

# Bridging Physical and Electronic Media for Distributed Design Collaboration

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## ABSTRACT

Research on distributed collaboration has predominantly focused on shared *electronic* media. We have found, as other researchers have, that users often have good reason to want to work with *physical* media. Yet they would still like to collaborate with each other. A fundamental tension exists in the design of systems to support remote collaboration when the interaction primitives are physical: physical objects live in one place. We have designed and implemented a remote collaboration system where users can still use physical objects. We introduce an interaction paradigm where objects that are physical in one space are electronic in the other space, and vice versa. Our distributed system is designed for two groups, with multiple users at each end. Our tangible approach is the first system to enable simultaneous, multi-input across locations. We have implemented this system as an extension to the Designers' Outpost [5].

## Keywords

CSCW, tangible, remote collaboration, shared workspace

## INTRODUCTION

In our previous studies into web design, we found that pens, paper, walls, and tables were often used for explaining, developing, and communicating ideas during the early phases of design. The Designers' Outpost embraces and extends this paper-based practice through a large electronic wall with a tangible user interface. With Outpost, users collaboratively author web site information architectures on an electronic whiteboard using physical media (Post-it notes), structuring and annotating that information with electronic pens. This interaction is enabled by a SMART Board augmented with a robust computer vision system, employing a rear-mounted video camera for capturing movement and a front-mounted high-resolution camera for capturing content.

Outpost's informal user interface supports fluid input, minimizing recognition. Unrecognized input embraces nuanced expression and suggests a malleability of form that is critical for activities such as early-stage design. The



**Figure 1.** Our remote system running on a SMART board and a digital desk. Notes that are physical in one place (see left) are electronic in another (at right).

combination of pen and paper input in Outpost provides flexible input means for teams.

Many of the designers we have spoken with work in collaborative teams at multiple locations. However, their preferred style of early design is physically based. As physical objects are located in only one place, they have difficulty maintaining their design process when working in distributed teams.

## RELATED WORK

Over the last decade, there has been compelling research in distributed media spaces for visual collaboration tasks, such as shared drawing through electronic whiteboards (*e.g.*, [6]). These researchers found, as we have, an interest by users in collaborating on design artifacts from different places. Clearboard [4] and VideoWhiteboard [7] introduced the idea of seamless interaction, where the visual representations of artifacts and communication are integrated on single display.

While most researchers have abandoned physical interaction to achieve remote collaboration, Brave et al took a different approach [2]. By providing an identical set of physical objects (in this case haptic rollers) to participants at two different locations, they achieve synchronized physical interaction. They point out that, "Since a generic pointing device is not needed to mediate interactions, many users can interact with a tangible system in parallel." When possible, coupling physical objects is an appealing paradigm, but our requirement of lightweight appropriation of common physical objects ruled out this possibility.

## SHARING INTERACTIONS

In our system, when a user performs an action, both the local and the remote system are updated. When a local user

*physically adds* a note to the whiteboard, the remote system *electronically displays* a photograph of that object (Figure 1). The vision system makes this photograph. A note is created by writing on a physical post-it note and placing it on the board. Both teams can interact with any note, regardless of whether it exists as a physical object or remote analogue.

### **Transactional Consistency**

We would like for all objects to be movable and editable by either team. When the objects are electronic (such as with ink), this is easily facilitated. When the objects are physical, multiple site editing introduces some difficulty. One option is to only allow the creator editing ability; that is not very appealing. We have taken an alternate approach. Physical objects in Outpost cast electronic shadows as feedback to the user that the system is aware of their presence. Normally, shadows are very faint. However, when an object's physical state becomes transactionally inconsistent, we cast a strong red shadow indicating to the user to remove the artifact. We introduced this feedback notion in our design history system [5], and have found anecdotally that it seems successful for remote collaboration as well.

### **Transient Deictic Ink**

When users would like to draw their collaborators' attention to a particular spatial position or artifact, they need some way to convey this deictic gesture. We found that a simple remote pointer did not convey enough information. For this reason, we have developed transient ink as a richer interaction technique for distributed users to be able to convey deictic information to each other. Transient ink is rendered on both displays for a few seconds, and then it fades away.

We connected a SMART Board with a digital desk, both within our lab, and used remote Outpost through these hosts. In our experience, the remote tool performed as expected and the functionality seemed sound. While in this setup no audio connection was necessary, we do plan to implement audio awareness as we recognize that this is key to effective collaboration. Transient ink provided some conveyance of spatial gesture, but a less explicit and more continuous awareness scheme would be more effective, and we plan to implement another scheme in the future.

### **SOFTWARE INFRASTRUCTURE**

Our remote collaboration system extends the Designers' Outpost. Outpost was built using the SATIN toolkit [3]. SATIN employs a command object system. We extended the command object model in a similar fashion to [1]. Because most of the changes were made at the toolkit level, other ink-based applications can benefit from this infrastructure with minimal application-level change. A command object represents a change between two states. The system works as a peer-to-peer system; both endpoints replicate their commands, sending them to the opposite endpoint. Each object contains a unique global identification tuple, composed of the creating hostname and

an integer corresponding to its position in the local command queue. This identifier is used to refer to objects between hosts. We modified the SATIN command queue so that when a command is executed, it is also marshaled for serialization over the wire, and sent to the remote host.

Design artifacts in Outpost are serialized to files as XML documents. We found this method to be successful for files, and so we chose to use it for network communication as well. The connection between the machines is socket based. Users have the option of connecting to different remote hosts, or not connecting at all if they wish to work alone.

Photographs of notes are stored on the host where they were created, and are accessed as needed over the file system by the remote host.

### **CONCLUSIONS**

We believe adding this functionality to Outpost will provide substantial benefit to users. With the addition of remote collaboration, we believe there is enough benefit to users of Outpost that early adopters will be motivated to learn our system, enabling us to gain a better understanding of longitudinal work practices and adoption.

We have implemented a system that allows users to interact both with physical and electronic media across large workspaces. We have presented the first system to enable simulations multi-user input in support of remote design collaboration. Thanks to our advisor James Landay.

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