Electronic paper - can it be real?

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Some people have used the phrase 'electronic paper' to suggest that electronic information displays may replace the printed page. Progress towards the ideal of electronic paper is reviewed along several dimensions: the technologies, such as the display surface, the appearance, such as the page layout, and the function, such as the styles of interaction, that are currently available and may become possible in the future.

Introduction

As increasing amounts of information are held and presented in the electronic medium, it is an appropriate time to reflect on whether 'electronic paper' is a realistic proposition now or in the future. This article looks at how far we have come towards the goal of replacing the printed page.

In many respects, electronic storage media such as CD-ROM, or network-accessible disks, offer significant advantages of compactness and accessibility. However, there are many attributes of paper that it is hard to emulate using current electronic technology - both statically, in terms of print quality and use of space, and dynamically, in terms of sense of location within the information and the ease with which it can be browsed.

In this article, it is argued that many valuable attributes of paper have so far been largely ignored in the translation to the electronic medium. To what extent can we hope to capture these attributes too?

The benefits of the electronic medium

We are all familiar with the potential benefits of electronic information. Digital representations are more amenable to cost-effective processing, communication and storage. For example, once text is captured in a digital representation it becomes possible to offer electronic processing functions that are otherwise impractical. It would be unthinkable to use full-text search for information retrieval if restricted to the printed medium. Electronic documents can be distributed in seconds over networks. Digital representations allow many more storage options, and may be especially attractive for archives since they may be copied between different storage media without loss of fidelity.

Beyond this, there are further advantages due to the representational flexibility of the electronic medium - for example, it can be used to convey dynamic information, such as animation, sound and video sequences.

However, given that there are many new possibilities opened up by digital representation, it does not necessarily negate the value of the printed medium. The widespread use of the fax machine shows that paper still holds its attractions at each end of a communication, despite a digital representation being used for intermediate data transfer. Indeed, so far computers appear to have led to an increase in the use of paper at work (Frohlich 1994), rather than the widely predicted paperless office.
To explore this further, it is necessary to be clearer about the attributes that are being compared between the two media.

Electronic paper and electronic books

For the sake of the subsequent discussion, let us distinguish between electronic paper and the more nebulous concept of the electronic book. The term 'electronic paper' will be taken to mean a relatively close electronic approximation to the marked page. The term has been used on a few previous occasions, most notably for a project at the National Physical Laboratory, which explored the use of a flat-panel LCD (liquid crystal display) with electronic pen input to capture handwritten notes (Thomas 1987, Brocklehurst 1991), and in Freestyle, a user interface developed by Wang Laboratories for capturing and annotating printed pages in the electronic medium (Millikin 1988).

On the other hand, the term 'electronic book' has become a phrase widely used to describe almost any information published in the electronic medium, whether it has any similarities to the paper medium or not. Here, we will confine our interest to a direct comparison with paper, and especially with the printed page.

In the following sections, some specific attributes of the printed page will be compared to the capabilities of electronic technology. The electronic medium will be found, currently, to fall short in several respects. Of special interest is whether these shortcomings are ones which can be minimised or removed altogether in the future.

The ubiquity of paper

A piece of paper is a ubiquitous carrier of information. It can be marked, with ink or other surface effects, via press, laser printer or pen. Once marked, it is difficult to unmark. It is light, cheap and durable enough for most daily tasks. It can be annotated, bound and filed away for later reference. Its weight, colour, texture and general condition give an indication of its provenance. Its size and shape have evolved into a number of form factors to suit the different needs for portability, readability and ease of handling.

How well do the capabilities of electronic technology match these characteristics? To date, the nearest electronic equivalent to a piece of paper, in terms of portability and richness of viewable information, is the notebook computer with a liquid crystal display. Desktop monitors attached to computers, though offering higher display quality, are not portable. However, the portable computer is perhaps better compared to a folio-case or box-file full of documents, as can be seen in Table 1.

Table 1. Comparison of weight, volume and cost of paper containers and portable computers.

	Single sheet of A4 paper	Folio-case with documents	Box-file with documents	Notebook computer	Sub-notebook computer
Page sides	2	1,000	1,400	45,000	20,000
Weight (g)	5	3,700	4,200	3,200	1,800
Volume (cc)	6	8,200	6,800	3,300	2,100
Total cost (£)	0.01	40	7.5	2,500	2,000
Cost per side (p)	0.25	4	0.5	5.5	10

The notebook computer is comparable in weight to a folio-case containing several documents, but has less than half the volume. If it is assumed that the full cost of the folio-case and the computer is included, the two are comparable in terms of overall cost per stored page. The sub-notebook computer has a size and weight advantage over the notebook computer, but at a greater overall cost per stored page. Either portable computer has considerably greater total capacity for documents, though the exact capacity depends on the storage medium, the document representation and the complexity of the document content.

Electronic display technology

The quality of the displayed information on a notebook computer is, however, nowhere near comparable to that of paper. The overriding factor in the quality of an electronic presentation system is the display technology. The nature of the display affects the readability and spatial layout of the information. With the batteries required to make it portable, the display also has a large influence on the weight, volume and cost of the resultant system. Table 2 shows the size and resolution of the LCD display used in current notebook computers compared to that of information printed in various ways on a piece of paper.

Table 2. Comparison of sizes and resolutions of printed paper versus liquid crystal displays.

	A4 offset printed colour	A4 laser printed colour	A4 fax monochrome	10.4" LCD 800 x 600 colour	Xerox P20 AM-LCD monochrome
Display area (sq. inch)	96	96	96	52	78
Resolution (pixels per inch)	2,400	300	200	75	285
Total pixels (Mpixels)	550	8.6	3.8	0.29	6.3
Depth of colour (bits per pixel)	3	3	1	8	1
Storage (MByte uncompressed)	210	3.2	0.48	0.29	0.79

It can be seen that 10.4" diagonal LCD displays, as used in current notebook computers, are still smaller in area and of much lower resolution than printed fax pages, let alone printed magazine pages. They attempt to make up for this with more colours per pixel (picture element), but this does not improve the quality of monochrome text.

The overall storage required for an uncompressed page image, shown in the last row of Table 2, gives a rough indication of the detail that can be shown using each presentation medium. The greater the storage, the finer the quality that can be presented.

Of course, future advances in display technology will allow gradual improvement in these size and quality factors. The last column in Table 2 shows, for comparison, the attributes of a research prototype display. The P20 display developed at Xerox Palo Alto Research Center (Martin 1993) is an active matrix LCD screen with 3072 x 2048 monochrome pixels at a resolution (285 pixels per inch) approaching the 300 dots per inch of an earlier generation of monochrome laser printers (which now are typically offering 600 dpi). However, this prototype would not only in practice be far too costly to manufacture for many years, but its high power consumption would also not allow it to be battery operated for the foreseeable future.

As far as the portable, battery powered display is concerned, research into new kinds of bistable passive LCD currently underway (Surguy 1993, Mosley 1994) may lead to larger, higher quality displays that consume power only when being updated. In addition, development of new flexible substrates may offer lighter, more resilient display panels.

Readability

It has been seen that display technology may take some time to reach the size and quality of the printed page, especially in fineness of detail. However, there is reasonable evidence that electronic displays can compete already in terms of readability of larger text fonts. Comparisons of the readability of information displayed on CRTs (cathode ray tubes) have been carried out since the days of character-based displays.

With the advent of raster graphics and higher resolutions, reading from CRT screens has improved to the point where, on some measures, reading speed and comprehension are found to be comparable to that of the paper medium (Muter 1991). However, in that experiment, skimming, in order to grasp a general sense of the content, was still found to be some 40% slower from a CRT. The latter may depend more on the spatial context of the text presentation than on the readability of individual words.

Very few studies have been carried out to date on the readability of LCD screens, or of using known techniques, such as anti-aliased text, to improve the fidelity to the printed form. In general, there are so many factors to be taken into account when assessing readability that the experimental evidence is rarely consistent (see Dillon 1992 for a review of the literature in this area).

With displays of text, readable screen fonts can be created provided there is sufficient screen resolution. Typically, finer details of the typeface that would be preserved on paper are lost on the screen, but without significant loss of readability. For handwritten text and drawing, however, and for finer graphical detail, there is still a long way to go before display technology can come even close to the quality of paper and pen. Even for screen text fonts, LCD displays do not currently have enough pixels to display a complete, readable A4 page.

The spatial layout of information on the page is an aid to recall (Lovelace 1983) and can be of help when browsing and finding one's way around a longer document. In systems in which information is reformatted to fit the arbitrary size of a display window, much of this spatial context can be lost. Research is in progress to see if the essence of graphic layout can be retained even when the parameters of the viewing space are different from those of the printed page (Weitzman 1994).

Despite the rate of progress of electronic technology, and though graphics designers are rapidly having to come to terms with new interactive paradigms, it would be foolish to imagine we can lightly discard the familiar conventions, developed over centuries, for paper-based presentation of information.

Distribution

The paper medium has been the main form of information distribution for centuries, but distributing information on paper involves significant time and cost. One of the prime advantages of the electronic medium is that, given a communication infrastructure, the time and cost to distribute information can be minimal.

With paper, the sender has reasonable confidence that the form in which the information arrives is the same as the form in which it was sent. Unfortunately, this is not yet the case with information distributed and presented electronically. There has been slow progress towards standards for information exchange that can convey sufficiently rich and accurate content to satisfy senders. This is especially the case for publishers, whose reputation can be linked to the visual quality of the received information.

The representation of electronic information has for many years been either as unstructured image, for which the Group 3 fax is by far the most widely used standard, or for structured formats that are tied to the application which generated the information.

In the last two years, new structured representations have been proposed for distribution of electronic information, with development of the associated software for presenting the information on standard platforms, often being offered at no cost. Examples of this approach include Adobe's Acrobat, Farallon Computing's Replica, No Hands Software's Common Ground and Novell's Envoy (Seybold 1994). Structured representations allow processing, such as searching, to be performed by the reader, as well as often reducing the storage required for a document.

All of the systems mentioned above aim to preserve the appearance of the information as it would be seen on the printed page. However, since current screens cannot display a whole page at a time while maintaining acceptable readability, much of the immediacy of the full page layout is lost. Often the screen is used simply to confirm the identity of the document, so that it can then be printed and read from the paper medium.

For less formal communication, paper can be used in many formats to support social interaction in the workplace (Frohlich 1994). Memos, stick-on notes and printed forms all have their place alongside documents and reports, with ease of annotation being an important attribute. Until recently, the electronic medium has only been able to offer single-font textual e-mail (electronic mail) to support inter-personal communication. Richer electronic formats are being developed, but their rate of penetration will depend on the rate of adoption of computer equipment, such as integrated pen-input devices, that can support the extra functionality.

Manipulation

The comparison so far has been of the static presentation of electronic information to that on the printed page. It is now necessary to look at the extent to which the electronic medium can match the versatility of paper in its dynamic use.

Many people in our culture learn how to manipulate paper documents from an early age. Turning pages, and especially the use of the thumb to control the rate of turning, is possible before the age of two. At the document level, the use of spatial location of a document on a surface, for example to separate those documents already browsed from those still to be considered, is also a concept learnt at a very early age. Perhaps it is simply because many of these behaviours have become automatic, and so invisible to us, that designers of electronic information systems have seldom provided analogous manipulations.

In recent years, interest has grown in addressing some of the less formal manipulations which are so natural for paper. For example, though folders have been used in the past in several contexts, no electronic filing system has yet successfully captured the notion of manipulating a pile of documents, even though this is such a common organising principle in physical offices. Electronic interface concepts based on this idea have now started to be explored (Mander 1992).

The keyboard and mouse may be good input devices for data entry and selection. However, they leave much to be desired as a mechanism for page-turning and riffling. A study carried out at Hewlett Packard Laboratories in Bristol has found positive reactions from users to a prototype hand-held electronic information browser. This allowed two-handed page-turning using thumb-operated pressure pads - more directly comparable to the way a book is held and manipulated than existing keyboard or mouse-driven interfaces (Hawkins 1993).

The work of others has, for example, been aimed at presentation techniques that are relevant for orientation and navigation in the electronic medium in a way that can be perceived by the user without additional cognitive load (Nygren 1992). As the latter paper states: 'one of the characteristics of a good interface is that it appears obvious to the user'.

Another phenomenon that is usually ignored is the impact that continued use has on the paper medium itself - general wear and tear. It happens without deliberate intent, but can convey useful information completely separate from the document contents, such as indicating regularly accessed pages. Here the conventional wisdom might be that the electronic medium has an advantage because it does not wear out - but this is at the cost of some potentially useful data. Retaining historical data within an electronic document concerning its use could add to the richness of the electronic medium (Hill 1992), provided it does not impose an additional burden on the user in capturing or accessing the data.

The aesthetics of paper

In the rush to provide additional functionality in the electronic medium, it is all too easy to forget some of the aesthetic factors that may be the ultimate barrier to our full acceptance of it.

The feel, texture, quality of binding and the experience of handling a familiar book are too subtle to have yet been captured. The personalised nature of the pencilled notes in the margin, or the turned-down corner of a page are absent. Above all, the simplicity and directness of perception and physical manipulation of the page remain beyond our ability to emulate.

Conclusions

This article has aimed to show that in terms of not only information content, but also many other tangible and intangible aspects, the electronic presentation of information is not yet comparable to that of paper.

Electronics offers compact, lightweight means of storage. In specific areas, such as ease of lookup for reference works, or support for animation to illustrate educational texts, the electronic medium could offer a particular advantage. This is especially the case if interaction increases engagement with the presented material. In general, however, the paper medium is not in any danger of being displaced in the foreseeable future. Its quality and universality will be hard to beat, especially with the need for power-consuming devices to mediate access.

An analysis of the places where the electronic medium falls short of the attributes of paper can be used to point to opportunities for further developments. It is not simply a question of emulating the paper medium, but of identifying the places where there is a real disparity and using them to motivate new advances in the electronic presentation of information.

In this way, it is hoped that in the future it will not be necessary to give up some important attributes of paper in order to reap the additional benefits of the electronic medium.

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