Beyond the Digital Capture of Paper Notes: Investigations of Enhanced Natural Notetaking based on Digital Pen and Paper Technology

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To my parents and my brother
Abstract

Even if digital approaches are often considered better than paper for the handling and management of information, research has shown that a paperless office is far from being achieved. Some practices are interwoven with a paper-based information capture—or, in other words, paper-based notetaking—in ways difficult to reproduce in digital systems.

Paper is the medium preferred to capture information especially in situations characterised by aspects such as spontaneity or a certain need to be flexible and unconstrained. For example, writing with a pen on a piece of paper is often the most straightforward approach for offloading details from mind in preparation for a different activity. Throughout this thesis, we refer to the aforementioned and similar situations as natural notetaking.

Anoto’s digital pen and paper technology and similar paper-digital solutions create the possibility to bring together the preference for using paper as capture medium with the benefits of digital information handling. With the aid of these technologies, handwritten information captured on paper can be made available digitally without an intermediary transcription step. Nevertheless, even though Anoto and similar technologies have now been around for approximately a decade, their use for everyday natural notetaking is limited. This thesis investigates possible reasons for this situation and makes a series of proposals towards aligning the use of Anoto’s digital pen and paper technology with natural notetaking.

Our investigations start with a study on natural notetaking practices. The study reveals two main areas to be investigated: support for recall of valuable handwritten notes and providing overviews of the use of paper notes in combination with other types of media. The latter is particularly relevant in collaborative settings. The study also shows a general reluctance of the users towards solutions that would require the adaptation of natural notetaking practices. At the same time, the study shows that some mechanism to support the processing of notes is necessary.

Existing solutions based on digital pen and paper rely on the use of certain rules or guidelines to enforce the processing of information captured on paper, such as requiring users to write within special purpose page areas or use predefined marking gestures. These user-driven processing approaches serve as support for deriving metadata based on which the organisation of notes in digital space is inferred. In an attempt to deal with potential limitations of user-driven processing on natural notetaking, we designed and implemented an extensible digital ink segmentation and classification framework. The framework supports the development of a wide variety of automatic approaches for processing the digital ink representations of paper-based notes, as well as the combination of automatic and user-driven processing approaches. The framework is meant to be used on top of existing frameworks and toolkits for developing digital pen and paper-based applications, with which it can be easily integrated. By allowing the easy
integration and experimentation with different digital ink data processing approaches, the framework supports the developers, enabling them to select and combine processing approaches in flexible ways.

Having the framework as basis, we further investigate ways of supporting the role played by paper-based notes in recalling information, as well as the use of natural notes which relate to other media. For the former, we investigate the extraction and subsequent integration of handwritten information with a range of digital systems offering some recall features. For the latter, we investigate the benefit of solutions providing an integrated view over the notes and the media to which they relate. We present insights gained through user studies performed for the evaluation of each of these systems.

In summary, the contributions of this thesis include: designing and implementing a general framework for developing customary digital ink data processing solutions; identifying two areas where existing digital pen and paper solutions are not likely to provide appropriate support for natural notetaking, and then, for each of these areas, investigating possible solutions.
Zusammenfassung

Obschon digitale Lösungen im Bereich Informationsmanagement und ganz allgemein im Umgang mit Informationen häufig als besser geeignet gelten als Papier, haben Forschungsresultate gezeigt, dass die Verwirklichung des papierlosen Büros noch in weiter Ferne liegt. Gewisse Methoden des Informationsmanagements sind eng verflochten mit einer papierbasierten Informationserfassung—oder, in anderen Worten, mit dem Erstellen von Notizen auf Papier—auf eine Art und Weise, die sich in digitalen Systemen nur schwierig reproduzieren lässt.


Bestehende, auf Digitalstift & Digitalpapier basierende Lösungen greifen auf die Verwendung bestimmter Regeln oder Richtlinien zur Verarbeitung von auf Papier festgehaltenen Informationen zurück; beispielsweise, indem Nutzer in speziell dafür vorgesehenen Seitenbereichen schreiben oder vordefinierte Schreibgebärden ausführen müssen.
Diese benutzergesteuerten Verarbeitungsmethoden unterstützen die Erstellung von Metadaten, auf deren Basis wiederum die digitale Organisation der Notizen erfolgt. Im Bemühen, potenzielle Beschränkungen der benutzergesteuerten Verarbeitung beim natürlichen Notieren zu beheben, haben wir ein erweiterbares Programmiergerüst für die Digitaltinten-Segmentation und -Klassifizierung entworfen. Das Programmiergerüst unterstützt die Entwicklung einer breiten Auswahl an automatischen Methoden zur Verarbeitung der Digitaltinten-Darstellung papierbasierter Notizen, sowie auch die Kombination automatischer und benutzergesteueter Methoden. Das Programmiergerüst soll auf der Grundlage der bestehenden Programmiergerüste und Werkzeugsätze, mit welchen es sich auf einfachem Weg integrieren lässt, eingesetzt werden und der Entwicklung von Lösungen dienen, die auf Digitalstift & Digitalpapier basieren. Indem es eine einfache Integration und ein einfaches Experimentieren mit verschiedenen Ansätzen zur Digitaltinten-Verarbeitung erlaubt, unterstützt das Programmiergerüst die Entwickler und erlaubt ihnen flexibel aus verschiedenen Verarbeitungsmethoden zu wählen und diese zu kombinieren.

Auf Basis dieses Programmiergerüstückes untersuchen wir schließlich Möglichkeiten, die Rolle papierbasierter Notizen beim Abrufen von Information zu unterstützen. Weiters beschäftigen wir uns mit der Verwendung natürlicher Notizen, die mit anderen Medien im Zusammenhang stehen. Im ersten Fall untersuchen wir die Extraktion und anschliessende Integration handgeschriebener Information mit einer Reihe von digitalen Systemen, die über Abruf-Funktionen verfügen. Im zweiten Fall untersuchen wir den Vorteil von Lösungen, die eine integrierte Übersicht über die Notizen und die Medien bieten, mit denen sie im Zusammenhang stehen. Wir präsentieren Einblicke, die wir im Rahmen der von uns durchgeführten Evaluationen dieser Systeme gewonnen haben.

Zusammengefasst enthält diese Dissertation Beiträge zu folgenden Themen: Der Entwurf und die Implementierung eines allgemeinen Programmiergerüstückes zur Entwicklung massgeschneiderter Digitaltinten-Datenverarbeitungslösungen; die Identifikation zweier Bereiche, in welchen die bestehenden Digitalstift & Digitalpapier-Lösungen das natürliche Notieren nicht auf angemessene Weise vereinfachen, und schliesslich die Untersuchung möglicher Lösungen für jeden dieser Bereiche.
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Introduction

Among multiple other novelties and innovations, the past few decades have brought forth digital solutions which could replace the use of paper in a range of our activities. PDAs and smartphones provide possibilities to capture and consult information on the go without having to carry along traditional paper-based notebooks or notes scribbled on loose pieces of paper. E-books or e-readers enable reading experiences where annotations are saved digitally together with the content to which they refer and direct access to additional media is provided. Tablet PCs support the direct integration of notes with different special-purpose digital tools, thus surpassing the need to transcribe notes digitally. Digital tabletops are the object of investigations towards more efficient collaboration. This state of things raises the question whether paper is disappearing and our activities will take place in the digital world.

Certainly, these new digital tools and devices are often motivated by valid issues and disadvantages associated with the use of paper and are meant to address drawbacks and surpass capabilities of traditional paper-based solutions. For example, a significant number of information workers engage in the time-consuming transcription of handwritten information into digital format, an issue raised by a considerable number of studies in the case of both office workers [102, 206, 68, 22, 24], as well as more specialised professionals such as chemists [116], biologists [118, 214], doctors [69], musicians [106, 105] and engineers [126]. According to these studies, a major reason why information workers may be required to transcribe paper-captured information is to be able to exploit services provided by special-purpose digital tools, such as complex processing of data, search or dissemination of information. Further reasons for undergoing this time-consuming process include characteristics of the paper-captured information which may affect its usefulness in the long term, such as poor organisation or sketchy content. Finally, the fact that paper is a physical construct may also create a series of incentives for transcribing information originally captured on it. Paper artefacts have low robustness to external factors that might deteriorate them. Furthermore, the physicality of paper may lead to deficiencies in managing and re-finding information within material accumulated over extended periods of time, may create inconveniences
when mobility is required and may trigger a certain anxiety or discomfort when large amounts of paper artefacts clutter an individual’s working or living environment.

Therefore, focusing strictly on a list of issues and disadvantages such as the previous ones would most likely lead one to question the future of paper in an era of new technologies and digital information management tools which could potentially replace it. However, an opposing list of advantages of paper can also be identified. This list includes some unique affordances of paper [171], which are likely to ensure its continued use, even with drawbacks that could be circumvented by completely digital practices.

Unique affordances of paper include “interactional affordances” that are difficult to understand, explain and recreate in the digital world [113], especially when critical aspects are involved, such as the timely delivery of services, health or safety [113, 69, 117]. Also, studies show that replacing paper-based interfaces can affect performance in tasks that involve pondering, thinking and solving problems [144]. In these cases, the effort put into using various elements of a digital user interface may limit the capacity to focus on the actual task. Similarly, scientists feel constrained when using digital tools instead of traditional paper notebooks, such as reported in the case of electronic lab notebook applications [116, 188].

Furthermore, attempts to replace paper often lead to high technology overhead or increased time to accomplish the same tasks, which may negate the benefits of the new and more sophisticated systems [149]. For example, it has been observed that paper-based notetaking continues to be a commonly used work practice in the preparation and capture of information circulated in meetings [56], even with remarkable advances in meeting support and review solutions [27, 209]. Similarly, the capture of information through handwritten input on various physical artefacts such as notebooks, paper scraps, calendars or post-it notes has been reported as preferred over digital tools in office environments [68, 32, 24, 22], as well as classroom situations [156, 184, 95].

Finally, in his book *Scrolling Forward* [107], Levy mentions that the likely reason for the persistence of paper-based practices could be a certain emotional value associated with physical paper artefacts. A paper-based artefact such as a book, a notebook, a letter or a simple receipt “is a stable physical object capable of travelling with me through time” (p.56), “something that can be held, kept, reread, and treasured” (p.78) and paper and digital versions of the same artefact “are markedly different in form and, what may come more of a surprise, in content” (p.42). Also, through its capacity to carry handwriting, paper has the “mark of the personal” (p.93).

While no definite conclusion emerges from his analysis, Levy foresees that users will discern between using paper or digital media by weighing the relative importance of sentimentality versus effectiveness for each particular situation and his prediction seems to have held until nowadays. Information is neither handled purely digitally nor purely paper-based—paper and digital tools are often used in parallel and may present complementary roles. For example, writing tends to be done digitally when the content has already reached a certain level of refinement, but pen and paper are often preferred in earlier stages when creativity, ideation and idea evaluation are involved [63]. Similarly, digital documents are in some cases printed for the ability to directly annotate content while reading it [141], or due to the better support for comparing and getting an overview provided by paper [143]. Investigations show that digital and paper documents impact differently the development of incidental memory for spatial location of text that could be used to guide visual attention [162, 142, 141].
Numerous works have drawn attention to the need to acknowledge the coexistence of paper and digital technologies in the practices of information workers. This includes *Scrolling Forward*, as well as works such as Sellen and Harper’s analysis of the likelihood of a paperless office [171], Luff et al.’s analysis of the resilience of paper alongside newer digital technologies [114], Bernstein’s analysis on information scraps which are often captured on paper [24] or Mackay’s analysis on the effects of replacing paper [117]. The recommendation made by some of these authors is to enhance rather than replace paper-based practices with the aid of emerging digital technologies [171, 114, 117]. The analysis of Lin et al. further clarifies that solutions accounting for a combined use of the two media should, on the one hand, respect the unique affordances of pen and paper for information capture and, on the other hand, exploit the superiority of digital tools in terms of information management [112].

In this thesis, we concur with the previous recommendations and investigate ways to materialise them in the case of natural notetaking. While the appearance and proliferation of new digital solutions for information capture and management makes it possible for information workers to use pen-based computers or smartphones in support of their tasks, the writing of notes on paper using a pen is unlikely to disappear in the near future. Especially in impromptu situations or when the digital devices are not required or particularly beneficial for accomplishing their tasks, information workers tend to prefer to spontaneously offload information from memory through lightweight notetaking on paper-based to-do lists, post-its or notebooks [22, 24, 74]. In such cases, paper becomes the preferred capture media due to characteristics such as allowing spontaneity and flexibility in the capture process, as well as due to a certain perception that, at least at capture time, it is more convenient to write the information on paper rather than integrate it with some digital application. Nevertheless, as pointed out by Lin et al., digital applications may be better suited to handle the same information in post-capture phases. Problems in using notes captured naturally on paper, such as the list mentioned earlier, persist and are part of the broader context where users have to deal with large amounts of information on a daily basis and have limited resources to process that information [21, 37]. To conciliate the two aspects of natural notetaking, preferred paper-based information capture and advantageous digital handling of the information, we will refer to paper-digital technologies. These allow the direct integration of information captured on regular paper with digital tools.

## 1.1 Paper-Digital Notetaking

Various notetaking solutions have been proposed to offer information workers advantages of both paper and digital media. For example, the ready availability of scanners and digital photocopiers, which makes it possible to easily produce digital versions of paper documents, enables a series of solutions where content captured on notebooks with a predefined page configuration can be extracted through an offline scanning process and further integrated with digital applications and services [155, 70]. Such approaches are concordant with requirements emphasised in Lin et al. [112] in that they permit the paper-based capture of information and provide digital services for managing the information. However, these solutions also introduce some limitations for the supported practices, such as the need to scan paper in a post-capture phase in the previous
example. For natural notetaking, where the flexibility and the speed in the capture process are of particular importance, this could be considered inconvenient by the users and lead to not using the solutions.

Anoto’s digital pen and paper [2] and similar technologies [168] enable a new category of notetaking solutions. Handwritten information captured on regular paper can be made available digitally without intermediary transcription steps or other in-direCTIONS. Among these, the Anoto technology is considered the most promising in addressing the duality in paper-based notetaking [168, 166].

The basic working principles of the Anoto technology are illustrated in Figure 1.1. The movement of the digital pen on paper is tracked by an infrared camera integrated with the pen. With the aid of a special Anoto dot pattern printed on paper via regular printers [202], handwritten information is encoded as digital ink data representing the succession of timestamped x and y coordinates of the pen on paper. Pen stroke data can either be transmitted directly to a computer via a Bluetooth connection or stored within the memory integrated within the pen. In the latter case, data is transmitted to a computer by connecting the pen to the computer via a docking station (Figure 1.1a). On the computer, pen stroke data can be further processed and integrated with digital applications. The way in which handwritten information is made available digitally, can be customised through different implementations of the handling of the digital ink data by the digital part of a notetaking solution. For example, digital ink data can be transformed into digital text based on handwriting recognition [7] or segmented so that entire pages or just parts of paper notes are made available for digital applications by the notetaking solution [12].

For natural notetaking, Anoto’s digital pen and paper technology creates premises to bring together the preference for using paper as capture media, on the one hand, and benefits attainable via digital information handling, on the other hand. Allowing the information capture on paper, characteristics of natural notetaking such as spontaneity and flexibility could be maintained. At the same time, handwritten information can be
made available for digital management and handling in post-capture phases. Nevertheless, notetaking solutions based on the Anoto technology are still not widely used for natural notetaking [29], even if around for approximately a decade and made available for end users through numerous commercial products, such as Livescribe’s solutions\(^1\), Oxford’s Easybook\(^2\), Oxford’s PAPERSHOW\(^3\), the range of Capturx solutions or solutions integrated with Logitech’s io pen\(^5\). This thesis investigates possible reasons for this situation and makes a series of proposals towards aligning the use of digital pen and paper technologies with natural notetaking.

### 1.2 Challenges

In our opinion, the current situation where notetaking solutions based on digital pen and paper technologies are not widely used for natural notetaking could be determined by two main aspects. First, the approaches for processing handwritten information used by existing notetaking solutions might interfere to a certain degree with natural notetaking. In particular, mechanisms relied upon for the extraction and subsequent digital integration of the notes might inhibit some essential aspects for which natural notetaking is preferred in the first place, such as its freedom or a certain \textit{unselfconscious engagement} of taking notes with pen and paper [122]. Second, this situation might result from a lack of alignment between the problems that users have with managing their paper-captured information and the kinds of support and sets of functionalities provided by existing solutions. We believe that the degree at which a notetaker’s needs with regard to these aspects are reflected within a digital pen and paper notetaking solution is likely to influence the use of the solution for natural notetaking. In what follows, we discuss in detail each of these points.

Existing Anoto-based notetaking solutions provide notetakers with a series of mechanisms for classifying and filtering their handwritten notes. These mechanisms rely on certain notetaking rules and guidelines, and are meant to support the processing of the notes in the view of their digital integration. With the aid of these rules and guidelines employed by the notetaker at capture time, the digital processing can be automated to a certain degree and different properties and classes of notes can be inferred. Such note metadata is then used for the digital representation, organisation and retrieval of notes. The rules and guidelines can be derived from certain observed notetaking habits [29, 211] and are driven by features of the technology used, such as underlying abstractions of the toolkits and frameworks used for the development of the notetaking solution or handwriting and gesture recognition accuracy. For example, the iPaper framework [140] provides support for defining active page areas and associating them with active components [178] to be invoked when ink written within an area needs to be processed. When using this processing mechanism, users are required to write within predefined page areas to enable the processing of their notes. Other custom digital pen and paper solutions such as the Anoto SDK for PC applications [12], Livescribe’s

\(^1\)http://www.livescribe.com
\(^2\)http://www.oxfordeasybook.com
\(^3\)http://www.papershow.com
\(^4\)http://www.adapx.com
Platform and Desktop SDKs [14, 13] or PaperToolkit [215] provide analogous abstractions. The digital ink processing can also be integrated with various approaches for gesture recognition such as supported by the iGesture framework [179]. Depending on the recognition rate of various gestures, tagging by using predefined marking gestures could be provided to the users as a way to support the processing of their notes.

We certainly agree that notetaking solutions should provide variable ways of handling notes extracted from paper, potentially in accordance with their perceived usefulness and including the possibility to discard parts of them. However, we also believe that the lack of support for natural notetaking results from different work practices and requirements in settings with natural notetaking as compared to settings where notetaking is a compulsory part of daily work. Existing solutions target particular information tasks, such as collecting field data [214], composing music [193], planning software development [76], holding presentations [10] or consulting recorded audio [3]. In such cases, it can be expected that users are more likely to accept certain notetaking guidelines if these will ensure that notes can be captured and processed digitally in support of the overall information task. Furthermore, it may be easier to identify some notetaking patterns from which processing mechanisms could be derived.

On the other hand, predefined processing approaches might interfere with the natural notetaking practice. Requesting notetakers to accommodate rules and guidelines in their spontaneous notetaking behaviour might represent a change which they are not willing to accept. Even if natural notes tend to include various marks or notations, it is difficult to identify some patterns so that the rules are derived from existing practices. In addition to interpersonal variations, individuals are also not always consistent in their choices for formatting their notes and the meaning of the marks used may even become unclear over time [123]. Furthermore, requiring users to categorise their notes at capture time might become a factor of discomfort. Several studies report difficulties in categorising information when it is captured [120, 92, 59, 126, 206]. Some studies report that defining appropriate information categories can be a challenging task even when the categorisation is performed in a subsequent post-processing step [126, 206].

Assuming that the processing approach is implemented in such a way that the altering of the notetaking behaviour is tolerated by the users, additional aspects need to be taken into consideration. First, having to use a certain notetaking system might increase the amount of time that users spend to execute familiar notetaking activities. This could generate a reluctance to accept new systems even if certain benefits are provided for the processing of the information in the post-capture phase, as reported by Yeh et al. in the case of field data collection [214]. Second, the error rate in recognising special purpose marks or the highly unstructured nature of natural notes, which complicates the mapping of content to the corresponding marks [29], can introduce several points of failure and affect negatively the perception that digital pen and paper is beneficial.

The alternative to using notetaking rules would be to rely on some automatic processing approach. However, even with remarkable advances in the digital ink parsing and processing domain [175, 18, 213], digital systems are still not able to classify different notes with the same accuracy that an information worker would achieve [163]. Furthermore, handwritten notes have a series of qualitative attributes, such as schematic nature or incompleteness, which may limit the use of automatically extracting and creating digital copies of the notes [123]. Due to these qualitative characteristics,
notes may be affected by crises of intelligibility or may lose their property to provide appropriate memory cues over time [122]. Furthermore, aspects such as the kinds of use attributed by the users to their different notes might be difficult to detect and handle accordingly by an automatic solution. Similarly difficult to detect are aspects such as the ones observed by Sellen and Harper in the case of paper documents, which transition through a series of hot, warm and cold states [171], or Barreau and Nardi, who introduce a similar idea for digital files that can be ephemeral, working and archived [21]. As showed for paper documents and other types of information, paper notes may also have different lifespans in terms of their use.

Given that both user-driven processing based on rules as well as automatic processing are likely to have a negative impact in some way on natural notetaking, it results that replacing the already used user-driven processing with automatic processing methods is not likely to improve the use of digital pen and paper technologies for natural notetaking. Nevertheless, we believe that ways to relax disadvantages of user-driven processing need to be investigated and consider that a possible way to minimise these drawbacks might be to combine user-driven and automatic processing approaches in an attempt to leverage their respective advantages and, at the same time, minimise their disadvantages.

Our second hypothesis regarding possible reasons for the limited use of digital pen and paper for natural notetaking refers to the kinds of digital support and functionalities provided by the notetaking solutions. Ideally, the digital support should be in accord with the use attributed to paper notes by their owners. Existing solutions based on digital pen and paper enhance notetaking by extracting notes from paper and transferring them directly to some kind of digital storage, be it as part of an application for managing exclusively paper notes or integrated with general tools such as email clients or other special-purpose tools. Referring to taxonomies for handwritten note use proposed in the literature, it becomes apparent that existing digital support might overlook some note categories. In what follows, we analyse this argument with respect to the note use categories proposed by Lin et al. [112].

In their investigation on how natural notes—or so-called “informal, hurried personal jottings”—are used, Lin et al. identify three use categories: temporary storage, immediate use and prospective memory aid. Notes in the first category are meant to hold information until the user has the possibility to integrate them with different digital tools, which may provide additional functionality such as search or listings of the different information items and are, therefore, better suited to supporting their subsequent use. The second category refers to notes which are used immediately after their capture and are no longer useful after that point. The third category refers to notes which need to be referred back to in order for them to be useful. What is characteristic for these notes is a certain striving to prevent failing to recall the information. Users try to maintain the notes in such a way so that they are visible and accessible, for example, by placing them “in-the-way in anticipation of a routine practice that will occur at the right moment” for them to be discovered [22].

Referring back to the enhancement consisting of transferring handwritten notes to some digital storage proposed by existing notetaking solutions, this type of support is compatible with the temporary storage notes identified by Lin et al., but less with the rest of the notes. In particular, we consider that this kind of functionality is not likely to provide appropriate digital support for prospective memory aid notes. While
no quantitative measures regarding notes in the three categories are provided by Lin et al., other investigations suggest that paper notes meant to be used for refreshing memory might be significantly numerous. For example, Khan catalogues recall as the main reason for taking notes [91].

Certainly, it can be assumed that extracting reminder notes from paper and making them available digitally can present benefits for their successful use. Given the amount of paper-captured information that we have to deal with every day [24, 206], leaving documents in-the-way might not always suffice. While it has been reported that users have developed various strategies for maintaining their documents in preparation for recall, such as the filing or piling strategy identified by Malone [120] or the no-filers, spring-cleaners and frequent-filers categories from Gwizdka [62], it has also been observed that such approaches can become ineffective over time [206] and that ultimately the “load for successful recovery of information remains on the user’s memory” [46]. This situation, where users need to remember to look for the information, combined with common memory issues [100, 164], leads to having no guarantee that paper notes will be re-found when they could be useful.

Nevertheless, the way in which paper notes are maintained digitally can have a great impact on the ease of their referral [112] and it might not suffice to simply transfer them to digital storage. Referring back to Scrolling Forward, Levy remarks: “Even when our desks have become desperately disorganised, the materials on them still have a stable and recognisable nature. [...] What sense can we make of this new cyber-substance?” (p.136). Once in the digital domain, using paper notes faces a similar problem with re-finding information or, in other words, “finding information that has been seen before”, extensively investigated in the field of personal information management (PIM) [86, 85]. PIM research observes that simply digitalising everything, such as attempted by MyLifeBits where an endeavour to scan all paper documents is reported [55], does not guarantee better management of the information [172]. First, given the high amounts of digital data accumulated nowadays by a typical information worker, there is a possibility that relevant pieces of information cannot be re-found. Second, notable information, a term introduced by Campbell and Maglio [32], loses a lot of its value for the information worker once it has been filed [92]. Given that knowledge workers rarely consult filed information, filing reminder notes might affect their visibility and accessibility and, therefore, their ability to remind.

In conclusion, it becomes apparent that the digital support provided by existing solutions might not be completely aligned with user needs. A brief analysis with respect to one of the existing taxonomies for note use reveals at least one additional functionality required. Complementary to digital integration and management, notetaking solutions should provide some mechanisms to enforce the re-finding of notes. Whether kept in notebooks or extracted and filed into various kinds of special purpose digital archives, there are high chances that notes are no longer used simply because they are no longer seen. Stressing that “there is a difference between keeping everything and making everything visible” [38], PIM research recommends that computer support should focus on the act of informing rather than passively filing large quantities of information in a “disembodied form” [92]. In accord with these recommendations, we believe that ways of making notes visible or, in other words, reminding about information contained in paper notes, represent at least one area to be further investigated.

No matter the direction of further investigations, the kinds of digital support that
are required to handle extracted natural notes in combination with related media also need to be accounted for. As already stated in the beginning of this chapter, paper is not the only type of media used by information workers. Rather, paper notes are often used in combination with other types of media. According to a notion of information ecologies introduced by Sellen and Harper [171], different forms of information are made useful through their interdependence with other forms of information. For example, a post-it note may have a different value when placed on a printed document to which it refers compared to interpreting its content in isolation. Sellen and Harper raise the issue that notes used in parallel with other types of information need to be transcribed and integrated with those other sources of information. Some research has already proposed solutions that do not exclusively manage notes, but rather notes together with other types of information to which they relate. Examples include the work of Reimer et al. [157] and Steimle et al. [185], which proposed solutions meant to help in classroom situations. In both cases, students can access learning material of different media types via a single digital interface. Similarly, meeting support systems use handwritten notes for indexing large amounts of material handled during a meeting [56, 208, 209].

### 1.3 Contribution of this Thesis

Results from related work gave us a basis for our hypotheses presented in the previous section regarding possible reasons for the limited use of digital pen and paper for natural notetaking. To verify these hypotheses, as well as gain further insights into the natural notetaking practice, we started our investigations by conducting a study on traditional paper-based notetaking. The aim of the study was twofold. First, our goal was to determine whether and how natural notes are used after their capture. By understanding what the types of notes are from the point of view of their post-capture use, we wanted to identify how they should be made available digitally and what types of functionality are required for their digital handling. Second, we wanted to understand whether and how natural notetaking could integrate with the use of digital pen and paper.

The study allowed us to identify a series of note categories from the point of view of their post-capture use. Relating these note categories with kinds of digital support able to enhance the note post-capture use revealed a lack of support for the recall of valuable handwritten notes. Furthermore, the functionality to transfer notes to digital storage provided by existing solutions appeared to be of limited use, unless notes relate to other media and the solution provides an integrated view over the notes and the media to which they relate. Finally, the study has revealed a general reluctance of users towards solutions that require the adaptation of natural notetaking practices to integrate certain rules or guidelines. At the same time, identified note qualitative aspects made it apparent that some mechanism to support the processing of notes is necessary.

In an attempt to deal with potential inconveniences of having to enforce user-driven processing approaches during notetaking, we implemented a framework for the development of digital pen and paper-based notetaking solutions which supports a combination of user-driven and automatic processing approaches. The framework creates premises for minimising potentially negative impacts on natural notetaking of each of the two approaches used independently and is meant to be used on top of existing frameworks
and toolkits for developing digital pen and paper-based applications, with which it can be easily integrated.

Having the previously mentioned framework at the basis of our implementation, we further investigated ways to support the role played by paper-based notes in recalling information. For this purpose, we implemented the integration of handwritten information with a range of reminder notes systems and tested it via a comparative study. While results in the field of reminder and notification systems played an important role in informing the choice and the design of our reminder solutions, we also observed that the handling of personally authored information, which is the category where paper notes fall, was only marginally addressed. Therefore, the study was also meant to determine an eventual need for and inform the re-tailoring of already identified models, concepts, ideas and assessment schemes for the different category of solutions: solutions targeted for personal use.

Finally, we addressed our observation that transferring natural notes to digital storage might be of limited use, except for cases when notes and other media are complementary sources of information. In these latter cases, digital solutions might be better suited to providing an integrated view over the different sources of information. To support the investigation of this hypothesis, we built a meeting support system which allows the integration of personal notes with media used for shared work supported by a digital tabletop surface. The system includes a post-meeting review component which allows meeting participants to consult both paper and digital material integrated according to their use during the preceding meeting. A study of the system use shows benefits of providing digital access to natural notes if the digital solution provides an integrated view over the notes and the media to which they relate.

The contributions of this thesis hence include:

- designing and implementing a general framework for the experimentation with and the development of customary digital ink data processing approaches limiting natural notetaking as little as possible
- identifying areas where the support provided by existing digital pen and paper-based notetaking solutions is not likely to correspond to actual user needs in terms of using the information
- investigating further and proposing solutions for each of the identified areas.

Note that, throughout this thesis, the first person plural pronoun “we” is used to refer to the author. Eventual collaborations are stated explicitly when describing the respective collaborative outcomes.

1.4 Thesis Overview

The thesis is structured as follows. In Chapter 2, we first review related work on notetaking with a view to identifying characteristics of handwritten notes and the roles they play for information workers and their activities. Further, we present existing notetaking solutions analysing the kinds of support provided to enhance notetaking.

In Chapter 3, we describe the method and present the results of our user study on traditional paper-based notetaking and the kinds of uses attributed to handwritten notes. We conclude this chapter with a discussion of the results and derive implications...
1.4. Thesis Overview

for the design of notetaking solutions based on digital pen and paper suited for natural notetaking.

In Chapter 4, we present our digital ink segmentation and classification framework and outline how it can be integrated with existing digital pen and paper development frameworks.

In Chapter 5, we follow up results discussed in Chapter 3 and investigate ways to support digitally the role in reminding played by paper notes. We start by looking into related work in the field of reminder and notification systems with a view to informing the design of reminder notes systems. Further, we present a series of prototypes that we developed to support our investigations. The prototype evaluation via a comparative user study, as well as a discussion of the results is presented subsequently. We also present some implementation details, including how our digital ink segmentation and classification framework has been used in the development process.

Building on previous work for bridging private paper-based and shared digital information spaces based on Anoto technology, in Chapter 6, we introduce a solution for digitally reviewing meetings that involve interactions on both paper and digital media along alternative phases of individual and shared work. We start by iterating over a list of requirements for meeting support and review and present the main features of the system that we implemented. Subsequently, we describe a study conducted to evaluate the benefits of integrating personal notes with related media and discuss emerging conclusions.

We conclude this thesis with a review of the contributions and provide an outlook on how these contributions could support future work.
2

Background

In the previous chapter, we have seen that unique affordances of pen and paper for the information capture process are likely to guarantee their persistence in information worker activities. Whether paper takes the form of bound notebooks, post-its, organisers, printed documents or loose paper sheets, the ability to write on it in a certain low-effort, spontaneous and unconstrained manner leads to a preference for paper over digital media for certain tasks. On the other hand, we have also reported difficulties in managing paper-captured information, as well as integrating it with other media and digital tools in the frame of the overall tasks. This twofold situation creates opportunities for a class of paper-digital notetaking applications that allow users to capture information on paper and enhance the post-capture experience digitally.

In this chapter, we take a closer look at the paper-based notetaking process with a view to identifying ways in which it could be enhanced with digital notetaking functionality. For this reason, we first review related work on notetaking, identifying characteristics of handwritten notes and the roles they play for information workers and their activities. The role played by paper notes in supporting memory will be given particular attention. While different conceptions of memory and remembering exist [130], throughout this and the following chapters we address memory and remembering from a cognitive psychology perspective. Further, we analyse existing notetaking solutions in terms of their support for enhanced notetaking.

2.1 The Natural Notetaking Practice

Research on notetaking has focused to a great extent on learning environments. Numerous studies have revealed a strong correlation between taking notes and being able to recall content taught in the classroom [53, 34, 93, 94]. The relationship between notetaking and learning has been formalised as the *encoding-storage paradigm*. The paradigm states that notetaking has two functions: *storage* and *encoding*. The *encoding function* refers to the fact that recording notes facilitates learning. Notetakers need
to identify important material which they transcribe into their own notes. Together with structuring the content, this procedure focuses attention, increases the processing of the material and augments learning. Learning can be further facilitated by reviewing the notes taken, students learning the most if they both record and review their notes. The review of recorded notes is formalised as the *storage function* of notetaking. In correlation with the encoding-storage paradigm, notes are considered an *external memory aid* as opposed to strategies such as mental rehearsing, mental retracing or mnemonic systems which represent *internal memory aids* [42]. For example, mental rehearsal improves memory by mentally repeating the information to be remembered.

<table>
<thead>
<tr>
<th>Communication</th>
<th>No Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Many : Many</td>
<td>E.g., noting own ideas and thoughts</td>
</tr>
<tr>
<td>E.g., meetings</td>
<td>E.g., noting features of the environment</td>
</tr>
<tr>
<td>1 : Many</td>
<td>E.g., telephone conversations</td>
</tr>
<tr>
<td>E.g., lectures</td>
<td>E.g., consultations</td>
</tr>
<tr>
<td>1 : 1</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2.1: Khan’s taxonomy of notetaking situations

Khan’s study on notetaking takes a broader perspective on the practice [91]. Khan explains that notes are typically written when a person knows that they will need to remember something and they have the opportunity to prepare for recall. A similar observation is made by Kalnikaitė and Whittaker, who explicate that, knowing that their organic memories might fail, users ascribe notes the role of a kind of prosthetic memory [88]. Therefore, in the taxonomy of notetaking situations proposed by Khan and reproduced in Figure 2.1, learning environments are just one situation where notetaking is used. Intons-Peterson and Fournier further elaborate on the topic of possible situations where paper notes are used as memory aids, emphasising the following attenuating circumstances [78]:

- a long temporal interval or an interfering event separates acquiring information and recall
- internal memory aids are not trusted
- knowledge is difficult to understand, does not cohere readily and external aids are needed to preserve important details
- memory load is to be avoided in order to be able to focus on other activities
- limited time is available for encoding and using rehearsal or other mnemonic techniques.
No matter what the environment or the situation are, researchers endorse the encoding-storage paradigm. Even if the assimilation of the noted content may depend on numerous factors such as how much focusing the situation allowed or how detailed the information written down was, the process of writing ideas or other pieces of information on paper with a pen is considered a memory support. While it is not clear how much remembering is related to encoding and how much it depends on storage, it seems that proper storage is at least as important as thorough encoding. Often, remembering depends on reviewing the notes, even if that consists of only quickly skimming through the text or if the notes are schematic and incomplete. Kalnikaité and Whittaker explain that the process has the role to trigger the memory and remembering, notes playing the role of so-called prosthetic cues \[89\].

The actual review of the paper-captured information depends on two main factors which could influence a user’s ability to re-access their notes at the exact moments when these could prove useful. First, reviewing depends to some extent on the ability to re-find the information, likely a reason why users tend to develop strategies to maintain and organise paper artefacts, such as the filing and piling approach \[120\]. Second, users need to remember that a certain piece of information is in their possession and actively look for it where they had placed it. Van den Berg points out that the major issue with remembering based on prosthetic cues is that reactivating the memory content depends on the presence of the adequate retrieval cues \[196\]. In other words, if users fail to revisit their notes, either because they forget that the cues exist or because they are unable to find them, remembering will not be triggered.

<table>
<thead>
<tr>
<th>Facts</th>
<th>names, addresses, telephone numbers, technical details, procedures, dates and other such information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actions</td>
<td>items which the notetaker had to do something about</td>
</tr>
<tr>
<td>Opinions</td>
<td>comments other people made</td>
</tr>
<tr>
<td>Ideas</td>
<td>best ideas mentioned by others or their own ideas and thoughts</td>
</tr>
<tr>
<td>Decisions</td>
<td>any major decisions made</td>
</tr>
<tr>
<td>Summaries</td>
<td>summary of what was discussed</td>
</tr>
</tbody>
</table>

Table 2.1: Notes categories identified by Khan

Among other aspects, Khan also inspected what is being noted on paper and identified the 6 categories of notes summarised in Table 2.1. Depending on very specific circumstances and often independent of the category, some notes are more likely to be reviewed than others. The most likely to be reviewed are the notes associated with a well defined goal, such as performing well in a subsequent examination, or with an assigned task, such as having to report on the evolution of a meeting. In the absence of such requirements or subsequent to having performed the required tasks, numerous works report that users rarely consult their noted information \[91, 92, 206, 22, 74, 197\].

While some authors speculate that users might not be reviewing their notes because these have only short-time benefits such as tracking current tasks \[206\], Hsieh et al. have an opposing view and argue that “there may be a substantial amount of latent value” in unreviewed notes \[74\]. The fact that users rather archive than delete or discard notes \[112, 206, 126, 197\] might indicate their tacit intuition of such a latent value.
contained by their notes. The situation is equally probable in the case of any information workers, including specialised professionals, the notebooks of which have been reported to contain other types of information considered important rather than notes strictly related to their main activity. For example, in addition to formal engineering information, an engineer’s logbook contains notes unrelated to design activities such as contact information, calculations or notes taken in meetings [126]. Similarly, the chemistry lab book is used both to record information required to accomplish scientific tasks and as a personal journal [116, 188]. Furthermore, while in some cases users have reported not to have accessed parts of their notes because they remembered the content anyway [22, 126], research on memory shows a limited capacity of short-term and working memory [131, 19] and that a limited amount of information units can be transferred into long term memory even when rehearsal or mnemonic techniques are used [42]. In this context and given the numerous sources of information with which we come into contact nowadays, Lamming et al. draw attention to a need for a new class of applications called “memory prostheses” [100]. These should help users deal with retrospective and prospective memory problems at work.

It becomes apparent that designing paper-digital notetaking solutions should account for ways to support the recall of information captured as paper notes. As recommended by Lin et al. [112], the role to remind is likely to be tackled better by the digital part of the notetaking solution.

Whichever the approach taken to support the recall of the notes is, proposed applications have to ensure that notes are made visible. As already mentioned in the previous chapter, several works made this recommendation [91, 92, 32, 112, 74]. However, a series of factors are likely to make this requirement difficult to enforce in the case of handwritten notes. First, investigations such as Kahn’s show that paper artefacts contain an amalgam of notes destined for multiple tasks, activities and purposes. This might indicate that noted information might have a mixed content and that some sort of filtering, as well as a way to correlate information that users are reminded about with their needs at specific moments in time might be necessary. Second, a series of qualitative aspects of the notes are likely to influence their ability to remind over time. Kalnikaite and Whittaker report that the efficiency and accuracy of pen and paper notes has been shown to be fairly high in the first days and week, but significantly lower a month after their capture [89]. This might mean that, if notes are not made visible over a certain period of time, they might no longer be effective in triggering memory.

The quality of a user’s notes could depend on factors such as personality traits, as well as on the perceived importance of the content [53]. Regarding the latter, notes with utilities and lifetimes correlated with specific goals to be achieved tend to be more extensive and well-structured. If the notetaker does not need to capture information with an incentive to perform well in the perception of an external instance, but for their own personal use, this can result in lower pressure to take complete and structured notes. Furthermore, in the context of a reported tension between the desire to capture information as quickly as possible and the rich information representation and structure [24], the speed in capturing information is more likely to take priority. As a result, notes can be represented at any level of detail from complete sentences to notes that are only elaborated enough to provide a salient cue [22]. Often, notes are characterised by terse language, highly subjective choice of keywords, abbreviations, few details, bad handwriting and little organisation other than a chronological one.
Finally, possible issues may result also from choosing the wrong prosthetic cues [89] or cues that are so minimal that they are only effective for a limited period of time while tasks associated with notes stay in memory [22]. Abbreviations and brief markings that are perceived as adequate memory cues at a given moment may lose this property over time if they are no longer understood.

2.2 Existing Notetaking Solutions

Revisiting Lin et al.’s recommendations [112], we consider that the success of any natural notetaking solution is likely to be influenced by two most prominent factors. The first factor is the degree of correlation between the information capture process supported and the characteristics of the natural notetaking practice. From this point of view, solutions should ideally alter natural notetaking as little as possible. The second factor is how well the solution has intuited the most relevant kinds of support to be provided in the post-capture phase. Often, the two factors are antagonistic. The more the natural notetaking behaviour is allowed, the less a comprehensive set of services can be offered in the post-capture phase. Contrarily, the more notetaking is regulated and less natural behaviour is kept, the more sophisticated services can be provided for the use of the handwritten information. The resulting challenge is to find an appropriate balance of the two factors.

<table>
<thead>
<tr>
<th>Capture Media</th>
<th>Management Media</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>Paper</td>
</tr>
<tr>
<td>Digital</td>
<td>Digital</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2.2: Notetaking solutions categories

In what follows, we present existing notetaking solutions and analyse their proposals in terms of the capture and management of information and how the notetaking process has been enhanced. Based on the paper or digital media used for the capture and management of information, we identified the categories of solutions shown in Figure 2.2. Traditional notetaking solutions are characterised by both paper-based capture and paper-based post-capture handling of information. Further, digital notetaking solutions seek to enhance notetaking by removing the paper-based capture and handle both information capture and management digitally. Solutions based on digital pen and paper and similar technologies constitute a third category of paper-digital notetaking solutions. As already discussed, in this case the information capture is paper-based and
management is performed digitally. The combination of digital capture and paper-based information management corresponds to situations such as printing digital documents and information management aspects relevant for this latter category will be discussed together with traditional notetaking solutions.

The discussion will pay particular attention to the question whether and how notes are correlated with other types of information. In our opinion, existing solutions address the three categories of situations shown in Table 2.2. Different solutions may address the integration of notes with other media already at capture time or provide support to combine notes with related information only in the post-capture phase. References to the different integration categories will be made where applicable.

| Notes only   | notes are the only type of data handled |
| Metadata notes | notes are attached to other types of information in the form of annotations or other kinds of metadata |
| Combination notes | notes appear as standalone information items combined with other types of information |

Table 2.2: Levels of combining notes with other media

### 2.2.1 Traditional Notetaking Solutions

Should we be considering information capture capabilities as the only criterion, traditional notetaking solutions would certainly be the most suitable to support natural notetaking. Post-it notes, paper pads, flipcharts, notebooks and other such well known tools pervade in any information worker’s environment and provide handy solutions whenever information needs to be offloaded from their minds for a more reliable retention. They come in various configurations so that user needs and preferences are met no matter the specific context. Considerable efforts have been made towards increasingly versatile, robust and appealing solutions. For example, Figure 2.3 shows just a few of the multiple patented notebook systems [50, 134, 16].

![Figure 2.3: Patented notebook systems](image)

Most likely not unrelated to the wide variety of notetaking solutions, numerous paper artefact organisation systems have been proposed. The first most notable solution for categorising and storing paper-captured information is considered to be Seibels’s vertical
2.2. Existing Notetaking Solutions

(a) Vertical filing system

(b) Rolodex rotaries

Figure 2.4: Paper artefact organisation systems

Filing system [11], which allows paper documents to be kept in envelopes standing vertically in a drawer (Figure 2.4a). Other well known examples include Rolodex\(^1\) rotaries used for contact information management (Figure 2.4b) and Filofax\(^2\) personal organisers (Figure 2.5). Filofax and similar systems propose an organisation system based on multiple tabs. Being equipped with binders, the notebooks permit moving pages of captured notes across tabs to maintain a certain organisation and various page templates may be used for further organisation on a per-page basis.

Figure 2.5: Filofax personal organiser

The result is that there is no single system that an information worker could use to organise all their paper artefacts. Rather, different types of artefacts are spread into those repositories which can accommodate them based on their physical properties. Furthermore, the different organisation solutions are inherently a way to archive paper-captured information and working with the information is less supported. In addition to fragmenting the information into multiple forms of storage, maintaining paper artefacts in different physical repositories limits the information visibility [120, 206]. This can be the case even with solutions such as post-it notes, if these become too numerous. Therefore, the successful use of information will likely depend on a user’s ability to

\(^1\)http://rolodex.com/Pages/index.aspx

\(^2\)http://www.filofax.co.uk
remember the existence of a piece of information in a particular form of storage and further conduct searches to retrieve it. Even in the case of more interactive approaches, such as the Smart Filing System [170] or SOPHYA [83, 82], where computer-aided searches are possible and the position of filed physical documents can be signalled by LEDs attached to folders, the user memory still plays an important factor. To circumvent this problem, Lansdale envisions that filing systems should be built around models of human memory [103].

Finally, there are limited possibilities to manage paper artefacts together with other types of media. Existing organisation approaches are almost exclusively meant to manage notes only. The only possible form of information ecology [171] is when notes are captured on printed documents in the form of annotations or when different paper documents are stored together, for example, in the same folder.

2.2.2 Digital Notetaking Solutions

Pen-based digital devices such as the graphics tablet and screen hybrids, Tablet PCs and PDAs have enabled a new range of notetaking solutions. The focus is on addressing issues related to the organisation of handwritten notes and their integration with related media. Given that information capture is performed with an interactive system, an unlimited number of options to manipulate and organise data exist.

For example, Dynomite [211], one of the earliest digital notetaking solutions, provides a wide range of options for handling handwritten information that are far beyond possibilities of an equivalent paper-based solution. These include the possibility to perform operations such as deleting handwritten notes or moving them to a different position, as well as transforming notes into digital text through handwriting recognition and issuing text-based searches. Furthermore, selected ink can be associated with properties from a pop-up menu containing a customisable list of keywords. Ink written in different regions of a predefined page template is associated with custom properties automatically. Finally, the system constructs note views based on associated properties and there is the possibility to store for later use both views and search results.

![Figure 2.6: Dynomite](image)

(a) Editing notes  
(b) Note views
In terms of integration with other media, Dynomite and similar systems, such as NoTime [101], FILOCHAT [207] or ChittyChatty [88, 89], support the integration of handwritten notes with audio and video recordings. Dynomite, NoTime and FILOCHAT are based on various types of tablets combined with a display, whereas ChittyChatty is a PDA-based notetaking solution (Figure 2.7). The major benefit is the creation of accurate records for meetings and similar situations. On one hand they solve the problem of incomplete notes. On the other hand, notes can be used as indexes for browsing recorded media, thus reducing the time needed to retrieve specific information. The approach has been taken further by sophisticated meeting support systems such as Teamspace [56], NoteLook [36] and NotePals [39], where notes could also be synchronised with presentation slides and other types of digital documents. All these solutions support combination notes. In addition, the systems which use the notes to implement some sort of indexing functionality, and thereby filter other content, also fall into the category of metadata notes.

More recent solutions provide ways to integrate handwritten notes captured via the digital device with a wider range of digital media. For example, the Microsoft OneNote\(^3\) variant for Tablet PCs allows handwritten notes to be integrated with any type of digital media supported by the notetaking application which includes pictures, links, other digital documents, as well as audio recordings. Moreover, notes can be interpreted through handwriting recognition and integrated with other tools from the Microsoft Office suite\(^4\). Another example is the InkSeine prototype tool proposed by Microsoft Research [73]. Also based on Tablet PCs, the tool provides further features such as radial menus for pen commands, as well as support for \textit{in situ} search and storage of search results as first class objects together with the ink notes. Figure 2.8 shows an example InkSeine note with queries, links and clippings from other documents.

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\(^3\)http://office.microsoft.com/en-us/onenote

\(^4\)http://office.microsoft.com
Another level of integration of notes with related media has been proposed by a category of solutions that address the annotation of content to be read. Solutions comply with the observation that users tend to read with a pen in their hands and enhance reading with support for handling annotations and annotated content. xLibris is one of the first systems to provide this kind of functionality and it addresses the annotation of book content based on a display tablet tethered to a PC [154] (Figure 2.9). The idea has been adopted by major companies such as Sony or Samsung and multiple modern e-reader variants are available nowadays. Similar systems have investigated support for annotating lecture notes in the Classroom 2000 project [15], documenting programming code in CodeAnnotator [35] and, in the PenMarked solution for grading student assignments, automatically parsing and recording scores in a database and sending feedback to the students [151]. All these solutions fall into the category metadata notes.

When using tablets and other pen-based computers, the pen can be used not only for taking notes, but also to interact with the rest of the digital applications running on the device, thus enabling new interaction paradigms such as the scrolling based on circular gestures proposed in InkSeine. An initiative around PenPoint OS, an operating system written specifically for graphical tablets and personal digital assistants, even advocated the use of the pen as unique input device [33].

In addition to new opportunities, using gestural commands also introduces a challenge in devising pen input disambiguation techniques. Especially in pen-based editing applications such as drawing or notetaking, there is a need to be able to distinguish between pen input representing content and pen input that is used to devise gestural commands. A widespread disambiguation technique consists of requiring the user to press a button to toggle the pen mode. Furthermore, various approaches for separating the selection and action part of gestural commands need to be implemented. The selection refers to the content that the command is going to be applied to, whereas the action represents what has to be done with the content. One example technique for delimiting a selection-action gesture phrase is the pigtail proposed in Scriboli [72] (Figure 2.10). Users need to first draw a lasso which has the purpose to select the ink. The lasso has to be followed by a small loop, which delimits the lasso selection...
from marking a command. The command is chosen based on the direction of the line mark that follows the loop, different directions resulting in choosing one of 8 configured commands disposed circularly. In Figure 2.10, a line mark drawn downwards issues the Copy command.

Digital solutions essentially redefine the notetaking process. Users need to learn sets of available operations and corresponding steps in achieving actions such as annotating content, sharing notes with other people or starting and stopping the recording. Furthermore, having to boot up a system, choose the right mode of a capture device or start up the right application might limit the freedom and spontaneity typically characteristic to natural notetaking and maintained by a paper-based capture of the information. Similarly, having to mix taking notes with note management directives at capture-time might be perceived as a constraint.

Nevertheless, handling handwritten notes could certainly benefit if notes are integrated with various special purpose digital tools without significant efforts for the notetaker. For example, features such as creating note views as provided by Dynomite or the in situ search functionality offered by InkSeine could significantly improve the finding of notes. Similarly, tools for managing post-it notes such as the 3M Post-it Digital Notes\(^5\) could better support reminder notes. To-do notes could be better managed with the aid of a dedicated to-do list application such as proposed in TaskVista \([22]\). Occasional notes could be better maintained by tools such as EverNote\(^6\). In the next section, we discuss how paper-based notes can be integrated with digital applications with the aid of paper-digital solutions.

### 2.2.3 Paper-Digital Notetaking Solutions

The category of paper-digital notetaking solutions refers to digital pen and paper and similar solutions which enable both the paper-based capture and the digital management of information. Protofoil \([155]\) and the Paper PDA \([70]\) are among the earliest approaches proposed to materialise the paper-digital duality. These rely on scanning paper notes captured on special page templates. Based on the template configuration of the page, scanned notes are processed and integrated with digital applications. However, having to write on pages with predefined structures does not provide a lot of flexibility. Subsequent solutions based on digitising tablets, such as the Audio Notebook \([186]\) (Figure 2.11a), the CrossPad proposed by A.T. Cross and IBM \([96]\), the IBM ThinkPad TransNote \([25]\) (Figure 2.11b) or the ACECAD DigiMemo\(^7\) (Figure 2.11c) introduced ways to overcome this limitation. Notes are captured on regular notepads placed on digitising tablets and the positions of a stylus on the tablet surface are digitised into \((x, y)\) coordinate data for further processing. To manage the notes, users may rely on a series of operations provided via menu controls placed on the pad margins. For example, TransNote supports the definition of keywords, to-dos and messages based on circled handwritten content. These properties defined at capture time are used to organise the notes on the computer within the InkManager Pro software. Initiating cut, copy and paste operations can be done in a similar manner. The Audio Notebook

\(^5\)http://www.post-it.com  
\(^6\)http://www.evernote.com  
\(^7\)http://acecad.com.tw
enables also the synchronisation of notes with audio recordings, the controlling of the recording also being enabled through menu controls.

![Image of Audio Notebook, ThinkPad TransNote, and DigiMemo](image)

Figure 2.11: Notetaking solutions based on electronic tablets

![Image of Interaction Lens in a-book](image)

Figure 2.12: Interaction lens in a-book

A more complicated form of integration of paper and other media has been introduced in the *a-book* augmented laboratory notebook proposed by Mackay et al. [118]. Based on the A4 WACOM Graphics Tablet, PocketReader and PDA devices available at the time of their work, the notebook allows biologists to take paper notes and, at the same time, integrate their notes with additional information which could be both paper-based and digital. The integration of paper-based content with digital information is done through an interaction technique called *interaction lens*. As shown in Figure 2.12, a PDA placed on top of a notebook page detects and displays the underlying page including any previously recorded handwritten text, the combination giving the viewer the impression of a transparent window. In the interaction lens obtained this way, page items can be selected with the non-inking pen of the PDA and further tagged or linked to other physical or digital objects. The augmented handwritten information can be accessed by replacing the lens on the notebook page or via a digital notebook application running on the PDA. While the handling of information is rather complicated, the work is revolutionary in that it introduces a new type of paper-digital
integration: using digital projections on paper. In terms of digital content types, the solution enables the integration of paper-based content with URLs and images.

Solutions based on digitising tablets could potentially provide digital support similar to their equivalent completely digital systems described in the previous section. In addition to that, notetakers are offered paper-based capture of the information. However, requirements such as having to take notes in the special configuration of a notepad placed on the tablet or having to switch on the system represent limitations for natural notetaking. Solutions based on ultrasound such as Pegasus Mobile NoteTaker\(^8\) and IOGEAR Mobile Digital Scribe\(^9\) (Figure 2.13) made some steps in overcoming some of the limitations by removing the tablet. They are composed of two devices: a receiver device attached to the top or corner of any kind of paper page and a special pen which contains a small radio transmitter. The pen sends a signal to the receiver which is used to infer the succession of pen coordinates on a page. The receiver is able to store a certain number of note pages, therefore making it possible to also capture notes offline and later transfer them to a PC through USB connectivity.

![Figure 2.13: IOGEAR Mobile Digital Scribe](http://www.pegatech.com)

Anoto’s digital pen and paper technology introduced major improvements over similar technologies [2]. No other tools or devices except for pen and paper are required to capture the information. The combination of a special dot pattern printed on paper and detected by the infrared camera placed inside the digital pen enables the tracking of the pen movements on paper. The precision achieved by this new tracking technology reaches 0.03 mm for the pen position \([90]\), which is much higher than capabilities of similar technologies based on ultrasound. Furthermore, the technology relies on an absolute positioning system which allows a much more flexible page management. Compared to solutions based on tablets and ultrasound, where users have to make sure that they specify explicitly when they write on a different page number than the one previously registered by them into the system, the page detection is done via software. Pattern management software enables the generation and registration of the different pattern address ranges printed on each physical page into a system database [176, 202]. Users are no longer required to specify the page number on which they are writing. Rather, pattern addresses detected by the infrared camera are checked against the data generated at printing time, enabling the automatic identification of different physical artefacts.

\(^8\)http://www.pegatech.com
\(^9\)http://www.iogear.com/product/GPEN200N
Commercially available notetaking solutions based on the Anoto technology rely on a number of digital pens including Nokia’s SU-1B [8], Logitech’s io and io2 [4], Magicomm’s G303 [5], Livescribe’s Pulse and Echo [3], as well as Anoto’s DP-201, ADP-301 and ADP-501 [2]. Furthermore, custom digital pen and paper solutions can be developed with the aid of a series of toolkits and SDKs, including the Anoto SDK for PC applications [12], Livescribe’s Platform and Desktop SDKs [14, 13], PaperToolkit [215], iPaper [140], as well as MIL’s Anoto Mouse Driver and SDKs [6]. These toolkits support the design of interactive paper applications based on active page areas with associated digital callback functions to be executed on the computer while processing the data transmitted by the pen. Content written inside a predefined page area is interpreted by the application logic assigned to that particular part of the page.

The approach based on dedicated page areas has enabled applications such as Anoto’s form-based processing of information shown in Figure 2.14a or the annotation of presentation slides based on printed handouts in PaperPoint [177, 160]. In these examples, the entire content written inside a predefined page area is interpreted in the same way and the interpretation is specified by the type of associated callback function. For example, in PaperPoint pen input inside the area covered by Show buttons printed below each slide is interpreted as a command to show the corresponding slide, whereas pen input on a printed slide area results in annotations of the digital slide (Figure 2.15). The Esselte Digital Notepad with Anoto functionality uses a similar approach for notetaking (Figure 2.14b). All notes written on a page can be sent to a digital application running on a computer or a compatible mobile phone when the Send button printed at the bottom of each page is touched with the pen. Examples of Anoto’s form-based processing include NOSTOS where the technology is applied to medical data capture [20] or the commercially available Capturx products from Adapx10.

![Anoto form processing](image1)

(a) Anoto form processing

![Esselte Digital Notepad](image2)

(b) Esselte Digital Notepad

Figure 2.14: Processing handwritten notes based on capture areas

10http://www.adapx.com
The use of dedicated page areas for handwritten content identification can be combined with gesture recognition to devise some further note classification. Commercial solutions such as solutions integrated with the Logitech io2 pen or Oxford Easybook [9] use such an approach. The Logitech io2 software introduced combinations of circled letter commands and vertical lines to delimit note content to be manipulated digitally in a specific way [138]. For example, sending an email based on selected notes can be achieved as shown on the left-hand side of Figure 2.16. Oxford Easybook uses a similar approach, with the difference that a combination of page areas are considered to accomplish processing tasks devised by a gestural command (right-hand side of Figure 2.16).
For custom solutions, general gesture recognition solutions, such as the iGesture [179] framework or the $1 recogniser [212], support the definition of custom gesture sets and enable the integration of gesture recognition functionality with digital pen and paper applications.

Relying on approaches based on active page areas and gestures in the information capture phase, existing digital pen and paper-based notetaking solutions have proposed various sets of functionalities to digitally handle notes. Typically, an exact copy of the notes captured with an interactive notebook is made available within some digital notebook application. The digital notebook application exploits properties of the notes devised at capture time to enforce various approaches to organising and browsing the notes. For example, NiCEBook [29] uses categories assigned to selected notes and page dog-ears to enable the searching and browsing of digital notes based on multiple views: overview of all pages, category-based view, selection of all dog-eared pages and single notes view. Support to further manipulate digital notes within the digital notebook application can also be offered. Examples include support to further edit and integrate selected handwritten digital notes with a range of applications from the Microsoft Office Suite as provided by the Logitech io2 Software or uploading notes to an online repository in Livescribe. In Figure 2.17, notes selected within Logitech io2 Software are integrated with Microsoft Word after having been interpreted by a handwriting recognition engine and proofed by the user in the Logitech io2 Text Optimizer.
2.2. Existing Notetaking Solutions

A wide range of solutions have also addressed the integration of paper notes with other types of media. For example, Livescribe provides notetaking solutions centred on the synchronisation of handwritten notes with audio recordings. Similarly to Dynomite or the Audio Notebook, notes are used to replay the recording either from paper or from within the Livescribe Desktop on the computer. In the paper-based case, the recording is replayed by the special Livescribe smartpens integrated with a microphone and speaker. Other examples include U-Note [146], ButterflyNet [214], MEMENTO [205] and CoScribe [185]. However, in the case of the latter, the digital content can be accessed only on a computer. U-Note augments student paper notes by linking them with documents used by the teacher in the class such as presentation slides, oral recordings or content written by the teacher on an interactive whiteboard. ButterflyNet synchronises a biologist’s notes with pictures taken in the field. MEMENTO [205] proposes a paper-digital scrapbook where paper content can be mixed with audio, video and pictures. Finally, CoScribe [185] proposes a series of interaction mechanisms to integrate and later enhance the review of complementary paper and digital material used in the classroom. Related paper and digital documents are presented digitally in an interactive graph visualisation if previously linked through association gestures made on the paper and the digital documents. The latter need to be displayed on an interactive tabletop surface.

Content annotations are dealt with by solutions such as PADD [58], iJITinLab [77] and PaperProof [203]. Observing that paper is the preferred medium for “nomadic uses” such as editing a paper during a flight or at a café terrace, PADD proposes a solution for always maintaining synchronised the paper and digital versions of the same document. Images of handwritten annotations made on a printed paper document are superimposed at an equivalent position within the original digital version. In contrast to PADD, in iJITinLab, annotations are not integrated with the original document, but maintained in external files linked to the digital document. PaperProof adopts a different approach where a set of annotation types defined with the aid of gestural commands are interpreted and used to modify directly the digital source document.

The described digital pen and paper-based solutions can have a series of drawbacks for natural notetaking. These are related to the requirement to write within predefined page areas, as well as to various difficulties in using gestural input. Users are not naturally used to writing different notes in different parts of a page, as it is required by these solutions in order to enforce the processing of the notes. Furthermore, to support natural or quasi-natural notetaking, the set of gestures has to be designed in such a way that its use does not constrain the notetaking process. In ButterflyNet, even a single simple gesture command used to mark specific paper content received negative reactions due to the increase in notetaking time.

As already mentioned in the previous section, using gestural input has to be combined with approaches for distinguishing between ink data that represents the content and ink data to be interpreted as gestures. The situation is more complicated in the case of paper-based interfaces in that no direct feedback can be given through the interface. Only indirect feedback about a user’s actions can be provided. Possibilities include digital pen feedback [110, 182, 3] or feedback via various other external devices such as smart cameras or headsets as used in ButterflyNet [214] or EdFest [139], respectively. While in the first case the pen itself provides feedback via vibrations, integrated speakers, LEDs or OLED displays, ButterflyNet relies on modified digital cameras of-
ferring real-time visual and audio feedback for pen-based interactions. Similarly, EdFest users are provided with feedback via wireless headphones that they have to wear. As a result, users have to either pay attention to indirect feedback, such as showing the current writing mode on a Livescribe smartpen’s OLED display, or they have to remember the current pen mode. Proposed approaches for switching between inking and gesture modes include having to perform gestures only in specific page areas in the case of EasyBook, or use dedicated page areas in the form of printed buttons to change the pen mode. An example of the latter has been used in NiCEBook [29], where printed buttons have to be touched with the digital pen before performing pen-based gestures for marking specific handwritten notes.

2.3 Enhancing the Memory Aid Role of Paper Notes

Coming back to the role of external memory aids played by paper notes and discussed in Section 2.1, Elsweiler [46] reiterates Lamming’s observations [100] and mentions two types of memory problems to be dealt with via memory support applications: retrospective and prospective. Elsweiler clarifies that retrospective memory problems are similar to “forgetting details of a past experience” and mentions that retrospective lapses occur when an individual realises a deficit in knowledge, but recognises that the required information has previously been in their possession. In this case, a way to support the user can be to provide them with solutions for re-finding the information. Prospective lapses are different in that they happen when a retrieval cue, in our case, notes written with the incentive to prevent possible memory failures, fails to remind us. Very often, this happens because the cue is not resident in working memory at the time. A way to deal with prospective lapses can be using reminder applications.

Most of the notetaking solutions presented in Section 2.2 are best suited to supporting retrospective memory problems and correspond to Elsweiler’s definition of PIM tools: tools intended to help people find previously stored information by allowing them to organise their information snippets. Given certain information that users remember having captured as notes, support is provided for locating the information snippets within digitised notes through browsing or searching. The vast majority of solutions based on digital pen and paper technologies, including Logitech io2, Livescribe, ButterflyNet, Prism [188], CoScribe and NiCEBook, are integrated with digital notebook browser applications which provide functionalities such as searching, sharing or further editing of the notes. Some of the systems further provide support to access other information related to the notes. For example, systems such as NoTime, Dynomite, FILOCHAT, Livescribe and ChittyChatty provide access to information recorded while taking the notes and CoScribe supports the retrieval of documents actively linked by the users with noted information. In addition to the cueing problem reported by PIM research, which consists of not remembering exact details to issue a search [47, 190], searching might not be adequate for handwritten notes given possible misinterpretations of handwriting recognition. In such cases, browsing the digital notebook becomes the only way to re-find notes. Except for the possibility to provide remote access to noted information via such a notebook browser application, it is arguable whether browsing digital notes can present improvements over browsing the physical notebook.

Prospective memory problems are dealt with mostly by providing support to inte-
egrate explicitly marked notes with email clients or notification systems. Logitech io2 and Oxford Easybook shown in Figure 2.16 are among the solutions that propose the integration with email clients running on a PC. In such case, an email addressed to the users themselves can potentially accomplish the function of a reminder [46]. The Paper IQ\textsuperscript{11} Digital Pen for BlackBerry\textsuperscript{12} integrated with Oxford Easybook M3 is an example solution for mobile phones. In addition to emails and faxes created based on paper notes that can be sent via a BlackBerry, the Smart Margins functionality can be used to specify that certain lines of the notes should be converted into tasks on the BlackBerry. Also in the category of systems that use paper for the capture of the information is the Txt-it Notes system shown in Figure 2.18 [189]. A post-it notepad placed on a graphics tablet is used to capture short notes. Notes are sent via email or SMS to a recipient chosen by drawing a line across the middle of the post-it note towards one of the pre-set recipient names (Figure 2.18b). In addition to restricting the notetaking activity to short notes, the setup leads to losing the advantage of mobility, which is often one of the reasons for preferring paper as capture medium.

Indeed, portable devices such as PDAs and other mobile devices are particularly suitable for providing information of interest given that this can be done no matter the user’s location. Furthermore, information such as the location or people in the vicinity can be used to provide the information in conjunction with context-aware mechanisms [173]. For example, Forget-me-not [99] is a \textit{memory prosthesis} application designed for the ParcTab [165] portable device. The solution provides assistance in retrieving personal documents and details from a user’s \textit{biography} by continuously capturing data, such as the person’s location, encounters with others, workstation activities, file exchange and printing and phone calls. Jiminny, also called the Wearable Remembrance Agent [161], is a wearable personal notetaking and note archival application for a head-up display which continuously displays old notes based on a user’s location and people in the immediate vicinity. While they are designed for assistance with retrospective memory problems, such systems could potentially be used to also deliver reminders and more recent systems have proposed such solutions [181, 195, 43].

It is debatable, however, whether integration with email tools or notifier systems integrated with mobile phones or PDAs is the most suitable approach to supporting the

\textsuperscript{11}http://www.developiq.com/content/sections/products.aspx
\textsuperscript{12}http://www.blackberry.com
prospective use of the notes. A body of work has shown that email provides insufficient support for handling tasks and other prospective information [60, 61, 183]. Furthermore, notification systems can generate unwanted distractions from the primary task if information is provided at inappropriate moments or with unsuitable presentation choices [127]. Email notifications and similar services implemented for mobile devices have also been associated with interruption problems [216, 66].

2.4 Supporting the Paper Notes Use for Collaboration

Given their physical nature, paper notes have always been considered inherently private and meant to primarily support their owner’s personal use. Therefore, sharing notes is achieved either by passing them around in their original paper-based form or by transcribing them digitally and relying on tools such as email and Wikis. The second option has been reported to be preferred, even if it involves more work for the users [122, 102]. Reasons include the low quality of paper notes, which makes them less useful if they are shared as they appear on paper, or the need to be able to keep parts of the notes private and not reveal the notes to others in their entirety.

With the advent of digital and paper-digital notetaking solutions such as the ones presented in Section 2.2.2 and Section 2.2.3, premises to improve this situation have been created and various notetaking solutions include support for sharing handwritten information. Based on PDAs or paper-based electronic tablets, NotePals [39] supports the sharing of notes taken in meetings and subsequent web-based access to minutes which are created by intermixing notes from different users in a number of ways [102]. Examples based on digital pen and paper technologies include PaperCP [111] and CoScribe [185], which support the sharing of notes and annotations made on lecture material. PaperCP supports the sharing of content written on slide printouts with the instructor, whereas CoScribe provides support for accessing lecture material annotated collaboratively.

Revisiting Khan’s taxonomy of notetaking situations shown in Figure 2.1, situations such as meetings and other forms of co-located collaboration may present a much more complicated sharing behaviour than the one supported by the previously mentioned tools. On the one hand, paper-based notetaking continues to be one of the most commonly used work practices in an individual’s preparation and capture of information. On the other hand, part of the work is captured also on other media than personal paper notebooks. Work may partly take place in shared interaction spaces and be captured on media such as whiteboards, flipcharts, digital documents shown via projectors and paper documents shared on tables. These may be edited or annotated collaboratively during the meetings.

To support the sharing of information in such scenarios, a number of collaborative systems have introduced shared interactive surfaces such as interactive whiteboards and tabletop computers. The interactive surface becomes a mediator for sharing artefacts from personal information spaces such as laptops and similar computing devices [159, 174]. The shared workspace provides a unified view of possibly heterogeneous artefacts and offers better support for structuring and getting an overview of complex information spaces [194, 210], as well as making it possible for multiple users to work simultaneously. Digital tabletops provide further advantages that make them particularly suitable for
specific collaborative tasks. These include encouraging communication in a face to face manner, providing better awareness, equitable collaboration through equal access to material or the direct manipulation of information [124, 169, 198]. Furthermore, the natural co-habitation of physical and digital artefacts on the table surface makes tabletops particularly suitable for supporting collaboration in cases where personal work is brought into a meeting in the form of paper documents [67].

To enable meeting participants to seamlessly switch between individual work on paper and collaborative work supported by digitally enhanced shared information spaces, systems such as Paperizer\footnote{http://www.mi-lab.org/projects/paperizer} [28], Shared Design Space [64], Diamond’s Edge [23], the NiCE Discussion Room [65] or DigiPost [84] employ Anoto’s digital pen and paper technology. Information written on Anoto-enhanced paper with a digital pen can be made available as digital ink data and rendered on tabletop or wall displays.

Inspired by previous work [158, 177], Paperizer proposes two sharing mechanisms. Printed content can be “pick-and-dropped” or paper sketches can be “sent” synchronously or asynchronously to a digital whiteboard surface. The Shared Design Space project implements the concept of “hyperdragging” [159], enabling the sharing of personal content on a digital tabletop including digital materials stored on a laptop as well as paper content. Heterogeneous sources of information are also supported in the NiCE Discussion Room by enabling interactions with laptop screen captures on an interactive wall. Diamond’s Edge uses a technique called “rip to share” to transfer paper content to a multitouch table. After tapping a designated page area, previously circled paper content is sent to the table and further edits inside the selected paper area are mirrored by the shared copy. DigiPost uses Anoto-enabled post-its to achieve a similar proxy approach. Once placed on the touch sensitive tabletop surface, the annotations written on a post-it are synchronised with their digital counterparts and succeeding edits of the physical post-it note will result in updates of the corresponding digital annotation.

There exist various forms of controls to further interact with paper content placed on a shared surface. For example, paper printed buttons to remote control shared content are used in Paperizer, Diamond’s Edge and PaperPoint [177]. While an indirection through paper for any editing operation that requires pen input is required in DigiPost and Diamond’s Edge, the use of Anoto technology has been extended to interactive surfaces in Shared Design Space, Paperizer and the NiCE Discussion Room, enabling the pen to be used as an input device for both paper and tabletop interactions. This allows further manipulations of shared content by means of top projected buttons controlled with the digital pen as in the Shared Design Space project. In the NiCE Discussion Room, a pen can also be used to manipulate whiteboard overlays that allow switching between layers of different types of content and interacting with content inside the laptop screen capture. The use of the digital pen as a universal input device resulted in an interesting effect in Paperizer, where the touch input is only mentioned for a vertical surface to which content from the tabletop can be sent.

Shared Design Space and Diamond’s Edge deal with evolving content by using overhead projections on the real printout to provide an overview of edits performed on the shared copy of the paper content. For this purpose, ARTag\footnote{http://www.artag.net} markers are attached to each paper page and tracked by a vision system. The drawback of the approach is that
the updated content is only available while working with the paper documents in the area covered by the tracking camera. Also, this means that the approach is likely to be effective only for simple editing operations. In the case of concurrent private and shared edits by multiple users, more sophisticated collaborative editing and consistency maintaining solutions are required [187].

More extended support for content management has been proposed by a series of vision-based systems, such as Pictionaire [67], DocuDesk [48] and Designer’s Outpost [97]. Pictionaire introduces the concept of “collection containers” to provide some sort of content organisation and review based on a timeline. Similarly, the workspace can be bookmarked and the bookmarks can be reviewed based on a timeline in Designer’s Outpost. Pictionaire further supports the recording and later replay of collaborative sessions. DocuDesk introduces the “task rehydration” feature that enables resuming previous workspace configurations comprising both paper and digital documents. For this purpose, documents displayed on the tabletop surface need to be explicitly linked by the user. In the revived workspace configuration, digital counterparts of the paper documents created by the vision system are presented, enabling comparisons with possibly updated paper versions.

These systems raise some privacy issues given that interaction is limited to the tracked surface and any information, including personal content, can only be manipulated on the interactive surface [67]. This means that privacy aspects are not taken into account when constructing views of the collaboration data [174, 209]. All participants have access to any tracked and recorded document, even if they are not meant to be permanently shared with other participants, but merely shown during a phase of collaboration. Another possible issue with the kinds of review functionality provided is that, with the exception of Pictionaire, no customised views are provided and different participants may have different perceptions of interesting content [102]. Furthermore, the review functionality is provided on the table surface in the same setup that is used for the capturing of content, but the collaborative content is not available for later access outwith the meeting room. An approach to deal with this situation is proposed only in Diamond’s Edge, where updated versions of the content are printed and attached to notebook pages.

### 2.5 Conclusion

In this chapter, we reviewed existing work on natural notetaking from a number of perspectives. The goal was twofold. First, the intention was to construct a view as complete as possible over the practice in terms of the reasons for taking paper notes, as well as the different uses attributed to notes. Second, by making a parallel between this view and a second view over the different support categories provided by existing notetaking solutions, we wanted to identify potential gaps in terms of uses attributed to notes which are not addressed by existing solutions. The motivation behind this undertaking was an assumption that, if such gaps would exist, they could be one of the reasons or lead to hints towards an explanation for the limited use of digital pen and paper in natural notetaking. Consecutively, addressing these gaps would contribute to extending the use of the technology.

One of the main roles played by paper notes is to support memory and remembering.
An analysis constructed around this role played by paper notes already revealed a series of misalignments between paper-based notetaking uses and existing paper-digital support. In particular, existing solutions do not provide suitable means to support the note review. We believe that addressing this problem would not only lead to better paper-digital notetaking solutions, but also increase user incentives to adopt and extend the use of paper-digital notetaking.

The existing work analysis already revealed potential problems. Nevertheless, paper-based notetaking is a complex practice and multiple aspects could an have an influence on the situation where paper-digital notetaking is not widely used. One such aspect is, for example, the tendency to use paper in combination with other media. It is not clear how observations such as the one mentioned previously should be correlated with the different paper-based notetaking facets with a view to improving the use of digital pen and paper. It became apparent that a more thorough analysis through first-order direct observation of the practice was necessary. We continue in the next chapter with a study of the use of traditional paper notes. The study is meant to verify already formed hypotheses and reveal other potential factors relevant for our quest to extend the use of digital pen and paper in natural notetaking. Subsequent chapters present more in depth investigations given a series of results of this initial study.
To determine what the types of notes are from the point of view of their post-capture use, as well as understand whether and how natural notetaking could integrate with the use of digital pen and paper, we conducted a user study on traditional paper-based notetaking [80]. By identifying the different types of post-capture use of the notes, the goal was to determine whether existing notetaking support has missed to address any note uses. As stated in the previous chapter, we consider this to be one of the reasons behind the currently limited use of digital pen and paper for natural notetaking. Furthermore, the study was also meant to investigate the feasibility of using digital pen and paper to enhance natural notetaking in current and newly identified uses. As compared to related work discussed in the previous chapter, with the studies performed by Khan [91] and in NiCEBook [29] being the most representative, the study focused on if and how paper notes are later used, and not only on their forms and situations when they are taken. Moreover, the feasibility of using digital pen and paper for natural notetaking has not been studied in any of the previous works. We wanted to understand whether any requirements imposed by the use of digital pen and paper, such as having to integrate specific guidelines and rules in the notetaking process, would influence the acceptance of notetaking solutions based on the technology. Furthermore, we planned to investigate to what extent such limitations could be circumvented via automatic processing of notes based on detecting and exploiting specific note formatting patterns. We present the results of our study and assess the implications for natural digital pen and paper-based notetaking solutions. Also, we emphasise directions considered for further investigations.

3.1 Method

With our study, we were interested in a setup that would result in a high variability in terms of notetaking situations, potentially covering the entire range identified by Khan (Figure 2.1). This was motivated by an assumption that a more complete range of note
post-capture uses could be identified this way. Therefore, in the recruiting process of our study, we targeted participants whose activities consist of multiple daily and weekly tasks, both collaborative and carried individually. We chose to investigate paper-based notetaking carried in relation to meetings forming part of the professional activities of researchers in a computer science department. These users are often involved in a range of activities such as teaching, research projects and administrative duties. Furthermore, they are typically not forced to take notes during or in relation to meetings and, if they take notes, this is because the act is perceived natural and useful. We also chose to focus on meeting situations motivated by the fact that notetaking in meetings often consists of an agglomeration of notes with different utilities and does not give participants a lot of time to think about the formatting of their notes [91]. Finally, we were interested in observing whether any collaborative aspects related to natural notes exist.

We recruited 11 computer science PhD students (7 male, 4 female). To achieve an appropriate mix of participants in terms of the set of meetings and activities that involve paper-based notetaking, we selected 4 participants who are in the first year of their PhD, 3 users who are in the last year of their PhD and 4 participants who are at an intermediate stage. In the prestudy phase, all of the participants declared that they make use of paper notes in meetings and none of them had used digital pen and paper notetaking solutions before.

Each participant was given a high-quality lined paper notebook and was asked to use it for a period of two weeks. Given that the academic semester had just started and typically the amount of meetings held in this period is higher, we assumed that the two weeks interval would produce a significant amount of notes. However, we planned to extend the notes collection period should this not have been the case. The users were instructed to use the notebook for meeting-related activities and that they should write down information as they would normally do outside the scope of the user study. At the end of the study, the notebook was given as a present to the participants to ensure that they would not lose their data and to compensate for their efforts.

After the participants had used the notebooks for two weeks, the amount of notes collected had already been considerable. Nevertheless, to increase the chances that potential memory issues occur [89], as well as observe how users perceive the usefulness of their notes after they had already used some of them and new notes had been taken in the same notebook in the meanwhile, we started the next phase of the study two weeks after the initial two week time frame of using the notebook. Users could continue using the notebooks throughout the entire time, but we considered only the notes taken in the first two weeks for our investigations.

The second phase consisted of semi-structured interviews carried out with each of the users. We chose to focus on semi-structured interviews given the strong evidence provided by related work regarding the wide variability of notetaking practices. We wanted to give the participants the opportunity to reveal their personal practices, while at the same time making sure that we address our already formed hypotheses and questions. Analogous to the auto confrontation methodology described in [133] and the cultural probes method [54], we asked the participants to explain their notes. The discussion was guided through the prepared set of questions which included topics such as the context in which the notes were taken, the purpose of originally writing the notes and the ways in which notes were used afterwards. In each particular case, the discussion evolved based on a participant’s experiences and further questions were
asked. The interviews lasted between 1 and 2 hours and were recorded. We also scanned each participant’s notes with their permission. Subsequently, the recorded interviews and scanned notebooks supported qualitative and quantitative analysis of the notes.

### 3.2 Study Results

![Figure 3.1: Example notes](image)

Some example notes taken by our study participants are shown in Figure 3.1. During the two week interval, participants took paper notes for a total of 133 meetings with
an average of 12.1 meetings per person (min: 4, max: 23, median: 11, SD: 4.99). The number of meetings per user is highlighted also in Figure 3.2, where it can be observed that the maximum number of meetings was 23, the minimum was 4 and the median was 11.

![Figure 3.2: Number of meetings per user](image)

The notes contained a total of 2693 lines (min: 41, max: 590, median: 201, SD: 163.03) on 162 pages (min: 3, max: 29, median: 15, SD: 7.39). Furthermore, we counted a total of 5955 words (min: 99, max: 1067, median: 490, SD: 263.82). The values were counted manually. The total number of words per user, and the minimum, median and maximum number of words per meeting per user are shown in Figure 3.3 and Figure 3.4, respectively.

![Figure 3.3: Total number of words per user](image)

From the three figures (3.2, 3.3 and 3.4), it results that the amounts of notes and meetings per user did not have the same trend. While User 9 had the most meetings, the amount of notes taken in each meeting was rather low, as compared to, for example, User 6, who took the most notes, but participated to only 8 meetings. On the other hand, the trend in terms of the amount of notes per meeting shows a certain correlation with how well specified each user’s notes were. The latter is illustrated in Figure 3.5, where we classified the notes into three categories. The *sentences* class contains notes with complete or almost complete sentences and has an average length of 23.9 words.
3.2. Study Results

Figure 3.4: Minimum, maximum and median number of words per meeting per user

Notes consisting mainly of keywords are grouped in the *keywords* class with an average length of 5.1 words per note. Last but not least, notes between these two extremes are classified as *fragments* with an average length of 11.1 words. It can be observed that User 9’s notes were rather schematic and consisted mainly of keywords, while User 6 showed a tendency towards writing more complete sentences.

Figure 3.5: Completeness of notes

Correlating these results with each participant’s experience, we were tempted to infer that participants took less notes the most experienced they were. While User 6 had recently began their PhD, User 9 was about to finish. Nevertheless, this hypothesis is infirmed by at least User 11, who was also in the beginning of their PhD, but took few and schematic notes. We can only agree with related work that notetaking is
very variate and attribute these results to personal differences in terms of notetaking practices, rather than try to identify some patterns.

In what follows, we first introduce a taxonomy of notes based on their support for different activities and highlight patterns in the use of notes for each identified category. As opposed to Khan [91], who identified categories of notes from the point of view of their semantic content (Table 2.1), we were interested in categories of notes from the point of view of how they are used in post-capture phases. Based on this classification, our goal was to identify types of functionality able to enhance the use of natural notes based on digital pen and paper. Further, we discuss our observations regarding identified note formatting strategies. This investigation was meant to inform the feasibility of using automatic note processing approaches. Subsequently, we present participant reactions towards having to change their notetaking behaviour to accommodate some mechanisms meant to support the processing of the notes as required by existing solutions based on digital pen and paper. Finally, we describe briefly the participant practices in managing their paper-based information. We emphasise aspects related to the use of notes together with other media, as well as reactions towards the sharing of notes.

### 3.2.1 Categories of Paper Notes

We asked participants how they used their notes as part of their professional activities and identified 7 categories of notes. In the following, we describe the types of notes for each of these categories.

**Figure 3.6: Percentage of words per category**

**Support for work in progress.** In this category, we classified notes taken as part of discussions that were related to producing or updating papers and reports, preparing presentations or designing software code and architectures. We also considered notes taken as part of the responsibility to update shared web resources (e.g. in a Wiki).
3.2. Study Results

Examples of notes in this category include, but are not limited to, feedback from others about deliverables, answers of other meeting participants for questions that were prepared before the meeting, as well as excerpts of programming code, sketches or diagrams. Notes that were taken to update shared web content included outcomes of meetings in terms of agreements, decisions, conclusions, tasks of team members and open questions. As highlighted in Figure 3.6, this category contains the largest number of notes, including 37% of the total number of words.

**Information to be communicated to others.** As part of this category, we classified notes that support some kind of collective responsibilities. This information is not relevant for the users themselves, but has a certain relevancy for other parties. Examples include ideas, feedback and recommendations related to a colleague’s work that are meant to be communicated after the meeting. Other notes in this category include information that has been written down before a meeting to be communicated to meeting participants. This type of information includes room numbers, URLs, instructions, reminders and questions.

**Support for work organisation.** This category includes notes that represent a user’s own tasks, such as to-dos, as well as reminders for next meetings, presentations or conference deadlines.

**Metadata.** A separate category is formed by the notes documenting a meeting’s content and containing information such as the meeting topic, date or participants. In most cases, metadata notes were represented by a single or two line text block at the beginning of a meeting entry. As shown in Figure 3.7, 112 out of the 133 meetings made use of this pattern and only notes from 11 meetings contained no metadata at all. We further classified notes as metadata if they marked the transition to a different topic during a meeting as occurred in 10 cases.

![Figure 3.7: Number of metadata text blocks per meeting](image)

**Diverting attention.** This category refers to those notes which at the moment of the interview were declared to be useless information and primarily included doodles. Another example are unspoken opinions or reactions to presented content or discussed
aspects. A special case of notes that we considered as part of this category were notes that are not related to professional activities including, for example, shopping lists. Users mentioned that these types of notes were only serving the purpose of fixing the information in their memory and would most likely not be of any use in the future: “writing helps me remember”.

Regarding the remaining notes, participants reported that they wrote them under the assumption that they might turn out to be useful in the future. At the time of the interviews, some of these notes were still considered as potentially relevant. The rest of them were qualified as most likely irrelevant.

Potentially relevant information. This category contains two sets of notes. First, there is the set of notes with an undefined future use. Examples include cue notes for open questions, references to papers, people, research groups and conferences, instructions and best practices, as well as technical terms such as names of technologies or frameworks. A second set of notes support post meeting tasks and this includes information about phone numbers, passwords, as well as shop or hotel names. This second set of notes were generally used within a short interval after the meeting took place. After this point, they were considered as having an undefined future use, similarly to the first set of notes.

Irrelevant information. Regarding the notes in this category, the participants reported that they would not check their personal notebooks to find them, but rather have a look at some digital version of the information. The notes mostly document the meetings and were written as a manifestation of a type of unselfconscious engagement mentioned in [122]. Examples include points of discussion or outcomes of a meeting that represent general information, organisational details, interesting facts or details extracted from larger documents, such as budgets or statistics. Usually, a designated user is responsible for updating a shared webspace (e.g. a Wiki) with such details. Users declared that the importance or the lack of importance of the notes was not obvious at the moment of taking them and that the material was captured “just in case”. In three cases, users declared that they write these notes in the case that disagreements might occur in the future. However, they also reported that such disagreements had hardly ever occurred to them.

3.2.2 Post-Capture Use of Notes

Notes that form part of the support for work in progress category are dealing with tasks and activities that are characterised by a certain urgency or importance. For example, the work on some deliverable that the notes refer to is most likely executed in a relatively short time after a meeting took place. A user’s attention is focussed around that activity and they are likely to rely extensively on their memories while creating the deliverable. In some cases, participants declared that they only referred to the notes in the final step to verify that nothing had been forgotten.

“Most of this I remember anyway. I wrote them down so that I don’t forget them, but in general I kind of push them in the front of my brain.”

“When I implemented the software, I still looked at it once in order to see if I forgot any important information.”
3.2. Study Results

Analogous to the hot and warm documents mentioned by Sellen and Harper [171], paper notes taken to support work in progress are a type of hot or warm information. However, paper notes show a faster and more definite transition into cold information than general paper documents. Notes are usually processed a relatively short time after being taken, point at after which they become no longer useful. One reason for this situation lies in the different quality of the information contained by paper notes. Notes are often incomplete and imperfect information and documents created based on their processing are a more refined and potentially more reliable representation of the same information.

“I write enough details so that I can hopefully reconstruct [...] I rely on myself to remember the general stuff and keep the details in the notebook.”

“I tend not to write them in the form of elaborated text, I tend to write bullet lists of what I think it is important”

“Here I have the term ‘Ken’, then the paper ‘see Heinz Schmidt ken gate model’. This was enough for me to remember that I should look up this paper [...] he hardly remembered the name so I just wrote up whatever he had on the top of his mind and based on this I did a search online to find the paper [...] this ended up in BibTEX [...] What I did is look it up, find the reference and, in the end, added it to the report.”

The forms in which information appears in the final document may be completely different from the original notes. Notes are integrated into the final deliverables through a process of modifying, restructuring, rephrasing, filtering and completing with additional details. For example, one of the participants describes the process of incorporating feedback for a paper that they were working on:

“[...] these are more to-dos, like I should work on this part, make it more clear [...] If I would have gotten any sentences or content directly I would have, maybe, copied it, but I did not get this kind of feedback [...] I would write feedback from all the sources, but some of the feedback is actually not usable, especially if comments from different people contradict. In this case, when I write on the document, I ignore some of the comments.”

Another participant describes the process of updating a Wiki:

“In the Wiki, information is more structured. Is structured on topics. With the notes, I go through them and I see to which topic corresponds each note.”

Users declared that they would most likely not consult their notes any longer after these had been processed and incorporated into the target deliverable. While three users mentioned that they are still keeping such notes for sentimental reasons or because they generally tend to keep everything, the rest declared that they would throw these notes away if they had not been written in a bound notebook.

We asked the users whether having a digital representation of the notes in the form in which they had been written on paper, possibly transformed into digital text via
handwriting recognition, would help them in processing their deliverables. Users were not convinced by the value of such a service. While some users declared that in certain situations it might be useful to have this as a starting point for their documents, a clear preference for starting fresh was observed. However, the idea of having a digital representation of their notes was found suitable for to-dos by those users who use a digital tool to manage their to-do lists:

“To some extent, yes [...] If you already have the text there and it is something that would end up as your task, like a to-do, then yes. I think for to-dos it would work well.”

The idea of having digital versions of diagrams drawn in meetings was perceived as “possibly useful”. However, participants were not able to describe in which way they would use the information: “It would be good to have it there to look at it”. After further discussions the usefulness of a digital version of this particular kind of notes was declared to be limited:

“A picture, I wouldn’t just put it on a Wiki [...] I would transform it somehow digitally [...] If it is a class diagram, I would do a class diagram”

To-dos and reminders were marked on paper in a particular manner in only a few cases. Reminders typically contained some time related information. Therefore, the meaning of the notes was easier to infer. The fact that certain notes represented a to-do was often only apparent to the participants themselves: “It is a task. It is just not written down so.” The relevancy, importance and urgency of to-dos was not explicitly marked on paper, except for a few cases where the participants had used circling, underlining or exclamation marks. Only part of the notes that were interpreted by the users as having the meaning of a to-do or reminder were still considered as something that they needed or wanted to do at the time of the interview. In some cases, the explanation was that the corresponding actions had already been performed: “I just went back to my desk and did it.” In other cases, they reported that the to-dos were not something that they “really needed to do”. Some users reported that they copied tasks on post-its. They kept the post-its on their desks in such a way that these were visible. For the same visibility reason, two users reported sending emails to themselves. For future tasks that were considered important, the tendency was to add entries into various digital tools, such as calendars or task managers. Users reported that they usually set automatic reminders for these tasks. Often to-dos and reminders were not sufficiently specified on paper and the participants explained that they added the rest of the required details when entering the data into a digital tool.

Users had no concrete strategy in processing to-dos and reminders. They did not actively go back to their notebooks to look for something that they needed to do. In some cases, the to-dos were processed after having been noticed while participants consulted the notes in the frame of other activities. For example, a user describes what could happen when they processed notes for updating a Wiki:

“And if there is something else I need to do, like reserve a room, I would probably also do it. I think it is useful that I have to go through these notes, because otherwise I would probably not look at them and forget that I had to do something.”
3.2. Study Results

There were also multiple situations in which users remembered about certain tasks only while going through their notes together with the researcher. There was a quasi unanimous statement that “I just do it when I remember”. Especially in the case of less important tasks, users declared that there were high chances that they would not do them, simply because of forgetting them.

Users mentioned multiple variations in managing information that was considered potentially relevant, but which they did not need at the particular moment when the notes had been taken. Examples include special purpose tools such as Outlook Notes, plain text files or browser bookmarks. However, none of the participants were consistent in extracting this type of notes. As in the case of to-dos, users extracted parts of the information while performing other more urgent activities. One user motivated the situation with the statement that “transcribing is boring”. Another reason mentioned was the fact that users were not particularly fond of their information management approach and thought that, even if they would extract the information from their notes and integrate it with their usual tools, that would not help to re-find it. The users declared that they were still looking for a better way to keep track of their data.

As shown in Figure 3.7, users did not put extensive efforts into an indexing mechanism based on metadata for their notes. Similarly to related work [126, 211], users reported that the approach in looking for information in their notebooks consisted of browsing through pages and looking at titles. At the same time, they reported that they rarely looked back at notes. Therefore, the use of notes representing metadata appears to be limited.

A similar observation applies to information to be communicated to others. Given the fact that the information is not necessarily directly related to a user’s interests, notes are written only “not to be forgotten”. The time until they are used is typically very short and, after the information has been communicated, they lose their relevancy and are not consulted again. Often this information is remembered “anyway” and does not have to be consulted on paper.

3.2.3 Note Formatting Strategies

Notes in the different categories described previously were not marked in any differentiating manner. Marks were used very scarcely by our study participants. Furthermore, the existing marks were not consistent in any particular way with the categories of notes and identifying what the different parts of the notes represented required the help of the users. On the other hand, notes had a visual representation that presented a few distinguishable elements. These were typically separated by empty spaces. We identified three major types of blocks of notes based on their visual formatting: bullet lists, paragraphs and sketches. Figure 3.8 shows the average number of words per user for each of the formatting approaches and the average number of words per block of notes in general. The order of the graph bars from left to right coincides with the order of the legend labels from top to bottom.

As also emphasised in Figure 3.9, bullet lists were the most commonly used approach for structuring notes. In some cases, entire meeting entries appeared as a single bullet list with the exception of the meeting description, which was typically emphasised through underlining and separated from the rest of the content as shown in Figure 3.10. Blocks of notes representing different categories are mixed inside a meeting entry. Fur-
Moreover, long bullet lists typically contained several categories of notes. Not all the points in a bullet list represented information that was used. In Figure 3.10, the first point was considered irrelevant, the following two represented to-dos and the last two points were reminders. From the two reminders, the first one was declared by the user as not really important for themselves.

As mentioned earlier, the use of various marks was rather limited. The marks that we encountered included underlining, deleting, circling, check marks, question marks, exclamation marks, arrows, parenthesis and “To-do”. Figure 3.11 shows a histogram with the number of underlined words per meeting. 73 out of a total of 133 meetings contained no such marks and there was only a limited use of them in the rest of the meetings. Similar results were found in the case of cross-out and strike-through marks used for deleting content (Figure 3.12) and in the case of marks used to encircle content (Figure 3.13). 98 meetings had no deleting marks at all, whereas 126 meetings contained no circling marks. Low values were also encountered in the case of check marks, used by 7 participants on average in 2 meetings. Exclamation and question marks were used by
6 users in an average of 4.5 meetings each. Arrows to annotate content were used only by 2 users and in both cases only once. Parenthesis were used by 4 users on average in 2.5 meetings. The marking of parts of the notes with the label “to-do” was performed by 7 users on average in 1.15 meetings.

### 3.2.4 Reactions towards Changes in Natural Notetaking

One of our assumptions regarding reasons for the limited use of digital pen and paper technologies for natural notetaking was the fact that their use implied adapting work practices. We briefly explained the basic technology to each user and asked whether they would be willing to use special sets of marks and conventions in notetaking. In exchange, they would get special benefits such as being able to digitally search and
consult notes based on categories or be automatically reminded of things that they are required to do. In each interview, the list of benefits was adapted to the user’s specific problems in notetaking that they had mentioned earlier in the interview. Overall, users were reluctant about having to switch to work practices that would require major changes or additional time for the notetaking process. Some users even explained that they would most likely not be able to adapt:

“I guess it depends on how big the benefits would be [...] I would probably not be able to fulfil a lot of the requirements. I would probably choose the
ones that are useful for me.”

“I don’t think I am that structured [...] I am a wild note taker.”

“I think the investment in time would be greater then the benefit.”

“I don’t think I will ever be a better note taker.”

“Must be something fast and easy to do.”

We also asked whether the marking of notes in a post-processing phase would be preferable, but their responses were similarly reluctant:

“If I have to do it as post processing, it doesn’t make sense, because I could just type it, if I do that anyway.”

Furthermore, users expressed a certain reticence towards a mechanism that would hypothetically extract and digitally organise their notes by processing their natural marks such as crossing out, underlining or circling words:

“I don’t like and I don’t trust that a machine takes decisions for me, what is important and what is not [...] If I say I don’t need this, then ok, but I don’t like that a machine does it for me.”

“I would really like to have them the way I took them [...] I just need to have the feeling that is true.”

Users were further asked whether they would like their notes to be transformed into digital text. We mentioned that there might be some handwriting recognition errors. Most of the users mentioned that they would probably discard a tool that would distort the content of their notes:

“If there are errors, I would have the feeling that something is wrong.”

“In the end I can understand the notes, but for me it is an additional burden to understand why did the machine not understand them.”

Users acknowledged that paper-based notetaking is not optimally integrated with their activities that relied on the notes. At the same time, they reported that they preferred paper to digital tools for notetaking:

“I really like to take notes on paper. I have a Tablet PC, but somehow it is not the same feeling. The notebook is small. I really can take it with me, but a laptop I don’t take it every time.”
3.2.5 Information Management Behaviour

We report on a series of additional aspects that were analysed during the final semi-structured interview phase of our study. We were interested in finding out what kind of material is prepared and brought into a meeting by the participants. We also made inquiries regarding the parallel use of paper and digital documents and whether participants experienced any difficulties in managing the combination of paper notes and other information sources after the meetings. Furthermore, we wanted to investigate if users had any strategies for managing information evolving along successive meetings. Finally, we wanted to learn in which manner personally created notes are shared with other participants.

Three predominant types of meeting material were prepared in advance by participants. First, users declared that they made notes in their personal notebooks regarding issues to be discussed during the meeting. In a few cases, these notes were interleaved with empty placeholders for information to be added during the meeting. A second category comprises printed documents, such as slide handouts, diagrams or document drafts, that are brought into a meeting by a participant to support the discussions. Electronic documents such as slides or Wikis containing the meeting agenda represented a third dominant category. In the case that the discussion was supported by publicly shown digital documents, the owner typically performed the changes directly in the digital document version. This was explained by the benefit of increased awareness of other participants. The rest of the participants either took paper notes in their personal notebooks or no notes at all. In the case that the discussion was supported by printed documents, users preferred to annotate the received copy instead of writing in their personal notebook. Participants were rather fuzzy in terms of their approach to managing annotated documents. These were usually kept in printed annotated form for later reference, without being transcribed into digital form. In a few cases, participants mentioned that they filed these paper documents within or in the vicinity of their notebooks, particularly a short time after the meeting. However, participants also reported that these annotated documents were often misplaced in the long term.

Normally, notes taken during a meeting were not completed with supplemental details after the meeting and there was a lack of managing evolving content. An exception were the participants who intentionally left empty placeholders in their pre-meeting notes and filled in information during the meeting. Only one participant managed evolving content by rewriting the updated content as a new entry in their notebook. The likely reason for this situation can be explained by the reported preference to produce more refined versions of meeting notes in a digital form, as mentioned earlier in the case of notes supporting work in progress.

Participants reported that they normally do not share notes by physically passing around their notebooks. They mentioned that the notes were too sketchy to be forwarded in the form in which they appear in the notebook and also, for reasons of privacy, they did not want to make the entire content of their notebooks available. Notes taken with the goal to be able to inform others were usually communicated verbally. In a few cases, participants used email communication after the meeting. In one meeting, participants used post-its to comment on a colleague’s presentation and gave these to the presenter after the meeting. When asked, the participants expressed an interest in a service that could potentially allow them to easily share occasional notes taken for
3.3 Implications

We asked the participants which aspects of their meeting material management practice could accommodate improvements. Three aspects were associated with the highest potential for improvements. First, participants mentioned that they were not able to find a single tool that could manage all of their information; a problem that has been investigated in the field of personal information management for quite some time. Second, they expressed their dissatisfaction about not having found a way to organise and get an overview of all their paper material, including printed documents as well as handwritten notes. Third, it was reported that it would be good to have a record of related content in cases when notes referred to other documents. For example, handwritten notes might be associated with the points in a printed agenda, since users tended not to copy the agenda content into the notebook.

3.3 Implications for Natural Notetaking Solutions

Our study has shown that it might be that not all notes are used. One reason why parts of the notes might not be used is because they are not considered useful as shown for the notes classified as irrelevant and diverting attention. A second reason applies to notes classified as work organisation and potentially relevant. They are considered useful, but it can happen that they are not used because they are forgotten or overlooked. We have seen that participants processed especially less urgent notes in these categories mostly when randomly encountered “in their way”. Notes for work in progress and information for others are the ones most likely to be used, however their usefulness is limited in time until they are integrated into some digital artefacts or communicated to the others, respectively. The use of metadata notes is correlated with looking back for notes in the paper notebook, their main role consisting in supporting this process.

Furthermore, notes used to create some sort of digital representation are typically not used in the form in which they appear on paper. Notes for work in progress were integrated into deliverables through a process of modifying their content by filtering, restructuring, rephrasing or adding extra details. The main way in which these notes were used was through a process of scanning visually their overall content in order to get an overview and capture their essence in terms of the main points to be refined into digital representations. Similarly, notes representing information for others had to be refined before being shared digitally. Notes used for work organisation had to be processed as well. However, users did this extra step because it was a requirement to be able to use the different digital tools and not because they considered that notes were not evocative or self explanatory enough. Since they were often not sufficiently specified, users had to provide additional details to create entries within digital calendars or similar tools. The additional effort often resulted in not taking the time to process and consequently forgetting some of the notes in this category. Notes in the potentially useful category required the least processing effort, but they were also the ones that were processed the least. We attribute this situation to their relatively small number and high variability, which reportedly made it difficult to find an approach for maintaining this kind of information. In addition, another reason could be the fact that their use was associated with the least urgency and an unspecified time frame when they could turn out to be useful.
As discussed in Section 2.2.3, most of the existing digital pen and paper-based notetaking solutions follow an approach where paper notes are digitised in their entirety and further support to manage them digitally within digital notebook applications is provided. Given our previously stated observations, we believe that, in the case of natural notes, simply creating their digital copy might not solve existing issues in using the information. First, the benefits of providing digital versions for work in progress (37%) and information for others (6%) notes are questionable given the way in which they are used to produce digital artefacts: through refining noted information. Second, the approach is unlikely to improve the visibility of work organisation (21%) and potentially relevant (8%) notes since users still need to remember to actively look for the information or, in other words, they must “remember to remember” [173]. While paper notes are reportedly rarely accessed, the same has been argued for digital archives [145]. Furthermore, advantages of digital tools such as search and organisation based on views and similar approaches might not always be completely accurate given handwriting or gesture recognition failures, as well as a probability that users might omit to use the necessary processing guidelines consistently. In addition, revisiting Sellen and Harper’s observation regarding hot, warm and cold states of paper-based information [171], it might be that the ability to locate these notes through browsing is diminished given that they are mixed with 65% notes that are likely to lose their usefulness earlier in time (work in progress: 37%, information for others: 6%, irrelevant: 20% and diverting attention: 2%). Especially for notes which are not considered useful (irrelevant and diverting attention), as well as for notes which are anyway used while still hot (work in progress and information for others), some mechanism to support their filtering out might be beneficial. Galloway qualifies filtering out parts of the information with which we come into contact equally important as supporting remembering by making information accessible and argues for forgetting machines [52].

It becomes apparent that some sort of mechanism to support the filtering of paper notes in the view of their customised digital integration in accord with their use might be beneficial. Furthermore, providing support to selectively extract paper notes and integrate them with some digital application which provides functionality in correspondence with their different use might increase the perceived benefit of using digital pen and paper for notetaking, as opposed to continuing to use regular pen and paper. The mechanism should at the same time support the filtering out of notes which are not necessary, for example, by not marking them for extraction.

Referring back to the note use categories presented in Section 3.2.1, processing natural notes should account for the differentiation shown in Figure 3.14. Based on our observations, the natural notes most likely to benefit from being digitised are the ones in the work organisation and potentially relevant categories if this is correlated with providing some sort of reminding support. Furthermore, we consider that there might be a limited benefit of digitising notes used for work in progress, unless notes relate to other sources of information and their digital presentation creates an overview of the entire set of resources and their inter-correlations. Depending on the particular context, notes representing information for others might benefit from both reminding support and providing an overview of notes and related material.

Going back to the role of external memory aids played by paper notes and discussed in Section 2.1 and Section 2.3, the two proposed categories of support are also correlated with retrospective and prospective memory problems, respectively. When notes are
consulted for details as it is done in the case of work in progress notes, they serve as “guides to remind us of what we have experienced” and according to Lin et al. support our retrospective memories [112]. Following assertions of the same authors, notes for work organisation and potentially relevant notes correspond to the category of prospective memory aids since they “focus on present information and its future use”. As discussed earlier, prospective memory problems can be dealt with through various reminder systems. Retrospective lapses can be dealt with by providing means to re-access the material and retrieve the missing details.

While not all existing solutions presented in Section 2.2.3 integrate notes with digital applications in their entirety, participant reactions reported in Section 3.2.4 indicate that existing mechanisms based on active page areas and gestures used to extract notes selectively might need to be reconsidered towards providing more natural processing approaches. Users are particularly fond of the flexibility provided by paper in notetaking and they are reluctant to adapt their notetaking behaviour to include user-generated metadata about how paper notes should be digitally processed. Nevertheless, user-driven processing approaches can not be completely removed. We have also seen that the note categories were rarely explicitly differentiated in terms of formatting and, thus, unlikely identifiable without user intervention via some automatic processing approaches. While allowing for more natural notetaking, the chances that automatic processing introduces errors in user data are likely to be high. Our proposal is that user-driven approaches are combined with automatic processing approaches in an attempt to relax as much as possible limitations on natural notetaking imposed by user-driven processing. Concretely, we propose that existing framework support for developing digital pen and paper solutions is extended with support for automatic processing, allowing developers to combine user-driven and automatic processing, as well as choose the relative degree of reliance on the two.

The rest of this thesis is correlated with outcomes of the study presented in this chapter as follows. In Chapter 4, we show how we have extended the iPaper [140] framework for digital pen and paper solutions with automatic digital ink processing. To verify both our idea to relax limitations on natural notetaking by combining user-driven and automatic processing, as well as our hypothesis on the need of providing support for filtering and integrating notes with digital application in accordance with their use, we designed and implemented notetaking solutions for the two categories of

Figure 3.14: Usefulness and recommended processing of notes
support emphasised in Figure 3.14. Both solutions are built by using the extended iPape... of notes with reminder systems. In Chapter 6, we present a system for the review of noted... related to other sources of information which we have implemented. By using this system as support, we investigate whether a digital overview of the entire set of resources improves the use of the information. While we consider that investigations around these two categories of solutions are likely to be the most revealing within the scope of this thesis, other solutions can be easily built by using the framework for user-driven and automatic processing that we have developed.
As mentioned in Section 2.2.3, existing frameworks for digital pen and paper application development focus on the design of the paper-based interface of a particular solution in terms of active page areas, as well as their association to digital callback functions. When processing digital ink data received from the digital pen, content written inside each defined page area is interpreted in a unitary manner according to the logic defined in the digital callback function assigned to that particular part of the page. The structure of the paper interface in terms of active page areas enforces the segmentation of the digital ink data and, at the same time, determines the granularity at which developers can handle digital ink data in the processing phase. This approach is used by the Anoto SDK for PC applications [12], as well as subsequent solutions, including the iPaper framework [140, 178], Livescribe’s Platform and Desktop SDKs [14, 13] or PaperToolkit [215]. To process the digital ink data, callback functions can further integrate various approaches for gesture recognition, such as supported by the iGesture framework [179].

The processing approach based on active page areas and associated callback functions imposes certain conventions and rules in the notetaking process. To support the digital integration of their notes, users are no longer free in their notetaking and have to make sure that they write information as expected by the processing step: notes with specific semantics have to be written within some accordingly designated page areas or marked with pen-based gestures chosen by the developers, possibly based on certain observed notetaking patterns. While this transformed use of pen and paper is suitable for applications such as Anoto’s form-based processing of information or the annotation of presentation slides based on printed handouts as realised in the PaperPoint solution [177], it might be perceived as a limitation for the freedom, flexibility and immediacy in capturing information provided by traditional pen and paper.

In addition to imposing changes on natural notetaking, the approach also leads to less flexibility in the implementation of the digital counterpart of a notetaking solution.
The digital ink processing becomes bound to the definition of the paper interface, which has to be performed in a previous step, and eventual changes in the paper interface may require to also have to adapt the implementation of the processing. Furthermore, developers are required to implement additional digital ink segmentation solutions when it is necessary to access lower granularity note structures than the ones resulting from the segmentation determined by the structure of the paper interface.

Given the apparent correlation between the lack of constraints and the preference for paper-based notetaking, it seems obvious that an enhanced notetaking solution should use automatic approaches for the digital ink data processing as much as possible. A body of work has pointed out that even natural notes have an implicit structure consisting of agglomerations of textual lines and sketches [201, 109] and systems have been proposed that exploit spatial and temporal relations between pen strokes to extract and provide access to such implicit notes structures. Examples include interactive whiteboard systems [135], “rough” document image editors [163] and interactive notetaking systems [109, 199].

However, even with remarkable advances in digital ink parsing and processing [175, 18, 213], digital systems are still not able to classify different handwritten notes with the accuracy of the notetakers themselves [163]. In the case of the previously mentioned interactive systems [135, 163, 109, 199], immediate and direct feedback can be provided, this giving users the opportunity to notice and intervene in the case of errors, misinterpretations or partial processing [121]. However, when using digital pen and paper technologies, feedback about a user’s actions can be provided only indirectly, with the aid of modified pens equipped with displays or speakers, or via external devices, as described in Section 2.2.3. A possible alternative could be to review processed notes digitally in a post-processing phase. Given their reportedly inconsistent behaviour in processing paper-captured notes and as shown by our study in Chapter 5, it might be that users will not take the time to perform this extra step and subsequently discard those solutions which are perceived as introducing errors in their data. Furthermore, given that users are typically not consistent in their notations or, sometimes, do not mark their notes in any differentiating manner, it can become difficult to identify automatically notes categories, as well as how they are meant to be used digitally.

It becomes apparent that a digital ink data processing solution for natural notetaking can neither solely rely on automatic processing nor extensively use user-driven approaches based on active page areas and gestures. We consider that a possible way to reduce limitations for natural notetaking introduced by existing digital pen and paper frameworks is to combine the use of active page areas and gestural commands with automatic digital ink data processing. Therefore, since none of the existing frameworks integrate approaches for automatic digital ink data processing, we propose that existing support for developing digital pen and paper applications is extended with support for automatic digital ink segmentation and classification. The benefits are threefold. First, rather than relying on complicated paper-based interfaces to enforce the digital ink data processing, parts of the processing could be shifted to the post-capture phase. Applications could rely on less complicated paper interfaces, thus relaxing changes imposed on natural notetaking by the use of multiple page areas and gestures. Second, developers can handle digital ink data at the level of automatically extracted structures, which reduces the amount of low level digital ink processing required and enables them to focus on the implementation of the digital counterpart of a notetaking solution. Finally, the
4.1 Digital Ink Data Processing Framework

Given that the support for the automatic extraction of notes structures is in place, we propose that developers are provided access to handwritten notes at the level of detail shown in Figure 4.1. For a writing area represented by a `PageArea`, a developer can access its structural elements represented as `PageElement` instances. The `BasicElement` specialisation of the `PageElement` class represents the most basic entity that can be generated by a given digital ink data segmentation algorithm. Therefore, `BasicElement` instances aggregate low level ink data that has been assigned to single structures by the segmentation algorithm.

![Diagram of Digital Ink Data Processing Framework](image)

Figure 4.1: Proposed segmentation and classification of the digital ink data

Typical representations for the digital ink data consist of providing a model for the handwritten strokes. We use here a representation based on `Traces` of timestamped `Points`, which is the representation introduced by the iPaper framework. The digital ink representations used by other digital pen and paper frameworks can easily be
transformed to the iPaper format, for example, by using as an intermediary format the InkML\(^1\) representation, for which iPaper provides an import functionality.

Multiple BasicElements positioned close to each other can be grouped to form BasicBlocks that represent collections of note elements. By default, page elements are grouped based on containment and intersection relationships between their bounding boxes. Custom heuristics for the grouping of note structures can be specified by overriding the protected cluster method. For example, two BasicElements corresponding to two lines of handwritten notes could be grouped into a single block if the temporal gap between their last and respectively first digital ink data strokes fits within a certain interval determined as the time for a notetaker to switch to the next line. The cluster method is invoked by default after the note segmentation step. A BasicBlock can be further specialised into various semantic structures such as the TextualElement, Sketch or Reminder classes. For this purpose, various heuristics for processing digital ink data at block level can be implemented. For example, blocks that can be parsed into digital text can be classified as TextualElement. On the other hand, a BasicBlock consisting of one or several PageElements for which handwriting recognition does not produce any accurate results might be classified as Sketch.

Figure 4.2: Paper interface for notes extraction and classification

In addition to automatic approaches for detecting and classifying note structures, notetakers are also given the possibility to mark blocks of notes to be treated as single semantic structures. An example for achieving this is presented in Figure 4.2, where a series of interactions are used. In the example, users can take freehand notes in the

\(1\)http://www.w3.org/2002/mmi/ink
main writing area covering most of the page. Notes written in this area are automatically separated into `BasicElements` and grouped into `BasicBlocks` based on the logic specified in the `cluster` method. Furthermore, users can also specify groups of notes by first touching the timeline printed at the bottom of the page with the pen and then selecting the notes by drawing a vertical line. The area covered by the timeline consists of a series of active page areas, each associated with some temporal metadata, and the result of the interaction is that `PageElements` positioned adjacently to the drawn vertical line are grouped into a single `BasicBlock` associated with a subtype of the `Metadata` class. In this case, the `Temporal` subclass is used to represent the chosen temporal details. Active areas are associated also with the buttons printed at the right of the timeline. The active component associated with the `Reset` button contains logic to reset the succession of pen-based interactions. The `Synch` button is used to trigger the synchronisation with the computer in the case that the pen is used in the online working mode. The controls are shown enlarged in Figure 4.3.

### 4.1.1 Automatic Digital Ink Data Segmentation

In our study of notetaking practices presented in Chapter 3 we have identified three major types of note structures analogous to elements visually perceivable by the users: paragraphs, bullet lists and sketches. Since, for the first two types of structure, API support for manipulating individual lines of text may be useful, we decided to take a bottom-up approach consisting of first extracting lines from the handwritten information and then grouping individual lines into blocks of notes according to their spatial relationships.

As mentioned before, several approaches for clustering digital ink data based on spatial and temporal proximity have been proposed [175, 18, 213]. Our implementation is based on the work of Ao et al. [18]. The authors present a technique for identifying textual lines based on the notion of a `link model`. Furthermore, they propose a solution for distinguishing between textual and graphical information. Inspired by their suggestions, we have chosen to distinguish between text and sketch classes of note blocks based on the fact that the handwriting recognition engine does not return valid results.

According to the link model, a set of blocks composed of tightly connected pen strokes belong to the same textual line if their corresponding bounding boxes are located close to each other in a linear way and have comparable sizes. This is based on the Gestalt laws [98], which state that some objects form a line if they have characteristics of good `proximity`, `continuation` and `similarity`. The three criteria are translated into measures applied to all segments formed between the centre points of all adjacent bounding boxes, called `links` (Figure 4.4). The links between the bounding boxes are identified by applying Delaunay triangulation [41].

In our digital ink data segmentation, we start with a set of note traces represented by the set of coordinates between successive pen down and pen up actions. As described in Ao et al., traces are first merged into blocks based on the timestamp information associated with a trace’s points. Further, the minimum bounding boxes of the constructed blocks are computed. The minimum bounding box provides additional information about its associated trace such as the rotation with respect to the x-axis. Our computation of the minimum bounding boxes is based on rotating calipers [191] that are applied to the convex hull of a trace’s points. For the Delaunay triangulation,
we use the implementation of Paul Chew\(^2\). The three text line criteria \(\mu_1\), \(\mu_2\) and \(\mu_3\) for the proximity, continuation and similarity in size are implemented as follows:

**Proximity**

We consider that the measure \(\mu_1\) of the closeness of two bounding boxes is inversely proportional to the length \(l\) of the link between them:

\[
\mu_1 = \frac{1}{l + 1} \tag{4.1}
\]

This results in \(0 \leq \mu_1 \leq 1\). Note that we add 1 to the denominator to avoid a division by zero in the situation where the two bounding boxes have the same centre point. In this case, we get the maximum value of 1 whereas a value of 0 results for \(l \to \infty\).

**Continuation**

Given the two angles \(\alpha_1\) and \(\alpha_2\) representing the rotation of the two bounding boxes relative to their link, we define the linearity \(\mu_2\) of two bounding boxes as follows:

\[
\mu_2 = \frac{1}{|\alpha_1 - \alpha_2| + 1} \tag{4.2}
\]

For \(\alpha_1 = \alpha_2\) the corresponding traces are positioned linearly.

**Similarity**

To verify that two bounding boxes have similar sizes, we compute the value \(\mu_3\) based on their corresponding areas:

\[
\mu_3 = \frac{1}{|A_1 - A_2| + 1} \tag{4.3}
\]

The areas of the two bounding boxes are represented by \(A_1\) and \(A_2\), respectively.

\(^2\)http://www.cs.cornell.edu/info/people/chew/Delaunay.html
Figure 4.5: Successive line segmentation steps
Link strength

The link strength \( \mu \) is computed based on the three criteria \( \mu_1, \mu_2 \) and \( \mu_3 \) and is used in the detection of textual lines:

\[
\mu = \mu_1 + \mu_2 + \mu_3
\]  

(4.4)

Given the original note page shown in Figure 4.5a, the final result of the line segmentation is highlighted in Figure 4.5d. In an intermediary step, we first apply Delaunay triangulation for the minimum bounding box computation shown in Figure 4.5b and then identify the strongest links shown in Figure 4.5c.

The separation into basic page elements, which is equivalent to extracting lines in the case of the algorithm proposed by Ao et al., is provided by the \texttt{separate()} method of the \texttt{Separator} class shown in Figure 4.6. Every time some digital ink data is provided, for example by the iPaper framework in the form of a \texttt{Note} containing a number of traces in combination with information about the page number, the document identifier and the pen ID, this data is added to the \texttt{Separator} class. The invocation of the \texttt{separate()} method results in a list of \texttt{BasicElement}s introduced earlier in Figure 4.1. The \texttt{cluster()} method that is invoked after the segmentation step generates a list of \texttt{BasicBlock} instances for each \texttt{PageArea}.

![Figure 4.6: Class diagram for the separation into basic elements](image)

Listing 4.1 shows how the segmentation process can be integrated with the iPaper framework for the sample paper-based interface described in Figure 4.2. As presented in detail in [178], iPaper active page areas need to be associated with active components, each having stub and logic components. The stub of an active component runs on the client machine and is responsible for the processing of the digital ink data captured within the associated page area. For the sample application, the main writing area is associated with the \texttt{DrawAreaStub} active component and the method \texttt{handleNote()} contains the code invoked to process notes captured in that area. As illustrated in the listing, the \texttt{addNote()} method of the \texttt{Separator} class is invoked every time a new note has been captured. The \texttt{SynchButtonStub} active component is associated with the active area covering the \texttt{Synch} button printed at the bottom-right of the page. In the online working mode, the button is meant to trigger the explicit synchronisation with the computer and the associated active component is instantiated when the user touches the button with the pen. As a result, the \texttt{separate()} method of the \texttt{Separator} class is invoked and a new segmentation of the content is done. Existing \texttt{PageArea} instances are then refreshed via the \texttt{update()} method to reflect the new page structure after the last segmentation step. The use of the \texttt{Synch} button is not necessary in the
offline working mode, where the synchronisation is performed every time the pen is connected with a computer by placing the pen into the cradle. It can be observed that using our framework is equivalent to simple method calls within the already provided constructs of the iPaper framework.

Listing 4.1: iPaper active components for sample application

<table>
<thead>
<tr>
<th>No.</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>public class DrawAreaStub extends CaptureNoteStub {</td>
</tr>
<tr>
<td>2</td>
<td>public void handleNote(String docID, int page, Note n) {</td>
</tr>
<tr>
<td>3</td>
<td>String penID = getDeviceAddress();</td>
</tr>
<tr>
<td>4</td>
<td>Separator s = Separator.getInstance();</td>
</tr>
<tr>
<td>5</td>
<td>s.addNote(n, page, docID, penID);</td>
</tr>
<tr>
<td>6</td>
<td>}</td>
</tr>
<tr>
<td>7</td>
<td>}</td>
</tr>
<tr>
<td>8</td>
<td>}</td>
</tr>
<tr>
<td>9</td>
<td>public class SynchButtonStub extends SingleEventStub {</td>
</tr>
<tr>
<td>10</td>
<td>public void finish() {</td>
</tr>
<tr>
<td>11</td>
<td>Separator s = Separator.getInstance();</td>
</tr>
<tr>
<td>12</td>
<td>PageArea writingArea = getWritingArea();</td>
</tr>
<tr>
<td>13</td>
<td>// redo the separation and clustering for all pages</td>
</tr>
<tr>
<td>14</td>
<td>List&lt;BasicElement&gt; basicElements = s.separate();</td>
</tr>
<tr>
<td>15</td>
<td>List&lt;BasicBlock&gt; blocks = writingArea.cluster();</td>
</tr>
<tr>
<td>16</td>
<td>// add all blocks and basic elements into an update list</td>
</tr>
<tr>
<td>17</td>
<td>List&lt;PageElement&gt; elements = ...</td>
</tr>
<tr>
<td>18</td>
<td>writingArea.update(elements);</td>
</tr>
<tr>
<td>19</td>
<td>}</td>
</tr>
<tr>
<td>20</td>
<td>}</td>
</tr>
</tbody>
</table>

4.1.2 Custom Classification

The segmentation into basic page elements and the subsequent clustering into basic blocks reveals some details about the high-level structure of handwritten notes. However, this grouping into basic blocks only reflects spatial and temporal properties of the different notes and the semantic of the content is not taken into consideration. In this section, we highlight how developers can further process automatically extracted notes structures based on the classification components shown in Figure 4.7.

![Classifier Diagram](image-url)

Figure 4.7: Classifier
Given a set of \texttt{PageElementClasses}, the \texttt{classify()} method defined in the \texttt{Classifier} class will analyse a collection of \texttt{PageElement} instances provided as input and create more specific \texttt{PageElement} subclasses. Each classification class returns a \texttt{ClassificationResult} instance consisting of a confidence score ($0 \leq \text{score} \leq 1$) for the membership of a given \texttt{PageElement} in a specific classification. The classifier generates this score for each of the classes configured in the \texttt{ClassifierConfiguration} and recommends the classification result with the highest score. The score has to be higher than a certain threshold, which in our implementation was set to 0.5. If there is no possible classification with a score higher than the threshold, the \texttt{Classifier} will return a fallback classification class as specified in the configuration. Listing 4.2 contains a basic classifier configuration.

Listing 4.2: Basic configuration for the classification

```java
1 List\<\textit{PageElement}\> originalElements = ...  
2  
3 // set up the classes to be checked against 
4 List\<\textit{PageElementClass}\> classes =  
5 \textit{new} LinkedList\<\textit{PageElementClass}\>\();  
6 classes.add(\textit{new} ExampleClass());  
7  
8 // set the fallback class to SketchClass  
9 PageElementClass fallback = \textit{new} SketchClass();  
10 ClassifierConfiguration config =  
11 \textit{new} ClassifierConfiguration(classes, fallback);  
12  
13 // classify the input elements  
14 Classifier c = \textit{new} Classifier();  
15 List\<\textit{PageElement}\> classifiedElements =  
16 c.classify(originalElements, config);  
```

Some default classifiers provided by our framework are as follows:

**Text Class**

The \texttt{TextClass} relies on the results of a handwriting recognition algorithm and the score is directly related to the confidence value of the used handwriting recognition engine. In our implementation, we used the MyScript Intelligent Character Recognition from VisionObjects\(^3\) for the handwriting recognition.

**Sketch Class**

The \texttt{SketchClass} is meant to be used as a fallback class with a classification score of 1. Typically, the classifier will generate a \texttt{Sketch} element, if every other configured classification fails.

**Indentation Class**

The \texttt{IndentationClass} verifies whether a \texttt{BasicBlock} that contains several \texttt{PageElement} instances represents a multi-level bullet list structure. In a first step, the indentation level of each basic element contained within a block is determined. Page elements

\(^3\)http://www.visionobjects.com/
are sorted in ascending order based on the upper left corner of their bounding box. The ordering is done first for the x coordinate and then for the y coordinate. After the ordering, the corner points are iterated over and it is checked whether the difference to the previous anchor point is greater than some threshold. The threshold value is used to define what is to be interpreted as simple white space and what has to be considered list item indentation. Depending on the result of the comparison, an element’s indentation level is set to the same value as the indentation level of the previous element or to a level increased by 1. Figure 4.8 shows the result of such a procedure.

Figure 4.8: Determining the indentation of a set of lines

List Class

The ListClass can be seen as a specialisation of the indentation class where the subelements represent an item list on a single indentation level, each of them starting with a given token.

To give an idea of the effort required for implementing classification classes, we refer to Listing 4.3. Given a set of PageElements, the TitleClass classifies a block as Title if all page elements can be parsed into text with a certain confidence and the element placed below all other elements is a straight line having the length comparable to or bigger than the length of all other elements placed above. An example of such a title element is shown at the top of the page in Figure 4.5a. The score of the class can be computed, for example, by averaging the score of the handwriting recognition with the score from the straight line detector, the score of the straightness being given a higher importance.

Listing 4.3: Custom title classification

```java
1 public class TitleClass implements PageElementClass {
2     ...
3 @override
4     public ClassResult classify(List<PageElements> e) {
5         double score = 0.0;
6         // get the lowest element
7         PageElement last = getElementBelow(e);
8         // is the last element long?
9     }
```
if (isStraightLineLong(e, last)) {
    // is the last element a straight line?
    score = scoreStraightLine(last);
}

// get text representation without the line
e.remove(last);
Result hwrResult = parseText(e);

// construct the classification result
ClassResult r = new ClassResult();
// create a new title page element
r.score = (score + 2 + hwrResult.getConfidence()) / 3.0;
e.add(last);
return r;
}

It can be observed that developers can work with digital ink data at the level of
automatically extracted structures. Further processing of the data can be done with
little implementation effort, such as determining relationships between the bounding
boxes of the various page elements.

4.1.3 User-Driven Segmentation and Classification

![Figure 4.9: Class diagram for the finite state machine framework](image)

In the case of the notetaking application interface described in Figure 4.2, we pro-
posed an interaction model consisting of two successive pen-based interactions through
which notetakers could provide guidelines for processing note subsets. The first interaction step consists of pointing with the pen to a specific part of the printed timeline. This action is interpreted as an upper bound value for the lifetime of the reminder notes which are about to be selected in the second step. The system will interpret the selected notes as forming part of a single block structure containing one or several basic elements depending on the length of the vertical line used to mark notes. The functionality is an example where traditional processing support provided by digital pen and paper solutions is used for manual user-driven segmentation and classification of a page’s structural elements. For the classification, various metadata specified at the design time of the paper interface and associated with specific active page areas will generate the corresponding block metadata.

To support developers in designing paper-based interfaces with a user-driven classification of free-form notes, we propose a framework for the description of paper-based interaction models based on finite state machines (FSM). Figure 4.9 shows the class diagram of our solution. The FSM specification framework provides an extensible set of States, each of which has a unique name. Based on a given Action of type GESTURE, TEXT, MESSAGE or TRACE, the FSM gets into a new state via the transition() method. Each state can be configured with a method to be invoked and executed whenever the state is reached by using the setInvokeMethod() method. An optional data value represented by the data field of a parametric type T can be configured for each Action. This allows the configuration of each action type with custom values such as the gesture class that has been recognised in combination with an action of type GESTURE or the text associated with an action of type TEXT.

Particular FSMs can be defined by a developer via an XML specification. Listing 4.4 shows the XML definition of a series of state types that are already provided by our framework.

Listing 4.4: XML representation of predefined state types

```xml
<machine>
  <state type="bridge" name="some new bridge state name">
    <next state="some already defined state's name"/>
  </state>
  <state type="final" name="some new final state name"/>
  <state type="gesture" name="some new gesture state name">
    <condition className="some gesture class" false state="some already defined state's name"/>
  </state>
  <state type="text" name="some new text state name">
    <condition text="some text" false state="some already defined state's name"/>
  </state>
  <state type="switch" name="some new switch state name">
    <case key="default" state="some already defined state's name"/>
    <case key="some other key" state="some already defined state's name"/>
  </state>
</machine>
```

- **Bridge state**: From this type of node, the FSM will always transition to the state
specified as `next`, regardless of the input action.

- **Final state**: When the FSM reaches a final node, it will continue its execution at the node that was marked as a start node as soon as the FSM receives a new input action.

- **Gesture state**: The FSM will transition from a gesture node to the state denoted by `true` when the condition is met. In all other cases, it will transition to the state denoted by `false`. The condition is met when the type of the input action is `GESTURE` and if the action’s `data` field contains the value denoted by the `className` attribute.

- **Text state**: The text node is similar to a gesture node, with the difference that the input action type must be `TEXT`. In this case, the `data` field must contain the string value defined in the `text` attribute.

- **Switch state**: A switch state may have several possible outgoing transitions. It requires an input action of type `MESSAGE` and the `data` field must be assigned a value equal to one of the `key` attributes of the `case` elements. When none of the keys match the passed value, the transition marked by the default key is followed.

![Finite state machine for sample notetaking application](image)

Figure 4.10: Finite state machine for sample notetaking application

The FSM for our sample notetaking application interface is shown in Figure 4.10 and the corresponding XML code in Listing 4.5. The code for the iPaper active components presented previously has to be adapted to account for controlling the FSM as shown in Listing 4.6. Note that a third active component is associated with the different parts of the timeline. When the user touches the timeline with the pen, an instance of the active component will infer the temporal metadata value associated with the page area and create an `Action` of type `MESSAGE` configured with a "temporal" string value for its `data` field. Similarly, the `SynchButtonStub` active component creates an `Action` of type `MESSAGE`, but configured with a specific "synch" string value. No additional data is required in the `data` field of an `Action` of type `Trace`, an instance of which is created by the `DrawAreaStub` active component.

```
Listing 4.5: XML representation of a sample FSM
1  <machine>
2    <state type="switch" name="WaitForTimeframe"
```
In this case, the separation is managed through method calls specified in the XML description of the FSM. As long as a user takes notes in the main writing area, the FSM remains in the *Wait For Timeframe* state as shown by transition (2) and notes have to be added to the buffer maintained by the *Separator* class as shown by the *invoke* XML element. The `addNote()` method defined in a custom class, represented by the *Logic* class in Listing 4.5, is responsible for forwarding the call to the previously mentioned `addNote()` method of the *Separator* class. When the user selects a timeframe with the pen, transition (1) into the *Timeframe Selected* state is triggered. From this state, transition (3) is taken only if a user selects a group of notes by marking them with the digital pen. Otherwise, the FSM does not leave the state as indicated by transition (4). The `selectNotes()` method invoked after transition (3) is responsible for creating a new *BasicBlock* associated with the corresponding temporal metadata. Since new content has been added since the last segmentation, a new separation into basic elements is done before updating the block structure of each page area defined on the pages. Further, *BasicElements* located next to the selecting vertical pen stroke will be grouped into a new block.

Listing 4.6: Adapted iPaper active components specification

```java
class DrawAreaStub extends CaptureNoteStub {
    public void handleNote(String docID, int page, Note n) {
        Action<String> action = new Action<String>(
            Action.Type.TRACE, null);
        Logic.getFSM().transition(action);
    }
}

class TemporalMarkerStub extends SingleEventStub {
    public void finish() {
        Date date = getTemporalMarker();
        Logic.addMetadata(new TemporalMetadata(date));
        Action<String> action = new Action<String>(
            Action.Type.MESSAGE, "temporal");
        Logic.getFSM().transition(action);
    }
}
```
In this particular case, the last pen stroke written in the main writing area is used for the selection of the page elements that have to be associated with specific metadata, independently of their content or shape. Another possibility would be to perform the selection only if users draw a specific gesture or write a specific keyword immediately after having defined the timeframe. For this purpose, a gesture or a text state could be introduced in the FSM after the Timeframe Selected state.

4.2 Developing Applications by Using the Framework

![High level architecture of prototypes](image)

Figure 4.11: High level architecture of prototypes

All prototypes which will be described in the remainder of this thesis have been implemented on top of the iPaper framework combined with support for digital ink data segmentation and classification as described in the previous section. In each case, an iServer database stores the structure of the paper interface in terms of active page areas and their association to active components [176]. Figure 4.11 describes the high level architecture of the solutions: data received from the digital pen is first processed by the iPaper framework and identified Notes containing Traces of ink data are forwarded to our PaperNotes component, which is responsible for the segmentation and classification.
of the data. Based on an implementation of the Observer pattern, the PaperNotes Main Controller notifies a list of observers whenever new PageElements are created or existing ones are updated. Each of the implemented visualisation tools have their own controller component which acts as an observer for notifications relied by the PaperNotes Main Controller and implements tool specific logic. The component can also assume the role of storing data persistently, for example, in a db4o⁴ object database. The front-end of each visualisation tool can be then implemented in any programming language provided that the communication between Java and the respective programming language is enabled, the corresponding communication between the controller and the front-end client components being highlighted in the figure. The front-end of the prototypes presented in the following chapters have been developed in one of Java, JavaFX⁵ or Adobe Flex⁶. The major challenge in realising the prototypes consisted of providing the appropriate set of functionality required by the end user, rather than the low level processing of ink data, which was taken care of via the framework.

4.3 Conclusions

In this chapter, we introduced the digital ink segmentation and classification framework which stands at the basis of the prototypes presented in this thesis and we have shown how the framework can be combined with existing digital pen and paper frameworks, toolkits or SDKs to simplify the digital ink data processing. Via automatic segmentation, the framework provides access to the main structural elements existent in handwritten notes and further clusters extracted elementary structures based on customisable logic. Automatically extracted notes structures can be further interpreted based on an extensible set of classification heuristics. In addition, we have presented a solution for the definition of paper-based interaction models based on finite state machines, simplifying the complex note processing and interactive paper interface definition. Last but not least, we presented some implementation details for the different prototypes which will be introduced in the next chapters of the thesis.

⁴http://www.db4o.com
⁵http://javafx.com
⁶http://www.adobe.com/products/flex
In Chapter 2 we presented an overview of existing notetaking solutions based on digital pen and paper. A parallel between the kinds of support for the digital management of paper-captured notes provided by existing solutions and the uses attributed to paper notes identified in our study presented in Chapter 3 has shown that better support for prospective memory problems might be beneficial. In this chapter, we investigate how natural notes correlated with some prospective use should be extracted and visualised digitally to support recall. We start by looking into related work in the field of reminder and notification systems with a view to inform the design of reminder systems suited for noted information. Further, we present a series of prototypes that we have developed with this specific goal in mind and the results of their evaluation.

5.1 Informing the Design of Reminder Notes Systems

Our proposal to integrate notes that have some prospective use with reminder systems is congruent with observations from related work such as Lin et al. [112] and Kidd [92]. Lin et al. have drawn attention to the fact that information that is “out of sight is out of mind”. As discussed in Section 2.1, paper-captured information is likely to get “out of sight”. Similarly, Kidd emphasised that valuable “marks are on the knowledge worker” and not on paper or on the electronic file since knowledge workers rarely consult such information. In this context, Lin et al. argue for improving the visibility of information and Kidd recommends that computer support should focus on the act of informing the user rather than passively filing large quantities of information.

Furthermore, the recommendation is congruent with psychological research on human memory mechanisms and remembering. Van den Berg mentions that the probability that an intention associated with a reminder is re-established in memory depends on the level of activation of its representation and the presence of the adequate retrieval cues [196]. A fully activated intention representation is accompanied by recall of the intention and, potentially, subsequent action. The author also emphasises that
the periodic review of an intention refreshes its activation and that the activation will
decay spontaneously in the absence of the review procedure. As already discussed in
Section 2.1, paper notes are used to cope with potential memory failures and play the
role of external memory aids. To prevent forgetting, users externalise memory content
and store it temporarily on paper as notes. In correlation with Van den Berg’s observa-
tion, a reminder notes system extracting a user’s notes from paper and bringing them
in some way into the user’s attention is likely to improve the activation of any intention
associated with the notes.

In addition to improving the visibility of information or informing the user, as sug-
gested by Lin et al. and Kidd, research on the design of reminder systems in correlation
with particularities of human memory and its underlying mechanisms goes further and
recommends reminding by keeping visible the activity that is to be reminded [132].
Miyata and Norman clarify that, from a theoretical point of view, reminders need to
reactivate relevant schemas and to re-establish whatever information is needed in short
term memory (STM) or the environment so that the appropriate trigger conditions
are satisfied. According to the authors, something that is physically present keeps its
memory scheme in an activated state.

These results support our proposal to extract notes from a user’s collection of noted
information and integrate them with reminder systems to support the recovery of an
earlier mindset associated with the notes. The question that remains is how should
reminding about notes be implemented. For example, should the recovery of an earlier
mindset be visually stimulated only or should any other mechanism be considered?
The reminder systems literature provides a series of recommendations regarding the
implementation of reminder systems. In what follows, we first review existing results
and then discuss their implications for our specific case of reminding about natural
notes. The discussion revisits relevant observations made in previous chapters.

5.1.1 General Considerations on Reminder Systems

Although reminders are valuable in re-establishing planned or suspended activities,
a number of aspects other than reminding need to be considered when designing a
reminder system. For example, Miyata and Norman emphasise that reminders can
interrupt ongoing activities which might not be desirable in some circumstances [132].
The authors propose a classification scheme for reminder systems based on levels of
signal and description features. The signal refers to the approach used to indicate
that something needs to be remembered and can have different levels of intrusiveness.
For example, an alarm or flashing lights are more intrusive than a note pinned on the
computer screen. The description refers to how the system indicates what needs to be
remembered and it can vary from being non-descriptive in the case of a ringing timer,
to being partially descriptive in the case of memory cues and fully descriptive in the
case of documents left in one’s way and containing all details to be remembered.

Among the well known reminder systems, to-do lists or the inbox of an email client
provide reminders with description, but no signal. Users need to actively check the to-do
list or their messages, respectively, to determine which items need to or can be switched
into the focus of their attention [43]. The combination of acoustic signals and pop-up
windows typically provided by email clients for defined appointments have a strong
signal and good or partial description, depending on the details provided by the user
at definition time. Post-its have both description and a good visual signal. However, physical post-its can also have drawbacks such as being tied to a fixed physical location or being visible also to other people and not solely to their owner. These drawbacks can be circumvented with digital post-its, which, with current technology advances, could be made available almost anywhere and any time.

McCrickard et al. introduce a similar scheme based on a model of 0 to 1 levels of three parameters: interruption, reaction and comprehension (IRC) [129]. Interruption is defined as an event prompting transition and reallocation of attention focus from a task to the notification. Often, low levels of interruption are desired. This means that the notification system should not intrusively disrupt user attention devoted to a main task. The second parameter, reaction, refers to the rapid and accurate response to the stimuli provided by a system. Notification systems present cues intended to inform the user of information of interest, often requiring them to differentiate between some values. Pre-attentive processing, which considers how information can be assimilated and understood rapidly by using colours, shapes and motion is considered one way to improve reaction to notifications. Remembering and making sense of the information conveyed by the reminder system is quantified by the last parameter, comprehension. Higher levels of comprehension are typically desired.

The IRC model determines a notification systems design space analogous to a cube with an edge length of 1, having one vertex placed in the origin of the three dimensional Cartesian coordinate system and the edges parallel to the axes. An image reproducing the original model of the authors is shown in Figure 5.1. Depending on the values assigned to the three model parameters, any notification system can be classified as a point inside or on the surface of this cube. Eight reference notification system classes are associated with the cube’s vertices. These are shown in Table 5.1 with examples for each class. Among these reference classes, ambient media and secondary displays refer to systems with the least interruption and most comprehension. The difference between the two classes is that systems in the secondary displays category are meant
to cause a user’s reaction and lead them to adjusting their activities in the case that some specific information is presented. While ambient media can be presented on a secondary display, ambient media systems are non-intrusive systems which provide effortless awareness and peripheral perception of some information, without requiring the user to react to changes or the appariation of some specific information. The high level of comprehension requires that the user takes the time to view and, sometimes, even decipher the meaning of the information shown. However, when this is done, it is usually perceived as a valued moment of rest and reflection. During the time of non-use, ambient media systems act as aesthetically pleasing objects.

(I, R, C) System Example

<table>
<thead>
<tr>
<th>(I, R, C)</th>
<th>System</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0, 0, 0)</td>
<td>Noise</td>
<td>listening to music in the background</td>
</tr>
<tr>
<td>(0, 0, 1)</td>
<td>Ambient media</td>
<td>dynamically changing desktop wallpaper to provide weather awareness</td>
</tr>
<tr>
<td>(0, 1, 0)</td>
<td>Indicator</td>
<td>vehicle navigation system</td>
</tr>
<tr>
<td>(0, 1, 1)</td>
<td>Secondary display</td>
<td>groupware tool showing information about the progress of a team’s members on a collaborative task</td>
</tr>
<tr>
<td>(1, 0, 0)</td>
<td>Diversion</td>
<td>pop-up showing jokes or other entertainment material</td>
</tr>
<tr>
<td>(1, 0, 1)</td>
<td>Information exhibit</td>
<td>supervision of overall operations in a specific context, such as a factory, to assess long-time strategy and determine trends, but with no immediate reaction needed</td>
</tr>
<tr>
<td>(1, 1, 0)</td>
<td>Alarm</td>
<td>calendar or email alerts</td>
</tr>
<tr>
<td>(1, 1, 1)</td>
<td>Critical activity monitor</td>
<td>network monitor used by a system administrator</td>
</tr>
</tbody>
</table>

Table 5.1: Categories of systems based on the IRC model

An obvious requirement for any reminder system seems to be that the reminder functionality is correlated with the kinds of tasks about which users might need to be reminded. According to Einstein and McDaniel, these fall into one of two categories: time-based and event-based tasks [45]. Time-based tasks have to occur at a specific time, whereas event-based tasks are correlated with the occurrence of a certain event, such as meeting a particular person or being in a particular place. In some cases, planning the recall of time-based tasks can be more demanding for the user in that it can be difficult to predict the exact moment when “remembering to remember” [100] should be set to occur. Event-based tasks require less planning and are less burdensome for the user, since reminding can be externally supported by the environment: users remember when their current environment contains cues for the task to be performed [173].

Numerous existing reminder systems provide functionality suitable to remind about time-based tasks. The systems require that users define the date and time when reminders should be delivered. Designing reminder systems for event-based tasks is, on the other hand, more challenging and requires some sensing of a user’s environment. For example, systems have been proposed able to deliver reminders via wearable de-
5.1. Informing the Design of Reminder Notes Systems

Services based on some contextual information, such as a user’s location or people in the vicinity [43, 181]. However, research is still ongoing and existing systems impose significant overhead and considerable configuration efforts. Therefore, for this second type of tasks, users are likely to still try to enforce reminding by manipulating their environment. Several studies on human practices for dealing with memory lapses observe that people tend to leave documents or other symbolic cues “in-the-way in anticipation of a routine practice” [22, 26, 74, 145]. Reminding is triggered when the cues are seen. Cues can either be left in the user’s physical environment or they can be virtual. Examples for the former include post-its or memorabilia stored in so-called memory boxes [145]. In the latter case, cues can be left in the way on a user’s computer desktop or in their inbox [46].

5.1.2 Reminder Functionality Suited for Natural Notes

In the previous section, we have seen some aspects that any reminder system needs to account for in order to be beneficial. First, reminders have to be delivered and noticeable by the users at appropriate moments. Second, users must be able to reconstruct their original intentions from the reminder specification provided. We add that any reminder system is likely to be adopted by a user only when the gained benefits and the efforts invested in the reminder definition are in balance.

The latter requirement becomes relevant especially in cases such as ours where reminders need to be constructed based on natural handwritten notes. Given that paper-based notetaking is preferred particularly for its freedom and low effort implied, imposing some rigour to define reminders could lead to not using the system. Ideally the system should not require users to adapt their natural notetaking behaviour at all. This could be achieved when notes to be reminded about could be automatically identified, extracted and integrated with some reminder functionality. We have seen, however, that users tend not to mark their notes in some differentiating manner and that potentially useful notes are often not recognisable without user intervention. The consequence is that it is likely to be unavoidable to have to recommend users to employ some mechanism to mark those notes which they want to have extracted and be reminded about. The mechanism introduced should, however, be as low effort as possible, potentially by being derived from some already used practices to mark notes.

Notes to be reminded about fall into both time-based and event-based categories. At least part of the notes for work organisation are likely to require time-based reminders, whereas potentially relevant notes and notes for others, as well as the remaining work organisation notes, could be reminded about via some event-based approach.

We believe that implementing time-based reminders based on handwritten notes is likely to impose considerable changes in the notetaking behaviour since exact details to configure the reminders would have to be provided in a manner recognisable by the system. We have seen that users tend to provide few details in their notes about when the information is expected to be useful. This information is sometimes not written because users do not find it necessary and consider that seeing the notes will prompt the other details in their memories anyway. Furthermore, potential interpretation errors might give the impression of a partially accurate system and lead to abandonment of the system [104].

The rest of the notes for which users would not usually define time-based reminders
tend to contain even less details regarding situations when they might turn out to be useful, sometimes because such details are not known as in the case of potentially relevant notes. Therefore, implementing some event-based reminding mechanism is likely to be challenging as well.

We propose that the most suitable way of digitally supporting the use of prospective notes is likely to be a kind of pseudo-event-based approach consisting of integrating notes extracted from notebooks within a user’s environment in some non-disruptive way via an ambient information system. We discuss our choice in what follows, after explaining the term ambient information system.

The term ambient information system was introduced by Pousman and Stasko as an umbrella term for systems with the following characteristics [152]:

- “Display information that is important but not critical.”
- “Can move from the periphery to the focus of attention and back again.”
- “Focus on the tangible; representations in the environment.”
- “Provide subtle changes to reflect updates in information (should not be distracting).”
- “Are aesthetically pleasing and environmentally appropriate.”

Pousman and Stasko explain that ambient display systems, peripheral display systems and notification systems can equally present these characteristics. According to the authors, the differences between the three system categories are very subtle. Ambient systems are a subset of peripheral display systems and both system types are meant to allow users to focus on their primary tasks and act as calm reminders [204] that can be occasionally glanced at to stay aware of non-critical information. Furthermore, both can be placed on secondary or primary computer screens. The difference is that ambient systems can take also other forms than information shown on a screen, such as lamps glowing in different colours [1] or sound [137]. The latter can be placed anywhere in a user’s environment. Furthermore, ambient systems focus more on the aesthetic aspects and this can be to the detriment of the number of information items presented, which is sometimes very small. On the other hand, peripheral display systems tend to focus less on the aesthetic aspects and more on presenting multiple information items, for example, as information bars such as in Sideshow [31]. Notification systems are also based on peripheral displays, but information of interest is delivered based on a divided attention approach [125]. The system is not meant to distract the users unless a certain severity level notified by an alarm demands it [17].

Revisiting the design space introduced by McKrickard et al. and presented in the previous subsection, ambient information systems correspond to the ambient media and secondary displays system classes. In particular, ambient and peripheral display systems having the above presented characteristics correspond to the ambient media class, whereas the respective notification systems correspond to the secondary displays class. As mentioned in the previous subsection, secondary displays are meant to cause a user’s reaction and lead the user to adjusting their activities in the case that some specific information is presented.

We consider that integrating reminder notes with the ambient and peripheral display systems subcategories of ambient information systems is likely to require the least intrusive mechanisms necessary to extract the notes and thus entail the least changes on
natural notetaking. Provided that the notetaking solution provides some nonintrusive mechanism meant to be used for the marking of any notes which should be extracted from paper, possibly without even requiring an explicit differentiation for the different types of notes, the extracted notes can be rendered on a display placed within a user’s environment. Given that the content of the notes has to be seen in order to trigger reminding, the use of a screen display is likely to be necessary, as opposed to relying on more abstract representations used sometimes by ambient systems. Therefore, following Pousman and Stasko’s explanations, the distinction between ambient or peripheral displays becomes less apparent and will be made based on the number of items shown on the screen and on the aesthetic aspects employed to show the notes.

Integrating notes extracted from paper with some ambient information system based on ambient or peripheral displays is likely to be compliant with the goal to remind about both notes with some unspecific use, as well as notes which need to be given attention within some period of time. First of all, the idea abides with the previously mentioned recommendation to improve the visibility of information. As compared to the non-enhanced case where users would have to remember and actively look up the information in their notebooks, users are provided the opportunity to notice and undertake actions related to tasks, useful facts, references or other noted information at convenient times and without undesired interruptions on their primary tasks. Users can simply decide not to take any action when some notes are noticed at moments when these cannot be switched into the focus of their attention. Alternatively, in the case of notes associated with some deadline, users could decide to take some time to define time-based reminders, either within their favourite tool for time-based reminders or via the ambient system itself. For this latter case, the system has to provide some complementary functionality to define and deliver time-based reminders.

In the case of notes with unspecific use, the proposed enhancement could also support creative thinking and developing associations between ideas, which is congruent with the imprecise use attributed by users to some of their notes in the first place. The idea has similarities with the opportunistic browsing introduced by Bruijn and Spence [30]. The authors have observed that people can come across knowledge incidentally and peripherally in their everyday locations such as cafés, meeting areas or bus stops and propose enhancing coffee tables and other ordinary objects with displays meant to show information of potential interest. They claim that the process of informing oneself in this way is unintentional and requires no cognitive effort. They also mention that such continuous but largely unconscious monitoring and filtering of information has the potential to trigger more purposeful behaviour. The observations are backed-up by psychological research on the role of the conceptual short term memory (CSTM) in the processing of information encountered in the everyday environment. According to this, the process starts with the perceptual registration of the content. Each item of meaningful content results in the rapid activation of the corresponding conceptual representation in CSTM. These concepts are equally rapidly forgotten and thus nonintrusive, if not selected for retention in a more permanent form of memory—the working memory.

In terms of description and comprehension, notes could be integrated with reminder systems either transformed into digital text through handwriting recognition or in their original uninterpreted form, as they appear in the notebooks. As we have already mentioned, in the former case, errors could occur and affect the credibility of
the system. Assuming that notes are integrated as cursive handwriting and given their qualitative characteristics, the description level of a reminder created based on such a representation is likely to fall under the partially descriptive category. On the other hand, given that the creation of notes is done via *encoding* and by the users themselves, the level of comprehension when presenting notes in their original form is likely to be considerably high. A potentially interfering aspect might be the fact that notes could be affected by intelligibility issues, especially after extended periods of time from their capture [89]. Since, in our case, users are repeatedly reminded about their notes, this could reinforce the details in the user's memory and prevent forgetting, as suggested by Van den Berg [196] or Miyata and Norman [132]. Another potentially problematic aspect could be that notes could lose their context when extracted from notebooks [122]. On the other hand, related work also indicates that a certain filtering can be beneficial, especially when this is driven by the user. Lamming et al. emphasise that users should not be overwhelmed with too many details and recommend triggering recall based on *partial* information [100]. Similarly, a preference for brevity and self generated cues was reported in an investigation of prospective memory failures regarding computing events [37].

The literature on reminder systems reports a number of best practices in terms of comprehension or lack of interruption of ambient information systems. Plaue and Stasko have studied various display sizes and positions and found the most distracting animations to be on angled displays [148]. Maglio and Campbell examined scrolling on peripheral displays and found that continuously scrolling displays are more distracting than displays that start and stop, but that they are equally memorable [119]. From the types of visually implemented notification systems presented on secondary displays, smooth tickering has been found most comprehensible as compared to blasting and fading text, with the observation that different speeds and sizes of the display can lead to interruption if monitoring becomes necessary [128]. Plaue et al. compared textual and graphical presentations and found out that graphical presentation of information is more comprehensible and supports better recall [150]. A significant reported issue is that users can get used to the display and not notice reminders when insufficient changes are implemented [51].

Unfortunately, there is a high number of possible combinations in configuring the different features of a reminder system and results are sometimes contradictory. Furthermore, these might apply differently to personally authored information, which is the category that handwritten notes fall into. Most existing ambient information systems focus on general interest information, such as weather information, bus schedules or news [152, 153], but not on personally authored information. Therefore, we consider that the most suitable forms of visualisation for handwritten notes within ambient information systems needs further investigation. In the next subsection, we review existent ambient information systems for personally authored information and, in the subsequent section, we propose and assess a series of reminder notes prototype systems.

### 5.1.3 Reminder Systems for Personally Authored Information

In Section 2.3 we already introduced and discussed prospective support provided by existing digital pen and paper solutions. Therefore, in this section, we focus on related work in terms of the ambient presentation of noted information. As already mentioned,
most existing ambient information systems focus on presenting information such as the weather forecast, traffic conditions, new e-mail notifications, news headlines and other similar monitored sources of information [152, 153]. Existing systems that deal with personally authored information focus on digitally created data and, to our knowledge, only Hsieh et al. have addressed handwritten information [74]. Two categories of tools can be distinguished: tools meant for personal use and tools meant to be used as a sort of interpersonal awareness or communication tool in a group.

Examples in the first category include MessyDesk [49], List.it [197] and Sideshow [31]. MessyDesk is mostly suitable for secondary displays and provides support for arranging informal notes, pictures, shortcuts or text snippets copied from any Windows application onto a user’s desktop. List.it is an information scrap management tool providing functionalities similar to a to-do list management tool and we include it in the category of ambient information systems due to its integration as a sidebar within a web browser. Compared to the two previous tools, Sideshow deals to a great extent with general purpose information. However, some of the tickets contained by the proposed information bar reflect the content of a user’s Outlook agenda, which is personally authored.

Transient Life [180], DropNotes [44], MessyBoard [49] and Notification Collage [57] are example systems in the second category. While Transient Life focuses on supporting group awareness regarding each person’s activities, the other tools can support communication and information passing between group members as well. Transient Life appears in the form of a modular sidebar tool allowing users to collect transient information, such as their personal state, to-do list, photos seen or interesting URLs, with a view to sharing it with the others. The information can be posted selectively as a today message to one’s community and a text essay composed based on the various information snippets can be posted on one’s personal blog. DropNotes can be used for both informal sharing of information within a small group and posting notes to oneself. Messages for the users themselves, the group or particular colleagues are managed on a user’s desktop within a sidebar component called DropDock. Notes have the appearance of sticky notes with the background colour indicating the type: self-notes are yellow, personal notes from others are green and notes sent to a group are blue. Notes are associated with an expiration date and when expired they are automatically removed from the display. MessyBoard, an extension of MessyDesk for shared use, and the Notification Collage provide similar features to DropNotes, but shared content can extend to other media than notes. They both function as shared bulletin boards running on each user’s computer in a window or on a secondary screen. In addition, Notification Collage can be shown also on public screens.

All mentioned systems focus on minimising interruptions and introduce a no-interaction-required interface. No animations, blinking, fading or other transition effects are used and the only notification consists of seeing the notes appearing. This means that there is a certain similarity with email and to-do lists where users need to check their inbox or the to-do list application to notice a reminder.

As already mentioned, Hsieh et al. are the only authors who proposed the integration of handwritten information with ambient information systems. Compared to our work, their notes are captured with a Tablet PC. The authors mention that notes contain a latent value that users are often not aware of and recommend their ambient presentation in the periphery of their attention. According to the authors, this form of presentation is less likely to produce unwanted interruptions, reduced productivity or frustration.
and likely to entail minimal extra cost for presenting information irrelevant for the user at the time as they could simply continue working on their task. In terms of the note representation, several notes fragments are shown on the ambient screen at the same time and the display is updated with new notes fading in at different times depending on a user configured speed. The authors have observed that users preferred their original notes as compared to notes interpreted through handwriting recognition stating that they felt more personal and visually richer. A notable reported issue was related to the missing functionality to pin notes on the display so that they do not disappear before users get the chance to read them.

5.2 Reminder Notes Systems

As discussed in Section 5.1.2, designing ambient information systems involves a high number of options in terms of both the different types of systems, as well as different features of a particular system type. Before deciding on a particular ambient information system and delving into the details in terms of its design and implementation, we developed a series of small prototypes and assessed their suitability for reminding about noted information. Our assessment is based on informal feedback from various members of our research group, as well as our own and a few colleagues’ experiences with using the different systems over a period of time. In Section 5.2.1, we describe briefly each system and the insights provided by each of them. This is followed by Section 5.2.2, where we describe in detail the design choices behind our final ambient information system prototype.

5.2.1 Reminder Notes Systems Prototypes

Our preliminary trials included a slideshow application, a ticker and a to-do list integrated with post-it functionality. We also integrated handwritten notes snippets captured via digital pen and paper with a general ambient news service used within our research group. Given potential handwriting recognition errors, we decided to represent notes as cursive handwriting. We rendered digital ink data corresponding to specific note snippets as images and used the images for our prototypes. Rather than being a drawback, rendering notes in their original uninterpreted form can actually be an advantage, given the more personal and visually appealing presentation.

The slideshow application shown in Figure 5.2 iterates over all blocks of notes captured on a notebook page and displays them one after the other in the centre of the application window via some fading transitions. The note shown in the centre is highlighted in red in the page overview shown in the upper-right corner. When all note blocks on a single page have been iterated over, the system switches to the next page. Both notes emphasised in the centre of the window as well as entire pages can be removed from the slideshow. When a user moves the mouse pointer over a highlighted note or a page, the pointer changes into a pair of scissors and by clicking the mouse the note or the page are deleted. While a deleted page is simply no longer shown, a deleted note still appears as a striken-through note on the overview page. The application is meant to run in fullscreen mode on a secondary display.

With this application, we wanted to investigate the case where no processing rules
or guidelines are required. The paper interface provides no controls and note blocks are determined via an automatic processing approach which consisted of identifying and extracting note structures based on temporal and spatial proximity. The processing of notes was meant to be done only in post-capture phases and users had to delete the information which they did not want to be informed about. Moreover, the page overview feature was meant to ensure that the context of individual notes could be reconstructed by the users. Furthermore, the page overview also represented a way to deal with potential processing errors. In the case that extracted note structures highlighted in the window centre did not correspond to a user’s interpretation of a standalone information unit, or additional details were provided in a different structure, users could simply consult the page overview.

It turned out that having to delete unuseful information was considered as too much effort. Users mentioned that in some cases they would have just one information snippet per page to be reminded about and having to delete all other notes from the slideshow would require too much time. Furthermore, they expressed an interest in having a better overview over their useful notes and they felt that the iteration over pages and notes per page was likely not to provide it.

Given these results, we introduced the slightly modified paper interface shown in Figure 5.3, which is a version of the interface already shown in Figure 4.2. The paper interface is meant to provide users with a way to mark notes that they want to have extracted and be reminded about, as well as a simple mechanism to specify time-based reminders. Except for a timeline and a few buttons positioned at the bottom, the page has the appearance of a regular notebook page with a writing area covering the rest of the page. In the writing area, notetakers can take freehand notes. In addition, they can use the timeline to indicate that the digital counterpart of the notetaking application should remind them about particular notes within a certain period of time. To mark handwritten notes, notetakers have to first mark the timeframe by touching the corresponding part of the timeline with the pen (1) and then select the notes by drawing a vertical line (2). As a result, all note structures located adjacent to the vertical pen stroke are combined into a single structure which is associated with the corresponding temporal metadata. The note structures are determined through
automatic segmentation as described in Chapter 4. A Reset button is used to reset the succession of pen-based interactions. The Synch button is used to trigger the synchronisation with the computer in the case that the pen is used in the online working mode.

The rest of the prototypes described in this subsection were integrated with this new paper interface and, for testing them, we included additional buttons next to the timeline control. While performing the procedure to mark notes described previously, users can also touch one or several buttons corresponding to the different prototypes before drawing the marking line. As a result, marked notes are integrated with each of the specified prototypes. Furthermore, the timeline does not need to be selected, a case in which notes are not associated with any temporal metadata.

The ticker tool that we have implemented is shown in Figure 5.4. Lines of extracted notes appear from the right and are scrolled continuously towards the left. Lines pertaining to different snippets are separated as shown in the figure. Furthermore, if temporal metadata has been associated with the notes, this will influence the frequency with which each snippet is shown. Notes due in the near future are shown more often than the rest and notes associated with no metadata are shown based on a random approach. The tool can be pinned on the screen on top of other windows.

We experimented with various ticker speeds. However, higher speeds lead to distractions and lower speeds gave users the feeling that they could not get the information with one glance. Instead, they had to focus on the tool until the entire information was shown, which was sometimes considered too time consuming. Furthermore, the overview of the entire set of notes was also missing.

The to-do list and post-its tool shown in Figure 5.5 was better received by the users, presumably due to user familiarity with similar tools, as well as the better overview of the information that the tool provides. The to-do list is implemented as a sidebar application and note snippets are integrated with the tool as separate to-do list items.
5.2. Reminder Notes Systems

Each item contains the notes, as well as details about their extraction and due dates. In the case that temporal metadata has been associated with the notes at capture-time, the due date is set automatically based on the value selected by the user via the paper interface and calculated relative to the current date. Otherwise, the due date is set to none. Double clicking a note item results in its expansion as a post-it note. In this second view, users can edit a note’s content, adding typed text or altering the due date via a calendar widget. Furthermore, post-it notes can be attributed different colours and their size can be modified. Post-it notes can also be pinned on top of the desktop. Expanded to-do list items are shown in the to-do list, even if users choose to maintain the expanded view open. Changes in the expanded view are propagated in the to-do list. The tool provides various controls to further manage to-do items such as changing their order within the list or organising them in named tabs. Each tab contains a search widget and providing details such as keywords or time intervals results in filtering out note items within the tab. New list items can also be created via the to-do list tool, and not only via paper. Notes are by default presented in handwritten form, but users can also switch to a version processed by a handwriting recognition engine.

Finally, we also integrated notes with the Awarenews ambient system [40], as shown in Figure 5.6. Awarenews is an ambient news and awareness display meant to improve the awareness of a group’s members about news and activities regarding the group.
itself as well as related topics and general news and events. In our group, the system is deployed in different shared spaces such as printer rooms, as well as in each office via peripheral displays. An RSS feed was created based on the extracted notes and added to the Awarenews configuration. Notes were shown randomly in alternation with other feeds including news feeds, picture feeds and SVN commit messages. While the problem with the lack of overview over one's notes collection persists, the visualisation as part of an ambient system placed on a peripheral display was better received than the ticker. The approach was perceived as non-intrusive and the content was easy to grasp at-a-glance. Furthermore, users appreciated its simplicity and not having to further manipulate the notes, as it was the case with our first ambient system shown in Figure 5.2.

![Notes integrated with Awarenews](image)

**Figure 5.6: Notes integrated with Awarenews**

Based on the experiences with these prototypes, we decided to further explore the idea of an ambient information system integrated within a user’s environment on an ambient or peripheral display. As opposed to Awarenews, which is designed for shared information, an ambient information system for handwritten notes needs to be deployed in such a way that it is visible only to the owner of the notes, for example, by being placed on a secondary computer screen. Furthermore, we decided to further investigate the idea of providing at-a-glance overviews over a user’s collection of extracted notes, especially since it also corresponded with our initial observations that people tend to have difficulties in managing their heterogeneous collections of paper-captured information. We also speculated that a graphical representation over a user’s notes collection could provide new perspectives and even convey the user new insights or lead them to new ideas.

As mentioned in the previous subsection, the difference between ambient or peripheral display systems is very subtle and depends on the amount of information items presented and the degree of focus on aesthetic aspects. For our final system prototype, we opted for more aesthetic aspects than typically provided by peripheral display systems. At the same time, based on the number of note items shown, which could
5.2. Reminder Notes Systems

vary between a few and multiple notes extracted by the users, the system can migrate between the ambient and peripheral display system categories. Given the fine line between the two categories, in what follows, we will qualify the system as ambient display system. The system is described in the following subsection. The system design, implementation and evaluation were done in close collaboration with Sarah Schöni as part of her semester thesis [167].

5.2.2 Ambient Display System for Handwritten Notes

Our investigations included different note layout and presentation approaches, as well as different animations.

Notes Layout

We started by laying out the notes based on a perpendicular tile grid, as shown in Figure 5.7. Given the tendency to read horizontally, at least in the parts of the world using the left-to-right and top-to-bottom writing direction, we considered the result problematic. We assumed that users would tend to combine visually neighbouring note items, this decreasing the possibility to distinguish different note items. To overcome this potential issue, we switched to a different approach shown in Figure 5.8, where we used a circle packing layout. Each note item is represented as a circle which contains the graphical image of an extracted note. The circle radius is defined relative to the size of the note on the paper. This second approach enabled both a horizontal and vertical displacement of the different note items, thus better supporting the ability to perceive them as different entities when quickly glancing at the screen.

Figure 5.7: Tile notes layout

The circle packing layout algorithm is a space filling approach meant to provide overviews of large datasets introduced by Wang et al. [200]. As shown in Figure 5.9,
starting from a note placed in the centre, the algorithm lays out subsequent circles compactly by following a spiral grid. The result is a set of circles packed into a broader circular area. The effective circle size is dynamically adjusted depending on the available screen space. The size of a circle is bigger when displayed together with a small amount of other notes as compared to the case when a larger amount of notes exist.

Notes Presentation

In a first approach, we presented note items as a direct reconstruction of the paper notes based on the digital ink data. Considering that more visual emphasis was still needed to support the perception of individual items, we proceeded with emphasising item borders, as shown in Figure 5.10. In a third variant, we also filled the item contours, as shown in Figure 5.11. After asking several colleagues for feedback, we decided for the third approach. The feedback revealed that the approach provides good visualisations from both far away and closer perspectives. A far away perspective provides a quick overview over the amount of note items and the closer the user gets, the more details are revealed. Furthermore, in the case that note items are shown in different colours,
the far away perspective can provide an overview of the most dominant ones. In the final prototype, we added a functionality to associate notes with different categories. Users can assign a colour for each category and notes in the different categories are coloured accordingly.

Figure 5.10: Notes with borders

Figure 5.11: Notes with filled contours
Animation

Animation is typically used together with ambient displays to prevent the system from becoming stale and to avoid users becoming accustomed to a certain view and no longer noticing the system. Furthermore, gradual changes in the displayed data can catch a user’s attention without becoming intrusive when their attention is focused on a primary task. We tested different animation approaches, all based on the idea of displaying the entire note collection while focusing successively on single note items. In the following we describe the different animation approaches.

**Fading to foreground.** The first animation approach that we tested consisted of highlighting note items successively by fading them to the foreground superimposed on the note collection shown in the background. Notes are faded to the foreground in a randomly chosen order. Figure 5.12 shows the animation approach in the case of the circle packing layout. After being highlighted, notes are faded out at random positions. We decided to abandon this approach based on the impression that users might have difficulties relocating emphasised notes if these were faded out while users were still focusing on their content.

![Figure 5.12: Fading to foreground animation approach](image)

**Fixed order focus switching.** We also tested an animation approach which exploited the circle packing layout. We assigned the note items a fixed order on the spiral grid and focused successively on note items by enlarging their size and placing the others around the focused note while also respecting the initial order, as shown in Figure 5.13. We felt that the mechanism behind the animation was difficult to follow and that the motion could be perceived as arbitrary. Therefore, we did not follow this approach any further.

**Outer-most to centre.** A second animation approach based on the circle packing layout repeatedly moves the outer-most note item to the centre of the spiral and enlarges it. The animation can be followed easily and the layout reflects the focusing history.
This supports the user in relocating a note item after it has been emphasised. Further, the focused note item is placed in the centre of the screen, which also corresponds to the visual focal point of a user when glancing at the screen.

**Random or due to centre**. The previous approach does not provide unexpected combinations of individual note items since the relative order of note items is fixed.
Our final animation approach is similar to the previous outer-most to centre approach. However, instead of always moving the outer-most note in the centre, the item to be emphasised is chosen based on temporal closeness to its due date and on randomness. Items close to their due date are shown with a predefined frequency and items chosen randomly are shown the rest of the time. In the final implementation, the animation runs continuously and consists of two phases: a transition and a pause phase. The transition phase refers to the time interval required for the update of note item positions and sizes, whereas the pause phase refers to the interval for which the state of the notes is kept unchanged. As described in the following, the duration of both phases can be adjusted by the user. This animation approach is illustrated in Figure 5.14.

Controls and further functionality

The ambient display provides more in-depth information about each note through an interaction which allows “opening notes” (Figure 5.15). When the user clicks on a note item, it is enlarged and information about the date when it was noted, the due date, as well as the notebook page on which it was written down are displayed in a details box next to the item. This information helps users refer back to the original paper notes, for example, in order to retrieve additional details originally not marked for extraction.

![Figure 5.15: An enlarged “opened” note item and the details box](image)

To meet individual user needs and preferences, a settings bar placed at the bottom of the display provides a series of user adjustable settings. The settings bar is normally hidden, but moving the mouse cursor over the bottom of the display reveals the settings elements shown in Figure 5.16.

To show or hide notes belonging to certain categories, the user has the possibility to select filters via checkboxes. Figure 5.16 shows the case where three notes categories
Figure 5.16: Settings bar
have been defined, To-dos/Reminders, Ideas and Miscellanea, users having the possibility to filter their notes according to these categories by selecting the corresponding checkboxes. The transition and pause duration sliders provide the possibility to individually define the speed of the animation phases. The highlighting slider allows users to adjust the time span within which note items are considered as close to due. Note items close to due are shown in a colour chosen from a separate set of controls and focused on with higher frequency. In addition to defining close to due note colours, users can define colours for each category of notes defined in the system. The scissors button toggles the display between the animation and a deletion mode. In the latter, the animation is stopped and clicking on a note item with the mouse cursor represented as a pair of scissors results in the deletion of the note from the ambient display. The delete action is emphasised by a short animation that follows the mouse click.

### 5.2.3 Implementation Details

All prototypes described in this chapter have been implemented on top of the iPaper framework combined with support for digital ink data segmentation and classification as described in Section 4.2. Both the slideshow tool shown in Figure 5.2 and the ticker tool in Figure 5.4 exploit directly the automatic segmentation into blocks and lines of text, respectively, and most of the effort consisted in implementing the user interface in JavaFX. Similarly, in the case of the to-do list and post-its tool shown in Figure 5.5, the processing of the digital ink data consisted of only verifying whether automatically extracted blocks of notes contained predefined circled characters. Notes within these blocks were further rendered as images and integrated with the tool implemented in Java Swing.

The Visualisation Tool Client for the ambient display system introduced in Section 5.2.2 is a Flex front-end which displays a user’s collection of notes based on an animation schedule and provides controls to interact with individual note items or customise the visualisation. We chose Flex for the implementation given the support for rapid development of highly interactive graphical applications.

The Flex application has two main components: the canvas and the settings interface component. The canvas component controls the graphical visualisation of the different note items and is based on the visualisation toolkit Flare\(^1\), an open-source ActionScript library developed by the UC Berkeley Visualization Lab\(^2\) for visualisations that run in the Adobe Flash Player. The second component, the settings interface component, supports interactions with the settings bar and notifies the canvas and the Visualisation Tool Controller accordingly.

The Visualisation Tool Controller is implemented in Java and acts as an intermediary between the PaperNotes Main Controller (Java) and the Visualisation Tool Client (Flex). Furthermore, the component is responsible for data persistence. Data received from the Main Controller, as well as changes operated by the user via the ambient display system controls are stored in a db4o object database. The communication between the Flex-based front-end and the Java-based back-end is enabled via the Merapi framework\(^3\), which acts as a messaging bridge between the Flex and the Java components.

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\(^1\)http://flare.prefuse.org  
\(^2\)http://vis.berkeley.edu  
\(^3\)http://code.google.com/p/merapi
5.3 Evaluation

It was our hypothesis that, in the context of various difficulties related to the processing of information captured via digital pen and paper, ambient information systems are the most suitable type of reminder systems able to support the role in reminding played by paper notes. The integration of paper notes with ambient information systems requires less and more relaxed notetaking conventions necessary in the processing of digital ink data representations of paper notes. This increases the chances that the system is successful in extracting and integrating useful details written on paper with a digital reminder system. The approach supports remembering by giving users the opportunity to notice useful notes casually in their environment. The solution provides a less comprehensive digital integration of the different note categories, for example, by not requiring users to specify exact time-based reminders on paper. However, there is a higher probability that notes are processed by the users in a post-capture phase. When noticing them, users can decide to digitise the notes in the form required by different digital systems. To assess this hypothesis, we conducted a user study around the use of the ambient information system presented in Section 5.2.2. We present the study design, as well as results obtained.

5.3.1 Study Design

To verify the feasibility and usefulness of integrating paper notes with ambient information systems, we chose to conduct a comparative user study. We compared the ambient notes system with two other reminder tools with which we also implemented the integration of paper notes. The choice of tools was driven by two main aspects that we were also interested to observe. First, since most information workers already use various reminder tools, we wanted to determine whether issues exist related to integrating notes with a different tool than the one in use. Therefore, one of the chosen tools was a solution that integrates notes extracted from paper with Outlook, as shown in Figure 5.17. As a secondary reason, this choice was also driven by the fact that existing solutions based on digital pen and paper mainly integrate handwritten information with email and task management tools. The tool forwards notes marked for extraction as emails to a user’s inbox and creates Outlook tasks and appointments. The email and appointment subjects fields contain typed text interpreted through handwriting recognition. Their content is represented by both interpreted text and note images. Second, we wanted to verify whether other presentations with which users are more familiar could be beneficial. We chose as a second system the digital to-do list tool shown in Figure 5.5, which was meant to be running on the user’s primary screen, as opposed to the ambient display. We installed the three tools on each participant’s computer. Notes were by default integrated with all three tools, but users could turn off any of them at any time. Figure 5.18 shows the system setup in one user’s working area.

As study participants, we recruited 10 computer science researchers (4 female, 6 male). The number choice was driven by a series of practical limitations. First, we considered the estimated effort to set up the software on the working stations of the participants. Furthermore, each participant had to have their own working area where showing notes on an ambient screen would not lead to privacy issues. Finally, we made sure that each user could have the ambient system running on a secondary screen and
provided users with additional computer screens where this was not the case. Finally, all participants had to use email heavily and rely on email clients or similar tools to configure time-based notifications for tasks associated with a specific time. A forwarding mechanism was setup for one user who did not use Outlook as email client. Out of the 10 participants, 8 also use on a regular basis various paper-based media, such as to-do lists and post-its, kept in visible locations on their desks. These are used in support of both daily or weekly tasks, as well as to store temporarily information for which setting a time-based reminder using their habitual tools would not be applicable. Examples of the latter include meeting notes or snippets of information which they want to keep for later use. The other 2 participants declared that they mainly rely on time-based alerts set in their digital reminder tools and that they rarely use paper as complement. They also mentioned that they usually keep in their mind details not integrated with digital reminder tools. All users were familiar with digital pen and paper and 7 participants
had already used various solutions based on the technology.

In terms of the paper interface and the method used to mark notes to be extracted and integrated with the three tools, we opted for the solution shown in Figure 5.19. The marking method consisted of drawing the symbol corresponding to a note category followed by circling it. The recognition of the category marks was implemented based on a feature to recognise circled characters provided by the MyScript Builder SDK. The notes to be extracted were determined via automatic segmentation into blocks of notes based on the approach described Chapter 4. If one or several category markers were detected at any position inside a block, the notes were extracted, associated with the corresponding metadata and integrated accordingly within the three tools. Our goal when choosing this marking method was to allow as much natural notetaking as possible. However, this also meant that users could not define time-based reminders within the three tools from paper. Users had to use controls provided by the three tools to define a due date for the notes. For the ambient display system, we setup a one-way synchronisation mechanism which allowed the immediate propagation of due date changes from the to-do list tool to the ambient display. Deleting note items in the to-do list was also propagated in the ambient display. The reason for this was to test whether users preferred to interact with the ambient display by using controls on the secondary screen where the system was running or whether some controls should be provided on the primary screen.

Each participant was given a spiral-bound notebook and a Magicomm G303, Magicomm DP-201 or Logitech digital pen. Notebook pages were printed with Anoto pattern for the offline working mode. This allowed users to take notes both while at and away from their desks. Each notebook page is ruled and contains the page number in the footer and a header where the markers provided for categorising the different notes are described. Given results in Chapter 3, which showed that extracting notes and integrating them in digital space makes sense for reminders and general ideas, we provided users with three markers corresponding to three note categories. A circled $T$ was provided to mark notes representing to-dos or reminders and a circled $E$ was meant

\[ \text{http://www.visionobjects.com} \]
to be used to mark ideas. To account for other possible uses, we provided an additional *Miscellaneous* category which could be indicated by a circled star.

To cope with possible errors in extracting notes, we provided a fourth tool: the notebook browser shown in Figure 5.20. The tool shows for each notebook page which notes have already been extracted and allows users to manually extract additional notes, either not marked at capture time or for which the marking had not been recognised. Moving the mouse over the notes emphasises the contours of blocks determined based on automatic processing and right clicking a block supports its association with a category metadata and subsequent extraction and integration with the 3 tools. Users can also mark notes manually by drawing rectangular selection shapes shown in yellow in the figure.

![Figure 5.20: Notebook browser tool](image)

The study participants used the three systems for a duration of 2 weeks. In the beginning, we presented the marking method and the features of the different tools to each user individually and we instructed them to use the notebook for activities where they would typically use paper, as well as in any other occasions that they find appropriate. We emphasised that they could use the system also while away from their computer. After the 2 weeks, participants filled in a questionnaire shown in Appendix A and semi-structured interviews were carried out. The interviews lasted between 35 and 55 minutes. With the permission of the participants, we recorded the interviews and copied system databases created on their machines for analysis. The interviews followed a set of prepared questions, but evolved differently based on the reported experiences of each participant. Topics of the interview questions included ways in which the different tools were used throughout the 2 weeks and summary impressions. The participants kept the notebooks after the study.
5.3.2 Study Results

It was our hypothesis that the use of prospective paper-captured information could be improved with the aid of digital pen and paper technologies. Therefore, our questionnaire included a section meant to assess whether participants considered beneficial to have their notes extracted from paper and integrated with reminder tools, as well as whether they considered that they could accommodate enabling mechanisms, such as the one we provided in the frame of the user study, with their current information capture and management approaches. A set of self-reported questions showed that, on a scale from 1 to 5 (5 - Strongly agree, 4 - Somewhat agree, 3 - Neither agree nor disagree, 2 - Somewhat disagree, 1 - Strongly disagree), study participants were generally favourable to the idea and declared that they would use enabling tools if it turned out that they could remember better their paper-captured information: min: 3, max: 5, avg: 4, SD: 1. This is also shown in Figure 5.21 and illustrated by the descriptive measures in Table B.1. We used a similar scale for the rest of the questions.

![Figure 5.21: Idea of extracting and integrating notes with reminder tools](image)

During the interview discussions, 5 of the participants pointed out that one thing they liked about our solution was that they no longer had to consult multiple paper documents to locate information of interest. Furthermore, they declared that they liked no longer having to keep “so many things” lying around on their desks. As shown in Table B.2, most participants declared that they never consulted paper notes after their digital integration with the provided tools. The exceptions were two users who declared that still consulting their notes had most likely been done unconsciously and because they were accustomed to doing that as part of their work routines.

Participants were slightly less convinced that it would be feasible to integrate this new approach with their existing practices. Clarifications during the interviews revealed that reasons were mainly related to missing functionality or to some improvements which users considered necessary. The missing functionality referred mostly to the
fact that annotations on paper media other than the provided notebook could not be captured, as well as not being able to configure fine grained time-based reminders. The improvements pointed out were mainly related to the automatic segmentation of the notes, which produced in some cases results different than what users expected and lead some of the participants to changing the way they took notes. These participants started to leave extra space between note snippets to make sure that they are extracted as separate items or marked larger snippets, containing composite information, for extraction. In the later case, they mentioned that they would have found it useful to have some functionality to delete parts of a note item, and not only entire items as supported by the tools. Also, two users mentioned that, rather than having to deal in a post-capture phase with errors resulting from automatic extraction, they would prefer to put more effort into marking the notes themselves at capture time. Some example strategies for extracting the notes, that the users suggested, included the use of selection lines or rectangles.

Regarding the possibility to set time-based reminders, users could manually set an expiration date for their extracted notes, but not the time. As already mentioned, the to-do list and post-its tool allowed users to set an expiration date for individual note items. The expiration date was further propagated to the ambient display and used to display highlighted the note items due within the interval defined manually by the user via the settings bar shown in Figure 5.16. For the notes integrated with Outlook, users had to set time-based reminders via Outlook controls. Especially the two users who rely heavily on Outlook time-based alerts, as well as 4 other users, mentioned that they would have found it useful to be able to set exact time-based reminders for urgent information and for other notes related to some concrete temporal details, such as meetings or deadlines. They mentioned that they had never set such reminders for their notes integrated with Outlook, even if aware of the possibility to do that, and they explained that they would have preferred that the temporal details were inferred based on the written notes and did not require extra effort in the post-capture phase. Participants suggested that the corresponding reminders could be delivered via some visual signal, such as successively fading in and out note items on the ambient display. The rest of the users declared that they did not miss a functionality to set explicit time-based reminders. According to these users, a potential improvement could have been to be able to set the time intervals when notes should be highlighted for each individual item, instead of relying on a global setting. They also emphasised that they would probably resent having to perform such settings in a post-capture phase via the digital tools and explained that whatever mechanism would be used to enforce such settings, this should be as simple as possible.

All the participants clarified that their observations regarded only information with concrete deadlines and that they considered that the functionality provided by the tested tools worked very well for notes without strict temporal associations, for which the approach improved remembering the content. Furthermore, they explained that they did not think that they remembered the information more often, but that they remembered when looking at the tools. The most frequent situations when users noticed the tools include just having synchronised the pen with the computer or deleting notes corresponding to a performed task. In the case of the ambient display, participants noticed it often when they “had nothing else to do”.

In terms of the different tools and how users rated each of them, the ambient display
was rated highest in terms of usefulness and user satisfaction, as shown in Figure 5.22 and illustrated by the corresponding descriptive measures in Table B.3. The values are computed based on the cumulated scores of 6 questionnaire questions, thus the maximum value of 30. The ambient display was rated particularly high with respect to the statements “helped me remember my tasks, ideas and other snippets of information”, “provides a valuable overview of my tasks, ideas and other snippets of information” and “it is easier for me to access my notes using the tool as compared to my usual approach”.

During the interviews, the majority of the participants declared they did not find the integration with Outlook useful, since they rarely consulted the integrated notes and, as already mentioned, alerts were not automatically set. They declared that in most cases no useful information was provided by the subject fields of the created emails and tasks and that they did not want to take the time to explicitly open these Outlook elements to see the contained notes images. On the other hand, users appreciated the
ambient display and the to-do list tool for the overview provided over their tasks and other snippets of information: “Stuff you need to do is there, you only need to look at it.”. They further emphasised that they preferred the overview provided by the ambient display over the vertical listing of the to-do list tool, since with the to-do list it was sometimes necessary to scroll down to see all information items.

Even if it was not the case during the two weeks time, some of the participants expressed a concern that in time the ambient display system could become overcrowded and suggested that items which are not relevant for the near future should only be shown once their usefulness period gets closer: “When I have a task to do in three months, I don’t want to see it constantly until then”. Furthermore, some of the participants mentioned that showing all the items could become frustrating. They explained that seeing numerous items on the ambient display would create a feeling that they still had many things to do and force them to perform the associated tasks, even if many of them would not actually be urgent and they would not do them as soon when not using the system. 9 users explained that seeing that they have not done something for a long time would make them “feel bad” and one user mentioned that if something that they did not want to focus on at the moment kept on appearing, they would start blocking it mentally. Furthermore, 8 participants clarified that only showing items due in the near future would give them an overview of their current tasks and, at the same time, of the progress made. They emphasised that deleting tasks gave them a particular satisfaction.

Another suggestion, given independently of each other by 6 participants, was to provide some mechanism to allow the grouping of notes into categories such as private and work or research and teaching, or some filtering according to such categories.

“Notes associated to tasks from other project don’t help me in this moment. I am not a ‘multitasker’.”

The participants clarified that they did not find the filtering based on the three provided categories very useful and that they seldomly used the mechanism. Furthermore, it resulted that the To-dos/Reminders was the dominant category assigned to note items and used almost exclusively by some participants. A similar observation was made regarding the different colours used, participants mentioning that they sometimes assigned different categories to their notes just so that their display was more colourful and not because they really pertained to the different categories.

Given distraction issues associated with reminder systems reported in the literature, we also assessed how much the different tools interfered with habitual tasks. We found that the participants were generally not distracted by the ambient display and that the to-do list and post-its tool did not interfere with other tasks, as shown in Figure 5.23. On the other hand, 7 participants felt that the Outlook integration tool interfered with their habitual mailbox use. Three users clarified that they found the default settings of the ambient display distracting and that they had increased both the duration of the transition and pause phases from the initial 10 seconds value. On average the transition duration was set to 31 seconds (min: 10sec, max: 143sec) and the pause duration to 27 seconds (min: 10sec, max: 136sec).

Regarding the aesthetics of the ambient display, 7 participants expressed a strong agreement with the statement “I found the design of the ambient display pleasing”, and
5.3. Evaluation

Figure 5.23: Levels of distraction or interference with habitual tasks

the rest declared that they somewhat agree. In the interviews, almost all participants mentioned that one of the things they liked the most about the system was the ambient display, which they enjoyed and found aesthetically appealing. One user described it as being a “functional picture”.

Figure 5.24: Would continue using the tool if minor points are improved

Asked whether they would continue using the different tools if various points were improved, participants answered as shown in Figure 5.24 and Table B.4, respectively. While we agree that the answers are hypothetical, we consider that the results show with a certain accuracy the participant preferences. The ambient display was rated best, with one outlier: the previously mentioned exceptional user. Further, five out of the ten participants would choose the combination of the to-do list and post-its tool and the ambient display, if they were given the opportunity to further use the system. Three participants would choose only the ambient display and one would choose none of the tools since “I can achieve the same benefits by other means”. The previously mentioned exceptional user chose only the to-do list and none of the participants reported that they would choose the Outlook integration tool for further use. The results are shown
in Figure 5.25. An interesting result, illustrated in Figure 5.26, is that the ambient display was the preferred tool to be used in the case of improvements even for the previously mentioned group of users who would have found useful a functionality to set exact time-based reminders. One of the users clarified that they considered the ambient display a valuable extension of their currently used tools, particularly suitable to deliver time-based reminders configured digitally.

![Figure 5.25: Further using the provided tools](image)

![Figure 5.26: Using improved tools distributed over user groups](image)

The participants were also asked a set of questions regarding the overall system usage in both the questionnaire and the interviews. The results provide a strong evidence that the marking method was convenient to use and easy to remember. Furthermore, we observed a pattern consisting in using the to-do list tool as a management component for the ambient display. While they preferred the ambient screen visualisation, users rarely used the controls of the ambient display. Even if possible also from the ambient
display, users preferred to delete items in the to-do list, knowing that the effect would propagate also in the ambient display. Furthermore, they mentioned that they liked the search functionality provided by the to-do list, but that they think that it would be less convenient to have to specify keywords via some control of the ambient display. When asked explicitly, users declared that they considered beneficial having a management component for the ambient display on the main screen and that during the study they used the to-do list for this purpose.

Other suggestions from participants include integrating support for recognising and removing digitally notes stricken-through on paper or emphasising digitally notes underlined on paper. Furthermore, several participants mentioned that they would find it useful to have remote access to extracted notes, for example, through web interfaces or instances of the same tools running on the remote machines. Finally, two participants felt that the circle representation of the note items within the ambient display was taking in some cases too much space, especially for long notes, and suggested implementing a wrapping functionality or experimenting with different representations, such as using ellipses instead of circles.

5.3.3 Discussion

We started with a premise which was confirmed that two types of reminder notes exist: with and without deadlines associated. The user study revealed that the approach to passively remind about paper notes via an ambient display was found suitable for notes without strict temporal restrictions. Furthermore, both users who did not find useful additional support for defining exact time-based reminders on paper and users who suggested this functionality preferred the reminding approach based on the ambient display. Participants of the latter group perceived the ambient display as a useful extension for the tools that they already used to configure alerts and which could not accommodate reminders with more relaxed temporal restrictions.

While not yet tested, we consider that the suggestion to deliver time-based reminders by the ambient system via some intense visual signals could render the system intrusive and affect its successful role in reminding about notes without exact deadlines. 3 users found the default setting of 10sec for the transition and pause animation phases distracting and set lower speeds. Furthermore, it is arguable whether urgent information should be delivered via a secondary display. What seems plausible is to aim for a solution where time-based reminders are integrated with and delivered by reminder tools already in use. These tools should be complemented by the ambient presentation of those notes which cannot be satisfactorily accommodated by them.

We found conflictual results in terms of the way in which eventual time-based reminders should be defined. Users did not appreciate errors in the processing and also did not like to have to post-process their notes to correct automatic extraction errors or set time-based alerts. This would suggest that defining time-based reminders should be supported from paper, but also that the procedure should be reliable. However, it can also be that complete accuracy is not likely to be achieved, especially if natural notetaking is to be maintained. An approach which could be further explored could be that of supporting the setting of time-based reminders via voice input, audio recording functionality being already provided by some Anoto pens such as Livescribe. The triangulation of audio and handwriting recognition could result in less processing
errors and lead to a reliable enough recognition of temporal details necessary to define time-based reminders. Also, further improvements of the automatic processing could lead to a solution reliable enough to be beneficial.

Regarding the suggestion to provide support for grouping notes into categories and category-based filters, we consider that a more dynamic process for defining notes metadata should be provided. Relevant note categories can differ among users and the same user could have different categories of notes over time. An approach similar to the one described in Figure 5.3 could be used for this purpose. However, instead of using preprinted controls, users could draw their own buttons as shown in Figure 5.27 and investigated in detail in [192]. Metadata defined this way by the users could be associated with notes by pointing with the pen inside the drawn area, followed by selecting notes via a vertical line.

Figure 5.27: Example approach for defining metadata dynamically

5.4 Conclusions

We started with a premise to improve the use of reminder notes via digital pen and paper and proposed that, in the context of current difficulties in processing digital ink data, the most reliable and at the same time natural solution relies on the ambient presentation of handwritten content to support reminding. We implemented a solution for the ambient presentation of reminder notes and performed a comparative study to verify our hypothesis. The ambient system was used in parallel with two other tools: a tool integrating notes extracted from paper with Outlook and a sidebar to-do list tool. The study showed that the approach works particularly well for notes without specific deadlines and suggestions have been collected regarding ways to also enhance the reminding about notes with exact temporal attributes.
Supporting the Use of Notes and Related Media

Existing Anoto-based solutions enhance notetaking by providing a digital copy of the paper notes and, in some cases, some post-capture handling functionality such as search or the possibility to manually devise the integration of the digital notes with different digital tools. Our study in Chapter 3 has shown that, for a considerable amount of natural paper notes, the enhancement might not be perceived as a benefit strong enough to motivate the use of the technology instead of traditional pen and paper. According to our study, this might be the case for 65% notes (work in progress: 37%, information for others: 6%, irrelevant: 20% and diverting attention: 2%). For some notes the support is not beneficial because the notes are not considered useful. For “work in progress” notes, typically refined into digital artefacts in post-capture phases, as well as notes representing “information for others”, which are in some cases digitised to enable their forwarding, the enhancement might not add a benefit given that these are usually reworked when producing digital content. We proposed that, in situations with combined media use, the type of digital support to enhance the use of “work in progress” and “information for others” notes rather consists of providing overviews of the paper-captured information and media related to it.

Meetings, which were the object of our initial study on natural notetaking, are an example situation where combined media use can occur. Often, paper is the preferred medium for documenting a meeting. However, during collaboration, paper can be used concomitantly with digital tools and media. In Section 3.2.5, we discussed some problems that arise from the use of combined media, such as the fragmentation of the information onto several media or the separation of paper-based notes from the content to which they refer, for example, when projected digital presentations are used. As a result, personal notes are limited in terms of the overview provided over collaborative work and often do not reflect the evolution of data across the private space of a user’s personal notes and shared interaction spaces. Furthermore, personal notes tend to have heterogeneous content related to multiple activities and some support for filtering
information relevant for specific collaborative tasks might be beneficial.

To support our investigations and verify our hypothesis, we built a paper-digital meeting support system where digital information handled collaboratively on a digital tabletop surface can be integrated with information captured privately by each user via personal paper-based notebooks [79]. Our goal is to show that providing an overview over the paper and the digital material handled during collaborative sessions improves the use of the entire information collection in post-collaboration phases.

Our paper-digital meeting support system builds on previous work for bridging private paper-based and shared digital information spaces based on Anoto technology, which we described in Section 2.4. We extend the contribution of existing digital pen and paper-based solutions with support for the management and review of collaboratively generated information in post-collaboration phases. Furthermore, in the design of our system, we followed closely results and recommendations of existing research on meeting support systems [208, 56, 27, 209], as well as tabletops [136].

Our system consists of a number of components that enable the data transition between media used during private as well as shared work along successive meeting phases. A series of features and functionalities provided by components for the pre- and in-meeting phases are used to derive metadata which is later used for organising paper and digitally edited data in the post-meeting review. We use virtual notes and digital document page annotations to cluster data representing interactions in the shared space. Workspace snapshots further group related and potentially heterogeneous content types. Appropriate privacy levels in reviewing meeting material are ensured via private and public folders provided by the in-meeting component. Furthermore, a browsing approach based on cover flow widgets integrated with the three components allows users to quickly identify potentially useful information in the captured data.

We start by iterating over a list of requirements for our meeting support and review system and then describe the main features of the system. Subsequently, we present a user study that we conducted to verify our hypothesis that, even if in some cases the digitalisation of paper-based content used for work in progress might not be of high enough value to motivate the use of digital pen and paper, the technology provides a compelling benefit in cases where the paper-based content is complemented by some digital information.

6.1 Paper-Digital Meeting Support and Review

In this section, we first discuss requirements for a paper-digital meeting support system which integrates well with natural notetaking. Further on, we present the main features of the system that we have implemented. The implementation was done as part of a Master’s Thesis under the author’s supervision [108].

6.1.1 System Requirements

Results from our study described in Chapter 3, correlated with related work on natural notetaking, lead us to the following main requirements for our paper-digital meeting support and review system.
Paper-based Notetaking as Primary Documentation Means

Geyer et al. report that, particularly in work environments where a meeting support system is not necessary to achieve collaboration goals, documenting meetings via paper-based notetaking is likely not to be replaceable by a meeting support system [56]. We derive that any kind of meeting support should not require that participants use the system instead of their habitual documenting approach, but that the system should rather complement existing practices. Consequently, we designed our system in such a way that users can refer to paper notes as a primary means of documenting their activities, and use the meeting support system to enhance the sharing and review of information.

Cross-media Transitions between Private and Shared Spaces along Collaboration Phases

As also emphasised by related work presented in Section 2.4, a mechanism is required to make private material, which could be both paper-based and digital, easily available for collaboration in shared spaces. In addition to functionality provided by existing systems, we consider that participants should be able to prepare meeting material not only when physically located in the vicinity of the shared space, but also on their personal workstations as part of a pre-meeting phase. Furthermore, the system should ensure the distribution of and easy post-meeting access to information generated in shared spaces. For the latter, the system should provide a mechanism to document transitions across private and shared spaces, as well as emphasise related personal and shared material.

Granular Content Sharing and Post-meeting Data Ownership

Given the mix of information in paper-captured notes, it is important that users are able to select the parts of their notes which they want to share. Furthermore, users should be able to control who gets what type of access to their data after the meeting. To enforce user privacy and data ownership, we implemented different access levels to material handled in shared spaces. In our opinion, this could also encourage the sharing of material in the first place, further improving in-meeting collaboration.

Relevant Paper-digital Material Review

A typical meeting support system creates highly accurate representations of in-meeting interactions based on multimodal recordings [27, 209]. Furthermore, multiple views of the recorded content can be consulted by means of integrated meeting browsers. However, the use of these systems in traditional working environments is not widespread, one of the reasons being the high complexity of locating content of interest from large amounts of recorded streaming data [56, 87]. Whittaker et al. explain that multiple meeting browsers have “failed to provide an appropriate level of abstraction to allow users to strategically focus on important parts of the meeting” [209]. Approaches to deal with low granularity levels of streaming data include the use of a timeslice-based model [87], the indexing of recorded material based on interactions with artefacts [56] or the use of snapshots in the form of still images [37].
To avoid generating too many or irrelevant stages of the collaboration in the final review, we chose to record only digital ink data. However, digital ink data can present similarly low granularity given its representation as streams of timestamped x and y coordinates of the pen on paper [147]. To ensure appropriate levels of granularity and intuitive entry points for navigating captured material, we propose two abstractions for structuring and presenting meeting material for review. These enforce two levels of relatedness of the content. First, related content can be added in the form of edits on the extent of the same virtual note or document page. Second, snapshots of the tabletop surface provide a way of saving intermediary work states and revive them on the tabletop. At the same time, snapshots group notes that are temporally related in that they were handled around the same time. Therefore, the reviewing approach based on browsing snapshots can be seen as a combination of a timeline and a kind of semantic grouping enforced by the user. We combine the two abstractions with a browsing approach based on cover flow widgets, which provide for a simple browsing interface and quick overviews of the data, both attainable with low level efforts on a user’s side.

The review based on snapshots requires that users take the time to create snapshots of their work during the collaboration. Fass et al. point out that such a user-driven mechanism is likely to be more effective than some automatic approach which would capture all the interactions taking place in the shared space [49]. However, the same authors mention that users are likely not to spend time to document their work when focusing on other activities, a reason for which Ju et al. introduced the idea of implicit and explicit data capture used in combination [87]. In our opinion, a form of implicit capture would have neglected our initial goal of providing quick and effective overview of paper-digital collaboration data. To enforce the efficiency of the navigation, we chose to make a compromise and rely only on user generated snapshots. However, the review component allows users to also access non-snapped virtual notes and digital documents. For the same purpose of avoiding the generation of unnecessary data, non-snapped notes and documents reflect the final result of edits performed during collaboration, intermediary states being captured only as part of snapshots.

The proposed solution is meant to support participants in processing meeting material, especially in cases when an overview of relevant material is required, for example, for producing an outcome artefact. In addition to supporting the active looking for relevant content, the mechanism may create opportunities to casually notice or increase the ability to remember other useful information which has also been handled in the shared space. Since our study in Chapter 3 has shown that documentation material is most likely modified when transcribed digitally and a digital copy of the paper content is not necessarily useful, we did not focus on supporting the creation or edits of digital artefacts based on content comprised by the overview.

### 6.1.2 Paper-Digital Meeting Support and Review System

The interaction design of our system is logically separated according to the pre-meeting, in-meeting and post-meeting phases. The in-meeting component supports co-located collaboration based on a top-projected and Anoto-enabled tabletop system that can be controlled via digital pen input. Participants may collaborate while seated around the tabletop and, at the same time, take notes in their private notebooks that can be com-
fortably placed outside of the projected tabletop interface as shown in Figure 6.1. The pre-meeting supports the preparation of upcoming meetings, while the post-meeting component provides support for reviewing paper notes and digital documents that have been worked on during a meeting. In what follows, we describe the functionality of each of these three components in detail.

![Figure 6.1: In-meeting interaction](image)

**Pre-meeting Component**

Before a meeting, participants are provided support for collecting and uploading both paper and digital material to a virtual document space. The material uploaded will be accessible for interactions in the shared interaction space during a specific meeting chosen from a list showing all upcoming meetings. To create a new meeting event, a user has to provide the relevant meeting details including a title, a list of topics and the participants as shown in Figure 6.2a. Similarly, new user profiles can be created by providing a name, a password and a list of the identifiers of their digital pens (Figure 6.2b). The information defined in a user profile will be used for access control during in-meeting and post-meeting phases. Furthermore, in-meeting interactions will be associated with individual users based on the unique digital pen identifiers.

To upload paper-captured content, participants are required to use Anoto-enabled notebooks. Paper notes can be selected via pen-based cropping gestures as shown in Figure 6.3. The Anoto digital pens are used in streaming mode so that paper-based user actions are continuously interpreted and feedback is provided on the user’s personal computer screen. A label is continuously updated and informs the user whether the pen is in inking or gesture mode, as well as whether the gestures they made on paper were successfully recognised. Selected paper content is represented digitally as a virtual
note and a thumbnail of it appears on the central cover flow widget of the application window as highlighted in Figure 6.4. Digital documents can be selected via a file chooser component shown in the figure. The first page of an uploaded document is shown as a thumbnail picture in the cover flow list of prepared documents in a similar manner to the virtual note thumbnail shown in Figure 6.4.

**In-meeting Component**

The tabletop application user interface used for the in-meeting phases provides several elements for organising meeting material, as shown in Figure 6.5. In the centre, a set
6.1. Paper-Digital Meeting Support and Review

Figure 6.4: Thumbnail of selected note shown within the pre-meeting component

Figure 6.5: Tabletop user interface

of buttons placed on a rotating Wheel of fortune are easily accessible by all participants and provide functionality to create workspace snapshots (Snapshot button) and
reestablish a previous workspace snapshot on the tabletop surface (Snapshots folder). Furthermore, the dropping of documents into the Public folder will later make them accessible to all participants in the meeting review phase. Any document that is dropped into the Trashbin is permanently deleted. In the margins of the tabletop surface, Private folders are provided for each meeting participant. Documents prepared before a meeting can be accessed via these folders. Also, documents created during the meeting can be saved in a user’s private folder at any time. The position of a private folder can be changed by simply dragging and dropping the folder with the digital pen. Note that the folders will reorient themselves when repositioned by applying an auto-orientation technique similar to MERL’s DiamondSpin¹.

Figure 6.6: In-meeting review of workspace snapshots

¹http://www.merl.com/projects/diamondspin/
By touching the *Snapshot button* with the pen, the current tabletop configuration is captured and stored as a snapshot. A previously captured workspace snapshot can be loaded to the tabletop by touching the *Snapshots folder* and dragging the corresponding thumbnail representation from a cover flow interface that contains all of the snapshots taken in the current meeting session, as shown in Figure 6.6. As emphasised in the figure, paper notes excerpts are represented on the tabletop user interface as virtual notes containing the digitised content of the original paper note. Digital documents are represented as virtual physical books that can be consulted through a simulated 3D page turning effect. Pen input on both a virtual note and individual pages of a virtual book results in pen-based annotations of the original content. In the case of notes, the new pen strokes update the digitised note content, while annotations on a virtual book page are associated with each page in the form of overlay information.

Paper notes and digital documents that have been prepared and uploaded in the pre-meeting phase are accessible during a meeting via each participant’s *Private folder*. When double tapping the folder with one of the user’s registered pens, a cover flow widget containing thumbnails of the available documents opens and documents can be drag-and-dropped to the shared space, as shown in Figure 6.7. Documents placed in a participant’s private folder can only be accessed by the participant. Once documents are made available in the shared space, they can also be edited by other users. However, in the post-meeting review, the documents will have restricted access unless the owner has explicitly shared them with other users by dropping them into the *Public folder*.

Figure 6.7: Browsing a private folder’s content and a note dragged on the tabletop

A series of further editing operations are available for both virtual notes and digital documents. These operations are provided through decentralised toolbars associated with each note or document, as shown in Figure 6.7. The toolbars include action items to save a public document in a user’s private folder (Figure 6.8a), delete the note or
document, change the colour palette and switch between different editing modes. The available pen-based modes of interaction are freehand inking to update a virtual note or annotate digital document pages, resizing, rotating and moving the corresponding note or document. Furthermore, the pen input is switched to selection mode after having touched the dedicated toolbar item. In the selection mode, contextual menus triggered by a double tapping gesture provide copy and paste, delete and deselect operations of previously selected parts of virtual notes as well as digital document annotations (Figure 6.8b). Figure 6.9 shows how a copy and paste operation can be executed.

Private folders are decorated with two icons indicating the number of documents contained and the current pen mode for the paper-based information capture, respectively. In Figure 6.10, the private folder contains one document and the pen mode is
set to 'I' for inking. In this mode, users can take freehand notes in their paper notebooks. When tapping with the pen a dedicated button printed on each notebook page, the pen mode changes to 'G' for gesture mode. In the gesture mode, users can issue various gesture-based commands to transfer parts of their notes onto the tabletop surface during the meeting. Two transfer options are provided. First, users can issue a selection of paper-based content through the same cropping gestures mentioned for the pre-meeting component (Figure 6.11). In this case, selected notebook content is made available as a virtual note in a user’s private folder. The pen mode icon changes to 'H' when the first part of the selection gesture is recognised. After the second part of the selection gesture is issued, the note appears in the user’s private folder, increasing the number of documents contained to two, and the pen mode switches back to inking. Second, selected paper notes can be made available directly on the tabletop without any indirection through a private folder. This is achieved when a second selection variant is used, the content being selected by using a circling gesture (Figure 6.12). The pen mode icon changes to 'C' when the circling gesture is recognised. As highlighted in Figure 6.13, the note appears on the tabletop at the position indicated by a double tap gesture performed successively to the circling selection operation. Please note that the choice of a circling selection gesture is based only on a differentiation criterion from the first selection gesture used and is not based on any previous research or observations.

New content can be created on the tabletop via new virtual notes. A virtual note is created by drawing a rectangle with the pen as shown in Figure 6.14(1). As soon as the
user lifts their pen, an empty virtual note appears on the tabletop surface at the same position and with the corresponding size as highlighted in Figure 6.14(2). By applying the auto-orientation technique mentioned earlier, the new note automatically faces its creator. Virtual notes created on the tabletop are by default public. A participant may claim the ownership of a public note by dragging the note to their private folder or by invoking the corresponding action provided by the associated toolbar widget.

**Post-meeting Component**

As mentioned earlier, the use of private and public folders to change the ownership of public material created on the tabletop during the meeting and private material created by individual participants within their private space, is reflected in the post-meeting review. If the ownership has not been changed, stored information about a document’s creator is used. Meeting material can be reviewed by using the same cover flow interface approach. Users may browse through collections of workspace snapshots as shown in
Figure 6.15: Post-meeting review by browsing snapshots

Figure 6.15. The cover flow is placed at the bottom of the application window and the thumbnail in the centre of the cover flow is shown enlarged in the upper part of the window. In the upper part of the application window, virtual notes and physical books representing digital documents are highlighted in different colours according to their ownership. Artefacts owned by the currently logged in user are highlighted in pink, public artefacts are highlighted in yellow and inaccessible artefacts pertaining to other users are not highlighted. When a user clicks on a highlighted thumbnail, the note or document is enlarged to expose more details (Figure 6.16a). The cover flow allows users to obtain a quick overview of all collaborative artefacts and the highlighting helps users quickly realise what content they can access.

It may be that not all documents are comprised within snapshots. A separate view allows users to browse through all non-snapped documents to which they have access. This includes personal documents from a user’s private folder, as well as public documents. This second view of the review component is shown in Figure 6.16b.

A final review functionality allows users to get quick access to updated versions of previously shared paper notes. When a user taps the pen within the extent of selection marks made on paper when sharing the note, the corresponding virtual note and all snapshots containing different versions of the note are retrieved and shown as thumbnail images in a cover flow widget in a third view of the post-meeting component, as shown in Figure 6.17. Each shared paper note may be associated with several virtual notes, depending on whether snapshots have been created or the virtual notes have been
deleted in the meantime. The corresponding virtual notes are highlighted in red when shown as part of a captured snapshot. The snapshots can be interacted with as described previously.

### 6.1.3 Implementation Details

Pen input on both paper and the tabletop surface covered with Anoto pattern is handled by the iPaper framework extended as described in Chapter 4. For the tabletop surface used during the in-meeting phase, we used an inexpensive solution consisting of a large paper sheet printed with Anoto pattern placed on a regular circular table under a protective glass layer. The in-meeting application user interface implemented in Adobe Flex is overhead projected onto the table surface and, through appropriate calibration, pen input is mapped to corresponding manipulations of the underlying projected content. To implement multitouch operations such as zooming, rotating and moving content on the table surface, which require fast transmissions in real time, the
pen input is mapped to TUIO\textsuperscript{2} messages. These messages are transmitted to the application driving the tabletop user interface and parsed into multitouch gestures. We use a modified TUIO cursor profile to also transmit information about pen identifiers and timestamps as part of the TUIO messages. The identifiers were used for operations on the tabletop requiring user identification, such as the auto-orientation feature. The iGesture framework was used for the recognition of the different gestures, such as the cropping gestures or the circle selection. A schematic description of the setup is shown in Figure 6.18.

![Figure 6.18: Setup](image)

The system consists of three modules, one for each meeting phase, as shown in Figure 6.19. A central database module stores information about meetings, users and documents handled in the virtual document space and is the mediator that allows data captured in different meeting phases to be accessible across phases as indicated by the blue arrows. The database module uses a db4o object database engine in client/server mode.

Data captured via the tabletop system is modelled as shown in the UML diagram in Figure 6.20. Administrative data is recorded as instances of the User and Meeting classes which capture user profile and meeting event details. In the case of users, details about their name, password and the unique pen addresses are stored. A meeting is described by its title and a list of topics as well as participating users. As already mentioned, the information is entered through the pre-meeting application user interface.

To be able to manage edits performed on the extent of various types of artefacts handled in the shared space, we introduced the high level abstractions of Documents and Notes. A Document models different types of content that can be displayed and manipulated on the tabletop surface, including virtual notes or PDF documents. Pen-

\textsuperscript{2}http://www.tuio.org/
based annotations made on the extent of a virtual note or digital document page are represented as Notes which are associated with the corresponding Document instance. A Note is composed of all the edits made on the extent of a Document page, consisting of traces containing collections of successive pen coordinates. A document is created by a user and is, by default, accessible to its creator. Access rights can be granted to other users, for example in the case of virtual notes created on the tabletop by a participant and devised public by the system or documents dropped into the Public
folder or personal folders of other participants than the creator, as modelled by the accessibleTo association.

Workspace snapshots are modelled as Snapshots which are associated with a specific meeting and refer to a set of document versions. When a new snapshot is created, the state of each document placed on the tabletop at that specific moment is captured with an instance of the Version class, which is associated with the snapshot object and the original document. A document version maintains information about a document’s representation on the tabletop and all contained edits at the moment of the snapshot. If a snapshot has been reconstructed, the document versions can be further edited, moved and resized. A subsequent snapshot will create new document versions.

To address differences in the manipulation of various types of documents and their annotations, extensions of the two general Document and Note classes can be implemented. In Figure 6.20, we show the extensions that we made to handle virtual notes and PDF documents in grey. The two specific implementations of the Document class are VirtualNotes and PDFDocuments. Pen-based annotations are represented by the VirtualNoteContent and PDFPageAnnotation extensions of the Note class. A PDFDocument can have zero or multiple PDFPageAnnotations associated to it. In contrast, a virtual note can have at most one associated virtual note content. Such document specific cardinality constraints over the Document-Note association are specified in the corresponding Document subclass implementations as indicated by the abstract addNote method.

6.2 Evaluation

Our initial study on traditional notetaking presented in Chapter 3 has revealed that, in cases where notes are used as an information source for some digital artefact, providing a digital copy of the notes might not be useful. Participants declared that they used the notes to orient themselves while editing the digital artefact, but that the notes were not used in the form in which these appeared on paper. However, participant feedback has also revealed that users tend to have difficulties in maintaining their paper notes over time in such a way that they do not get displaced from other media which complements their content. This observation lead us to forming a hypothesis that the digital integration of paper notes used as source for digital content might still be useful in cases where the notes are not the only source of information. In particular, we assumed that providing users a digital overview over paper-based and related digital material would not only improve the process of editing the digital artefact, but also support users in managing their collections of heterogeneous personal information over time.

To verify this hypothesis, we referred to the support to integrate personal paper-based notes and material used to support collaboration provided by the meeting support and review system presented in the previous section. We conducted a quasi-naturalistic study [115] where participants had to perform a familiar task using the system. Furthermore, to verify that the integration of the material improves the process of using the combination of notes and related media, we also carried the study in a configuration where the participants performed the same task in a non-enhanced setup. The goal was to compare the performances in producing a final document of the two different user
groups. This final document had to be created based on digital documents containing the relevant details passed on to them during a previous meeting, as well as their own notes taken during that meeting. In the following, we describe the details of the study.

6.2.1 Study Design

For the purpose of our study, we designed a task which consisted of participants having to prepare a report specifying details about the organisation of a conference dinner. Each test person was asked to participate in a two person meeting, together with one researcher. During this meeting, information prepared by the researcher in advance was passed on to the test person verbally as well as by showing them several digital documents. The meetings were held in one of two conditions, the final goal being to compare the performances of the two participant groups in recalling the details necessary for preparing the final report. A similar study around the use of tabletops and memory aspects was conducted by Hunter et al. [75]. We recruited a total of 22 study participants (4 female, 18 male) and, for each condition, we had 11 participants (2 female, 9 male). The participants were computer science students: 4 students working on their Master’s theses and 18 PhD students, distributed evenly in the two conditions.

**With system condition.** The meetings were supported by the paper-digital meeting support system presented in the previous section. Documents prepared in advance were uploaded before the meeting and shown on the tabletop surface by accessing the researcher’s private folder. The test persons were informed that they could document their meeting experience by making edits on documents shown, creating new notes on the tabletop, creating snapshots, or by taking notes on paper sheets printed with Anoto pattern. They were also told that all these would be accessible to them after the meeting via a meeting review system component, which was shortly demonstrated to them.

**Without system condition.** The meetings took place in a regular meeting room and a projector was used to show prepared digital documents. Test users were told that they can take paper notes or use their laptop devices to document the meetings. Furthermore, they were informed that the projected digital documents would be made available to them after the meeting.

A total of three digital documents were prepared and shown to the participants. The first document contained brief descriptions for two restaurant options, together with the overall price estimates computed by the researcher. The remaining two documents contained detailed descriptions for the two restaurant options. This included two menu options, wine options and a proposal in terms of additional drinks, each of these with the corresponding costs. Furthermore, an initial proposal in terms of the quantities, as well as price estimates were provided. Each document contained also the exact address of the corresponding restaurant and how the restaurant could be reached by public transportation. The documents are presented in Appendix C, together with further details of the task description. The information regarding the budget limit was presented only verbally.

Each meeting started with an introduction to the topic of a conference dinner, the task of producing a document, and—depending on the condition—the means available during and after the meeting, in order to gather and recall relevant information. The participants in the with system condition were shown how to use the meeting support
system based on the tabletop surface. Then, the meeting followed an agenda consisting of three tasks. For each task, the information prepared in advance was presented, discussed and decisions were taken. The three tasks are as follows:

1. The choice of restaurants, as well as corresponding menus, wine, additional drinks, quantities and prices, was presented to the test person. A short discussion was held, in which a restaurant and a menu were selected and eventual changes in the researcher’s proposal were made.

2. The travel plan for the participants was discussed and the test persons were reminded that the final document should contain a paragraph of text telling conference attendees when to be where, which transportation to take, which station to get off, and whether travelling as a group is going to be organised.

3. The allocation of tables in the restaurant was specified. The participants were told that the final document should contain a floor plan reflecting this specification. An empty floor plan sketch was provided and edited during the discussion with concrete planning details in terms of the number of tables and their location.

In a second phase, taking place two days later, we met each test person again. In the previous meeting, we had told the participants that in this second meeting they would be asked to recall the information and decisions relevant to their task of producing the conference dinner organisation report. To be able to compare the performances of the two participant groups, we asked each participant the 10 questions in Appendix C and recorded the time they needed to answer each question. They had to answer the questions verbally and had to write down information only for question 6, for which they had to fill numerical data in a given table. To answer the questions, participants in the with system condition could use the meeting review component of our system at any time. The review component provided access to all snapshots taken during the first meeting, all non-snapped documents, as well as personal paper notes. If their personal notes had not been shared on the tabletop surface and subsequently captured as part of snapshots, then these were shown only in the tab of non-snapped documents. In the without system condition, participants were allowed to use a laptop where the three documents we had shown during the first meeting had already been opened for them, as well as their personal paper or digital notes. Only two participants took digital notes in a text editor. In their case, we printed the digital notes and gave them the option to use the printed version in addition to the digital one. We kept all the material in between the two meetings and, therefore, none of the participants could review the material before the second meeting.

Furthermore, we also asked the participants a series of self-reported and open questions. For the with system condition, the goal was to understand what are participant opinions regarding the paper-digital meeting support system, as well as the idea of integrating paper and digital material used as support for collaborative activities. For the without system condition, we wanted to get further insights into possible problems that participants might generally have with managing the different kinds of material, as well as confirm the initial observations made in the first study described in Chapter 3.
6.2.2 Study Results

Without System Condition

A series of self-reported questions regarding the user experience during the two phases of the study have revealed problems similar to those observed in our previous study on traditional paper-based notetaking. Generally, they considered that their current practices, where they have to use paper and digital documents in parallel to carry out various tasks, could accommodate improvements. A particular problem that they reported was related to the maintenance of the mixed media information over time. A recurring statement was that they would like to have a way to integrate the paper-digital material in a single place. However, they also reported that this should be done for them “magically”, without requiring that they adapt their practices too much. 8 out of 11 participants described their approach in performing the task as “random, but somehow it works”, which is seemingly also the reason why they do not adopt more thorough paper-digital information management schemes in their every day activities.

A series of open questions regarding the overall experience while performing the task revealed that participants felt that having to look for information in both their notes and the digital documents made their task less efficient:

“Gathering all information for the report from different documents was time consuming, especially finding the right details inside my notes.”

The participants felt that their overall experience would have been better if the information had already been integrated in some way. One participant suggested integrating the entire information set in one single file, while another one would have preferred to be able to make annotations directly in the digital file that we have shown to them during the meeting:

“Having all information in one place, categorised and understandable. Hence, putting all in one file.”

Other reported problem had to do with being able to reconstruct the information after a longer period of time. Participants felt that some post-processing consisting of completing their notes with details would be necessary in order for them to be able to perform the task with the same success:

“I think I was able to recall most of the things. However, I am not sure whether I would have been able to do so after a longer period of time. I should have spent time consolidating my notes.”

Furthermore, participants emphasised that the use of two different media affected the quality of their notes and, thus, their takeaways in general:

“Documents with information were available beforehand. Those documents were not created by me and I did not have copies of them. I knew roughly the information in those documents, but not in details. While taking notes on paper, I sometimes hoped that certain information is in the digital documents and so I did not write it down. I was not 100% sure though that this information is actually there.”
6.2. Evaluation

**With System Condition**

The participants in the *with system* condition took overall less private notes on paper than the participants in the previous condition. Most likely this was due to the fact that they could directly annotate the digital files on the tabletop surface and that they knew that they would have access to the annotated documents after the meeting. Therefore, they did not need to copy details from the shown documents in their private notes, as done by the participants in the *without system* condition.

We also asked the *with system* condition participants a series of self-reported and open questions with an incentive to understand what are their opinions about the paper-digital meeting support system, as well as the idea of integrating paper and digital material used as support for collaborative activities. Participants liked especially the integration of the two kinds of media in one place and being able to track the evolution of the material in time. They mentioned that it would be a definite improvement over their current approaches, where they have the paper-based material piling up on their desks and they hardly ever look at that material again. They felt that having their notes organised together with the rest of the used material is something which they would like to have integrated in their every day activities. However, they felt that having to use the meeting support system to obtain that integration could be too time consuming. They explained that it might be that they would change their opinions if they used the system more often and got used to it, but that generally they prefer to be more spontaneous and not have to setup too much before a meeting. Some quotes are given below:

> “This was a great experience and I see many benefits of it.”

> “I like the system as a general means for recording details and the whole planning process. But, if the goal of the meeting is to remember only a few conclusions of the final result, I find other means more efficient.”

> “System was less efficient than traditional alternatives for data entry, but it was very nice for reviewing information to compile the report.”

**Comparison of the Two Conditions**

Since we held the second phase of the study only two days after the first meeting, we expected that participants would remember a fair amount of the high level details. However, we were not interested in comparing their abilities to remember based on their memories, but in their performances in re-finding relevant details in the two conditions: integrated paper-digital material versus a setup where no integration of the material was provided. Therefore, our questions referred to very specific details, such as the exact address of the chosen restaurant or the dinner starting time. We assumed that the participants would not remember such details and would need look them up in the provided digital documents or their own notes. Furthermore, we made sure that the questions included both details already provided in the digital documents we had shown to them, as well as details which had been discussed and agreed upon with the participants and were mostly captured as personal notes. The first two questions included general details and were included as a kind of warm up. As expected, the participants
relied almost exclusively on their memories to answer these questions. Therefore, we did not include the time required for these two questions in the final dataset. We also removed question 6 from the dataset, where we had asked the participants to fill in price details. Depending on the progress of the discussions in the first meetings, some of the participants had to recompute the cost estimates, whereas the others agreed with the proposal made by the researcher and had to merely copy the details provided beforehand. Since a few participants had some problems with the computations, we felt that the question was compromised and no longer corresponded with our original goals to compare the participant performances in finding details relevant for their reports.

Based on the total time required to answer the questions, we observed a significant effect of the participant condition at the $p < .05$ level, the with system group performing better, $F(1, 20) = 9.988, p = 0.005$. In Figure 6.21, we plotted the timing details for the two participant groups. The same information is shown both as box plot, on the left hand side of the figure, and as scatterplot, on the right hand side. Please note that the different symbols used in the scatterplot diagram have the sole purpose of making some overlapping data points visible. Appendix D contains the corresponding descriptive measures.

Furthermore, we also tracked for each of the questions which of the participants had any problems in finding the relevant information, such as giving partially accurate answers or not giving an answer at all. We scored their difficulty in answering a particular question on a scale from 1 to 5 (1 = very low, 2 = low, 3 = medium, 4 = high and 5 = very high) and summed up the overall difficulty scores per user for the 10 questions. Numerous users did not encounter any problems and answered correctly all
6.2. Evaluation

The details regarding the number of questions where we encountered any difficulties per user are as follows: min = 0, max = 4, mode = 0, mean = 0.73, SD = 1.12. In Figure 6.22, we show the difficulty scores for the two participant groups on the left-hand side. On the right-hand side, we plotted the scores for those participants which had problems in answering at least one question. Again, it can be seen that the with system group performed better, the effect of the participant condition being significant at the \( p < .05 \) level, \( F(1, 20) = 7.676, p = 0.012 \).

6.2.3 Discussion

Our study has revealed a better performance of the group that used our paper-digital meeting support system and, consequently, an integrated version of the paper-digital material, as compared to the group which benefited of no paper-digital integration. This result refers to the time required by the participants to answer questions regarding very specific details contained by digital documents and personal notes that they had used during a previous collaborative activity, as well as a quantified measure of the difficulties that they encountered while locating information relevant for the different questions. While the two measures capture only efficiency and effectiveness aspects of the user experience, the result supports our hypothesis that a paper-digital integration of the material is likely to improve the use of the two related information sources.

While having appreciated the resulting paper-digital integration, some users in the with system condition have similarly shown a certain reticence towards having to integrate a new system in their current practices in order to achieve it. They declared that the post-meeting review system could greatly improve their current practices, but that the integration should be achieved in a more seamless way and without having to use
other tools than the ones that they are currently using.

In conclusion, while having verified our hypothesis, we consider that further investigations on ways to achieve the paper-digital integration are required. To achieve the more seamless paper-digital integration requested by our study participants, further investigations might need to focus on specific domains and information tasks, so that truly useful solutions, that users are willing to potentially adapt to using, are identified. Furthermore, some forms of implicit information capture could turn out to be beneficial in certain situations.

### 6.3 Conclusion

It was our hypothesis that integrating paper and digital material used in combination in support of information worker tasks is an area where the use of digital pen and paper could present benefits. We implemented a system that supports the integration of the two media based on digital pen and paper technologies and designed a study meant to compare a condition where participants used an integrated version of the material to a second condition where an integration of the same material was not provided. The study showed that the group having used the integrated version of the material has performed better and had less difficulties in finding the information. Furthermore, self-reported questions revealed that users appreciated having access to all their paper and digital material in one place and that they considered it to be an improvement over their current practices.
In this thesis, we have motivated a need to enhance digitally the use of information captured on paper via natural notetaking. By natural notetaking we refer to notetaking situations where paper is the preferred capture medium given a more flexible capture process supported. We argued that digital pen and paper notetaking solutions create the possibility to bring together this preference for using paper for the information capture with the benefits of digital information handling. At the same time, we observed that, even though around for approximately one decade, the technology is still not widely used for natural notetaking. In this context, we investigated possible reasons for the limited use of the technology, as well as solutions for aligning the use of digital pen and paper with natural notetaking.

We started our investigations with a study on traditional paper-based notetaking. The goal of the study was to determine how natural notes are used after their capture, as well as understand whether and how natural notetaking could integrate with the use of digital pen and paper technologies. The study allowed us to identify a series of note categories from the point of view of their post-capture use. A parallel between the identified use categories and the kinds of digital support provided by existing digital pen and paper-based notetaking solutions revealed two areas where user needs in terms of using natural notes are not met. First, we observed a lack of support for the recall of valuable handwritten notes. Second, it became apparent that the functionality to transfer notes to digital storage provided by existing solutions might be of limited use, unless notes relate to other media and the solution provides an integrated view over the notes and the media to which they relate. Finally, the study has revealed a general reluctance of users towards solutions that require the adaptation of natural notetaking practices to integrate certain rules or guidelines, such as proposed by existing notetaking solutions. At the same time, identified note qualitative aspects made it apparent that some mechanism to support the processing of notes is necessary.

Before undertaking investigations in the two identified problem areas, we addressed the need to relax potential limitations on natural notetaking of existing user-driven approaches for processing paper-captured information and proposed the use of a combined
user-driven and automatic processing. For this reason, we designed and implemented a framework which supports the development of a wide variety of automatic approaches for processing the digital ink representations of paper-based notes, as well as the combination of automatic and user-driven processing approaches. The framework can be used in combination with existing frameworks and toolkits for developing digital pen and paper-based applications and supports developers in selecting and combining processing approaches in flexible ways.

Having the framework as basis, we further addressed the need to enhance the role played by paper notes in recalling information. For this purpose, we investigated kinds of digital reminder systems best suited for reminding about noted information. We started by performing a survey of related work in the field of reminder and notification systems. Based on this survey, we concluded that ambient information systems might be best suited to digitally support reminding about paper notes. Further, we implemented an ambient information system with integrated handwritten notes and, in the scope of a user study, compared its support in reminding with other two more traditional reminding approaches. Our solution based on ambient displays was well received by our study participants and perceived as complementing reminding solutions that they already used.

To verify our hypothesis that transferring paper note copies to digital storage is useful in cases when the notes relate to other media and the notetaking solution integrates both the notes and the media to which they relate, we performed a quasi-naturalistic study. The study focused on meeting situations with combined paper and digital media use. These have been enhanced with the aid of a paper-digital meeting support and review system which we have designed and built for the purpose of the study. The system supports the integration of personal paper notes with shared work supported by an interactive tabletop surface. In addition to participant feedback which confirmed the benefit of providing an integrated view over the different material used to support collaboration, we have observed a better performance in re-finding information when the system had been used, as compared to a traditional setup where paper and digital media had not been integrated.

To conclude this thesis, we discuss the contributions. Subsequently, we provide an outlook of future research ideas emerging from work presented in this thesis.

### 7.1 Discussion

From the very beginning, we were guided in our work by a twofold observation. On the one hand, daily information worker activities are still affected by a number of inefficiencies, among which the use of various information pieces that they capture on paper has potentially improved the least over the last two decades. Seemingly, valuable affordances of paper for the information capture process lead users to accepting drawbacks for the information handling and management, which follow from a paper-based capture of the information. On the other hand, numerous solutions have repeatedly been proposed to address various of these drawbacks, including a series of solutions which support both the digital information handling and management and the paper-based capture of the information. Focusing on digital pen and paper technologies as the facilitator, our constant endeavour has been to find reasons and corresponding solutions
for this situation where the basis for improving information worker activities exist, but have not yet been widely adopted in practice. We set out to look for explanations in both the use of paper in practice, as well as enhancements attainable by the use of the technology and the way these have been integrated with existing practices. Our goal was to find any potential misalignments, as well as ways to bring the two together.

Certainly, fully comprehending human behaviour is not any less challenging than technological undertakings are. Information workers are amazingly resourceful in the ways in which they use paper to support their practices. This freedom provided to them by paper is the reason why they prefer the medium in the first place and, at the same time, the reason why they are very reticent to accept any changes in their notetaking that might limit it. From early stages of our investigations, it became apparent that the best way to tackle the problem that we had embarked on solving would be to find a way to make the technology imperceptible and enable its benefits without interfering with the information capture process. Unfortunately, this also seemed a very hard to achieve task, if not impossible. Nevertheless, it gave us some first clues of where the problem might lie and led us to investigating ways to automate the processing of paper-captured information in an attempt to reduce the interference on natural notetaking of using the technology. For this purpose, we implemented a framework which supports the combination of user-driven and automatic processing approaches. While user-driven processing had already been supported by existing digital pen and paper development frameworks, automatic processing approaches have not been investigated and enabled through framework support. Our goal was to support experimentation with different processing approaches and try to relax any encumbering on natural notetaking caused by the use of user-driven processing approaches by combining this already used processing method with automatic processing. While we are aware that no two fields of activity or even no two users have the same requirements, we hope that the framework will provide application developers room to experiment and come up with solutions as close as possible to the needs of their users, solutions which at the same time are based on processing approaches that users are willing to accommodate in their notetaking. We took ourselves this approach for all the solutions that we have built and reported our experiences.

Looking at the kinds of enhancements for notetaking provided by existing digital pen and paper-based solutions, on the one hand, and whether these are concordant with the uses attributed to paper in practice, on the other hand, we identified two possible misalignments between these. First, we observed that the most basic use of paper-captured information, which is to support memory, had not been reflected completely in the kinds of digital functionality provided by existing notetaking solutions. In particular, we observed that notes meant to remind about future activities—called prospective memory aids in the literature on memory mechanisms—might fail to serve their role to remind when simply integrated within some digital storage, as proposed by existing solutions. Second, we observed that the support provided by existing solutions, consisting mainly of making a copy of the handwritten content available in digital space, might not be useful in the case of certain noted content parts. We identified this as possible reason why the technology is not yet widely used. We also observed that the same kind of support might be useful in the particular case where paper notes are used in combination with other kinds of media in the frame of a user’s tasks. While in our investigations we tried to address a wide variability in terms of paper-supported
practices, we cannot guarantee that we have identified all possible critical aspects and that no other areas exist where the use of digital pen and paper for natural notetaking could be further extended. Nevertheless, we have followed each of the two directions in depth and consider that the insights that we have gained and reported in this thesis are a valuable contribution towards our goal of extending the use of digital pen and paper technologies for natural notetaking.

Looking into possible ways to enhance digitally the reminding about notes, we found that integrating reminder notes within a user’s environment via ambient information systems might be the most suitable way to digitally support the role in reminding played by the paper notes. While extensive research on ambient information systems already exists and we have tried to follow these findings closely, the particular case of reminding about information authored by the users themselves—as a user’s personal paper-based notes are—has been addressed only to a limited extent. The series of prototypes which we have built and tested have certainly given us valuable insights. We have confirmed that the idea of using ambient information systems to remind about noted information integrates well with existing practices and already used reminding approaches. We have also collected valuable feedback from our users to improve the existing prototypes. However, we are aware that our undertakings represent merely a beginning and that further iterations, potentially including a series of new prototypes tested via user studies, are necessary to reach a point where such a reminder notes system could become an integral part of any information worker’s working environment.

Regarding support for cases with combined media use, we have obtained original indications in support of our hypothesis that a digital overview over paper-based and related digital material could be a way to improve the use of notes taken with the goal to support the editing of digital artefacts together with material related to them. However, we have also realised that further investigations are required in terms of achieving the integration of paper and related material in more seamless ways. Given the wide variability of tasks with combined media use, this might require domain specific investigations.

In what follows, we list ways in which our endeavours could be extended.

**Reminder Notes**

While our investigations on supporting the role in reminding played by paper notes have shown that the use of ambient information systems is a promising approach, we have also gathered a series of valuable suggestions from our study participants. These range from details regarding the rendering of the handwritten information within the ambient system that we have proposed, such as providing some functionality to wrap around the handwritten information, to providing new kinds of interaction with information items displayed, such as touch interaction. These suggestions alone open up numerous directions for further investigation via new prototypes deployed and tested in the frame of user studies.

Furthermore, our study has shown that part of the users would appreciate a functionality to integrate handwritten information with their currently used time-based reminder tools. This would require that a way to specify such time-based reminders at capture time is supported by the notetaking solution. While currently this would require the use of approaches which would deviate from a natural notetaking practice,
further investigations could look at ways to support this kind of functionality with as few as possible recognition errors, as well as few changes in a user’s existing notetaking practices.

**Paper-digital Integration**

Our investigations have shown improvements over existing practices when paper and digital media are integrated digitally. However, users have also reported that they would prefer a more seamless approach to achieve the integration. They have shown a certain reluctance towards having to adapt to using a new system for their practices, such as our paper-digital meeting support system, even if they appreciated the gained benefits. Therefore, we consider that additional ways to integrate paper and digital material which do not involve changing existing practices should be further investigated. This could involve ways to enforce some implicit integration of the information, potentially combined with mechanisms to reduce the amount of information generated.

**Digital Ink Processing Approaches**

Based on our experiences, the results of the handwriting recognition, as well as the performance of the automatic processing based on the recognition of various digital ink elements are the aspects with the most room for improvement. Users have repeatedly pointed out that errors in interpreting their notes, as well as the processing mechanisms that we have implemented for our studies, could be a reason why they would not adopt a digital pen and paper notetaking solutions and continue using traditional pen and paper.

A straightforward next step to improve the experiences supported by our solutions could consist of experimenting with other algorithms for digital ink segmentation than the one that we have implemented and integrated with our framework. While integrating other segmentation algorithms can be easily achieved given the flexibility with which the framework has been designed, we have not tried any other approaches so far. More robust results than the ones that we have already obtained could result from the use of other segmentation algorithms.

**Remote Access to Handwritten Information**

We think that, in addition to reminding about notes, providing remote access to information captured on paper might be another functionality for which users might be willing to integrate slight changes in their notetaking for the benefits that they would be offered. Possible ways to achieve this might be, for example, via web-based tools, which are accessible nowadays almost anywhere via portable devices such as smartphones. Some initial investigations that we have done in this direction, where we have integrated handwritten notes with WordPress\(^1\), show promising results [192]. Also, some of the existing solutions based on the technology have started to shift their kinds of support in the direction of remote access, examples including the very recent Livescribe Connect\(^2\).

\(^1\)http://wordpress.org

\(^2\)http://www.livescribe.com/blog/press/?p=3367
7.2 Outlook

Our original goal in the beginning of this work was to investigate reasons for the current situation where digital pen and paper technologies are not in widespread use and further propose ways to deal with this situation. While we made several proposals in this direction, we consider that a series of aspects need further attention before a state where a truly pervasive use of digital pen and paper can be reached.

First, we consider that improvements in terms of the digital ink data processing are still required. While handwriting recognition has come a long way, in setups such as ours, where we had to use a general handwriting engine configuration for English language, it was often the case that the results were rated poorly by our study participants. The handwriting recognition engine is more likely to return correct interpretation results when information can be captured via forms. In such case, the engine can be instructed what kind of information is expected in each form field, such as a person’s name or an email address, and customised language resources can be used in each case. However, given our endeavour to support natural notetaking, we could often not provide such hints regarding the meaning of the different digital ink data snippets to the recognition engine. Consequently, the engine load in terms of the number of possible combinations was greater and the results often poorer. Similarly, automatic segmentation, gesture-recognition and various other automatic processing approaches cannot always return results concordant with a user’s intentions. Throughout our studies, it was often pointed out by the participants that the various recognition errors would need to be solved or at least reduced, before they would really commit to accommodating the new technology within their practices, no matter how useful the different tools were.

What we have also observed is that often the person responsible for the implementation of an application’s processing approaches tends to obtain better interpretation results. A plausible explanation seems to be the fact that the application designer is likely to have chosen those processing approaches which had worked better for themselves. Unfortunately, it seems that such experiences can not always be ported directly to solutions meant to be used by other users. A way to exploit this observation, in an attempt to achieve more reliable digital ink data processing, could be to investigate ways to support a certain personalisation of the processing, potentially performed by the users themselves. For example, users could be given the possibility to configure for each application their desired processing approaches, as well as define guidelines for the underlying processing engine based on their own practices in taking notes.

A second possible explanation for the still restricted use of the technology is the limited access of end-users to custom solutions such as the ones we have presented in this thesis. Most of the solutions available commercially are tied to a specific application and require the use of digital pens sold as part of the solution bundle. Also, only a handful of pens available commercially provide Bluetooth connectivity, the production of some of them having already been stopped, as it is the case with Logitech’s digital pens. A more successful model could be one where any Anoto digital pen could be used with any application obtained, for example, via some web-based platforms. While Livescribe uses such a model, the use of the special Livescribe pens is still required and the only custom applications available are penlets which can be run only on the Livescribe pens. The extensibility does not refer to the information use and management after having downloaded the digital ink data from the pen onto a digital device. The company has
started only recently to support the integration of the information downloaded from the pen with various social media sites and other web-based tools. This has to be done via the Livescribe Desktop. However, the data has to be explicitly exported by the users and the export operation can only be done on a per page basis. Furthermore, the list of applications that the information can be integrated with is limited to a list of connectors.

Finally, using the technology is still dependent on a series of configuration steps which have to be done on each user machine for each application and each digital pen used. Furthermore, the information capture has to be done only on the specially printed Anoto paper. Also, the pattern printed on each piece of paper has to be associated beforehand with an application able to process the information transferred from the digital pen. The application has to be either running at transfer time or registered as a service on the user’s machine. Finally, users have to make sure that they use a digital pen, often the only one that they own. This situation is not consistent with natural notetaking, where it is often the case that users refer to whichever pen and piece of paper they have at hand at the moment. In our opinion, a future where the technology is widely used should permit a certain pervasiveness of the Anoto pens and paper. Users should be able to own numerous pens which they can spread at different locations where they might need to capture information, such as at work, at home or while on the go. This means that digital pens should become much cheaper. Furthermore, Anoto printed paper should be easily procured, for example via regular stationery stores or by allowing the users to generate Anoto-enabled artefacts themselves. While, Livescribe now provides the possibility to print new A4 paper sheets via their desktop application, other useful support could be the easy generation of other paper formats such as post-its or envelopes. This way, users could spread Anoto enabled artefacts in their environments and use them in support of habitual activities. Obviously, this would require a different business model in terms of the management of the pattern, which is currently very limiting and would not permit the unique identification of every paper artefact generated this way. For example, providers of such solutions could register the different parts of the pattern used for each user globally. At a simple synchronisation of the pen with any kind of digital device, users should be able to have their data processed, no matter which piece of paper they happened to have used to capture the information.
Thank you for taking the time to fill in this questionnaire!

The questions are grouped in two parts. The first part contains general questions. The second part contains questions related to your experience in using the different tools.

Personal Information

1. ID:

General Questions

Capturing Information in Ad-hoc Scenarios

2. Imagine that your attention is focused on writing a paper/report. During a discussion regarding a particular aspect of the paper/report in one of the co-author’s office, an idea related to a different aspect of your work occurs to you. How do you capture it?

   ( ) I quickly jot it down on a notepad, post-it or other piece of paper.
   ( ) I always have my smartphone with me, so I use one of its tools such as email or a notes tool.
   ( ) I keep it in my mind until I can get back to my computer and record it within my favourite tool.
   ( ) This never happens to me.
   ( ) Other. Please describe:
3. Imagine that you are having a casual discussion with your colleagues when you suddenly remember something you have forgotten to do. How do you ensure that once the discussion is over you will not again forget it?

( ) I quickly jot it down on a notepad, post-it or other piece of paper.
( ) I always have my smartphone with me, so I use one of its tools such as email or a notes tool.
( ) I keep it in my mind until I can get back to my computer and record it within my favourite tool or perform the task.
( ) This never happens to me.
( ) Other. Please describe:

4. Imagine that you are attending a presentation and an interesting technology you haven’t heard of is mentioned. You want to look it up, but at the time you have to focus on the presentation since you will have to give extensive feedback at the end. How do you make sure you will remember to look up the technology?

( ) I quickly jot it down on a notepad, post-it or other piece of paper.
( ) I always have my smartphone with me, so I use one of its tools such as email or a notes tool.
( ) I keep it in my mind until I can get back to my computer and record it within my favourite tool or perform the task.
( ) This never happens to me.
( ) Other. Please describe:

5. Did it happen to you that you did not capture some information in one of the previous or similar situations and this resulted in a certain inconvenience for you, such as having forgotten to perform some associated actions?

( ) This happens to me quite often and it is usually quite inconvenient.
( ) This happens to me quite often, but I usually manage to make up for it with some effort, such as by searching the Internet or asking colleagues.
( ) This happens to me in some occasions and it usually is quite inconvenient.
( ) This happens to me in some occasions, but I usually manage to make up for it with some effort, such as by searching the Internet or asking colleagues.
( ) This never happens to me.

6. In the context of the previous question, what is the most likely cause why you did not capture such information?

( ) The time did not permit.
( ) I never know how to capture such ideas so the latter I can find them again.
( ) Even if I capture them, I forget them because I do not actively consult the tool (paper notebook, email, notes application on smartphone etc.)
( ) I thought my memory would be enough.
( ) Other. Please give details:

7. Did it ever occur to you that you captured some information and still forgot to
perform associated actions?

( ) Often.
( ) Sometimes.
( ) Rarely.
( ) Never.

8. In that situation, which approach did you use?

( ) Paper.
( ) Email or another digital tool.
( ) Trying to keep it in mind.
( ) It varies. It happens to me with multiple approaches. Mention which ones:
( ) Other. Please describe:

Paper-based Notetaking

9. Do you use paper-based notetaking to capture information in your everyday life?

( ) Heavily (It is the most likely approach I will use to capture information related to a particular subset of my habitual activities.)
( ) Moderately (I use it to capture information related to a particular subset of my habitual activities in combination with/alternatively to other approaches.)
( ) Casually (I use it for particular tasks which are happening only sometimes in my everyday life.)
( ) Scarcely (I cannot identify a certain pattern, but sometimes I happen to use it.)
( ) Never.

10. In which situations do you use paper-based notetaking to capture information (check all that applies)?

( ) When I need to quickly capture some piece of information and there is not enough time to integrate it with the tool I usually use to manage that type of information
( ) To manage my current to-dos, because post-its or paper-based to-do lists are more visible
( ) When I need to think something through or, in other words “Thinking with a pen and paper”
( ) Whenever I participate to some event, meeting, etc., that requires that I am away from my desk and it is likely that something might come up that I need to remember
( ) Other. Please describe:

11. Please describe how you manage your paper notes.
( ) I always go through my notes as soon as the time permits and integrate my notes with my usual digital tools
( ) I sometimes go through them and transcribe what is important
( ) I always leave the information on paper. Transcribing takes too much time.
( ) I have a system, e.g. to-dos are always separate from other kinds of information, so for me it is easy to manage everything in paper form
( ) Other. Please describe:

**Non Paper-based Notetaking**¹

12. What is the reason for not using paper-based notetaking?

**Opinions about the Different Tools**

**The Idea of Extracting Notes**

13. I think that the idea of extracting selected notes from paper and integrating them with reminder tools is useful.

   ( ) Strongly agree
   ( ) Somewhat agree
   ( ) Neither agree nor disagree
   ( ) Somewhat disagree
   ( ) Strongly disagree

14. It is feasible to integrate this idea with my current information capturing and management approaches.

   ( ) Strongly agree
   ( ) Somewhat agree
   ( ) Neither agree nor disagree
   ( ) Somewhat disagree
   ( ) Strongly disagree

15. I would use it if I realised that I can remember the content of my notes better.

   ( ) Strongly agree
   ( ) Somewhat agree
   ( ) Neither agree nor disagree
   ( ) Somewhat disagree
   ( ) Strongly disagree

¹Optional based on answer for question 9.
**Tool Usage**

16. Was the tool always on and not minimised?

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outlook integration</td>
<td>()</td>
<td>()</td>
</tr>
<tr>
<td>To-do list and post-it tool</td>
<td>()</td>
<td>()</td>
</tr>
<tr>
<td>Ambient display</td>
<td>()</td>
<td>()</td>
</tr>
</tbody>
</table>

17. How often did you take notice of the different tools?

<table>
<thead>
<tr>
<th></th>
<th>Never</th>
<th>A couple of times per week</th>
<th>A couple of times per day</th>
<th>A couple of times per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outlook integration</td>
<td>()</td>
<td>()</td>
<td>()</td>
<td>()</td>
</tr>
<tr>
<td>To-do list and post-it tool</td>
<td>()</td>
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<td>()</td>
</tr>
<tr>
<td>Ambient display</td>
<td>()</td>
<td>()</td>
<td>()</td>
<td>()</td>
</tr>
</tbody>
</table>

18. When did you focus on one of the different tools? (check for each tool all that applies)

<table>
<thead>
<tr>
<th></th>
<th>After having synchronised the pen</th>
<th>After having extracted notes with the browser</th>
<th>After having completed a task to delete the note</th>
<th>While talking on the phone with someone</th>
<th>When I had nothing else to do</th>
<th>When I wanted to check for open tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outlook integration</td>
<td>()</td>
<td>()</td>
<td>()</td>
<td>()</td>
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</tr>
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</tr>
<tr>
<td>Ambient display</td>
<td>()</td>
<td>()</td>
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<td>()</td>
</tr>
</tbody>
</table>
When I wanted to refer back to a certain note Before leaving the office in the evening Each time I got back to my desk More often than it was necessary or informative I didn’t really notice the tool Other

<table>
<thead>
<tr>
<th></th>
<th>( )</th>
<th>( )</th>
<th>( )</th>
<th>( )</th>
<th>( )</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Outlook integration</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>To-do list and post-it tool</strong></td>
<td></td>
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<td></td>
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<tr>
<td><strong>Ambient display</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**Usefulness and User Satisfaction**

19. Rate your agreement with the following statements.

<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I found the ambient display distracting.</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>The Outlook integration tool interfered with my habitual mailbox use.</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>The to-do list and post-its tool interfered with carrying out other tasks.</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
</tbody>
</table>

20. I liked the tool and would continue using it, if minor points are improved.

<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outlook Integration</strong></td>
<td>( )</td>
<td>( )</td>
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<td>( )</td>
</tr>
<tr>
<td><strong>To-do list and post-its tool</strong></td>
<td>( )</td>
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<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td><strong>Ambient display</strong></td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
</tbody>
</table>
21. The tool helped me remember my tasks, ideas and other snippets of information.

<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>

22. Did you rely on other tools or approaches to remember your tasks, ideas or other snippets of information? If yes, which ones?

23. The tool provides a valuable overview of my tasks, ideas and other snippets of information.

<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
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<td>()</td>
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</tr>
</tbody>
</table>

24. The tool provides enough information for me to carry on actions associated to my notes.

<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
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</tr>
</tbody>
</table>

25. It easier for me to access to my notes using the tool as compared to my usual approach.

<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
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<td>()</td>
</tr>
</tbody>
</table>
26. The tool provides a reassuring feeling because I know that all my tasks, ideas and other snippets of information are captured in one central place.

<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outlook Integration</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
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</tr>
<tr>
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<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
</tbody>
</table>

27. I found the design of the Ambient Display pleasing?

( ) Strongly agree
( ) Somewhat agree
( ) Neither agree nor disagree
( ) Somewhat disagree
( ) Strongly disagree

28. How much did you need to adapt your natural notetaking behaviour to meet the conventions of the tools?

( ) Strongly agree
( ) Somewhat agree
( ) Neither agree nor disagree
( ) Somewhat disagree
( ) Strongly disagree

29. Which tool or combination of tools would you choose, if you were given the opportunity to use it further on? (check multiple answers if needed)

( ) To-do list
( ) Outlook Integration
( ) Ambient Display
( ) None of them

**Effectiveness of Pen and Paper Interface and Note Browser**

30. Rate your agreement with the following statements
<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I had difficulties to assign an appropriate category to my note items</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>Marking notes with circled letters was easy and convenient to use</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>I easily could remember easily the three marker types</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>Most of the marked note items were extracted automatically and correctly</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>Having to use the notes browser to extract notes that were not accurately extracted was inconvenient</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>Once my notes were extracted I didn’t refer anymore to their paper version.</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
</tbody>
</table>

Comments and Observations

31. Do you have any additional comments or observations?
Table B.1: Ratings of the idea of extracting notes and integrating them with reminder tools (5 – Strongly agree, 4 – Somewhat agree, 3 – Neither agree nor disagree, 2 – Somewhat disagree, 1 – Strongly disagree)
Once my notes were extracted and integrated with the digital tools, I never went back to paper.

Table B.2: Going back to paper notes (5 – Strongly agree, 4 – Somewhat agree, 3 – Neither agree nor disagree, 2 – Somewhat disagree, 1 – Strongly disagree)

<table>
<thead>
<tr>
<th>Mode</th>
<th>Median</th>
<th>Minimum</th>
<th>Percentile 25</th>
<th>Percentile 75</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
<th>Valid N</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

Table B.3: Usefulness of the different tools (5 – Strongly agree, 4 – Somewhat agree, 3 – Neither agree nor disagree, 2 – Somewhat disagree, 1 – Strongly disagree)

<table>
<thead>
<tr>
<th></th>
<th>Mode</th>
<th>Median</th>
<th>Minimum</th>
<th>Percentile 25</th>
<th>Percentile 75</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
<th>Valid N</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outlook integration</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>To-do list and post-its tool</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Ambient display</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

Table B.4: “I liked the tool and would continue using it, if minor points are improved”. (5 – Strongly agree, 4 – Somewhat agree, 3 – Neither agree nor disagree, 2 – Somewhat disagree, 1 – Strongly disagree)

<table>
<thead>
<tr>
<th></th>
<th>Mode</th>
<th>Median</th>
<th>Minimum</th>
<th>Percentile 25</th>
<th>Percentile 75</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
<th>Valid N</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outlook integration</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>To-dos list and post-its tool</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Ambient display</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>
Documents Used to Support the Task of Planning a Conference Dinner

Restaurant Options

Restaurant “Spice”

- Modern cuisine, 1 Michelin star
- Great view over Zurich - Rigiblick
- 200 m2
- Price estimation: 15,200 / 16,000 CHF

Restaurant “Quaglinos”

- French cuisine
- near Zurich lake
- 300 m2
- Price estimation: 13,100 / 13,900 CHF

Detailed Description for Restaurant “Spice”

Restaurant “Spice”

Features

- Address: Germaniastrasse 99, CH-8044
- Transportation: Funicular 23 from Seilbahn Rigiblick
Option 1

<table>
<thead>
<tr>
<th>Number</th>
<th>Price (CHF)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Menu</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>beef</td>
<td>80</td>
<td>140</td>
</tr>
<tr>
<td>vegi</td>
<td>20</td>
<td>120</td>
</tr>
<tr>
<td><strong>Wine</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>red</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>white</td>
<td>20</td>
<td>35</td>
</tr>
<tr>
<td><strong>Additional</strong></td>
<td>mineral</td>
<td>25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Option 2

<table>
<thead>
<tr>
<th>Number</th>
<th>Price (CHF)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Menu</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fish</td>
<td>80</td>
<td>130</td>
</tr>
<tr>
<td>vegi</td>
<td>20</td>
<td>120</td>
</tr>
<tr>
<td><strong>Wine</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>red</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>white</td>
<td>20</td>
<td>35</td>
</tr>
<tr>
<td><strong>Additional</strong></td>
<td>mineral</td>
<td>25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Detailed Description for Restaurant “Quaglino’s”

Restaurant “Quaglino’s”

Features

- Dufourstrasse 4, CH-8008
- Transportation: Tram 2, 4 to Opernhaus

Option 1

<table>
<thead>
<tr>
<th>Number</th>
<th>Price (CHF)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Menu</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>beef</td>
<td>80</td>
<td>120</td>
</tr>
<tr>
<td>vegi</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td><strong>Wine</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>red</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>white</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td><strong>Additional</strong></td>
<td>mineral</td>
<td>25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Option 2

<table>
<thead>
<tr>
<th></th>
<th>Number</th>
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<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Menu</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pork</td>
<td>80</td>
<td>110</td>
<td>8800</td>
</tr>
<tr>
<td>vegi</td>
<td>20</td>
<td>100</td>
<td>2000</td>
</tr>
<tr>
<td>Wine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>red</td>
<td>30</td>
<td>40</td>
<td>1200</td>
</tr>
<tr>
<td>white</td>
<td>20</td>
<td>30</td>
<td>600</td>
</tr>
<tr>
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<td>mineral</td>
<td>25</td>
<td>20</td>
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<tr>
<td>Total</td>
<td></td>
<td></td>
<td>13100</td>
</tr>
</tbody>
</table>

Task Description for the Participants

The two of us are in charge of organising the Conference Dinner for a conference organised by your department. I have already looked up possible options in terms of the location, the menu and the drinks and have already gathered relevant details, such as the budget, the number of participants and the number of special dietary requests. Your task is to compile the final proposal to be handed to the conference organisers. The proposal should contain the following details:
- The chosen restaurant and the proposed set-up for this location in terms of the number of tables and their placement.
- The menu option(s) and the wine and other drinks offered.
- Timing details.
- The proposed travel route for the participants, including timing and any eventual group meeting points.

We are now going to have a meeting where we will go over my findings together, discuss these findings and find an agreement about the content of our proposal. To compile the proposal, you will have access to all the documents that I have prepared and I will be using during our discussion, as well as to your own notes, if you decide to take any.

Questions Related to the Conference Dinner Planning Task

Please try to give as accurate as possible answers (as if you would be writing the report for the conference organisers). If something was not decided upon or you do not remember how to find certain details, simply state that.

1. What are your and your colleagues’s tasks?
   You:
   Your colleague:

2. What are the main elements that the report has to contain?
3. Which restaurant is the dinner going to take place at?

4. What are the specific and the exact address of the chosen restaurant?

5. What is the budget originally allocated for the conference dinner?

6. What are the menu details? Please fill in the dotted spaces.

<table>
<thead>
<tr>
<th></th>
<th>Number</th>
<th>Price (CHF)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Menu</strong></td>
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<td>...</td>
</tr>
<tr>
<td>vegi</td>
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<td>...</td>
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<td>...</td>
</tr>
<tr>
<td></td>
<td>white</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
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<td>mineral</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>...</td>
</tr>
</tbody>
</table>

7. Does your planning include any other elements, such as other drinks or food?

8. What time does the dinner start?

9. How can the participants reach the dinner location?

   Starting point (if any):
   Group meeting time (if any):
   Tram(s) to take:
   Tram station to exit:
   Will a map be provided on the conference website?

10. Draw a simple plan or explain how the tables are going to be arranged for the conference dinner.

**Additional Questions for the With the System Condition**

1. When I have a meeting to discuss some aspect and I have to make sure that I remember some of the details presented by colleagues by using digital documents, I . . . (please check all that applies)
( ) take paper notes
( ) take my laptop with me and write notes in a digital document
( ) ask for a copy of the digital documents presented
( ) rely on my memory
( ) other:

2. As compared to my usual way of working, using such a meeting support system was . . .

<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>more efficient</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>more time-effective</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>more motivating</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>more pleasant</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
</tbody>
</table>

3. When looking for specific information for my final report, using the review system was […] compared to consulting multiple paper and/or digital documents.

<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>easier</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>faster</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>more convenient</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>more pleasant</td>
<td>( )</td>
<td>( )</td>
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<td>( )</td>
</tr>
</tbody>
</table>

4. I would rate the overall experience . . .

<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>productive</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>easy to understand</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>easy to use</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>time-effective</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
</tbody>
</table>
5. On a scale from 1 to 5 with 5 being the highest, I would rate the user satisfaction ...

6. Do you have any additional comments or observations?

**Additional Questions for the Without the System Condition**

1. When I have a meeting to discuss some aspect and I have to make sure that I remember some of the details presented by colleagues by using digital documents, I ... *(please check all that applies)*

   ( ) take paper notes
   ( ) take my laptop with me and write notes in a digital document
   ( ) ask for a copy of the digital documents presented
   ( ) rely on my memory
   ( ) other:

2. I feel that my above mentioned way of working ...

<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>is efficient</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>makes it hard for me to be organised</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>is time-effective</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>is something that I’d like to have it improved</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>is comfortable</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>is optimal</td>
<td>( )</td>
<td>( )</td>
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<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>is a compromise</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
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<td>( )</td>
</tr>
</tbody>
</table>
3. Looking for specific information for my final report in a combination of multiple paper and/or digital documents was . . .

<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>efficient</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>fast</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
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</tr>
<tr>
<td>systematic</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
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</tr>
<tr>
<td>convenient</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>frustrating</td>
<td>( )</td>
<td>( )</td>
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<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>something that I’d like to have it improved</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>random, but somehow it works</td>
<td>( )</td>
<td>( )</td>
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<td>( )</td>
<td>( )</td>
</tr>
</tbody>
</table>

4. I would rate the overall experience in performing the given task . . .

<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>productive</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>time consuming</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>normal, but not optimal</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>efficient</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>satisfactory</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
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<td>( )</td>
</tr>
</tbody>
</table>

5. How do you think achieving the task could have been improved?

6. What circumstances affected your experience, if any?

7. Do you have any additional comments or observations?
## Descriptive Results

<table>
<thead>
<tr>
<th></th>
<th>Mode</th>
<th>Median</th>
<th>Minimum</th>
<th>Percentile 25</th>
<th>Percentile 75</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
<th>Valid N</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>With system condition</strong></td>
<td>154</td>
<td>154</td>
<td>76</td>
<td>103</td>
<td>160</td>
<td>210</td>
<td>142</td>
<td>39</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td><strong>Without system condition</strong></td>
<td>121</td>
<td>211</td>
<td>121</td>
<td>154</td>
<td>272</td>
<td>304</td>
<td>214</td>
<td>65</td>
<td>11</td>
<td>11</td>
</tr>
</tbody>
</table>

Table D.1: Time required for the post-meeting task

<table>
<thead>
<tr>
<th></th>
<th>Mode</th>
<th>Median</th>
<th>Minimum</th>
<th>Percentile 25</th>
<th>Percentile 75</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
<th>Valid N</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>With system condition</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td></td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td><strong>Without system condition</strong></td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>8</td>
<td>13</td>
<td>4</td>
<td>4</td>
<td></td>
<td>11</td>
<td>11</td>
</tr>
</tbody>
</table>

Table D.2: Quantification of participant difficulty
Bibliography


Curriculum Vitae

Particulars

Name Adriana Ispas
Date of Birth January 28, 1983
Birthplace Cluj–Napoca, Cluj, Romania
Citizenship Cluj–Napoca, Cluj, Romania

Education

2007–2011 Research and teaching assistant supervised by Prof. Dr. Moira C. Norrie in the Global Information Systems research group at the Swiss Federal Institute of Technology Zurich (ETH Zurich)
2006–2007 Master of Science in Computer Science, “Babeș–Bolyai” University, Cluj–Napoca, Romania
2001–2006 Diploma Engineer in Computer Science, Technical University of Cluj-Napoca, Romania
2001 Baccalaureate degree (A Levels), Cluj-Napoca, Romania
1997–2001 “Avram Iancu” High School, Computer Programming Class, Cluj-Napoca, Romania

Professional Experience

2006–2007 Academic guest in the Global Information Systems research group at the Swiss Federal Institute of Technology Zurich (ETH Zurich)