Collaborative Paper-based Annotation of Lecture Slides

Jürgen Steimle[1], Oliver Brdiczka[2] and Max Mühlhäuser[1]

[1]Department of Computer Science, Darmstadt University of Technology, Hochschulstr. 10, 64289 Darmstadt, Germany // steimle@tk.informatik.tu-darmstadt.de // max@tk.informatik.tu-darmstadt.de
[2]Palo Alto Research Center (PARC), Palo Alto, CA 94304, USA // oliver@parc.com

ABSTRACT

In a study of notetaking in university courses, we found that the large majority of students prefer paper to computer-based media like Tablet PCs for taking notes and making annotations. Based on this finding, we developed CoScribe, a concept and system which supports students in making collaborative handwritten annotations on printed lecture slides. It includes mechanisms for the paper-based sharing and semantic tagging of annotations and slides. Moreover, we present a novel visualization of shared handwritten annotations providing an integrated access to annotations from all learners. The results of a user study indicate that CoScribe efficiently supports student annotation and can be easily integrated into current annotation practice.

Keywords

Annotation, Digital paper, Digital pen, Anoto, Lecture, Computer-supported Collaborative Learning (CSCL)

Introduction

University lectures are often considered as suboptimal learning settings, as the communication is centered around the instructor and learners easily become rather passive listeners. Collaborative notetaking and annotation processes are important elements to overcome these problems and foster active learning (Prince, 2004): Taking personal notes stimulates students to actively follow the lecture, to consciously select important content, and to rephrase it in their own words. Moreover, notes have a reminding effect during review after class (Kiewra, 1989). The sharing of notes with other learners may support students to complete their notes, to critically examine their own understanding, and to co-construct a shared understanding with other learners.

Many electronic systems for student notetaking and sharing have been proposed, e.g. (Davis et al., 1999, Kam et al., 2005, Anderson et al., 2006, Berque, 2006). However, as we found out in a field study, most students do not use electronic tools for notetaking and annotation but prefer traditional pen and paper. Paper can be intuitively annotated, manipulated with both hands, is highly mobile and cheap. Moreover, paper documents can be laid out in physical space for comparing and organizing pages (Sellen and Harper, 2003). Empirical work further indicates that working with paper does not only imply a lower cognitive load than working with traditional computers, but it also has lower cognitive load than working with a digital stylus on a Tablet PC or a graphical tablet (Oviatt et al., 2006). Therefore, combining the advantages of paper with the benefits of digital documents (like electronic search and collaboration) presents novel opportunities for improving classroom annotation, review, and collaboration.

In this paper, we present CoScribe, a concept and system which enables students to collaboratively annotate lecture slides. During class, students use a digital Anoto (http://www.anoto.com) pen to make handwritten annotations on printed slides and empty pages as with a traditional pen. The interaction is therefore intuitive and lightweight. When reviewing the contents after class, a software viewer provides for access to both one's own annotations and to shared ones of other learners.

This article has three main contributions: 1) Based on two quantitative studies, we present new insights on how students use printed and digital media for taking notes and making annotations in lectures. 2) We discuss the design of paper-based user interfaces for the annotation of course handouts and present two mechanisms for the semantic tagging, indexing, and structuring of printed content. The paper-based user interface is complemented by a novel visualization of shared handwritten annotations for the efficient overview and access to annotations of other users. 3) The design has been validated in a user study, which indicates that CoScribe efficiently supports student annotation and can be easily integrated into current annotation practice.

The remainder of this article is structured as follows. After reviewing related work, we will discuss the field studies on lecture notetaking. Based on these results, we will present the design of CoScribe before we finally provide results of the user study.

Related Work

Much research has been conducted on systems enabling users to annotate documents on *pen-sensitive displays* imitating the use of pen and paper. XLibris (Schilit et al., 1998) is a digital reading device which enables the user to create handwritten annotations with a stylus. With NotePals (Davis et al., 1999) students can take notes on a PDA during a lecture. These notes are automatically associated with the appropriate slides. Own and shared notes can be retrieved later on in a software viewer. Dynomite (Wilcox et al., 1997) combines handwritten meeting notes, made on a pen-enabled display, with audio recordings. Its so-called properties, semantic types for classifying individual handwritten annotations, inspired our tagging function. Livenotes (Kam et al., 2005) focuses on the synchronous sharing of classroom annotations on lecture slides. Each user disposes of a Tablet PC. All annotations are shared in real-time with the other members of the learning group. Hence, lecture slides form a shared workspace for several learners. Classroom Presenter (Anderson et al., 2006) and Dyknow (Berque, 2006) use Tablet PCs for communication within the classroom. Students can annotate lecture slides and submit their handwritten solutions to given questions to the instructor.

All these systems have the disadvantage that the user is limited to interacting with one single pen-sensitive display, which does not provide all affordances of paper. For this reason, several systems use *real paper* as an input medium for digital notes and annotations. Augmented paper notebooks, such as the AudioNotebook (Stifelman et al., 2001), the A-Book (Mackay et al., 2002), ButterflyNet (Yeh et al., 2006), and LiveScribe (http://www.livescribe.com), enable users to make handwritten notes on empty paper sheets and to access a digital copy of them in a document viewer. Some of these systems moreover link handwritings to additional media, such as audio recordings (AudioNotebook, LiveScribe) or photos and physical specimen (ButterflyNet). However, it is not possible to annotate already existing documents. In contrast, PADD (Guimbretière, 2003) and PaperPoint (Signer and Norrie, 2007) enable users to print a physical version of an existing PDF or PowerPoint document. Handwritten annotations made on these printouts using a digital pen are automatically added to the digital version of the document. While PADD does provide support for collaborative settings, PaperPoint supports only co-located collaboration. PaperCP (Liao et al., 2007) (an extension to the Tablet PC-based Classroom Presenter) integrates paper input with synchronous collaboration: During class, students can submit annotations they made on printed slides to the teacher or to their classmates. But each slide is printed on an own paper sheet resulting in extensive printouts. AirTransNote (Miura et al., 2007) offers functionality similar to PaperCP, but only supports taking notes on an empty page instead of annotations. While borrowing the idea of paper input, we focus on asynchronous collaboration, the visualization of shared handwritings, and mechanisms for paper-based tagging.

The PaperPDA (Heiner et al., 1999), combining a conventional paper notebook and organizer with electronic capabilities, includes interaction techniques for manipulating and tagging content on paper. It introduces the general idea of buttons which are printed on paper and enables users to create links between paper pages with adhesive stickers. PapierCraft (Liao et al., 2008) presents a set of gesture commands, like copy/paste and linking, for manipulating paper documents. PaperCP (Liao et al., 2007) expands on that and discusses other techniques for tagging paper content. These have in common that they require an additional device, like a foot pedal or a second Anoto pen. In contrast, the techniques proposed in this paper do not require this.

Field Studies on Notetaking in University Courses

Before designing the system, we conducted two field studies to examine notetaking and annotation processes in university courses, since notetaking in general and the use of annotation software in learning settings are not well studied (Boch and Piolat, 2005).

The first study was a quantitative questionnaire-based investigation with 408 students in four computer science (316 participants) and one pedagogy lecture (92 participants). The goal of the study was to investigate 1) how many students take notes during lectures, 2) which media are used for this purpose and why these media are preferred, and

3) the effects of taking notes on collaboration with other students. In the statistical analysis, we investigated correlations and performed χ^2-tests and t-tests to identify significant group differences. All these tests were based on a level of significance of 95 %. The results were as follows:

Notetakers. The majority of the students indicated taking notes during the lecture. However, the proportion considerably varied between the disciplines. While 93.3 % of the pedagogy students took notes, only 62.3 % of the computer science students did. When asked for the reasons for not taking notes, the largest group of answers to an open question considers the course slides offered by the instructor to contain sufficient information (N=16). Eight respondents indicated that taking notes distracted them from listening.

Media use. We further asked the students on which media they take their notes. This aspect is of central importance for the design of notetaking systems, as it should be able to support the most frequently used media.

Figure 1 shows the percentage of notetakers on single media or on combinations of several media. Both in computer science and pedagogy, traditional notetaking with a pen and paper clearly outperforms notes on a laptop. In the computer science courses, 77 % of the respondents took their notes exclusively on paper. This group consists of three subgroups of roughly equal percentages which took notes either on empty sheets of paper, on printed course slides or on both of them. 8 % made an exclusive use of a laptop, while 15 % indicated to prefer cross-media notetaking, which combines notes on a laptop with notes on empty sheets of paper or on printed course slides. In the pedagogy course, laptop use was almost not existent. 98 % took their notes exclusively on paper. The two largest groups (about 45 % each) took notes either only on empty sheets of paper or combined them with printed slides or the printed course script. It is worth noting that the percentage of students taking notes on a laptop was small even though 78.6 % (N=180) of the notetakers possess a laptop. Only 19.6 % (N=35) of the students owning a laptop took notes on this device. The hardware equipment does therefore not seem to be relevant. Summing up, the large majority of the participants do only use paper for taking notes in lectures. The results further show that an annotation system should offer both the possibility to annotate printed handouts (e.g. slides of the lecture) and to take longer notes in free areas or on empty sheets of paper.
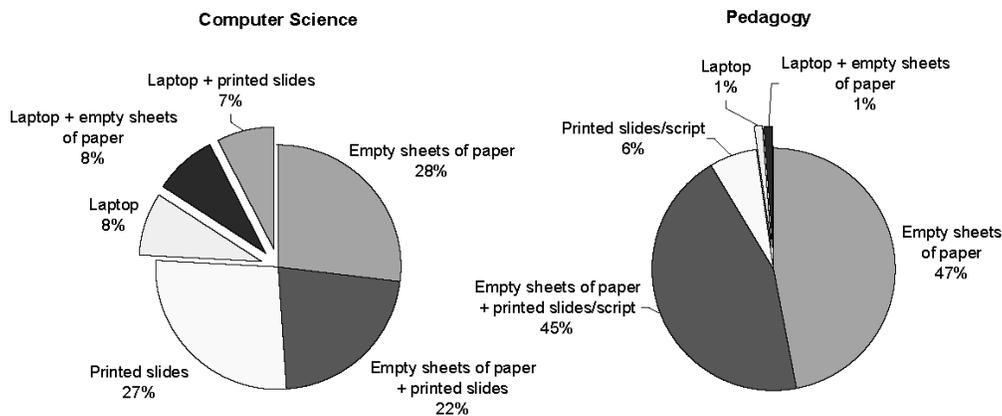

Figure 1. Media used for taking notes

Taking a closer look on laptop users, we asked them about the software they took their notes with. Responses fell under two categories of almost equal frequency: Software that allows to annotate the electronic course slides (e.g. Adobe Acrobat) (N=16) or word processors and text editors (N=17). Four students indicated to use both annotation software and a word processor, three students annotated on a tablet PC, and two students employed a specific software tool for creating mind maps. These data show that for laptop users, we can identify approximately the same distribution between annotating slides and taking notes on a blank document as for the paper notetakers. The main device for the input of electronic notes is the keyboard, since only few students own a Tablet PC (1.2 %).

Advantages of media. Besides assessing the distribution among different notetaking media, we aimed to gain information about the reasons for choosing those media as well as the advantages respondents associated with paper or electronic notes on a laptop. The results of the quantitative question are depicted in Fig. 2. They show that the

free-form flexibility was regarded as the most important advantage of notes on paper. This is followed by the fact that paper can be easily transported. As far as electronic notes are concerned, all proposed advantages were rated almost equally. Long-term archivability was rated significantly more important for laptop than for paper notes [T=-5.935, df=234, p=.000]. Similarly, good readability of typescript is rated significantly more important than good readability on paper [T=-5.907, df=230, p=.000].
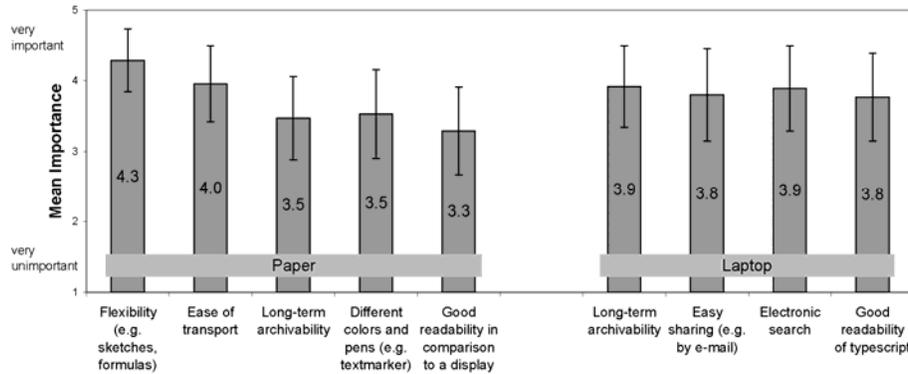

Figure 2. Advantages of notes on paper and on laptops

Notes vs. Annotations. The responses also indicated reasons for preferring annotations on course material or notes on blank sheets of paper. Annotations on printed course slides are regarded as advantageous, since these allow to establish a direct reference to the context by taking the notes on the place they refer to (N=27). 24 respondents particularly valued that they do not need to write everything down on the slide, but only add additional important information. On the other hand, blank sheets of paper are favored because they allow to create an own structure and to note own ideas more individually (N=12). Moreover, in contrast to course slides, they provide sufficient free space (N=5). Three students indicated to combine notes on paper and on printed course slides in order to separate their own ideas from additional information given by the instructor.

Subsequent use. Respondents who took notes were asked how frequently they review and complete their notes after class and when preparing for the exam. These results allow to estimate in which phases an electronic notetaking system would be used. Mean values are depicted in Fig. 3. (Results for exam preparation relate only to the computer science courses, since in the pedagogy course, no final exam took place.) The results show that, in contrast to the wrap-up phase after class, where frequencies are rather low, students become more active when preparing for the exam.
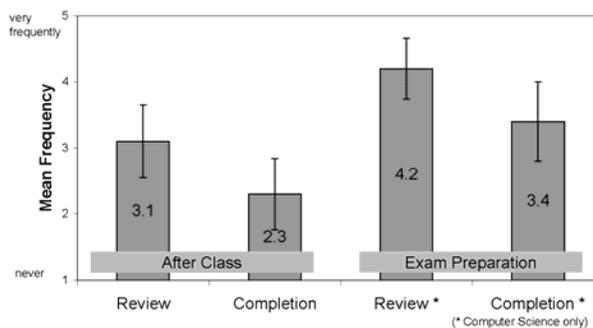

Figure 3. Subsequent use of notes

No significant differences were found between laptop and paper notetakers. However, taking a closer look on the group which took notes on paper, our data indicate that annotations relate to more frequent follow-up activities than notes on empty sheets of paper: In review after class as well as in review and completion before the final exam, mean frequencies of respondents annotating printed course slides or the course script were .4 to .6 points higher (p < .006) than of students taking notes on blank sheets.

Collaboration. We further asked the respondents to indicate their collaborative activities which make use of their notes. 54.4 % (N=135) of the respondents who took notes during class indicated to use them for collaborative work. The most important point (71.1 % of this group) consisted of using the notes as a basis for group work and discussion with other students. 51.1 % compared their notes for completion with those of others. 45.9 % gave their notes to other students or used those of others, e.g. in case of illness. Collaborative use of notes does not seem to relate to a specific medium on which respondents took their notes.

Quantity of annotations. In a second study, we analyzed annotations created by 24 postgraduate students during nine sessions of a university course. One group made handwritten annotations with pen and paper, another group typed annotations on a laptop using specific software for typewritten annotations on lecture slides. A main finding was that the use of a keyboard to type annotations seems to constrain the annotation process. Participants of the notebook group in average made considerably less annotations per participant and session (M=7.0, SD = 4.6) than those of the paper group (M=21.6, SD = 11.8). We infer that the user interface of an electronic annotation system should impose as little constraints as possible.

Semantic classification. Another outcome relevant to our system design was that many learners used semantic classification schemes to mark document passages or own annotations for later retrieval. These schemes comprise specific symbols, such as question marks, exclamation marks or asterisks. An important proportion of 11.0 % of the total of 1081 handwritten annotations acted as semantic markers containing nothing but one of these symbols.

We derive the following implications for the design of CoScribe: The system shall support users in taking handwritten notes on paper and in accessing them on a computer. This combines the flexibility and the mobility of paper with the capabilities of digital support. Accounting for the highly individual annotation style, the paper-based user interface should impose as little constraints as possible on the flexible interaction with paper documents. Further, the system shall support both notes on empty sheets and annotations on printed documents. Moreover, it shall provide a mechanism for semantically classifying contents. Finally, collaboration with other learners shall be fostered.

Overview of the Design of CoScribe

We will now provide an overview of the design of CoScribe, which will be discussed in more detail in the following sections.

CoScribe enables students to 1) create handwritten annotations on printed lecture slides, on empty sheets of paper and/or on a pen-sensitive display, 2) to semantically tag annotations, 3) to bookmark document pages, and 4) to collaborate with other learners by sharing own annotations and accessing shared ones in a digital viewer. This is illustrated in Fig. 4.
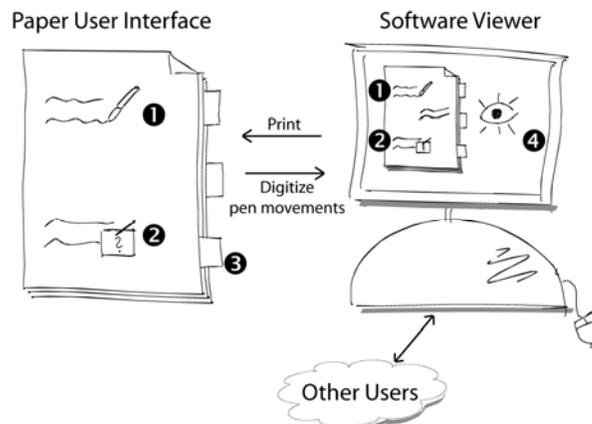

Figure 4. Overview of the design of CoScribe

Our design was guided by the goal of finding an appropriate trade-off between a paper-based user interface which is as unconstrained as possible, permitting each student to maintain his or her personal annotation style, and imposing only minimal structuring, which can be leveraged for computer interpretation of informal annotations. Moreover, we judge it important not to suddenly impose major changes to the personal annotation process, which often has evolved over years. Therefore, CoScribe provides for a smooth transition from traditional paper annotations to an electronic collaborative annotation process. Moreover, the system is easily deployable in real university settings.

The system comprises a *mobile part*, which can be used for in-classroom annotation and only requires paper printouts of the lecture slides and a digital pen, which can be used to write normally on paper (Fig. 5). The equipment is thus highly mobile, lightweight, and comparable to that used traditionally for notetaking in lectures, so that the technology remains in the background as much as possible.

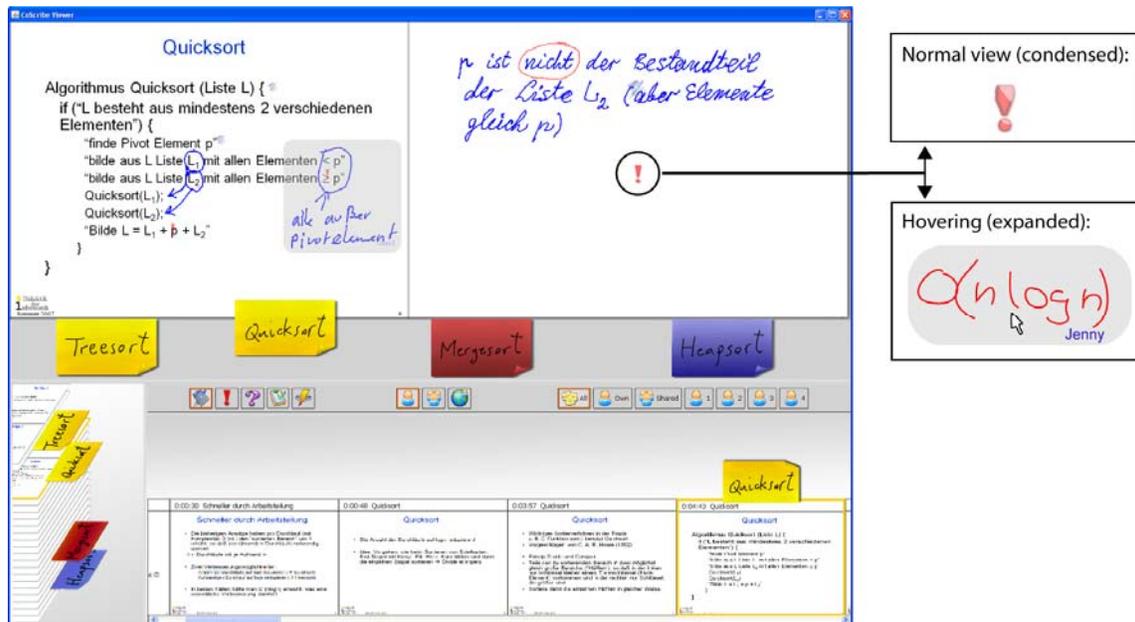*Figure 5.* Annotating printed lecture slides with CoScribe

Figure 6. The CoScribe software viewer and the visualization of shared annotations

After class, CoScribe offers a *combined printed and digital user interface*. Students can use a PC to synchronize their annotations with the backend system, which stores them in a database on a central server. The CoScribe software viewer (Fig. 6) then provides access to a digital version of the lecture slides including own annotations and shared ones of other learners. Moreover, the annotations made by the instructor during the course (on paper printouts or on a pen-enabled display) are digitally available. At any time, the user can add or modify annotations – either on the printout using the digital pen or in the viewer using a stylus on a pen-enabled display. A print module enables the

user to print updated versions of the lecture slides including his or her own annotations, the annotations of another learner or a selection of the most relevant annotations made by several learners. CoScribe is implemented in Java and supports PowerPoint lecture slides.

Mobile Paper-based User Interface

Digital Paper Technology

For the electronic synchronization of the user actions on paper, our system relies on the Anoto technology (http://www.anoto.com) and Logitech io2 digital pens (http://www.logitech.com). During writing, the digital pen identifies both the page and its position on this page by detecting a specific, nearly invisible dot pattern with a built-in camera. An ordinary laser printer can be used to print out documents including this pattern. If used during a lecture, the pen stores its movements as vector graphics, which are synchronized with the backend system once it is docked. Alternatively, when a computer is nearby, the pen streams data continuously to the computer via a Bluetooth connection. As a consequence, the digital view can be updated in real-time.

In contrast to other solutions for capturing handwriting on paper, no manual calibration of paper sheets and no sensing device other than the digital pen are necessary. This provides for real mobile use and for naturally writing and switching between multiple paper sheets like with a traditional pen and paper.

Flexible Annotation and Notetaking

The printouts were designed to constrain the personal annotation style as little as possible. Handwritten annotations, including free-form content such as drawings or formulae, can be made anywhere on printouts. In addition to the printed lecture slides, the pages can optionally contain free areas (see Fig. 7 for one example printout). Our observations have shown that free areas seemed necessary to most students, because firstly the slides often do not contain enough empty space for extensive annotations and secondly it is considered important to take notes independently of the instructor's structuring.
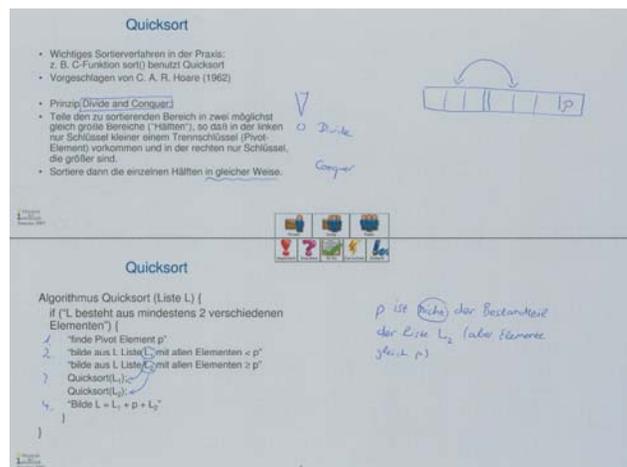

Figure 7. Example layout of a printed page

Various printout layouts of slides and free areas are possible, providing for an adaptation to the course and the user's preferences. One physical paper sheet can contain up to four slides with or without free areas. In addition users can dynamically add empty notetaking areas when more space is needed: Additional empty paper sheets can be written on and associated with the corresponding slide by drawing a link gesture. This is a line connecting a slide printout with an empty paper sheet and has been earlier suggested in (Liao et al., 2005). All annotations made on paper are automatically transferred and displayed in the CoScribe viewer (Fig. 6).

In a typical lecture setting, the slides are annotated by the instructor and projected onto the wall of the lecture hall. For this purpose, CoScribe includes an instructor interface. He or she can make handwritten annotations on a paper printout of the slides or on a pen-sensitive display in the software viewer. These are projected in real-time and moreover can be accessed by the students in the software viewer later on. In addition, the instructor can use digital pen and paper as a remote control for the projection. By tapping with the pen on a printed slide, this slide is automatically projected.

Paper-based Tagging using Tag Buttons

Tagging lecture content with semantic markers is closely related to annotating: It can support individual structuring of the content (e.g. marking the beginning of new sections) and classifying passages (e.g. as important or unclear). Our field study has shown that these tagging processes occur frequently. Moreover, in a collaborative system, tagging can be used to define if an annotation should be visible to other users or not. We therefore developed two paper-based tagging mechanisms that can be easily integrated into current annotation practice.

CoScribe provides for tagging annotations with explicit semantic categories, adding a more formal representation to the informal annotations. The interaction was inspired by buttons in Graphical User Interfaces. A toolbar containing several printed "buttons" is printed in the center region of each paper sheet (see Fig. 8 and 7). Tags are associated to an individual annotation by tapping with the pen on the corresponding button(s) before or after writing the annotation. Moreover, tags can be associated or modified later on by making two consecutive pen taps on the button and on the annotation. In the CoScribe viewer the tags are visualized with specific symbols and colors (Fig. 6).

Figure 8. Toolbar with printed tag buttons

Applying tags to entire annotations instead of unstructured sets of pen strokes requires clustering these pen strokes made by one user. For this reason, CoScribe uses a clustering algorithm for handwritten input that relies on temporal and spatial information. Possible errors can be manually corrected by the users. The software viewer therefore provides two functions for splitting annotations and merging pen strokes into one annotation.

Annotations can be tagged on the two levels of semantic types and visibilities. CoScribe offers four semantic types, derived from the needs identified in our field study (important, question, to do, and correction). In addition, learners can use tag buttons to define the visibility of the annotation. An annotation can be defined to be private, visible to the members of the user's learning group or visible to all students attending the lecture.

This slight formalization of informal handwritten annotations provides benefits both for search and retrieval of one's own annotations and for the orientation within shared annotations of other users. In addition, the semantic types act as instructional scaffolds stimulating students to perform meta-cognitive self-control processes (see for example (Scardamalia, 2001)), such as assessing where the important points of the topic are and where the student has gaps in his or her understanding and must perform further work.

This "tag button on paper" approach has several advantages over the classification means discussed in related research (Liao et al., 2007, Liao et al., 2008), which are spatial differentiation and pen gestures. Providing on the printout separate areas for each type and requiring the user to write a note in the corresponding area is impractical for annotations, which often have to be made at specific context positions on the slides. Another suggested solution consists in classifying notes by performing specific pen gestures. However, current Anoto pens cannot recognize gestures. Gesture recognition would have to be made by the backend system. Hence, it is not possible to provide feedback on success or failure of the gesture recognition in the mobile setting where pen data is not immediately transferred to the backend system. Moreover, the system would have to distinguish gestures from ordinary handwritings or drawings. For this purpose, the cited research papers suggested to use additional hardware like a foot

pedal or a second pen. In contrast, tagging with paper buttons does require only one single pen. A correct interpretation is guaranteed, as determining the pen position on a paper button does not imply uncertainty. The pen moreover provides graphical feedback to the user at the moment the button is tapped on. However, no graphical feedback on the tagging is provided on the printed slide unless the user makes additional markings. Yet, the tags are visible in re-printed versions of the slides and in the digital viewer.

Tagging with Digital Paper Bookmarks

While the "tag button on paper" approach provides for a fast classification of fine-grained objects with a set of pre-defined classes, the second approach allows to tag entire slides with freely chosen keywords. This approach is inspired from interaction with traditional paper and provides full feedback on paper. Adhesive page marker stickers are a well established practice for structuring documents, marking specific passages and accessing them later on. Impressive examples are books of law students, which often contain several dozens of bookmarks attached to the margins of the pages. As a metaphor, bookmarks also quickly became familiar in the electronic world for marking documents on the Web. Empirical work shows that their use positively influences the perceived ease of finding information (Thakor et al., 2004). Moreover, bookmarks provide a means to individually structure documents and to create structural knowledge (Jonassen et al., 1993).

We augment traditional practice by printing the Anoto pattern on adhesive stickers of different colors (Fig. 9). Stickers can be attached to physical pages of the printed document at arbitrary positions. A simple link gesture with the digital pen then informs the system about the position (1). Handwritten labels are electronically captured as well, providing for free tagging with user-defined tags (2).

Figure 9. Digital Paper Bookmarks

Once associated, the paper bookmarks are also visualized in the digital document, in the slide preview panel and in a separate bookmark panel (Fig. 6). This latter displays a three-dimensional representation of the paper stack and visually indicates the number of pages of the document, the current position within it and the bookmarks associated to it (see Fig. 6 lower left). We designed this view with the goal to support cross-media navigation in settings where the user works with both the printed and the digital version of a slide set. The view provides visual information helping to find the corresponding paper instance of the page currently displayed in the viewer. At a single glance, the user gets information about the approximate position of the page within the paper stack, about the nearest bookmark and the page distance to this bookmark. She can then find the paper page by recurring to its approximate position or by choosing an appropriate bookmark located near this page. Furthermore, the bookmark panel also supports orientation and navigation within the digital document. Pages can be displayed by clicking on the three-dimensional representation of the paper sheet or on a bookmark.

Visualization of Shared Annotations

A challenge with shared handwritten annotations is their clearly arranged visualization, particularly for a large number of users. We explore two approaches:

By separating the annotations of different users into different views, each of these views in itself becomes easier to read. CoScribe provides a *single-user view* for each member of the user's learning group. This view can be accessed by selecting the button in the toolbar which is associated with the view of a specific user. Yet, this implies the need to manually switch between views. This becomes particularly cumbersome in larger communities. Therefore, we developed a novel visualization of collaborative handwritten annotations.

The *multi-user view* displays both one's own and shared annotations in an integrated manner supporting overview and access to shared annotations without the need of explicitly switching. One's own annotations are visualized as they are written on paper. However, shared annotations of other users are displayed in a condensed form to account for the restricted space within the document. Instead of the shared annotation itself, a small icon is visualized at the position of the shared annotation (Fig. 6, upper right). This icon corresponds to the type of the annotation and varies in size according to the size of the annotation. When hovering the mouse over the icon, the annotation is expanded and displayed at the correct position in its original size (Fig. 6, lower right). Shared annotations considered especially relevant can be permanently expanded (Fig. 6, annotation with grey background). An additional preview function provides for an overview on all shared annotations on a page by expanding all of them in a scaled-down manner.

Evaluation

We conducted two user studies to evaluate the appropriateness of the system both for in-classroom annotation and for the collaborative review of annotations. Our goal was first to assess if the paper interface is easy to learn and to use. Second, we explored the use of Digital Paper Bookmarks. Third, we evaluated the multi-user view for shared annotations and compared it with the single-user view.

Method

First the in-classroom setting was evaluated with 29 computer science students who used the paper interface of the system during one of their normal lectures (each lasting about 90 min.). 24 of the participants were male, five were female. Their task was to make annotations on digital paper printouts during the lecture as they usually do; in addition, we asked them to semantically classify and/or to share annotations using the paper buttons when it seemed appropriate to them.
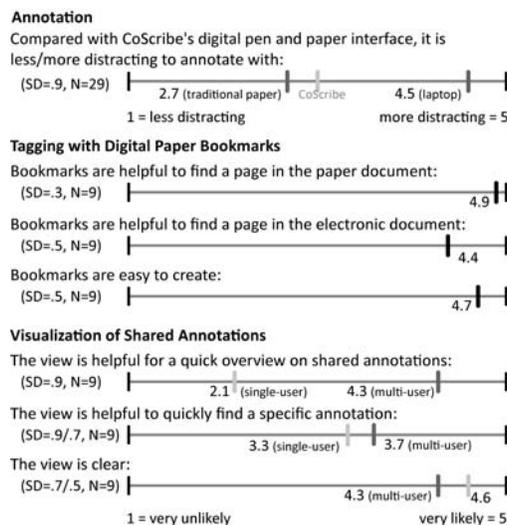

Figure 10. Main quantitative results of the evaluation. (All statements are transformed to their positive form.)

Second the review setting after class was evaluated in formal experimental sessions with nine participants (7 male, 2 female). Each session lasted about one hour. Participants had the task to create bookmarks and annotations on paper and to use the software viewer for browsing through shared annotations of other users, which were made during the

first study. In both studies, the participants were initially trained for about three minutes on how to use the pen and the printed interface. Feedback was gathered with Likert-scale questionnaires and semi-structured interviews. To avoid positive bias, none of the students was personally known to us nor did they attend one of our courses.

Results and Discussion

Main quantitative results of the evaluation are depicted in Fig. 10. In the answers to the questionnaire, annotating with the digital pen was considered only slightly more distracting than with a normal pen, but significantly less distracting than annotating with a laptop (T=-9.0, df=26, p<.001). Although the users have had only a few minutes for familiarizing with the system and used it during one of their normal lectures, they were able to make a considerable amount of annotations. In all three lectures, a total of 1983 handwritten annotations were made. This results in an average of 68 annotations (SD=29, N=29) per user during a lecture. The participants were active throughout the entire lecture, each user annotating on average 63 % of all lecture slides.

The participants had different preferences concerning the layout of printed slides. This underscores the importance of flexible layouts. Three out of four of the participants reported in the interviews to prefer only two slides per paper sheet, as this leaves free areas for annotations. The remaining participants preferred four or more slides per page. All left-handers wished having free annotation areas to the left of the printed slides, while right-handers preferred them to the right. Positioning the free areas below instead of besides the slides was judged less appropriate, since the items on the slides are typically organized in vertical order.

The participants valued the possibility to classify annotations with semantics directly on paper. They were up to accept the additional effort of tapping on the appropriate tag buttons during the annotation process. This is reflected by a substantial percentage of 18.7 % of all 1983 annotations that was tagged with a semantic type. These findings and qualitative feedback from the interviews lend support to the assumption that paper-based classification imposes little overhead. The two most frequently chosen types were 'important' (12.5 %) and 'question' (3.2 %). Although tagging with visibilities was performed only for a small percentage of annotations (2.4% private and 1.6% public; the default was group visibility), the interviews indicate that this functionality is important. Several participants expressed the wish to define individual types like 'to revise', 'definition' or 'example'.

The bookmark-related quantitative responses show that users judged bookmarks being helpful for finding specific pages both in their paper version and in the software viewer. Several participants particularly valued the possibility to fade away from the given structure and instead to create an individual structure of the document.

In the questionnaires, the participants expressed a clear preference for the multi-user view over several single-user views when seeking a quick overview of all comments. This result is highly significant (T=-6.64, df=10, p<.001). They also judged this view slightly better for quickly finding specific shared comments. The multi-user view remained clearly arranged with four learning group users in the evaluation setting. We assume this view to scale to a larger user community within university lectures as well, since, according to our first experiences, the total number of users does hardly affect the number of shared annotations a specific user can retrieve. This relates to the fact that by default, annotations are shared at the intermediate learning group level and that only a very small fraction of annotations is published to the entire community.

Conclusions

Based on the findings of two preliminary field studies, we have developed CoScribe, a concept and system for the collaborative annotation of lecture slides on digital paper. CoScribe significantly reduces the gap between the use of paper, which is frequent in university lectures, and electronic annotation systems. The results of a user evaluation indicate that the combination of paper with computing is very promising for supporting student annotation and collaboration.

Although the system was designed with a special focus on university lectures and evaluated in lectures where the students were physically present, we envision it to be helpful in other settings as well, encompassing distance learning and the collaborative creation and editing of presentation slides. CoScribe provides strong support for

autonomous and group-based learning. More enhanced forms of tagging and linking of documents are under development and will be integrated in a future version of CoScribe

Now that digital paper can be used as an input medium for collaboratively creating user generated content in large communities, we envisage studying how principles of the Web 2.0 can be applied to paper-based computing in order to foster learning processes. For example, by performing automatic analyses and statistical aggregations on paper-based contents, particularly relevant annotations of other users could be highlighted. Digital Paper Bookmarks could be a basis for combining electronic social bookmarking with physical documents. This could lead us a further step towards bridging the paper world with state-of-the-art collaborative technologies.

Acknowledgments

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