Horizontal Interactive Surfaces in Distributed Assemblies

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Abstract In recent years we have seen a huge growth of interest in tabletop research and technologies. Apart from the increasing research into underlying hardware technologies and interaction mechanisms, there has also been a significant interest in the dynamics of collaboration that happens "on" and "around" interactive tabletop surfaces. Most of this work has focussed on collocated interaction, exploring issues such as equity of participation, territoriality, orientation and coordination. This body of work has highlighted several important aspects of tabletop form factors, particularly in terms of impact on collaboration dynamics. Much less attention, though, has been given to collaborative work practices happening around interactive horizontal surfaces in the presence of other media, technologies and artefacts, and especially in the context of remote collaboration. This chapter presents research and findings of interactive tabletop settings in environments that include various other artefacts and devices. We label these settings with the term 'assemblies' to describe and emphasises the real-world character of settings that draws on the concepts of Ubiquitous Computing and Media Space, as well as everyday objects such as pen and paper. We conclude this chapter by highlighting important aspects of distributed assemblies with respect to the interactivity and the orientation of these environments.

Introduction

Interactive tabletops have been under investigation over a decade. Research effort has concentrated on appropriate technologies for the tabletop hardware, as well the software for interacting with the displayed information. In addition, research has been conducted to further our understanding of collocated collaboration at tabletops and how to best support users in these settings. The tabletop interface has unique characteristics that differentiate it from others, such as desktop computers,

handheld devices or electronic white boards. For example, with tabletops, the notions of "top" or "down" as observed on traditional vertical desktop computer displays do not exist in the same ways. Together with the use of direct touch and gesture interaction, these properties have crucial consequences for the design of tabletop interactions and technologies. Placing objects on the interactive tabletop is another example where new avenues for tangible interaction research are opened. Traditional applications with a graphical user interface designed for use with mouse and keyboard need to be refined when interaction is by direct touch input devices. Similarly, the ability to rotate objects such as application windows or digital documents, imitating some of the handling of paper documents has become another important issue. Another uniqueness of the tabletop interface is the computer display and interaction space no longer belong to an individual. Due to its size and horizontal layout, the interface is considered semi-public rather than private. Furthermore, the tabletop interface is highly suitable for small group collaboration, whether seated or standing around tabletops.

As well as office based applications, entertainment and domestic applications have emerged, as well as the use in public spaces such as cafes and museums. The most valuable body of research on tabletop settings has focussed on the tabletop display and how to interact with it. However, more work is necessary to build on the research that has sought to understand the role of tabletops in the real world application scenarios. With this in mind, today's real world collaborations neither consist of solely using tabletops for interaction nor are they limited to only co-located joint activities. Laptops, netbooks, and mobile phones amongst others have become increasingly used for collaboration while applications may run in a computing cloud or data centres. Collaboration across multiple sites beyond traditional phone and video conferences has also becomes more important when it comes to teamwork using groupware applications on high-speed networks. These scenarios may involve the use of video mediated communication with shared interactive workspaces. In addition, today's hybrid work environments consist of digital workspaces as well as real spaces with users fluidly selecting and switching between them effortlessly as they carry out their work. An interactive tabletop also combines aspects of real and digital workspaces. The table is a physical surface around which a small team can work together, while the horizontal interactive display provides team members access to any digital information, documents, and applications.

In the following discussion, we will provide a brief background of the role of tabletops in combination with other information and communication artefacts – both digital and physical. We use the term 'assemblies' within our research context and, in particular explore '*distributed assemblies'* that incorporate interactive tabletops. We provide an overview of our related studies targeting aspects of interactive tabletops in distributed assemblies. Finally, we discuss the results of our findings.

Background

Consider office workers in typical everyday settings: besides having their own standard desktop computer, they utilise a variety of other devices and artefacts that constitute and contribute to their work environment. These devices and artefacts are either directly or indirectly related to the desktop computer, such as attached portable digital storage units, mobile phones or a collection of data CD-ROMs on the shelves. Even more traditional media exist and are still used in today's offices, such as books, journals, pens and paper documents. White boards and pin-up boards, are still useful to quickly support discussions in face-to face meetings, jot down notes, or to sketch out ideas. Often, interactions with applications on the desktop computer or laptop are complemented by using paper and pen, e.g., for note taking and sketching. During a presentation of electronic slides to a small group, a traditional flip chart might be used to capture topics, or discuss side ideas. In other words, nowadays work environments still draw on traditional media and technologies for everyday work practices. What holds true for today's work environments for individuals may not be any different to collaboration environments in the domestic domains or when small groups gather around interactive tabletops.

Tabletops in scenarios of Ubiquitous Computing

Integrating tabletop settings into everyday environments, whether in the work place, public spaces, or domestic environment, relates to scenarios described and envisioned by Mark Weiser in the early 1990s [1]. He introduced the paradigm of Ubiquitous Computing (Ubicomp) in which computing was embedded into everyday objects and environments. Tabletop computing fits neatly within these envisioned scenarios of Weiser. What is important here though is the need to consider the tabletop in the context of the broader ecology of interactive devices and everyday objects that comprise the everyday scenarios of the Ubicomp vision.. Early research works have explored how interactive tabletops can be integrated into an office environment with other enhanced room elements [2, 3] or with a set of laptops [4]. Research continues into recent times using hand held devices (e.g. [5]) or mobile phones (e.g. [6, 7]). Further research is necessary to articulate other aspects of artefact assemblies with respect to tabletop computing.

Tabletops in Media Spaces

Although an interactive tabletop is well suited for the work of a small collocated group, tabletops can also be considered for distributed collaboration scenarios.

When accepting slightly tilted interactive display to be classified as tabletops, the ClearBoard System from 1992 by Ishii and Kobayashi [8] can be regarded as one of the most important landmark research publications. The ClearBoard can be considered as one of the first examples of a distributed collaboration using tabletops. Interaction on shared displays was accompanied by video link between two sites to provide eye contact amongst collaborators.

In the same year, the Hydra desktop video conferencing system was presented by Sellen et al. [9]. Their work explored the possibility of maintaining the correct spatial configuration of the conference partners. The Hydra system was combined with the Active Desk [10], also a slightly tilted interactive display, to showcase the use in video conferencing application with shared applications. In the late 1990s the Agora system [11] was developed to study mediated remote collaboration around a shared desktop. The system was designed to allow up to four participants to collaborate by monitoring each others' activity naturally. Similarly, the goal of the t-Room project [12] was to allow users in multiple t-Rooms feel as if they were in the same room. In the centre of the t-Room was a worktable that was monitored with a video camera and replicated in the display on the worktable at the remote sides. Recent studies have investigated implications for the distributed collaboration "around" shared workspaces on interactive tabletops (see e.g., [13, 14]), while some of these works are in the tradition of the ClearBoard system, where a video link was integrated, others rely on audio communication only (see also previous chapter in this book).

Distributed assemblies

The focus of this chapter is to discuss tabletops in the presence of other media, technologies, devices, and artefacts. We use the term *assembly* to refer to an environment or space for interaction and collaboration consisting of multiple devices and artefacts with a wide range of different properties. Devices and artefacts may be large interactive displays, standard desktop computers, laptops, netbooks, smart and mobile phones and also includes other technologies such as audio and video communication technologies. Further possible elements of assemblies are white boards, flipcharts, books, folders, paper and pen, as well as other room elements such as tables, chairs etc. This definition of assemblies strives to comprise not only scenarios of Ubiquitous Computing and of Media Spaces, but eventually also those of Tangible User Interfaces, Multi-Display Environments (MDE), as in [15, 16] and Roomware [3], amongst others. Not only does the term attempts to integrate the above listed devices, scenarios and approaches, but it also to highlights the heterogenic and hybrid character of everyday interaction and collaboration environments. The concept of *distributed assemblies* then refers to scenarios of distributed collaboration where one or more remote spaces form assemblies for users to work with.

Studies in distributed assemblies

In this chapter, we also offer reflections on issues arising from tabletops in distributed assemblies. In particular, we explore the relationship between *interactivity* and *non-interactivity*, and the implications of video mediated communication in distributed settings using tabletops. These are presented through a number of studies. We first look at a field study of an interactive table deployed in the public setting of a café bar. The notions of interactivity and non-interactivity are raised. Related to these notions, we then present a second study which offers an examination of the role of a table rim in managing artefact assemblies in collocated use. Following this we report on a field study of distributed meetings in an office environment in which an interactive horizontal surface is used to interact with shared vertical displays. Finally, we report observations from a more formal investigation into tabletops in distributed collaboration. These studies highlight and emphasise the boundaries of interactivity as well as the influence of video mediated communication on the perceived orientation of the setting in distributed assemblies.

Collocated tabletop interaction

The focus of the majority of the tabletop research is on the interactive horizontal display area and on understanding how best to support interaction and collaboration at tabletops. Research has been conducted to gauge the physical reach at tabletops in terms of ergonomics [17], and the use and organization of the space around tabletops during collaboration [18]. These concepts need careful examination when designing tabletop interfaces for successful deployment in real-world settings. Little attention so far has been paid to the fact that most horizontal interactive displays still require a physical support base or frame around the display area, which we refer to as the rim around the tabletop. The rim usually frames the entire interactive display area, and we can assume that the rim can be reached without much effort and used very easily. Therefore, it is very likely that the rim, though non-interactive, can serve specific needs of users, for example, to physically lean upon, to rest arms, or to place and work with artefacts such as paper. Of additional interest is the rim exists in the area that can be characterised as the individual's 'personal space' [18] used exclusively by a single user when considering group collaboration at tabletops. Upon realising the concept of personal space in digital tabletop settings, it is apparent this personal space includes both a non-interactive area on the rim and an interactive area on the horizontal display.

Unsurprisingly, tabletop research has so far focused exclusively on issues of interactivity with tabletops, from different sensing and mechanisms to application design and social studies of tabletop usages (e.g. see [19, 20, 21]). Little explicit

attention has been given to understand the role of non-interactive areas on tabletops and the relationship between interactivity and non-interactivity. Actions in the interactive area may constrain action in the non-interactive area and vice versa and this could impact and shape the ways interactivity is managed.

In this subsection, we offer reflections on the relationship between interactivity and non-interactivity in the context of artefact assemblies in tabletop settings. These are presented through a number of studies. The first is a field study of an interactive table deployed in a café bar, while the second is a more formal experiment that explicitly looks at the role of a table rim in managing artefact assemblies in tabletop use.

Café-bar

The relationship between interactivity and non-interactivity is both dynamic and complex. At times it is clearly delineated through design (e.g. a rim around a table) while at other times the relationship is fluid - something negotiated by actors in the accomplishment of social action. As Crabtree argues, this accomplishment and organisation of social action relies upon the spatial and material arrangement of artefacts [22]. In any setting and with any technology, these arrangements comprise both interactive and non-interactive elements and the relationship between them. In any particular engagement with an interactive table people will move fluidly between interactive and non-interactive intentions or actions with a continual negotiation of the regions and boundaries where interactivity and non-interactivity should occur. In this respect we can draw some parallels with Palen and Dourish's [23] discussion of how people continuously negotiate boundaries of public and private dissemination and the work of Bellotti et al [24] in their discussion of sensing systems where inherent ambiguities exist between intentional and non-intentional interactions and where there is a need to continuously negotiate the boundaries between them.

The field study involved the deployment of an interactive table in a café-bar. The interactive table was situated in a room in the bar with a large sofa and wooden bench arranged for sitting around the table (see figure 1a). The rest of the room consisted of several small coffee tables each with 3-4 chairs arranged around them (see figure 1b). The interactive table consisted of a PC and a horizontal touch screen display housed in a low coffee-table format style casing. The touch screen display was a 40-inch plasma with a screen resolution of 1280x768. A wooden rim of approximately 11 cm surrounded the screen on all sides. The touch screen was single touch only. The content on the display consisted of home page with graphical links to a range of short films, interactive installations and games from *dShed* (www.dshed.net) the Watershed's online showcase of creative digital media.

To set the context for discussion of interactivity and non-interactivity, we begin an analysis of the relationship between people and standard table surfaces in the room without interactive consequences. The spatial properties of the tables are of

significance here because they essentially position people at particular physical distances from each other and in particular postures with respect to other social actors on the table. Physical distance, being related to zones of social distance has bearings on the way the table surfaces are used and touched under different social circumstances. We illustrate this by examining an episode where two young women were having a meeting at one of the coffee tables depicted in Figure 1b. On the table they had separate paper documents for discussion arranged on the table among their drinks. At different points during the conversation the girls engaged with and touched the surface in different ways. One of the girls rested her elbows as she leant over the document on the table to read it. The other girl then leant into the table with her arms touching the surface as a way of signalling her interest and attention. Through the conversation they leant in and out of the table in a carefully choreographed manner. Where and how the surface was touched during the ongoing course of these encounters are intimately bound by the unfolding action, in-the-moment social action the relationship with the material arrangements of artefacts on the table and the relationship with table itself. The spatial properties of where and how the surface was touched were something continuously negotiated by all parties. It was highly contingent and something done unknowingly without awareness. It was done with great social significance but importantly, as we shall discuss later, without interactive consequence. In other conversations we observed, there was similarly choreographed use and touch of the table surface but with different spatial properties reflecting the different social relationships, artefact configuration and unfolding conversational trajectories of the particular episodes.

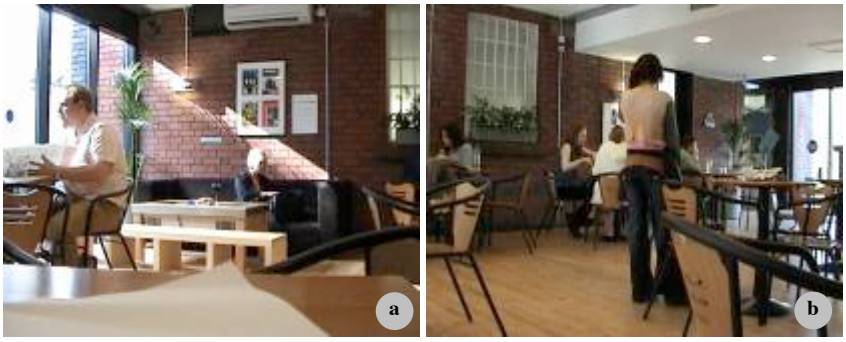

Fig. 1. Images of (a) the interactive table; (b) the room in which the table was situated – the table is situated to the left of the area shown in (b).

The significance of this dynamic use and touch of the non-interactive surfaces becomes apparent when we place these issues within the context of the interactive table where interactive and non-interactive intentions in relation to the horizontal surface come together. Let us consider an episode where the non-interactive intentions and actions impacted on subsequent interactive opportunities with the table. In this episode a woman arrived at the interactive table. She was struggling to carry a large handbag, several packets of crisps and peanuts and a glass of red wine in

both hands. She dumped them all down together on the glass surface of the interactive table, without initial concern for the arrangement of the objects. With her hands free she was able to then arrange things properly on the interactive surface as she settled down.

In this episode, as the woman arrived at the table, its primary function was as a physical surface onto which an awkward-to-carry group of objects needed to be rested. At this point in her encounter, the interactive properties of the table were of secondary concern. In performing this activity, though, the non-interactive placement of objects then rendered the interactive properties of the table inaccessible. This was not simply through obscuring the information on the table but rather that this particular touch screen technology did not gracefully deal with touch detection in the context of other objects on the table. By doing these non-interactive actions at the beginning of her encounter with the table, further uses of the interactive properties were blocked.

What is apparent in this episode is the multi-faceted nature of the table surface and actor intentions within the context of the café environment. We have highlighted here the behaviour on arrival but of further significance here is how encounters such as these unfold over time during the visit [25]. For example, other people arrived to join the woman at the table later on in the encounter and they too placed drinks and objects on the surface that inhibited interactive use. Similarly, bar staff brought plates of food to the table and placed them down on the surface. During a typical café episode, then, the points at which there was a clash between non-interactive intentions and interactive potential were many. More importantly, these points involved other parties. Any management of the boundaries between non-interactive and interactive use was then something to be dealt with collaboratively within the context of other well-established social and behavioural schemata for café episodes.

In managing the boundaries between interactive and non-interactive intentions, we observed a number of notable behaviours. In the first instance, we saw some placement of bottles and glasses on the rim of the table in order to allow interaction with the content on the display. Important to this strategy is the clear delineation in the design of interactive and non-interactive properties of the table - the wooden rim being understandably non-interactive in these instances and thus affording placement of objects in the context of interactive intent. For some people though, the rim was too narrow and raised, leading to concerns about precarious placement of drinks at the edge of the table and the potential to spill onto the table and damage the technology. For these people, while there was clear delineation, the particular dimensions of the design created hindrances to such a strategy.

Exploratory rim study

A rim around an interactive display can be found in various settings and in different combinations of display technologies and interaction devices. Lets consider

first research tabletop systems that showcase possible patterns of use of the rim and commercial tabletop systems to investigate how the rim is configured and used. The UbiTable [26], for example, is based on a collaboration scenario that includes personal laptops in an ad-hoc meeting around a coffee table-like surface. The multi-touch device [27] rests on a real table and comes with an approximately 5cm rim elevated several centimetres from the real table. Possibly due to reasons of stability, laptops are placed on the rim and partially occlude the personal interactive display area, while the public display space in the centre remains visible for both collaborators. In recent research about the equity of interaction participation [28], the same multi-touch device in a similar setting is used. The physical table under the touch device serves as an area to lean on, place sheets of paper and operate with computer mice.

For the tabletops used in the Augmented Surface system [4] no explicit rim is realised since the whole surface of a table is used for top-down data projection. However, the laptops in the collaboration scenario are placed on the edge of the physical table within reach of the users leaving a central space on the table for group usage. In other research work, the rim is explicitly introduced to support the comfortable use of mice and for leaning on the table while standing around it [29, 30].

Most commercially available systems using display technology such as rear projection and Liquid Crystal Displays (LCD) come with a rim around the display [31, 32]. The predominant design of each of the three tabletop systems we examined comprises a non-interactive rim around the interactive display area that is smaller at the long side of the display than at the short side. This holds for the design of table systems with a 4:3, as well as with a 16:9 screen ratio. The analysis of technical specifications reveals the rim at the long side of the table systems varies from 11, 18 and to 28cm, respectively. The short side of the table has a rim of 18, 25 and 55cm. We considered also two other tabletop systems that come with a uniformly sized rim: the DiamondTouch DT107 [33] and the reacTable* [34]. With this is mind, one can assume this is a frame for physical support of the technology rather than a rim designed deliberately for users (see Figure 2). While the small tabletop systems [31, 32] are designed for sitting around, the InteracTable [35] with its larger rim is designed for small groups standing around the table [3].

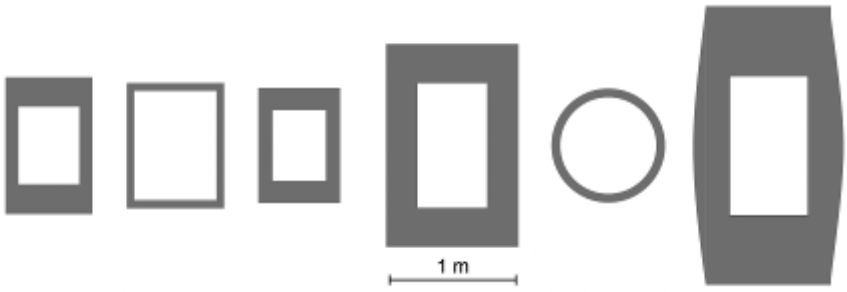

Fig. 2. Rim designs around horizontal interactive display spaces. The available systems depicted are (LTR): Microsoft Surface [31], DiamondTouch DT107 [33], Smart Table Model 230i [32, 36], table shape used in our study, reactTable* [34] and InteracTable [35].

To further understanding of how the rim around a digital tabletop is used with an assembly of artefacts, we conducted an exploratory study collecting quantitative and qualitative data through questionnaires, objective measures and observations. We configured a 46-inch diagonal LCD display (ratio 16:9) as a multi-touch tabletop. The height of the tabletop was 73.5cm, chosen to accommodate comfortably seated positions around it. The table had a non-interactive rim of 25cm on the long side, and 31cm on the short side, of the interactive display (see fourth table shape from the left in Figure 2). This design was guided by those of commercially available tabletop systems and by the form factors of a standard laptop (footprint of 33cm by 23cm), a wireless keyboard (44cm by 16cm) and the A4 paper size (21cm by 29.7cm). We decided to have one side of the rim slightly thinner than a standard laptop's width and the other side shorter than the height of an A4 page. The aim was to elicit participant preferences regarding the placement of items on either interactive or non-interactive areas.

A group of three participants worked collaboratively on the interactive tabletop sorting task with 18 magazine covers (electronic copies of cover pages only) by defining two categories and organising the pages on the digital multi touch tabletop. Additionally, the group was provided with one set of spiral bound print outs of the 18 cover pages, one laptop with digital copies of the cover pages to flip through, and a wireless keyboard/ mouse set to control the pages on the tabletop.

After the participants filled out an initial questionnaire, we briefed them on the task. The participants were asked to come to an agreement as to who would take each of the three items to the tabletop area. We informed them they could change their seating position, swap the selected items with their colleagues and use multi-touch surface at any time. The participants were then asked to bring their selected item to the table, take a seat, and make themselves comfortable, awaiting further instructions. The tabletop display showed electronic cover pages in a pile, rotated at various angles. We captured the seating positions of the participants, and the location of the items each placed on the table, before they began the task. When asked to begin, the group worked on the task (see Figure 3) until the pages were organised to the group's satisfaction. Finally, they filled out a post-task questionnaire.

We collected data from 12 participants (4 groups). They were on average 26.6 years old (standard deviation (SD) = 3.1), 3 were female and 10 reported to know the other group members. With respect to the participant's experience of using display technologies, 8% reported having no experience with large screens, compared to 50.0% having some, 34% regular and 8% daily experience. Regarding their experience of using horizontal computer displays, over a quarter of the participants had no experience, while 75% were somewhat experienced. Most of the participants had some or regular experience with touch interaction. We asked the

participants also about the assembly of artefacts they usually bring into their meetings. Among the most mentioned were pens (100%), note paper (67%) and mobile phones (67%). Other items brought into meetings are print outs (92%) and laptops (50%). However, 25% reported to always bring their laptops into meetings.

Our observations revealed that 75% of the participants sat on the long side of the table. The predominant group seating arrangement had one participant sitting at each long side and the third sitting at the short side of the table (see Figure 3). Only in one trial, two participants sat side-by-side at one long table side facing the third colleague on the opposite long side. Furthermore, we observed that participants who brought the laptop to the table sat down exclusively at the long side. 25% of the participants with the keyboard and 50% with the print outs sat at the short side. The participants positioned keyboard and print outs predominantly in front of them, while they placed the laptop on the side and slightly oriented the laptop display towards them. One participant explained that the laptop "screen prevented seeing the [horizontal display]. So it had to be sideways." The participants aligned the items with the border of horizontal display so as to not obscure the display, though they were not instructed to do so. During the course of the task they neither changed their initial seating position significantly, nor did they swap the items they brought to the table. In one trial, a participant with the laptop quickly rearranged her initially selected seating position at the short side and moved to a long side of the table to sit side-by side with a colleague. When asked about the motivation for this, she suspected that she would have better access to the pages on the table in her new position. In all trials, the participants occasionally used the items they placed on the table, while in the final phase, the interaction on the multi-touch table dominated.

Fig. 3. Team of participants completing the classification task using an assembly of artefacts such as laptop, keyboard, mouse and set of printouts.

In the post-questionnaire, we captured basic ergonomic factors of the tabletop setting. Nearly all of the participants (11) reported having good reachablity of the digital cover pages on the horizontal display. Seven participants agreed they had enough visibility of the pages, but 4 participants raised issues on this point. Three of these four participants were sitting at a short side of the table. One participant explained after the trial his strategies to cope with this shortcoming: he compensated for the poorly visible cover pages on the opposite side of his seating position by looking up and investigating them in his print outs in front of him. Almost all participants assessed the size of the rim to be appropriate and reported that they had enough space to place their items. Concerns were raised as to whether the small rim at the long side of the table is sufficient for supporting the laptop. One participant rated the rim to be a "[g]ood size but too small for laptop" and another criticized that "the [long] sides are too small for A4 to fit."

Distributed collaboration

In everyday work, it is well established that paper plays a vital role in the ways work practises are conducted (e.g. [37]). Given the particular affordances of the paper medium, it is likely paper will continue to form a part of the artefact assemblies within which tabletop-based work interactions will be done. While there

have been efforts within tabletop research to accommodate paper artefacts in the interaction, this has typically involved an explicit attempt to provide computational links between the physical and digital worlds (e.g. [38]). However, there has been little effort in looking at the behavioural practices of everyday paper documents in the context of tabletop settings (though see recent work by Ruiz et al. [39]), in real world settings and in particular in distributed environments.

Our concerns in this section are in understanding the role, value of and behavioural practices with paper documents and other artefacts in the context of distributed tabletop settings. We would also like to understand the impact of the orientation of the setting on the ways distributed tabletop collaboration is carried out.

Collaboration appliance Meeting Wizard

In articulating these concerns, we draw in particular on observational studies of a distributed collaboration appliance called Meeting Wizard. With Meeting Wizard, a large vertical projected display is used to present information to a group of users. To interact with this display surface, multiple interactive tablets are placed on a horizontal surface used by the group members to simultaneously point to, navigate through and mark up the information on the vertical display. Using this arrangement, the pointing and marking technology is decoupled spatially from the viewing surface providing the benefits of both vertical display and the configuration of the group around a horizontal interaction surface. As we shall see in the fieldwork, this arrangement has particular implications for how shared interactivity is managed and the clear demarcation of personal versus shared resources.

Fig. 4. A distributed meeting in which personal paper resources are marshalled around the tablet while interacting with the large shared projected surface.

From our fieldwork observations of Meeting Wizard use in distributed collaboration, a notable feature was how individuals in the meeting would often have their own paper version of the digital document being shared over Meeting Wizard. While the fact that paper documents are brought into a meeting is of course not a new phenomenon, the distribution of activities across the same document together in digital and paper form is nevertheless worth some commentary in light of our concerns with distributed media assemblies. In particular, the role they play in the management of ongoing individual and collaborative activities. The key here is the distinction in the shift between personal and shared use of information.

If we consider the documents presented on the shared surface, these are essentially visible and "owned' by all those present in the distributed meeting. Changing the view or marking up the document is in essence something that has to be achieved collaboratively; something that has to be negotiated with other present parties. Typically then, people would use some form of conversational device or signal in order to negotiate changing page or view. While this shared view works for coordinating attention, individuals may also want to look at different parts of the document at different times to support a particular cognitive strand they were taking. For example, in response to an ongoing conversation, a particular issue might have been evoked in an individual's mind that relates to another part of the document. They might use their own paper version of the document to go to that page and explore the relationship without disrupting the current conversation flow

around the shared view. This is an important way of, for example, fluidly managing conversational threads and introducing new topics. The important point here is that as a personal resource, the paper version can be controlled and manipulated without incurring the social cost associated with negotiating over a shared resource. An example of this can be seen in a tele-meeting between one group in London and another group based in Hong Kong. One of the junior members of the meeting, J, was examining a printout of the photographs currently being displayed on the Meeting Wizard and currently being discussed. Having examined the paper version of the photographs, J leaned over towards PK sitting to the left of him, orienting the printout in PK's direction. While pointing to the printout J had a short discussion with PK. A few moments later when appropriate and when the other thread was completed, PK used the Meeting Wizard display to draw everyone's attention to the point that was raised in the prior side discussion. So the paper, in this example, as a personal resource had supported some individual cognition and then transformed fluidly into a conversational resource for a parallel side discussion in preparation for a new thread while the main discussion over the shared document continued. This illustrates an example of using multiple surfaces were to support the parallel analysis and threads in a very fluid manner.

> "It was useful to have paper copies in front of us as well as on the screen so that two separate discussions could happen at the same time in the same meeting area" PK, facades, London

The public personal boundary is not fixed but something that can be negotiated according to different circumstances ([40, 23]). Indeed, when it comes to introducing new technologies, the delicacy of this negotiation is often underestimated in many tasks and many organisational activities (e.g., [37]). The tangibility and micromobility of the paper document allowed them to be managed fluidly making it clear exactly who should view the document. Another way to allow information to move from a personal resource to a shared resource is when the projected version of the document was pointed to the same page as on the paper version of the document. For opening up to the larger group, the paper version was less useful in their ability to bring the information more into the collaborative domain for shared visual reference. It was only by combining it with the electronic version that the shift could be made but this was indirect. Having separate spaces (paper and electronic) was important in creating a clearer permission management as well as allowing these personal and shared uses of the document to happen simultaneously.

Paper versions of the document were also important in providing and managing multiple surfaces. As O'Hara and Sellen [41] and O'Hara et al [42] have argued, concurrently viewable multiple surfaces are an important part of the cognition underlying reading. Quick-glance access to information on different pages allows the information to be assimilated together in ways that is difficult without concurrent visibility. Observations were made of people moving attention between their paper printouts and the shared display in support of information processing and communication activities. This behaviour applied more broadly to marshalled information

in the table space immediately in front of the individual. Indeed one of the key values demonstrated was the ability to interact with the shared conversational resource within the context of documents that had been brought the meeting and personally marshalled around the tablet (see Figure 4).

Having a single shared horizontal collaboration surface, as in standard tabletop setting would only be part of the solution in the way real world distributed collaboration gets managed. Having information distributed across multiple media surfaces (in this instance paper and projected displays) plays an important part in how activity fluidly moves from individual, to loosely coupled collaboration onto more tightly coupled collaboration during the course of a typical distributed meeting.

However, there were times to when such distributed assemblies across paper and digital surfaces created difficulties within distributed setups. In some of observations of Meeting Wizard in use during a distributed collaboration, we saw a local group begin to use a flip chart as shared visual resource. The work being done on the flip chart needed to be displayed as well as the information on the meeting wizard – again an example of the need for multiple surfaces. But conversational attention of the collocated group was then focused around the activities occurring on the flip chart. As this paper part of the assembly was not available to the remote group, i.e., not part of the distributed assembly it was more difficult for them to maintain involvement in the conversation. In this sense the asymmetry of distributed assemblies (see, e.g. [43]) resulted in certain presence disparities.

Negotiating study at a shared tabletop

Another more formal study we carried out provides us with further insights into the use of distributed assemblies. Rather than focusing on the formal approach and methods of the experiment, we concentrate in particular on observations and findings of the whole setting to further understanding on the use of tabletops. The experiment was designed to capture effects of the input device and the workspace orientation of the shared tabletop on various objective and subjects parameters. However in this subsection, we emphasise the observations and findings during and after the experiment that were not directly under scrutiny of the main experiment. To understand the context of these observations we begin by describing the setting and task the participants worked on.

The study was conducted on the Braccetto research platform [44, 45] composed of a horizontal tabletop unit and a vertical unit for teleconferencing. On the horizontal LCD display, participants could manipulate the presented digital content using touch or mouse devices as used in prior studies such as [30, 29]. Two rooms were set up with these workstations and connected via a computer network. The vertical display showed the video image of remote participants. Two participants per site worked collocated and also remotely together. The experimental setup at one site is shown in Figure 5. Only a few controlled experiments exist that use a complex problem solving tasks for the investigation into distributed team collabo-

ration. We aimed to create a task that was complex and quasi-realistic, relevant and interesting for participants to ensure their engagement, and which addresses both external and internal representations of the artefacts in the workspace. Thus, we chose a bushfire survival scenario [46] that functioned as a subject of a negotiating task: group members were asked to rank several items based on their value in surviving a bushfire. Due to the fact that Australia, where the experiment was conducted, is highly affected by bushfires, it was assumed that this topic might stimulate their engagement.

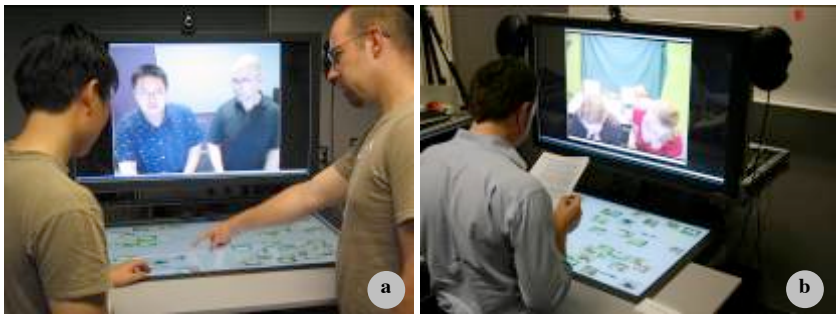

Fig. 5. Setup of the experiment. a) Participants are interacting with a shared workspace (horizontal display) with their remote collaborators (seen on vertical display). b) A participant read the printed description of the bushfire scenario.

Participants in groups of four were introduced to the task by viewing a video describing the following hypothetical situation: Their group in a cottage in the Australian bush received news of a nearby bushfire approaching their location. They were then presented with a set of 12 items (woollen blankets, cell phone, map of area, etc.) found nearby. After viewing the video scenario the participants were randomly assigned into two groups and separated into two rooms. Each participant received an A4 page with a written description of the scenario presented in the video. This gave them the opportunity to review some of the facts. The task was completed in two steps: First, participants ranked individually the items based on their survival value (priming activity), and second, they ranked the items as a group (consensus activity). The participants ranked the sets of digital images by attaching digital post-it notes with ranked numbers on the items (see Figure 6 a). In the individual ranking, each participant had their own set in the workspace. In the group ranking, a single set of items and post-it notes were available to all participants, i.e., shared across the sites.

With respect to the topics of this chapter, we observed the following behaviour that shed more light on the integration of the tabletop in the distributed setting. Participants used the written description of the scenario on the sheet of paper to recall some of the facts. They did this during the individual as well as the group ranking part of the study. In most cases, the participants retreated from the actual group activity to find further hints to improve the ranking (see Figure 5 b). When not used, the paper was placed at the side of the table on the rim.

The rim around the interactive tabletop also had the function of allowing standing participants to lean against or rest their forearms on. Since the tabletop was raised higher than a standard table for sitting, they acted more like at a bistro table or a bar table. Although the trial lasted about 30 – 40 minutes each, no participants complained about the fact that they had to stand during the trial. For those partici-

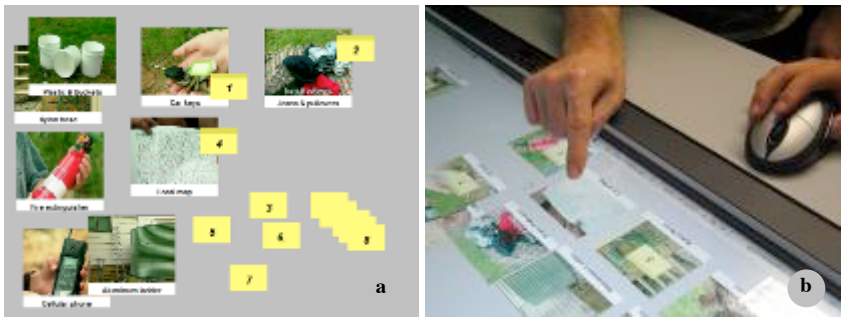

Fig. 6. a) The detailed view on the workspace. The participants can attach and remove the numbered yellow cards like virtual post-its on the items to mark their rankings. b) The participants used either direct touch or an optical mouse device to manipulate the artefact.

pants that were asked to use the mouse to control the software artefact, the rim around the tabletop also served as the location where they placed the mouse to operate with it. The setting used in this study was different to that described before with the Meeting Wizard. In the field study the vertical display space was used to provide a shared information space and audio conference call was used to communicate. In the study a rich video link between the sites was established and the horizontal interactive surface was used to display and access shared information.

While this seems to be a major difference between the distributed settings, we can observe commonalities in the way the settings are used with respect to orientation and direction. To further investigate this aspect, we draw on the results of a follow-on mock-up study [47]. This study was conducted after subjects had participated in the previous experiment. The preceding activity can be seen as a primer for this mock-up study where we captured their preferences for alternative platform-setups and configurations. The subjects were asked to work on the following design task. They were given a set of small scale models of the basic elements of the platform, such as displays in landscape and portrait layout and workspace platforms with different tilts. The models were created from thick foam and we provided blu-tack, e.g., to place 'screens on the wall'.

The important outcome of the study was that over 70 percent of the participants tilted the horizontal workspace in the mock-up design. Asked for their preference the users clearly showed that they conceptualized basic ergonomic issues of the interactive horizontal tabletop in front of them with regard to visibility of information on the display and reachability of elements when using the touch input devices. One subjects stated that "Tilted table allows a better view […] of the pictures stuck onto it" and other subject stated that "A small slope for a touch

screen would be more natural for me because I could reach all parts of the touch screen easily in this case."

Discussion

Our field studies and findings from the more formal experiments revealed two important aspects regarding deployment of interactive tabletops in distributed assemblies. First, whether addressing collocated or distributed collaboration, the use of paper and other artefacts of the everyday environments such as offices and semi public spaces plays an important role. Given this, we discussed the significance of the boundaries of interactivity of tabletop settings, i.e, the interplay of interactive and non-interactive areas on a horizontal surface. Second, our investigation into distributed collaboration emphasises that presence of vertical shared workspaces or video mediated communication shape the way collaboration is organised and carried out around tabletops. This has implications on how the horizontal interaction surfaces are used in distributed assemblies.

Boundaries of Interactivity

Our concerns with respect to interactivity and non-interactivity are not with the specifics of the particular interactive tabletop deployed in the field study or used in experiments. We recognise some of the specific issues discussed here may not be manifest with other systems, such as multi-touch interactive surfaces. We recognise too, that there may be design solutions for the difficulties highlighted in the café-bar study. However, our intent was to show a demonstrable relationship between the interactive and the non-interactive areas and to provide early insights while conducting the exploratory rim study. In light of this, we would argue that this relationship should be given further attention in the context of emerging interactive surface solutions and distributed assemblies. As we have seen from the findings, this relationship between interactivity and non-interactivity is a complex and dynamic one that is continuously managed and evolved within the context of the different social settings.

How we design for this is an important question. While there were times when the clear delineation between interactive and non-interactive elements was important (e.g. rim vs. touch screen), this is only a small piece of the design puzzle, and the relationship goes beyond a simple static specification of interactive areas and non-interactive areas. This is because spatial arrangement of interactive vs. non-interactive touch was shaped by multiple and dynamic factors, including dimensions of the table surface (e.g. height, length, width, diameter), number of actors around the table, the relationship between them, particular topics of conversa-

tion and arrangement of artefacts on the table. With many of these factors continuously changing, the movement between interactive and non-interactive is ultimately a social accomplishment collaboratively achieved by a group of actors. In designing for this relationship then, it is important to go beyond the static delineation of interactive and non-interactive regions on the surface. Rather, the focus should be on supporting social mechanisms that enable and manage fluid transition between interactive and non-interactive.

Directionality

In the field study with the Meeting Wizard as well as in the experiment in the horizontal shared workspace it became clear that both the shared vertical and shared horizontal work space with a video link imposed directionality on the local setting. Moving away from an artefact within the distributed assembly and working on flip charts may interrupt flow of the conversation and collaboration. In the mock-up study we saw users' preferences for tilted workspaces. This may be based on their intuition of what constitutes a more effective work environment that has more comfortable reach and better viewing angles. However, tilting the interaction surface has implications for its orientation and. Observers of a vertical whiteboard display perceive displayed information in the same orientation from any position in front of the display (i.e., position independent orientation). The perceived orientation around a horizontal surface on the other hand, depends entirely on the position of each observer relative to the display. Attributes such as top, down, left or right do not exist. Any tilt angle as suggested by the participants reintroduces *directionality*, i.e., the notion of top, down, left and right to the tabletop display. This might encourage users to situate themselves in front of the lowest side of a tilted tabletop. In this arrangement, the viewing angle on the horizontal workspace is optimal for all participants. Since users stand or sit at the tilted tabletop side-by-side, the size of the group will be directly proportional to the size of the screen. The participants may not have realised the ramifications of tilting a fully horizontal tabletop leading to the loss of the affordance of placing and supporting objects on the surface.

The important aspect of our findings is that artefacts in the distributed assemblies have the potential to provide directionality to a setting. This holds for vertical as well as horizontal shared workspace and may be a key convention to facilitate the collaboration in distributed settings. Having too many shared display in a distributed setting may lead to ambiguous situation where participants of the meeting address different areas in the shared environment. Finally, the directionality of the horizontal surface may become aligned with the directionality of the work environment imposed by the vertical video display.

Conclusion

We presented our work on horizontal interactive surfaces in distributed assemblies. With the term distributed assemblies we want to emphasis that real-life tabletop setting may not be considered isolated points of interaction, but rather as part of an assembly of artefacts with which users can interact. The boundaries of interactivity of tabletop settings have been identified as important for better understanding the integration of horizontal interactive displays. The non-interactive rim around the area of interactivity on the surface provides the affordance to place other, possibly interactive artefacts of the assembly. The observation in the studies in distributed settings show how a video mediated communication display or a shared vertical display have a tendency to impose directionality on the settings toward the remote parties. Implications for tabletop setting have been discussed such as tilting the horizontal interactive surfaces for better ergonomics.

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