

Adapting Paper Prototyping Techniques for Interactive Workspaces

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Introduction

Low-fidelity paper prototyping is a well-known and effective technique for expressing, communicating, and evaluating design ideas for interactive systems [8]. This technique enables and encourages rapid iteration on a design, which can lead to significant usability improvements with minimal investment of time and resources. In our work, we have sought to bring the benefits of paper prototyping to the design of user interfaces for interactive workspaces. The term *interactive workspace* refers to a pervasive computing environment in which multiple independent devices are networked through a distributed infrastructure. An interactive workspace can be formed by instrumenting a fixed physical workspace (e.g., [4, 9]) or by networking an ad-hoc collection of devices (e.g., [6]).

Though computer tools have been developed for specifying and simulating certain types of pervasive computing applications (e.g., [5, 11]), the use of paper prototyping offers at least two powerful advantages. First, designers are able to quickly explore a broad range of interaction designs that support complex user tasks (e.g., relocating applications across machines) that would otherwise be difficult or impossible to explore with existing tools. Second, designers are not required to learn any new software tools or have access to any special hardware. Another useful method for low-fidelity prototyping is the "wizard of oz" technique. With this technique, researchers simulate some functionality in a partially implemented interface to provide the user with the illusion of a fully-functional interface. This can be particularly useful for speech, audio, and video-based interfaces (e.g., [12]). With paper prototyping, researchers create and manipulate physical artifacts to simulate an interface without any software implementation. As interactive workspaces become more prevalent, we believe that paper prototyping will provide a valuable method for designers to explore novel interfaces in these environments, just as it has for the desktop.

However, paper prototyping techniques have evolved with the tacit assumption that the interface being designed would eventually be executed on a desktop-size display by a single user. Interfaces for interactive workspaces break this assumption by integrating displays of various sizes and in various spatial configurations and by coordinating input from more than one user – just to name a few. As a result, we have had to adapt existing paper prototyping techniques to effectively explore interfaces for interactive workspaces.

Over the past three years, we have been investigating the design of various user interfaces for interactive workspaces. We have conducted about half a dozen low-fidelity prototype evaluations, produced over a hundred physical design artifacts, and worked with about

thirty users. When exploring our interface designs through the use of paper prototypes, we encountered several basic problems. For example, we quickly learned that standard size artifacts are ineffective for simulating information screens on large displays, a single “computer” is unable to provide acceptable response times when needing to move among multiple displays, and the method for eliciting responses needs to be adapted when there is more than one user. In this paper, we describe our related projects, discuss problems encountered when applying traditional paper prototyping techniques to explore interfaces for these projects, and share practical recommendations for overcoming them.

Interactive Workspace Projects

Our research encompasses two ongoing projects related to interactive workspaces. One project investigates the use of iconic interfaces and visual interaction techniques for relocating applications and redirecting input among independent machines. The second project investigates how groups of users can use personal devices to interact with content on a large shared display to collaboratively sketch, compare, and refine ideas for complex design problems.

Both of these projects presented significant interface design challenges. To address them, we followed an iterative design process that always began with paper prototypes. We felt that iterating on paper prototypes first would be particularly beneficial since the design space was relatively wide open. This allowed us to explore more design alternatives with less investment compared to building functional prototypes. The rough, informal nature of the prototypes helps focus users away from specific details and more towards high-level issues about the design, which can lead to novel solutions that might not otherwise be considered [10]. We initially approached the paper prototyping process using accepted design practices [8]. Prototypes were constructed using physical tools such as paper, overlays, sticky notes, colored pens and pencils, etc. Once constructed, prototypes were evaluated with representative users in a representative workspace. During an evaluation, users would perform a few key tasks with the prototype. As the user interacted with the prototype, researchers would perform distinct roles: the “computer” manipulated artifacts to simulate responses to interactions; the facilitator instructed the user, answered questions, and encouraged the user to “think aloud” to better understand how they were reasoning about the interface; and the note taker documented the session. Lessons from each evaluation would be used to seed the next iteration of the design. Figure 1 shows images from our paper prototype evaluations in progress. In the next sections, we describe how we applied this standard paper prototyping practice to our projects, focusing on the problems encountered and how we addressed them.

Interfaces for Managing Digital Information

In this project, we have been exploring the use of iconic interfaces and visual interaction techniques for relocating applications and redirecting input in an interactive workspace [1, 2]. Our interest in iconic interfaces stems from the fact that users are able to utilize their spatial reasoning abilities when performing related tasks. Specifically, user tasks included relocating applications from a personal device to a large shared display, from one large display to another, from a large display back to the personal device, etc. Tasks also included redirecting input to another device either as part of or separate from the relocation tasks.



Figure 1. Evaluations of our paper prototypes in progress. On the left, a user interacts with the prototype of our iconic interface while one researcher takes notes and another prepares to show the interaction results with a transparency. On the right, two users interact with the prototype of our interface for group design on their personal devices while viewing an electronic artifact on the shared display. A researcher works with each user to keep their interfaces up to date.

To explore interfaces supporting these tasks, we constructed paper prototypes and had users attempt to perform the tasks following the methodology previously described. One of the first problems was how to best simulate a specific configuration of displays in the workspace. One idea was to just arrange the artifacts onto separate regions of a large table, each region representing a different display. However, we felt that this method would not adequately depict the actual size and spatial configuration of displays in a real workspace. Our solution was to use the displays available in our workspace as props in our study, placing the design artifacts on the surfaces of the displays in the evaluation.

Another problem was that we had created our design artifacts from standard size paper (8.5" x 11"), which is common practice. This worked fine when the user was interacting with a tablet size display, but when an "application window" was moved to a large display, the same sheet of paper now reflected an inaccurate scaling of the content. This made it difficult to view the content from a distance and suggested an inappropriate resolution of the corresponding display (see figure 2). We thus had to create additional versions of each artifact for each size display, a process that would have been much more efficient and less frustrating had we created all the artifacts up front in a single batch.

During an evaluation, the "computer" had to quickly move among the displays to update them based on the user's interaction. This caused two problems. One was an overly slow response time, which hindered our ability to simulate realism in the evaluation. The other problem was that the physical act of the "computer" moving around the workspace implicitly informed the user of where to look for the next screen. This was particularly problematic when we were trying to determine how well users could detect an application's new location based solely on the feedback of the interface (see figure 3). We addressed these issues by having multiple "computers" available in the workspace, one per display. This setup resulted in much faster response times and reduced the overt physical acts of having to walk to the displays to place artifacts.

The last issue stemmed from our observations of users interacting with the prototypes during the evaluation. We found that different interaction designs were causing users to



Figure 2. In this figure, an artifact is correctly sized for a tablet PC, but is much too small for a large display. Using artifacts of a single size across different size displays can result in incorrect scaling, which makes it difficult to view the content and suggests an inappropriate resolution.



Figure 3. A user is waiting for the researcher to move an “application window” from one display to another in response to his input. With only one researcher acting as the “computer,” updating multiple displays can be time-consuming and may implicitly inform the user of where to look.

have to physically move different amounts in the workspace (e.g., an early prototype required the user to move to the source screen to move an application while others designs did not) and, from the responses to questionnaires, that users were very sensitive to this issue. Thus, minimizing the amount of physical movement imposed on a user such as footsteps and head turns became an important design consideration for our interface.

Computational Tools that Facilitate Creativity

In this project, we are leveraging creativity theory to guide development of computational tools that support creative design practices for both individual and groups of designers [3]. Our basic approach is to enable personal devices such as Tablet PCs to network to a machine driving any large display, which provides a shared visual workspace. The user interface is designed to support several tasks, including sketching multiple design ideas, replicating ideas to (or removing them from) the shared workspace, accessing ideas created by other designers, and manipulating shared designs from the local devices.

As in the previous project, we began our exploration of the design space by constructing paper prototypes, preparing a realistic environment, and having users perform key tasks. This project posed new challenges for the use of paper prototyping because groups of users were involved in the evaluations, the large display being simulated was a high-resolution wall-size display, and its use was tightly integrated into the interaction design of the interface. Though we encountered many of the same problems with paper prototyping that were encountered in the previous project, we focus our discussion here on the unique problems encountered in this project or similar problems that were addressed with a different solution.

One issue immediately encountered was how to get *group* responses to our prototype, rather than just multiple individual responses. While a think-aloud protocol could be adapted for multiple users by providing a note-taker for each user, this would not allow for the added insight that comes from users building off of each other’s responses.

Brainstorming research has established that group responses typically provide the most insights when the responses are done in two stages: individual responses followed by group discussion, which facilitates re-interpretation and generation of ideas [7]. To get each user's individual response, we asked them to write answers to questions about the interface on paper. These notes were then used to seed the group discussion.

Similar to the previous project, we found that overlaying standard size artifacts on a large display was ineffective. Rather than create multiple artifacts of different sizes, this time we scanned the artifacts and showed the electronic versions on the large display, which was now turned on. This allowed us to more realistically move the artifacts on the large display in response to user interaction on the local display, which was an important part of our interface, and position the artifacts in locations that would otherwise be difficult to reach by hand.

The final issue was how to provide a reasonable sense of working together among users who were not previously acquainted. Our solution was to have users sit directly next to each other so that they could maintain an awareness of each other's interface actions and corresponding results. This would allow the users to better understand how the interface behaves and give more informed feedback. It also aids in understanding changes in the interface, e.g., one user might think that a change in the shared display was caused by their own actions when it was actually caused by another user's interaction.

Recommendations

From our experience on these projects, we provide practical recommendations that can be used to improve the use of paper prototyping for interactive workspaces:

- *Simulate the size and configuration of participating displays in the workspace as realistically as possible.* The size and spatial configuration of displays in an interactive workspace impacts both the interaction design of an interface as well as a user's perception of how the displays function together. Therefore, simulating these physical characteristics is important when evaluating paper prototypes. In our projects, we physically positioned representative displays and used them as props to reflect the expected configuration. During an evaluation, the "computer" would move around the workspace and literally place design artifacts right on the displays. In situations where the necessary displays are not available, e.g., you are designing for a client's workspace; the use of physical props, such as white boards or poster board, appropriately sized and positioned could serve a similar function (see figure 4).
- *Explain the functional relationship among the (simulated) displays.* At the onset of our evaluations, we quickly learned that many users struggled to understand how the paper prototype would "function" across multiple displays, i.e., how and when input on one design artifact would cause changes to artifacts associated with other displays. This is likely due to years of interacting with the desktop where application I/O is tied to a single device. Though an experimenter should always explain the application and relevant domain context as part of pre-evaluation instructions, we recommend taking a few extra minutes to thoroughly explain and demonstrate how the paper prototype is divided and functions across the displays.



Figure 4. The size and spatial configuration of displays in a workspace can affect a user’s perception of the interface and the functional relationships between devices. On the left, we show how artifacts might be placed into separate regions on a table to represent multiple displays, but this does not reflect their true size and position within a workspace. On the right, we show how a more realistic setup could be created by using two whiteboards to simulate the size and expected configuration of large displays in a workspace.

This can reduce confusion and misunderstandings during the evaluation. However, in cases where a user’s understanding of these functional relationships is being tested, less detail may be provided.

- *Size design artifacts relative to the size of the corresponding display.* Using paper design artifacts of standard size (8.5” x 11”) on a large display (or prop) results in an unrealistic visual scaling of the artifact. For example, in an early evaluation of our interface for group design, we created artifacts out of standard size paper. This worked fine when using the artifacts to simulate local interactions on a tablet display. But, when the artifacts were manipulated on the large display to simulate changes to the shared context, users were unable to effectively view the interface representations. We recommend creating multiple versions of the artifacts, one for each size of display that they will be shown on. Alternatively, artifacts could be scanned and then placed and sized on working displays during the evaluation using a simple software tool.
- *Station an experimenter at each display to decrease interaction response times.* In an interactive workspace, having only one “computer” manipulate the design artifacts in response to user interaction can cause unacceptably slow response times as the user must physically move to the displays. In addition, this practice can inadvertently lead a user’s attention to a particular display. We recommend assigning one experimenter to each display in the workspace, which, assuming effective coordination, can substantially reduce interaction response times and mitigate leading the user’s attention. An alternative would be to scan the artifacts and show them on working displays as needed using a simple software tool.
- *Use physical movement as an additional metric by which to evaluate the usability of interfaces for interactive workspaces.* From evaluating prototypes of our iconic interface, we observed that different interaction designs caused users to have to physically move about the workspace in different amounts and that they were

very sensitive to this issue. Because interactive workspaces are intended for daily work, this ergonomic impact of an interface becomes an important issue. Thus, the amount of physical movements required such as footsteps and head turns should be considered when evaluating interfaces for these environments. Though we uncovered this metric through paper prototyping, we believe that it would be applicable regardless of the specific evaluation technique used.

- *Elicit better group responses with two-stage feedback.* Applications designed for coordinated or parallel tasks across multiple users create challenges for evaluating paper prototypes because they must often be evaluated by multiple users at once. When evaluating such an interface, important insight can be gained from both individual and group feedback. However, social dynamics often lead to one user dominating a discussion, which leads to production blocking and the generation of fewer ideas [7]. To address this issue, we asked users to respond to questions individually in writing and then discuss the questions together as a group so that we collected both individual responses and a refined group opinion. We believe that using such two-stage feedback would be useful in many group evaluations.

We have utilized these recommendations in our own paper prototyping practices and our experience is that they can enable evaluations to be performed more efficiently and can lead to more informative results. Leveraging our recommendations requires only minor modifications to existing paper prototyping practices and can thus be broadly applied. This set of recommendations should not be considered exhaustive. We fully expect that additional experiences using paper prototyping for interactive workspaces and other pervasive computing environments will continue to produce useful lessons.

Conclusion

Pervasive computing enables new applications and interaction designs within existing applications. We thus believe that the use of paper prototyping will be a valuable method for UI researchers in this domain, as it can facilitate rapid exploration of this relatively unfamiliar design space with minimal investment. However, our experiences using paper prototyping to explore interfaces for interactive workspaces shows that existing practices must be modified to remain effective. This is mainly because interactive workspaces integrate the use of multiple displays of various sizes and in various configurations and have a greater focus on group-oriented tasks. By applying paper prototyping in several of our research projects, we were able to identify and learn how to overcome many of these challenges, and distilled our experiences into practical recommendations for others. Since our recommendations require only minor modifications to existing practices, they can be broadly used and their use can lead to more efficient evaluations and improved results.

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