Combining Physical and Digital Documents

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INTRODUCTION

Paper has been the dominating means for capturing and storing written language for several centuries. Recently, computers have been established in this domain at the same time offering a far wider range of features. This has led many to believe that the use of paper might be completely replaced by computers in the near future. Yet there is no empirical data supporting such a hypothesis. (1)

Let us try to offer some explanation for this phenomenon by highlighting the key properties of pen and paper in contrast to the common computer workplace consisting of screen keyboard and mouse or an alternative indirect pointing device.

Paper itself is lightweight, cheap and readily available. It is flexible, durable and recyclable, furthermore quick to skim and navigate. Its visual properties, such as contrast and resolution, are superior to computer screens. It requires neither batteries nor external power sources for reading, and writing, unlike printing, also works without external energy. Paper is available in many standard and custom sizes at almost linear costs, and users can easily adapt stock sheets to individual sizes and forms using scissors and adhesive tape. Writers use pens seamlessly for text and graphics alike. Small or flat physical objects can be attached to a sheet of paper. Paper mixes well with other materials employed for special purposes, such as transparencies.

However, paper is static, its contents, especially if printed, can hardly be changed. Reproduction and distribution are relatively expensive. Large quantities of data require costly archives while single sheets can get lost due to their weight. Textual context on paper is not easily searched for or copied and reformatted. In the end there are also subjective, hard to measure factors of taste and fashion that may swing the pendulum in either way.

pro	con
cheap	expensive archiving
light	single sheets get lost
easy to navigate	not searchable
durable	static
very flexible	difficult to reproduce
readily available	difficult to distribute
high resolution	
excellent contrast	

Table 1: Paper properties

There are many ways to get contents onto paper depending on the means and purposes and all can be mixed with each other. They range from individual editable input using pencils and eraser over more persistent pens or stamps, mechanic typewriters, electronic printers and copiers to mass production printing presses. We shall restrict ourselves to pens and printers for the rest of this paper.

If one plans to describe and compare different approaches to combining paper and electronics, it is essential to differentiate between the abstract concept of a "document" and its several material forms, i.e. mainly, as either sheets of paper with printed or handwritten ink (typographic / chirographic) on it or as a computer file comprised of bits.

RUNNING EXAMPLE

In recent years, several approaches to combine paper documents with electronic ones have been tried. These generally evolve around a specific purpose or application and present a possible solution where paper and digital versions of documents are combined to make use of advantages of both sides.

To offer a basic understanding of the ideas, technologies and problems involved we, too, will present an example setting which we will use to demonstrate some of the approaches.
While examples presented in scientific publications generally stem from knowledge work, often in scientific environments themselves (for instance (2), (3), (4)), we would like to offer our readers a different starting point.

We chose pen and paper role-playing games (P&PRPG) as our setting and we want to suggest possible solutions to enhance the gameplay by using means of combining electronic and paper documents.
These games are played in groups of around four to six people and usually last more than one session. Although there exist computer RPGs alongside P&PRPGs, sometimes even sharing common basic rules, we do not aim at combining those two game types. Combining those two distinct interaction systems would be a totally different matter than combining electronic and paper versions of documents.

Our example RPG group consists of six players, of which one will be the game master who will run the game as narrator and referee. Our players are all grown-ups and have little spare time due to demanding jobs. The players meet about once a week and play in the living room of one of the participants. The system played is The Dark Eye (TDE, German: *Das Schwarze Auge, DSA*) which has very complex rules compared to competing systems. The tools used by the players are pen, paper and dice.
The basic problem we are aiming at is that often data is lost in between game sessions and the game group has to reconstruct it. Players use two documents to keep track of data relevant to them: *Character Sheet* and *Journal*.[1] But being kept on paper these documents, too, are often lost or left in the wrong place due to some short notice changes.
One possibility to address these problems would be to use common handheld devices like smart phones to handle these documents. However the paper form has several advantages as stated in the Introduction. Apart from the speed of access to the data, players may feel computer-like devices do not fit into a game which is set in a medieval fantasy setting. Atmosphere is a major aspect of the game and cannot be neglected.

We suggest to use paper documents during the game sessions and to make electronic backups that can be distributed over the web or stored on electronic devices that people usually carry with them. As the game sessions are held at a player's home there is commonly a printer available to reprint the electronic versions at the start of a new session. In the exceptional case that this is not possible the players may also continue to use previous print-outs. The interesting part of this suggestion is the quest of how to synchronize paper and electronic version of the documents.

The first document, the Character Sheet, is basically a fill-out form where the data is kept in

[1] Both document types also appear in CRPGs where we have taken the name Journal (also known as "Quest Log") from. In pen and paper scenarios the term most often used is "notes".

specific fields. The fields usually put validity constrains on their values, e.g. numbers in a certain range or few words from a limited set. When numeric fields are changed this is often an increase or decrease by a small integer amount. The paper versions of the Character Sheet do provide additional free fields where changes during a game session are to be noted.
Since this form already is available as electronic versions and there also exist software tools to handle ruleset applications on them, this document seems to be the ideal candidate for our suggestion.
But how to connect those different versions?

SCANNING

The first group of technologies that comes to our mind is scanning and photography. Optical scanning of physical documents has long been established. There are devices available to automatically recognize a batch of full pages (flatbed scanners with automatic feed) or complete books (overhead book scanner) as well as ones for reading single words or lines of text (portable pen scanners). Apart from such special-purpose devices, which are optimized for certain tasks, photos taken with digital cameras and mobile phones containing one can be analyzed by software in much the same way, it may even run on these mobile devices instead of a full-size computer. The contents read this way can be analyzed for typographic macro structures, like lists and headings, and text is recognized ("optical character recognition", OCR) with impressive accuracy, even when written by hand.

In the RPG example this would enable us to connect the paper form with an electronic version which could then be used as a data source for a character administration tool to handle to complex ruleoperations. However that two step transition of the data may result in additional workload of correcting and checking to use the administration tool.

As advanced as the scanning technology may have become, this approach can only ever examine a finite state of a physical document. This is sufficient for recognition of known documents, but the scanner cannot know the exact sequence of actions that were used to arrive at any given state. The best a user can expect is an automatic comparison to a known previous state and some heuristics to reconstruct parts of the writing process. When scanning books and similar media which are unlikely to be changed on a regular basis since they needed to be in some sort of a final state before going into mass production, this usually is not an issue at all.

In case of the the RPG character sheet, on the other hand, the genesis can give useful information for the character management. The simplest idea to tackle this problem would be to add more fields to the form to collect all the other possibly relevant data. This however does not comply with the demands of use of the character sheet during game sessions.

PEN-STROKE RECORDING

Very different to scanning is the approach to just record the changes, i.e. the pen-strokes themselves, which is also closer to the original use of pen and paper.
Scientists and engineers have devised a number of methods to record pen strokes. Each has advantages and disadvantages; none works without electricity, battery or wall socket, available at the time of writing. It is possible to classify all different known methods into the following four cases.

The first class of methods employs a camera to film the process of writing. Even if automatic tracking was employed, this requires the hand, pen and paper to be in a restricted area at all times to be visible for the camera. Since the ink may be covered by hand and pen the software needs to analyze all kinds of different angles to derive the actual strokes and distinguish random hand and

pen movements from them. In such a setup it is easily possible, though, to identify any recurring document coming into the field of view of the camera, but it cannot be distinguished from a facsimile and recognition may fail if the paper was modified outside the observed area.

In the second class, instead of a video camera other sensors that do not rely on a line of sight are used to capture the movement of the pen itself. These can be based on radio or magnets for example. These sensors have to be attached to the paper or vice versa. Clips or Clipboards are the common form for this. The characteristic of this class of methods is the use of a relative coordinate system, fixed to the paper. Either the clipboard surface or the pen or both need to be equipped with additional pressure sensors to recognize the pressure that is applied while inking, necessary for recording strokes. (3)
Sheets may be remembered if they are tagged, for instance with a page number at a standard position that is drawn again or manually selected from the electronic device's user interface (UI) that can be incorporated in the clipboard. Otherwise changes to a reinserted physical page will result in a new logical document or, worse, are applied to a different existing one. If circuitry is only in the board, color support (and other features) can be added in a similar way: The writer needs to issue a command either in a designated area on paper or with a gesture, i.e. an unusual and conventional pen stroke, or by using special device controls – the actual ink color then not necessarily resembles the one stored electronically.

The third class of methods employs an absolute coordinate system and seems currently the most prominent solution among researchers. It uses special paper that has many tiny dots printed on it, which are practically invisible to the human eye due to size or, possibly, ultraviolet color. The unique pattern of dots makes it possible to locate even small areas unambiguously within a virtual space of more than 2^{44} m², which, although incredibly huge, is in the magnitude of hundred times the area of all paper annually consumed in the United States. (5)
A camera is needed to record that pattern and is usually put inside an electronic pen ("e-pen"). To recognize dots covered by pen strokes a special kind of ink is used. The commercial system of this type most commonly used is called *Anoto*.[2] The e-pen may be extended to offer handwriting recognition and interactive applications instead of mere recording, for example the rolling of dice of arbitrary sides can be simulated this way if they should be missing[3] in our scenario and calculations can be done semi-automatically. If a microphone is included internal audio recordings can be used, which avoids the aligning of timestamps that often is necessary when combining pen stroke recordings with external audio or video recordings for synchronized playback.

Finally, there are paperless systems using inkless pens ("stylus"), sometimes substituted by fingers, as input devices; track pads, touch screens and graphic tablets are the most prominent among them. Since our topic is the combination of electronic and physical documents and not, at least not primarily, the transfer of physical habits and actions to the purely electronic domain, we will leave these out of our discussion for now.

Many stroke recordings today are done in proprietary formats, but several companies are actively working together at the World Wide Web Consortium (W3C) in developing an interchange format called "Ink Markup Language" (InkML)[4]. It even is human-readable.

GESTURES

This technology enables us to fill the gap between paper character sheet and computerized administration tool that bugged our example so far. Gestures in the pen and paper environment can be linked to standard commands for the tool for example value increments. These gestures would

[2] http://www.anoto.com
[3] http://www.livescribe.com/store/p-424.htm
[4] http://www.w3.org/TR/InkML

still need certain reserved spaces on the paper sheet to be recognized but they can be stacked since it is not their visual output that is relevant.

The standard Anoto-paper blocks available for the commercial Livescribe[5] system come with a special page that shows amongst other options the interface of a common calculator which can be used for input by tapping with the pen on the paper.

Capturing the time as a third dimension of the input enables new was of interaction. Pen and paper then are not only restricted to a mere textual input device, but can also recognize commands for execution on the electronic document that need not be inked in the next printout.

Proof reading marks, for example, have been used for centuries in the typesetting industry and were standardized by DIN 16549 and others. Using them, editors can make elaborate notes to text where orthography or typography has to be corrected, including line or paragraph breaks, misaligned letters or words and font formatting. These can be seen as a predecessor to systems such as PaperProof. (6)

Modern hypermedia needs more than editing marks for deleting or inserting characters and breaks, thus PapierCraft (7) introduced command gestures for associating text with graphics of any kind, among other things. Whereas the authors, Liao and Guimbretière, decided to have distinctive curls in gestures to mark them unambiguously as such, later applications (2) chose a more practical, author-friendly approach with simpler and quicker gestures, moving the burden of distinction from the human to the computer side.

We now take a look at the second document used by the RPG players, the Journal. The Journal is meant to keep track of all information the player character acquires during the game which might turn out to be relevant – in a way it is the character's memory. As a document it consists of all notes the player takes to remind himself of certain facts as well as documents, pictures or maps handed out by the game master. So the Journal is an agglomeration of very different document types that have variable links to each other.

Let us focus first on the most basic function of the Journal, taking notes.
Players take notes when they want to remember certain facts. Due to the nature of the game the future relevance of those facts is mostly unclear and several weeks may pass before any relevance surfaces. In many cases players do not actively keep those facts in their own minds but, instead, fully rely on their Journals to work as a memory extension. Therefore quick access to this external memory is very important.
The players use blank sheets of paper for the notes and try to keep the number of pages low for quick access. The single entries are grouped by context where applicable and timestamps are used to identify the game sessions. Hence there are two possible search parameters, time and content, to find specific entries.

The pen stroke recording solutions introduced above are applicable here, too. They do not only enable the user to transfer the writing from paper to a computer but also provide timestamps for each pen stroke. This enables the user to focus on the logical connections of their notes and still get the data necessary to search the notes by time. However while pen stroke recording enables this sort of enhanced recording there is currently no established format to print it out again for easy access. Because we focus on paper input in this text we leave further research in this direction to the reader.

[5] http://www.livescribe.com/de/smartpen/dotpaper.html

	Electronic marker	Visual marker	Fiduciary marker	Word geometry feature	General image feature
Typical tool or algorithm	RFID	QR	Anoto	BWC	FIT, SIFT
Tagged document types	generic	generic	generic	text	generic
Author effort and cost	high	middle	middle	low	low
Computational complexity	low	low	low	middle	high
Required sensor	RFID	camera	e-pen	camera	camera
Visual guidance	—	inherent	—	—	—
Reader-defined tags	—	—	arbitrary	arbitrary	arbitrary
Spatial tag density	low	low	high	high	high
Encoded data capacity	low	high	high	—	—
Max. interaction distance	close	far	contact	far	far
Robustness, scalability	high	high	high	limited	limited

Table 2: Tagging technologies compared, after (12).

LINKING AND TAGGING

In our example, the Journal does include more than taking notes. It embeds pictures, sketches and maps. The blank sheets of the Journal do allow free drawing but during the game the player will often not draw them himself. They may be provided prefabricated by the game master or can be handed on from another player with better artistic skills.

Besides different kinds of drawings there are also other handouts provided by the game master: text passages or lists of character names. Text handouts are used to represent in-game documents, name lists serve the purpose to enhance note taking by reducing the workload of figuring out how to spell fantasy names, also some basic data on the characters referred to can be provided.

The advantage of all the above forms of document sharing lies in the fact that the Journal writer can include the shared documents without the need to copy the content. Manual copying with pen and paper takes too much time. However the writer needs to establish links between these documents. Just taking them as a set with no order or links would not go well with the demand of quick access.
The PapierCraft system presented in Gestures does provide support for this problem. Its possibilities to mark paper space are not restricted to existing text but can also mark blank spots. Thereby the writer can reserve areas on his Journal pages where the computer should embed the corresponding document upon synchronization. The real problem lies in establishing links between the documents, because that needs a means of identification for each document.

As explained above documents and paper sheets should be uniquely identifiable by electronic systems in order to facilitate harmonic and transparent integration. Not only that, but also other physical objects may have to be identified to successfully associate them with documents. Many working solutions exist for most use cases, see Table 2 for an overview and quick comparison.
Optical recognition from (live) photographs or videos using algorithms like FIT and SIFT is the most universal, but also the most computationally complex and demanding solution. Google

Goggles[6] is but one example of a commercial application that maps visual data to related information in almost real time.
The identification is much simpler if only textual data is to be interpreted. This should suffice to identify most resources in our RPG scenario, for example manual pages, that do not use fiduciary markers, i.e. *Anoto* paper, so the players do not have to explicitly label them.

For decades, machines have been aided by explicit visible tags, especially in the form of one-dimensional barcodes, but increasingly two-dimensional matrix codes are being used. These are usually provided by content creators, rarely by readers. While our game master may have bought a rule book online after he had seen an advertisement in a magazine or on a poster which used a Quick Response (QR) or similar code to direct him, using his camera phone, to the correct web address without manual input, he will not use such technology during the game.
Machine-readable radio frequency identification (RFID) tags are also becoming common-place where optical recognition does not suffice and higher costs are acceptable. The latter, at least, is not the case for casual P&P RPG players.
Instead of pictures the game master may introduce figurines from his collection to the players to better illustrate characters. He will not want to alter their appearance, not even with labeling stickers, but after the game he puts them back into their boxes which carry the tags instead. Other objects, due to their size, material or value, might also be tagged indirectly, some may fit into envelopes. (2) Since physical objects cannot be copied as easily and not every player owns a copy, they may be replaced by photographs, drawings or 3D models in the electronic version for the other players.
Tags need not be restricted to an item-identifying function, they can also work as commands as described in (8) where the term *tooltags* is coined for them.

AUGMENTED REALITY

Unlike much of the other technology suggested for integration of physical and electronic documents there already exists a considerable market penetration of mobile networked computers with cameras ("smart phones") that are able to use visual tags with only minor software modification. At least one of our players probably carries one with him at all times.
These devices almost always also feature a small color screen of ever-increasing high resolution. It is therefore a small step from recognizing documents (or other physical objects) using the camera to displaying them in an optimized version or with information overlays on the screen. Photo or video altering technology like this is usually called "augmented reality" (AR).

Augments can include annotation from several sources, e. g. confidential details, videos and animations or even interactive applications. In our example the game master may use a device similar to the interaction lens described in (3) that reveals hidden information on maps only to him. The complex setup of the interaction lens, with a graphic tablet and 4D mouse for positioning and a PDA screen for displaying, can be simplified with today's "smart phones", but this only works as long as its camera can capture enough of the surface, i.e. it hardly works with the device laying atop the document.
Even within the limited scope of P&P RPGs, the possibilities of augmented reality are manifold. We shall leave details of this particular topic to other groups.

FRAMEWORK

So far we have seen some examples of how paper documents can be combined with electronic counterparts. We now want to present some basics for an underlying theory, for that part we mainly rely on the works of Steimle. (9) (10)

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[6] http://www.google.com/mobile/goggles/

Sheets	Paper	PPUI	GUI
1	writing	inking	text entry
1	pointing	clicking	pointing / clicking
1	moving	moving	dragging
1	altering shape	altering shape	*(combined)*
n	arranging, combining	combining	—
n	pointing in sequence	associating, bridging	—

Table 3: Syntactic level: "core interactions", after (10)

The first step on the way to a theory is to precisely describe the topic. All our examples have in common that the user interacts with pen and paper and those interactions are transposed to a computer by the technological solution. Hence the pen and paper can be understood as a kind of user interface. Due to its static nature the paper does not provide any feedback from the computer like established GUIs would. But there is no substitution for the missing feedback in our example situations. Therefore we accept the topic of our theory to be Pen and Paper User Interfaces (PPUI).

With this we have already established the lack of output from the computer to be a major downside for this kind of user interface. Thus our focus now has to be an analytic approach to the input. As seen, the input is done by user actions. For each action performed by the user with pen and paper there is an action performed by the computer on the electronic document. As these two actions do not exist independently from each other but are closely connected we speak of just one interaction, which has a *syntactic* and a *semantic level*. The syntax defines what user interactions can be acceptable while the semantics define the meaning of those actions, in other words the conceptional activities they stand for.

The semantic level is not tied tightly by the affordances of paper, as the concepts it refers to stem from the abstract idea of a document. But even if technological restrictions do not fully apply here, human users of electronic documents are trained to their use and are likely to transpose the way they interact with them to the semantics of PPUIs. However, the concepts of electronic documents themselves go back to older forms of documents, i.e. paper documents.
In the examples we have used the semantic concepts of *annotating*, *linking*, *tagging*, *selecting scope* and *writing*.

The syntactic level also profits from our century-old experience with handling paper. While we might think of possible actions with paper that have never before been performed this is not a good approach for user interfaces. Actions on the syntactic level have to be understood by the user, they have to fit his experience and have to be distinguishable. Yet for a systematic approach to PPUIs it is necessary to try to gather all viable P&P interactions. Steimle used empirical observations of test persons as a basis and identified six categories of actions which he calls core interactions:[7]

Inking: Writing with the digital pen on a page area. This includes free form

[7] "Core interaction is defined as an operation that a user performs by manipulating one or more page areas using his or her hands and / or a digital pen." (9)

handwritings and drawings that are digitally captured. Moreover, specific symbols and pen gestures may be performed to issue a command.

Clicking: Performing one or more pen taps on a paper area to issue a command (e. g. on a printed "button" area). This is inspired by pointing gestures.

Moving: Changing the physical location of the page area. This includes picking it up and putting it down as well as flipping pages.

Altering Shape: Altering the physical shape of a page area, for example by bending, folding or tearing it.

Combining: Physically re-arranging or combining two or more page areas. This may be either a loose arrangement (e. g. paper sheets in a binder or on a pile) or a fix attachment (e. g. paper stickers or staples).

Associating: Performing a connecting pen gesture on two or more page areas. This is inspired by consecutive pointing on several items. See also Table 3 for connections to GUIs and traditional paper documents.

These definitions are taken verbatim from (10).

To further the understanding of the problem of finding candidates for syntactic actions, let us take an example from a field Steimle neglects, as he only takes into account actions performed with paper. In a pen and paper setting one may observe user actions only performed on the pen, for example gnawing on the pen. While this may sound meaningless or even like a bad habit, human beings can interpret such an action. Maybe it is a sign for the writer extensively reflecting the current text.
Interpreting a sign is the same as referencing semantics to a syntactic element. Hence gnawing the pen could be a candidate for a syntactic action in PPUIs. But for our current mental model of documents and computer actions we find it difficult to include a semantic concept fitting pen gnawing in a PPUI.
Of course any PPUI may disregard some of the candidates for syntactic actions. Only in the context of a well-defined PPUIs these candidates become syntactic elements and are assigned a specific semantic concept. The choice for these elements for a PPUI depends on the specific task that interface is designed to support.

Taking Steimle's core interactions as syntactic elements is not entirely correct. As noted, the action *inking* does include writing textual phrases as well as issuing commands by gestures. In a strict sense these different semantic concepts each require syntactic representations of their own. Since there will likely be several different syntactic elements using inking in any PPUI establishing subsets where the actions share similarities in their execution can provide an easy access. The PapierCraft system from (7) is a good example for this with the typical swings it includes in its gestures, see Gestures.

The ideas and concepts presented for PPUIs can be applied and adapted for a wider focus of human-computer interactions. Similar writing based settings come to mind, such as whiteboards in class and conference rooms. Any approach to integrate different settings of interaction has to concentrate on the shared syntactic actions. That is one strong reason why certain paper specific actions, like altering shape, are unlikely to get any significant use as long as there are no other versatile computer input methods that allow the same actions.
By integrating different user interfaces into one system the user can be enabled to choose what

interface suits him best in his current situation. In this way the integration is most beneficiary when rather different interfaces are combined, so the range of choice is most variable.

One example which offers a GUI and paper is DocuDesk. (4) The DocuDesk system uses a large flat screen as a desk and a overhead camera to recognize paper on this desk. Different sheets can be identified with 2D barcodes as explained in L. So the work process on the electronic copy of the document can be synchronized. The screen that forms the desk enhances paper sheets with graphical buttons for some standard interactions. In the design of the system a special focus was set on linking, as the DocuDesk itself does not provide the full range of advantages of either paper or computer its strength lies in the combination of both.
Links between different documents, paper or electronic ones, are quickly established on the desk or with a digital pen and with other people over e-mail which is one of the standard actions for each document. If later on a cluster of linked documents is reopened ("rehydrated") physical documents are automatically replaced by their digital counterparts if they are no longer available. Other actions are not featured in this system but are left for either side, the paperwork or the computerwork.

REVIEW AND OUTLOOK

Over the past two decades many technologies have been developed to identify, link, share, synchronize and amend digital and analog documents with each other in order to benefit from the best of both worlds. Some approaches concentrate on personal content generation under practical conditions, others are aimed at adding value to public information, either with explicit tags on author side or with recognition of deployed documents and objects for readers.
Availability of required technology is a key factor for the success of one approach or the other. Unlike some companies our players have little incentive to invest hundreds of euros for digital pen and Anoto paper to improve their game experience, but camera phones are already available to them which would let them access several of the technologies for no or little extra cost if it did not interfere as much with atmosphere.
One of them probably also owns a touch screen device where he could possibly use some of the P&P concepts without paper and maybe even without a pen.

Creation	Target	Electronic marker	Visual marker	Fiduciary marker	Word geometry (content)	Generic image (content)
User defined	Fine			PapierCraft	—	Pacer
	Coarse			—	HotPaper	BookMarkr, ReBoard
Auto-defined	Coarse	—	DynamInk	—	—	—
Manual predefined	Coarse	Marked-up Maps, O'Neill, Paper++	Rohs, designable markers	iPaper, Anoto	—	EMM

Table 4: after (12).

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