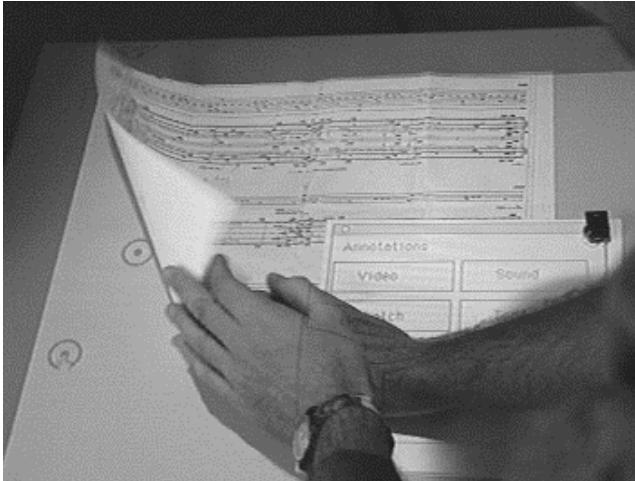


Figure 7: Movable annotation hot spots are projected onto the drawing. Ariel follows the paper "window", detected via the red *led* in the corner.

Every engineering drawing already contains information about the author of the drawing and other responsible individuals. Ariel lets the user take advantage of this information to establish live video connections with people at other Ariel sites (figure 8), via a media space [20]. The supervisor can also send multimedia mail and look at annotations made by her colleagues.

The main advantage of using engineering drawings as the interface is that they are never "down"; they always work. Yet with Ariel, these same drawings provide a simple and effective interface to a sophisticated distributed multimedia network, with all its capabilities for information exchange. By capturing informal annotations, Ariel also provides a more accurate account of what was actually built.

Caméléon: Mixed paper flight strips

Caméléon [15] addresses a very different kind of problem. The current air traffic control system uses a combination of RADAR and paper flight strips to track the progress of each plane. Controllers annotate the flight strips to highlight problems, remind themselves to do things and to communicate the status of each plane to other controllers (figure 9).



Figure 9: Controllers at Paris Athis Mons en route control center. Two controllers annotate different paper flight strips at the same time.

Although various on-line tools are being developed to help controllers handle the ever-increasing traffic loads, much of the information they need remains in hand-written form on the paper flight strips. The most common solution for developers of new technology is to remove the flight strips and replace them with electronic versions presented on a computer monitor. Unfortunately, this overloads the controller's visual channel and makes it more difficult for them to handle the planes.

We decided to try a different approach: rather than replacing the strips, we would augment them. We began with a four-month ethnographic study of a team of controllers at the Paris Athis Mons en route control center, emphasizing how they interact with paper flight strips [11]. We found that annotations (figure 10) serve a variety of functions.

Controllers write for themselves, for each other and as a legal record of decisions made. Only a subset of these annotations need to be interpreted by the computer. We can take advantage of the existing layout of the strips and the agreed-upon ways of annotating them. For example, one section of the strip is devoted to the "exit level" of an airplane. The next sector (of the air space) is already recorded, as is the planned exit level.



Figure 8: Users access a media space to converse with others at different bridge locations.

					MHD	REM	BSN	P0	TE
19	LFJL LFPO 220	190	180	Mu	12	21	30	41	73 68 77
	0453	RB dec 0501 0511		0459	05	05	05	05	
5	7.U LG75659	270	*	090					TB
74	LF00 LFPLI CLM	190	190	240 220	CB	TALLIN	CTL	15 14 77	
T	0454	LR dec 0445 0455		0458	06	14	19	155	
				LEQ	05	05	05		
0	0 P GC3721D	1450	*	090					TB
40	LF00 LFJL 170	190	190	1A3	DENIN	MHD	HTZ	L0U	13 14 77
	0455	DEC 0455 0505		0459	03	22	33	37	
				LEQ	05	05	05	05	
0	0 T Z 7607	1500	*	090					TE
40	LFSP LFPLI AFSII-DII	150	(09)	—	DEREM	REM	VATRI		13 14 77
	0459	TC dec 0501 0510		10	10	10			
				LEQ	05	05	05		
6	7.A PG63553	260	290	260	DPE	900KH	MERLIE		TP
	REC			80					
41	PARA LPNG 250				145	18	21		13 14

Figure 10: Annotated paper flight strips

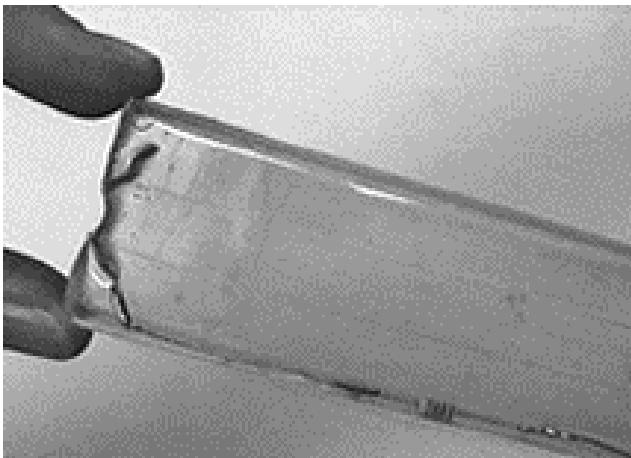


Figure 11: Modified paper strip holder containing a resistor.

We engaged in a year-long participatory design project, exploring different techniques for capturing information written on the strips, presenting information to the controllers and tracking the strips themselves. Figure 11 shows a prototype in which the plastic flight strip holder has been modified to contain a resistor.

A frame with metal contacts on the sides (figure 12) detects the level of resistance (unique to each strip holder). The system can then tell which strip is located in which position on the stripboard. This frame is placed on top of a graphics tablet, which captures the annotations made by the controller.

A touch-sensitive screen adjacent to the stripboard displays information about each strip. For example, if another controller wishes to suggest a new flight level, it appears on the screen adjacent to the relevant strip. The controller can underline the level if she agrees, write a new one or click on the "telephone" icon to discuss it further. The controller can also generate commands, such as tapping once on a particular strip to see it highlighted on the RADAR, or twice to see route and other information (figure 13).

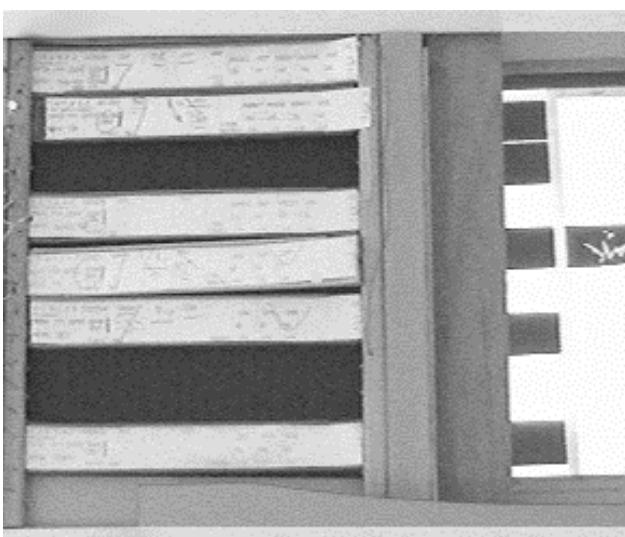


Figure 12: Caméléon's stripboard detects paper flight strips. A graphics tablet captures annotations and a touch screen displays relevant information.



Figure 13: Prototype of Caméléon

A-Book: Augmented Laboratory Notebooks

Research biologists face a complex information processing task, managing physical paper documents, physical research specimens, on-line documents and on-line services. They require paper laboratory notebooks for legal, historical and practical reasons, but they are also active computer users. This forces them to constantly juggle paper and electronic forms of the same information.

As in the previous projects, we used a participatory design approach in which we observed, interviewed and brainstormed ideas with over twenty research biologists, plus archivists and laboratory managers, over two years. Participants brought their notebooks and data and we experimented with different strategies for bringing computation directly to the notebooks.

We found that different users had different needs. Biologists track oft-repeated research procedures and note their findings. They write, draw and paste in images, such as X-rays and digital microscope photographs, or physical lab specimens, such as gels or films. Some notebooks point to external objects, such as refrigerated or frozen specimens, surgical results stored on slides and even live laboratory animals. Notebooks also included computer printouts and provide links to on-line information, including important research articles and web sites.

Archivists are concerned with the notebooks when biologists leave the Institut, both from a historical and a research perspective. They need methods of indexing and accessing data and need to maintain links between notebooks and physical specimens stored in secure facilities or refrigerators. Archivists are concerned with the growth of on-line data, which quickly becomes inaccessible when stored in obsolete software formats on out-moded computer media. Archivists are also conscious of their role as historians: today's inconsequential finding may become extremely important in twenty years, as other research changes the context in which it is interpreted. Research managers are also interested in laboratory notebooks, because a third of the Institut Pasteur's financing derives from patents. They would like to more easily identify patentable ideas and register them in an efficient manner.

Augmented lab notebooks

The *a-book* is third in a series of augmented laboratory notebooks that we have developed in collaboration with the Institut Pasteur [16]. The idea was inspired by two biologists who needed to record genetic, lineage and other information about specific mice in their experiments. They wanted a portable database tool for recording the characteristics of each mouse in the animal lab and linking them to experimental results. The idea was also influenced by a biologist working with the tuberculosis virus, who needed a small portable device to record information during surgery. Access to the operating room is highly restricted and physical objects cannot be carried back and forth, so data needs to be transmitted electronically and linked to the notebook outside.

The A-book hardware includes a graphics tablet with three peripherals: an inking pen (for writing on paper), a non-inking pen (for interacting with the Interaction Lens) and a 4D mouse for tracking the position of the *Interaction Lens* (figure 14). A small, screenless Single Board Computer fits underneath the tablet and runs the database server and other a-book software.

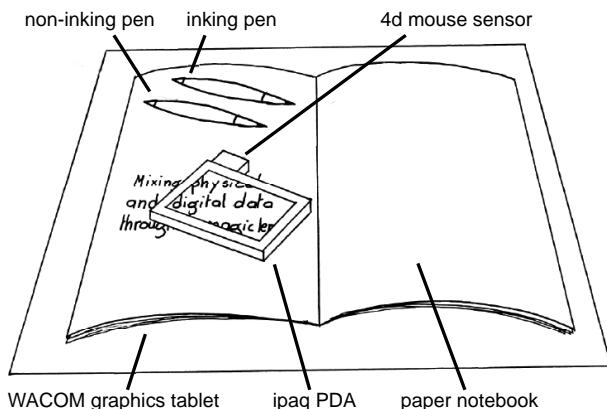


Figure 14: A-book components

The *a-book* detects the biologist's gestures and uses them to reconstruct individual notebook pages. These pages can be viewed on an ordinary computer monitor if desired. However, the primary use involves the *Interaction Lens* (figure 15). Influenced by Xerox's on-line toolglasses [2] and magic lenses, the *Interaction Lens* acts as a physical, movable filter and as an interaction tool. The biologist places it a paper notebook page and immediately sees the underlying page, including any previously recorded handwritten text or data. The viewer's immediate impression is that of a transparent window. The illusion is maintained for any orientation of the PDA.

The biologist uses the non-inking pen to select items from the page through the *Interaction Lens*. For example, he can create a link to the name of a procedure. If he presses the pen and does not move (with some tolerance) for half a second, a pop-up menu appears. He selects 'lien' (link) to define the first anchor of the link, which is displayed as a small icon (figure 16). He can then specify the target of the link to be an item on another notebook page, using the same technique, or call up another program, called the object-tracker, to associate it with a tagged physical object. Although this is a two-stage process, the biologist need not identify the second anchor point of the link immediately. The system maintains a per-user list of pending actions, which can be consulted

when the main *Interaction Lens* menu appears. This allows biologists flexibility when engaged in complex tagging operations, such as registering and tracking live mice, while allowing them to remember that some actions are still pending.

The biologist can add items to the table of contents either by drawing a rectangle around the item on the paper page or by placing the *Interaction Lens* over the desired location on the paper notebook and selecting "toc" (table of contents) from the pop-up menu. A resizable, translucent window appears. He can adjust the size of the window as necessary (figure 17) and save the entry by clicking the "ok" button or else "cancel".

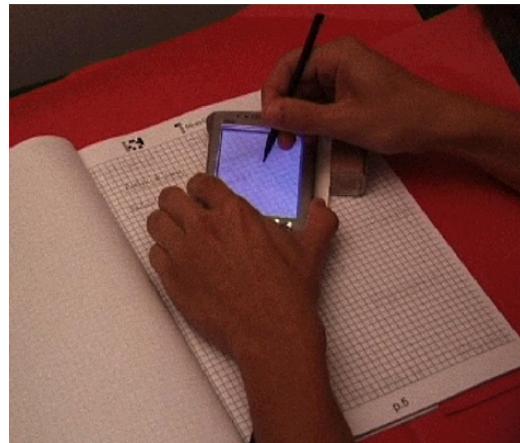


Figure 15: A-book: Interaction Lens for annotating or creating links to external physical objects.

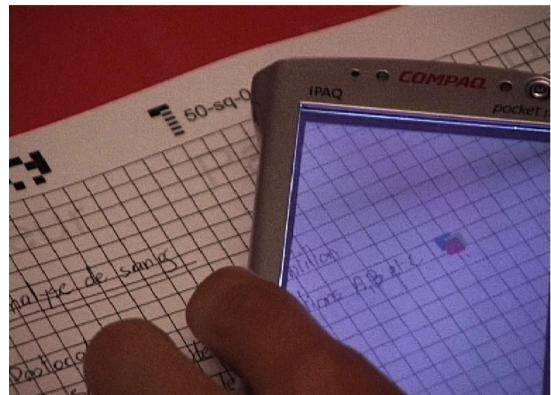


Figure 16: Interaction Lens: selecting an anchor for a link to an external, physically-tagged object.



Figure 17: Interaction Lens: Identifying an item to be added to the table of contents.

The table of contents is updated in real time and the biologist can browse it via the Interaction Lens. Entries, which are graphical snapshots of human-written text or sketches, are displayed chronologically, in the order in which they were originally time-stamped, with date and page number. The biologist can also use the Interaction Lens to make on-line annotations of the paper notebook pages. Such annotations make it possible to add informal remarks or ideas to an otherwise formal document.

The Interaction Lens is also used as a stand-alone PDA, which can be used to browse the notebook or perform other tasks. Figure 18 shows a browser (left) with a thumbnail of a notebook page, which selects the current page and helps determine whether a particular page has annotations or links. The object tracker (right) maintains a database of externally tagged objects. The Interaction Lens can also display the table of contents and has a print function for printing new notebooks, individual pages, the table of contents and labels.

The next step for us is to create a version that biologists can use over a period of time. We are developing a new prototype using Anoto pen technology [3] and expect to test it over the next several months.

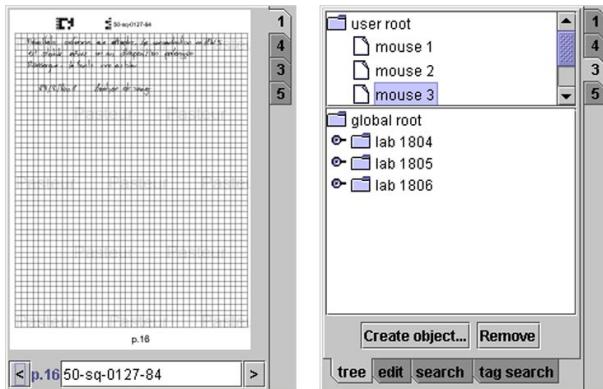


Figure 18: Interaction Lens, stand-alone mode. Left: Thumbnail notebook page. Right: Object tracker.

DISCUSSION

When is mixed reality appropriate? Our strategy is to look at what users already do with objects in the real world and then examine what functionality the computer can add. If an off-line, paper document has important characteristics that cannot easily be duplicated with a standard mouse/keyboard/monitor style of interface, then it makes sense to explore a mixed reality approach.

However, integrating physical and virtual objects is not always easy [9]. Mixed reality can create as well as solve problems. A simple example is the act of erasing information. Erasing pencil marks on paper is simple and straightforward. Similarly, in most on-line text editing applications, erasing is easy for users to learn. Yet what does it mean to erase when physical and on-line documents are linked? What happens if marks are erased on paper and the computer version does not detect the change? Or similarly, what happens if the computer erases information, but it remains physically on the paper? Mixed reality applications merge electronic and physical objects; when the methods of interacting with each are not in sync, the result can be confusing.

Mixed reality application designers must consider how to make the integration of real and virtual as seamless as possible. Each application must include the best combination of techniques for detecting information from the real world and presenting electronic information to the user. For example, a number of options are available to track the position of a user's hands. A data glove or special dots on the hands be detected with a sensing device. A video camera and image analysis algorithms can identify location. In each case, the choice depends upon the nature of the application. If the user is already wearing gloves, a data glove makes sense. If low-resolution pointing is all that is required, the combination of a camera and light pen makes for a lightweight, portable system. If very accurate position information is needed, a graphics tablet may be required.

Similarly, many possibilities are available for displaying information. A doctor can wear a head-mounted helmet and see a video image of the real world mixed with electronic information. Electronic images can be presented over one eye. A video projector can project information directly onto the patient's body. Electronic ink or paper will provide a lightweight, stable mechanism for displaying almost any information. Finally, imagine a kind of transparent, flexible screen that shows critical information when placed over the patient. The choice depends on the specific characteristics of the application: constraints of the user, the object or the environment.

Mixed reality applications also present interesting user interface design challenges. For example, when superimposing virtual information onto real objects, how can the user tell what is real and what is not? How can the correspondence between the two be maintained? Actions that work invisibly in each separate world may conflict when the real and the virtual are combined. For example, if a computer menu is projected onto a piece of paper, and then another piece of paper is placed on top of the first paper, the computer project continues to be on top. In a paper world, each piece of paper obscures the ones beneath, giving a clear view of the one on top. On a computer screen, the same thing happens with overlapping windows. But when the paper and electronic information are combined, odd things occur. For Ariel, we created a blank sheet of paper that the computer could detect via a tiny infrared light on the corner. The computer would track this sheet and project pop-up menus onto it, solving the "overlay" problem.

The most innovative aspect of mixed reality is not the technology: it is the objective. Instead of replacing physical objects with a computer, we create systems that allow people to interact with the real world in natural ways and at the same time, benefit from enhanced capabilities from the computer. The goal is to provide the missing link between physical and on-line documents.

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