BIS*i*: A Blended Interaction Space

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CHI 2011, May 7–12, 2011, Vancouver, BC, Canada.
ACM 978-1-4503-0268-5/11/05.

Abstract
Distributed collaboration has been enhanced in recent years by sophisticated new video conferencing setups like HP Halo and Cisco Telepresence, improving the user experience of distributed meeting situations over traditional video conferencing. The experience created can be described as one of "blending" distributed physical locations into one shared space. Inspired by this trend, we have been exploring the systematic creation of blended spaces for distributed collaboration through the design of appropriate shared spatial geometries. We present early iterations of our design work: the Blended Interaction Space One prototype, BISi, and the lessons learned from its creation.

Keywords
Collaborative computing, media spaces, blended spaces

ACM Classification Keywords
H5.3. Information interfaces and presentation (e.g., HCI): Group and Organization Interfaces

General Terms
Design

Introduction
Organizations are continually changing the way that they structure themselves to get work done. In the past two decades they have been operating increasingly within a global context, which has motivated them to develop work practices that take place more and more over a distance. In these organizations, work teams are no

longer put together just to work in collocated settings. Instead, the use of computer-mediated communication technologies make it possible to compose teams based on the expertise required regardless of where it is geographically located.

However, despite the technological progress made within the area of collaborative technologies, the user experience of distributed teamwork is still challenging and frustrating. Physical travel between sites still remains an essential part of any effective distributed collaboration in order to enable face-to-face interaction. Environmental impact aside, this requirement for travel is also expensive and time consuming, and only facilitates intermittent collaboration rather than the more fluid, regular and serendipitous interaction that characterizes collocated teamwork.

The development of video conferencing technologies has largely been motivated by the aim to overcome some of these difficulties. However, the literature has documented that in practice the rhetoric behind these technologies have never quite matched the reality of the collaborative user experience created. Over the last two decades there has been a lot of research seeking to understand and explain why this is the case. This research includes the works of Buxton [6], Dourish et al. [7], Finn et al. [8], Gaver et al. [9], Harrison [11], Heath and Luff [12], Hirsh et al. [13], Mantei et al. [17], Nguyen and Canny [20], Noll [21], O'Connaill et al. [22], Olsen and Olson [23], Olson et al. [24], Sellen et al. [25], Sellen [26], Sellen and Harper [27], Short et al. [28], and Tang and Isaacs [29].

One of the general findings from this body of research is that although traditional video conferencing technologies do support communication within distributed teams, they often remain under utilized for collaborative activities of any realistic complexity. This is due to poor user experience and other organizational factors, e.g. booking rooms, that often hinder their use. This finding is confirmed in a recent study conducted in one particular organization, which indicated that traditional video conferencing systems were used on average for only 12 hours per month [30].

Figure 1. Hewlett Packard's Halo Collaboration Studio

In recent years however, we have witnessed the introduction of more sophisticated video conferencing technologies leading to improved collaborative user experience in meetings between distributed teams. Teleconference systems such as HP Halo (see figure 1), Cisco Telepresence, Tandberg T3, and Polycom TPX are designed to provide a better experience of distributed teams being located in the same room. According to research these systems are used as much as ten times more than traditional videoconference systems [30]. This is partly attributable to the associated enhanced user experience, with users stating that the technology "disappears" enabling them to focus on the collaboration [10,30].

While the findings of Gorzynky et al. [10] and Weinstein [30] have surely motivated our work, it is not our intention here to overplay the significance of such comparative statistics, as there are a number of factors other than better user experience influencing them. For example, the fact that traditional video conferencing units are more numerous in workplaces relative to HP Halo and similar systems may be a contributing factor to the more intensive use of these high-end systems. At the same time, however, the reported user experience and observed usage rates with these high-end systems do indicate that some of the previously well-established limitations with traditional video conferencing systems can be overcome through better design solutions.

The user experience of systems like HP Halo can be described as one of “blending” distributed physical locations into one. Through careful design and setup of the whole video conferencing environment these systems create an illusion of being and interacting in a shared space. This illusion is effective, and the improvement in user experience over traditional “hole in the wall” video conferencing setups is significant. However, little information exists in the literature that describes the design of Blended Interaction Spaces, such as, explaining what factors make distributed physical locations appear blended, how these factors are related, and how to systematically build one.

The purpose of this case study is to offer such explanations and descriptions. Based on the iterative creation of a concrete prototype installation, we have deconstructed the design of a Blended Interaction Space, BISi, and identified a number of factors that influence the effect of blending. Reflecting on our process, we have devised a sequence of steps that will guide others towards the creation of similar installations.

First we present some of the related work that has inspired our research and design. We then briefly describe our research and design method. Following this we describe the design of our prototype installation in detail, presenting and discussing the contributing and competing factors that we have found influence the effect of blending. This includes details of the room setup, the design of our custom-built tabletop, and the setup of cameras. We then turn the discussion towards the brittle nature of Blended Interaction Spaces and how the illusion of blending is potentially broken. Following this, we present a sequence of steps as a guideline for a structured approach to dealing with the trade-offs between some of the interdependencies discussed when creating a Blended Interaction Space. Finally we conclude on this work, sum up our contribution and outline some opportunities for further research and design.

Related Work

Many research projects have studied digitally facilitated meeting spaces for distributed collaborative 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 those that have inspired the development of our Blended Interaction Spaces concept. This includes work within the areas of shared digital workspaces, telepresence, and media spaces.

Shared digital workspaces are systems designed to enhance real time collocated collaboration through, for example, file exchange and screen sharing. Several shared digital workspaces have been reported on in the literature. Of particular relevance to our work, the iRoom [19] demonstrated benefits of working in technology-augmented 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. Experiences with 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 a similar way, the WeSpace multi-surface collaboration system [31] demonstrated the value of users being able to “walk up and share” scientific data and applications on their laptops using a large data wall and a multi-user multi-touch table designed specifically for collaboration in a small collocated group.

Contrasting this work is the research within real time distributed collaboration involving media space technologies and concepts such as telepresence.

Telepresence [15] can be characterised by the feeling of “being there”, achieved primarily by establishing audio and video channels between distant locations [14]. 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, and 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 [14].

One of the most common ways to create an experience of telepresence is through the use of media spaces. A media space is a system that uses integrated video, audio and computers to allow individuals and groups to work together when spatially distributed [17]. 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” [2]. Media space technologies should support both shared workspaces and interpersonal spaces also present in ordinary face-to-face meetings [5]. Media spaces need to account for spatial, social, and communicative interaction [3].

Today, the most widespread media space technology is traditional video conferencing systems. However, as described above, it is well known that this particular technology has serious drawbacks in terms of user experience. In response to this, several more advanced designs have been proposed to enhance the feeling of connectedness and natural working practices between distributed workers. The Hydra system [25] supports multiparty participation in a meeting while preserving each participant’s 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 a 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 [18] 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, and in this way they are sharing the communication space. The Agora system [16] 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. Finally, the Halo Collaboration Studio [10] 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.

One of the current challenges within this area of research is that current telepresence and media space technology is typically poorly integrated with shared digital workspaces. For example, while HP Halo creates an impressive experience of blending distributed work environments into one, support for sharing and working with documents and artefacts is very limited.

Research and Design Method

In this project, we set out to design a distributed collaboration space that combined a shared digital workspace with natural face-to-face interaction as seen in advanced video conferencing systems. Our design work was informed by a number of field studies of distributed hands-on collaboration involving 1) medical experts, 2) material scientists, 3) radio astronomers, and 4) military operations planners [4]. Field study outcomes were explored through design sketching, working with mock-ups (figure 2) and creating scale models, resulting in a detailed design concept.

Figure 2. Physical mock-up of BISi.

We then realised this design concept as a functional installation, creating two identical setups in two separate rooms through iterative prototyping with state-of-the art technology.

Blended Interaction Space One: BISi

Our prototype Blended Interaction Space installation (BISi) was designed to facilitate collaboration within a small group of distributed participants. It was designed as a “walk-up-and-use” system where the user does not have to deal with camera and audio setups or launching of specific software to enable sharing of displays between sites. BISi has a shared digital workspace and allows easy connection of personal computing devices such as laptops. This enables users to display and share “live” content across distributed sites, or to use their laptop’s keyboard and mouse as input devices for interacting with content on the shared displays.

BISi 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.

In working with the physical setup of a Blended Interaction Space there are many factors influencing the effect and level of blending obtained. Some of these factors are independent and can be optimised for a particular environment, use or desired effect. Others however are closely related and often diametrically opposed in the sense that optimising one will have a negative effect on another. This means that in practice, a series of trade-offs need to be made to accommodate for these competing requirements. Below we describe and deconstruct the design of the BISi prototype installation, revealing the factors that influence creating the effect of blending, the relations between some of these factors, and the trade-offs made in our physical setup. First we focus on the overall room setup and furniture. Then we focus on table design, how it accommodated multiple purposes of the room and the use of laptops and other artefacts. We then look at the camera setups, highlighting the different factors that affect blending, and finally the aesthetics of the design.

The room setup

The BISi environment consists of a purpose built table with embedded multi-touch screen and four chairs positioned in front of a wall with four 42” LCD panels and two high definition cameras (figure 3). The shared workspace is displayed on the table display and on the two top displays. The lower two displays are used to blend the two spaces via a high-definition video connection. The LCD panels and cameras are embedded into the wall.

Figure 3. Blended Interaction Space one (BISi)

To create a better viewing angle, the top displays are tilted 18 degrees from vertical. This angle is optimal for viewing this particular screen size and resolution at the specific distance and heights that we are working with in this physical environment, making it easier to read detailed information. The tilting of the displays is matched by identical tilting of the surrounding wall.

Furniture

The furniture used in the BISi environment was designed and selected with great care. The table shape was designed with respect to the angle, field of view, and focal length of the two cameras used for video conferencing. The shape of the table also takes into consideration the need to position participants to their best advantage for both inclusion in the blended videoconference space and for interacting with the computer displays. The table height is set at 72.5cm and cannot be adjusted independently as the distances and angles between table, displays and cameras have significant influence on the blending effect.

The chairs chosen for the BISi environment have adjustable heights to set individual eye levels and both tilt and swivel capabilities. The tilt facilitates comfortable viewing of the top two displays. The swivel supports collocated interactions.

Backdrop partition

The BISi installation is designed to create a self-contained area within a larger work environment where the users can be immersed into a Blended Interaction Space. In order to create this experience, a purpose-built back partition is placed behind the row of chairs, (figure 4). This back partition has two purposes. Firstly it physically and visually separates people from their workplace environment, enclosing them in the Blended Interaction Space. Secondly, it removes any clutter, lines, joints and corners in the background that would otherwise appear on the displays at the remote end, thereby bringing attention to the optical distortions caused by the cameras.

Figure 4. Curved back wall in the BISi setup

Colours

To achieve a blending of the two distributed rooms into one coherent environment, it is important that the wall colours in both rooms appear visually similar. Hence, great care was taken to ensure that the background on the shared workspace displays, the colour behind the videoconference participants, and the embedded wall colour were all visually similar (figure 3). To achieve this, we had to use slightly different colour shades for the wall panels around the displays and for the backdrop partition in order to compensate for the slight distortion of colours introduced by the cameras and displays. In order to ensure consistent colours across the two installations, we also had to install identical lighting fixtures (i.e. same colour temperature, intensity and distribution of lights) in the two prototype rooms, and maintain identical fixed settings on the monitors and cameras in terms of colour, contrast, white balance and sensitivity.

The colour chosen for the BISi environment is a blue-grey. This colour was chosen to make use of the effect that blue recedes [1], so that documents on the display as well as people sitting in the conference environment would be the focus of attention. The specific colour chosen had low saturation and low brightness, so that it did not flare in the cameras. The lighting in both rooms was changed from “cold” to “warm”, resulting in more natural skin colours for participants when displayed on the remote displays.

The table design

The table for the BISi environment was designed and built to fit the geometries of the particular setup. The shape of the tabletop allows two different scenarios of use. Firstly, it supports comfortable seating for up to four people along the curved edge facing the displays for distributed collaboration in the Blended Interaction Space. Secondly, it supports seating for up to four people around the interactive tabletop surface for collocated collaboration with no video conferencing enabled (figure 5).

Figure 5. Table shape supporting collocated collaboration

Distributed collaboration
The front edge of the table (where people are seated) and the back edge (along the displays) are curved in respect to the specific camera perspectives used. The front edge of the table is shaped so that it appears as a continuous curve along the composite panoramic video image displayed at the far end. To achieve this effect the actual table shape is not a true radial curve but a combination of two curves that relate to the focal curves of the two cameras. To stop the video image of the table edge from curving downwards at the intersection of the two displays, the two curves extend outwards along the middle before they join. This shape also considers that parts of the table along the middle are in the "dead zone" of the combined camera view (figure 6).

Careful vertical alignment of the two cameras is also needed so that a representative "slice" of the table edge is included in the video to give the impression that the distributed group is sitting at the same table. Thorough alignment of the two cameras is needed to ensure that the table edge appears as a horizontally joined continuous curve across the bezel between the far end displays (see figure 8).

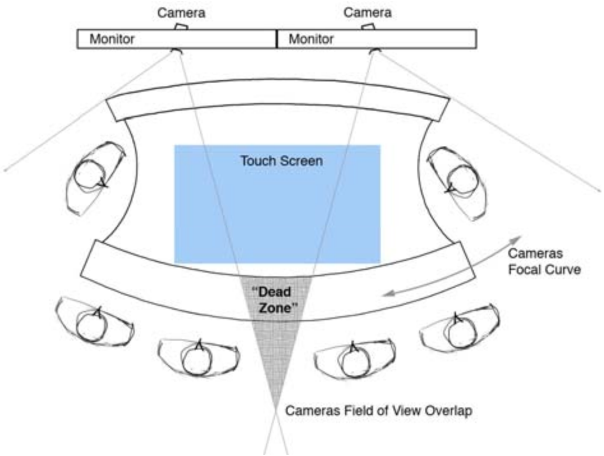

Figure 6. Plan sketch of BISi tabletop showing impact of camera view angles

The table edge is purposely painted a light colour so that it shows up clearly in the displays providing a clear contrast between the table and the people seated at it. The back edge of the table is the same colour as the front edge, and follows a curve that echoes the table shape displayed across the two video displays. The back edge of the table is narrower and not as wide as the front. This introduces an impression of perspective distance along the cameras angle of view – moving it perceptually further back than it is, and therefore closer to the place where the remote participants table edge would be if it was in the same physical room.

Collocated collaboration

Supporting a more flexible use of the collaboration space, the table is also designed to flexibly accommodate a four person collocated meeting around the interactive tabletop which may or may not include the wall displays as workspaces. In this configuration, two participants sit along the front edge of the table, and another two sit on the sides (see figure 5). The sides are inset to allow better access to the touch table. At the same time they also curve slightly toward the front edge. This allows the two people on the sides to easily face the people seated along the front by rotating slightly in their chairs or swiveling towards the wall displays if required. While the viewing distance from these seats is not ideal, the tilting of the top row of displays does make them viewable.

Laptops and other artefacts

The front edge of the table is designed to appear as a bench top, that is, a place to put laptops, digital interaction devices, documents and other artefacts (figure 7). It was designed as a compromise between the need to have space for these items on the table in a way that will not interfere with the table display, and the need to be able to comfortably interact with the touch screen. A distance of 21 cm, the depth of small laptops and A4 documents in landscape orientation, was found to be a suitable compromise. The bench top's secondary role is to guide the placement of the third and fourth (outer) participants in a four-on-four Blended Interaction Space configuration so that they sit along the cameras' focal curves, and within the cameras' angle of view for the optimal effect of blending. The trade-off here was to minimise the overall size of the table while still providing the outer participants with a table space in front of them large enough to be functional.

Figure 7. Bench top area for laptops and interaction devices

The camera setup

The blending of the two rooms into one environment is created by means of two high definition cameras mounted in between the upper and lower row of displays on the wall. Each camera feeds into a corresponding display at the other end via a network based video link, creating a panoramic view into the remote location. Rather than using one centrally placed wide-angle camera, we found that two cameras creates a more natural, and undistorted panoramic image of the four people seated at the table. Using a single wide-angle camera at the very short distance between the wall and the people seated at the table in the BISi environment would result in fish-eye type optical distortions being introduced to the video image, such that people seated to the sides would appear smaller than those seated in the middle. Computer-based solutions to dealing with this problem include software intervention to remove these distortions in real time by flattening and cropping the video image before transmitting it. Alternatively, people could be seated in a round curve along the focal line of the camera. However, seating people at the same distance from one single camera in the middle would place some people significantly closer to the displays on the wall than the minimum comfortable viewing distance for the screen size and resolution used.

Working with 3D modeling software and scale-models, we found that the ideal camera setup for a blended space would require one single camera placed several metres behind the monitor wall. This placement would introduce the least amount of optical distortion and also eliminate any "dead zones" caused by multiple cameras as in the HP Halo and Cisco Telepresence configurations (discussed below). While such camera placement is obviously not physically possible, we speculate that the required camera view from behind the wall could be obtained through "virtual camera" technology enabled by arrays of cameras placed along the edges of the displays on the wall [32]. However, this approach requires more research and, like other computer-based solutions considered, was not viable within the time frame and resources of the project.

Gaze direction

One of the challenges of Blended Interaction Spaces is to create a setup that preserves a sense of people's gaze direction when they appear on a video display. The primary factors that influence the sense of gaze direction experienced in a Blended Interaction Space setup are the offset from the line of sight of the camera, and being seated towards the edge of a video display. Hence, it is not possible to perfectly preserve gaze direction in physical setups like the commercially available systems mentioned earlier or in the BISi environment. This is simply because all people in the room are seeing the same camera views on the video displays and not viewing individual perspectives into the remote location matching their own relative viewing point. Consequently, gaze direction is preserved better when seated straight in front of the camera/screen and deteriorates the further one moves to the left or the right of this line. This means that for a panoramic view into a remote location, gaze-direction is better supported with a larger number of cameras and screens mounted side by side, than with only one wide-angle camera and screen, as this creates a larger number of areas with lower offset from the line of sight of the camera/screen pair. This approach does, however, not counteract the problem of skewed individual perspectives. Also, the more camera/screen pairs placed side by side, the more vertical bezels are created in the panoramic view, and the more overlaps and dead zones are introduced.

Figure 8. Preserving geometries for gaze and gestures

From our experience with the implementation of the BISi environment, we found that for four people seated in each room, two cameras and displays side by side resulted in a preservation of gaze good enough to tell who someone at the remote site was facing. It was also possible to tell which of the top workspace displays a person was looking at (figure 8). In combination with display-level mirroring of the two displays between the two rooms, this level of gaze preservation meant that a conversation could naturally unfold around shared interactive content on the upper displays.

Overlap and dead zone

While providing a less distorted panoramic camera perspective and acceptable preservation of gaze direction, the use of multiple cameras introduces two problems related to the point at which two cameras' fields of view cross over: overlaps, and dead zones (see figure 6). This plan view illustrates that beyond a certain distance both cameras will pick up the same object, making it appear on both displays at the remote end. In order to support the experience of blending between two locations, it is important that this does not occur along the line where the participants are seated but somewhere behind people and therefore not visible given the neutral background partitioning. In fact, to preserve the experience of a blended space, it is important that even lively gestures, as a part of natural conversation, are supported in a way where body parts such as arms, hands, elbows etc. are never picked up by more than one camera and thus appearing on more than one video display. At the same time, figure 6 also shows a triangular "dead zone" before the point of intersection, where objects are not picked up by either of the two cameras. The further back the overlap between camera views is placed the bigger the dead zone becomes. This introduces a difficult trade off between the point of overlap and the size of the dead zone.

In our implementation of the BISi environment, we placed the overlap between camera views immediately behind the line of seated participants. This created a visual dead zone that reached into the space between the two people sitting in the middle of the table that matched the 6 cm width of the bezel between the two video displays. In this way, people would not appear on more than one display at a time, while at the same time allowing arm gestures, such as pointing, across the field of view of two cameras to appear naturally jointed across the two displays. The extent of the dead zone resulted in a triangular area (25cm at tables edge in our setup) in the middle of the table where no one can be seated without them appearing disjointed on the video display. However, as this particular area right in front of the bezels between displays is not a good place to sit anyway, we accepted this trade off. We also designed the table with a wide table leg (25cm) at this position to deter people from sitting right in the centre of the table, even though this leg was not structurally needed for the table.

Focal length

Another important factor in the cameras setup, which also impacts on all of the issues above, is the focal length setting. It is important that the cameras' focal length is set to create "natural" images the way we see them with our naked eyes (as with 50mm lenses in 35mm photography). At the same time, the focal length has to create a natural size representation of people at the far end on the chosen video display, so that they appear in the correct size as if they were sitting on the opposite side of the virtually joined table. The optimal focal length is also dependant on the distance of the table from the cameras.

In order to create an experience of blending it is important to have the front table edge in shot, while not cutting off the top of people's heads. Having the edge of the table in shot contributes to the experience of a continuous shared surface while experiencing that someone's head is partly cut off on the video diminishes the experience. Ultimately, this would undermine peoples' trust that they are themselves appearing properly on the video, re-introducing a desire for the “self-view” of traditional video conferencing systems, which goes against the “natural to use” philosophy of a blended space explained earlier.

Given the relatively small size of our video displays in terms of representing people as life sized, the focal length setting was particularly fragile in the BISi setup. The size of the video displays was carefully chosen using standard monitor sizes, to maximise the width of participants being displayed as a perceptually natural size, while minimising the height above eye level of the workspace displays, for comfort of viewing data and interacting with these screens.

Field-of-view

Using multiple cameras side by side creates a very wide composite field-of-view. This has an impact on the room layout required for creating a Blended Interaction Space where no joins between walls, floors and ceilings are picked up by the cameras. In the specific case of the BISi environment, this required a very wide and short room of approximately 3x9 meters. Purpose building a room of those dimensions, or similar, is obviously not always possible or desirable. As an alternative, the BISi installation uses a moveable, curved partition (as described earlier) to provide a smooth backdrop. The advantage of the curved partition is that it covers the edges of the joint field-of-view at a much shorter distance than a straight back wall, hence limiting the physical area behind people required for the effect of blending. Since the cameras are also tilted downwards, the height of the partition can be reduced to approx. 1.5 meters while still covering the field-of-view. In the development of the BISi environment, we did not have time to experiment with different materials for the back partition but the use of a smooth, truly curved surface is recommended.

Aesthetics

Aesthetic considerations were made in respect to the tabletop design. To minimise the visual “weight” of the table, the front and corresponding back curved edges are painted and textured to appear as “floating” narrow bench-type surfaces. This impression is reinforced by the fact that they extend slightly beyond the main body of the tabletop. This keeps the actual tabletop to a reasonable “small group” size while providing the length of work area needed to accommodate four people seated along it. The intention being that this set up should not need a dedicated large room to accommodate it, but that it can be located in the corner of a shared area, or a large office. The table surface between the two edges is painted black to match the touch table when it is turned off, but also to visually recede below the lighter coloured bench area.

In line with classical architectural theory, we decided to work with the golden rectangle and golden section in defining the proportions of our table for aesthetic appreciation (figure 9). The core rectangle shape of the table design is in the proportion of 1:1.618. Overlaid on this are the two curved edges. The widths of these edges correspond to golden section proportions of 1(back edge):1.618 (front edge). For visual cohesion, the angle of the sides of the front edge follows the camera line and the angle of the sides of the back edge is determined by a line drawn from the golden section point on the side curve of the table to the far ends of the monitors. This use of classical proportion and subtle alignment with camera lines gives the tabletop harmonious aesthetic qualities designed to contribute to the positive user experience of the blended interaction space environment.

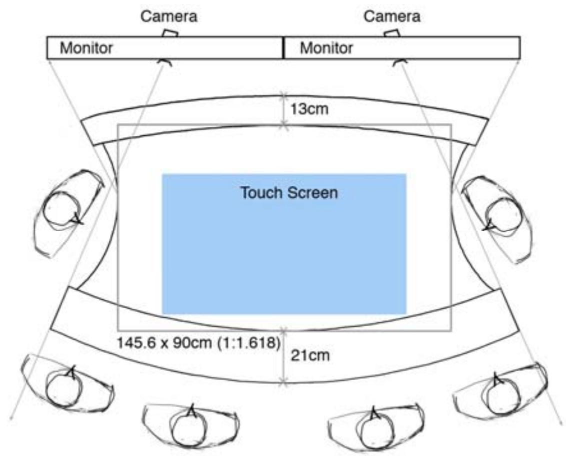

Figure 9. Plan sketch of BISi tabletop showing aesthetic proportions and alignment to cameras

Breaking the Blending

Given the brittle nature of the focal plane in which distortions are not visible, it holds that it is very easy to break the illusion of blending by, for example, shifting the table or moving out of the optimal distance and camera view (rolling the chair backwards, leaning forwards, or standing up). How people perceive and whether or not they happily accommodate for these breaks in the perceptual illusion of blending needs to be evaluated. As discussed earlier, preserving the blending can be achieved to a large degree by designing the space to have strong affordances for staying within the focal plane in which the illusion functions well. In the case of BISi this is done, for example, by placing a table leg in the centre of the front edge of the table, thereby making this area in the cameras' dead zone unappealing to sit in. Similarly, the need to stand up has been eliminated by providing only interaction mechanisms that work best while seated. However, including an interactive tabletop surface in BISi exemplifies how affordances in the design can have the opposite effect and cause people to interact in a way that breaks parts of the experience of blending. Such an embedded display of course has the affordance to lean forward and interact directly with content displayed on the table, which causes arms and hands to be "lost" from view and causes upper bodies to appear unnaturally large on the video displays at the far end.

Blended Interaction Space in 10 steps

Based on our experiences, there is no simple configuration representing the optimal room and camera setup for a Blended Interaction Space. Setting up such space for distributed collaboration in practice involves a series of trade-offs and best-fit solutions while working iteratively within the interdependencies discussed above. As it only takes a slight change in any of these factors to break the illusion of blending, the setup has to be iterative while continuously reviewing the effects of particular choices – ideally in relation to real world use over time. Having said that, it is our experience that the most important overall factor in creating the illusion of blending is the precise setup of appropriate camera views. Once suitable camera views have been achieved, improving on secondary factors such as colours, lighting and the shape of furniture will only contribute to the effect. However, if the camera views are not appropriate, no amount of work on these factors will create a good illusion of blending.

In summarizing our experiences with developing the BISi environment we have developed an overall guideline with ten steps providing a structured approach to dealing with the trade-offs between some of the interdependencies discussed above when creating a Blended Interaction Space:

1. Choose the number of people to accommodate at each location. Match the total width of the video displays to the width of this number of people seated side by side as perceived from across the table.
2. Choose the desired distance between seats and wall displays taking into consideration optimal viewing distance and required table size.
3. Match the focal length to the display size used, ensuring that people appear life size. Ensure that focal length is identical for all cameras.
4. Tilt the cameras vertically to get a shot from waist up while keeping peoples' heads in shot.
5. Pan the cameras horizontally to place the overlap between individual fields of view just behind the line of seats at the table.
6. Measure the size and position (curvature) of the back partition required to cover the cameras' joint field of view, ensuring that the floor is not in shot.
7. Choose appropriate lighting for the rooms creating a colour temperature on the video displays where skin tone appears natural.
8. Choose front and back wall colours so that the colour on the background shown on the video displays matches the wall along side these displays.
9. Create the precise table shape so that it appears natural in the video with a continuous front line curve across the displays. This can be done by simply drafting a shape on a piece of form board placed horizontally in front of the cameras at the desired table height.
10. Optimize the shape and aesthetics of the table to suit the requirements for collocated and/or distributed collaboration, group size, etc.

Using these steps, and iterating between them where needed, you will be able to create the effect of blending two distributed physical locations into one coherent workspace.

Conclusions

Inspired by new types of high-end videoconference systems, we have presented the design of a "Blended Interaction Space" for distributed team collaboration. Using this prototype installation as an example, we have highlighted and discussed the contributing and competing factors influencing the effect of blending. Unlike traditional videoconferencing setups our design takes factors into consideration such as the physical configuration of rooms, shape and positioning of furniture, and exact camera positioning and configuration. From our experiences with the iterative work on optimising and trading off these interdependencies, we have presented ten steps to guide the creation of other Blended Interaction Spaces.

The challenge of creating Blended Interaction Spaces is a non-trivial one. The overall goal of merging distributed locations into one coherent whole through appropriate geometrical configurations of rooms, furniture and cameras is a seemingly simple one, but in practice this requires a significant amount of iterative design work. By documenting and reflecting on the process of designing and implementing a Blended Interaction Space prototype installation, we have captured a selection of the contributing and competing factors that influence the effect of blending as well as some of their interdependencies. It is our hope that by making these factors explicit we are able to provide a better informed starting point for other researchers and interaction designers intent on similar challenges to create and improve Blended Interaction Spaces for distributed team collaboration.

Further work

Our work leaves several opportunities for further work. Firstly, the user experience of the BISi prototype installation should be evaluated through lab experiments and field studies of real world use. Secondly, it should be investigated how the effect of blending scales down to "discount" installations in the cheaper end of the technology spectrum using, for example, Skype and smaller video displays in a geometrically appropriate configuration.

Acknowledgements

BISi was developed in 2007-08 as a part of the HxI project by CSIRO, DSTO and NICTA in Australia. The authors thank everyone who worked actively on the project. In particular, we acknowledge Michael Broughton's significant contribution to the detailed design and implementation of the BISi prototype.

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