# Being Here: Designing for Distributed Hands-On Collaboration in Blended Interaction Spaces

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## ABSTRACT

This paper describes a concept for supporting distributed hands-on collaboration through interaction design for the physical and the digital workspace. The Blended Interaction Spaces concept creates distributed work environments in which collaborating parties all feel that they are present "here" rather than "there". We describe thinking and inspirations behind the Blended Interaction Spaces concept, and summarize findings from fieldwork activities informing our design. We then exemplify the Blended Interaction Spaces concept through a prototype implementation of one of four concepts.

### Author Keywords

Blended Interaction Spaces, distributed collaboration, hands-on collaboration, video conferencing, CSCW.

### ACM Classification Keywords

H5.2. [Information interfaces and presentation (e.g., HCI)]: Group and Organization Interfaces – Collaborative computing.

## INTRODUCTION

When collaborating with collocated colleagues we benefit from the ability to meet in-person face-to-face enabling natural communication, body language, gestures, spontaneity, and flexibility. Hence, co-location is often the preferred way of organising, for example, project teams. However, physical co-location of teams is not always achievable for several reasons. Members of a project team may be distributed across the city, interstate or even overseas. Typically as the distance to travel increases, so does the time and cost associated with getting there. From this dilemma arises a strong motivation to design and develop well functioning computer-supported collaborative workspaces that aid in increasing the effectiveness of distributed teams without the excessive reliance on commuting.

A lot of work has been done in the area of computer supported collaborative work (CSCW) over the last three decades. This has led to the development of a broad range of systems facilitating synchronous and asynchronous collaboration amongst distributed co-workers and allowing for a much more physically distributed workforce than in the past. The very development and general availability of technologies such as the Internet, email, mobile telephones, desktop sharing, instant messaging, video conferencing etc. have generated new work practices in which physical location matters very little. Project teams are often created across several physical locations, and we have an expectation to be able to collaborate in such ways with the aid of technology.

However, as many times in the past, our emerging work practices are pushing the boundaries of what can be done with current technology. Technologies such as high-end video teleconferencing systems can aid in creating an experience of collocatedness in distributed meeting situations, but as distributed organizations become more and more common, collaborative activities other than *meetings* are in need of being supported better. One of these is distributed hands-on collaboration.

The work presented in this paper is inspired by the HP Halo B2B Studio (Gorzynski et al. 2009). Exploring the design rationales behind HP Halo further, we explore the concept of *Blended Interaction Spaces* for the design of hands-on collaborative work environments supporting the feeling of distributed collaborators being *here*. This is in contrast to the telepresence paradigm of attempting to put yourself *there* through the remote viewing and controlling of distant physical objects, such as conducting specialist surgery with a camera and controls (Minsky, 1980). The Blended Interaction Space is configured such that distributed attendees appear represented in a setting that is a natural extension of the local meeting space, as if they were seated at the opposite side of the table. Arrangement and design of the physical space in a manner that is consistent with the displaying of the remote end provides a sense of collocation. Hence, we are not trying to support the feeling of being somewhere else, nor are we supporting the feeling of being connected through digital media. We are creating a shared physical and digital workspace by perceptually joining distributed locations into one.

Our Blended Interaction Spaces include dedicated CSCW software, referred to as *Tapestry*, that enables

OZCHI 2009, November 23-27, 2009, Melbourne, Australia.

OZCHI 2009 Proceedings ISBN: 978-1-60558-854-4

collaborating parties to share computer-based content via the user interface in a what-you-see-is-what-I-see (WYSIWIS) format, on large shared computing surfaces with simultaneous multi-user interaction. The collaborative software provides an additional sense of distributed persons *being here,* as their interactions with the shared computing surface can be seen as if they were pointing from within the same room.

The combination of Blended Interaction Spaces and Tapestry facilitates a novel user experience during distributed hands-on collaboration aiming to improve the experience of conventional video conferencing.

The following sections of the paper describe related work and our own empirical observations from four separate domains, before introducing the Blended Interaction Spaces concept in greater detail together with its supporting collaborative user interface. Finally the paper summarises the contributions and proposes future work.

## RELATED WORK

There are many research projects that have studied digital meeting spaces for supporting collaborative distributed work. It is beyond the scope of this paper to give a detailed summary of all related work in this area. However, we would like to set the scene with respect to some of those that have inspired the development of our Blended Interaction Spaces concept. This includes work within the areas of telepresence, media spaces, and shared digital workspaces.

Our research has grown out of the related areas of Telepresence and Media Spaces. Telepresence is a central concept within telecommunication technologies such as video conferencing (Ishii et al., 1993). Telepresence can be characterised by the feeling of "being there", achieved primarily by establishing audio and video channels between distant locations (Hollan and Stornetta, 1992). Users are provided with stimulation to their senses giving them the feeling or appearance that they are present at a different location other than their true current location. However, rarely do systems actually provide users with the feeling that they are in a different place. Consequently, there is an acknowledged need to develop better telepresence technologies and tools that allow us to interact with others that are far away just as we do with those that are near (Holland and Stornetta, 1992).

A media space is a system that uses integrated video, audio and computers to allow individuals and groups to work together when spatially distributed (Mantei et al., 1991). A media space is defined as "a computer-controlled teleconferencing or video conferencing system in which audio and video communications are used to overcome the barriers of physical separation" (Baeker, 1993). Media space technologies should support both shared workspaces and interpersonal spaces also present in ordinary face-to-face meetings (Buxton, 1992). Media spaces also need to account for spatial, social, and communicative interaction (Baecker et al, 2008).

Shared digital workspaces have the potential to impact peoples' existing work practices. Several systems have been designed to enhance how people work together in a collocated situation. For example, Dynamo (Izadi et al., 2003) is designed for the sharing and exchange of information across public surfaces that users can easily access and interact with. The i-Land environment (Streiz et al., 1999) integrates design of virtual information spaces and real architectural spaces, providing a whole room environment with computer-augmented room elements. This adds to the concept of media spaces by supporting new and effective "radical collocation" work practices such as the flexibility to work in different modes and to form ad hoc work groupings (Teasley et al., 2000). The Interactive Workspaces project created the iRoom (Johanson et al., 2003) to explore team-based collaboration in technology-augmented environments. This demonstrated the benefits of working in environments designed to enhance free-flowing collaborative activities where participants can flexibly and quickly combine information from computing devices along with information from paper, models, whiteboards and other physical materials. iRoom also highlighted the effectiveness of supporting multi-person interaction using social protocols to dictate operational control rather than fine-grained electronic floor control. In respect to understanding group dynamics around a collaborative tabletop surface, Ringel Morris et al., (2006) demonstrated the importance of tabletop interface design aimed at mitigating negative social dynamics by encouraging cooperative gesturing and facilitating group problem solving, which in turn encourages participation and socialization amongst participants. WeSpace (Wigor et al., 2009) is a walk up and share multi-surface collaboration system. It integrates a large data wall and a multi-user multi-touch table designed specifically for scientific collaboration in small collocated groups for data exploration and visualisation. It evidenced the importance of users being able to "walk up" and share their personal applications and laptops with their collaborators. Users benefited from the use of large display areas and multi-touch input models. The researchers were able to show that data-intensive visual collaborative workspaces: improved the group's work practices; allowed them to collaborate in new ways; and changed their workflow processes such that new scientific discoveries were made.

Many existing distributed work environments rely heavily on traditional video conferencing systems to provide a communication channel but have with only limited support for shared digital workspaces. However, several designs have been proposed to enhance the feeling of connectedness and natural working practices between distributed workers. The Hydra system (Sellen et al., 1992) supports multiparty participation in a meeting while preserving each participants personal space by placing a Hydra unit in the place around a meeting table that would otherwise be occupied by a remote participant. Each Hydra unit has its own camera, monitor and speaker, acting in effect as "video surrogates" for the participants. This conveys conversational acts such as gaze and head turning in a meaningful way to those in the meeting. The HyperMirror environment (Morikawa and Maesako, 1998) solves the issue of feeling collocated by providing relaxed conversation communication where participants feel they are sharing the same virtual space. This is achieved by presenting both local and remote participants on the same, shared video wall, in this way they are sharing the communication space. The Agora system (Kuzuoka et al., 1999) works within the roundtable meeting metaphor and tackles the issue of supporting the ability to share remote documents through top projected images of artefacts from a local desktop to a remote desktop. Agora also supports a direct video connection between sites, showing gestures and body orientation of participants on two sides of a square desk arrangement to aid effective communication by supporting natural face-to-face interaction. Hewlett Packard's Halo Collaboration Studio (Vlietinck, 2008) is a system that uses constraints in the physical environment such as seating positions, camera angles, lighting, furniture design, background design and colour, to create the impression that participants are seated and conversing with each other at the same table in a virtually co-joined space. This achieves a "blending" of the distributed work environments, however, support for sharing and working with documents and artefacts is limited.

Inspired by the literature described here, we set out to investigate distributed collaboration involving the use of telepresence, media space, and shared digital workspace technologies. The goal was to understand the nature of such collaborative work, potentials and shortcomings of current technology, and to inform the design of Blended Interaction Spaces for collaboration. Our method is described below.

## DESIGN RESEACH METHOD

Our design work was informed by a number of field studies of distributed hands-on collaboration. These were guided by the Contextual Inquiry method as described by Beyer & Holtzblatt (1998). The field studies involved a combination of contextual interviews, work practice observation in naturally occurring context, and analysis of the physical layout of workplaces including offices, meeting rooms, laboratories and shared breakout areas. Following the field visits and data collection, data was analysed in order to produce a series of analytical abstractions as appropriate including flow models, artefact models and physical models. The field studies covered four different work domains: 1) medical experts, 2) material scientists, 3) radio astronomers, and 4) military operations planning staff. The field studies took place over periods of time between 2007-09.

The Contextual Inquiries informed a process of iterative open-ended design involving design sketching, storyboarding, scale models, 3D modelling, full-scale mock-ups, and functional prototypes. The purpose of this design activity was to develop ideas for the set-up of work environments for distributed collaborative work. The design activity explicitly focussed on ideas based on specific observations and findings from the field data *and* ideas that could be applied across the different domains studied. In this way the design ideas remained grounded while at the same time general.

Working with sketches, storyboards, models and mock-ups allowed us to explore a broad variety of ideas for both physical and digital workplace set-ups in an open-ended way without technical constraints. This led to the development of four conceptual designs all including an integrated physical and digital workspace. Working with the functional prototype implementation of one of these conceptual designs allowed us to explore details of the physical and digital workspaces further, addressing challenges such as geometrical shapes, colours, camera angles, screen placement, interaction devices, and interaction techniques further. This led to the development of an actual Blended Space for distributed hands-on interaction.

### Summary of the four domain studies

The four different domains studied are all highly complex, involve physically distributed workforces, highly trained personnel, and collaboration involving shared digital artefacts such as very large datasets, 3D models, and other multimedia representations. The four domain studies are summarised below.

*The study of collaboration in healthcare* took place over a period of six months from 2007-08. The medical experts studied make up a multidisciplinary team of surgeons, oncologists, pathologists, radiologists and nurses collaborating to treat patients with breast cancer. The collaboration within the multidisciplinary team takes place between two Sydney hospitals in the form of regular team meetings using videoconference and file sharing technology. Our goal was to understand how the team collaborates in their face-to-face meetings and in their discussions using videoconferencing, and to identify obstacles and issues to their primary tasks. Detailed findings from this study are described in Li et al. (2008).

Figure 1: X-ray Imaging scientist showing images and 3D models of timber cross sections to two research scientists from Forestry, to determine additional x-rays required.

*The study of material scientists* took place over a six-month period from 2008-09 at the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The study focused on the collaboration within and between teams of material and computational scientists located in Melbourne, Hobart and Sydney. The collaboration between the scientists studied include collection of very large data sets from specialized equipment, such as x-ray scanners and synchrotrons, the collaborative and iterative analysis of this data, and the presentation and discussion of results to external clients and collaborators (figure 1). These activities are all supported by the use of different types of information technology, graphic workstations, file sharing, and videoconferencing. Contextual Interviews were conducted on-site during discussions between scientists and clients over x-ray imaging results, to observe their information and communication practices. These interviews were videotaped and transcribed. To feed this information into the design process, the ethnographers participated in design workshops, sharing their understandings with the team.

*The study of radio astronomers* was considerably shorter than the other domain studies. It took place during a three-day intensive field visit in May 2008 to two major radio telescope sites, Parkes and Narrabri, run by the Australia Telescope National Facility (ATNF). The focus of this study was on the work practices surrounding and directly related to the operation of Australia's radio telescope installations in rural New South Wales. This included the control of the radio telescopes' physical movements, the collection of datasets, and the computer-supported collaboration between sites. Our goal was to explore potentials and challenges for supporting remote control and use of the radio telescopes from the ATNF headquarters in Sydney. Due to interference issues, the telescopes are located in remote and deserted locations. While providing benefits such as silence to do work, this obviously implies a logistic challenge for the scientists using these instruments in their daily work.

*The study of Australian Defence Force operations planning staff* took place during a small exercise held in October of 2006 and subsequently in October 2007. The exercise provides the opportunity for Defence Science and Technology Organisation (DSTO) scientists to trial emerging technologies and to identify further requirements. From the various technologies evaluated during the distributed exercises, the Livespaces concept (Phillips, 2008) and selected CSCW tools for both collocated and distributed personnel were of particular interest. Participants were each provided an individual workstation allowing them to develop content in isolation and to share their screen's content with other team member's workstations or onto the large shared displays within the room, also viewable by the distributed site. Additionally, videoconferencing between distributed sites was used frequently in combination with hands-on interaction with the shared displays. Findings from this work highlighted the potential benefits of shared interactive displays during planning meetings across distributed sites. Similarly the potential value of high quality video conferencing was acknowledged.

## HIGHLIGHT FINDINGS FROM FIELD WORK

From the findings across our field studies, we can see that there is (still) a real need to support distributed hands-on collaboration better than is currently done with traditional video conferencing setups and other interactive tools such as file and screen sharing applications. Specifically, we found the following:

1. Video conferencing systems are not perceived as real alternatives to face-to-face collaboration. When a collaborative task is highly important, people would rather travel great distances "to get it right". This is partly due to the quality of current systems. There is a need for higher quality audio and video links capable of supporting both verbal and non-verbal means of interpersonal communication including gesturing, pointing, eye gaze, and head gaze.
2. The user experience of video conferencing suffers from the physical setups of technology. Typical configurations with video screens placed on available wall space disjoint from the rest of the meeting room creating a feeling of "speaking to people in the next room through a hole in the wall". This introduces a strong sense of "us-and-them" where people at each individual location feel that *they* are at the gravitational centre of the conversation.
3. Hands-on collaboration differs from meetings. Videoconference technology is typically available in "board room" type workspaces supporting a particular type of working pattern. This is insufficient for hands-on collaboration, which requires workspaces that allow more flexible working patterns beyond structured conversation and one-to-many presentation. This includes, for example, synchronous interactive application sharing, parallel streams of interaction with digital content, and parallel streams of conversation between people that are collocated as well as distributed.
4. Hands-on collaboration is highly dynamic in terms of factors such as group sizes and formality of interactions. Current videoconference setups do not support this dynamic well. Workspaces for distributed hands-on collaboration should support variable group sizes without degrading the experience for each participant and support different types of working interactions, from formal meetings to informal chats.
5. The user experience of video conferencing is limited by the overhead involved with setting up the system, connecting, and dynamically changing the configuration during use. The time spent on this is often significant and frustrating, and takes focus away from work activities. In order to better support distributed hands-on collaboration, systems should be no harder to use than a physical workspace. They should provide the ability of "walk up and use" and the ability to effortlessly bring other resources into the collaboration such as laptops and other devices.
6. The user experience of video conferencing is impeded by the technology not being pervasive and well integrated into peoples' workplaces. Ad-hoc, daylong, and peripheral use as an integrated part of day-to-day collaboration is limited by videoconference facilities typically being limited resources located in dedicated meeting rooms. Not only is there a prohibitive overhead involved with planning ahead and booking these shared facilities,

they are also typically disjoint from peoples' and groups' normal places of work.

These findings were used as a baseline for our subsequent use cases, design and prototype development activities.

### Two themes of design ideas

Based on our fieldwork, and reading of the literature, our early design work divided into two themes: working with the *physical* and the *digital* workspace set-ups. This led to the development of two separate, but related, design concepts: 1) Blended Interaction Spaces, and 2) Tapestry.

*Blended Interaction Spaces* are shared physical-virtual workspaces that connect distributed locations in geometrically appropriate ways, through careful physical configuration of videoconferencing hardware and shaping and positioning of furniture and rooms, to approximate working in a single collaboration space.

*Tapestry* is a distributed application framework shared across multiple displays and across multiple physical locations. It allows collaborating teams to see and share a common interactive workspace onto which users can drag files and application windows.

These design concepts are described in more detail below.

### An ecology of Blended Interaction Spaces

During the design phase, we developed a preliminary "ecology of Blended Interaction Spaces" to support distributed collaboration in various workplace scenarios (McEwan, et al. 2008). Each instance of this ecology combines both physical and virtual workspaces and was designed to explore a particular scenario with unique requirements. The ecology included: 1) an informal collaboration space with couches and low tables akin to a coffee room; 2) a small group collaboration space for two to eight people; 3) a larger´ collaboration space for eight to twenty people; and 4) a corridor-space with digital pin-up boards for collocated and remote offices.

From the initial four concepts, it was decided to develop a functional prototype of the small group Blended Interaction Space. This choice was informed by the relevance of the set-up to the end-user domains studied, the contrast to existing meeting room set-ups in terms of research, and the commercial availability of technologies required to implement the concept. For the remainder of the paper, our discussions will be centred on this concept.

## THE SMALL GROUP BLENDED SPACE

Our Blended Interaction Space for small group collaboration, (referred to as BIS*i*), has been designed to improve collocatedness for distributed meetings by providing a sense of distributed participants *being here*. It has been designed for ease of use such that the end user does not have to be concerned with camera and audio setups or launching of specific software to enable sharing of displays between sites. As a walk up and use environment, BIS*i* also allows personal computing devices such as laptops to be simply connected into the environment, enabling the user to display and share a "live" version of their specified content between the distributed sites, or to use their own laptop's keyboard and mouse as an interaction device during collaborative development of new content on the shared displays.

BIS*i* is optimised for collaboration between two separate sites of up to four participants per site. The physical configuration of furniture and displays provides a "blending" of the local physical workspace with the video conferencing imagery of the other site such that the two appear as *one* workspace. The use of a BIS*i* environment can be illustrated in the following use case:

*Bob and his team have arranged a meeting with interstate colleagues to discuss his most recent research findings. Bob walks into the* BIS*i environment across from his office. He turns on the system and connects his laptop as he has a presentation that he wants to show to his colleagues. Bob knows that his laptop is connected when an "interchange gate" widget appears on its screen. He then connects to the interstate team from a list of favourites. As his colleagues appear on the screen they are discussing amongst themselves, but they stop talking as if Bob had just walked into the room. Whilst informally catching up with each other, three of Bob's team sit down next to him and also join the conversation as if they are all sitting around one large table. Bob then begins his presentation by dragging a window on his laptop on to the shared display. Both sites can now see and interact with the presentation as if they were in the same room.*

The BIS*i* prototype materialises our conceptual designs from the 3D computer models, sketching, and physical mock-ups (figure 2) under the constraints of implementation with current technology.

Figure 2: Physical mock-up of blended interaction between people and electronic documents.

Figure 3 shows the most recent iteration of the BIS*i* prototype. The implemented design comprises four vertically mounted 42" full high-definition LCD displays, each operating at 1920x1080 resolution. The Tapestry shared digital workspace is displayed on the two top displays whilst high-definition video teleconferencing is shown on the lower two. In order to optimise viewing angle, the top displays are tilted downward. In-between the upper and lower displays are two high definition video cameras providing parallel video streams to the two corresponding displays at the other end.

Figure 3: The physical size and geometry of the BIS*i* blended workspace for distributed collaboration.

The table in front of the vertical displays was designed to facilitate two different meeting scenarios – either collocated or distributed – whilst also having a suitable geometry for blending via the video conferencing system. Built into the table is a horizontal display cell from MultiTouch comprising of a 46" full high definition LCD display, capable of displaying at 1920x1080 pixels and detecting multiple touch points. The camera based sensing technology of the MultiTouch Cell enables tracking of individual fingers or multiple fingers either from one hand or several different hands. This allows for interaction techniques where users can interact with the displayed content in a similar manner to working with physical documents on a horizontal surface.

Figure 4: The seating configuration of the BIS*i* blended workspace for distributed collaboration facilitates both collocated and distributed collaboration.

The table's plan shape, texture and colour enable video conferencing from compatible sites to be blended into the space, providing the illusion that people are sitting around *one* table. The table's exact curve along the front edge has been derived from the location and field-of-view of the two video conferencing cameras such that the table is represented geometrically correct across multiple displays at both sites. In addition to the table shape, colour and position, other factors such as camera positions, camera angles, zoom and focus settings, lighting, and wall colours also impact seriously on the blending of the two sites. These are all factors that have been incorporated into the BIS*i* prototype.

Our table design enables people to sit around three sides of the table – one person at each end of the table and two to four people along the long side facing the vertical displays. During distributed collaboration when blended with another site, BIS*i* has been designed for all participants to sit along the long side of the table's front edge (facing the vertical displays). In this configuration, they will all appear geometrically correct on the screens at the remote end. For collocated collaboration, however, the table shape allows people to sit around it rather than shoulder-to-shoulder. This is preferable as it enables better interaction between each other and with the shared workspace. In this configuration, the table comfortably sits up to four people.

It should be noted that sitting at the ends of the table during distributed collaboration results in the undesirable effect of being shown disproportionately large, and only partly, on the video displays in the other end. This is a consequence of the short focal length needed by the cameras to achieve the required field-of-view.

Moving beyond current high-end videoconferencing systems, our BIS*i* prototype also incorporates a digital shared workspace called *Tapestry*. Tapestry is available on the two top vertical displays and on the table display.

## THE DIGITAL WORKSPACE: TAPESTRY

Similarly to the physical implementation of BIS*i*, the prototype implementation of Tapestry's GUI components and user interaction design were gleaned from storyboarding, use cases and anecdotal evidence gathered from our previous collaborative work areas. In order to provide a collaborative computing environment for our Blended Interaction Spaces, we developed a range of collaboration tools that seamlessly integrate to provide a natural interaction experience for participants. Tapestry supports the use of large shared display surfaces in hands-on collaboration. It allows people to work together on digital documents and applications, in collocated or distributed settings, and is able to handle window move and scale requests from across sites. Tapestry also allows embedding the display of application windows hosted on any other computer into the shared workspace, enabling shared interaction with these applications. In order to achieve the design aspirations of Tapestry, several novel technologies were integrated. This includes the multi-device capable windowing system multi-pointer X (MPX), the OpenGL-based sharing application Virtual Terminal (VT) and a combination of multi-touch horizontal displays and multiple large vertical displays.

MPX (Hutterer and Thomas, 2007) enables multiple pointers on a single computer, giving multiple users the ability to interact with multiple applications on the shared display simultaneously. For example, a user at one physical site can be working on a spreadsheet on the Tapestry display whilst a user at the other physical site modifies a shared text document on the same display.

Virtual Terminal (VT) provides the functionality to share a computer desktop with another computer, in our case the Tapestry display. Desktop sharing is not a new invention, but our VT implementation goes beyond other systems by enabling sharing of individual application windows rather than the entire desktop. VT also provides near real-time screen updates, which makes it useable for sharing applications with heavy graphic contents, such as 3D models, video content etc., which is currently not possible with off-the-shelf desktop sharing applications.

### Small Group Collaboration with Tapestry

The Tapestry user interface has been designed for both collocated and distributed collaboration. From a GUI perspective, Tapestry builds upon ubiquitous windows based operating systems, utilising the visual and functional aspects of windows, icons, menus, and pointing devices. Moving beyond this capability, multiple cursors have been incorporated for both collocated and distributed participants – and vertical Tapestry displays are shared amongst distributed participants in a WYSIWIS format. As Tapestry is a collaborative space for document and application sharing utilising several display surfaces, including those on personal laptops and other computing devices, there is a need to be able to move electronic artefacts between them. This includes moving pointers, desktop and application windows between personal and shared spaces, for example between a laptop and a Tapestry display, or between the shared horizontal and vertical Tapestry displays (figure 5). This fundamental functionality of Tapestry is supported via a new GUI component referred to as the Interchange Gate.

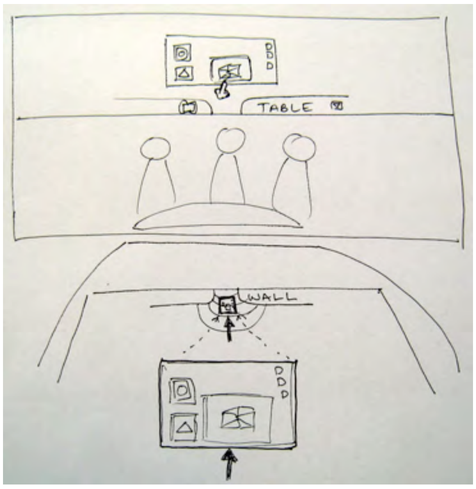


Figure 5: Early design sketch moving electronic artefacts between Tapestry displays through Interchange Gate

The Interchange Gate (figure 6) appears on all Tapestry displays, both vertical and horizontal. It also appears on any personal computing devices connected to the Tapestry.


Figure 6: The Interchange Gate.

The Interchange Gate has two separate methods for moving documents, application windows and pointers between displays. The first method involves 'dragging and dropping' documents, windows, or complete virtual desktops at the "drop zone" of the interchange gate, represented as a shaded zone prior to entering the gate. Once documents have been released at the drop zone, they appear on the destination interchange gate in an iconified format awaiting further action.

The second method is more direct and entails dragging content completely through the gate, exiting on the specified destination display. This functionality also allows moving individual pointers between displays, enabling, for example, a pointing device associated with a personal computer to be used on a Tapestry display.

The drop zones primary role is for sharing several documents quickly without having to navigate through the gate in each instance. Dragging application windows or documents through the Interchange Gate together with the user's pointer is intended to allow a continuous movement from one display to another. In this way the user can continue pointing or working with the object on the destination surface.

The interface and interaction design of Tapestry supports the blending of the two distributed sites by, amongst others, mirroring the location of digital content on the vertical displays across sites, and incorporating a colour scheme that matches the walls, table, and other furniture.

## CONCLUSIONS

In this paper we have proposed the design of a distributed work environment for hands-on collaboration in which users feel that they inhabit the same physical space. This new concept that we refer to as a Blended Interaction Space, emulates the collocated aspects of natural face-to-face communication and shared digital interaction for distributed work teams. It is the combination of the blended spaces physical environment with shared digital interactive workspaces, including personal laptop computers or similar, and there ability to be used in a distributed manner, that makes this design novel and sets it apart from research that has gone before.

We have reported on empirical fieldwork studying distributed collaboration in our different real-world use domains, and described how these findings informed an iterative design process leading to the implementation of a functional Blended Interaction Space prototype for a small, distributed work group. In the description of our functional prototype we have provided details on the physical as well as the digital interaction design produced in order to achieve a Blended Interaction Space for hands-on collaboration. This includes the physical configuration of the distributed sites, and the core functionalities of the Tapestry system: multi-pointer interaction, desktop and application window sharing, touch interaction on the horizontal display, and WYSIWIS distributed digital workspace sharing on the vertical display.

From the initial use of the Blended Interaction Space prototype we have found that the set up does in fact facilitate a strong user experience of being collocated. The configuration of cameras and displays along with the matching of colour schemes and furniture makes the two sites appear blended into one. The positioning of the two life-size video displays supports natural interpersonal communication, and the shape of the table facilitates different group sizes as well as either collocated or distributed collaboration. The static BIS*i* set up, with cameras, displays, microphones, and tables fixed at optimal settings, makes the distributed room a walk-in-and-use facility with very little overhead required.

The Blended Interaction Space presented here does not constitute a final solution to the challenge of supporting distributed hands-on collaboration. It is merely a first step on the way. What we hope to have achieved here is a proof-of-concept set up that will allow us to explore the design of Blended Interaction Spaces further. A lot of valuable lessons have been learned about the design challenges associated with the creation of distributed workspaces that blend into one coherent whole. Several factors that influence the level of blending have emerged from this iterative design work. It is our aim to use the prototype setup to further investigate the effect of these factors and their interdependencies. We also wish to compare the user experiences afforded by Blended Interaction Spaces with those of traditional videoconference systems and face-to-face collaboration.

## ACKNOWLEDGMENTS

This paper is based on work conducted in the HxI Braccetto Project, involving teams from CSIRO, NICTA DSTO and the University of South Australia. We would like to thank the different user groups studied as part of our fieldwork.

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