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A Study of Digital Ink in Lecture Presentation

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ABSTRACT
There is growing interest in integrating digital ink with lecture slide display systems. We have developed and deployed one such system, where the instructor uses a Tablet PC to write on computer-projected slides. In this paper, we report on our study of classroom use of ink in the system. Through a detailed analysis of lecture archives, we identify key use patterns. In particular, we categorize a major use of ink as analogous to physical gestures; we explore the relationship between the ephemeral meaning of many ink annotations and their persistent representation; and we observe that instructors make conservative use of our system's features. Finally, we discuss implications of our study to the design of future pen based presentation systems and related applications.

Categories and Subject Descriptors
H5.0 [Information Interfaces and Presentation]: General

General Terms
Human factors

Keywords
Classroom presentation, digital ink

INTRODUCTION
Digital inking systems — *i.e.*, computer applications that accept pen based written input — offer the promise of infinite malleability and detailed archiving of ink. Ink can change colors; it can be moved and resized; it can be transformed into typeset text. Inking systems can record time, pressure, context and other information for every stroke drawn. To effectively explore this vast space of possibilities, it is critical to understand how digital ink is actually used in practical contexts.

One promising context for digital ink is the university classroom. A current technological change in the university classroom is the increasing use of digital projection of slides. Although this is controversial [6], there are a set of advantages including the ability to structure material in advance, prepare high quality examples and illustrations, and easily share and reuse material [2]. However, many instructors feel these come at a price in the lack of flexibility to adjust the lecture based on audience reaction and to work through examples in real-time. A natural response is to integrate digital ink with the slides, giving instructors the flexibility to adjust prepared material. Advances in digitizing and digital ink technologies have facilitated efforts to do this. We developed one such system, Classroom Presenter which allows the instructor to write on slides with Tablet PC digital ink and project the results to the class.

In this paper we present results on how instructors used digital ink in our system and discuss ramifications for future systems. We identify three themes of interest: the substantial amount of ink used in a manner analogous to physical gestures, the tension between the ephemeral meaning of ink and its persistent representation on the display, and parsimonious use of system features by instructors. A natural application of our observations is to improve systems for digital inking in presentations and related applications.

In the next sections we give a survey of related work and then describe our system, Classroom Presenter, and our deployment of the system. We then describe in more detail the specific courses that we used as the basis for this study. and give some general results to establish usage patterns. Next, we analyze usage in the context of the three main themes described above. Finally, we conclude with the implications of these themes for future systems.

RELATED WORK
We believe that analysis of our system will inform design of related systems. There is a long history of research on related systems supporting computer-augmentation of shared viewing spaces for collaboration and presentation [8,11,14,15,16]. Some recent commercial systems [12,13] integrate projected materials and inking on a modified whiteboard. Other commercial systems support presentation of training material or classes for remote audiences [5,17]. Several classroom systems integrate presentation materials with instructor inking. Lecturer's Assistant is one early system that integrated slides with student and instructor writing [4]. Many similar systems exist for tablets, PDAs, and whiteboards [7,10]. Applications such as PowerPoint and

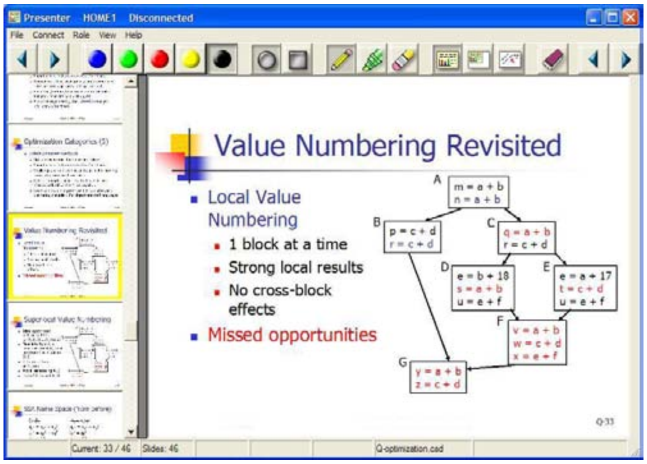

Figure 1 Presenter's instructor interface with pen controls (top), slide navigation (left), and current slide (right).

Figure 2 Detail of controls: Color change (5), Pen tip (2), Pen Mode (Pen, Highlight, Erase), Whiteboard (3), Page Erase.

Journal can be also used to project and annotate material from the Tablet PC. One other notable system for writing on slides is ZenPad [3], the presentation component of the eClass system (formerly Classroom 2000) [1]. The eClass system captures audio, video, and ink streams and integrates them for replay as our system does.

Our system differs from those above in several ways (*e.g.*, in enabling technology, deployment requirements, and architecture). However, the critical point for this paper is that all of these systems integrate digital ink into classroom presentations; we believe that a deep analysis of inking in our system can inform the designs of such similar systems and others in the future.

SYSTEM DESCRIPTION

Classroom Presenter (henceforth, just Presenter), is the slide based presentation system that we developed. The instructor runs Presenter on a Tablet PC which communicates with a second machine driving the data projector. Figure 1. shows the instructor interface. The instructor has controls for manipulating both the slides and the ink. The display shown by the data projector would include only the slide image and the ink. The instructor's ink is displayed in real time on the projected display.

Figure 2 shows the button controls for manipulating ink. The buttons are in five groups. Group one controls pen color, offering five colors. Group two controls the pen tip: round or square. Group three controls the pen mode: regular ink, highlighter (transparent ink with a large pen tip), and erase mode. Erasures are stroke-based. So, an entire ink stroke — *i.e.*, the ink created by one continuous contact between pen and screen — is erased when touched by the pen-controlled cursor in erase mode. Group four controls annotation space. The middle button navigates to an auxiliary white board, and the right one introduces extra annotation space on the slide. The left button returns to the normal slide display. The final button is page erase, which erases all the ink on the slide.

PRESENTER DEPLOYMENT

Between Spring 2002 and Summer 2003, Presenter was used in 21 different computer science courses, taught by 15 different instructors. Over 1,000 students at three different universities have been in classes where the system has been used. The deployments covered a broad range including classes from a dozen students to hundreds, introductory and Master's level courses, instructors who walked with the Tablet PC, and others who lectured from a fixed podium.

We studied system use by observing classes, capturing sessions with a logging tool, and conducting surveys of students and instructors. In addition, we received detailed usage notes from some of the instructors. Overall, instructors and students were enthusiastic about the system's ability to improve the classroom environment. In a survey[1] of 479 students from these courses, 55% of the respondents said it increased their attention to lecture, compared to 10% who said it decreased their attention. 69% of students said they would encourage other instructors who currently use PowerPoint slides on the computer to use Presenter, while 8% would discourage Presenter. Most instructors that we surveyed also believed that Presenter improved their students' learning experience while none believed it detracted.

STUDY COURSES

For this study, we focused our attention on three courses offered in the evening Master's program in our department[2]. These courses were video conferenced between two sites, and archives of the audio, video, and inking were created. This provided a rich source of data: we were able watch the use of Presenter with the corresponding audio and video and analyze logs of Presenter commands and ink strokes.

We recognize that the focus on just three courses at one institution limits the scope of our results. However, this focus on a small number of courses also enabled us to gain a deep understanding of the style and context of each course; furthermore, the results we report here coincide in tone with our less extensive observations of many other Presenter deployments.

Table 1 summarizes the archived course data used for this study. (Henceforth, we refer to the courses and instructors by the labels displayed in Table 1.) Full audio and video archives were available for all three courses. Ink capture and replay was under development during Prof. A's course;

[1] Survey results from classes taught by Presenter researchers (including their students) are excluded from all survey results given in this paper.

[2] None of the study instructors were involved in Presenter research or in the HCI or education research areas.

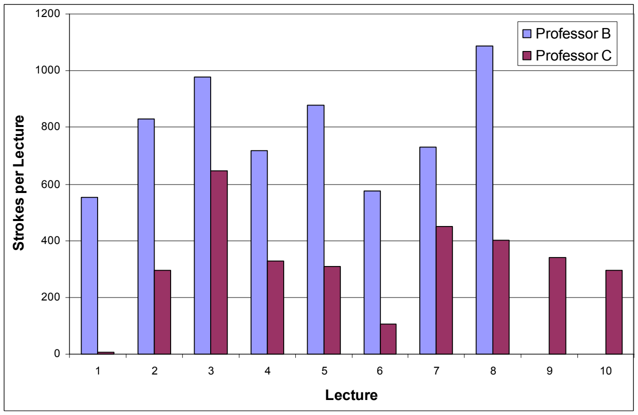

Figure 3 Number of strokes per lecture. Lectures 9 and 10 by Prof. B were excluded since they were student presentations.

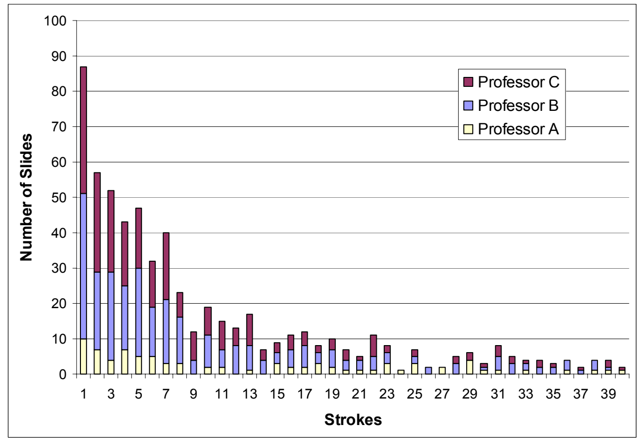

Figure 4 Distribution of strokes; each bar shows the number of slides across all lectures in each class with that number of strokes.

so, we have logs for only four of the lectures late in the term from that course, and even these logs are limited. We excluded the final two lectures of Prof. B's course from the study because they were student presentations. Prof. A's course met twice weekly for one and a half hours a session. The other two courses met once weekly for three hours.

Table 1 Recorded lecture material for study.

	Lectures	Time	Full logs	Topic
Prof A.	4	6 hrs	No	Compilers
Prof B.	8	20 hrs*	Yes	AI
Prof C.	10	23 hrs*	Yes	Databases

*Some class sessions ran short for Profs. B and C.

The instructors lectured from a podium and used Presenter to display PowerPoint slides. These slides, accompanied by audio and video signals, were synchronously broadcast to a remote site. All three instructors had taught similar courses in the past using lecture slides (but not Presenter). The lecture slides were "content heavy", and were primarily from slide decks that had been designed for projection without inking.

All three instructors used ink extensively throughout their courses. Figure 3 shows the per lecture ink usage by Profs. B and C. We were unable to extract data for Prof. A, but our observations established that he used ink at least as extensively as the other instructors. Another measure of ink usage is the percent of slides containing ink marks: 39%, 64%, and 66% for Profs. A, B, and C respectively. Figure 4 shows a Zipf-like distribution of the number of slides with differing numbers of ink strokes.

STUDY RESULTS

In this section, we discuss three themes that arose in our analysis: uses of ink, which we call *attentional markings*, that seem analogous to physical gestures; the tension between ephemeral meaning of ink and its persistent representation; and instructors' parsimonious use of system features.

Attentional Markings

Attentional markings are ink annotations which provide linkage between spoken context and the shared display. These markings serve a variety of purposes including resolving deictic references (as with physical pointing gestures), grouping related slide elements, and emphasizing important points. Although attentional markings often took the form of arrows, circles, or underlines, they also included boxes, overbars, ticks, check marks, tracings, brackets, and dots. Figure 5 shows several examples of attentional markings. Figure 6 shows a particularly effective attentional mark which simultaneously drew attention to a topic, linked items, and stressed the importance of the items.

Instructors generally used attentional markings in the same situations that they would otherwise use physical gestures. McNeill [9] identifies the following linkages between hand gestures and language: gestures occur only during speech; gestures and speech are semantically and pragmatically co-expressive; and gestures and speech are synchronous. We found that attentional markings share these same linkages with speech, supporting a view that attentional markings are analogous to physical gestures.

McNeill further classifies physical gestures into iconics, metaphorics, beats, cohesives and deictics. Iconics and metaphorics are gestures with associated meaning. Iconics are direct representations while metaphorics are abstract. Beats track the progress of the narrative. Cohesives link temporally separated portions of the discourse, and deictics are pointing gestures which provide reference.

This classification covers a broad collection of the attentional markings we observed, and all five types are represented. The exclamation mark in Figure 6 is primarily iconic since it has a commonly understood symbolic meaning independent of its context. The circles in Figure 7 are metaphoric since they are abstract representations whose meaning was constructed in context. Figure 13 below shows cohesives and deictics. The bracket connecting two bullets is a cohesive, indicating the connection between these

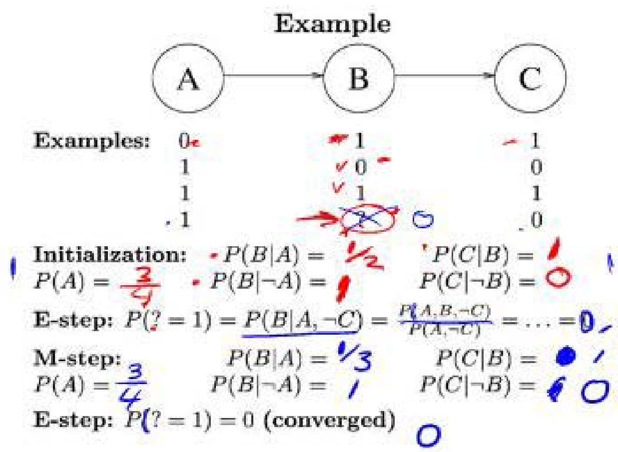

Figure 5 A slide from Prof B's course heavily annotated with attentional markings including circles, underlines, checks, ticks, and tracing of slide contents. For example, the two check marks and an arrow near the middle of the slide are attentional markings.

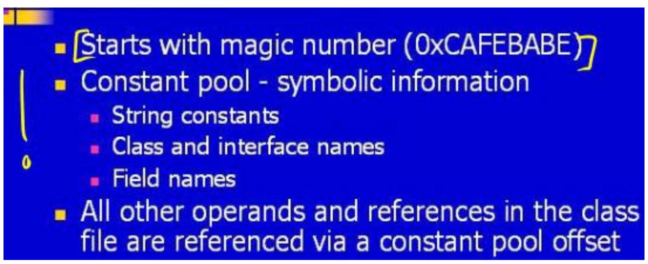

Figure 6 A slide from Prof. A's course with attentional markings.

points. The check mark on the final bullet was used as deictic to clarify which bullet the instructor was referring to during discussion. Beats are difficult to identify although markings that seem to be idle doodling or retracing of existing ink may function as beat gestures. In practice, some strokes, like the exclamation mark in Figure 6, function in more than one category. The close fit with McNeill's classification is further evidence that attentional markings are analogous to physical gestures.

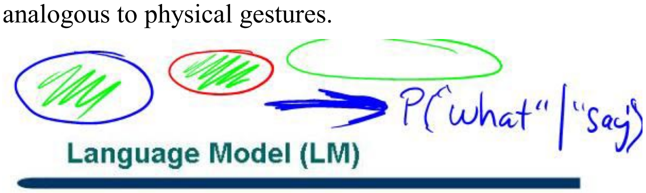

Figure 7 Circles drawn by Prof. B. The circles are in three different colors to illustrate different concepts.

Both instructors and students saw attentional markings as critical elements of Presenter. Nine out of ten instructors we surveyed (including Profs. A, B, and C) indicated that they frequently drew attention to points on slides with ink. 414 out of 479 students across the classes surveyed felt that these attention-directing marks contributed to their learning.

To measure the extent of attentional marking, we coded all uses of ink in two of the recorded lectures we have been studying, one from Prof. B and one from Prof. C. (Prof. A's lecture was not used because of problems with the logs.) The two lectures, Prof. B's sixth and Prof. C's eighth, were selected arbitrarily but seem representative in terms of quantity of strokes as can be seen in Figure 3.

To code the lectures, two researchers independently broke the inking into coherent episodes — *i.e.*, atomic meaningful groupings of ink strokes — and classified each episode in one of four categories: attentional marking, textual writing, diagramming, and other unusual markings. Where the researchers' segmentation of ink strokes into episodes differed, they agreed on a consensus segmentation and reclassified resulting episodes. (These resegmentations usually involved trivial splitting or merging of episodes which did not affect codes.) The researchers then resolved differences in classification by agreeing on a consensus code for each episode. The two researchers' initial coding agreed on 91% of episodes (92% for B and 91% for C). The resulting data are shown in Table 2. Coding was per episode, but we maintained stroke counts for each episode since writing episodes usually include many more strokes than attentional marking episodes. For example, the writing episode in Figure 8 accounts for seven strokes compared to one or two for most attentional episodes.

Table 2 Segmented episodes and ink strokes in each coded category for Prof. B's lecture, Prof. C's, and the two combined.

	% of episodes			% of strokes		
	B	C	B+C	B	C	B+C
Attentional	77	74	76	49	53	51
Diagram	8	8	8	9	7	8
Writing	14	16	15	41	38	40
Other	2	2	2	1	2	1

The coding confirmed that attentional markings occurred in significant number. We expect similar numbers would hold for the other lectures given by Profs B and C. Prof. A would likely have higher percentages associated with diagrams and writing, although he also made substantial use of attentional markings.

Figure 8 A single word from Prof. C's course with 7 strokes.

Ephemerality and Persistence

The prevalence of attentional markings highlights the tension between the *persistent* representation of ink on the display and its often *ephemeral* meaning. Ink is represented persistently in the sense that it remains visible until explicitly erased or hidden by a slide transition. In contrast, spoken words and physical gestures have no persistent, external representation. They must be perceived when they occur, or they are lost. (Even in an archive, a spoken word or physi-

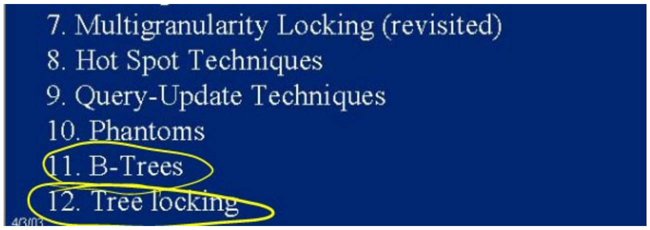

Figure 9 A slide from Prof. C's course with attentional markings used to point out content that will be ignored.

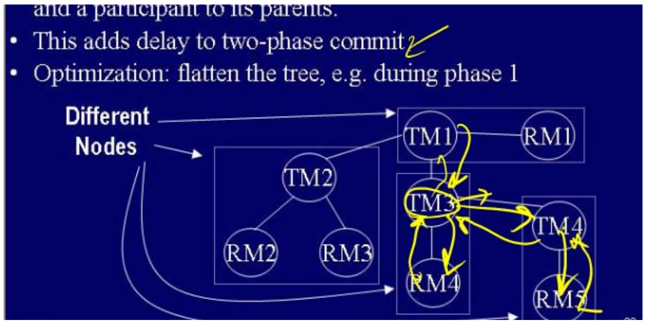

Figure 10 A slide from Prof. C's course with ink showing how communication among nodes "adds delay to two-phase commit."

cal gesture is only available during its moment of the replay.)

Because ink is represented persistently, it outlasts its spoken context. Yet, much of this preserved ink (including most attentional marks) is difficult to comprehend *without* its context. In this sense, ink's meaning is ephemeral. Figures 9 and 10 illustrate this point. In Figure 9, the instructor circled two points in a numbered list, apparently distinguishing these from the others. A natural assumption is that these points are particularly important. However, Prof. C's spoken commentary identifies these as points that he will *not* discuss. Figure 10 shows a complex diagram traced atop existing slide content. Most of the information provided by the ink comes from the order and relative timing that nodes were traced and arrows drawn, but the static image does not show this information.

Persistence of attentional markings

For attentional markings in particular, we can examine the length of time that meaning persists in light of McNeill's framework for physical gestures [9] described above. Iconic marks are likely to last the longest of these markings since they have inherent meaning. The meaning of a metaphoric gesture is less likely to outlive the spoken context which grounds its abstract representation. Cohesives may provide lasting evidence of connections (although Figure 13 has both positive and negative examples of this, described below). Beats' and deictics' meaning will persist only briefly, since their primary function involves fleeting spoken utterances.

Patterns of use that preserve ephemeral information

Several other uses of our system highlight its ability to render ephemeral information more persistent. The second

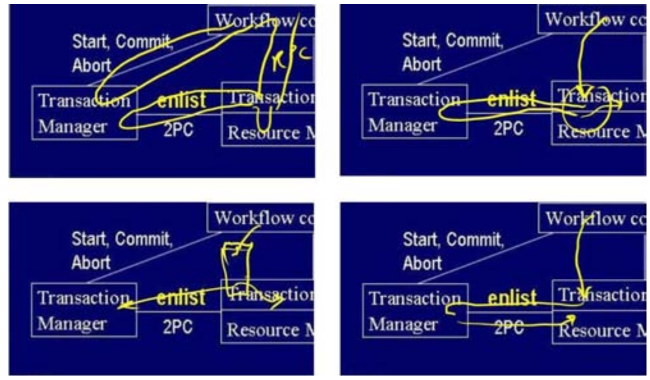

Figure 11 A slide from Prof C's lecture that he erased multiple times to show several different examples.

most common use of the system was writing text to annotate diagrams or add information to a slide. Writing the phrase `P("what"|"say")` in Figure 7 makes the information clear to students and allows the instructor to draw on well-understood symbolic notations, such as mathematical symbols, that are more easily grasped when read than when only heard. Figure 5's numerical values are examples where the *location* of written text provides added value. This location information would be only fleeting if the instructor pointed rather than writing the information down. Written labels on diagrams functioned similarly. While text annotations often rendered spoken information more persistent, it was still difficult to ascertain the full meaning of the text without spoken context.

Instructors made creative use of Presenter to render ephemeral information about diagrams and processes more persistent. Prof. C often drew multiple examples on the same slide. Rather than relying on students' attention to the spoken discussion and the appearance of new ink to discriminate between examples, Prof. C made extensive use of page erase to separate new examples. Figure 11 shows a few of the examples drawn on one slide where the instructor used page erase a total of six times. Of course, the same erasures also limited the lifetime of the diagrams. Other instructors used color to distinguish between ideas or phases in a process. Figure 7 shows how Prof. B used colors to distinguish concepts in a diagram.

Presenter's real-time rendering also helps convey certain ephemeral information. For example, the loop in the top left diagram in Figure 11 was drawn from the "Workflow" box at the top of the slide, down to the "Transaction Manager" box at the left, and then back to the top. While the instructor could have added directional arrows to make the information more persistent, as he did in other diagrams, he chose instead to rely on real-time rendering to express the progression of this process. While this ephemeral information is *not* captured in the static ink, the fact that the stroke was rendered in progressive stages did convey this information as it was presented. Several instructors commented that real-time rendering was important to them.

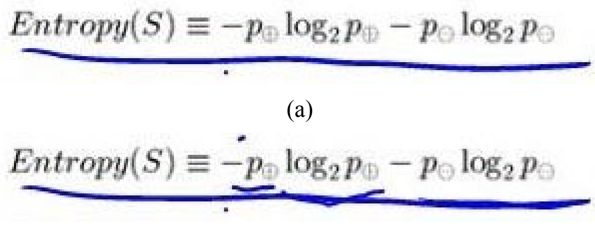

Figure 12 Two snapshots of a slide from Prof. B's course with ink annotations breaking down a formula of interest. Note the underline under the rightmost "$p_o log_2 p_o$" term in (b).

Breakdowns in persistent representation

We observed several common and instructive breakdowns in the expression of ephemeral information as persistent ink. These breakdowns occurred because our rendering made strokes difficult to distinguish from each other and lacked a persistent representation of strokes' age and order.

Along with many digital ink applications, Presenter renders ink in a single color which is constant across the area of the stroke and as the stroke is rendered over time. This style of rendering makes it difficult to distinguish newly drawn ink from existing, overlapping ink. Figure 12 shows an example of this. In Figure 12 (a), Prof. B draws attention to a formula on the slide with an underline. Then, he discusses individual parts of the formula. Figure 12 (b) shows the formula with three new underlines under these parts. Unfortunately, the new marks are difficult to distinguish from the underlining of the entire formula. The rightmost, under the final term, is particularly indistinct.

This is not strictly a case of ephemeral information left uncaptured in the static ink representation. Indeed, even as the instructor drew the final underline in Figure 12 (b), it was largely invisible on the public display. (The instructor, on the other hand, can track new ink by the location of her physical pen.) However, even if, *e.g.*, an animated pen drew the ink on the public display, the *static* slide image would still lack this ephemeral information and therefore give no persistent indication of stroke boundaries.

Figure 12 (b) also lacks information about the order that strokes were drawn. There is no way to tell from the static image whether the instructor began with the parts, underlining them, and then moved on to discuss the whole formula or in which order he discussed the parts. Figure 10 above illustrates a similar problem.

Instructors used temporal grouping of attentional markings to create cohesives between conceptually related slide elements. Figure 13 shows a typical example. The instructor began the discussion by saying "there are separate instructions for creating new classes and new arrays." As he said this he checked the first two bullets, indicating that they were conceptually linked. He then talked about the third bullet and checked it. He then indicated that the fourth and fifth bullets were conceptually linked with a bracket mark.

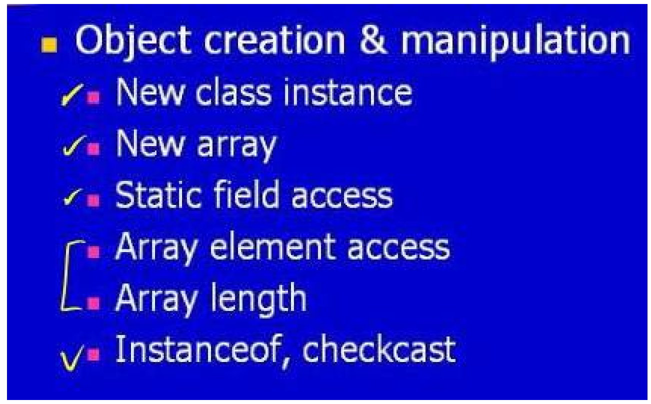

Figure 13 A slide from Prof A's course with multiple attentional markings. The top two check marks were temporally grouped.

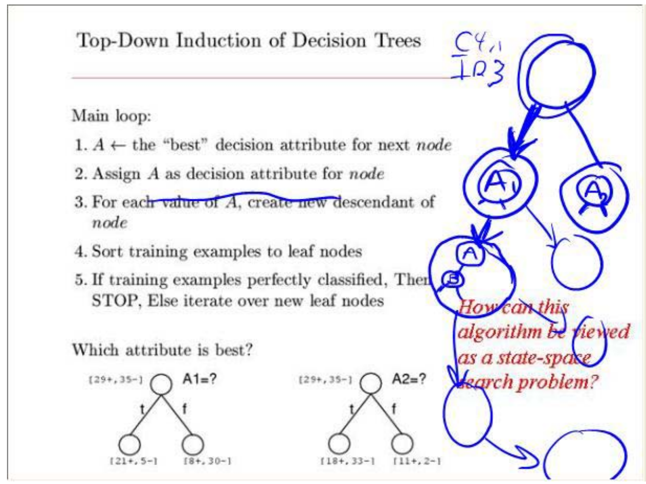

Figure 14 A slide from Prof B's course illustrating many breakdowns in persistent representation of ephemeral information.

Prof. A used two cohesive gestures in this example, one spatial (the bracket) and one temporal (the checks on the first two bullets). Both ephemerally linked the topics, but only the spatial marking retains this information in its persistent representation.

Figure 14 shows one slide in Prof. B's course which illustrates all of the breakdowns described above: overlapping strokes, ordered strokes, and temporally grouped strokes. The heavy arrows along the left of the diagram were retraced to illustrate successive passes through the diagram, but because of homogenous ink, it is difficult to tell how many times each arrow was traced. The four unlabeled nodes toward the bottom of the diagram were drawn in a surprising order, but this is impossible to discern from the static image. (The leftmost unlabeled node was drawn first, followed by the other three in order from bottom to top. Prof. B used this ordering to explain a relevant process.) Finally, the underline on the left of the slide was temporally grouped with the left edge extending from the "A_2" node, but this connection is absent in the persistent image. Although single slides with all of these breakdowns were rare, the individual breakdowns were common across the courses we observed.

Parsimonious use of System Features

Instructors were strikingly restrained in their usage of Presenter's features. Table 3 below gives some basic information for instructors' use of features. The information for Profs. B and C are from the logged data, and Prof. A is from observation of the lectures recorded with ink.

Table 3 Usage of Presenter features.

Course letter (hours of lecture)	A (6)	B (20)	C (23)
Slides	220	618	399
Slides with ink	39%	64%	66%
Highlighter use	0	0	0
Color change	71	124	24
Page erase	0	42	435
Stroke erase	8	4	5

We had anticipated that the instructors would use the highlighter to draw attention to slide content. We were interested to observe that this feature received no use. (Instead, instructors replaced highlighting with attentional markings such as underlining or circling.) We believe that the low use was due to the extra effort highlighting required: switching to highlighter mode, often changing colors, and then returning to the original mode when done.

Color use

Use of color varied among instructors. Profs. A and B made moderate use, changing pen colors on average 11.8 and 6.2 times per hour of lecture, respectively. Prof. C changed pen color on average only once per hour of lecture. Most instructors we surveyed (including Prof. A) reported that they used multiple pen colors frequently or occasionally and viewed the feature as fairly important or most important. Profs. B and C rated color change as not very important and least important, respectively.

Ensuring color contrast accounted for most color changes: either contrasting with existing ink or with the slide background. Profs. A and B both used multiple contrasting ink colors to visually distinguish distinct concepts. Figure 7 shows an example where Prof. B changed color to distinguish different concepts in a diagram. All three instructors also changed colors to ensure that ink contrasted with the slide background.

We believe that this pattern of color changes supports the notion that instructors made parsimonious use of the UI. The critical point is that instructors did *not* follow what might seem a more natural pattern: choosing a preferred color for common use and consistently returning to that color after changes. Instead, when an instructor changed color to contrast with existing ink, she would then almost always continue to use that color even when the current example was finished. Following this pattern requires one fewer UI actions than returning to a preferred color.

Erase patterns

Another surprise for us was the way that instructors erased the ink on slides. Two approaches for erasing were available: erasing a stroke at a time by using the pen in erase mode, or erasing all of the ink on a slide by using the page erase button. Instructors rarely used the stroke eraser. The most frequent user was Prof. A, averaging just over one erase episode per hour of lecture. The other instructors used the stroke eraser less than once per hour of lecture. Interestingly, there were several occasions where Prof. A just crossed out mistakes instead of erasing them.

Page erases were more frequent. Both Profs. B and C used page erase far more often than stroke erase. Prof. C was observed using page erase on average more than once per slide, and there were slides that he erased up to 10 times. His predominant use of page erase was to clear the ink context (as described above), although there were cases where he used page erase to clear mistakes. In several cases Prof. C used page erase to clear a diagram after making a mistake and then reconstructed the diagram from scratch. Insight into Prof. C's use of page erase comes from examining the cases where the stroke eraser was used instead. In these cases, the erase activity was very intentional. One observed case was when a moderate sized diagram had to be corrected, and redrawing it would have been a challenge. Another was when Prof. C used marks in a diagram to indicate a resource was being reserved, and then used the eraser to show that the resource had been released. Perhaps the most interesting example occurred when Prof. C wrote a word as a correction which later turned out to be incorrect itself. In this case, Prof. C used the stroke eraser to give extra emphasis to the word's erasure.

The use of page erase is consistent with the hypothesis that instructors use Presenter in a manner to minimize operations. In this case, the page erase is a single click operation while stroke erase requires a click to activate the eraser and a click to return to the pen, in addition to the actual erase operations. In most cases, the ease of using page erase makes up for its lack of precision.

IMPLICATIONS OF THE STUDY

The observations we describe in the previous section lead naturally to design directions for future digital ink presentation systems and related applications. We focus in our design discussions on the themes of attentional marking and ephemerality vs. persistence. However, system designers should bear in mind the lesson of parsimony: busy and focused instructors may well respond to new features, new buttons, or new mode changes by ignoring them. The best designs may be those that work smoothly without effort or thought on the part of the instructor.

The clearest design lesson that emerges from our work is that plain ink archived without the context of the audio channel loses much of its value. We had envisioned early on that ink archives from presentations would add significant value to the bare slides. However, the prevalence of ephemeral attentional markings, unlabelled diagrams, and fragmentary text makes the spoken context critical for understanding these annotations. This is an affirmation of eClass's holistic approach to capture [1].

Conversely, our observations suggest that designers of digital ink presentation systems should try to understand which ephemeral information is important to their systems and consider how to capture that ephemeral information in a persistent ink representation. Successfully capturing this ephemeral information will ease the task of understanding presentations, extending the window of opportunity for participants to perceive, connect, and construct meaning from the many available streams of information. Furthermore, simple, static archives of ink will be more valuable resources if they encode this critical ephemeral information.

Instructors' practice of reifying gestures into ink-based attentional markings is one method we have already described for extending the window of opportunity for understanding ephemeral information. These attentional markings help participants who might have missed a physical gesture. Some types also persist effectively throughout discussion on a slide.

Digital ink has the potential to encode much more than the simple location of ink strokes. Future designers can make ink representations that respond to any of the breakdowns we discussed above. Ink strokes might indicate the direction they were drawn or their boundaries with other strokes through non-homogenous coloring across their area. Ink strokes that change color with time (like physical ink drying) could encode the age and temporal grouping of strokes. Ink might brighten conspicuously when first drawn to more clearly convey the current focus of attention.

CONCLUSIONS

In this paper, we analyzed a set of rich data on use of digital ink in presentations. We identified three major themes in the data: (1) establishing that a substantial amount of digital ink in these presentations acted analogously to physical gestures, (2) exploring the tension between the ephemeral meaning of many ink annotations and their persistent representation as it plays out with our ink rendering, and (3) observing that instructors tend to make parsimonious use of Presenter's features. We also extrapolated from these observations to design recommendations for future digital ink presentation systems. We believe that these results and recommendations establish fertile ground for more ambitious digital ink rendering and control in presentation systems and broader future studies of the themes we identified.

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