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# PLink: Paper-Based Links for Cross-Media Information Spaces

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**Abstract**

PLink is a system for integrating physical and computer desktops by creating paper links to digital resources. PLink leverages diverse formats of physical paper, ranging from tiny stickers that can be easily incorporated into traditional paper media to very large deskpad sheets that make the physical desktop partially interactive. We present PLink and initial results from a multi-week field study.

**Keywords**

Interactive paper, linking, deskpad, document, information management

**ACM Classification Keywords**

H5.2. Information interfaces and presentation.

**General Terms**

Human Factors

**Introduction**

Although an increasing portion of our professional and personal activities involves digital media, pen and paper remain centrally involved. We affix post-it notes to the edges of displays and jot down notes and sketches on scraps of paper, in notebooks, and on deskpads. Our work areas increasingly are an amalgam of digital and

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paper media with little but physical location and our memories to link them together in useful ways. This mixture of paper and digital materials supports a view that each has unique beneficial properties difficult to replace with the other. Sellen and Harper extensively document this view in their seminal work [8].

In this paper we describe a system that leverages interactive paper as a cheap and simple means for integrating the physical and the computer desktops. A large paper deskpad makes the physical desk surface semi-interactive (Fig. 1). *Paper links* (PLinks) created on this surface can be used to manage digital information spread across the desktop computer and the web. The deskpad provides an always-on, peripheral display surface that offers a very high resolution. Due to its large size, it does not only allow to have a large number of links in direct reach. In addition, we envision it to offer appropriate support for reasoning processes that require relating many different pieces of information. We present a first version of the PLink system and initial results from a multi-week field study.

### Background and Related Work

A combination of paper and digital documents is often used to organize information [8]. Paper-based practices let people save, filter and transform information, by helping select and synthesize information. Practices involving post-it notes and casual piling are recognized as effective information management techniques [1, 5].

With information storage and management moving off the desktop into the cloud, Web-based information assumes an increasing importance. Studies of Web usage (e.g. [12]) document that bookmarks are often difficult to retrieve, mainly due to lack of visibility or awkward

representations, or because of cumbersome automatic labeling based on Web page metadata. By enabling users to create bookmarks on their physical desktop, we begin to address these problems by laying out digital information on the physical desktop and supporting casual paper-based practices.

A range of augmented paper systems have been presented in the literature that support hybrid paper-based and digital notetaking [2,10,11]. The Interactive Giga-pixel prints [13] integrates large printouts with overlaid real-time digital information. WebStickers [4] support interlinking of paper and digital resources, Print-n-Link [6] enables the publishing of interactive PDF documents with integrated hyperlinks, while PapierCraft [3] enables linking from paper to related digital documents. CoScribe [9] allows users to create paper-based links to Web pages, integrating paper and digital documents on one single tabletop surface.

In contrast to previous systems, PLink introduces large *deskpads* as a medium for physically linking digital resources. Moreover, it remains unclear how paper-based linking can be effectively integrated into work practice, since to our knowledge no studies have been undertaken to evaluate longer-term usage of paper-based links. We present results from a multi-week field study of PLink to address these questions.

### The PLink System

PLink relies on Anoto digital pens. These behave like ordinary ballpoint pens, but in addition capture all traces in digital form by decoding a specific dot pattern printed on paper. Pen position is streamed in real-time via a Bluetooth connection to the user's computer, on which the PLink application is running in the back-

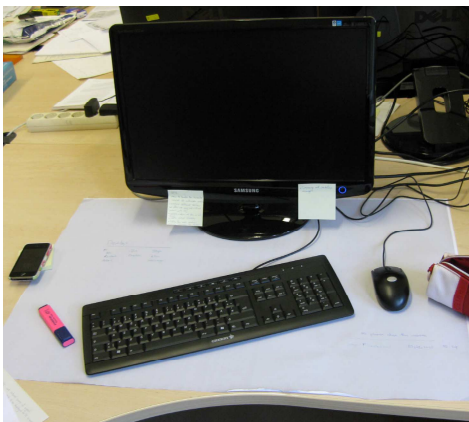


Figure 1: The PLink system setup. A large paper deskpad makes the physical desk surface partially interactive

ground. In our approach, hyperlinks are the key mechanisms for integrating paper and digital resources. They provide physical structuring and access to digital resources. Figure 2 shows an overview of PLink.

PLink supports different types and formats of paper media covered by the Anoto pattern, reflecting the wide variety of paper media used in the office. We currently offer very large *deskpads* (A0 or A1 format), which can be placed on the desk surface and provide a large “always-on” space with a high degree of awareness for noting information and creating links. Moreover, we offer empty sheets of A4 or letter-sized pages, post-it stickers, also covered with the Anoto pattern and very small stickers (1.5 x 1.5 cm in size) for conveniently adding links into traditional, non-patterned paper media, such as books or notebooks.

PLink enables linking regions on paper to digital resources. Previous work [12] pointed out that the systematic separation of bookmarks, files and e-mails is inconvenient. Therefore our goal is to integrate different types of digital resources by means of hyperlinking. The prototype allows creating links to common kinds of documents: 1) web pages, 2) any folder or document in the local file system, 3) PDF files. PLink is designed in a modular way. It currently contains plug-ins for Mozilla Firefox, Windows Explorer, Mac OS Finder, and Adobe Acrobat. By providing more plug-ins, the system can be easily extended to link against other kind of resources, such as emails. PLink is implemented in Java and runs on MS Windows and Apple Mac OS.

Links are created using a simple pen ges-

ture. This gesture links a region on paper to the digital resource of the currently active window (the URL displayed in Mozilla Firefox, the page of a PDF document in Adobe Acrobat or the currently selected folder or file in Windows explorer, the Finder application or on the desktop). We designed this gesture with the goal to be easily integrated into established note taking practices.

Figure 3 shows the steps for creating a link. By holding down the pen for 500ms without moving, the link creation mode is entered. Any one-stroke symbol that is drawn before lifting the pen is recognized as a link gesture. The link gesture serves as a visual indicator of the link anchor. Tapping on the gesture with the pen activates the hyperlink. The target document is opened or set to the foreground. Since information written on paper is persistent and cannot be removed easily, PLink allows for deleting content of the digital representation of the document and then reprint the document.

### First Results of User Studies

A pilot study with twelve participants was conducted with a first prototype of PLink in the lab. PLink was compared in a within-subject design to a purely digital setup. The study consisted of performing two Web-search tasks that each required that the participants integrated information from many Web sources. The results revealed that paper links are effective in supporting users organizing digital resources during web searches, rapidly access these resources, and quickly reinstate the context of a prior search.

A multi-week explorative field study of PLink allowed us to analyze how the system gets appropriated and integrated into existing work practices. This seems particularly relevant since prior work on paper-based linking

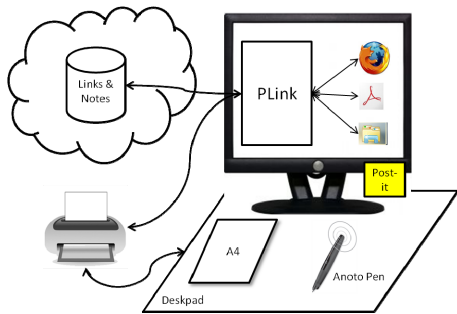


Figure 2: Overview of the system architecture

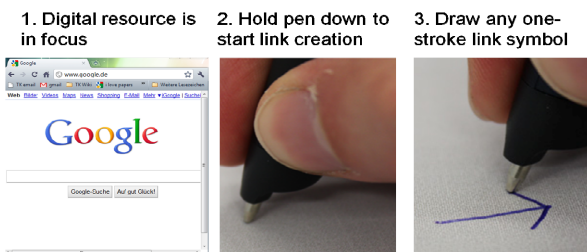


Figure 3: PLink creation process

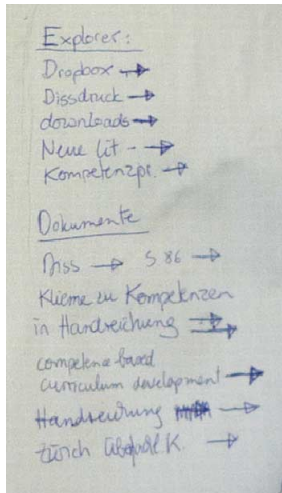


Figure 4a: PLink list

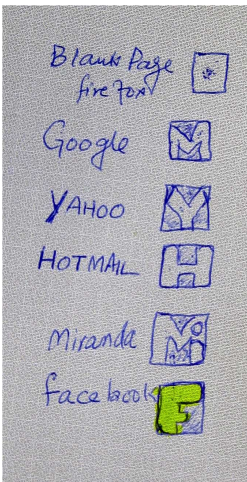


Figure 4b: PLink Portals

[3,4,6,9] did not examine longer-term use. We documented the temporal and spatial usage of PLink and assessed how the system integrates with traditional pens and paper media. Ten volunteer participants used PLink over a period of four weeks at their workplaces. They were initially shown how to use the basic functionality for creating and to following hyperlinks. However, they were completely free to use the system for any purpose and in any way they wanted. In particular, we did not showcase any way of how PLink could be used. For gathering feedback, we conducted three semi-structured interviews with each participant, took photos of their desks each workday, and collected and analyzed usage logs. In the following we report on our initial data analyses.

*Closer Integration of the Physical and Digital Desktops*  
PLinks were mainly created as a means for directly and rapidly accessing digital resources through paper-based link lists (Figure 4a) or personal “portals” (Figure 4b) which allowed users to quickly access files, folders, programs and web pages. Such lists and portals consisted of several hyperlinks which function as *bookmarks* to resources that are frequently accessed.

Users commented on the importance of accessing these resources quickly and having them at a fix location on the desk. P5 commented that “*PLinks are always available, [they] are always in my view*”. P10 stated “*it is great when there is paper lying right in front of me and [...] then I click on it and I am directly there*”. Accessing PLinks was characterized as “*quick*” (P4, P5), “*faster*” (P9) and “*save[ing] mouse clicks*” (P1). Portals were created at the side of the desktop associated with the user’s dominant hand and at locations not normally occluded by other documents or objects. One exception

was an online banking link which the user hid on purpose below the keyboard.

In addition to portals, the high awareness of information on the physical desk was leveraged for quick reminders. Four participants (P1, P3, P7, P9) used the desypad as an external memory for quickly noting information that would be required soon thereafter, e.g. noting information during a phone call which would be used in writing an e-mail message.

#### *Flexible Spatial Organization*

Physical space turned out to be a key dimension for flexibly structuring information with PLink, both on the macro-level of the entire desktop and on the micro-level of an individual document. On the desktop, physical space was effectively leveraged for information portals and quick reminders. A fixed anchoring in space and the resulting high degree of awareness of information on the physical desktop was central to supporting long-term access to links.

On the micro-level of individual documents, participants leveraged the flexibility of PLinks, pen and paper for organizing information in spatial, non-linear structures. In contrast, without PLink users structured their results in a rather linear way. Figures 5a and 5b illustrate a typical example of how users structured information differently using the PLink system: while without the PLink system users almost exclusively relied on noting down information in linear sequences, in the order it was retrieved, with PLink the notes were more topically structured following a spatial arrangement. Moreover, during information gathering tasks (such as Web searches) generally users externalized less information when using PLink. This resulted in lists of links with

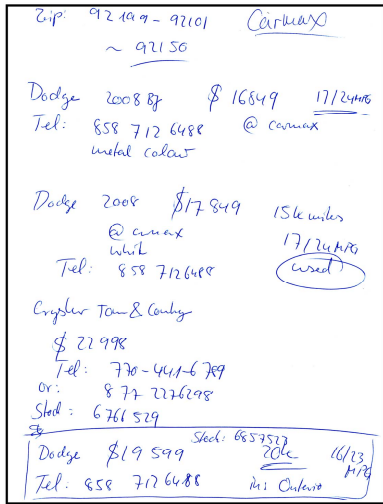


Figure 5a: Spatial organization without PLink

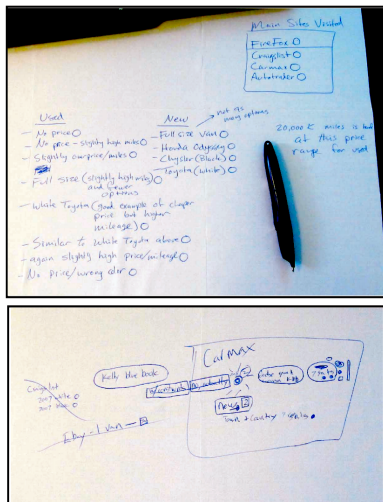


Figure 5b: Spatial organization with PLink

only little additional description or details about the content of the linked resource, since the contents could be quickly accessed using the hyperlink.

In addition to flexible spatial structuring, participants eased refinding information by choosing individual link descriptors and individual link gestures. These were comprised of arrows, small circles, labels (in which the link symbol was the first character of the label) or specific symbols which resembled the logo of the application or web page the link pointed to (Fig. 4b).

#### Temporal Use of Links

We analyzed how long and during which periods of time PLinks were activated and how this was influenced by the paper medium PLinks were created on. For comparison, we used the study by Obendorf et al. [7], which analyzed revisitation of web pages. They examined different types of revisitation, one of them being 'direct access' which is comparable to the bookmarking function of PLinks. They found that most direct access revisitations occur shortly after the page was initially accessed. Over time revisitations decrease continuously. Their data is shown by the dashed line in Fig. 6.

We analyzed how PLink activations in our study were distributed over time. This is also depicted in Fig. 6.<sup>1</sup> We identified two different patterns. P6 and P9 can be classified as *short-term linkers*. Most of their link activations occurred during the first hour after link creation with constantly decreasing percentages over time. This is consistent with Obendorf's findings. In contrast,

<sup>1</sup> Only participants who created and accessed links until the end of the study. We removed link activations occurring during the first minute after link creation, assuming that these were made for checking if the link was correctly created.

three other participants (P1, P4, P10) expose a pattern of *long-term linking*. These participants activated links most frequently in the week following their creation (P4) or after more than seven days (P1, P10). It is noteworthy that overall we identified a considerably higher frequency of long-term use than Obendorf.

Figure 7 compares the activation frequency of links created on A4 sheets and on the larger deskpad. Like browser bookmarks [7], activation of links on A4 sheets was highest during the hour following their creation and constantly decreasing over time. In contrast, activation of links on the deskpad remained fairly constant over time. Links on the deskpad were activated almost twice as frequently (in average 4.9 activations per link, SD=57, N=292) than links made on A4 sheets (2.6 activations, SD=29, N=305). This is inline with statements from the interviews indicating that the deskpad is a better medium for long-term links and long-term bookmarks. We assume that the visibility of the links is an important factor for long-term use. While participants had constant awareness of links on their deskpad that remained in their view, links on A4 sheets (and within the browser) tended to be out of sight.

#### Usage of the Digital Pen

Most participants disliked the Anoto pen and preferred using other pens. The pen was perceived as too large and too thick for writing (P3, P4, P5, P6, P10). P3 stated: "With this pen, one really cannot write. (...) The form factor is terrible." In addition to the inadequate form factor, other characteristics of the Anoto pen were problematic in comparison to a normal pen. Sometimes the pen vibrated, which frightened several participants (P1, P4, P9).



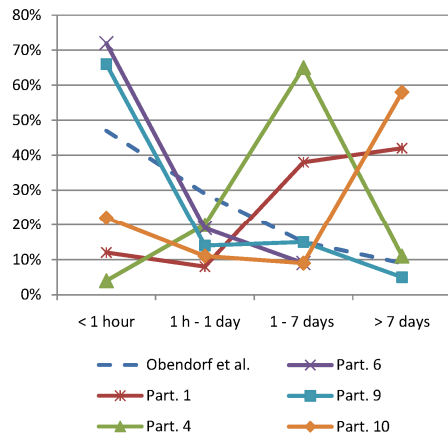


Figure 6: Temporal usage of links (points are interconnected for better readability)

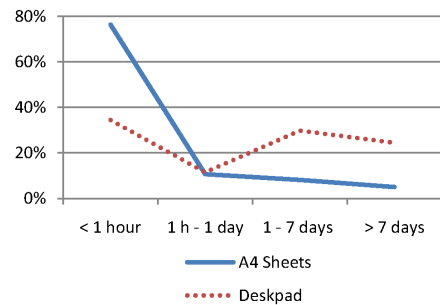


Figure 7: Temporal usage of links per paper type

As a consequence, all participants continued using their traditional pens. All but P7 considered the Anoto pen not to be a tool for writing, but only for linking. As an extreme case, P5 used the Anoto pen only for creating the link gesture by writing the first character of the link label. The remaining characters of the label were written with another pen. These findings stand in contrast to the common argumentation in the literature that Anoto pens can be used like traditional pens.

### Conclusion and Future Work

Our initial observations highlight how PLink integrates the physical and digital desktops more tightly. PLinks have proven to be useful for rapidly accessing digital resources. This comprises “portals” consisting of links to digital resources needed on a long-term basis that participants created on their physical desktops and tightly integrate different types of digital resources. Physical space turned out to be a key dimension for flexibly structuring information with PLink. A fixed anchoring in space and the high degree of awareness of information on the physical desktop appears to be central to supporting long-term access to links. In future work we plan to extend the PLink system to support implicit linking of resources by automatically detecting temporal and spatial relations between the use of paper documents and digital resources.

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