Where the Wild Things Work: Capturing Shared Physical Design Workspaces

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ABSTRACT

We have built and tested WorkspaceNavigator, which supports knowledge capture and reuse for teams engaged in unstructured, dispersed, and prolonged collaborative design activity in a dedicated physical workspace. It provides a coherent unified interface for post-facto retrieval of multiple streams of data from the work environment, including overview snapshots of the workspace, screenshots of in-space computers, whiteboard images, and digital photos of physical objects. This paper describes the design of WorkspaceNavigator and identifies key considerations for knowledge capture tools for design workspaces, which differ from those of more structured meeting or classroom environments. Iterative field tests in workspace environments for student teams in two graduate Mechanical Engineering design courses helped to identify features that augment the work of both course participants and design researchers.

Categories and Subject Descriptors

H.5.3 [**Information Interfaces and Presentation**]: Group and Organization Interfaces—evaluation and methodology

General Terms

Design, Documentation, Experimentation, Management, Measurement, Performance

Keywords

Collaborative Design, Knowledge Capture/Reuse, Memory Augmentation, Physical Environments, Workspaces

1. INTRODUCTION

What kind of environment best supports design? The answers to this question are as varied and vast as the objects and ideas that are created by designers. For all this diversity, however, design workspaces—from the dining room table where the family assembles jig-saw puzzles to the staging area in an automotive design studio—share many features and needs. The environment, as the locus for activity, must be easily accessible to all participants, must support communication among design team members, and must have affordances for physical tools and artifacts. While the physical aspects of these shared workspaces are generally persistent, the activity and ideas generated in these environments are often ephemeral. There is broad agreement that effective capture and reuse of generated information can improve team collaboration, reduce the effort expended, and improve the design product, process and documentation [27]. However, prior work in this area, such as that of Baya [3] and Tang [26], primarily examined the capture and reuse of data for design teams working on design exercises that were specially formulated for the sake of experimentation or of limited duration. This paper investigates the larger issues and design requirements associated with using such tools "in the wild."

Our project, WorkspaceNavigator, explores how knowledge capture and access tools can enhance work in real-world physical design environments. WorkspaceNavigator was designed to enhance a class of collaborative environments, where:

- design activity takes place in a dedicated physical setting.
- products evolve over the course of multiple iterative design cycles.
- collaboration occurs in both structured and unstructured meetings.
- designers use a variety of informal visual and physical artifacts, such as sketches, tools and prototypes.

The information captured in the design environment is intended to serve two constituencies: the team using the physical design workspace, and those in an oversight role, such as instructors, clients, managers, and design researchers.

The WorkspaceNavigator system was initially developed for use in an interactive room [12], and was subsequently field-tested in the work environments of fourteen student design teams in two year-long graduate mechanical engineering courses. Its usage was assessed through various means throughout the course of its design and deployment.

These WorkspaceNavigator deployments illustrate how knowledge capture and access tools can help design teams document their process, improve flow of information from iteration to iteration of the design process, combat loss of critical knowledge artifacts and improve group interaction. These deployments also suggest ways to ease the difficulty of

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getting design teams to adopt these new tools so that they might enjoy such benefits in the long-term. Finally, our test deployments empirically indicate that such knowledge capture tools can help design teams to retrieve critical documents and data artifacts generated in their shared physical design workspaces even with a fairly low data-capture rate.

2. DESIGN WORKSPACE NEEDS

One of the key challenges in any extended design task is the *recall* of the information produced and used during the design process. Although the problem of recall is common across many computer-supported cooperative domains outside of physical design workspaces, the challenges of knowledge capture and reuse in such an area are unique.

2.1 Problem Domain Analysis

Beyond the obvious challenges of the extended duration of observation and the increased quantity of information gathered, there are challenges that result from the nature of the communication that takes place in the design workspace. One key aspect of design processes is that they are *loosely structured*, taking place in a dispersed fashion over a lengthy period of time. Unlike typical classroom activities, such as those augmented in Classroom2000 [2] or NotePals [8], in design it is difficult to anticipate what information will be necessary or useful later. In addition, the work sessions in a physical design space are often *fluid,* impromptu and ad-hoc. The irregular episodic nature of this work that hinders recall also differentiates it from the type of applications addressed by meeting capture tools such as Tivoli [19], NoteLook [5], and TeamSpace [22]. Finally, design processes are *multi-threaded,* dispersed across people with different tools at different times, making it difficult for any single person to assemble a coherent narrative of the process as they might in personal memory augmentation applications, such as Forget-me-not [14], the Rememberance Agent [23], and MemoryGlasses [8]. These inherent characteristics of shared design processes not only drive the need for knowledge capture and reuse tools, but also make the creation of new kinds of such tools necessary.

To illustrate the difference between the sort of information that is generated in a design work session, and that presented in a class presentation or in a meeting, Figure 1 shows "sketches" of a concept created in a design meeting and later presented in-class. Whereas Figure 1(b) is detailed and explicit, the sketch in Figure 1(a) is spontaneous and loose. It is a lot more difficult for a viewer to parse the key points presented in the original sketch, and hence far more context and commentary is necessary to make it useful. Such considerations drove the specific knowledge capture and recall needs encapsulated in Workspace Navigator.

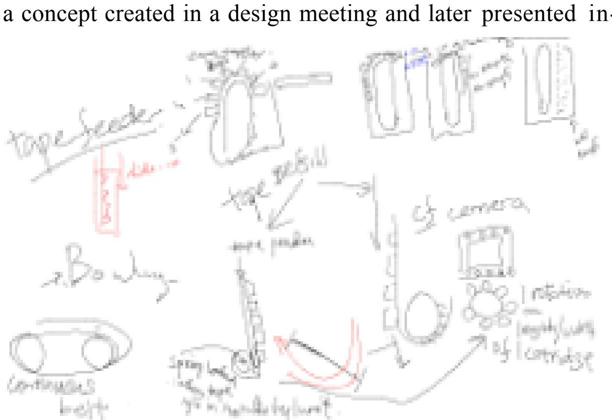
2.2 Knowledge Capture Needs

Two major concerns drive the knowledge capture requirements of design workspaces. First, the data captured must be *rich,* rich enough to be worthwhile for future use. Second, the data capture must be incredibly easy; otherwise, there is a risk that design team members will not bother to capture information. These issues drive the following needs.

Multiple inputs: The activity in a physical design workspace commonly takes place across a number of different media. In order to get a high-level view of the design, it is necessary to integrate all these views of the design activity. The workspaces we studied contained whiteboards, workbenches for assembling physical devices, dedicated computers, laptops brought in by the students, and additional devices such as digital cameras.

Implicit and explicit capture: Since users may not know what information will be valuable later, and because design work is so often impromptu and ad-hoc, it is important that knowledge capture and reuse systems for physical design spaces act without requiring explicit instruction. WorkspaceNavigator is designed around the idea of implicit instruction—it responds to an inferred need for information capture. In contrast to previous systems [22] that require users to explicitly start and stop capture, WorkspaceNavigator monitors the environment for motion, delineating periods of activity. Users are able to place annotations on already captured information they know they want to refer to later, but no information is lost if they do not annotate. The use of implicit and explicit capture bears similarity to the use of "invisibility with override" by Cooperstock's Reactive Room [6].

System integration: Not only must the initiation of design activity capture require little effort, so must the task of integrating the multiple inputs and performing implicit actions be simple, inspectable, and robust. Previous research into meeting capture systems that make use of multiple tools,



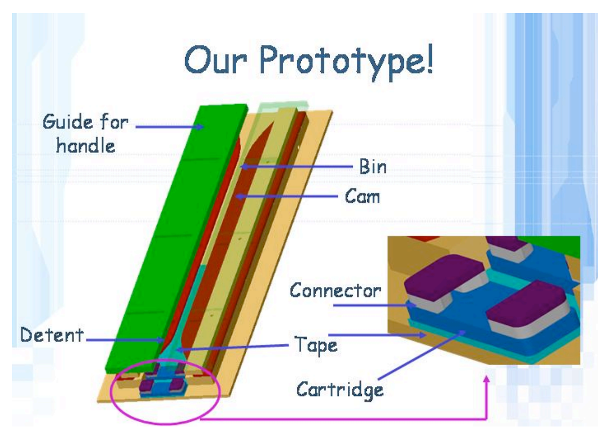


Figure 1. Sketches generated by a design team
(a) for the purposes of collaboration, *left,* and (b) for purposes of presentation, *right*.

such as the Coral system [17], have drawn attention to the need to a good system infrastructure. By using the EventHeap, a flexible middleware technology for physical spaces [11], WorkspaceNavigator is able to integrate numerous data capture devices in the timeline, to address the heterogeneity of the physical design process.

2.3 Knowledge Recall Needs

The primary difficulty of knowledge capture for physical design workspaces is one of a surplus rather than a paucity of data. The difficulty of extending traditional meeting capture systems into physical design workspaces is one of scale. Reviewing weeks or months of continuous video or audio data is simply impractical—the task of recalling data must be significantly easier than either recreating or proceeding without it.

Discrete level of detail: To help users focus only on relevant data, one key system goal was to control the level of detail. WorkspaceNavigator's capture and access model is based on discrete event-based data rather than media streams. This reduction of temporal resolution makes the challenge of capturing and reviewing months-long activity more tractable, and made the system implementation more practical as well. Work conducted by Czerwinski [7] comparing the use of video and still images from work sessions suggests that this use of still images should adequately jog user memories at substantially lower technological and cognitive cost.

Contextual organization: Another important aspect of data reduction is organization. WorkspaceNavigator's browsers make use of a timeline and overview snapshots of the physical space to help put collected data into context. This synthesis of multiple data streams into a unified interface is similar to that of the Coral project [17], in which continuous multimedia streams from different sources in a meeting were unified using user-defined and automatically created indices. Using Coral, Moran [18] showed how users come to rely on the linkage of audio with pen strokes when creating meeting summaries. However, whereas Coral project focused on synthesizing continuous data streams in limited duration meetings, our system synthesizes discrete data objects in order to scale the data capture as previously mentioned.

Visual organization: The strength of human spatial memory has also been harnessed by a number of researchers in designing related interfaces [10], [24]. Renaud [21] found that visual and pictorial representations are far superior to verbal descriptions when trying to resume work after an interruption. By linking captured information, such as computer files or whiteboard sketches, with their visual representations, we help to improve the ability of design team members to recollect the meaning of the data artifacts. WorkspaceNavigator's browser interface also provides for textual annotation of snapshots and supports search over those annotations.

Multiple views: WorkspaceNavigator also incorporates different views into the captured information to allow adaptation of the data for different kinds of uses. The type and level of detail needed by team members to track their own design process is different from the needs of managers, instructors or design researchers engaged in overseeing the design process. As such, our current implementation of WorkspaceNavigator provides several different views into the captured data (see Figure 2).

3. WORKSPACE NAVIGATOR

WorkspaceNavigator has to main components the knowledge capture system and the knowledge access interfaces.

3.1 Knowledge Capture System

To provide a rich data stream of information artifacts, WorkspaceNavigator uses a variety of implicit and explicit networked capture tools. One of our goals was to affect the existing design work environment as little as possible. In order to achieve this we created a flexible system architecture that allows different tools to be added to suit the specific needs of different work environments. We also worked to minimize the amount of change each capture tool imposed upon the space.

3.1.1 *Implicit Capture*

To relieve users of the burden of mindfully capturing design events, implicit data capture is initiated by a central server, rather than by the users. Every thirty seconds, a centrally deployed synchronization event is sent by the EventHeap [11] via TCP/IP to trigger each of the active implicit capture tools to contribute to that *timeslice*. The following data are used:

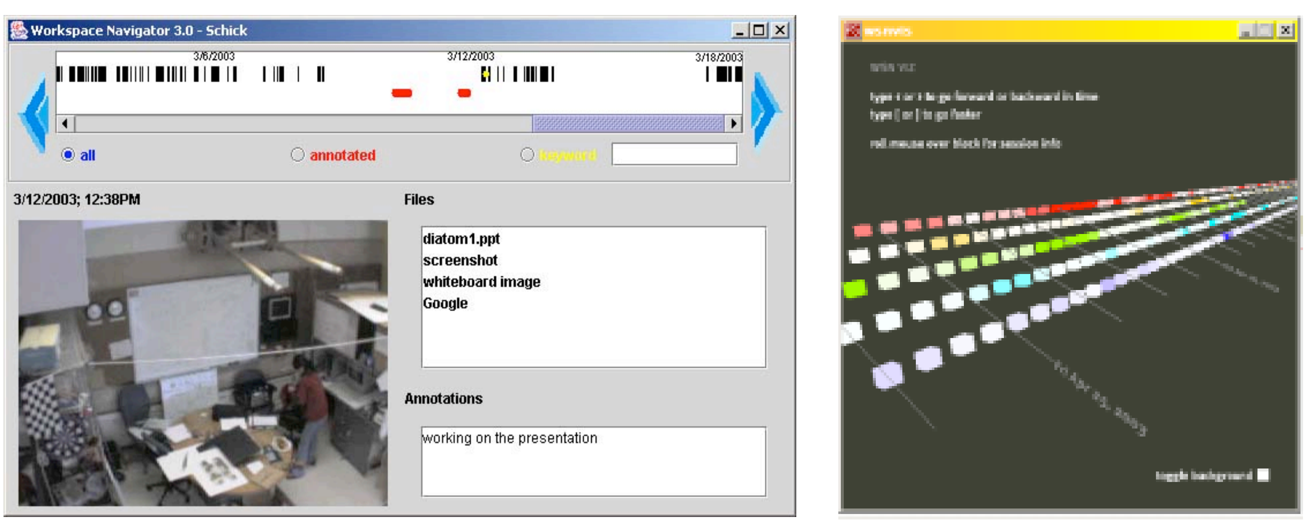


Figure 2. (a) Interfaces of WSN Browser, *left* and (b) WSN Viz, *right.*

Overview Imaging: A networked camera mounted above the space takes overview images. These images are later used in the WSN Browser to index the other stored information. All of the instrumented workspaces used this capture tool.

Motion Detection: Successive images from the networked camera are analyzed to detect motion in the workspace. These motion events are used by WSN Browser to filter potentially relevant timeslices and by WSN Viz to determine periods of workspace activity.

Computer Capture: Each instrumented computer in the space provides a screenshot and an inventory of all open URLs and Microsoft Office application files (Word, Excel and PowerPoint) at each timeslice. URLs are stored by reference.

Whiteboard Capture: Ultrasonic pens and white-board mounted transducers allow WorkspaceNavigator to capture the whiteboards, which are the primary medium for group ideation and brainstorming in many design environments. This augmentation of existing tools and practices shows similarities to Designer's Outpost [13], where website designers' use of "stickies" on whiteboards was captured to help build a digital record of the design process. Here, we retrofitted existing workspace whiteboards using commercially available hardware (http://www.e-beam.com). Flat-panel monitors mounted next to each whiteboard provide feedback on what strokes are captured, and an adjoining PC sends captured board-shots to the EventHeap server. One such setup is shown in Figure 3.

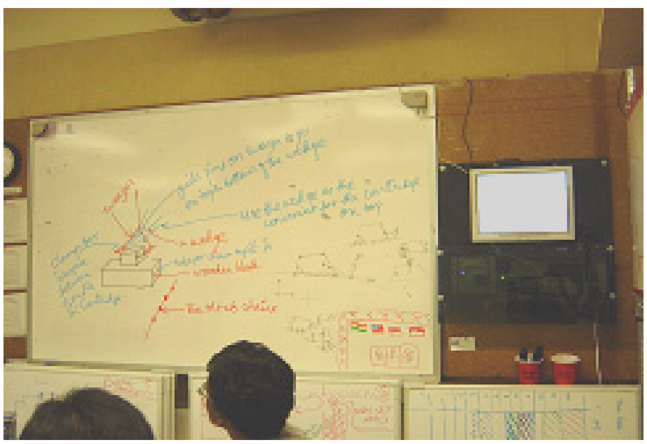


Figure 3. WorkspaceNavigator whiteboard capture setup

3.1.2 Explicit Capture

Whiteboard snaps: We put a button on the whiteboard that allows users to explicitly store the current image into the WorkspaceNavigator database at any time. In addition, we took advantage of natural usage without regard for capture and provided a button to print the current image. Although printing is not an explicit capture action for the users, it serves the purpose of identifying salient images and we store all printed images in the database.

Digital Pictures: Users can integrate digital camera images into the data stream by uploading the images to a designated computer. Uploads are monitored and copies of the images are submitted to the central database, with timeline integration taking place using the timestamp in the JPEG image's EXIF header.

Annotations: We provide three tools for users to make annotations. Users can make annotations in real-time during a session by using wireless buttons that send a marker via the EventHeap. They can also provide text annotations during the session using a stand-alone application or during subsequent review using the WSN Browser.

3.2 Knowledge Access Interfaces

There are three ways to access the data captured by the WorkspaceNavigator. We designed and built two browsers, the *WSN Browser*, created primarily for design team members, and *WSN Viz,* for observers and researchers of the design process. Both browsers allow users to visually track activity in the physical workspace, but at different levels of detail. The third method for accessing captured data involves using Internet Explorer to browse the raw data stored on the webDAV server.

WSN Browser presents captured project data for a single team. It provides a unified interface for accessing all of the captured information from a physical design workspace, as shown in Figure 2a.

The focal elements of the interface are a timeline and an overview wide-angle image of the workspace. The timeline contains two rows, one representing implicitly captured discrete data acquired at regular intervals, and the other representing explicitly uploaded digital images. Users can navigate through the captured timeslices either by directly clicking on the timeline, or by using the arrows to step forward and backward. The text area at the bottom right displays annotations and various files associated with the displayed timeslice. A timeline has been used by many researchers to present data. One example is Rekimoto's TimeMachine Computing [20]: confined to a computer desktop only, it allows users to step backwards and forwards to previous desktop states.

Clicking on the image of a captured device (such as a whiteboard or computer display) in the overview image opens a condensed screenshot of its contents. Along with the condensed screenshot is a list of files and URLs displayed on that device when the shot was taken. Clicking on any element in this list allows the item to be reopened and displayed.

WSN Viz provides a graphical visualization of activity n several team spaces simultaneously, as shown in Figure 1b. Each row represents a different physical space, each block represents a time period, and the brightness of each block represents how much activity was occurring at a given point. Course milestone markers provide the researchers with landmarks as they look at patterns of activity in the space. This view presents high-level information about workspace activity and patterns to facilitate cross-team comparisons.

Internet Explorer was often used by teams to access raw data stored in the webDAV folders. Users browsed through folders and long textual file lists to find various images that had been stored. We did not anticipate this method of accessing the data, but in retrospect we have come to realize that folder and file lists are familiar, and Internet Explorer is a standard piece of software available on any computer one uses.

4. EVALUATION

We conducted both controlled studies and an extended field test of WorkspaceNavigator. The findings from these studies are discussed in the next section.

4.1 Pilot studies

4.1.1 Entrepreneurial Meeting

The main purpose of this first pilot study was to validate the timeslice-based capture model. The subjects were members of a business school research group who used WorkspaceNavigator in an interactive meeting room to capture a three-day meeting studying the entrepreneurial process. We provided this group with computer capture on their laptops and the large shared displays. We also provided button and text annotation tools.

This pilot was evaluated through observation and interviews. This study validated the use of 30-second time intervals, and encouraged further development of the system. More detailed observations from this study will be presented in subsequent sections of this paper.

4.1.2 Trip Planning

Our second pilot study focused on the usability of the WSN Browser, particularly its use of spatial cues to organize information. In this study two teams of three recruited subjects worked on a multi-session design activity in three sessions over an eight day period. The teams were given the task of planning a trip to Bangkok with different constraints in each session. The constraints were designed so that users would find it useful to recall and reuse previously located material.

These sessions were evaluated through observation and interviews. This study validated the visual method of finding information using the WSN Browser. More detailed observations from this study will be presented in subsequent sections of this paper.

4.2 Field tests

To test our system in actual design environments, we deployed WorkspaceNavigator in a variety of pre-existing design workspaces associated with two courses in the Mechanical Engineering department. Both courses involved team-based design projects and had large laboratory spaces with specific areas designated for each team's use. The study and data collection took place over nine months

One class was a three-quarter graduate sequence where student design teams of four or five students worked on industry-sponsored projects to produce a final product prototype. We instrumented four project team spaces, as well as a shared class space. All five spaces in the design project course were augmented with overview image capture, motion detection, whiteboard capture, and explicit digital picture capture; one team also had a personal computer which ran the computer capture tool.

The second class was a three-quarter graduate sequence on mechatronics. Ten teams were instrumented during the course of two final projects in the winter and spring quarters of this course. These classes involved greater use of computer workstations, so every workspace was outfitted with the computer capture tool, overview image capture, and motion detection. The shared space was instrumented with whiteboard and overview image capture.

Teams were able to access their collected data both through the WSN Browser and through a direct web-based interface into the data repository. Both interfaces were password protected so that only team members and design researchers had access to collected data. Data about the usage of the system were collected through server logs, student and instructor interviews, questionnaires, as well as analysis of student documentation. This data was collected both to evaluate WorkspaceNavigator as a tool for the design teams, and as a dataset for researchers studying the behavior and practices of the design teams. Information about team usage of WorkspaceNavigator tools was not shared with and did not influence the academic evaluation of team performance.

5. FINDINGS

The Workspace Navigator system evolved considerably during its extended deployment. Our experiments and field test refined our understanding of what makes knowledge capture and reuse tools effective, both for the design teams themselves and for those observing them. In this section, we discuss our experiences and how they inform the design of knowledge capture and reuse systems in general.

5.1 Lessons about knowledge capture

Knowledge capture tools need to accommodate both active and passive users. One of the benefits of designing WorkspaceNavigator with both explicit and implicit capture mechanisms is that it addressed this diversity of behaviors. The extremes of the spectrum between low and high adoption of WorkspaceNavigator were embodied in two of the teams in the team-based design class, which we will call Team A and Team Z.

From the outset, the members of Team A were our most enthusiastic users. They eagerly used and experimented with the system and suggested many improvements. "I totally like the idea…that it can be accessed anywhere," stated one Team A member in an interview about WorkspaceNavigator, "Even before using this system, whatever points I would write on paper, I used to email myself or put online so that… I can just access it at any time."

Although Team A's eager adoption of WorkspaceNavigator, was heartening, it also suggests a pre-existing inclination towards documentation that would have found other tools to use if WorkspaceNavigator had not been in place.

Team Z, on the other hand, made no secret of their disinclination to explicitly capture artifacts from their design process. "Personally, I hate spending time on documenting things. Period. I feel like it impedes my process of designing," one Team Z member confessed in interview. "I hate that if we have a brainstorm session we have to draw little things about what we did instead of just getting to our idea." In later

Figure 4. Activity levels for Teams A & Z

questionnaires, Team Z reported, "We never really got on track with using [these tools]."

Team Z did *not* in fact do *any* documentation, and subsequently found themselves turning to WorkspaceNavigator in the two weeks before their winter document was due. In the words of the course instructor,"[Team Z] always seemed to be a step behind . . . WorkspaceNavigator really saved their asses." In this way, WorkspaceNavigator converted its biggest skeptics into avid proponents of the system.

WorkspaceNavigator data (Figure X) shows that Team A and Team Z had similar activity levels throughout their projects, so they likely did similar amounts of work. Without WorkspaceNavigator, though, Team Z's documentation would have suffered from lack of foresight.

Design teams have real-time and near-term knowledge capture needs. Our design was based around knowledge reuse scenarios where design teams would access captured information after a considerable time had elapsed since the event of interest. However, our field deployments helped us to realize that teams have many "near-term reuse" needs. In both field test deployments, teams like Team A used the ability to print out copies of the whiteboard images to generate copies for everyone present at the meeting, and a few more for those who could not make it. In interviews, team members indicated that this near-term reuse increased the flow of ideas during brainstorming sessions, because they felt the ideas were captured and hence acknowledged.

In the mechatronics course, participants creatively used the overview capture from their homes to tell if teammates were in lab. One asked us to change the firewalls on the system so that their parents could observe their project progress online. This indicated to us that one key use for WorkspaceNavigator was to provide real-time updates on location and activity to team members and other interested parties in far-flung locations.

WorkspaceNavigator could be made more useful by integrating capture tools into the building phases of the design process. During the mechatronics course field test, in fact, we observed that one team had redirected their camera 60 degrees away from their computer workspace. We worried at first that this might be an indication that the team had privacy concerns with the web camera, but discovered in fact that the team wanted to record the work they were doing on the workbench when they were building their mechatronic robots.

Use of implicit capture vastly increases adoption and usefulness. In our field tests, we found that explicit use of WorkspaceNavigator data capture tools tended to drop off after the initial introduction. Team A made extensive use of the ability to explicitly save and print whiteboard images, capturing 168 shots over two quarters compared to the 64 shots captured by the other three teams combined, but even they made far greater use of the whiteboard images in the first than second quarter.

While this discrepancy partially be attributed to the fact that sketches and diagrams made on a whiteboard are more prevalent during early conceptual design phases than later when the designers are busy building, we found that many of the implicitly captured images were deemed to be useful after the fact. This may be interpreted to validate our assumption that much valuable information is found to be useful after the fact, and that users adapt readily to having the system implicitly capture data for them.

One of the major issues with implicit capture is privacy. Many of the system users expressed concern about privacy issues and hence the initial implementation included capture pause/resume buttons for each captured screen. However, in the pilot studies, users repeatedly demonstrated that in the heat of actual work, users would forget that capture was occurring or forget how to turn capture off, no matter how simple or visible the pause and resume mechanisms were. This indicated to us that requiring an explicit action to trigger privacy during a meeting is not a viable option.

The need to differentiate between public and private information in a shared workspace complicates implicit capture. There are explicit and implicit aspects to privacy. First, it needed to be more obvious to users that their actions were being captured, so that they could modify their behavior accordingly. In addition, however, a knowledge capture system needs to be proactive about protecting user privacy. Our users informed us that their biggest privacy concern was email, so subsequent screen capture applications blacked out all email web-based e-mail windows.

5.2 Lessons about Information Reuse

Captured knowledge can be adapted to many design needs. The strongest finding from our pilot studies and field tests is that the capture of the workspace overview images, the computer screenshots and the whiteboard sketches were actively used for a wide variety of purposes.

In the pilot study with the entrepreneurial team, team members routinely referenced WorkspaceNavigator screenshots over their own notes in writing up meeting summaries. Similarly, three of the four the teams in the industry-sponsored design course used data from WorkspaceNavigator in their project *documentation*. Team Z strongly dismissed the explicit use of WSN Browser during their design work, stating in a questionnaire, "People need to be more organized to use those tools." At the end of the quarter, the design team realized that they had not done a good job documenting their process but were able to use WorkspaceNavigator to help reconstruct their design process and locate whiteboard images that WorkspaceNavigator had automatically saved to use in their final documents.

The trip-planning pilot study indicated WorkspaceNavigator's promise for knowledge *reuse* applications. Participants were able to use spatial cues from overview images to find information they had previously used—for instance, they relocated a website while reviewing overview images by recognizing the color of the screen in the location they had viewed it previously. They also used WorkspaceNavigator to help recover lost data. The participants forgot to save a Microsoft Excel file, and were able to recreate the desired information from a screenshot.

Finally, we heard that design teams would use WorkspaceNavigator to improve group *awareness*. Frequently team members deeply engrossed in design work will become lax in telling other team members when they are coming into work or what they have gotten done, causing major issues in workload sharing or project integration. Team members often used WorkspaceNavigator to review their teammate's design activity and progress, and found it useful to have the onus of getting such information shifted to the interested party.

Implicit artifact capture affords post-facto analysis. One of the key benefits of implicit artifact capture for designers was that they could pick out key sketches and documents retroactively, with the benefit of hindsight. Similarly, those in design oversight roles benefit from the ability to form and test hypotheses after the fact. In the case of the field tests, design researchers were able to use the multiple months of collected data make observations about work activity patterns, to analyze utilization of the physical workspace for different tasks, to compare roles played by different team members, and to characterize typical behaviors in different design phases.

For instance, the design researchers were able to observe a long-term correlation between the quantity of data artifacts generated and overall project performance; prior studies, establishing such correlations were limited in duration (usually design exercises instead of real projects as in [26]) or focused on one data stream (primarily inter-team e-mail, for instance, in [16]). The researchers could choose what data streams, time slices or people to focus on with the knowledge of how teams performed on the project. This greatly reduces the amount of work demanded of the researcher, and is critical to making such a long-term study feasible.

Such uses of the captured data might correlate with industrial design needs such as process improvement reviews or project post-mortems.

Users prefer web-based interfaces over dedicated client applications. Although the WSN Browser offered teams a nicer interface with which to browse their workspace history, teams by and large chose to access their data through the web browser interface. When pressed why, many observed that the WSN Browser was not fast enough, but also admitted that, though they had already been introduced to the browser, they had not *even installed* the browser on their own computers to test it out until we asked. They preferred to use the web interface even though it precluded them from seeing the captured data in an integrated setting because they already use web browsers in their design work.

Speed of data browsing is more important than data density. In discussing the concept of WorkspaceNavigator, we are routinely asked if the system would not be better if it used continuous audio and video streams instead of discrete timeslice information. However, in the pilot studies and the field studies, none of the participants commented on the need for greater continuity of data or complained about any missing information. Instead, the chief concern—particularly in the field studies when the design teams were browsing through many weeks of data—was the speed with which they could locate the desired information.

Although speed was not an issue in the pilot studies, field test participants invariably commented on the speed of the WSN Browser in feedback sessions where users were observed using the tool. This concern is manifest in the actual use patterns, when design teams predominantly accessed stored data through the web browser rather than through the WSN Browser application.

Design oversight benefits from richer data and adjustable levels of detail. Those engaged in overseeing design—whether from a managerial, instructional or research role—do not have the benefit of having been involved in the captured process the first-time through. Hence, it is sometimes difficult to establish exactly what the design teams are working on without the benefit of a continuous audio stream. The design researchers examining the field test data often struggled to establish what the context of captured images, and hence made more regular use of the ability to cross-reference data generated simultaneously across different data streams (screenshot and whiteboard, for instance) than did the students. The researchers indicated that an audio stream would greatly improve their ability to establish what was going on. Video was less salient due to the time-scale of the field tests, but it is possible that smaller-scale gestures could be of interest when examining a critical meeting or disagreement.

For the design researchers, it was important to look at the collected data from a high level view, across larger chunks of time, across different teams, over the entirely of the project. WSN Viz provided those performing oversight roles with a quick snapshot of what was occurring across the workspaces at any given time, to help identify periods of high activity, to allow cross-team comparisons, to indicate overall workspace activity level. It would have been useful to link the WSN Viz to WSN Browser so that users could more smoothly control the degree of detail presented in the information interface. As the data set grows richer, the need for good indexing of prominent moments and periods is really critical to make rapid insight possible.

6. DISCUSSION

We have generalized our specific findings from our real-world design and deployment of WorkspaceNavigator to the following high-level themes:

6.1 Multiple inputs

One of the strongest aspects of the WorkspaceNavigator system was its extensibility. It was easy to add additional capture tools to the mix as long as the data being collected could be posted to the central server. The digital camera capture mechanism, for example was created a couple months into the field test after we realized that students made extensive use of digital pictures to record the progress of their mechanical prototypes. Such extensibility is valuable for any general purpose knowledge capture system.

6.2 Multiple Views

We differentiated WorkspaceNavigator's browsers to address the needs of different user groups. Over the course of its deployment, however, we noticed ways that WorkspaceNavigator could be extended to further support design teams. For example, one design engineering team spent considerable time filling up several portable whiteboards with information to prepare for meetings. The WSN Browser could easily have been used to capture this advance preparation and play it back during the meeting, but the tool was not optimally designed for immediate review. In discussing the information presented in WSN Viz, we discovered that researchers often wanted to have finer grain control over the granularity of presented information, to allow them to "drill down into the data." In general, this suggested that the framework for storing and accessing the data needs to be flexible enough to support a variety of possible outputs, to better allow the system to respond to newly discovered needs.

6.3 Implicit and Explicit Capture

Implicit capture overcomes many of these obstacles of adoption of capture mechanisms. Users often choose not to use new technologies because it is not immediately obvious why they are useful—as we noted in our findings, some field-test designs teams were very grateful to make post-facto discovery of the WorkspaceNavigator functionality.

It is important, of course, in any system with implicit actions to provide functionality for redundant input and override. Using the implicit capture model, for instance, it is not really necessary to explicitly save files; however, we noticed that teams used this much in the way they used real-time annotations in the pilot studies, to denote a record of interest. The fact that users used this facility suggests that users can make explicit decisions about topics of immediate concern in the way that they do not for topics of peripheral concern.

6.4 Variable Granularity

One of the chief differences between our system and those of meeting capture systems, aside from domain area, was the use of discrete time-slices and data objects rather than continuous streams of data. We found that while the design teams in the pilots and field studies found the thirty-second timeslice workable for finding key data, design researchers found the timeslice model to be somewhat limiting.

This difference is driven by two factors: whether the person reviewing the data was present when the data was first captured and what the information captured is worth to the reviewer. The general principle derived from this tradeoff between data density, usefulness and usability is that different applications demand different degrees of information *granularity*. We use the word granularity to emphasize the degree to which discretizing data objects improves the flexibility of the data reuse, permitting differing levels of detail and richness and easing the process of integrating multiple sources of information. While the degree of discretization needs to vary in accordance to the specific of the way the data will be accessed for reuse, we found that varying granularity is the key to having an application that can help one person get a high-level understanding of team dynamics while, or helping another locate for a specific whiteboard drawing.

7. CONCLUSIONS

WorkspaceNavigator is a data capture and access system that supports work in shared physical workspaces. We found that examining the needs of collaborative teams working in the wilder, unstructured environment of design workspaces led to design requirements very different from those of existing meeting capture tools. These needs led us to focus on creating a system that allowed both implicit and explicit data capture, that extended the feasible duration of operation through appropriate reduction in data resolution, and that allowed greater configurability both in types of data captured and in the fashion that the captured data is accessed and presented. In the future, we hope to extend this body of research to other unstructured activity environments.

We would like to delve further into the difference in the design of implicit and explicit interactions, and into the way that these types of interactions might influence one another. We would also like to experiment with augmenting the discrete captured data with continuous streams such as audio, exploring how discrete data can provide indices to help users navigate more unwieldy continuous data, and to allow explicit comparison of our timeslice model to a continuous timeline model. Finally, we would like to work more explicitly on interface improvements to WorkspaceNavigator to provide designers and researchers better access to captured information.

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