Chapter IX
Interactive Displays and Next-Generation Interfaces

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Until recently, the limitations of display and interface technologies have restricted the potential for human interaction and collaboration with computers. For example, desktop computer style interfaces have not translated well to mobile devices and static display technologies tend to leave the user one step removed from interacting with content. However, the emergence of interactive whiteboards has pointed to new possibilities for using display technology for interaction and collaboration. A range of emerging technologies and applications could enable more natural and human centred interfaces so that interacting with computers and content becomes more intuitive. This will be important as computing moves from the desktop to be embedded in objects, devices and locations around us and as our desktop and data are no longer device dependent but follow us across multiple platforms and locations.

In face-to-face meetings, people share a wide range of verbal and non-verbal cues in an attempt to communicate clearly. In a business meeting, for example, people often collaborate around a table. The space between them is typically used for sharing communication cues such as gaze, gesture and non-verbal behaviors, and sometimes for interacting with real objects on the table, such as papers and models. There is free and easy interchange of ideas and natural communication. As displays become available in our everyday surroundings, co-located collaborators will more easily be able to access their digital information and media during their social and work exchanges. Furthermore, as our local and remote devices become increasingly able to communicate amongst each other, collaborators can more readily share personal data, or include remote colleagues in their discussions.

A key activity that often occurs during these collaborative exchanges, and one that is not well supported with current computing environments, is brainstorming. Technology is often abandoned for traditional media (e.g. notepads, whiteboards, flipcharts, and napkins) during collaborative brainstorming ses-
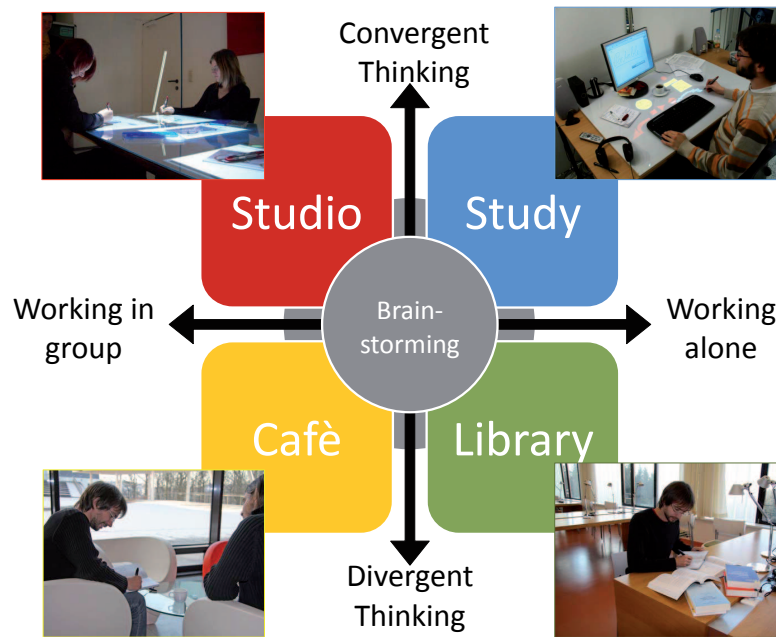
FIGURE 1   Brainstorming happens in many different environments. Thus, we need
                  tools that are embedded in convenient, everyday furniture such as tables,
                  walls, armrests etc.

sions. While this practice is not ideal in co-located environments (as someone
often must later translate the results into digital format), using traditional
media also restricts contributions from remote colleagues. Future collabora-
tion environments will provide opportunities to access and manipulate data
both locally and remotely, enabling substantive contributions from even ge-
ographically distributed team members (see Figure 1).

   The increasing number of videos of multi-touch surfaces available on
YouTube, show that users' expectations about using these devices in their
daily lives have increased. The reaction to these natural interface implemen-
tations has been very positive. This is because people are still interested in a
simpler way of navigating information and content where the computer inter-
face is not a barrier, but enables them to accomplish tasks more quickly and
easily. Multiple metaphors and interaction paradigms using pen, touch, and
visual recognition are coming together with the other elements to create a
new experience. In education, intuitive interfaces lower the barriers to using
IT, allow for a better understanding of complex content and enhance oppor-
tunities for collaboration. In the near future it is likely that emerging display

technologies such as electronic paper and OLED (Organic Light-Emitting Diode) screens will be delivered on flexible substrates. This will enable bendable/rollable displays that can be made larger than the dimension of the mobile device they are used with. E-paper could also enable inexpensive, very large digital displays to be incorporated into walls and other surfaces more widely. Speech recognition, gesture recognition, haptics, machine vision and even brain control are all improving rapidly to support more natural interactions with these new display technologies. This article concentrates on developments in different multi-touch surfaces and related applications. It also describes particular challenges and solutions for the design of tabletop and interactive wall environments and presents possible solutions for classrooms.

With the increasing development of interactive walls, interactive tables, and multi-touch devices, both companies and academics are evaluating their potential for wider use. We see that display technology is not just improving in quality, but also in the way that we interact with large surfaces. These newly emerging form factors require novel human-computer interaction techniques. Although movies such as Minority Report and The Island popularised the idea of futuristic, off-the-desktop gesture-based human-computer interaction and direct manipulation-based interfaces, in reality, making these interfaces is still a challenge. Conventional metaphors and underlying interface infrastructures for single-user desktop systems have been traditionally geared towards single mouse and keyboard-based WIMP (Windows, Icons, Menus and Pointing) interface design. However, a table/wall setting provides a large interactive visual surface for groups to interact together. It encourages collaboration and coordination, as well as simultaneous and parallel problem solving among multiple users and therefore needs new kinds of interface.

Interactive Surfaces 1

In late 1988, Xerox PARC developed the Live-Board, the first blackboard-sized touch-sensitive screen capable of displaying an image. Many in education will now be familiar with the interactive whiteboard. SMART Technologies Inc.[1] introduced its first interactive whiteboard SMARTBoard in 1991. The tracking is based on the DViT (Digital Vision Touch) technology and uses small cameras mounted in each of the four corners of the panel to track the user input. The system is mainly designed to be used with pens, but it can also track finger touches. A great number of digital whiteboards have also been sold to universities and educational institutions.

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[1] http://www.smarttech.com

A similar technology is the touch frame provided by NextWindow[2]. Again, embedded cameras track up to two points at the same time. The MIMIO[3] and eBeam[4] ultrasonic tracking devices, where participants use special styli, are a good and cheap alternative tracking surface. However, they are limited in their range, and line-of-sight restrictions reduce the tracking performance.

More recently, touch interfaces have been able to respond to multiple touches and gestures, increasing the possibilities for interaction and for multiple users to collaborate. Interactive tables, for example, have begun to move from prototype to product and combine the benefits of a traditional table with all the functionalities of a digital computer. Although interactive tabletop environments are becoming increasingly common (see for example Diamond-Touch from Mitsubishi Electric Research Laboratories (MERL), Surface from Microsoft), there are few applications which fully show their potential. One area where they could be expected to be very useful is in supporting creative collaboration. In the creative process, people often sketch their ideas on large tables. A digital tabletop set-up could therefore provide an ideal interface for supporting computer-based collaboration. To better understand the design requirements for interactive displays in a business setting, we carried out an exploratory field study at Voestalpine, an Austrian steel company, which wants to use a tabletop surface for brainstorming sessions. We found the following design recommendations for an interactive, large vertical/horizontal display:

- multi-point interaction and identification,
- robust tracking under non-optimal conditions,
- hardware robustness,
- physical objects should not interfere,
- user can interact directly with the system,
- reasonable latency, and
- inexpensive to manufacture.

Related projects have demonstrated the possibilities of digital tabletops in different scenarios. These approaches vary in the enabling technologies as well as the applications that are implemented for these surfaces.

1.1 DiamondTouch

Up to four users can sit on special chairs around the DiamondTouch table interface developed at MERL [DL01]. The sensing technology behind Diamond-Touch is an XY pair of antenna arrays embedded in the surface of the

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[2] http://www.nextwindow.com

[3] http://www.mimio.com

[4] http://www.e-beam.com

table. Each user sits in a wired chair that broadcasts a unique radio signal. These signals are capacitively coupled through the user's body and into the antenna array whenever touches occur. Since each user sits in a different chair, the table is able to distinguish touches among the users.

The DiamondTouch Table. Based on an array of antennas embedded in the touch surface, the DiamondTouch can detect up to four different users simultaneously.   FIGURE 2

The DiamondTouch is not only able to track multiple touches, but also able to identify different users (we can therefore call the system a multi-person system). The digital content is always projected onto the table's surface. Another advantage of this table is the fact that additional objects placed on the surface do not interfere with the system. The interpolated resolution of the DiamondTouch is 2736×2048 points (with a physical screen size of 42 inches) and the table can read out tracking information with a refresh rate of 30Hz. A similar set-up is presented by Rekimoto with the SmartSkin project, where he uses a mesh-shaped sensor grid to determine the hand position.
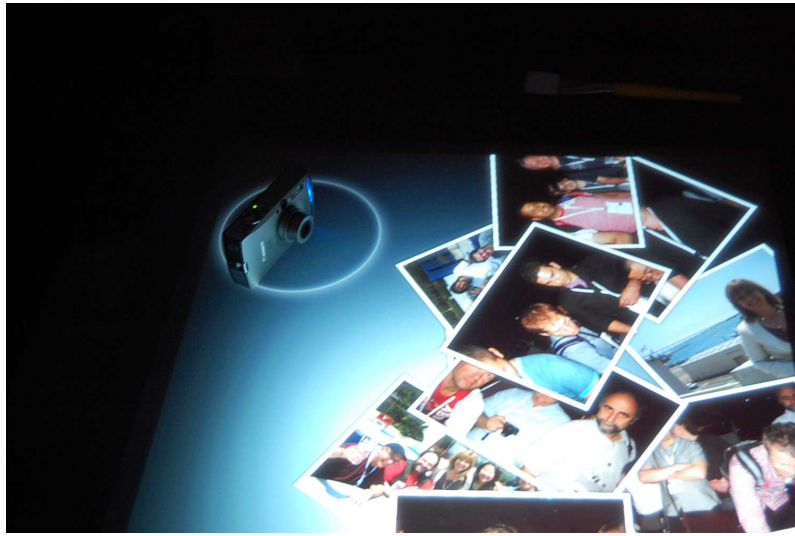
FIGURE 3   The Microsoft Surface. All pictures are sent to the table's surface, once the Wi-Fi-based camera is put on the table. Alternatively, RFID tags on the devices can help for tracking devices on an interactive large surface.

1.2   Microsoft's Surface

More recently, Microsoft presented the Surface table[5]. The system enables interaction with digital content through natural gestures, touches and physical objects. The Surface can track up to 40 simultaneous touches. In contrast to the DiamondTouch, the Surface is based on an optical tracking set-up, where five embedded infra-red cameras track the entire table (the current prototypes have a screen size of 30 inches). A special rear-projection surface and an embedded projector allow an optimal image. With the special projector, the engineers developed a relative low-sized table with a maximum height of 56cm. The Microsoft team demonstrates the table's advantages with effective demonstrations developed for Sheraton Hotels, Harrah's Casinos, and T-Mobile. In the photo-sharing application, for instance, friends can put their WiFi digital camera on the table and share their photos in a very natural way.

An alternative is to recognise and pair a device with RFID (Radio-Frequency Identification) tags or NFC (Near Field Communication). In this case, the table includes RFID readers which in combination with RFID tagged objects can be used to save and load different content. NFC allows devices

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[5] http://www.surface.com

to set up a link when brought together in close proximity. It is primarily designed to be used on mobile phones. The content, however, has still to be sent over Bluetooth or another suitable link), since the NFC technology is not designed to transfer large amounts of data. RFID/NFC is likely to be included in increasing numbers of mobile phones and other devices, so in the future it may be possible for a user to have content from a mobile device appear on a large screen just by bringing their device within close range of the display.

Other Interactive Tables   1.3

Similar to the Microsoft Surface, the LumiSight table captures the objects on the table using cameras and a projector mounted inside the table [MIO+04]. The InteracTable, a single-user system, allows interaction using a stylus. In contrast to related research, this system is based on a plasma display. The DViT cameras mounted in each of the four corners of the table track the users' input. The lens of each camera has an approximately 90° field of view. The current version allows two simultaneous touches. Similar to the Microsoft Surface, people cannot place any physical objects (a coffee mug, for example) on the surface without achieving un-wanted touches. Stanford's iRoom table, an interface mainly designed for brainstorming discussion in schools, is another example, which is also based on the DViT tracking with multiple DViT frames.

One of the first larger tabletop setups has been presented by Ullmer and Ishii [UI97]. In their installation, they implemented a set-up for engineers discussing urban planning. The system supports multi-layering of 2D sketches, drawings and maps in combination with 3D physical (tangible) objects, and is primarily designed for group sizes up to 10 people. The setup consists of two projectors hanging from the ceiling. Two cameras (also mounted above the setup) capture all the users' activities. Finally, Han [Han05] demonstrated an impressive scalable multi-touch interaction surface that takes advantage of frustrated total internal reflection (FTIR), a technique used in biometric applications such as fingerprint scanning. When light encounters the interface to a medium with a lower index of refraction, the light becomes refracted and beyond a certain angle, it undergoes total internal reflection. In contrast, another object (such as a finger) at the interface can frustrate this total internal reflection, causing a visible blob on the backface of the surface. This tracking system is highly scalable and very accurate—even under different lighting conditions.

As seen in this section, many companies and research laboratories are working on interactive tables, since they combine the advantages of a tradi-

tional table (face-to-face communication) with the advantages of a computer
(easy archiving of data, and sharing of content for example).

1.4 Digital Pens

Pens have been used as tools for interacting with horizontal as well as vertical
digital surfaces in various research projects. The affordances of a pen make
it a suitable input device for tasks like writing or sketching. Users are well
practiced with traditional pen use, and can easily translate their knowledge
to the digital surface with minimal cognitive impact. Moreover, pens provide
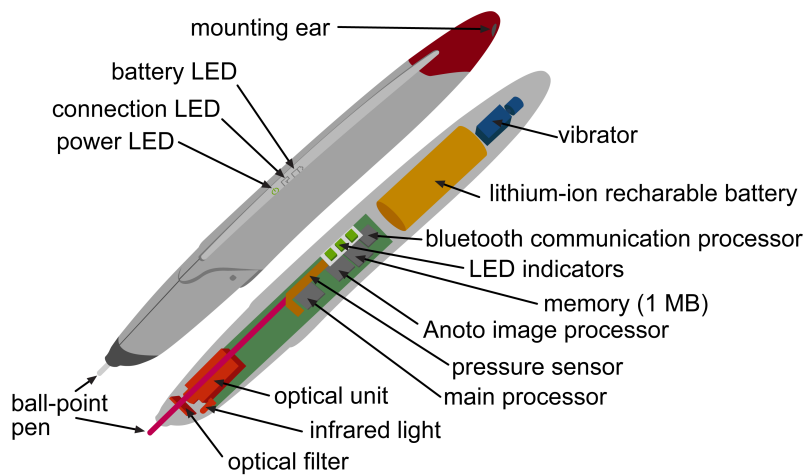a precise tool for pointing and can further include extensions like buttons or
pressure sensors.

FIGURE 4   The Anoto digital pen.

The Swedish company Anoto[6] developed the *Digital Pen and Paper* tech-
nology. The main tool for interaction is a pen with a small infrared camera in-
tegrated in the tip that derives the pen's position on a unique high-resolution
dot pattern. Figure 4 depicts the components of the Anoto digital pen. The
Anoto pattern consists of tiny dots that are slightly displaced from a regu-
lar grid. By setting the dots with offsets in horizontal and vertical position
from the grid, each dot encodes two bit of information. The combination of

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[6] www.anoto.com

several dots makes a unique sequence that defines the position on the paper. To enable stable tracking, the digital pen has to see at least an collection of six by six dots. In practice, the camera in the pen's tip manages to see this minimum 36 points with a high frequency (70Hz). Once the dots are recognized, the pen not only sends its coordinates, but also additional information about the current page ID and a pressure level.

(a)   (b)

Anoto pens are available in two versions: a USB only version (a) and a Bluetooth streaming version (b).   FIGURE 5

The Anoto digital pens are available in two different types: a USB and a Bluetooth streaming version. Figure 5 shows the two different versions of data transfer from the Anoto pen to the PC. The USB pen, which is commonly used for storing a digital copy of ones handwriting, can only be synchronized with the PC when placed in a docking station. Once the pen is connected to the PC via the docking station, all stored data from the pen is transmitted in a single step. Afterwards, the memory in the pen is emptied. The second version of Anoto pen not only stores handwriting in the pen, but also allow one to stream data in real-time over Bluetooth to the PC. With this streaming input, the user can get feedback from the PC in real-time. Moreover, this real-time streaming makes the Anoto technology suitable for direct interaction on large digital surfaces. Currently, three commercial pens with Bluetooth are available from Nokia (SU-1B), Logitech (io-2), and Anoto (PenIT).

Design Challenges 2

In order to gain a better understanding of the requirements and potentials for interactive workspaces that arise from real meeting and workshop situations, an explorative field study at a big Austrian steel company has been

carried out in fall 2005. The field study has been focused on the collaborative interactions between the participants and how these are mediated by the documents and tools used as well as the physical setup of the meeting room itself. The field study included six meetings and workshops of the companie's IT-service division with internal and external customers. The meetings took between 1 and 3 hours and covered topics such as business process modeling, requirements specification, evaluation of mock-ups, and project coordination. Both participants and locations varied across the meetings. Data collection included the notes taken manually during non-participant observation in the meetings as well as qualitative interviews with the chairs before and after the meetings. In order to structure the data collection and allow for comparison across the meetings a self-devised protocol was used. The protocol draws on cultural-historical activity theory (e.g. [Eng99, BCT95]) and provides a set of questions aimed to identify

1. core activities addressed in the meeting,
2. relevant stakeholders and communities as well as
3. actors involved,
4. rules and values guiding the interaction,
5. specific actions performed,
6. the artifacts and tools used,
7. physical properties of the meeting venue as well as
8. problems and breakdowns occurring in the meeting.

Based on the data collected a set of preliminary design challenges was formulated. Afterwards the outcomes were validated against the judgment of the meeting chairs as well as prior research on synchronous collaboration.

The following section provides a synopsis of the design challenges that emerged from our analysis. A brief description of the design challenge itself is given, and the resulting requirements for the design of interactive spaces and collaborative tabletop devices are outlined.

2.1 Interactive Spaces

Interactive rooms incorporate different digital surfaces such as tabletops, digital walls and portable devices in a single space to facilitate work processes [SGH+99, JFW02]. However, the design of such a room and the according applications can hardly accomodate the requirements posed by the huge variety of collaborative work activities. For instance, a workspace for presentations and customer meetings will pose different demands on the system than a creative brainstorming session. Considerations about the room design must involve various situation specific aspects such as work group size, group characteristics, required tools or used media during the meeting.

Multiplicity and Heterogeneity of Tasks

Even though workshops and meetings are usually focused on a limited set of topics, they regularly encompass a multiplicity of heterogeneous tasks. For example one and the same session might entail phases of presenting, brainstorming, decision-making, collaborative modeling, and planning. As each of these tasks requires different types of collaborative behavior, a meeting room has to be adaptable according to the changing needs. While during a presentation it might be useful that the presenter can guide the participants through a set of documents other tasks such as collaborative modeling might require active contribution to the development of a shared artifact by all participants. The change from one task to another often occurs spontaneously based on the situational demands emerging in the meeting. Consequently, interactive spaces and collaborative tabletop devices for meetings and workshops have to account for the diversity of tasks at hand. Input and output devices should be selectable on demand and there need to be seamless mechanisms for floor and access control. Furthermore, it has to be possible to switch between different tasks, and to save the current system status to come back to a task later on.

Integration of Individual and Shared Spaces

Most collaborative tasks also include subtasks to be carried out by the different participants in parallel [JK01]. Accordingly, all participants have to have access not only to a shared but also to an individual workspace where they can create and store their own documents. In order to integrate individual and collective activities a smooth transition between individual and shared spaces has to be ensured while the integrity of the personal workspace must be ensured. For example, the notes taken might not be intended for the eyes of the other participants. The use of multiple documents renders the coordination of activities more difficult. In order to prevent misunderstandings it is important to support natural pointing gestures and direct manipulation of objects [WCFB06].

Fostering the Creation of Shared Documents

Shared documents play a fundamental role in collaborative working environments as they foster the creation of a shared understanding, support the coordination of activities and provide a shared memory for the group [Sch01]. The

creation of shared documents also fosters the objectification of thoughts and ideas, a process highly relevant for creative and constructional tasks [Hac02]. Therefore, an interactive workspace also has also to provide means to create and manipulate shared documents collectively. In order to foster the joint creation of documents concurrent document manipulation should be enabled and documents should be readable by all attendees simultaneously.

Multiple and Interrelated Documents

The set of documents used in professional workshops and meetings are often quite extensive and heterogeneous in nature. For example software mock-ups, requirements specifications and business process models might be used in parallel. In addition these documents are often highly interrelated and relevant information is often spread across the various resources. The use of multiple and interrelated documents requires interaction metaphors that allow for easy navigation across documents. Furthermore, the relation between documents should also be visible to ease orientation [WCFB06].

Integration into Overarching Activities

Meetings and workshops usually do not constitute an end in itself, but are part of more overarching activities such as project work, or other ongoing work processes. Hence, it is important that meeting attendees can easily access previous information and store the results of the meeting for further processing. The access to one's own information is especially relevant when different organizations are attending a meeting.

2.2 Interactive Tabletops

The horizontal layout of a table along with the possibility of multi-user interaction requires new concepts that have been researched under a variety of different perspectives. Assuming that the hardware supports interaction with the table's surface, the main attention has been focused on the application design for digital tabletops. The following summary shall provide an overview of the most important features and related published approaches.

Shared Input and Display Surface

As related work on interactive tabletops has shown, it is possible to use standard Windows applications on a horizontal surface [ER06]. But such an approach will never explore the full functionality of a tabletop, since the input is restricted to a single cursor and the output is tailored for viewing from only one distinct orientation. In an interactive tabletop setup, multiple users expect to interact simultaneously without restricting their workflow to turn taking. Studies about traditional tables and the interaction of groups around them have shown that table surfaces encourage people to use physical objects simultaneously [Tan91, Sco05, KCSG03]. This behavior must be supported by the design of a digital tabletop by providing mechanisms that allow for concurrent input. With a horizontal surface, people tend to develop new forms of collaboration and communication when working with applications that are tailored for this kind of surface [RHBL04]. The DiamondSpin tabletop groupware [SVFR04], for example, supports the development of such applications for tabletops. Among others, it provides a feature to replicate the system menu for each user at the table and place it at an appropriate position on the surface. Projects like the Personal Digital Historian [VLS02, SLM$^+$01] and the UbiTable [SER03] show implementations based on the DiamondSpin toolkit with different duplicated personal menu layouts. The menus provide the tools for multiple users to interact with the table. This process also involves the digital artifacts that are manipulated by the group. Since multiple users work simultaneously, the concurrent access of objects must be handled. The DiamondSpin groupware allows for this collaborative interaction so that users can manipulate objects and enlarge them to gain shared access. A different approach has been explored for the InteracTable within the i-Land project [SGH$^+$99]. Their table is based on the BEACH software [Tan04, SPMT$^+$02], which allows for the making of copies of an object for each user and further manipulating the object through these references.

In contrast to the collaborative manipulation of objects on the shared surface, hand-over techniques have been investigated for tabletops. In such applications, only one user has the right to work with an object. To grant access for other users, the object must be passed on. Four different hand-over strategies have been explored with the release, relocate, resize, and reorient techniques [RRS$^+$04]. All four techniques suffer from the strong dependency of the hand-over action on the user currently owning the object. Without the action initiated by the owner, any other user that hinders a fluid interaction in a group cannot access the object.

Use of Space and Accessibility

The use of space during collaborative sessions is shaped by several partially competing factors. The access to and manipulation of objects requires them to be in reach of the meeting attendees [TT06]. Accordingly, collaboration around a tabletop device requires the attendees to be relatively close to each other. At the same time, this vicinity is at least partially at odds with social norms in professional settings where distance can demonstrate respect for each other's privacy and interests. Furthermore, having direct access to a document or input device often provides an essential prerequisite for active participation but also for control over the situation. As a consequence, the meeting attendees should be able to regulate their distance but also the access to documents and input devices on demand. As Scott's studies on territoriality in collaborative tabletop workspaces suggest, the management of data on the table leads to the effect of partitioning in the user's personal space [Sco05]. This observation has influenced the implementation of separated workspaces for digital tabletops. DiamondSpin, for example, allows for the creation of *personal* and *public spaces* that are visually demarcated in the application. But Scott noticed that visible boundaries of the workspace might have a negative effect on the territorial behavior on a tabletop. Moreover, our field study revealed, that in traditional meeting-rooms a significant proportion of the tabletop is covered by objects irrelevant to the task at hand, such as additional documents, beverages, day-timers or mobile phones. In order to reduce the amount of unused documents on the tabletop attendees should be able to easily store, search, and retrieve the digital artifacts currently unused.

Orientation of User Interface Elements

With a table setup, people will naturally sit or stand around the table. Once people sit at different sides around the table, individual views onto the surface vary, creating the problem of orientation of visuals on the table's surface. This is the reason why traditional Windows interfaces cannot be simply ported onto the table, because they rely on a distinct orientation. A lot of research into the field of tabletops has been invested on this issue already [KCSG03, Sco05, WB05, FSWB06, SVFR04, FS05, HCV+06].

Privacy

With a single large display that is visible to all users in the room, a lack of privacy exists. There are possibilities to arrange the space of the surface in a way that each user has at least a visual boundary of his workplace

[Mor06, Sco05]. But there are only a few prototypes that allow for real privacy. The *LumiSight* table uses orientation dependent views on the surface, for example [MIO$^+$04]. On the other hand there is a natural constraint to work in the proximity space of another user. This is supported by the work of Scott [Sco05] who noticed that users avoid reaching into the personal space of others.

Shadow and Occlusion Problems

Front-projected tabletop systems suffer from shadow and occlusion problems once a user reaches with his hand over the surface. But interestingly, the assumed problems are not affirmed in practical tests. Consistent with Ashdown's observations of the *Escritoire* setup [Ash04], we found out that shadow and occlusion problems turn out to have less effect than expected. This is due to the fact that people are used to cast shadows in illuminated rooms. They are not surprised if the same happens while interacting with a front-projected table. Moreover, if they occlude information on the surface with their hands, it is again a familiar effect that also appears with physical objects.

Table Size and Group Size

When building a table for collaborative work, the physical size is of course an important factor. The size of the table is related to the size of the group that is expected to use the table for their work. Ryall et al. [RFSM04] conducted an interesting experiment that gives valuable insights about the correlation of table and group sizes. They identified three main effects: first, the table size had no effect on the speed a task could be completed. Second, the group size effected collaboration; smaller groups collaborated more strongly than larger groups. Finally, they noticed that other users respected personal spaces so that they did not reach into their proximity. This is in tune with the findings reported from Scott [Sco05].

2.3 Digital Whiteboards

Due to the different physical orientation of horizontal and vertical surfaces, the user's perception of the workspace will vary. Hence the design parameters from digital tabletops cannot be directly applied to wall displays.

Vertical vs. Horizontal Display

Rogers and Lindley [RL04] report about the effect of physical affordances of an interactive workspace on the social interactions and collaborations. On the tabletop, they observed that users would switch more roles, explore more ideas and have a stronger perception of the other user's actions. In contrast, horizontal displays tend to disturb the collaboration aspect in groups as the physical distance between the person at the whiteboard and the rest of the group becomes larger. To compensate for this effect, we included a close connection between the digital whiteboard and the digital tabletop in our room design. For example, interaction with the digital whiteboard should be possible while being seated at the table without the need to physically walk to the whiteboard. To support this feature, the applications running on both displays must have a technical connection on a protocol layer as well as tools for the user to allow the transfer of data between them.

One Person as Presenter Role

Through the changes in collaboration between horizontal and vertical displays, the role of the users during a work session is altered. The fluid role changing that Rogers and Lindley [RL04] observed on tabletops changed to a "one person as presenter" situation when they used a digital whiteboard. The same behavior of one person taking the lead and the others stepping back was noticed by Russel et al. [RDS02].

Turn-Taking Behavior

Since most interactive whiteboard solutions are still designed for single person usage [SMA03], turn taking is required in these environments. But looking at the way people work with traditional whiteboards [Tan91] suggests that this turn-taking behavior would not change even if the technology would support multi-user interaction. This is again in tune with the findings of Rogers and Lindley [RL04] who observed that it is generally difficult to notice what

other people are doing at the wall without stepping back. Moreover, people felt uncomfortable working too close together at the wall display.

Tasks on the Whiteboard

A vertical display is well suited for presentation tasks as all viewers have the same view on the displays. In contrast to a tabletop setup, there are no rotational problems with a vertical display. Although the exact task will depend on the context of the work group, there is a tendency towards using the digital whiteboard for displaying information that is relevant for everyone in the room. This is coherent with the role of a single person taking control over the display instead of multiple persons working simultaneously. This person is normally the presenter, which is also communicated through his standing position in contrast to the sitting position of the users at the table. If the whiteboard is used in a creative task together with an interactive table, Rogers and Lindley [RL04] noticed that the connection of the person at the whiteboard to the table group was disturbed. The whiteboard requires the user to turn his back at the others while his body occludes parts of the display, making it harder to follow his actions. To re-establish the connection to the group, a specific effort was necessary. In a presentation situation, this might be less of a problem, because everyone is paying attention to the presenter instead of working on a different task simultaneously.

Design of the Whiteboard

Guimbretière [Gui02] describes in his work about large interactive walls that they faced three major challenges when building a wall for brainstorming sessions: First they had to find a command mechanism that allows for working with the wall with a minimum distraction from the task. Moreover, they describe the need for a novel space management to support creative sessions without the limitations of a conventional analogue whiteboard. And finally, a digital whiteboard will only be accepted when the latency is minimized and the user can experience fluid interaction. We found similar expectations from our users in the partner company when we discussed the requirements for the digital whiteboard. Since traditional whiteboards and flipcharts are frequently used during meetings and discussions in this company, the standard of a digital whiteboard should at least meet the known quality. Therefore, ease-of-use and fast input processing were basic features for a successful implementation of the whiteboard.

UI design

In contrast to the digital table, UI elements on the digital whiteboard are closer to the traditional WIMP paradigm. With the vertical setup, there is one specific orientation for the elements, so users face the display like in a desktop computer situation. This is the reason why products like the SMARTBoard[7] offer WIMP style applications for their digital whiteboard. Although rotation is not an issue for a vertical display, the placement of UI elements is a key factor for the design. Unfortunately, the commercial software solutions for interactive whiteboards are following a too traditional WIMP implementation, which leads to obvious problems on large surfaces. The top located task bar, for example, is hard to reach on a SMARTBoard, and for smaller persons it may be even impossible to reach. The user interface design has to account for the large size of the digital whiteboard, especially in terms of reachability.

2.4 Input Devices

Digital Pens

To complement the design of the interactive room that includes a digital tabletop and a digital whiteboard, we explored the potential of several input devices. The aim was to incorporate a selection of input devices that enable convenient interaction directly with the table and whiteboard as well as the transfer of data between them. Our research focused on digital pens as the primary input device for the tabletop and the whiteboard. In addition to the pens we thought of direct touch as ancillary input for the interactive surfaces.

Tangible Palettes

Other types of input devices are tangible objects. Previous studies suggest that tangible objects can enhance collaboration among groups, as the perception of the others' actions is naturally supported [RLH06]. Although these studies have been based on tabletop setups, we thought of an extension to our interactive room concept. As demonstrated by Streitz et al. [SGH+99] in the i-Land project, tangible objects can also be used to transfer data between

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[7] http://www2.smarttech.com/st/de-DE/Products/SMART+Boards/

surfaces. They used wood blocks that could be recognized by every surface and linked data to the blocks. Consequently, they could transfer data through the physical placement of these blocks. In our concept, we designed tangible palettes as control interfaces for the digital surfaces in the room. The functionalities assigned to the palettes are shortcuts for frequently used actions or tools that allow for a fluid interaction with the system. By defining the number of available palettes, different parameters of the collaboration can be influenced. First, if options are only available on a unique palette, a group has to share that object which again leads to stronger collaboration. Second, multiple palettes with the same function will require a distribution across the table or the whole room with respect to the screen estate and reachability. Compared to a digital menu, a hardware palette is a very natural control object. It can be easily accessed and also removed on demand. Moreover, the tangible aspect makes it easy to share and hand over.

Interactive Paper

A special kind of tangible device is paper. Despite the predictions of the paperless office, we still see paper as part of many activities in office environments. Sellen and Harper have explored the reason why paper has not been replaced by digital systems until today in their book *The Myth of the Paperless Office* [SH01]. They report about the concept of *affordances*, which describes the activities that an object allows or affords. Using this concept, they compare the affordances of paper to the digital world. Paper is tangible; it is easy to pick up and flip through the pages while getting a sense of the length of a document. While navigating in a paper document, the reader gets feedback about his location from the amount of pages already seen and the ones still to be read. Paper can be tailored; it is easy to annotate a paper document, which can be done simultaneously to reading it. It is a common practice to use a notebook for taking notes while reading in another paper document [SGP98]. Furthermore, paper is spatially flexible; it can be spread out and organized in a structure that suits our needs for a specific task. We are able to read across multiple pages at the same time and can further structure them to define a new order. Finally, paper has its own affordances in collaborating groups. Because paper is a tangible object, the actions performed with the paper are visible to the other group members. The exact content of a user's note on the paper may not be recognizable by the others, but the action of taking a note is clearly visible. This affordance especially makes paper a highly interesting tangible device in an interactive room context. Referring to the proximities and orientations that people used to establish personal and group spaces on tables [Tan91, KCSG03], paper provides an ideal device through its affordances. The transition from personal to group space, for example, can be easily accomplished by putting a

paper document on the table's surface. The action with the paper document already informs the group about the intention and the social context.

Switching of Devices

Input devices like digital pens, tangible palettes and real paper serve as the connection between the single digital surfaces in the room. One key factor for the successful integration of the input devices is the fluidity of interaction and consequently the effect on the work flows. A common approach is to associate different input devices with different activities, like wireless keyboards for text input and pointing devices for selecting and manipulating digital objects [FJHW00, SLV$^+$02, SGS$^+$02]. However, switching between a variety of different devices distracts the natural work flow because the attention is focused on the handling of the devices instead of the process itself. Therefore, a consistent integration of devices with a minimum of necessary switches is desired. In our observations of work processes with our partner company, we noticed that digital pen interaction allows for a great variety of different actions. Handwriting and free sketching are tasks that are well suited for the affordances of digital pens. Moreover, a pen offers a highly accurate device for precise pointing and selection tasks. User interfaces for digital pens can be generally smaller than for direct touch, for example.

2.5   Discussion

The design challenges outlined before are not dissimilar from the guidelines for interactive spaces and collaborative tabletop devices that can be found in the literature. In fact, the design challenges can be mapped quite easily to the guidelines put forward by [SGM03]. According to this guidelines, tabletop displays for co-located collaborative work must support:

1. natural interpersonal interaction,
2. transitions between activities,
3. transitions between personal and group work,
4. transitions between tabletop collaboration and external work,
5. the use of physical objects,
6. accessing shared physical and digital objects,
7. flexible user arrangements, and
8. simultaneous user interactions.

The design challenges described here, nevertheless go beyond the existing guidelines in that they put emphasis on the requirements that arise in pro-

fessional meeting and workshop situations. Towards that end the following points appear to be particular noteworthy:

- The development of interactive spaces and collaborative tabletop systems cannot be reduced to the question of the most appropriate interface technology or interaction design, but inevitably has to take into account the dynamics of the social activities to be supported. For example, moving between activities is not only a question of the appropriate input device, but also about the assignment of roles and the internal division of labor.
- Collaborative activities are not always consensus oriented nor can it be assumed that participants work towards the same objectives. Questions of territory, access, and control over documents or input-devices, therefore have direct bearing on the scope of actions of the various participants.
- Finally, when used in support of professional meetings and workshops multiple types of mediation have to be taken into account simultaneously (see [BR00]). This is to say that the creation and work with knowledge artifacts, the organization and coordination of the collaborative effort as well as the shaping of the social relations among participants cannot be treated in isolation. For example to allow for concurrent document manipulation does not only affect the content of the document created, but also the work processes as well as the relation among those involved in this exercise.

Design and Implementation of a Multi-Display 3 Environment for Collaboration

To gain a better understanding of how present meetings are held and how our vision of an interactive room could improve collaboration, we observed several meetings in one of our partner's companies (see Section 2). Through this approach, we collected valuable insights about the current situation and further iteratively refine our designs and implications. Once we collected data from the observations, we designed a prototype that addressed potential aspects of the workflows which were then tested in the company again. The first setup of our interactive room is shown in Figure 6.

The interaction with the surfaces in this room is enabled through Anoto technology (see Section 1.4). Since the pen tracking is relying on the special dot pattern, a surface can be made interactive by overlaying it with a printout of this pattern. Our first demonstration, the Shared Design Space, was accurate, fast, and highly scalable [HLL+06].

Figure 7 (a) depicts the top-projection table in combination with the Anoto pen. The middle layer consists of the pattern, which is protected by a scratch resistant Plexiglas, placed on the top of the surface. For the Plexiglas, a maximum thickness of 3mm is recommended, since thicker layers on top of
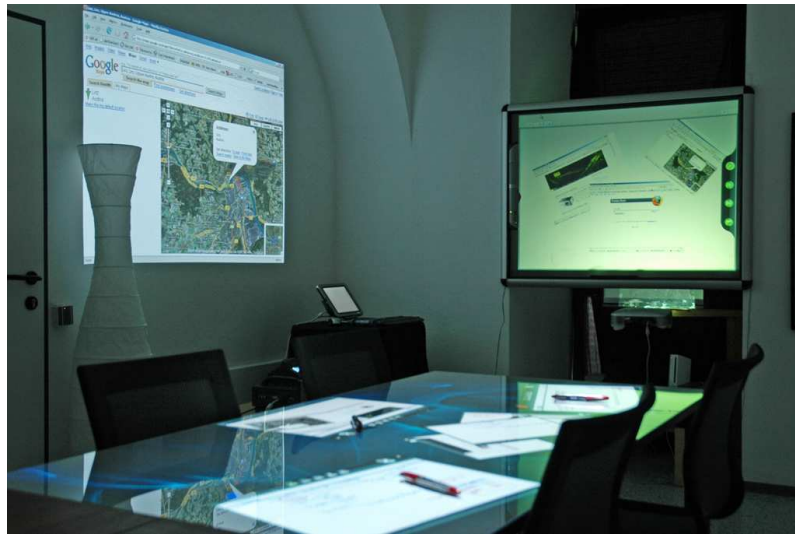
FIGURE 6   The interactive room consisting of a digital tabletop, a digital whiteboard
                and a presentation display.

the pattern interfere with the tracking. To prevent ink traces from the pens
on the Plexiglas, we exchanged the ballpoint pens with plastic stylus tips.

Alternatively, we also implemented a rear-projection solution for digital
tables and walls, see Figure 7 (b). Since the Anoto pen tracking technology is
designed to be used in combination with a special dot pattern that is printed
on traditional paper, materials that allow for rear-projections are not initially
supported. We faced this problem when we tried to print the dot pattern on
different surfaces such as transparent foils. The optimal base-material should
reflect the IR light that is emitted from the pen's integrated IR-LED. For
the camera in the pen's tip, the area appears as a bright surface with a high
contrast pattern on it. If the material is too transparent or too glossy, the
contrast between background material and dot pattern is not high enough to
ensure stable pen tracking. A transparent surface would not reflect enough
infrared light and therefore appear as a dark background with nearly invisible
black dots on it.

We found a solution that allows to apply Anoto pen tracking to large rear-
projected surfaces. The tracking is realized by using a large Anoto pattern
printed on a special rear-projection foil. This foil diffuses the illumination
from the rear LCD projector resulting in an image with no visible hotspots
at the front of the screen. Backlit foil is used in order to produce an image
with sufficient contrast for the embedded Anoto pen camera to recognize the
dot pattern. This provides translucency for projection while being opaque
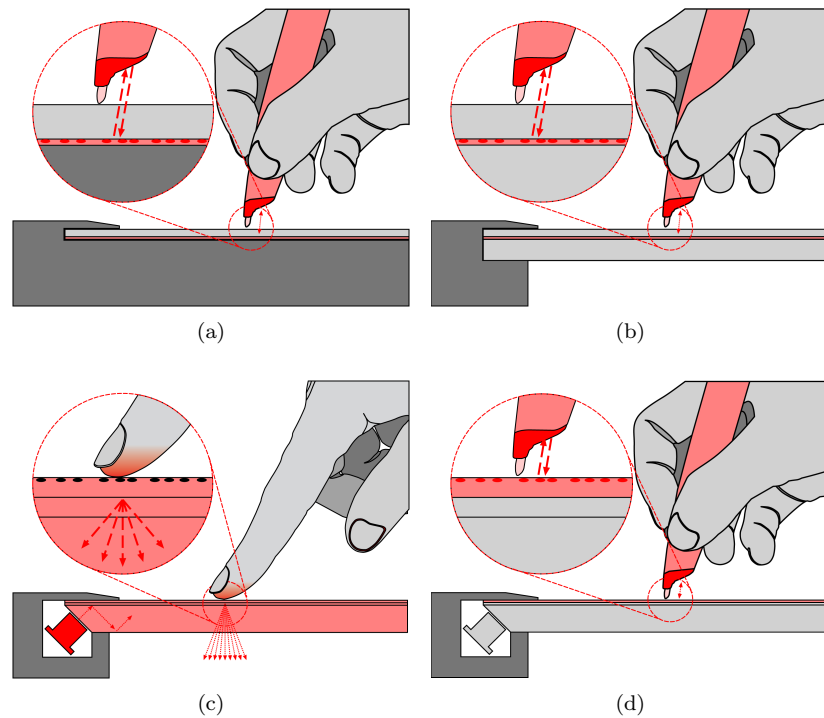
The front-projected layer composition (a). Anoto pattern for a rear-projected interactive surface (b). The three layers needed to track the finger touches (c). In the final layer composition only the top layer is relevant for the Anoto tracking (d).

enough to enable the Anoto IR-tracking. Figure 7 (top right) depicts the final layer composition that provides good results for the pen tracking. The dot pattern on the backlit foil is placed between two acrylic panels. The panel in the back has a width of 6mm and guarantees a stable and robust surface while the panel in the front has a width of only 0.8mm to protect the pattern from scratches.

To augment the Anoto input tracking with the advantages of direct, multi-touch interaction, we further extended the rear-projection layer composition. For the touch tracking, we used an approach based on FTIR. Unfortunately, a user must press hard on the surface to trigger the FTIR effect. The friction caused by dragging a finger on the surface, such as to perform a motion gesture, can also decrease the FTIR effect. Therefore, we used an additional layer (compliant surface layer) on top of the polycarbonate material to improve the sensitivity of the surface. We use a thin layer of latex to provide a soft, transparent compliant layer. Figures 7 (c, d) highlight the relevant

layers of our final composition. When pressure is applied on the surface, the coupling of the diffuse top layer and the bottom polycarbonate surface triggers the FTIR effect; this effect is intensified by the middle compliant surface layer (c). The latex must be combined with the projection layer with an air gap between the latex and the polycarbonate base plate. As shown in Figure 7 (d), the digital pen tracking is enabled through the dot pattern printed on the top projection layer.

3.1 Design of an Interactive Table

Our goal was to integrate a table into the room in a way that traditional work flows are supported with the possibility to use the additional features of a digital system. The table should provide space for four people and it must allow to place additional objects on the surface without interfering with the application. It should be possible to turn the digital tabletop off and use it like a normal table.

There are basically two different display-based hardware solutions that can be used to build an interactive table: a front projected or a rear-projected setup. LCD or plasma screen-based solutions as used by Streitz et al. for the InteracTable [SGH+99] were not relevant in our case, because they were too limiting in size and shape factors. Compared to a front-projected solution, rear-projected setups are normally more restrictive in terms of materials that can be used for the table's surface. This is due to the fact that the surface must be suitable for a projection with sufficient contrast and brightness qualities while minimizing the effect of a visible hotspot. Moreover, a rear-projected setup restricts the possible size of the table because the stability of the surface is only guaranteed through the surrounding edges of the table's frame. In a front-projected setup, the projection surface can be placed on top of the table, thus supporting the sturdiness over the whole surface area. The choice of possible materials for a front-projected setup is broader compared to rear-projected solutions; for example, a simple white surface already fulfills the requirements. These considerations led us to the design of a front-projected setup for our interactive table.

Through an additional requirements analysis with our company partner, we identified another important feature that the table design had to address. As the domain was focused on meetings, people would sit most of the time around the table, with occasionally exceptions when someone walks to the whiteboard or joins the side of another person. For a sitting position, however, appropriate space for the feet under the table is very important, as staying in an awkward position at the table for an extended period of time has a negative impact on the user's comfort. These ergonomic issues are supported

by a front projected setup, but they are hard to satisfy with a rear-projected setup if users should be able to sit around the table.

The table is a modified product provided by the company Team 7[8], featuring a 170×90cm large surface with digital pen interaction as primary input technology. In order to allow users to interact with the table, we extended the surface with a large Anoto pattern printout. This modification provides a high accurate input solution for the tabletop with the additional advantage of robustness and independence of environmental conditions. Moreover, the digital pen solution offers an input device that is tailored for fast sketching input and annotations. The modification of the table still allows to use it like a traditional table, as there are no electronic parts integrated into the table. Finally, the top projected setup enables users to sit in a comfortable position with enough space for their feet under the table. To achieve a high resolution projection on the tabletop, three projectors are mounted above the table.

Personal workspaces on top of a common shared space.   FIGURE 8

In our interactive room context we implemented two different versions of tabletop GUIs, one based on separated personal workspaces and another one with a common shared space. For the first version the whole table served as public space that was overlaid with multiple personal workspaces (see Figure 8). Each user could manipulate the layout of his personal workspace. By clicking on an empty spot on the surface the workspace would appear at this

[8] http://www.team7.at

position. Each workspace was uniquely assigned to a digital pen, thus each user could configure his workspace independently. Options for manipulating the workspace included resizing, rotating and showing/hiding. The workspace was automatically rotated towards the nearest edge of the table seen from the activation position. To exchange data between workspaces, the object had to be placed in the public space where the other user could pick a copy of it.


Figure 9   Tabletop with one large common shared space.

Our second approach was based on a common shared space concept. Without the visible boundaries of personal workspaces, each user has the same rights to work on the surface, to create, manipulate and share data. Without the need to actively grant access to objects for other users, we expected the workflows to be more fluid compared to the separated workspace version. Figure 9 shows the tabletop with the shared public space across the whole surface. Since the tabletop is equally shared by all users, the interaction is influenced by the *social protocol* of the group. But previous studies showed that the *social protocol* among users is not always sufficient on multi-user tabletops [MRS+04]. Actions that effect the whole workspace, like changing the view or clearing it for example, are critical if controls are replicated and each user has the right to perform them. In this context we experimented with tangible palettes that can physically restrict controls to a single user, if there is only one palette available for a certain task. With this one copy it is assured that only one person takes over the control. Moreover it is visible for the group who is in charge of it and when it is used.

Tangible Palettes 3.2

The tangible palettes were also used to change the properties of the digital pens for interacting with the tabletop [HBL⁺07].
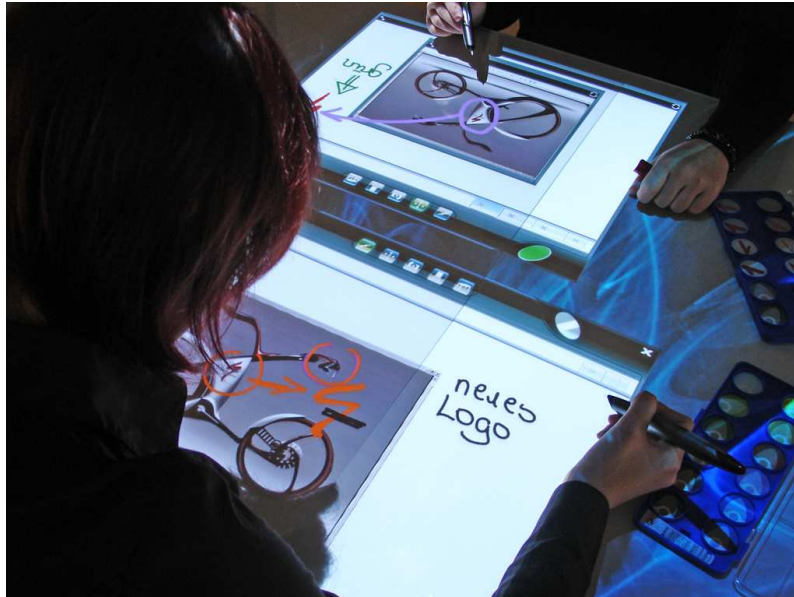
Tangible palettes are used for changing pen properties such as color and stroke width.

FIGURE 10

The palettes are based on the same Anoto technology that is integrated into the table's surface. The single color and stroke width areas of the palette include the Anoto pattern in the background of the printout. The overlaid graphics are the visible hint for the user to distinguish between different functions that are invoked by the area. There is no interference of the graphics with the tracking. Figure 10 shows the two palettes for picking different colors and stroke widths on the tabletop.

3.3   An Adaptable Rear-Projection Digital Whiteboard

The digital whiteboard is installed as a replacement for the traditional paper flip chart. The activities that are assigned to the digital whiteboard include presenting and brainstorming. As shown in Figure 11, our display features a novel combination of digital pen technology from Anoto with a rear-projected setup [BHH+07]. Using the Anoto pen tracking, not only multi-user functionality is possible, but also the identification of each user.
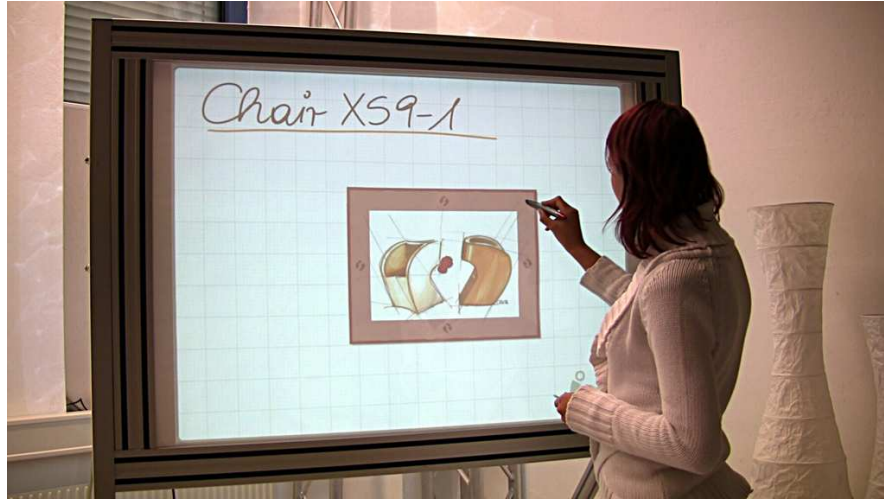

FIGURE 11   The digital whiteboard combines Anoto pen tracking with a rear-projected setup.

In our setup we used HP Colorlucent Backlit UV foil to generate the pattern. The Backlit foil is mainly designed for rear illuminated signs so it generates a diffuse light. Thus, no spotlights from the projectors are visible at the front of the screen. Moreover, the rendering and the brightness of the projected image is still of high quality. In our setup, we used one A0 sized pattern sheet (118.0cm×84.1cm). The pattern is clamped in-between two acrylic panels. The panel in the back has a width of 6mm and guarantees a stable and robust surface while the panel in the front has a width of only 0.8mm to protect the pattern from scratches. The front panel is made of a special scratch resistant acrylic. We noticed that the acrylic cover in the front does not diffract the Anoto pattern at all. However, using thicker front panels (e.g. 4mm) produced bad tracking results.

Application for Collaborative Tasks 3.4

The room application is designed to support typical activities during a meeting. The application features one large workspace that is organized in pages across a session. A page represents the current work area that is accessible for all users. Each page is treated as an infinite large work space which can be controlled through the two functions `Move()` and `Zoom()`. With these controls, the current view on the page can be either translated or scaled. As shown in Figure 12, these functionalities provide the flexibility to create new space if needed and to spatially organize data within the workspace. Since the control of the current view changes the whole workspace, it affects all users in a multi-user session. Therefore, the control over the view locks the current workspace and can only be used by a single person exclusively. The same exclusive control is used when when skipping pages or changing to the page overview.
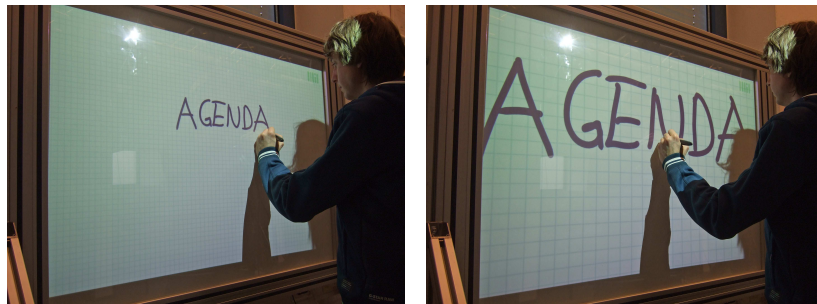
Controlling the view on the session. Original view (left), and zoomed in view (right).   FIGURE 12

The main session control functions can be either used through the appropriate item in the user menu or by performing a simple gesture. The gesture area inside the user menu allows for these shortcut navigation. Possible gestures include stroke up (new page), stroke down (page overview), stroke left (previous page) and stroke right (next page). The page overview provides a collection of all pages of a current session. By clicking on a specific page the session manager appropriately sets the view on it.

During a session, multiple users can work on the current page simultaneously. Each user has a menu that can be used to set custom parameters for the interaction. Different colors and stroke widths are available to customize the input. In addition to the tangible palettes, selections can be made through the projected menu. The palettes provide shortcuts (as there is no

navigation in a menu necessary), but the same parameters can also be set through the digital menu.

3.5   Occlusion-Aware Menu Design

Interaction with large direct digital surfaces is strongly influenced by physical restrictions. Reachability of items or occlusions through the user's body require novel design considerations for appropriate interfaces. As Apitz et al. noticed for example, traditional menus are not very well adapted to direct pen interaction. Menus that appear on the location where they are activated seem to be a better choice for large interactive surfaces, where the input is normally done with a pen or a direct finger touch. Circular context (or pie) menus are a convenient solution, as they fulfill most of the requirements of direct input on large displays. As described by Hopkins, pie menus pop up at the users' click location and due to their circular layout, the motion required to make a selection is minimized.

Direct input on digital tabletops is strongly affected by the handedness and the position of the user. Hancock et al. [HBS04] studied selection times for pop-up menus with pen input and noticed that adapting to the user's handedness is necessary. Otherwise, either a left or right-handed user will be discriminated, depending on the application settings. In their study, the authors noticed a slower performance for occluded areas. These are mirrored for left and right-handed users. This observation shows that occlusion is strongly related to handedness and hand posture. Moreover, the study showed that not occluded menus are better accepted by the users and can enhance performance.

Based on these results, we designed a menu for direct input surfaces with the key design criteria to avoid occlusions and to adapt the menu placement to the user's handedness and position on the tabletop. To address the occlusion problem, we observed several users and noticed that the visibility of the menu is mainly influenced by the occlusion caused by the user's hand. Figure 13 shows the results of our observation. The mirror effect of occlusions for left and right-handed participants is clearly visible.

Referring to a full 360° circle of possible item placements around an invocation point, we found that 92° of the circle are occluded on average. According to this result, we designed a menu with items placed only in areas that are not occluded by the hand. Our design is inspired by the layout of circular menus [Hop91]. The position of the menu is centered at the point of activation (see Figure 14).

We propose to use the occluded area as part of an interactive area for gesture input inside the menu. Our observations showed that occlusions are not a problem in this case if the area can be recognized and the user knows
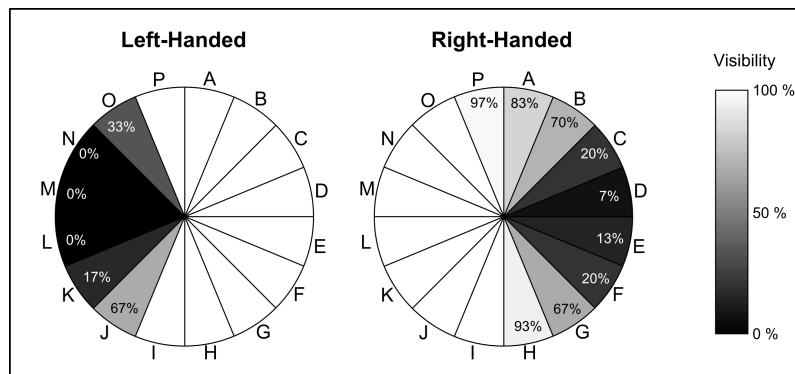
The visibility of each segment for left-handed and right-handed users shows a mirror effect.   FIGURE 13

where he can start a gesture and which gestures he can use. The outer region of the menu should be used for the items which can be accessed with a simple point-and-click.

Users can perform gestures on the circular gesture area inside the menu.   FIGURE 14

3.6 Bridging the Gap Between Real Printouts and Digital Surfaces

Sketching ideas and taking notes is a basic task that is performed frequently in the phase of preparing or during a meeting or presentation. For this reason, tablet PCs have been used as a good alternative to notebooks, because they allow an easy-to-use interface for sketching ideas. However, they are currently too heavy and too big to be used in different environments (e.g. people still do not like to use a tablet PC during a flight for making a quick note - instead, they still prefer pencil and paper).

This is the reason why paper still has a lot of advantages: it is lightweight, easy to navigate, people get a fast overview, it is easy to annotate, it is socially well accepted, and it does not need any power. The usage of real paper and digital information combines the advantages of paper and additionally enhances them through the possibilities of the digital world.

The integration of real paper into our interactive room concept is supporting the rule to avoid frequent switching of input devices. Based on the Anoto tracking technology, we could use the same digital pens to interact with our digital surfaces as well as the paper interfaces. This allows for a very fluid work process even with the integration of such different input sources as paper and digital surfaces.

The benefits of paper for interaction in the room context are plentiful. Firstly, paper supports the storage of written information on a page automatically, with the additional advantage to easily archive pages. Secondly, paper is lightweight and can be moved around the room and spread out to access an overview of the content. It can be handled in different working positions like sitting or standing. Depending on the placement of paper in relation to the group, it can be used to define workspaces that support private, personal and public boundaries. Previous research on tabletop setups has shown that users are frequently transitioning between their private space and the group space [EKHH⁺90, MO94]. With paper, this continual transition between the spaces is a very natural process that happens by simply changing the arrangement of paper documents. To transfer a document from a public position on the table to a private view, the document can be simply picked up from the table, restricting the group further seeing its content. Another advantage of paper is the immediate feedback of written content without latency or resolution problems. Digital systems that capture handwriting are commonly facing the problem of input latency, which hampers the experience of fluid interaction.

Moreover, digital systems require switching between tools to support different activities such as writing, sketching or manipulating digital object, whereas studies that focused on traditional tabletop work sessions showed that people are frequently transitioning between writing and drawing without making a distinction of their activities [Bly88, Tan91]. Sketching and writing on paper is naturally supporting this work practice, as there is no

difference in the type of input. A sketch or a note is treated equally on a sheet of paper. With paper as the input surface, interaction is not effected by additional technology imposed overhead.

Motivated by the opportunities and challenges that paper could offer together with a digital environment, we investigated the potential of this combination. We present a new paper-based interaction device which enables a seamless usage of a digital pen for manipulating real printouts and for controlling digital surfaces [BHOS08].

Pick-and-Drop

Similar to Rekimoto's Pick-and-Drop metaphor with mobile devices [Rek97], users can pick up data from a printed document and drop it on the interactive surface. Once in selection mode, each item of the printout becomes a selectable content and can be transferred without losing quality - since we transfer the raw data. In our scenario, users have to click with the pen on the corresponding data of the real printout. By using the digital pen, we can calculate the exact position and we can identify the according item. The data gets transferred when clicking again on the digital surface (see Figure 15).

(a)   (b)
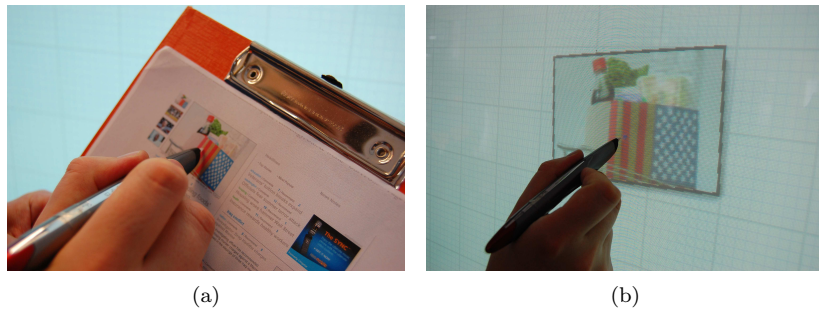
Users can pick up content from the real printout (a) and drop it on the digital surface (b).   FIGURE 15

Remote Control

Influenced by the ideas of PaperPoint [SN07], the real printout can also be used as an alternative *input device*, where all sketched notes are sent to the digital whiteboard in real-time over Bluetooth.

| (a) | (b) |

FIGURE 16   Different possibilities for the additional interaction. We either support a unique palette (a) or special ID cards where the additional functions are printed on the backside of each card (b).

In addition, special printed control elements on the paper allow further operation with the digital wall (e.g. adding a new page/changing the ink color of the digital flipchart etc.). In our demonstration, we implemented different possibilities for changing the ink properties (see Figure 16).

We tested our application by using a tangible tool palette, which was either embedded in an acrylic palette (a), or by adding the functions on the back of an ID card (b). In each scenario, we simply had to put the Anoto pattern on the corresponding surface (e.g. embed it into acrylic, or to put it on the backside of the ID card). Therefore, our solution is really cheap and does not require any additional electronic sensors.

Sketch-and-Send

The first method allows to send a group of strokes on demand. The strokes are transferred to the system in a single step and appear on the digital surface. In this mode, the user has the control over the moment when the sketches should be sent. The alternative way to send sketches to the system is via a real-time streaming paper. In this case, the strokes show up on the digital surface immediately. For example, this mode is useful for explanations that require to develop a sketch in front of the group step by step. The group can

watch the digital representation of the sketches that the presenter draws on his paper.

Our system supports additional annotations on the real printout that can be performed with the real ink of the pen. The digital version of the ink can be either visualized in real-time on the digital surface or stored on the pen's integrated memory. In both variations, all data that is entered with the pen while in inking mode is processed in one or the other way.

Real-time streaming is useful for explanations that require to develop a sketch in front of the group step by step, for example. The group can watch the digital representation of the sketches that the presenter draws on his paper. The data transfer is accomplished through Bluetooth streaming from the Anoto pen to the server PC. Figure 17 shows an example where a user is annotating with real ink on the paper document.
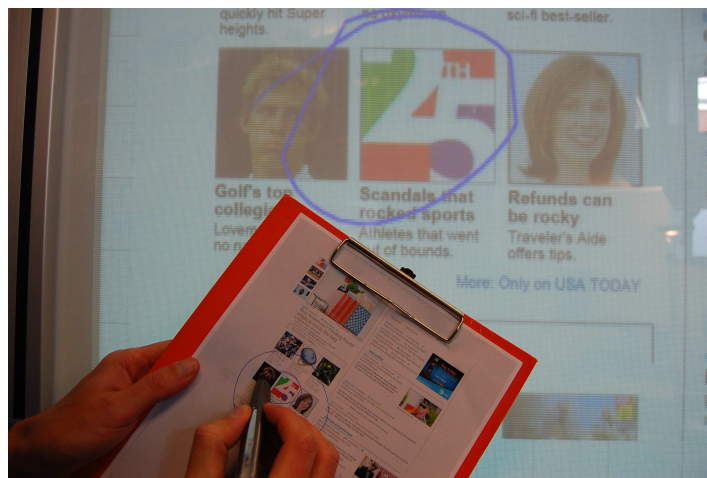
Annotations on the real printout are immediately visible on the digital whiteboard.   FIGURE 17

Offering remote sketching in our system allows the participants of a meeting to keep seated around a table and share their ideas by sketching with real ink directly on a paper while the digital whiteboard acts as presentation area. This means that the users have two possibilities: they can either sit at the table and work on the digital whiteboard from their place; or they can stand up, go to the flipchart but still make their comments on the paper, which also automatically get transferred to the digital whiteboard. In both cases, all sketched information is sent to the whiteboard in real-time, regardless of the user's location. In our system, multiple people (we tested the scenario

with 7 participants) can interact simultaneously - independently if they are sitting or standing.

Working in offline mode, the sketched notes can be stored in the pen's integrated memory in advance and moved seamlessly to the whiteboard during a presentation. People can sketch offline on the real paper, come to the meeting and send all sketched data to the digital whiteboard. In this case, the pen allows to store up to 70 full-written pages. This whole functionality can of course also be used during a meeting to prepare sketches on the paper without displaying them in real-time on the whiteboard; presenting it to the audience can be done at any time later during the meeting.

4 Conclusions

Multi-touch and interactive surfaces are becoming more interesting, because they allow a natural and intuitive interaction with the computer system. These more intuitive and natural interfaces could help users to be more actively involved in working together with content and could also help improve brainstorming activities. As these technologies develop, the barrier of having to learn and work with traditional computer interfaces may diminish. It is still unclear how fast these interfaces will become part of our daily life and how long it will take for them to be used in workplaces and classrooms. We also have sill only quite vague understanding of how these technologies will change the way we work and learn together and which practices will actually emerge. However, we strongly believe that the more intuitive the interface is, the faster it will be accepted and used. There is a huge potential in these devices, because they allow us to use digital technologies in a more human way. We are just at the beginning of a new decade, where books can be displayed on e-paper devices such as the Sony Reader.

On the other hand, we will still work with traditional interfaces including paper. The integration of real notes, for example, in a digital environment seems to be a very important motivation for people using these new technologies, since it combines the affordances of a traditional medium such as paper with the capabilities of digital content and displays.

users who tested the implementation and all the team of the Media Interaction Lab.

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