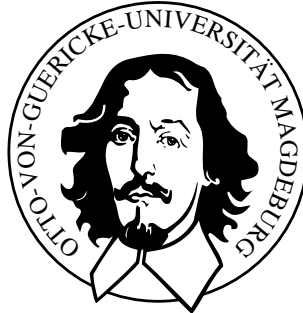Uta Hinrichs

Interface Currents: Evaluating a Fluid Interface for Tabletop Collaboration

Otto-von-Guericke-University Magdeburg

Faculty of Computer Science
Department of Simulation and Graphics

Diplom Thesis

Interface Currents:
Evaluating a Fluid Interface for Tabletop Collaboration

Author:

Uta Hinrichs

July 6, 2005

Supervisors:

Prof. Dr. Sheelagh Carpendale
Dipl.-Inf. Marcel Götze

Universität Magdeburg
Fakultät für Informatik
Postfach 4120, D–39016 Magdeburg
Germany

Abstract

Large horizontal displays provide new opportunities to support individual and collaborative activities involving creative and organizational tasks. Interface Currents are an interaction technique specifically developed to enable intuitive organization and sharing of digital information around tabletop displays. With Interface Currents users can easily share items via flexible containers that provide a controllable flow of interface items. This thesis presents the realization and findings of an exploratory user study conducted to explore how users interact with Interface Currents and for what purposes they would use them during creative tasks. For the study, an interactive tabletop workspace was developed, including an enhanced version of Interface Currents. The study revealed that Interface Currents facilitate browsing through and searching for information, s well as, structuring and organizing information. Furthermore, they support collaborative work by enabling smooth transitions between work phases that independent or collaborative.

Tabletop Displays, als große, horizontal ausgerichtete Anzeigegeräte, bieten neue Möglichkeiten zur Unterstützung von individuellen und gruppenbasierten Aktivitäten, die kreative und organisatorische Aufgaben beinhalten. Mit Interface Currents wurde eine neue Art von Interaktionstechnik entwickelt, die die Organisation und die gemeinsame Nutzung digitaler Informationen auf Tabletop Displays erleichtern soll. Interface Currents sind verschieb- und verformbare Gebiete im virtuellen Arbeitsbereich, auf denen sich virtuelle Informationen entsprechend einer bestimmten Strömung kontinuierlich bewegen. Diese Diplomarbeit stellt die Realisierung und die Ergebnisse einer Benutzerstudie vor, die durchgeführt wurde, um zu erforschen, wie Benutzer mit Interface Currents interagieren und für welche Zwecke sie diese in kreativen Gruppenaufgaben einsetzen würden. Für die Benutzerstudie wurde die Realisierung von Interface Currents um einige Funktionen erweitert. Die Ergebnisse der Studie belegen, dass Interface Currents gruppenbasierte Arbeit unterstützen, indem sie es Nutzern erleichtern, einen Überblick über Informationen zu bekommen, und sowohl das Suchen nach als auch das Strukturieren und Organisieren von Informationen unterstützen. Ferner ermöglichen sie fließende Übergänge zwischen Arbeitsphasen die individuelle oder gruppenbasierte Arbeit erfordern.

Publications from this Thesis

The redesign of Interface Currents and Interface Folders that is based on this research's findings (see Chapter 6) will appear in the following publications.

UTA HINRICHS, SHEELAGH CARPENDALE, and STACEY D. SCOTT. Interface Currents: Supporting fluent face-to-face collaboration. *Sketch presentation at the 32nd International Conference on Computer Graphics and Interactive Techniques (SIGGRAPH)*, August 2005.

UTA HINRICHS, SHEELAGH CARPENDALE, and STACEY D. SCOTT. Interface Currents: Supporting fluent collaboration on tabletop displays. In: *Proceedings of the 5th International Symposium on Smart Graphics*, (in Press), 2005.

Acknowledgement

Contents

CHAPTER 1

Introduction

Many activities, such as planning, organizing, and brainstorming are performed in cooperation between people. Collaboration is usually supported by traditional media, such as tables, pens, and paper. However, more and more information becomes available in digital form. In addition, computers offer a lot of functionalities that can be beneficial for collaborative work. Thus, within the field of Human Computer Interaction (HCI), one research area focuses in particular on computer-supported collaborative work (CSCW), that is, how the use of computers can support collaborative work between people, including distributed and co-located collaboration.

This thesis focuses on the area of co-located collaboration, more precisely Single Display Groupware [SBD99], where people are physically located around one single display. Large displays such as wall and tabletop displays have the potential to support this kind of collaborative work since they offer enough digital space for several people to work in groups and to display large amounts of information. In particular, large tabletop displays are predestined to support collaborative work because people usually have longtime experiences with collaborating around traditional tables. Thus, they perceive digital tables as a natural work environment [SGM03].

However, large tabletop displays demand for different interactions and user interfaces than common desktop displays. The design of such interaction techniques and interfaces is still a challenge [SGM03]. This thesis describes the realization of and findings from a user study designed to evaluate the concept of Interface Currents, a novel form of interface component that was developed to support co-located collaborative work around tabletop displays. In this chapter the motivation for the presented research will be discussed, followed by a brief summary of the results.

1.1 Motivation and Problem Statement

While size and angle of tabletop displays are beneficial for activities involving several people, they also cause interaction problems that need to be considered when developing interfaces for such displays. For example, items on large displays are often hard to reach because they are located on the opposite side of the table from a user's current position. Reaching across a table into someone else's personal workspace can also have territoriality issues [SCI04]. In addition, sharing items on a tabletop display is complicated by orientation issues. People collaborating around a tabletop display see the workspace from different perspectives. This can be problematic because orientation dependent items, such as text documents, are hard to read when they are viewed upside down.

Addressing these problems, HINRICHS et al. [HCS05a] have introduced the concept of Interface Currents. Interface Currents are fixed or mobile interface components that are dominated by an ongoing flow (see Figure 1.1). Information placed on an Interface Current is continuously moving. A Current's path is flexible in terms of shape and location in the tabletop workspace depending on the purposes it is used for. Interface Currents
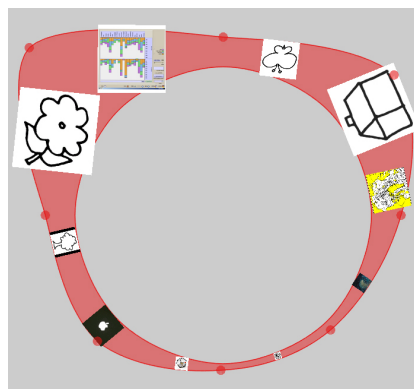
Figure 1.1: Interface Current [HCS05a].

have the potential to support fluid and flexible collaboration between users. However, this potential has never been assessed in terms of effectiveness. Thus, the underlying research question of this thesis is:

Do Interface Currents support collaborative work around a tabletop display?

In order to gain more insight in users' interactions with Interface Currents an exploratory user study was conducted. The results of this study are outlined in the following.

1.2 Results

For the user study, an interactive workspace was designed that, inter alia, consists of an enhanced version of Interface Currents and Interface Folders, an extension of Interface Currents that enables users to share information that is organized in folders on a tabletop display. All study tasks took place in this interactive workspace.

The exploratory user study revealed that Interface Currents support collaboration around tabletop displays for creative tasks that involve interaction with large amounts of visual information. Large Currents that are installed around the perimeter of the tabletop workspace facilitate browsing through and searching for information. Due to the continuous flow on such peripheral Currents, users are able to quickly gain an overview of information in a convenient and comfortable way.

Smaller stream- and pool-shaped Currents are used for collecting, organizing, and structuring information. Users perceive stream-shaped Currents as workspace containers where information can be shared. In contrast, pool-shaped Currents are used as personal storage areas that have a more private character.

In general, Interface Currents help users to structure their tasks and to smoothly transition between different work phases that require collaborative and independent work.

Beside these general findings, the study revealed a number of usability issues concerning the realization of Interface Currents. These usability findings led to the realization of a new, enhanced version of Interface Currents.

The following section describes the structure of this thesis.

1.3 Thesis Organization

Chapter 2

In order to understand how interfaces and interaction techniques for tabletop displays need to be designed to support collaborative work, Chapter 2 describes the factors that influence collaborative work. Furthermore, an overview of the technical characteristics of tabletop displays is given, followed by a discussion of the resulting interaction issues. The last section of the chapter discusses several interfaces and interaction techniques that were developed to support collaborative work and fluid interaction, respectively, around tabletop displays.

Chapter 3

In Chapter 3 the methodological approach of the conducted user study is discussed. First, the concept of Interface Currents, as proposed by HINRICHS et al. [HCS05a], is introduced. Based on this, the questions this concept raises are explained. This is followed by a discussion about the appropriate research approach and method to assess the effectiveness of Interface Currents with regard to collaborative work.

Chapter 4

A user study requires a workspace setup for the study tasks. Chapter 4 describes the design of the tabletop workspace that was developed for the user study. The components and interaction techniques the workspace contains are explained, among them, Interface Folders, an expansion of Interface Currents.

Chapter 5

Chapter 5 describes the experimental methodology of the exploratory user study, including, what kind of participants were recruited for the study, the technical setup of the study workspace, a detailed description of the study tasks, and a description of the applied study procedure. Furthermore, it is explained what kind of study data were collected in what way and how these data were analyzed after the study.

Chapter 6

The description of the experimental methodology is followed by the discussion of the study's findings. Chapter 6 discusses the usability issues that the study revealed. It concludes with the introduction of the redesigned version of Interface Currents and Interface Folders that was developed in order to solve some of the discovered interaction problems.

Chapter 7

The theoretical findings of the user study concerning the influence of Interface Currents on collaborative work around tabletop displays are presented in Chapter 7.

Chapter 8

Chapter 8 summarizes the main contributions of this thesis and outlines future research directions.

CHAPTER 2

Related Work

Many activities in our everyday life are performed in cooperation with other people. In offices, educational, and medical environments people often meet each other in order to discuss and solve different ideas and problems. While some tasks are performed in groups for efficiency, people also engage in group work to produce higher quality or to benefit from comfortable work conditions. Common tasks performed by groups or pairs include project planning, decision making and any form of creative problem solving [OOCS92]. Consultations can also be considered as a form of cooperation [RRHT03].

In particular, solutions for complex tasks requiring creativity, benefit from the cooperation of people because more ideas and more knowledge are brought together [AEF$^+$00]. In medical environments, for instance, physicians meet regularly with colleagues in order to discuss specific cases and methods of treatment. Advertising agencies, similarly, use group meetings to get new ideas through techniques such as group brainstorming. Collaborative work usually brings together different points of view, which helps developing alternative solutions and finding new innovative ideas. In contrast, individual work may not always produce satisfactory results, in particular, for ill-defined problems, or problems that require a large amount of creativity and knowledge at the same time.

Recently, collaboration not only takes place in traditional environments but can be supported by technology, such as interactive walls and tabletop displays. However, in order to develop interfaces for this kind of technology it is important to understand both, the factors that influence traditional collaboration and the characteristics of the technology where the collaboration takes place. This is described in the following sections. First, the factors influencing traditional collaborative work are discussed. After this, the technical characteristics of tabletop displays are described and the design implications for interfaces that follow from these characteristics. The last section of this chapter discusses particular fluid interaction techniques and systems that claim to support collaborative work on tabletop displays.

2.1 Factors Influencing Collaboration

The word *collaboration* describes the "action of working with someone to produce or create something" [JA01]. Collaboration always involves several people that "work jointly on an activity or project" [Pre05]. The effectiveness of collaboration between people in traditional sense, that is, without electronic support, is influenced by specific factors: Problems and tasks discussed in groups are characterized by the fact that they fluidly change during the collaborative process. So are the work strategies people use when they are collaborating. Furthermore, the ability to interact simultaneously influences the character of cooperative work as well as the ability to communicate and—linked with this—to coordinate the group work. Awareness between group members plays an important role as well. These factors are explained in the following. Although addressed separately, they are closely connected.

2.1.1 Fluidly Changing Tasks and Problems

Real-world problems are often ill-structured and ill-defined. In addition, individuals working together have different points of view due differing backgrounds and motivations. Thus, the focused problem changes fluidly during group work [MO94]. For example, some arguments that may have seemed crucial first become less important while others suddenly appear more relevant [AEF+00]. Because the focus on problems shifts fluidly during group meetings, the work strategies during group work change fluidly as well.

2.1.2 Fluidly Changing Work Strategies

Depending on the task groups do not work cooperatively all the time. People work both, independently and interdependently in groups [RL04]. They switch fluidly from periods of parallel to collaborative work and vice versa [TFB91, Tan91, MO94, SGM03]. *Divide-and-conquer* strategies are often applied: tasks and group members are split up into subtasks and subgroups to work individually or in smaller groups on subtasks [SCI04]. After some time, they bring together their results and discuss them—they switch back into "collaboration mode". This strategy can be very time-saving if the environment in which the group is working supports it well enough. Otherwise, transitioning between parallel and cooperative work disrupts the work flow, which can be frustrating and time consuming for group members [TFB91]. Environments supporting cooperative work not only need to provide spaces for collaborative work but also private or partly-private spaces for individual work in order to support smooth transitions between personal and group work [SGM03].

2.1.3 Concurrent Interaction

Studies have shown that collaborators using traditional media often interact with one another at the same time. TANG [Tan91] and SCOTT et al. [SMI03] observed concurrent interaction when people were working in paper-based settings. They both found that concurrent interaction conveys engagement and participation during collaborative work. In fact, people feel awkward when they cannot interact simultaneously during collaboration, in particular during face-to-face collaboration. When concurrent interaction is enabled, enjoyment of the activity increases, because all group members can engage actively into the task. Enabling simultaneous interaction encourages all group members to participate and, thus, fosters the equality of all group members.

However, in office environments whiteboards are often used to jot down ideas during brainstorming sessions or to present results to a group [MIEL99]. In these situations, one person usually stands near the whiteboard interacting with it through a pen while the other group members are sitting in front of it. Being able to interact with the tools— the whiteboard and the pen—the person at the whiteboard often takes over the role of a moderator that leads the group discussion. Such a clear role allocation abolishes the equality between group members. However, this can be useful when a task has time constraints. Having a form of hierarchy within a group, makes it possible to structure the task by only a few people. This can save time that, otherwise, has to be used for discussion concerning task coordination. On the other hand, less discussion can hinder creative thoughts and, therefore, useful solutions of the problem or task. Furthermore, concurrent interaction is a requirement for parallel work which can be part of useful work strategies for groups as mentioned above. It becomes clear that the benefit of concurrent interaction depends strongly on the character of the task or problem a group tries to solve.

2.1.4 Communication

One of the most important elements of collaboration is communication between collaborating people. Many studies have shown that communication has a huge impact on the efficiency and the results of collaborative work [Tan91, TFB91, OOCS92, SMI03, BOO95]. Unhampered communication prevents misunderstandings between group members that, otherwise, can have disruptive and distracting impact on collaboration. Furthermore, it helps to coordinate activities. Communication includes *explicit communication* such as spoken and written messages and gestures and *implicit communication* where information are communicated unintentionally [GG00].

Explicit Communication

Explicit communication [GG00] is characterized by the fact that it is intentional and planned. During collaborative work people communicate verbally to express ideas, to discuss problems, or to explain actions or ideas [OOCS92]. Beside discussing the actual problem a lot of communication takes place to clarify ideas, to coordinate activities within the group, and to summarize new insights or partial results. During collaborative work people often comment about their actions verbally to focus the attention of co-workers on specific actions [Cla96].

Verbal communication is often accompanied by gestures, for instance, pointing to a certain object or a person, indicating size or simulating an interaction [BOO95]—so called *deictic references* [GG00]. People naturally use gestures to emphasize their spoken messages. Hand gestures alone are frequently used during collaboration to express ideas and to mediate the group's interaction [Tan91]. Gestures facilitate communication during collaboration enormously. Although people are able to replace gestures with words when it is not possible to apply them, for instance, when the other person is not in the same room, this is much more time consuming [BOO95].

Implicit Communication

In contrast to explicit communication, implicit communication happens unintentionally [GG00]. People communicate implicitly through body language or interaction with artifacts. Co-workers are aware of those interactions and, in that way, they can pick up information about what group members are working on or intent to do. This supports smooth group interaction. For instance, when a group of people is working around a large table and person A tries to reach an artifact close to person B, B is aware of the reaching gesture of A and can easily guess her intention. Without having to explicit communicate, B can hand A the artifact because B is aware of what A was trying to do.

2.1.5 Awareness

Awareness plays an important role in cooperative work. As explained in the example above it is important for group members to know where and how co-workers are currently interacting [GG00]. This can save time and avoid misunderstandings. For instance, one group member can silently start to work on a certain subtask without having to announce this loudly if the rest of the group can actually see the group member's interactions. Furthermore, co-workers can intervene when something goes wrong. Awareness is closely coupled with implicit communication. It is a requirement for mediating group interaction [Tan91].

2.1.6 Coordination

As mentioned above, beside discussing the actual problem, groups spend a lot of time coordinating their activities [OOCS92, Tan91]. Coordination is important when several people are working in the same space with shared tools. It can avoid conflicts, such as interferences between group members that try to access the same tools [GG00]. In particular, when groups switch between collaborative and parallel work mediating interaction is necessary. As mentioned before, hand gestures and awareness are an important resources for coordinating interaction [Tan91].

The impact of these six factors on collaborative work was discovered in several studies where people doing collaborative activities with traditional media were observed [LHG92, OOCS92, Tan91, BOO95]. In traditional work environments, traditional media and tools such as tables, whiteboards, paper, pens, and erasers for drawing sketches or jotting down ideas are used. Due to lifetime experience people are very skilled to work with these media types and tools [SGM03]. Additionally, paper as a main tool used during collaborative work is very flexible and can be tailored easily depending on the task it is used for [LHG92]. However, in spite of the flexibility of traditional tools in terms of use, these physical tools lack of some very useful functionality, such as saving, retrieving, and modifying content [MIEL99, BFBK00, LHG92], image processing, numerical calculations or spell checking [Wel93]. These functions, in contrast, are offered on electronic workstations. Furthermore, today, more and more media, for instance, documents, photos or videos, are available in electronic form. The process of transferring the results of a group meeting written down by hand on paper to a computer is very time consuming. Vice versa, printing out several copies of documents and pictures in order to discuss them in a meeting is financially and environmentally expensive [SGM03]. Therefore, it seems appropriate to augment traditional work environments electronically. However, developers of computer systems built for supporting collaborative work need to consider the factors that influence traditional collaboration explained above.

For a long time, computers were developed only for single users. Today, common workstations are still build based on the one-user-paradigm: They usually have one single keyboard and mouse and therefore only are prepared for one single user [SMI03]. Although it is possible to attach several mice to a normal workstation, the operating system would only handle one input at a time. Conventional desktop computers do not support multiple inputs. Hence, working collaboratively on a personal computer sharing one mouse, one keyboard and a rather small display (17 or 19 inch) is problematic, as studies have shown [RL04, SBD99, SMI03]. Having one single input device fixes the active role within a group to one participant—the other group members are forced to passiveness and can only make a contribution to the task through gestures or verbal expressions. This can be frustrating and disables fluid collaborative work [SBD99]. Additionally, adults feel uncomfortable when sitting in close proximity next to each other, especially, when they do not know each other well [Som69].

In contrast, large displays, for instance, with the size of 33 inch [MSI02], provide enough space for working comfortably in groups and displaying large amounts of information that is often required during group work. Furthermore, large displays enable smooth transitions between different work strategies. Transitioning between collaborative and parallel work is a common work strategy within groups (see Section 2.1.2). While these transitions are naturally accompanied by slight disruptions of the work flow, the disruptions are much more severe for the work progress, if group members have to change the work environment to do parallel work. Working comfortably in parallel requires an appropriate amount of workspace to not interfere with other group member's work [RFSM04]. Large displays offer enough room for independent and shared workspace for collaborative work.

Based on their orientation, large displays can be divided into two categories: Vertical displays, such as electronic whiteboards [MIEL99, SGH+99, IBR+03] (see Figure 2.1), and horizontal displays, such as digital tables [TPMT+01, AEF+00, SGH+99, dBS01] (see Figure 2.2). This thesis concentrates on co-located collaborative work around

(a) Dynamo by IZADI [IBR+03].

(b) DynaWall by STREITZ et al. [SGH+99].

Figure 2.1: Interactive walls.

tabletop displays. The following section will describe the concept of a tabletop display including the technical characteristics, appropriate input devices in order to understand the interaction issues that occur particularly on such a horizontal display.

2.2 Concept of Tabletop Displays

Large horizontal displays represent a rather new technology. In 1993 WELLNER [Wel93] presented one of the first systems supporting work on a large horizontal display, the so-called Digital Desk. Digital tables offer a very natural and comfortable way to collaborate [IHMS01, MSI02, RL04]. People intuitively interact on tabletop displays just as they would on traditional tables, as long as this is supported by input devices and the

(a) Café Table by Philips [N.V04].

(b) InteracTable by STREITZ et al. [SGH+99].

(c) Tangible tabletop system by ARIAS et al. [AEF+00].

(d) ConnecTables by TANDLER et al.— overview [TPMT+01].

(e) Connecting two ConnecTables [TPMT+01].

(f) The DiamondTouch by DIETZ and LEIGH [DL01].

Figure 2.2: Tabletop systems.

interface. People can sit or stand around a digital table in the same way as on a traditional one. The possibility to sit makes a tabletop display very suitable for longterm work activities [RL04]. In addition, people can place unused artifacts such as input devices or coffee cups on the table surface and do not have to hold them in their hand all the time.

Another advantage of tabletop displays with regard to collaborative work is that people can work in a face-to-face or right-angled arrangement (see Section 2.2.3). This helps to maintain a shared understanding about the task and to stay aware of the activities of other group members (see Section 2.1.5). People collaborating on a horizontal display can easily communicate their intentions using deictic references [IHMS01]. Gestures and facial expressions can be interpreted by co-workers which facilitates communication and coordination (see Sections 2.1.4 and 2.1.6). Eye contact can be used to draw each others attention, for instance, to request the input device from a co-worker if only one single input device is provided.

This is why more and more tabletop systems are built that claim to support cooperative work, such as the DiamondTouch [DL01], the InteracTable [SGH⁺99], ConnecTables [TPMT⁺01], the Café Table [dBS01], and the Lumisight Table [MLO⁺04]. This section discusses the technical configuration of tabletop displays and explains what kind of input devices are appropriate for such displays. Furthermore, the interaction issues that can occur on tabletop displays are explained in detail. The section closes with a discussion of the resulting design implications for interfaces on tabletop displays.

2.2.1 Technical Settings

Most tabletop systems were prototyped by researchers in order to explore co-located collaboration, that is, they mainly were built for research purposes. Companies selling technology that can be directly used as a digital tabletop are rare. MERL with the DiamondTouch [DL01] and, for a short time, Hitachi [Hit04] (see Figure 2.3(a)) do sell displays or, respectively, surfaces that can immediately be used as digital tables. Yet, there is no standard technical configuration for digital tables [SGM03]. However, nearly all of the developed systems can be classified in three categories: *top-projected*, *bottom-projected*, and *self-illuminated* displays. The characteristics of each these categories, their advantages and disadvantages are discussed in the following paragraphs.

(a) Tabletop system by Hitachi [Hit04]   (b) OpTable by SCOTT et al. [SLK02].   (c) Tabletop display of the University of Calgary.

Figure 2.3: Tabletop systems.

Top-Projected Digital Tables

Maybe the simplest and inexpensive way of building a digital table is to use a traditional table and top-project an image onto its surface via projectors and mirrors. The OpTable [SLK02] is an example of a top-projected display (see Figure 2.3(b)). The advantage of tabletop systems using top-projection is that no bulky artifacts, such as projectors, are installed under the table. In that way, people can sit at the tabletop display comfortably. A disadvantage is that if direct input through styli or hands is provided (see Section 2.2.2), shadows caused by hands and arms appear on the table surface. These shadows can obscure in particular small items, such as menus, which can complicate the

interaction. However, because lamps are often installed over traditional tables, people are quite used to this problem and know how to deal with it although it has a much higher impact on a digital table. Another problem is that, because the projector has to hang above the table surface, the table cannot be moved easily without having to move the projector as well. Furthermore, although this is given on all large displays that are driven using projection, projectors do not support a very high resolution yet (usually 1024×768 pixels). Thus, the digital table used for the evaluation this thesis is about uses two high-end projectors to gain a better resolution (see Section 2.2.2).

Back-Projected Digital Tables

On bottom-projected digital tables, such as the old version of the InteracTable [SGH$^+$99] (see Figure 2.2(b)), the projector is installed under the table. This has the advantage that shadows by hands or arms do not obscure items on the table surface. On the other hand, bulky projectors and mirrors force users to stand rather than sit around such a digital table. This is not very comfortable during longterm activities.

Self-Illuminated Digital Tables

More comfortable are self-illuminated horizontal displays as used for the Café Table [dBS01], The Pond [SWH$^+$02] and the ConnecTables [TPMT$^+$01] (see Figure 2.2). However, they do not always support simultaneous interaction and, furthermore, they are very expensive, in particular, when they are of large size.

No matter to which of the categories mentioned above a tabletop display belongs to, the problem of how to make the table interactive has to be solved. The next section shortly explains what kind of input devices are appropriate on tabletop displays and why the support of simultaneous user interaction is required and gives some examples of tabletop systems that realize this.

2.2.2 Input Devices

A large variety of input devices can be used on tabletop displays. However, not all of them are appropriate for collaborative tasks. For instance, the cursor of a mouse or a laser pointer appears very small on a large horizontal display and is hard to see and to hard to follow by other co-workers [MSI02, IHMS01]. The interaction with mice or laser pointers on a large display is not very natural because they only provide indirect interaction. In contrast, people use their hands or pens when they are interacting with traditional tables. Thus, using hands or particular styli supports natural interaction as well as fluid collaboration around a tabletop display. Several tabletop system such as The Pond [SWH$^+$02], ConnecTables [TPMT$^+$01], the InteracTable [SGH$^+$99], and the PDH table [SLV03] provide this kind of input with good results.

Using styli and hands as input devices also gives people the possibility of using gestures to communicate with each other. This facilitates communication within a group in general as stated in Section 2.1. INKPEN et al. [IHMS01] found that people using styli during collaborative work around a tabletop display use gestures much more frequently than using mice. In the same study people stated that they would always prefer styli over mice.

Simultaneous User Interaction

Traditionally, people interact simultaneously when they are working together (see Section 2.1.3). Thus, enabling simultaneous user interaction is a requirement for fluid co-located collaborative work [SCI04]. Several studies by different researchers have investigated the impact of sharing one input device within a group versus providing one for each group member [SMI03, SBD99]. These studies showed that providing an input device for each participant and, therefore, allowing simultaneous interaction has a very positive impact on collaboration. SCOTT et al. [SMI03] found that all group members participated more actively when simultaneous interaction was provided. People were much more engaged in the task and clearly enjoyed the collaborative work more.

Different technologies, for instance, ultrasonic pen trackers such as mimio[1], can be used to enable interactivity on a digital table. However, pen trackers are often too slow to support real-time interaction and can only track one pen at a time which forces users to turn-taking interaction. In contrast, the DiamondTouch [DL01] (see Figure 2.2(f)) by the Mitsubishi Electronic Research Laboratory[2] (MERL), provides simultaneous multi-user interaction and in addition, is able to track who is interacting and where. The DiamondTouch is a board where images can be displayed by top-projection. Users working on the DiamondTouch have to hold or sit on receivers. When a user is touching the table, signals, transmitted through antennas in the table are coupled through the user to the receivers. In that way, the receivers can identify the parts of the table each user is touching. This information can then be used by a computer in the same way as mouse or tablet data. Unfortunately, due to this technology, the size DiamondTouch is limited to 42.13 inches which is the size of a coffee table. Groups of four or more people would usually not work on such a small table. Additionally, the technology requires that people are in physical contact with a receiver that is, for instance embedded in a chair. Thus, they cannot move around during collaboration which is often limiting, in particular during creative tasks.

Another way of providing simultaneous multi-user input is to use vision based systems, that is, cameras are tracking the interaction of users on the table surface. The Digital Vision Touch Technology[3] (DViT) by SMART Technologies applies this approach. This technology is built in a rectangular SMART Board which is placed on a traditional table.

---

1 http://www.mimio.com
2 http://www.merl.com
3 http://www.smarttech.com/dvit

In each of the four corners of the surface, infrared (IR) cameras are built in (see Figure 2.4(a)) while in its edges arrays of IR LEDs are located. Whenever a user touches the surface with a pen or a finger, a shadow is produced on these LED arrays. Using the four IR cameras, the exact position of the touch point is calculated by triangulation.

(a) Cameras in the corners of the SMART Board™.

(b) Mirrors and projectors above the digital table.

Figure 2.4: Tabletop display of the University of Calgary.

The tabletop system at the Interactions Lab of the University of Calgary where this thesis' research project took place, uses this technology for their tabletop system (see Figure 2.3(c)). A 4-camera SMART Board™DViT 1810 interactive whiteboard is placed on a traditional table. To achieve an appropriate resolution two projectors are installed above the tabletop surface that project the display on the SMART Board™ using two mirrors (see Figure 2.4(b)). The technical setting of this tabletop display is explained more detailed in Chapter 5.

Beside the technical setting of a tabletop display, the form of user arrangement can have impact on collaboration as well as explained in the following section.

2.2.3 User Arrangement

On a tabletop display many different user arrangements are possible. For instance, people can sit across from each other, work shoulder-to-shoulder or sit right-angled to each other. Each of those arrangements have different impacts on the collaboration dynamics.

Shoulder-to-Shoulder Arrangement

People sitting shoulder-to-shoulder on a digital table as shown in Figure 2.5(a) have a shared perspective on the information displayed. In that way, all information can be oriented in the same angle and, in doing so, no participant has to read information in an awkward angle. MANDRYK et al. [MSI02] found in their study that participants preferred this arrangement. Nevertheless, sitting shoulder-to-shoulder can be perceived awkward

(a) Shoulder-to-shoulder [RL04].   (b) Right-angled [SCH05].   (c) Face-to-face [IHMS01].

Figure 2.5: Different user arrangements around digital tables.

by users if the tabletop display is not very large. On small digital tables, participants have to sit very close to each other which was found uncomfortable especially by adults, in particular, if they do not know each other very well [Hal66]. In contrast, RODDEN et al. found that shoulder-to-shoulder arrangement is comfortable especially for strangers because they can avoid eye contact [RRHT03]. In fact, it is more difficult to make eye contact or monitor co-workers gestures and body movement in shoulder-to-shoulder settings. This has a negative impact on communication within a group [MSI02]. A clear disadvantage is also the restriction of the freedom of movement. Participants can impede each other while interacting in the workspace, in particular, when gesturing and writing with the adjacent arms [MSI02]. Establishing personal spaces (see Section 2.2.4) is problematic as well, because participants have to share the space right in front of them with their neighbors.

Right-Angled Arrangement

Arranging cooperating people right-angled around a table (see Figure 2.5(b)) is a compromise between the shoulder-to-shoulder arrangement and the face-to-face arrangement. Sitting right-angled, both participants have more personal space because they only share one corner of the table. Thus, the workspace can be utilized more efficiently [MSI02]. In addition, participants can look at their co-worker easier, which facilitates the communication within the group. People sitting in a right-angled arrangement do not share the same perspective on the workspace but can find a compromised angle more easily than sitting on opposite sites of the table. Right-angled arrangements are appropriated for tasks that require close collaboration, because people sit close to each other but not too close as in a shoulder-to-shoulder setting and can share information more easier than in a face-to-face arrangement.

Face-to-Face Arrangement

In general, face-to-face arrangements (see Figure 2.5(c)) support non-verbal communication within a group the best [IHMS01]. Co-workers are in the peripheral visual field of each other, which facilitates the reciprocal awareness. Working face-to-face enables

visual contact, which was found to be important during conversations [Som69]. Gestures, body language and facial expressions can be interpreted easily. During a study participants rated face-to-face collaboration the "most effective" and the "most enjoyable" [MSI02]. The big issue with face-to-face collaboration, however, is the different perspectives from which co-workers see the workspace. Sharing information on documents, for instance, is difficult because one participant has to read upside-down or at an awkward angle. Different systems have offered more or less successful solutions for this problem (see Section 2.2.4). Interestingly, KRUGER et al. [KCSG03] found that orientation is also a resource to communicate and coordinate users interactions. The orientation of items in the workspace actually reveals valuable information about it as discussed in the following section.

The three types of user arrangements blur if more than two people are collaborating together which is actually very often the case in reality. A group of three or more people usually works in a mix of right-angled and face-to-face arrangement. It becomes clear that the user arrangement has a huge impact on collaboration and has to be considered when developing interfaces for tabletop displays. The following describes interaction issues such as the orientation problem and territoriality on tabletop displays with respect to work within groups of three people or more.

2.2.4 Interaction Issues on Tabletop Displays

As mentioned before, the physical setting of a tabletop display supports co-located collaborative work very well due to the longterm experiences that people have gained on collaborating around traditional tables. However, even if intuitive input devices such as styli and simultaneous interaction (see Section 2.2.2) are provided, there are still problems that complicate interaction. Similar to all large displays, interactions such as reaching items can be difficult due to the large size of the workspace. Furthermore, users can easily lose the overview of information spread out over a large horizontal display. In contrast to an interactive wall, it is more difficult to step back from a tabletop display in order to enlarge the visual field. In addition, people working on horizontal displays have to deal with the orientation problem of information. Furthermore, the factors that influence collaboration have to be considered, for example, fluidly changing tasks and work strategies, communication and cooperation, and awareness (see Section 2.1). While these factors were described in Section 2.1, the special issues with regard to collaborative work around tabletop displays are discussed in the following sections.

Orientation Problem

Artifacts carrying information, such as documents, maps, or pictures are often orientation dependent. Oriented upside down, they are hard to read or not understandable at all. Groups working around tables have to deal with this problem all the time: Documents that are oriented the right way up for one group member might appear upside-

down for another participant. Although traditional media such as paper are easy to reorient, this complicates group work. In traditional environments, groups often work with several copies of the same document to provide each participant with a document that is oriented in the right way. However, this overcrowds the workspace very quick and, for instance, deictic references cannot be applied as easily because participants do not necessarily look at the same document [MLO⁺04].

Because the technical design of tabletop systems usually is inspired by to traditional tables the orientation problem also arises on digital tables. Several approaches were developed to handle orientation on tabletop displays.

Fixed Orientation The simplest way to deal with the orientation problem is to orient all items on a table in the same way [KCSG03]. All information displayed on the Café Table [dBS01], for instance, is rotated towards one end of the table. However, fixed orientation of information forces groups to work in shoulder-to-shoulder arrangements, which limits the mobility of the group. Furthermore, shoulder-to-shoulder arrangements, as explained in Section 2.2.3, can be problematic when more than two people want to work together.

(a) Person-based Orientation on the InfoTable [RS99].
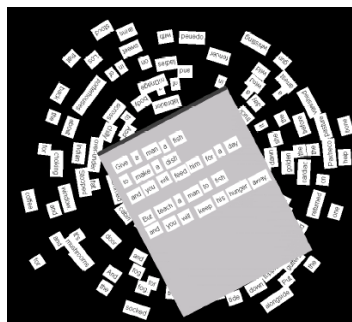
(b) Environment-based Orientation—the Poetry-Table [RFSM04].

(c) Manual orientation on the Inter-acTable [SGH⁺99].

Figure 2.6: Different orientation approaches.

Automatic Orientation A few systems were designed that automatically try to find the best orientation of information depending on either who has most recently accessed the information item (*person-based approach*) or where in the workspace the item is located (*environment-based approach*).

The person-based approach assumes that the person that manipulates the information should get the "best view", that is, the information is always oriented towards the person accessing it. An example of this technique is the InfoTable (see Figure 2.6(a)) where

items on the tabletop display can be accessed by people using the pointing device on their laptops that is located on the table as well [RS99]. When the person drags an item on the digital table towards herself, the item automatically orients toward the table edge that is closest to the person's laptop. This system is limited to special technology such as the DiamondTouch [DL01] because it needs to know the location where the person seated in order to decide the direction to rotate the information. Another example of the person-based approach is the STARS system [MSP03] where all items orient to the player that is currently in turn.

In the environmental-based approach, information is always oriented automatically to the closest edge of the tabletop display [KCST05] (see Figure 2.6(b)). Most systems built on the DiamondSpin toolkit follow this approach [SVFR04, RFSM04, SLV03]. Because information is always oriented to the outside of the tabletop display, items that are located near a person are always oriented into the person's direction. Another example of environmental orientation is the "flow zone" on the Café Table [dBS01] that is described more detailed in Section 2.3.

The Lumisight Table by MATSUSHITA et al. [MLO$^+$04] provides another form of automatic orientation. Its screen material, called "Lumisty", has specific optical properties that allows users to see images only if they are projected in a range of plus minus 10 degrees from the users' optical axis. Two sheets of Lumisty film are attached orthogonally to each other to the transparent surface of the Lumisight Table. Thus, the table supports at most four people. Information that is not orientation sensitive, such as maps are displayed in a single orientation, that is, every user sees them from a different view. Orientation sensitive information such as words is rotated suitable for each user [MLO$^+$04]. In that way, information can be shared easily. However, moving around the table seems to be difficult because an optimal view on the table is only supported from certain locations. This also makes collaboration between more than four people difficult.

Manual Orientation   The most flexible and intuitive approach to the orientation problem is to support manual orientation. The approach of manual orientation is based on the way orientation is handled in the real world. Participants have the possibility to rotate documents by hand the way they want. While this approach offers more flexibility than fixed orientation, rotation is often clumsy in electronic settings compared to the real world. Input devices such as mice and styli only provide few degrees of freedom and often users have to switch into specific "modes" in order to rotate an item [KCSG03]. However, for instance the InteracTable [SGH$^+$99], ConnecTable [TPMT$^+$01], or [SVFR04] facilitate manual orientation by providing simple gestures that rotate documents (see Figure 2.6(c) and 2.6(b). Usually a "corner to rotate" [KCST05] is provided, whereas a point-and-touch gesture rotates the item.

KRUGER et al. [KCST05] developed a technique that allows both, the translation and the rotation of an electronic item in a single motion. The underlying metaphor of the concept
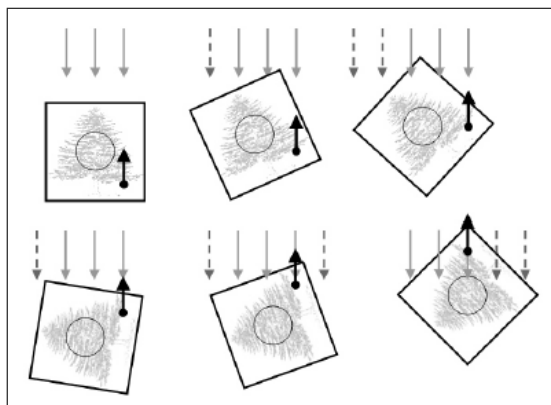
Figure 2.7: Unbalanced movement resulting an an upward translation and counterclockwise rotation [KCST05].

of *Rotate'N Translate* (RNT) is that a "current" is continuously acting against an item's movement vector. When the direction of movement changes, the current acts in opposition to the movement vector which places pressure on the object. As a consequence, the item rotates "until a balanced relationship with the current is achieved"(see Figure 2.7). Once in rotational balance again, the item translates as long as the movement vector remains unchanged. The greater the unbalance between the movement direction of the object and the current, the greater the rotation per unit of movement [KCST05]. According to this interaction metaphor, touching the object at its exact center point would only translate it. Because this would be very difficult for people due to accuracy problems, the "translate-only" center point was expanded to approximately 20% of the object's width. KRUGER et al. conducted a user study that compared the RNT technique with the traditional corner-to-rotate technique [KCST05]. They found that RNT is faster and more efficient, in particular for document passing, than the corner-to-rotate technique while it is equally accurate. Participants found the RNT technique easy to learn and to use.

It seems obvious that the approach of fixed orientation is too limiting for a tabletop system that claims to support co-located collaboration in various situations. Although the approaches of automatic orientation seem to be more comfortable for participants because they do not have to orient items by themselves, they are limiting as well, because orientation influences not only the comprehension of information during a group task but also coordination of activities and communication within a group as described in the following.

Roles of Orientation   So far, orientation of information was described to be important for comprehension. However, orientation of items also has an impact on the coordination and communication within a group [Tan91]. Comprehension, coordination and communication were found to be the three roles of orientation within cooperative work [KCSG03]:

- *Comprehension:* Documents or pictures on tables are often rotated by people to facilitate reading, writing or drawing. The common upright position of a document is not always the most comfortable for people, which argues more for techniques that allow manual orientation to let the user decide which orientation works best. Comprehension includes also reorienting information in order to change the perspective, for instance, when looking on a map or during a chess game [KCSG03].

- *Coordination:* Orientation is used to establish special spaces in order to clarify the ownership and accessibility of items. Studies have shown that people establish personal and group spaces during collaborative work (see Section 2.2.4). The orientation of information can show whether items belong to a person's personal space and whether the person is currently working with them: If an item is lying close to a participant and is clearly oriented to her, other participants hesitate to move it away without asking—the item belongs to the personal space of the participant. In contrast, if an item is located in the middle of the workspace and not oriented clearly to any participant, it is perceived as being available for everyone— it belongs to the public space. Items located in the group space are usually oriented in an compromised angle, that is, they can be perceived by all group members in an equal way. While groups are often switching between parallel and collaborative work, establishing spaces and clarifying ownerships over items in an intuitive way facilitates transitioning smoothly between the different collaboration strategies. By reorienting information can be made available to everyone or blocked for public use in a very social and subtle way. Hence, orientation helps groups to coordinate their work.

- *Communication:* How people orient items in the workspace gives information about their intention to communicate. A person orienting an item directly to another person signals, that she wants to discuss something concerning the item or relinquish it. Orienting an item into a compromised angle so that it is equally visible by all group members guides the attention of the whole group to the item, which can raise easily a group discussion or collaboration. Although reorienting information is sometimes accompanied by other gestures or verbal expressions, it can be perceived as a stand-alone act. KRUGER et al. found that people actually rarely commented or gestured directly to other people while reorienting items [KCSG03]. Orientation alone seems to be communicative enough to be understood by other group members.

Based on their findings, KRUGER et al. [KCSG03] suggest that digital tabletop systems should support free rotation as well as lightweight interaction techniques in order to give groups the possibility to use orientation of items in such a wide variety as they do in traditional environments. Manual rotation seems to support these various purposes of orientation the best while automatic support for rotation has to be designed carefully to prevent interferences with the user's intentions.

Territoriality

As mentioned above, orientation was found to be helpful to establish group and personal spaces on a table. Indeed, TANG [Tan91] and KRUGER et al. [KCSG03] found that partitioning the workspace is an important mechanism to coordinate group activities and mediate social interactions. SCOTT et al. [SCI04] conducted two studies observing groups working with traditional media on a tabletop that substantiate these early findings. During the first study three interaction areas were discovered: *personal spaces*, *group spaces* and *storage spaces*. These areas seem to help participants to coordinate and perform their activities, similar to how territories in our broader environment that help us to mediate social interactions. This is why SCOTT et al. [SCI04] talk about *territoriality* when observing people establishing spaces on tabletops. According to them, tabletop territories have both, spacial properties and functionality, which is described in the following.

Personal Territories   Personal territories are usually established directly in front of participants (see Figure 2.8(a)). Hence, the size of the group and the location of participants plays in important role to the size and location of personal territories. SCOTT et al. [SCI04] found in their first study that the personal territory of a person working alone on a table ranges over the whole table. When more people work on a table they are seated closer. Thus, their personal territories are smaller. Furthermore, depending on the size, the amount of task materials, and the task activity, personal territories can contract or expand. The general function of personal territories is to ease a person's actions.
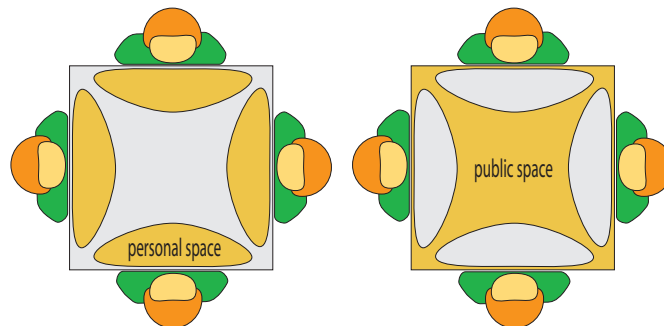
(a) Personal territories on a table.   (b) Group territory.

Figure 2.8: Different territories on tables.

Often, activities that are independent from the group task take place in the personal territory of a person. The personal territory of a participant is usually exclusively used by her. It helps to disengage from group activity in order to do individual work. This exclusive use does not have to be negotiated verbally but it seems to be a social norm, automatically accepted by people [SCI04]. When orientation dependent items are used in personal territories, they are usually oriented to the relating person [KCSG03], as already described in the previous section.

Group Territories   Group territories are located everywhere on the table where no personal territory has been established. In many cases this is at least the center of a table and the space between participants (see Figure 2.8(b)). In group territories, the main collaborative activities take place [SCI04]. Here, users help each other or transfer task resources to other group members. In tightly coupled tasks, orientation is used to provide context and support for information in the group territory, and people feel free to build on others' work or to change it. In contrast, during loosely coupled collaboration participants tend to partition the group territory depending on their seating position. For instance, in the second study SCOTT et al. [SCI04] conducted people were working on a floor plan that was basically handled as group territory. However, each participant was in charge more or less for the area right in front of her on the floor plan. People obviously had partitioned the group territory in order to facilitate work activities.

Storage Territories   Storage territories differ from personal and group territories in terms of their location. While personal and group territories are basically fixed to a location with flexible size, storage territories are mobile and often moved within the workspace. They cannot be considered as specific spaces on the table because they sit atop on personal or group territories depending on their function. In general, storage territories are used for storing task resources such as sticky notes, pieces for a game or tools such as pens, scissors, or erasers. Furthermore, items are often stored that are not task related, such as coffee cups or goodies.

The location of a storage territory depends on the nature of stored resources and who uses them. A participant, for instance, that is working with puzzle pieces showing heaven and clouds would place the relating storage territories holding all these pieces near or inside his personal territory. Resources that are used by several participants are piled up in shared storage territories near or inside the group space. Whether a storage territory is used exclusively or shared among participants can change easily because of its mobility. Sometimes storage territories are even split, for instance, if several participants want to use them.

Establishing territories happens often at the very beginning of the group work in a very natural way and without explicit negotiation. Territories provide a rich resource for coordinating the actual group task. They facilitate transitioning between parallel and collaborative work, which was in particular observed in larger groups working around a digital table [RFSM04] and, furthermore they support sharing task resources and mediating social interaction. Thus, it is strongly recommended that interfaces for digital tables support territoriality.

Sharing Information

One of the most common activity performed in groups is exchanging information. Information is often available physically in the form of documents, papers etc.. However,

sharing information around a large surface can be a problem, because not all participants have physically equal access to information, for instance, when they are hard to reach [Gei98, BCR⁺03]. Interaction across large displays proves to be difficult, in particular, on touch/pen operated screens [BCR⁺03]. For instance, interaction techniques such as drag-and-drop are difficult to perform. Tabletop displays that are build to support group work should be rather large in order to provide enough space for both, participants and information. Thus, interfaces for tabletop displays should provide interaction techniques that support easy access to items that are hard to reach. GEISSLER [Gei98] describes a technique called *throwing* where items can move across larger distances by applying small gesture. The throw gesture is similar to the gesture used in the physical world to slide an item over a smooth surface: The user has to touch the desired item, move it shortly in the opposite direction the item should be moving and then into the desired direction. The longer the second stroke is performed, the faster the item will move. While GEISSLER [Gei98] proposed the gesture for wall displays, SCOTT et al. [SCI04] successfully adopted a similar gesture on a digital table. Although people found the technique very intuitively [SCI04], this technique was found to be too inaccurate, especially when the desired target was rather small [BCR⁺03, SCI04].

(a) Drag-and-pop on a single screen.   (b) Drag-and-pop on a large wall accross bezels.
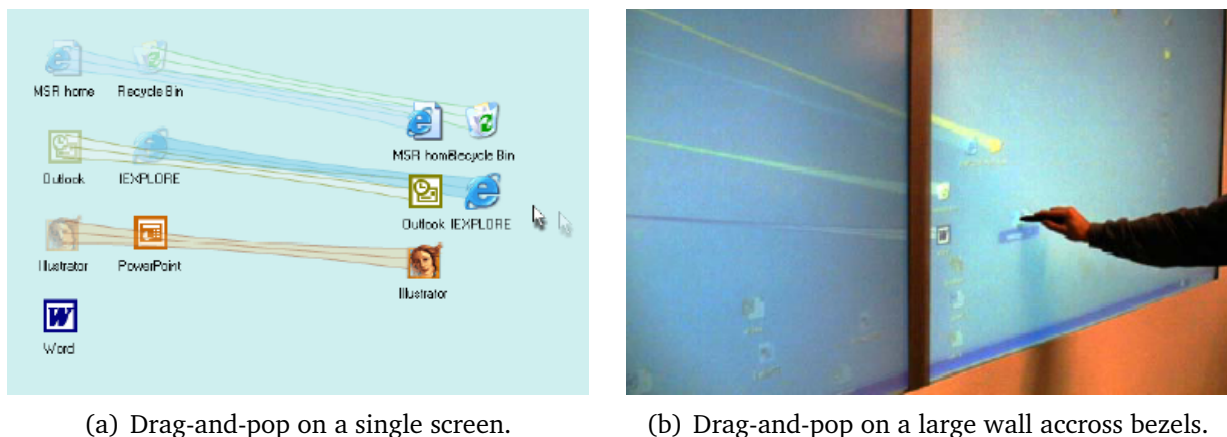
Figure 2.9: Drag-and-pop by BAUDISCH et al. [BCR⁺03].

BAUDISCH et al. [BCR⁺03] introduced another interaction technique for large displays, in particular for walls, that should facilitate accessing content on large touch- and pen-operated displays. The *drag-and-pop* technique is an extension of the well known drag-and-drop technique used on nearly every common single-user workstation. When the user starts dragging an icon, for instance a Word document, all other icons in the workspace that are of compatible type and located in the direction to which the user drags, *pop up* right in front of the user's cursor. This means that a copy of each icon is created (the so-called *tip icon*) and moves towards the user's cursor while still being visually connected to its "parent" item—the so-called *base icon* (see Figure 2.9) [BCR⁺03]. The user can now comfortably drag the icon to the targeted icon. After releasing the icon all tip icons disappear.

Drag-and-pick allows users to activate icons such as folders. The user has to perform a dragging gesture on an empty part of the screen. All icons that are located in the direction of the dragging movement, move towards the user's cursor. The user can select easily the desired icon. This technique provides a possibility to reach icons easily that are located far away from a user. However, it is not clear how this interaction technique could be applied in situations where several people are interacting at the same time. The existence of several tip icons as well as several visual connections between tip and base icons that are crossing each other would overfill the workspace and, even worse, confuse users.

Sharing information on interactive tables is additionally complicated by the fact that the character of a table is generally very public. While simultaneous interaction should be supported by a digital table to encourage cooperation, this can cause several conflicts, for instance, when multiple participants try to access information at the same time or try to perform incompatible actions [SBD99, MRS$^+$04]. These conflicts complicate cooperative work between people. Social protocols can prevent or resolve these conflicts to a certain extent but they are not sufficient. RINGEL et al. [RRS$^+$04] and MORRIS et al. [MRS$^+$04] found that despite of these social protocols conflicts arise even in small groups of people. They suspect that such conflicts increase the more people interact and the more information items are involved. Therefore, they have introduced a set of coordination policies that—applied to a tabletop system—could handle such conflicts in different situations. These policies declare rules, for instance, that the global state of an interface can only be changed if it is not selected by any other person. Different policies can be applied depending on the task or the group size [MRS$^+$04].

RINGEL et al. [RRS$^+$04] have introduced fluid sharing techniques such as release, relocate, reorient, and resize.

- *Release:* When user A holds a document that user B attempts to take, the program just reacts just like in the real world: User B has to wait till user A releases the document.

- *Relocate:* While portions of the table are associated to specific users, documents are private or public depending in which region they are located. Flexible partitions by the user is provided.

- *Reorient:* A document oriented to the center of the table is handled as sharable while an item oriented towards a specific user transitions it back into personal mode.

- *Resize:* Information scaled down smaller than a specific threshold size are considered as private, while enlarging them makes it accessible by every participant on the table.

RINGEL et al. [RRS$^+$04] found that the relocate and resize techniques had the lowest error rates and that the relocate method was more efficient than the other techniques.

Furthermore, users clearly favored the relocated technique although all techniques were easy to learn. However, managing information access automatically by the system can cause problems since group task are changing quite fluidly as described in Section 2.1. Therefore, systems should offer very flexible techniques that do not restrict people's interactions.

Many factors that influence cooperative work on horizontal displays have been discussed in this section. As already pointed out, all these factors should be considered when the designing of interfaces for horizontal displays. The design implications for interfaces on tabletop displays are concluded in the following.

2.2.5 Design Implications for Interfaces on Tabletop Displays

Technically, tabletop displays should support enough space depending on the size of the group [SCH05]. Furthermore, intuitive input devices, such as styli should be provided as well as simultaneous user interaction. However, due to their size, their orientation and the fact that several people should be able to interact at the same time simultaneously, the requirements for interfaces on large horizontal displays differ from those for common single-user workstations. A tabletop system should be arranged around the requirements of the users, that is, the support of human-human interaction should be focused while the computer should step into the background [TPMT+01, SVFR04]. People should be able to focus on the interactions with each other and on their task, rather than on their interactions with the computer. Since people successfully use traditional media for collaborative work, computer-supported systems have to prove themselves as at least as easy and comfortable to use [Gru88]. Interfaces for tabletop displays should draw on traditional interaction techniques that people use when working in groups with traditional media. They should provide lightweight interaction techniques for individuals, as well as for collaborating people. Furthermore, sharing information plays an important role in collaboration. On tabletop displays this is not only complicated due to their size but also because of the fact that information cannot be seen by all participants from the same perspective. Interfaces for tabletop displays have to provide intuitive and lightweight techniques that facilitate reaching items from a long distance and support free rotation of information. Manual and automatic techniques can be utilized for this purpose although the latter have to be handled carefully in order to prevent intervention with the user's desired activities that can fluidly change [KCSG03].

In order to help coordinating the task activities and to handle the shared access to information tabletop systems have to support the establishment of personal and group territories. In doing so visibility and transparency of actions should be provided in order to foster awareness between group members [SCI04]. Furthermore, expanding and diminishing territories must be supported because group tasks change fluidly and more space can be required for collaboration or parallel work. Grouping information should

be enabled as well since people working in traditional environments do this routinely. Shuffling [Gei98] or storage territories [SCI04] can provide this functionality.

Tools on a tabletop workspace should be generally located where they are used frequently. However, tools that are used by more than one group member should be placed in the public space. Local tools that are mobile in the workspace can be beneficial because they can be moved to any position in the workspace and, thus, be shared between several users easily [BHD$^+$96].

The following section will discuss specific tabletop systems and interfaces that support fluid interaction and/or collaboration.

2.3 Interfaces Supporting Fluid Interaction and/or Collaboration

As mentioned above, tabletop systems that support collaboration enable users to concentrate on interaction between each other rather than with the system. Traditional workstations for individual users focus on the interaction between the user and the computer. The computer is all present. The system described in the following shows that tabletop displays have the potential to completely hide their computational components by providing an innovative interface based on a ecosystem metaphor.

2.3.1 Information Exploration Using The Pond

The Pond developed by STÅHL et al. [SWH$^+$02] is a touch sensitive tabletop system used for searching and visualizing information (see Figure 2.10(a)). The interface of The Pond is based on an ecosystem metaphor. The workspace is visualized as a 3D presentation of a virtual pond. Users can start queries concerning information about music, for instance artists or musical genres. The resulting information objects are visualized as shoals of marine creatures. Each creature represents a certain information, such as an album of an artist.

Information creatures that belong together semantically, for instance, albums of the same artist, move together in shoals and try to avoid different shoals as well as the Pond's walls (see Figure 2.10(b)). This constant moving of shoals gives The Pond a very dynamic appearance. When there was no interaction with particular shoals for a long time, they sink down to the bottom of The Pond and disappear. The same happens if The Pond becomes too crowded. This function provides a natural garbage collection. All interactions with the Pond are done by point-and-touch gestures. Tapping on a creature gives the user additional information about the artist and the album that was selected or allows the user to listen to sample tracks. Personal areas are provided, so-called *creels*, that allow
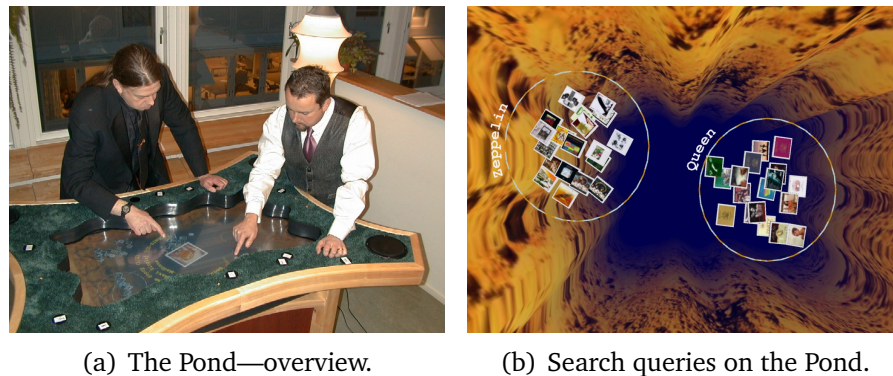
| (a) The Pond—overview. | (b) Search queries on the Pond. |

Figure 2.10: The Pond by STÅHL et al. [SWH+02].

the user to save information creatures. A sound environment supports the immersion into the systems. The user hears constantly low bubbling, splashing and whirling sounds that make the whole systems appear more realistic. These sounds work as functional feedback which was found to be very supporting for the user interaction.

An informal user study revealed that people found the system easy and intuitive to use. Because of the unusual interface that is based on an aquatic environment rather than on a classical user interface The Pond provides an easy access to information, in particular for people that do not have computer skills. The Pond is a good example of how tabletop systems can support simple tasks electronically, while the computer system stays in background and is not clearly visible to the user. The user interacts with information rather than with a computer displaying information and, therefore, can concentrate on her purposes. However, the interface was found to be too inflexible for more elaborate queries. Parallel work is not possible because the touch screen does not support multiple simultaneous interactions. In addition, it is not clear, how The Pond could support realistic group tasks.

The systems described in the following focus on tools from the real world to support collaboration on tabletop displays.

2.3.2 Lazy Susans on Tabletop Displays

The question how to support co-located collaboration around table systems is already answered in the real world: Information can be rotated and piled up physically very easy. Sharing can be facilitated by so-called lazy Susans known from Chinese restaurants.

A lazy Susan is a rotatable, usually round plate made of wood or glass located in the middle of a table (see Figure 2.11). People sitting around the table can place items on it, for instance food or dishes. By rotating the lazy Susan these items can be passed easily

Figure 2.11: Lazy Susan in a Chinese restaurant.

between people. Some tabletop systems have adopted the principle of a lazy Susan in the broadest sense. These systems are described in the following.

Interactive Table

The Interactive Table [OPH+00] was developed in a cooperation between the Museum of Modern Art [4] (MoMA), New York and the MIT Media Laboratory[5]. The MoMA was planning an exhibition that consisted of 26 architectural exhibits. Each of the exhibit was emphasized by lots of electronic information that is usually displayed by computers located apart from the exhibition. The design of the Interactive Table was motivated by the intention of integrating electronic information more into the exhibition and, furthermore, to motivate visitors to interactively browse through this information and share impressions with others [OPH+00].

(a) Lazy Susan on the Interactive Table.

(b) Top-projected displays on each place setting.

Figure 2.12: The Interactive Table at the MoMA [OPH+00].

---

4 `http://www.moma.org`
5 `http://www.media.mit.edu`

The Interactive Table is a five-legged round dining table with a surface with eight feet at diameter. It provides space for eight people. For each of these place seatings a display is projected from above which is 14 inches by 18 inches (see Figure 2.12(b)). This space acts as a "personal territory", as described in Section 2.2.4. In the middle of the Interactive Table a five-foot-diameter lazy Susan is placed that has 26 holes on its outer edge. In each of these holes one coaster is located that represents one of each exhibits in the showroom (see Figure 2.12(a)). In middle of the lazy Susan a display is projected as well. In order to get information about a specific exhibit, the user has to place the corresponding coaster from the lazy Susan to a certain position in the displayed workspace in front of her. An interface appears that allows the user to choose the desired information. This information including text, images, and animations is then displayed. Visitors that browse through information on the Interactive Table have the possibility to share such information with others. To do that, the user can send certain images to the center of the lazy Susan, the "group territory" of the table. First, the image will be oriented to the person who has send it, but by rotating the lazy Susan physically the image would be rotated, as well, which makes it possible for others to see it in an appropriate angle [OPH+00].

The concept of the Interactive Table shows a possibility of using a physical lazy Susan in order to facilitate sharing of information in electronic (certain information about the exhibits) and physical (coasters representing those information) form. A lazy Susan can ease the orientation problem and act as a public space or group territory, respectively, at the same time. Furthermore, people use it intuitively since they know the principle from the real world. The systems described in the next section use the principle of a lazy Susan as well but in an electronic way.

UbiTable, Personal Digital Historian, and Poetry Table

The UbiTable [SER03], the Personal Digital Historian (PDH) [SLV03], and the Poetry-Table [RFSM04] were all developed by the Mitsubishi Electronic Research Laboratory (MERL)[6](see Figure 2.13).

For all of these systems the DiamondTouch [DL01], a touch sensitive display that supports simultaneous user interaction, was used. The implementation of the interfaces was based on the DiamondSpin toolkit [SLV03]. The DiamondSpin toolkit facilitates rapid prototyping of interfaces for interactive shared displays. It provides functionality concerning visual document management, document control and interaction, manipulation of items by hand or styli, multi-user support and, particularly, management of personal and public spaces and orientation of interface components [SLV03]. The common ground of UbiTable, PDH and Poetry table is that they provide a public space in the middle of the workspace. Information items are oriented to the edges of the digital table to provide sharing.
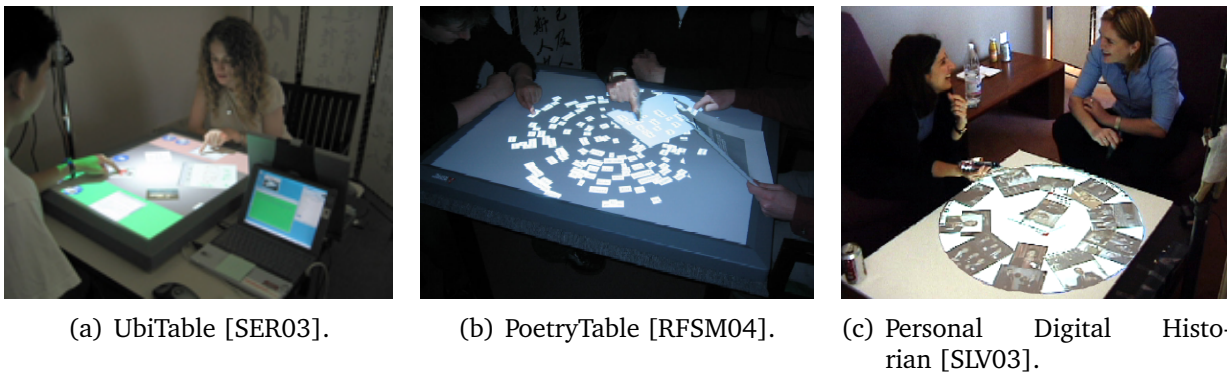
---

6 http://www.merl.com

(a) UbiTable [SER03].   (b) PoetryTable [RFSM04].   (c) Personal Digital Historian [SLV03].

Figure 2.13: Tabletop systems built by MERL.

(a) UbiTable—personal and group spaces [SER03].   (b) PDH—rotatable group space [SLV03].
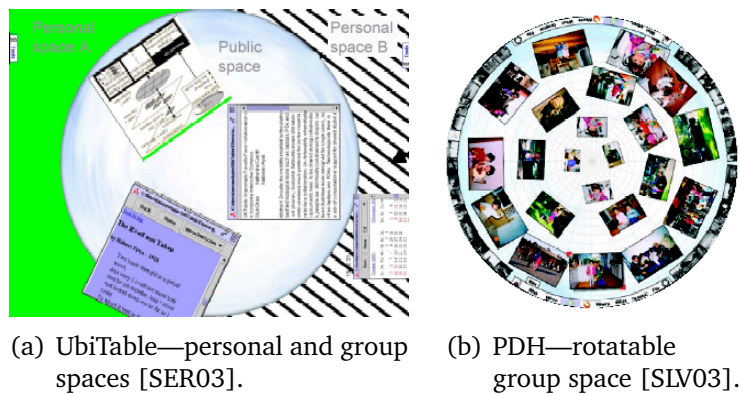
Figure 2.14: Group spaces on the UbiTable and the PDH.

UbiTable

The UbiTable [SER03] allows people to connect portable devices such as laptops or USB-devices with it in order to exchange or transfer documents easily. In this way, the UbiTable supports a private area in form of the laptop. Passersby cannot see information that a user wants to keep private without coming very close. Furthermore, the interface of the UbiTable provides a personal (semi private) space in front of each user and a public space in the middle of the table. All collaborators at the digital table have access to information in the public space. This space acts like a group territory as described in Section 2.2.4. The public space reminds of a physical lazy Susan, because it is circular and all information items are oriented towards the edges of the table (see Figure 2.14(a)). However, as far as SHEN et al. [SER03] describe the public space, it is not rotatable. This would be useful, in particular if the application is used on a larger table, where people cannot reach everything in the public space that easy. In addition, the public and personal space have a fixed size. Because the amount of items in the personal or group space can increase during collaboration this could cause problems.

PoetryTable

The PoetryTable was developed for an educational game inspired by "magnetic poetry"[7] where people can construct little stories or poems by combining word tiles. Similar to the UbiTable, the setup of the PoetryTable described by RYALL et al. [RFSM04] consists of a large circular group space in the middle of the table where word tiles are spread out. Each word tile is oriented to the outside of the group space. Pop-up menus allow users to duplicate or to change the prefix or suffix of a word. A user study where groups of people had to reconstruct given poems with the word tiles showed that in particular groups of more than two members often worked in parallel by dividing up the task. The PoetryTable, in contrast to the UbiTable, does not support personal spaces which can cause problems when people are doing more complicated tasks involving more resources. Furthermore, as already stated in the last paragraph, it would be useful to have a rotatable group space to facilitate the sharing of resources.

Personal Digital Historian (PDH)

The PDH [SLV03] supports "interactive informal storytelling" for multiple users. Most of the tabletop space is used for a large circular public space called the *story-space*. In the story-space, photographs and images that the users want to share are spread out. All images are oriented to the outside of the circular space similar as on the PoetryTable described above. They can be oriented manually, as well (see Figure 2.14(b)). Furthermore, the whole story-space can be rotated such as a lazy Susan [SLV03]. The story space is surrounded by a rim where arched control panels are located. The control panels can be used to display certain content in the middle of the workspace. They are repositionable along the perimeter of the workspace and, depending on the number of users collaborating, the number of panels can be increased in order to provide each user with an own control panel. A stream of moving pictures can be optionally projected on unused spaces of the perimeter of the digital table [SLV03]. These pictures can relate to other pictures in the story-space. They can also be explored in greater detail if desired.

The PDH is suitable for tasks that require very close collaboration. Due to the setup of the workspace it does foster working in parallel because it does not provide personal spaces. The whole workspace is more or less a public space. Thus, the PDH does not support a large variety of collaborative tasks but only very specific ones. However, sharing information benefits from the fact that the whole story-space is rotatable.

These three tabletop systems show how the orientation problem can be solved in the public workspace of a tabletop display. In particular the rotatable public space on the PDH provides an easy way to give all people working on the digital table the same access to information. An interesting part of the PDH is the option to have a stream of pictures. The design of the Café Table, described in the following section, focuses more on this idea of streaming information.

---

7   http://www.magneticpoetry.com

2.3.3 Conveyer on Tabletop Displays

Similar to the concept of a lazy Susan is the concept of a conveyer that can be found in sushi bars where it carries by sushi to people or at the airport where it is used for carrying luggage (see Figure 2.15). The following system uses a virtual conveyer for carrying information.

(a) Conveyer in a sushi bar.

(b) Luggage conveyer at the airport.

Figure 2.15: Principle of a conveyer.

The Café Table

The Café Table (see Figure 2.16(a)) was developed by Philips Electronics[8] as part of the so-called *Living Memory project* (LiMe) which purpose it was to give people in a community the opportunity to share and explore their "collective memories". The Café Table as part of this project should enable users to view, access, and manipulate electronic information that is generated by other people of their community. It is basically a small table such as those in coffee houses in which a flat-screen is embedded. The interface of the Café Table is half tangible(see Figure 2.16(b)).

So-called *Tokens*, plastic chips holding electronic information, can be placed on the *Token Dish* in the middle of the table. Content can then be dragged to the interface that consists inter alia of a *Flow Zone* and a *Work Zone*. The Flow Zone runs along the perimeter of the display. Within the Flow Zone minimized information constantly *flows*. Information, that appears as small icons, is carried just like a conveyer in a sushi bar. In that way, the user can browse through it. DE BRUIJN and SPENCE [dBS01] call this browsing mechanism *opportunistic browsing* because it happens unintentionally. People sitting in a coffee house do not search for information on purpose, but while they are drinking their coffee and chatting with a friend information is floating by and they might see something interesting. In this case, they can just touch the information with their finger and drag it into the Work Zone, which occupies the central area of the screen to get more details. Opportunistic browsing means, according to de BRUIJN and SPENCE, "information

---

8 `http://www.design.philips.com/about/design/section-13507`

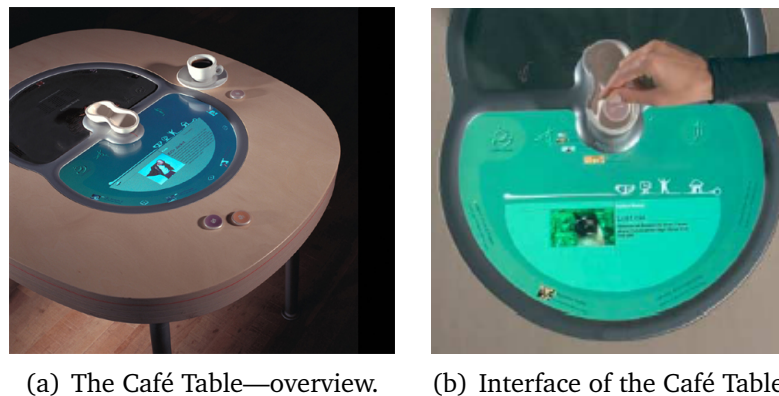(a) The Café Table—overview.   (b) Interface of the Café Table.

Figure 2.16: The Café Table by Philips [dBS01].

gathering on the fly". Information is monitored and filtered unconsciously while floating by. The user does not have to concentrate on browsing, but can have a conversation or read a newspaper while still peripherally being aware of the information floating by. The movement on the Flow Zone can be manipulated by the user. As long as it is touched, the movement of information is stopped. As soon as the user removes the finger again, the information start floating again. Moving the finger while touching the Flow Zone will cause the flow to accelerate or change its direction.

The Flow Zone as a conveyer carrying information promises potential for co-located collaborative work around shared displays. It could help groups to share information easily. However, the Café Table is not designed for groups to collaborate, since it is too small and the interface does only provide fixed orientation of information for each side of the table. Thus, it provides a personal space for each user but no group or public space where information could be shared. Furthermore, the Flow Zone is rather inflexible. It cannot be changed in shape or moved to another position of the table which could be necessary for specific stages in tasks where more space is required. Furthermore, the flow of information cannot be stopped completely.

While the example of the Café Table shows that streaming information can be useful for browsing through information opportunistically, the movement of information can also be used for searching or getting an overview of specific information. The principle that stands behind this theory is explained in the following.

2.3.4 Rapid Serial Visual Presentation

DE BRUIJN and SPENCE [dBS01] have defined the idea of *opportunistic browsing* as an unintentional browsing through information. They define *browsing* as an activity that is more directed and focused on getting an overview, for example, of a folder of images [dBS00]. People browsing through information want to know "What is there?".

Searching as a specific form of browsing, is more weighted. While searching people are asking "Is it here?". *Rapid serial visual presentation* (RSVP) is a technique developed by DE BRUIJN and SPENCE [dBS00] that displays electronic information, for instance, images from a folder, very fast one after another. The user can see every image only a brief moment and, thus, can quickly form a mental model of the folder's content. This is particularly useful if a folder holds large amounts of images that cannot be displayed all at once.
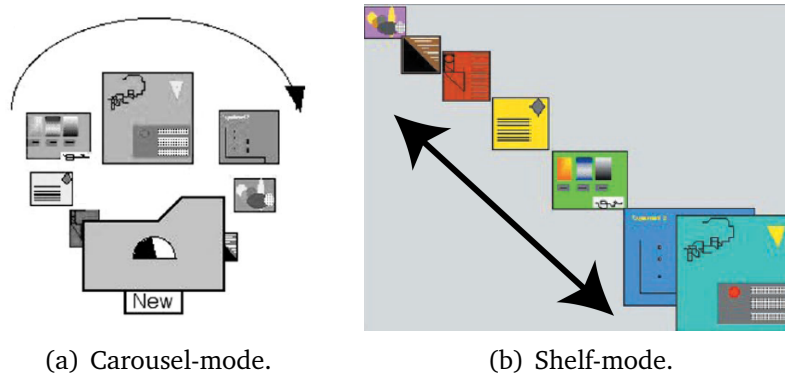

(a) Carousel-mode.   (b) Shelf-mode.

Figure 2.17: Dynamic RSVP techniques [Spe02].

There are different RSVP techiques. *Static* RSVP displays images at the same location. Each image is only visible until it is replaced by the following image. In contrast, *dynamic* RSVP displays images in a stream. In that way an image can be visible even if other images are being displayed, as well. Static RSVP can be useful when the user is searching for a certain image, while dynamic RSVP can support browsing in a better way. People working in groups often have to deal with large amounts of information. Often everybody brings in own material and the other group members have to get an overview of this material before it is possible to start with the actual task. Dynamic RSVP techniques, such as carousel- or shelf-mode (see Figure 2.17), could be applied to interfaces on tabletop displays in order to support this functionality.

2.4 Chapter Summary

This chapter has given an overview of potential and problems of supporting co-located collaboration around large horizontal displays. First, the factors influencing collaboration between people in general were described followed by a short motivation for supporting collaboration by computers. After that, characteristics of tabletop displays were explained including possible technical settings, possible input devices, and interaction issues. The last section described a number of approaches of developing systems that support collaborative work in a certain way and ideas that have the potential of facilitating co-located collaborative work. These systems and ideas were very inspiring for the

concept of Interface Currents, this thesis is about. The following chapter introduces the concept of Interface Currents together with the issues and research questions it raises and outlines an approach how these issues can be solved.

CHAPTER 3

Methodology

As described in Section 2.3, lazy Susans and conveyer belts in the real world support the sharing of items and information between multiple people. Similar to the PDH [SLV03] and the Café Table [dBS01], the concept of Interface Currents developed by HINRICHS et al. [HCS05a] is strongly motivated by these principles from the real world. It combines the principles of lazy Susans and conveyer belts flexibility and mobility to integrate the advantages of the physical techniques with the digital domain. Interface Currents, as a fluid and flexible interaction technique, offers the potential to help people share information around a large horizontal display while supporting creativity during group collaboration. Subtle environmental orientation can be installed in certain areas of the workspace to ease the orientation problem. Furthermore, Interface Currents provide functionality for establishing public, personal, and storage territories and for transitioning between parallel and collaborative work [HCS05a]. However, the potential benefits of how people will use Interface Currents have not been studied yet. In order to begin to understand the effectiveness of Interface Currents for supporting information sharing and creative activities during collaboration an observational user study was conducted. To provide sufficient background for this study this chapter begins by briefly explaining the concept, characteristics, and functionality of Interface Currents. Then the issues and research questions that arose from this concept are described, leading into an explanation of the study methodology used to expand the understanding of the purposes and roles Interface Currents can play in collaborative and creative tasks.

3.1 The Concept of Interface Currents

A current is a continuous onward movement traditionally thought of as existing in a body of liquid or gas. An Interface Current is defined as a mobile, flexible container that is dominated by an ongoing flow [HCS05a]. Digital information such as images or

documents can be placed on an Interface Current and are affected by the flow moving constantly similarly to leaves driven by a current in a river. An Interface Current is characterized by its directional flow, speed, confining boundaries, and its location.

3.1.1 Properties of Interface Currents

The fundamental properties of an Interface Current are the *flow* and the *path* in which the flow travels. Depending on a Current's location in the workspace its visibility can also be changed.

Flow

An Interface Current's flow is defined by its direction and velocity. Both, direction and velocity, are adjustable by the user independently. In the prototypes that HINRICHS et al. [HCS05a] presented, the Interface Current's flow is invisible unless information items are placed on it (see Figure 3.1(a) and 3.1(c)). Adding an item, however, causes it to follow the flow's direction and velocity.

Path

An Interface Current flows in a path that has a location and some type of boundaries. The location of the path can either be fixed or mobile. The Current's boundaries define its shape and size, indicating the areas that are affected by the flow. They can be rigid in that they are defined initially and not changed or they can be flexible and controlled by either the user or the system. A *pool-shaped* Current is bordered by one single boundary (see Figure 3.1(a)). It is comparable to a lake where the water flows in circles. The flow

(a) Pool-shaped Current. (b) Flow on a pool-shaped Current. (c) Stream-shaped Current. (d) Flow on a stream-shaped Current.
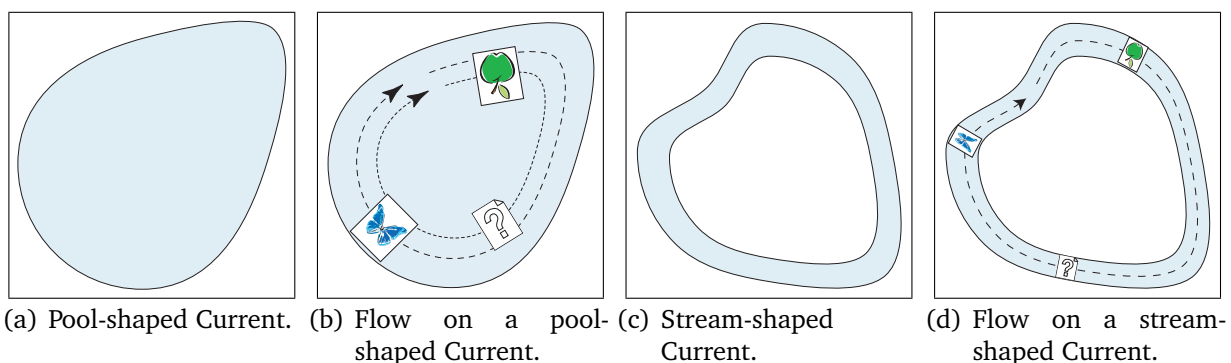
Figure 3.1: Pool- and stream-shaped Interface Currents [HCS05a].

of a pool-shaped Current runs parallel to its boundary (see Figure 3.1(b)). A stream-shaped Current is confined by an inside and an outside boundary (see Figure 3.1(c)). Thus, items on a stream-shaped Current will flow like leaves on a river as mentioned above (see Figure 3.1(d)).

Visibility

While the path of an Interface Current defines its visual appearance, the location of the path determines its visibility. Depending on the purposes a Current is used for, its path can be totally visible, partly visible, or invisible (see Figure 3.2). If an Interface Current is used as a personal storage it can be reasonable to move it partly out of the workspace in order to save personal space (see Figure 3.2(c)). In contrast, Currents used in a group space for sharing items can be totally visible (see Figure 3.2(a) and 3.2(b)). Information items that are not currently needed can be moved out of the workspace by placing them on an Interface Current and moving this Current out of the workspace (see Figure 3.2(c)).
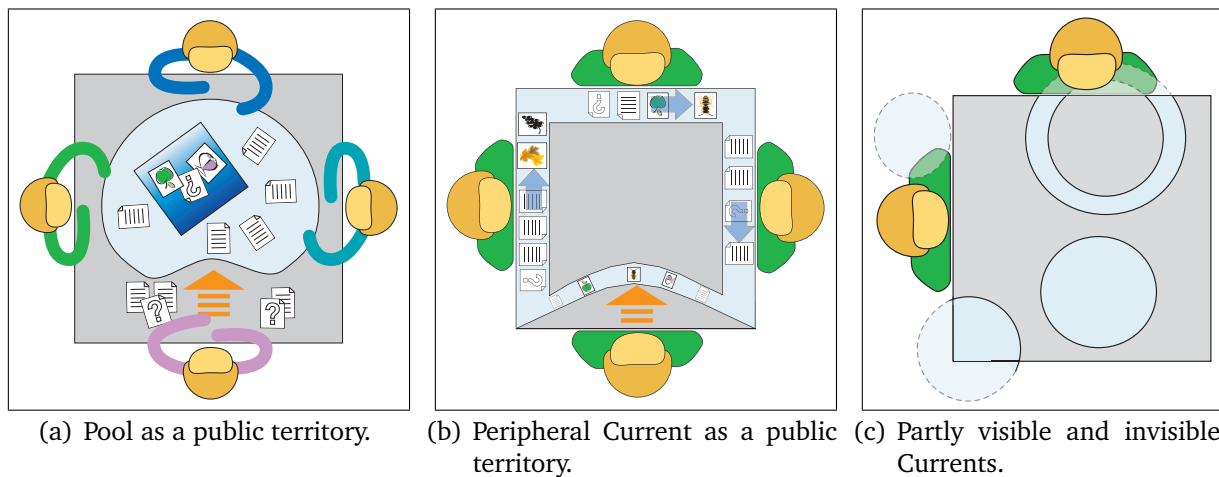

(a) Pool as a public territory.   (b) Peripheral Current as a public territory.   (c) Partly visible and invisible Currents.

Figure 3.2: Visibility of Interface Currents and reorientation of items.

Interface Currents were developed to support fluid interaction during collaborative work. Possible purposes that Interface Currents could fulfill in a tabletop workspace are described in the following Section.

3.1.2 Possible Usage of Interface Currents

Interface Currents were not developed to fulfill one specific functionality. They were designed to support collaborative work, which can include several features. The following presents possible usages of Interface Currents that are imaginable when considering the findings from previous studies where tabletop collaboration was explored [SCI04, SGM03].

Providing a Group Space

An Interface Current can be used as a group space where information items can be shared among collaborating people. A large pool-shaped Current, for instance, placed in the middle of the workspace could be used as a virtual lazy Susan that is extended by reshaping and resizing functions (see Figure 3.2(a)). A stream-shaped Current surrounding the workspace could also be considered as a group space which helps people to share large amounts of information (see Figure 3.2(b)).

Providing Personal Storage Areas

Small Interface Currents can also be used as personal storage territories for storing personal items. Large amounts of items can be stored on a partly visible Current in order to save personal workspace (see Figure 3.2(c)).

Facilitating Item Sharing

Items floating on an Interface Current always orient themselves towards the Current's outer border (see Figures 3.2(a) and 3.2(b)). While information is floating, each group member can easily see information that passes in front of her. This approach of environmental orientation should ease the orientation problem on tabletop displays (see Section 2.2.4) and, furthermore, supports the sharing of information within a group. Items can be placed on an Interface Current that runs around the periphery of the tabletop workspace (see Figure 3.2(b)) in order to automatically pass them among group members. Pool-shaped Currents stretched out over a tabletop display can be used for sharing items, for instance, in order to work on the same task (see Figure 3.2(a)). At the same time, the flexibility of Interface Currents enables users to disconnect from collaborative work in order to work independently (see Figure 3.2(a) and 3.2(b)).

HINRICHS et al. [HCS05a] have described the concept and proposed possible implementation approaches for Interface Currents but how effective these Interface Currents are and what roles they can play during collaboration has not been formally studied. An exploratory user study was conducted to gain more insight in how people actually interact with Interface Currents, for what purposes they use them, and whether or not they would find them helpful. The questions and issues raised by the concept of Interface Currents are described in the following section.

3.2 Problem Statement

As discussed in Sections 2.1 and 2.2.4, ease, efficiency, and effectiveness of tabletop collaborative work is influenced by various factors including: each group member's awareness of each other [GG00], the orientation problem (see Section 2.2.4), territoriality on tabletop displays (see Section 2.2.4) [SCI04], and the difficulty of reach on large displays

(see Section 2.2.4) [SGM03]. Interface Currents have been designed with these issues and problems in mind. With their properties and functionalities just described they have the potential to support collaborative work. However, an important remaining task is to assess the effectiveness of these interface components. In general, the research questions the concept of Interface Currents raises are:

Q1: *Do Interface Currents support co-located collaborative work around a horizontal display and if so, in which way?*

Q2: *How do people interact with Interface Currents in general?*

Q3: *For what purposes do people use Interface Currents?*

Q4: *How would people set up a workspace based on Interface Currents?*

Q5: *Do people enjoy interacting with Interface Currents?*

On the one hand, the general usability of Interface Currents is questioned, on the other hand, issues concerning collaboration in general are raised. Both types of questions can only be answered by careful observation. Thus, a user study has to be conducted. The study results always depend on the methods that were used for gathering the information [McG94]. Depending on the goals of the study, decisions have to be made, for instance, which data collection methods should be used and what kind of data should be collected. The study design, that is the methodology, is a critical part of the evaluation process because all decisions that are made in this stage have influence on the credibility and generalizability of results. There are many different methods and strategies to conduct a user study and each have different advantages and limitations that need to be considered. Furthermore, evaluating collaborative group work itself is not a trivial process that brings its own difficulties and issues. This is discussed in detail in the following section referring to which strategy, method or technique would be the appropriate for the design of an evaluation of the concept of Interface Currents.

3.3 Study Design

The design of an evaluation is critical for the reliability and validity of the gathered results. Which method to choose for an evaluation depends strongly on the research problem and goals [McG94]. The question, for instance, if interaction technique X is faster than interaction technique Y can be answered through a controlled experiment where participants have to perform tasks using both interaction techniques. The performance times can be measured and analyzed. Although there are more things to consider for this example, for instance, the randomization of conditions [McG94], the methodology for such an evaluation is comparatively easy to develop. In contrast, the evaluation of computer-supported cooperative work and, therefore, the evaluation of concepts and tools supporting it is much more complicated [NCR04]. The underlying variables that

influence collaborative work are very complex and still not fully understood. An individual's cognitive factors have to be considered, as well as cooperative and collaborative factors of the group (see Section 2.1). There are usability issues that are affected by individuals and groups that have social and organizational impact [NCR04, Gru88]. These factors are hard—if not impossible—to control during an evaluation and depending on the case, it is not clear how much they influence the results of the study. For instance, if a program does not support collaborative work very well, groups are usually able to cope with the situation by changing their work strategies. At the end it is not possible to clarify which strategies were "natural" and which were adopted because of the awkward work environment.

Furthermore, it is difficult to measure the quality of cooperative work. Although it is possible to measure the performance for specific activities, this does not necessarily say anything about the quality of the collaboration itself. For instance, the group might be much more satisfied with their results or they had much more fun while working together, although finishing the task took them a long time. Group work in general is not always more efficient compared to individual work although the quality of results can be better, for example when creativity comes into play, as described in Chapter 2. For these reasons, the evaluation of applications supporting collaborative work requires different approaches than the evaluation of single-user applications [Gru88]. For the study design it is first of all important to define research goals and objectives and to choose the appropriate research strategy and approach. After that, it must be decided which data should be measured (according to the research question) and how they can be measured, collected and analyzed.

3.3.1 Research Goals and Objectives

The research goal for the evaluation of Interface Currents was to investigate how people interact with Interface Currents in a collaborative situation and how the continuous flow would influence the style of collaboration. The underlying research question was:

Would Interface Currents support collaborative work and if so, in what manner?

As a secondary goal, the study looked at particular interaction issues of the realization of Interface Currents and the related interaction techniques.

3.3.2 Research Approach

There are basically two research approaches that can be chosen depending on the purpose of the evaluation: the quantitative and the qualitative approach. The design of user studies that follow the quantitative approach is static. That is, concept, variables, and hypothesis have to be defined before the study is conducted and cannot be changed

throughout the study [Cre98]. Usually, numerical data is collected, such as the time that is used for performing a task or the number of times an interaction technique is performed. This data is then analyzed using statistics, for instance, to reveal if users can accomplish a specific task faster with technique X or Y. To obtain data that is objective as possible variables that could bias the outcome are eliminated or controlled and the investigator has to remain as distant and independent as possible [Cre98]. The quantitative approach is often used for controlled studies, when a certain hypothesis is to be proven or two systems are to be compared with each other.

In contrast, in user studies that follow the qualitative research approach data is derived from observations or interviews [MH94]. This data comes in the form of words rather than numbers. It is less objective than quantitative data because, for instance, the social background of the researcher can bias the observations or the way she interviews people. Qualitative data, however, is very rich in information: They can provide descriptions and explanations about the processes that happen during collaboration and which events lead to which consequences [MH94]. While quantitative data can answer questions about *what* people are doing during a study, qualitative data gives impressions about the *how* and the *why* people are acting the way they do. Thus, the qualitative research approach is suitable for studies evaluating computer-supported collaborative work.

For the evaluation of Interface Currents an exploratory user study was conducted following a qualitative research approach. This approach is suitable because the purposes and research questions for the study were of rather general nature. As mentioned in the last section, the goal of the study was to explore how people would interact with Interface Currents and why they would choose certain ways to interact. Qualitative methods such as observations and interviews can give a deep insight in these rather general questions. In addition, horizontal displays are a rather new research area. Although several studies have been conducted to investigate group behavior on tabletop displays [SCH05, KCSG03, RL04, AEF$^+$00], the fact that group behavior strongly depends on the task, the environment, and social factors makes it difficult to derive generalizations. Furthermore, integrating flow in interfaces for tabletop displays to support collaboration is an innovative approach. As a result, there are no appropriate interface components with which to run comparisons. For example, one aspect of Interface Currents is that items can be moved from one side of the table to the other. There are several single function interface components that have been specifically designed to address reach as described in Section 2.2.4. In a direct comparison such a single function component is likely to prove faster, however, this type of comparison removes considerations of the interplay of the multiple functionalities that Interface Currents provide.

For exploring new and complex concepts, such as the concept of Interface Currents, where theories and well defined hypotheses are not yet available but need to be developed, an exploratory user study is appropriate [Cre98]. Furthermore, when the reactions of users cannot be anticipated beforehand, it is more appropriate to choose a research approach that is more flexible and does not restrict the researcher to predefined question-

naires. Instead, the researcher can be responsive to comments participants make during the study or to problems they encounter.

3.3.3 Research Method

The qualitative research approach offers several methods for the actual study design, and how the data is to be collected and analyzed. The most common qualitative methods are ethnographies, grounded theory, case studies, and phenomenological studies [Cre98]. These methods are mostly based on observations and self-reports, such as interviews and questionnaires. These forms of data collection provide rich information about the activities of participants but also have weaknesses [McG94]. Self-reports can give direct information about the activities of participants through the participants themselves. Participants can state what they found useful or not and give reasons for certain behaviors. This can be very helpful for the investigator in order to understand what he or she actually observed.

On the other hand, the responses of participants might be influenced by social factors. It could be an act of courtesy, for example, to laud an interaction technique or to not state difficulties with it [McG94]. That is, self reports are not objective and are always biased by the participant's social background. Observations can abate this problem because they give the investigator the possibility to question arguable statements of participants that do not match with the investigator's observations. Nevertheless, observation as a method of data collection has issues, as well, because it is work intensive and subjective. It needs skilled observers that are able to take down notes while observing people. This is difficult, particularly, in studies that involve collaborative tasks performed by groups. More than one observer might be necessary, since it is not possible to thoroughly observe the activities of two people at once. Many interesting interactions could be overlooked. Thus, observations are costly in both time and resources [McG94].

Furthermore, the behavior of people knowing that they are being observed is biased and not completely natural [McG94]. The observations the investigator records by annotation are biased, as well, because they are influenced by the researcher's social background and underlying assumptions. Often, investigators have a certain opinion about what they saw during the observation which does not match with reality [JH95]. The data based on direct observation or self reports is reconstructed and augmented by interpretations and assumptions. Nevertheless, it is often discussed as primary data although the actual events have been replaced by subjective interpretations [JH95]. Video recordings can inhibit this bias. Recording the behavior of participants as well as their verbal statements produces data that mirror the actual events rather than interpretations of them. The investigator can compare the observations in form of field notes with the video data and correct interpretations that were made based on wrong assumptions. Video records enable researchers to observe events as often as necessary. Researchers can show the records to others which can be very helpful for the analysis, because other re-

searchers can bring in new ideas based on their own background and experiences [JH95]. In addition, the investigator is not under such pressure during the actual observation to take notes of everything she observes, because it is always possible to replay sequences of the interaction. Video recodings are also helpful during interviews, because the investigator can concentrate on the actual interview without having to write down detailed answers of participants.

For the evaluation of Interface Currents all three methods for data collection explained above were used in combination. All verbal and nonverbal activities of participants were videotaped. Field notes were made during each study session and participants were interviewed in order to get more insight in their opinions about the interaction techniques and specific activities that were observed. This qualitative data was enhanced by quantitative data gained from a data logging program that logged all interactions of participants with the tabletop system (see Chapter 5). This *triangulation* of methods [Cre98] can neutralize the biases that are inherent in each single method of data collection. For instance, hypotheses based on the analysis of the collected qualitative data can be substantiated by quantitative data. This approach is well-known for exploratory user studies [SCH05, SMI03, BIF+04]. The analysis of the evaluation of Interface Currents, however, was focused on the qualitative data following the *Interaction Analysis* according to Jordan and Henderson (see Chapter 7) [JH95].

3.3.4 Tasks and Study Scenarios

After defining the research goals and choosing the methodology of the evaluation tasks and scenarios have to be developed. The tasks that participants have to do during a study have to be based on the purposes and goals of the evaluation, as well, because they form the foundation on which the data is collected. If the task does not fit with the purposes of the study, the results will not be reliable. Group tasks are often based on planning [AEF+00, RL04] or on organization [SCH05, RFSM04]. The problem is, however, that there is no clear definition for group tasks. When a new email client gets evaluated for usability, for example, it is clearly defined what kind of tasks a user should be able to perform (writing, sending and retrieving emails, making new entries into the address book, etc.). In contrast, the tasks that could be performed within a group supported by Interface Currents are ill-defined. Appropriate tasks should be creative, collaborative, and involve large amounts of items that need to be shared within a group. Developing the right tasks for the evaluation of the concept of Interface Currents was a challenge because it was not clear which tasks Interface Currents could support concretely. In fact, as mentioned above, the study should indicate for which purposes groups use Interface Currents. On the one hand, a task scenario had to be designed for the participants to provide a starting point for them, on the other hand the task scenario should not bias their natural tendencies on how to use or not use Interface Currents.

This challenge was solved by dividing the study in two parts (see Chapter 5). The first scenario contained a clearly defined task where participants had to interact at least minimally with one Interface Current. This was intentional to let them experience the interaction with this new form of interface component. The possibility to use more than one Interface Current was given but not enforced. In the second scenario the groups got much more freedom to solve the task. They could use their experiences gained from the first task scenario that could be positive or negative with respect to the interaction with Interface Currents. In that way it could be observed, how people would interact with Interface Currents and for which purposes people would use them. For more details see Chapter 5.

3.4 Chapter Summary

This chapter described the concept of Interface Currents that was introduced by HIN-RICHS et al. [HCS05a] and the questions and issues it raises. Although the concept of Interface Currents seems promising in terms of supporting and facilitating co-located collaborative work around large displays, no assessment or evaluation has ever been performed to explore the functionality of Interface Currents. The research goals for an evaluation of the concept of Interface Currents were:

- To investigate how people would interact with Interface Currents in general,

- to understand the purposes for which Interface Currents would be used, and

- to explore how Interface Currents would influence work strategies of collaborating groups.

To find answers to these questions an exploratory user study was conducted following a qualitative research approach. The qualitative research supports the investigation of Interface Currents as a highly new and innovative interaction technique on a general level without actually providing underlying hypotheses beforehand. Qualitative methods do not necessarily involve the creation of hypothesis and focus on observations and self-reports as techniques for data collection. Since these methods are very vulnerable to biases, the evaluation of Interface Currents was performed as a triangulation of methods:

1. Observations were made and field notes were taken during each study session and the interviews with the participants.

2. Each study session was videotaped recording nonverbal and verbal activities.

3. Qualitative data was enhanced by quantitative data gained from a logging program that logged every interaction of participants with the system.

Two distinct tasks were designed. The first was a more structured task providing the participants with the opportunity to experience the interaction with Interface Currents. The second task involved a more free form scenario and let the participants decide how to use Currents. Both scenarios are described full detail in Chapter 5. The two task scenarios required more interface components than Interface Currents. Otherwise, the tasks would not be realistic. Thus, before the actual procedure of the evaluation is explained, the underlying system, that is the implemented task workspace and its components, is described and illustrated in the following chapter.

CHAPTER 4

Workspace Design and Implementation

The previous chapter exemplified that the study design is a very important aspect in the process of planning an evaluation. Based on these findings, this chapter discusses the workspace design which plays another important role. The workspace has to provide a stable work environment that allows users to perform tasks within the scope of the user study. Therefore, for the exploratory user study evaluating the concept of Interface Currents an environment has to be developed where people can perform collaborative tasks. Such an environment has to provide Interface Currents as the component to be evaluated, but also other components that people can interact with, such as text documents or photos. For a normal single-user environment this may sound trivial since many tools were developed that facilitate building single-user interfaces, for instance the Jigloo GUI Builder[1]. In contrast, developing a workspace that can be used by multiple users collaboratively is still a challenge [SVFR04]. Interfaces for horizontal displays have special requirements, as explained in Section 2.2, and for this reason it is not possible to hark back to predefined solutions provided by single-user applications.

Furthermore, a virtual work environment that is used for an evaluation is required to run stable. Program crashes are very disruptive during a user study and, thus, it is critical to avoid them. While crashes during a study session where an individual participant is performing tasks are annoying, they are especially problematic for study sessions where groups of people are involved. Group tasks usually require more time than individual tasks due to the time that has to be invested in the coordination of activities among group members. Thus, it is usually not possible to resume the task when the system crashes. Even if data can be recovered, crashes disturb the group's work flow and interrupt their interactions. This can have a huge impact on all following group activities.

Program crashes also bias the opinion that users develop about a system or an interaction technique that is to evaluate. This will influence the statements given in self-reports. Furthermore, while the interactions of individuals are much easier to control without

---

1   http://cloudgarden.com/jigloo/index.html

constraining them too much, systems supporting collaborative work between multiple people have to handle a high variety of interactions that can, in addition, occur simultaneously. Thus, developing collaborative workspaces is also a challenge in terms of stability.

Finally, all implemented interaction techniques within the workspace should be tested by sample participants, so-called pilots, to discover interaction problems before the actual evaluation takes place. As mentioned before, people are able to work around awkward interaction techniques or work environments although this can be frustrating. However, if work strategies are changed due to awkward interaction techniques or other problems, this will influence the results so that the actual research goal cannot be achieved anymore. Thus, such problems have to be discovered and eliminated or minimized in a user centered design process where the system is continuously tested by individual pilots or pilot groups. This approach slows down the design and implementation process but is very useful to prevent problems or breakdowns during the actual user study.

The interactive workspace, that was used for the evaluation of the concept of Interface Currents was developed in a collaborative process where several people were involved. The prototypes of Interface Currents as described by HINRICHS et al. [HCS05a], were build in a strictly 2-dimensional workspace that provided interaction with virtual images and Interface Currents but did not support simultaneous multi-user interaction. Furthermore, most of the interaction techniques with components such as virtual images were not intuitive and fluent enough to really support collaborative work between people. Habelski [Hab04] used this workspace as a base platform and redesigned it for a user study conducted by SCOTT et al. [SCH05]. In particular, he improved the interaction techniques with the virtual images in the workspace (see Section 4.1) and enabled simultaneous user interaction with the help of Tse and Greenberg's SDG Toolkit [TG04]. The user study by SCOTT et al. [SCH05] was an evaluation of so-called *storage bins*. Storage bins are containers in the workspace that offer people the opportunity to organize items in restricted areas that can be fixed or mobile (see Figure 4.1). While the visual design of storage bins follows the design of Interface Currents to a great extend, they have very different characteristics. For instance, storage bins do not provide no flow interaction. Within the scope of this thesis' research project, an advanced version of Interface Currents in terms of interaction and concept was installed into the workspace of SCOTT et al. [SCH05] although only certain interface components and interaction techniques were adopted. The workspace is implemented in Microsoft Visual C# and OpenGL using the Tao OpenGL library[2]. All interface components described in the following sections are based on simple OpenGL primitives. The following section will describe Interface Objects — the information items in the workspace — and the relating interaction techniques. After this, the general concept of Interface Currents is explained with the basic algorithms and interaction techniques, followed by the introduction of the new version of Interface Currents that was developed based on several pilot tests. The last section

---

2 http://www.mono-project.com/Tao

Figure 4.1: Mark-up menu on a storage bin [SCH05].

of this chapter describes the concept of Interface Folders, a new interface component for tabletop displays that form a functional extension of Interface Currents.

4.1 Interface Objects

One of the main components in the workspace are the so-called *Interface Objects*. Interface Objects are small items that carry information in form of images or text (see Figure 4.2(a)). Every Interface Object can be moved and rotated freely within the workspace. For the realization of translation and rotation of Interface Objects, KRUGER et al.'s [KCST05] Rotate'N Translate (RNT) technique was used. It allows the user to perform rotation and translation of items in one single point–and–touch gesture (see Section 2.2.4). While the RNT technique alone is found very intuitive and easy to use [KCST05], Habelski [Hab04] extended this technique with the possibility to *toss* and *catch* items, an interaction technique based on the "throwing" gesture by Geißler [Gei98], described in Section 2.2.4. When the user touches an Interface Object with the finger or stylus, it will change into "interaction mode" indicated by a half-transparent blue circle surrounding the area around its center (see Figure 4.2(b)). A touch-and-move gesture with the touch point within the blue circle causes the Interface Object to move without reorienting itself (see Figure 4.2(c)), that means that it will translate only. A touch-and-move gesture with the touch point outside the blue circle will cause the Object to Rotate'N Translate (see Figure 4.2(d)). To toss an Interface Object, the user has to point-and-touch the desired object and make a short touch-and-push gesture. This will cause the Interface Object to slide into the direction it was pushed. Depending on the applied pressure and the location of the touch point, the Object slides slower or faster or rotates while sliding. Furthermore, sliding Interface Objects can be caught by users, i. e., the sliding can be interrupted. SCOTT et al. [SCH05] found that people used the tossing technique extensively for passing items to each other or just for presorting them. Besides alternatives for moving, Interface Objects also provide a technique for resizing. Each Interface Object is furnished with a little resizing handle on its right lower corner

(see Figure 4.2(e)). A touch-and-move gesture allows the user to scale it whereas it is possible to scale width and height independently.
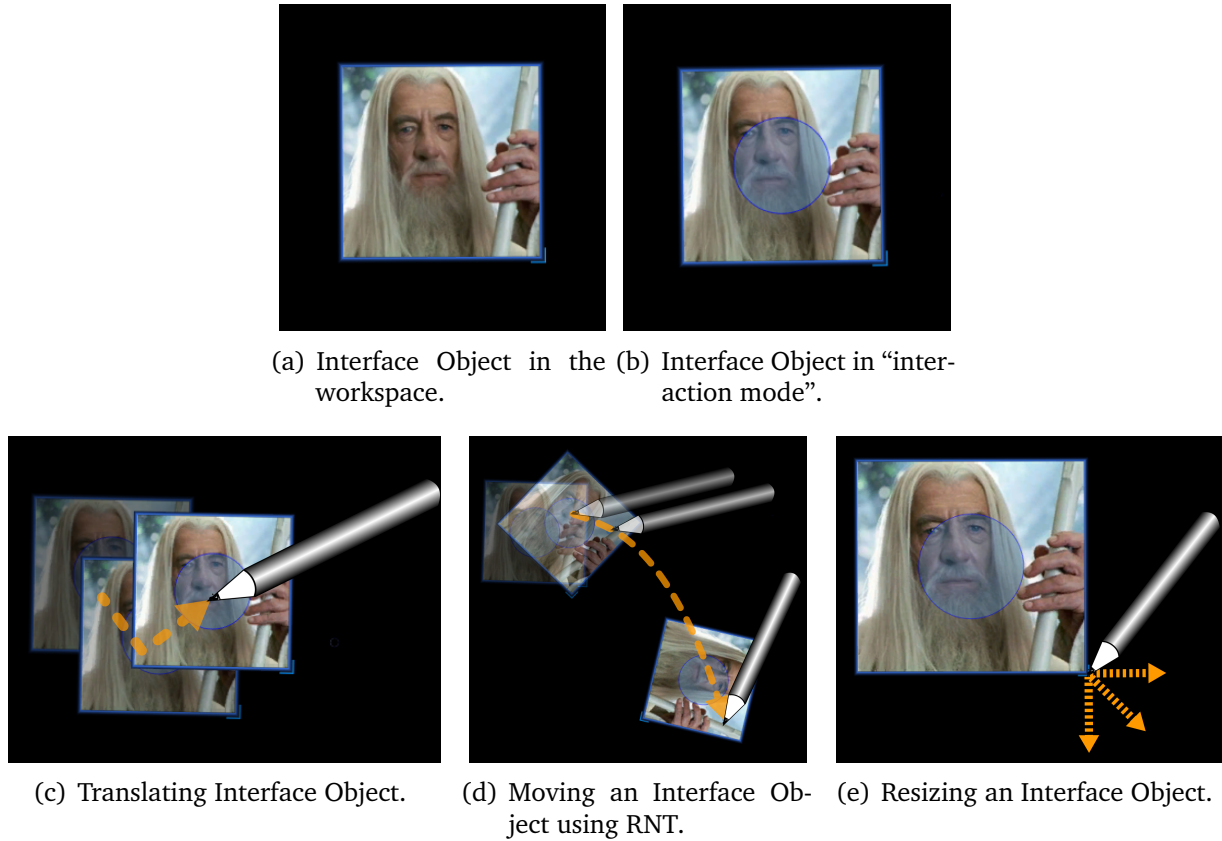

(a) Interface Object in the workspace.

(b) Interface Object in "interaction mode".

(c) Translating Interface Object.

(d) Moving an Interface Object using RNT.

(e) Resizing an Interface Object.

Figure 4.2: Interaction with Interface Objects.

Due to one of the tasks people should perform during the exploratory user study, an extension to the Interface Object, the so-called *Page Object* was developed. Page Objects have the same characteristics as Interface Objects, however, when an Interface Object is placed over a Page Object, it "sticks" to it just like a sticky note. When the Page Object is moved by the user, rotated, or tossed, all Interface Objects sticking on it, will stay on their positions on the Page Object and, thus, follow all transformations of the Page Object (see Figure 4.3). Only resizing the Page Object will not cause sticking Interface Objects resize as well. The functionality of Page Objects is useful for building collages or page layouts as demanded from participants during the study.

As mentioned above, Interface Objects form the foundation for the tasks that people were ask to perform during the study. Thus, it is very important that people can interact with them fluently and intuitively. Both RNT and tossing are light-weight interaction techniques similar to gestures that are used on traditional tables. People find them so easy and intuitive to use [KCST05].

Figure 4.3: Interface Objects sticking on a Page Object.

While Interface Objects represent the information items for realizing the task itself, other components in the workspace, such as Interface Currents, were installed in order to support the realization of the task, that is, the processes that were leading to the final results. These interface components are described in detail in the following sections.

4.2 Interface Currents

The user study was conducted in order to evaluate the concept of Interface Current (see Section 3.1). While the concept of Interface Currents was adopted completely for the evaluation, some changes were made in the realization, in particular with regard to the interaction techniques. This section describes the general approach to the realization of Interface Currents, introduced by HINRICHS et al. [HCS05a], and its problems. Furthermore, the new version of Interface Currents that was developed within this research project is introduced while the new interaction techniques are focused in particular.

4.2.1 Realization of Interface Currents—The General Approach

The implementation of Interface Currents is based on an algorithm by DYN, LEVIN, and GREGORY [DLG87]. In order to achieve a maximum of flexibility, the boundaries of each Interface Current are defined by one or two basic 4-point interpolating subdivision curves, depending on the type of Current (stream- or pool-shaped). For each subdivision curve, eight so-called *control points* are predefined and in five iteration steps the number of sub-points between the predefined control points is constantly increased according to Equation 4.1 in order to produce a visually smooth curve (see Figure 4.4). All points generated by this method are situated directly on the boundary. A subdivision curve gen-

erated by DYN, LEVIN, and GREGORY's algorithm offers C1 continuity which is acceptable given that it offers direct interactive control at the same time.

$$w_{2i} = v_i$$
$$w_{2i+1} = -\frac{1}{16}v_{i-1} + \frac{9}{16}v_i + \frac{9}{16}v_{i+1} - \frac{1}{16}v_{v+2} \tag{4.1}$$
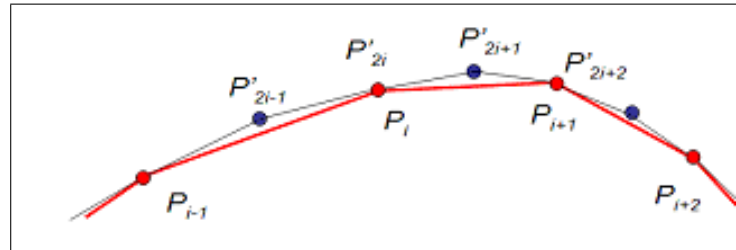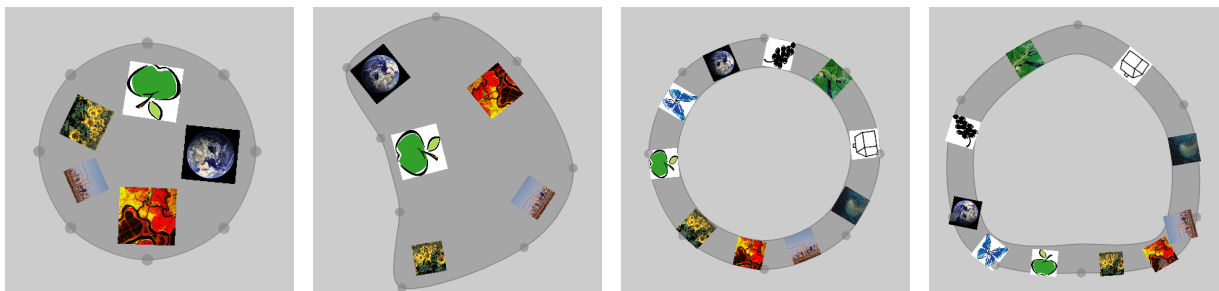

Figure 4.4: Calculation of an interpolating subdivision curve [DLG87].

The results of this approach are shown in Figure 4.5. For the pool-shaped Current, only one single interpolating subdivision curve has to be determined while stream-shaped Currents require two curves—one for the inside and one for the outside border. HINRICHS

(a) Pool-shaped Current in default shape. (b) Pool-shaped Current manipulated by user. (c) Stream-shaped Current in default shape. (d) Stream-shaped Current manipulated by user.

Figure 4.5: Prototypes of Interface Currents [HCS05a].

et al. [HCS05a] use the eight control points not only to define the boundaries of Interface Current but these points also provide the basis for all interactions concerning the manipulation of Interface Currents. The manipulation of Interface Currents according to HINRICHS et al. [HCS05a] contains three functions:

- manipulating the shape of the Current,

- manipulating the location of the Current, and

- manipulating the width (concerning stream-shaped Currents).

These three functions are integrated in each of the control points that are visualized on the outer border of every Interface Current (see Figure 4.5). The touch of one of the control points invokes a mark-up menu [TK95] that contains three icons, each presenting one of the functions explained above (see Figure 4.6(a)). A touch-and-move gesture from the control point to the desired menu icon allows the user to accomplish the desired manipulation (see Figure 4.6(b), 4.6(c), and 4.6(d)). SCOTT et al. [SCH05] integrated
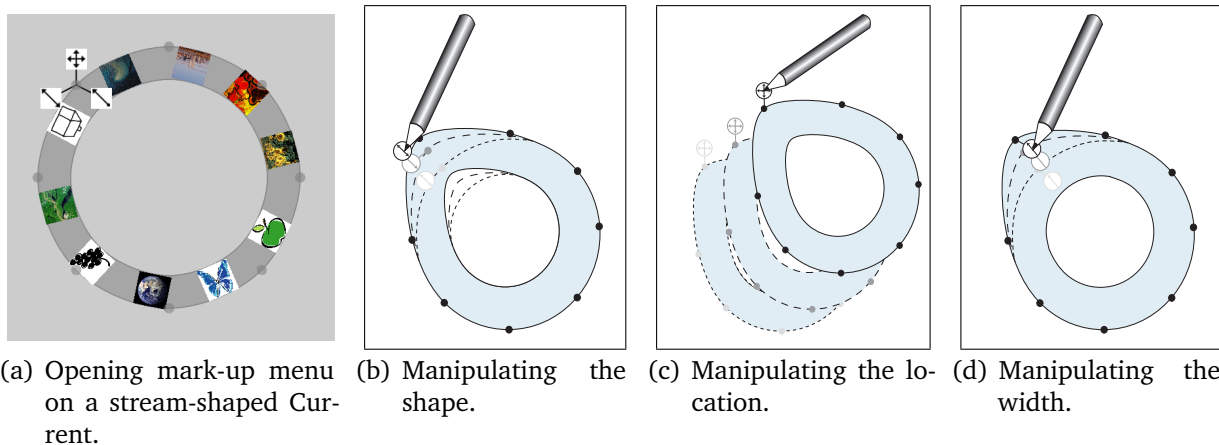

(a) Opening mark-up menu on a stream-shaped Current.

(b) Manipulating the shape.

(c) Manipulating the location.

(d) Manipulating the width.

Figure 4.6: Manipulating Interface Currents [HCS05a].

this approach in their design of storage bins. However, they found in the user study they conducted that participants had major difficulties with this menu-based interaction technique. The interaction technique for moving a storage bin or Interface Current according to the prototype by HINRICHS et al. [HCS05a], for instance, is inconsistent compared the the interaction technique for moving an Interface Object. The user has to perform a touch-and-move gesture to any point of the Interface Object in order to move it. Often, participants tried to apply the same interaction technique on storage bins and got frustrated when this was not working. Furthermore, the icons are too small and too similar in their appearance so that participants obviously had difficulties to identify the desired menu icon (see Figure 4.1). While the new version of Interface Currents is still based on the approach of using an interpolating subdivision curve, the problems of the mark-up menu were taken into account. Furthermore, some modifications, in particular on stream-shaped Currents, were conducted. Some of this modifications were motivated by early pilot tests, as described in the following section.

4.2.2 The New Version of Interface Currents

First of all, the visual appearance of Interface Currents was changed in order to make them more appealing to users. Since the idea of Interface Currents was inspired by a water metaphor in the broader sense as described in Section 3.1, a transparent dark blue

seemed to be the appropriated color for Currents (see Figure 4.7). Interface Currents are basically a container tool for facilitating collaboration and thus, it was important to design them clearly visible but unobtrusive since the flow itself already attracts a lot of attention. People should be able to focus on the information floating on Interface Currents rather than on the Currents themselves. However, some other modifications were made that focus more on functionality issues than on visual design considerations.

New Types of Interface Currents

While a pool-shaped Current only requires one single boundary and, therefore, control points have to be integrated on the outside border (see Figure 4.7(a)), a stream-shaped Current offers the possibility to install them either on the outer or on the inner border. During pilot tests the latter configuration was found to be very useful, especially
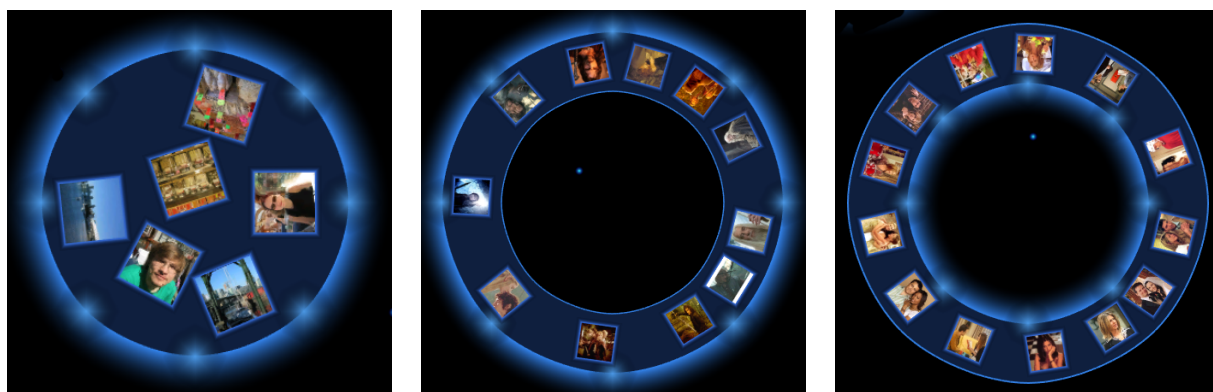
(a) Pool-shaped Current in default shape.

(b) Stream-shaped Current with control points on the outside border.

(c) Stream-shaped Current with control points on the inside border.

Figure 4.7: Different types of Interface Currents.

for stream-shaped Currents that are stretched around the edges of the workspace (see Figure 4.8). If the control points would be installed on the outer border of such a *peripheral* stream-shaped Current, it would be hard to interact with them because they are too close to the borders of the workspace (see Figure 4.8(a)). Thus, two different forms of stream-shaped Currents were implemented, one with the control points on the outside and one with the control points on the inside border as illustrated in Figure 4.7(b) and 4.7(c). Furthermore, pilots requested to integrate more than eight control points on a large peripheral Current, to be able to better control the shape. For instance, on a large peripheral Current, this seems useful as shown in Figure 4.8(b) and 4.8(c). Integrating eight control points, every user has only one control point in front herself to interact with which restricts the shape of the Current to only a few variations (see Figure 4.8(b)). With 16 control points, in contrast, the user has much more possibilities to create magnification areas or personal territories (see Figure 4.8(c)). For this reason, the number of control points was increased to 16. With 16 control points three control points can
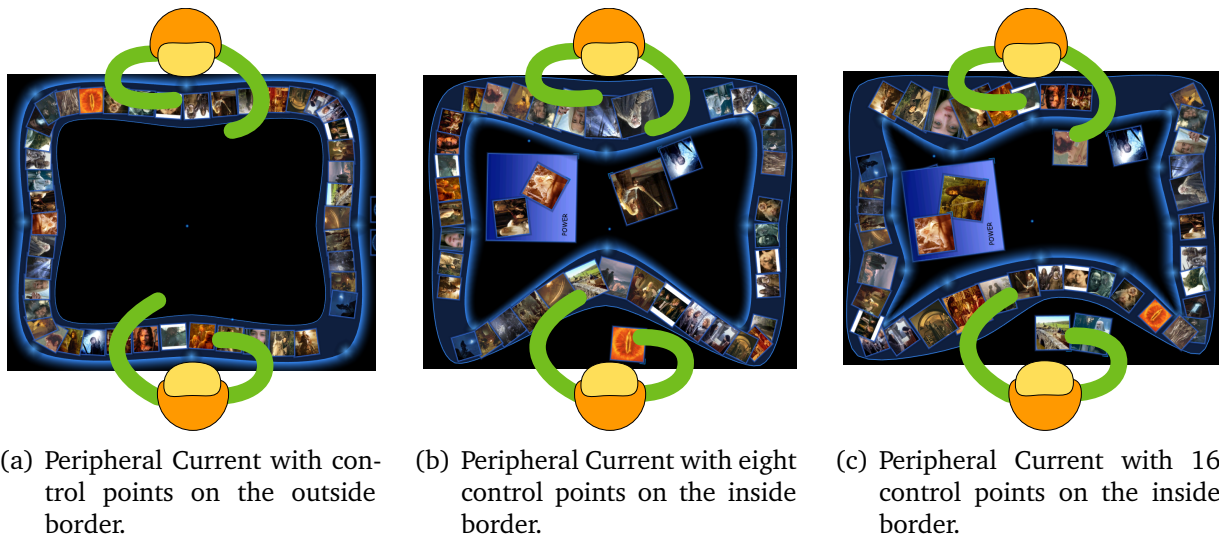
(a) Peripheral Current with control points on the outside border.

(b) Peripheral Current with eight control points on the inside border.

(c) Peripheral Current with 16 control points on the inside border.

Figure 4.8: Control point issues with peripheral Currents.

be placed around each edge of the table which gives users the opportunity to adjust the Current right in front of them in various ways. However, in particular, when Currents are rather small this can cause problems because the density of control points on the border becomes too dense so that users will have difficulties to select the desired control point (see Figure 4.9(a) and 4.9(b)).

(a) Stream-shaped Current with 16 control points.

(b) High density of control points.

(c) Changing the shape of a Current with 16 control points.

(d) Changing the shape of a Current with 8 control points.
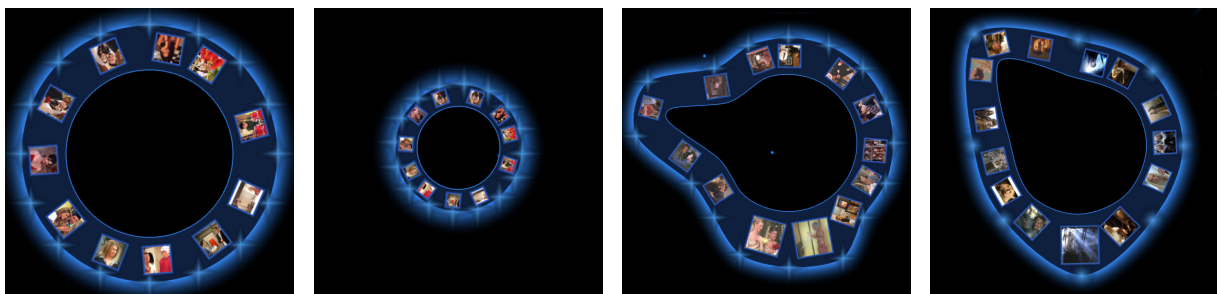
Figure 4.9: High amount of control points involves interaction problems.

In addition, several control points have to be moved in order to achieve the desired shape as illustrated in Figure 4.9(c) and 4.9(d) which was found to be frustrating for users. For this reason, in the user study evaluating the concept of Interface Currents, only the peripheral Interface Current was provided with 16 control points (see Chapter 5). All other Currents, that the participants were able to create by themselves, only contained eight control points. Of course, the number of control points is not manda-

tory but can be changed in the program depending on the number of users or the shape of the table, for instance. An interesting feature could be the adding and removing of control points by users but this remains future work (see Chapter 8). A serious problem

Figure 4.10: "Pop-in-front" functionality on peripheral Current.

that was observed during the pilot tests is the overlapping of information items (see Sections 4.3.2 and 6.1.4) that occurs when large amounts of items are added to an Interface Current. This problem was perceived as very disturbing by test participants, in particular on stream-shaped Currents where items cannot spread out that easily than on a pool-shaped Current. To ease this distracting difficulty a feature was added to the peripheral Current where the problem occurred mostly. Whenever an information item flows by certain control points, it is brought in front, shifting itself in front of other information items (see Figure 4.10). As position triggering this function, the two control points in front of each user were chosen. This prototypical approach was not enhanced further for the study due to time constraints but it offers the potential for other more mature solutions (see Sections 6.1.4 and 8).

Beside the expansion of the Interface Current by new types, the new version of Interface Currents provides direct manipulation of the flow's velocity as described in the following.

Flow on Interface Currents

Continuous flow is the most important characteristic of Interface Currents. It has the potential to be very supportive for sharing information as explained in Chapter 3. However, it can also be very distracting, especially, if users do not have the possibility to stop the flow or to slow it down. The prototype of Interface Currents introduced by HINRICHS et al. [HCS05a] provided only one basic velocity that would vary depending how far the control points of the Current are stretched out. The longer the distance of one control point to the next, the faster items flow between these points. This approach allows only indirect manipulation of the flow. Forcing people to change the shape of the Current in order to slow down the speed of information floating by is inappropriate. Thus, the new version of Interface Currents allows people to change the velocity of the flow on a Current directly in an intuitive way.

As explained in the last section, the boundaries of an Interface Current are defined by one or two subdivision curves. Such a subdivision curve based on eight initial control points and five iteration steps consists in total of 128 points that are stored in a double-linked list. The movement of items on an Interface Current is based on the points in this boundary list. When an item is added to a Current, the closest corresponding point P_1 of the boundary list is determined. Then, the distance D from the center point m of the Current to the corresponding point P_1 is determined and the distance d from m to the center point c of the item (see Figure 4.2.2). The calculation of new location of the item
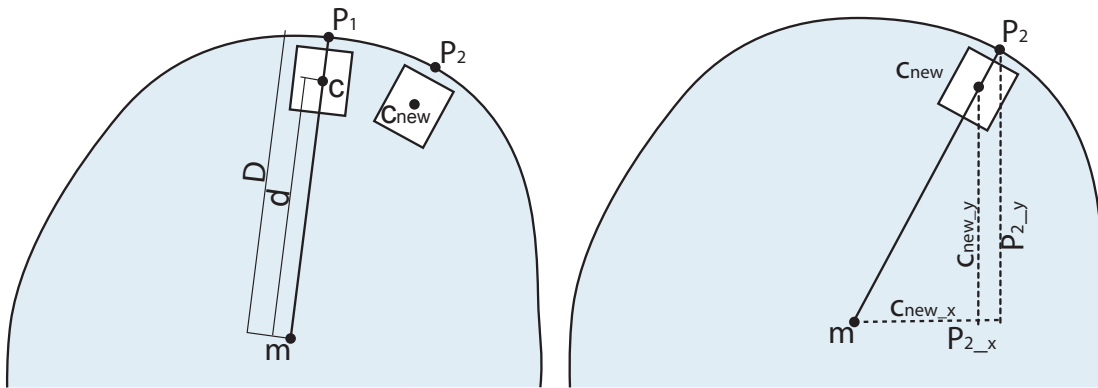
Figure 4.11: Calculation of the movement of items on a Current [HCS05a].

on the Current is based on the following point P_2 in the boundary list. It is assumed that the ratio between d and D always stays the same while the item is moving [HCS05a] on the Current. Thus, the theorem of intersecting lines can be applied (see Figure 4.2.2).

$$\frac{d}{D} = \frac{c_{new\_x}}{P_{2\_x}} = \frac{c_{new\_y}}{P_{2\_y}} \tag{4.2}$$

Equation 4.2 is solved to c_{new_x} and c_{new_y}, respectively, that define the new center point of the item. A timer that is used for refreshing the whole workspace triggers this calculation that is performed for each point in the boundary list and each item located on an Interface Current so that they seem to move continuously driven by an ongoing flow.

This algorithm, derived by HINRICHS et al. [HCS05a], implicates that the the more an Interface Current is stretched, the longer the distance between the locations of the 128 points in the boundary list, and the faster items are moving on the Current. Thus, the velocity can be changed indirectly by changing the shape of the Current as mentioned above. For the new version of Interface Currents, the algorithm was changed slightly in order to realize different flow velocities on the Current that can be manipulated directly by the user. Three different so-called velocity lists are determined for each Current that are used instead of the boundary list for the movement calculation of each item. Therefore, the number of iteration steps that are applied to the eight initial control points to derive a boundary list representing the subdivision curve was increased from five to

eight. This results in a list containing 1024 points. From this list, four different lists were derived: one boundary list and three velocity lists. The visual appearance of the Current is based on a boundary list, containing 128 (every 8th point of the 1024-point-list) points as explained above. The three other lists containing 256 (every 4th point), 512 (every 2nd point), and 1024 points represent the three velocity lists that are used depending on how fast items on the Current should flow. Depending on the velocity setting (slow, medium, or fast) that was chosen for an Interface Current (see Section 4.2.3) the relating velocity list is used for the movement calculation of each item. For the slowest velocity setting the velocity list with 1024 points is used. In each timer step an item on the Interface Current is moved according to the relating point in the velocity list. The more points are in a velocity list, the more timer steps are required to let an item go round on the Current. This is why items seems to move slower when the velocity list with 1024 points is applied for the movement calculation than with the velocity list with 512 or 256 points. In this way, three distinct velocities are available to the user. Note that always one certain velocity list is applied to one Current and not to an item. Thus, a Current is always dominated by one certain flow velocity and all items flow in this velocity.

The next section describes inter alia how the user can manipulate the flow and therefore the rate of floating items.

4.2.3 Interaction with Interface Currents

The flexibility of Interface Currents is reflected by the possibilities of changing its shape, location and flow by the user. Interface Currents can be tailored to different tasks and purposes. This section describes the interaction techniques that Interface Currents provide.

Manipulation of the Appearance of Interface Currents

As discussed in Section 4.2.1, SCOTT et al. [SCH05] found in an observational study that participants had severe problems in using the mark-up menu in order to change the shape of storage bins that are visually designed according to the prototype of Interface Currents by HINRICHS et al. [HCS05a]. Because similar problems with the mark-up menu were to expect in the evaluation of Interface Currents as well, the appearance of the menu was redesigned for the new version of Interface Currents. The first problem seemed to be that the menu icons were very small and hard to distinguish. Thus, they were enlarged and redesigned as shown in Figures 4.12 and 4.13. Pilot tests revealed that the new menu icons are better to distinguish and to interact with due to their size. In addition, pilots were able to associate them with the related actions. Furthermore, the menu was implemented so that menu icons would never obscure items floating on the Interface Current but always be oriented to the outside the Current (see Figures 4.12(a), 4.12(c), and 4.13(a)). This was achieved by determining the orientation of the menu based on the vector between the center point of the Interface Current

(a) Menu on a stream-shaped Current (outside).

(b) From left: reshaping, resizing, changing the width.

(c) Menu on a stream-shaped Current (inside).

Figure 4.12: Mark-up menu on stream-shaped Currents.

and the corresponding control point. The menu is always oriented to the direction of this vector.

Regarding the functionality represented by the menu, the function of relocating the Current was replaced by the possibility of resizing the Current. Thus, the menu of a stream-shaped Interface Current consists of three menu icons representing reshaping the Current, changing its width, and resizing the Current (see Figure 4.12(b)). Since a pool-shaped Current has no actual width, its menu consists only of icons for reshaping and resizing (see Figure 4.13(b)).
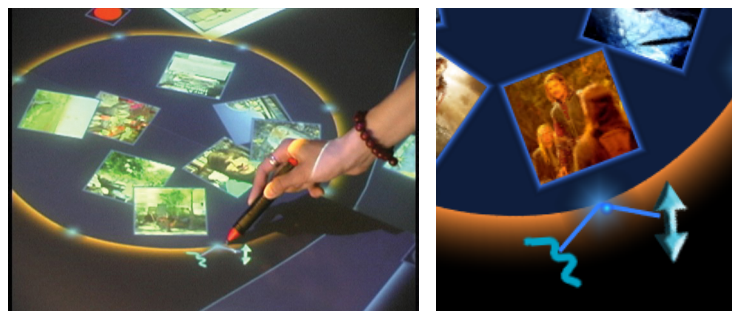
(a) Invoking the mark-up menu.

(b) Reshaping (left) and resizing (right).

Figure 4.13: Mark-up menu on pool-shaped Currents.

A new interaction technique for relocating a Current was developed due to the findings of SCOTT et al. [SCH05] that revealed the inconsistency between moving Interface Objects and storage bins. All these interaction techniques and their underlying implementation are described detailed in the following paragraphs.

Reshaping a Current   Reshaping an Interface Current means for a stream-shaped Current that the course of its path is changed, that is, inside and outside boundary are changed equally. On a pool-shaped Current, the single outer border is adjusted. When the user performs a point–and–move gesture using the pen or finger to one of the control points on a Current, the mark–up menu invokes as described above. A move–while–touching gesture to the reshaping icon (see Figures 4.12(b) and 4.13(b)) brings the Interface Current into *reshaping mode*. Moving the pen while touching the menu icon will cause the corresponding control point to follow the moving pen (see Figure 4.14). After the pen is removed from the table surface and the user does not select one of the menu icons again, the menu disappears. While the Current is reshaped, the subdivision curve(s) are recalculated continuously. To save computing power, in this phase only five iteration steps are performed that calculate only the 128 points in the boundary list. As soon as the pen is removed from the table surface, however, eight iteration steps are performed to recalculate the points for the three velocity lists as well. Thus, the visual appearance of the Current is recalculated in real time but the flow of icons is stopped temporary while menu interactions are performed on a Current.
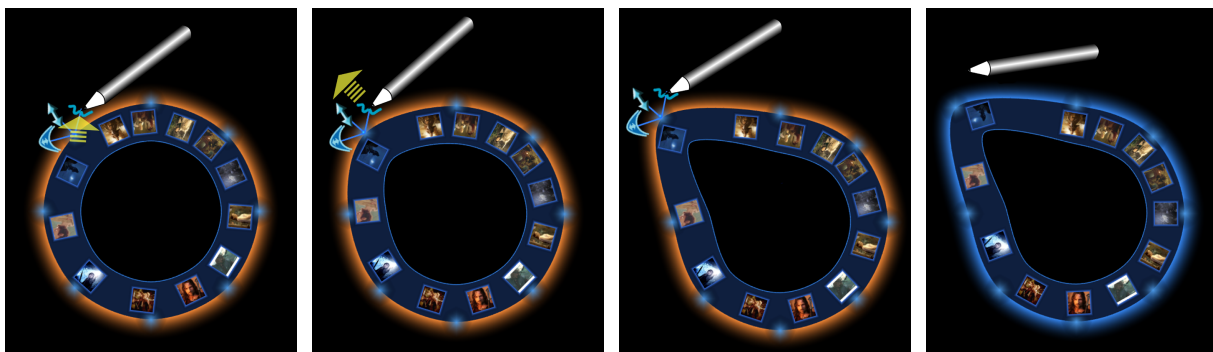
Figure 4.14: Reshaping a stream-shaped Current.

Changing the Width of a Current   Changing the width of the Current, as mentioned earlier, is only possible on stream-shaped Currents. By only adjusting one of the boundaries of a stream-shaped Current—depending on where the control points are installed—the width of the stream can be changed for one part of the Current. That is, the width is not constantly changed for the whole Current but only for a certain area. Items floating on a stream-shaped Current are scaled depending on the Current's local width. In that way, magnification areas can be established depending on how details of information are desired. Particular areas of the Current can be kept very thin, for instance, in order to save space. For changing the width the user has to perform a similar interaction technique as for manipulating the shape (see Figure 4.15). The algorithm used for this technique is very similar as well, except, that only one of the subdivision curves has to
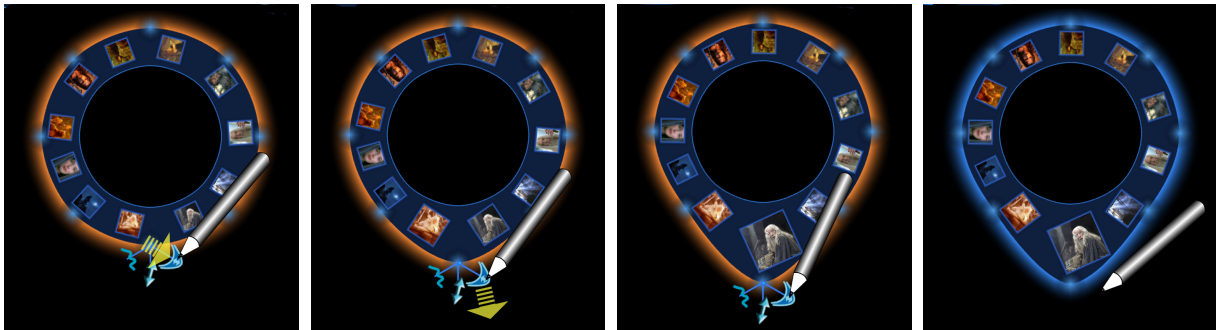
Figure 4.15: Changing the width on a stream-shaped Current.

be recalculated. Again, while the user is interacting with the Current, information items do not move.

Resizing a Current   Resizing is a new possibility of manipulating a Current. It can be very helpful to enable users to expand or collapse Interface Currents, for instance, when they want to switch from parallel to cooperative work or vice versa as explained in Section 3.1. Resizing a stream-shaped Current means that the radius of the Current changes as well as its width (see Figure 4.16(a) and 4.16(b)). The size of items located on the resized Interface Current, is adjusted depending on the Current's new width.

Resizing a pool-shaped Current changes its radius and items floating on the Current are scaled depending on the new size of the Current as illustrated in Figure 4.16(c) and 4.16(d). A resized pool-shaped Current acts similar to an elastic fabric: if it is stretched, its structure becomes wider. If a pool-shaped Current is resized, items floating on it become bigger. This magnification effect is very useful because it enables the user to collapse unused Currents with their content in order to safe space and enlarge them when the content of these Currents is of interest again. The interaction technique, again, is very similar to the ones introduced before (see Figure 4.16).


(a) Resizing a pool-shaped Current. (b) Resized pool-shaped Current. (c) Resizing a stream-shaped Current. (d) Resized stream-shaped Current.

Figure 4.16: Resizing Interface Currents.

The algorithm behind the resizing interaction technique is based on basic calculations: The distance D_{old} between the center point of the Current and the old position of the control point that is involved in the interaction is calculated. The new position of the control point is known, so the distance D_{new} between the center point of the Current and the new position of the control point can be determined. The ratio between D_{old} and D_{new} is computed and applied to all other control points. These new calculated control points form the basis for a the new subdivision curve—the new resized boundary of the Current. Items on a stream–shaped Current have always the height of two-thirds of the Current. This value was chosen to omit a some space near the boundaries of a stream–shaped Current which enables user to control the flow on a Current even if large amounts of items are floating on it. If the Current is resized, the items are scaled as well. The algorithm on pool-shaped Currents works similar: When an item is added to a pool-shaped Current, it is scaled depending on the radius of the Current. The ratio between the new size of the item and the radius of the Current always stays the same. In this way, the "stretched-fabric" effect is achieved.

Relocating an Interface Current   In the prototype of Interface Current as introduced by HINRICHS et al. [HCS05a], the relocating function was installed in the mark-up menu. However, for the new version of Currents it was removed from the menu due to the observations of SCOTT et al. [SCH05]. The most intuitive interaction technique for moving or relocating an Interface Current would be to just point-and-touch anywhere on the Currents' area and drag it to the desired location in the workspace. However, such an interaction technique would interfere with the interaction technique for manipulating the flow, described in Section 4.2.3. Thus, the boundary on a Current on which the control points are installed was broadened so that the users can easily interact with it. For relocating the Current, the user has to touch the "fuzzy border" of the Current anywhere except on the positions where the control points are located (see Figure 4.17(a)). In that way, the Current can be moved to any desired location in the workspace (see Figure 4.17(b) and 4.17(c)). It can also be moved halfway or completely out of the workspace if desired.
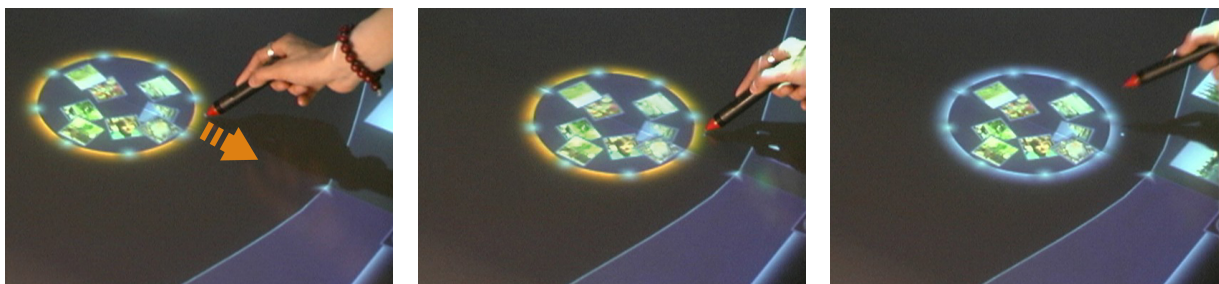
(a) Touching the fuzzy border of the Current...

(b) ...dragging Current to the desired location...

(c) ...releasing the Current.

Figure 4.17: Moving an Interface Current to any desired location.

This concludes the discussion of the interaction techniques to manipulate the actual Interface Current. The following sections describe the interaction with Currents in terms of adding and removing items and manipulating the flow on the Current.

Adding and Removing Items

Interface items can be added and removed from an Interface Current. To add an item, the user has to point-and-touch the item with a pen or finger and drag it onto the desired Current. As soon as the touch point comes into the area within the Current, the item starts to scale down depending on the width or radius of the Current. When the user releases the item, it is rotated towards the outer border and scaled depending on the width or radius of the Current as illustrated in Figure 4.18. The resizing button of an item disappears when it is added to a Current, thus, it is not possible to resize items that are floating on a Current. The interaction technique for removing an item from a Current is similar to the one that adds an item (see Figure 4.19). When the item comes from the Current into normal workspace, it is scaled back to its original size and the resizing button appears again.
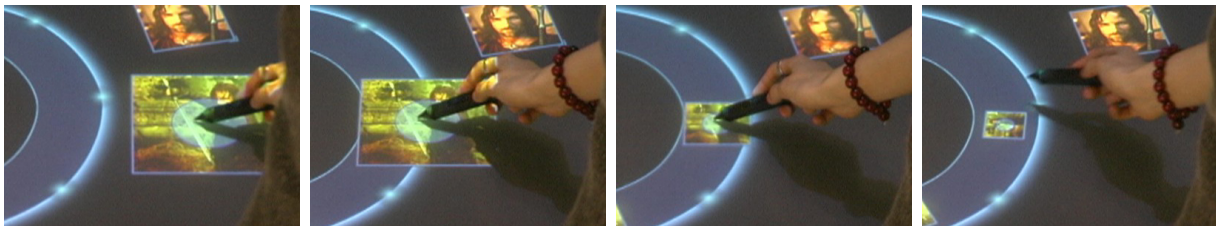
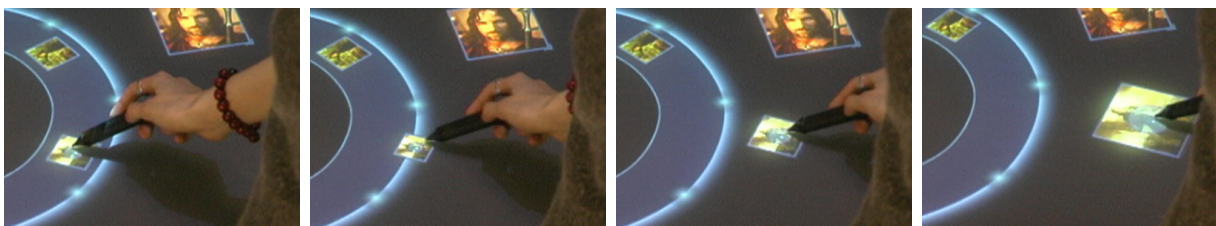**Figure 4.18:** Adding an item to an Interface Current.

Figure 4.19: Removing an item from an Interface Current.

Manipulating the Flow

Besides the possibility to change the position and shape of the Current, the user is also able to manipulate the flow on a Current, for example, its direction or velocity. As already mentioned, the flow on a Current is invisible as long as no information items are floating on it. The movement of information items indicates, its direction and velocity as well

as whether the flow is enabled at all. Since flow in an interface can be very attraction attracting it can be perceived as distracting. Thus, it is very important to give users the possibility to change it depending on their tasks. The interaction techniques regarding the flow on a Current are explained in the following.

Starting and Stopping the Flow   The user is able to stop the flow on a Current at any time. For doing so, she just has to touch the area of the Current shortly with a pen or finger (see Figure 4.20(a), 4.20(b), and 4.20(c)). This means that the interaction technique is based on a short point-and-touch movement. To start the flow again, the Current needs to be touched again while moving the pen or finger into the desired direction within the area of the Current (see Figure 4.20(d)). In doing so, the pen has to be
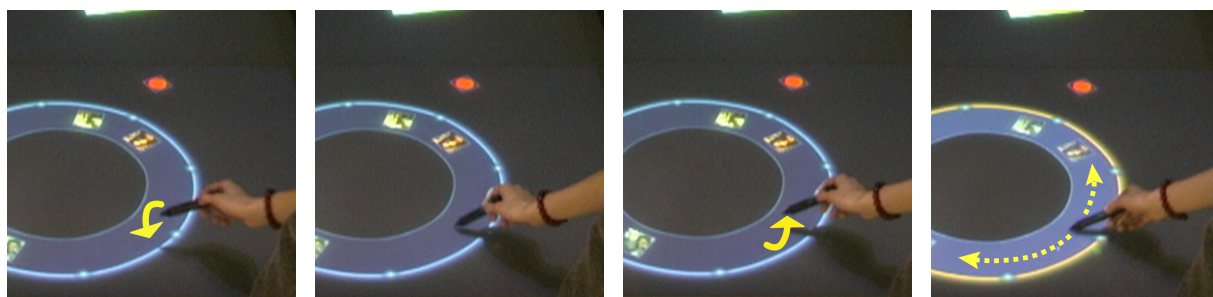
(a) Approaching   Current..   (b) ..touching it shortly..   (c) ..releasing Current.   (d) Starting flow.

Figure 4.20: Starting and stopping the flow on a Current.

kept in touch with the table surface. As soon as the flow on the Current is started again, information items will flow continuously into the direction the pen was moved.

Changing the Direction of the Flow   Depending on the direction to which the pen is moved on the Current, the direction of the flow can be changed as mentioned above. For example, if the pen is moved counterclockwise, items will flow counterclockwise as well. This in fact trivial interaction technique brought some algorithmic challenges because of the angle of the display. Depending on the side of the table where the participant is located she will move the pen in opposite directions in order to achieve the same flow direction (see Figure 4.21(a)). Thus, for the system, two opposite movements on the table surface could refer to the same flow direction on the Current or to the opposite flow direction, depending on where people are located on the table.

This problem was solved by using a simple inside-outside-test algorithm: When a user touches the area within a Current (without touching any of the floating objects or the fuzzy boundary), the point $P_{boundary}$ in the boundary list that is the closest to the touch point P_{start} is determined by testing the distance between P_{start} and each of the 128 points in the boundary list until the smallest distance is found. When the user is moving
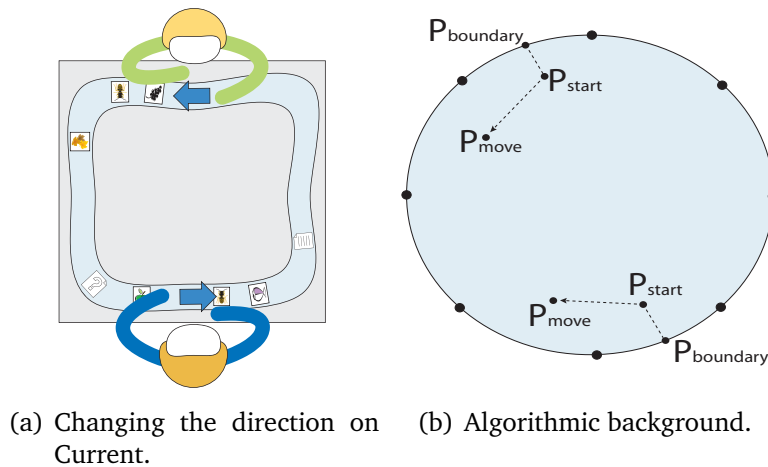
(a) Changing the direction on Current.

(b) Algorithmic background.

Figure 4.21: Calculating different flow directions of a Current.

the pen, the end point of this movement, P_{move}, is determined. After this, it is tested, if the point P_{move} is located on the right or left side of the line that $P_{boundary}$ and P_{start} form (see Figure 4.21). This can be achieved by calculating the value for the determinant of $P_{boundary}$, P_{start}, and P_{move}. If the calculated value is larger than zero, P_{move} is located on the left, thus, the user has moved the pen from the right to the left and the flow moves in clockwise direction. If the value is smaller than zero, P_{move} is located on the right of the line that $P_{boundary}$ and P_{start} form. Thus, the user has moved the pen from the left to the right and the flow direction is counterclockwise. This algorithm can be applied, independent from which location the user is interacting with the Current. In certain situations, however, it could fail theoretically. No matter how much an Interface Current is stretched out, the number of boundary points never changes. Thus, the more a Current is stretched out, the more the distance between its boundary points increase. Stretching out a Current extensively, can lead to a wrong determination of the direction of flow: When the user interacts very near the outer border of the Current and P_{start} is located exactly between two boundary points, the algorithm could determine the wrong result for the determinant depending on which of the two boundary points is chosen for the calculation (see Figure 4.22). This unstableness has to be considered but was accepted for the study because the probability that such a case occurs is quite low. It never appeared on any Interface Current, weather it was spread out extensively or not, neither during pilot tests nor during the actual user study.

Manipulating the Velocity of the Flow As mentioned in Section 4.2.2, the new version of Interface Currents provides three distinct velocities for the user to choose. the user can choose the velocity setting of a Current by moving the pen or finger over the Current's area. Depending on how far the pen is moved, one of the three velocity lists (see Section 4.2.2) is applied for the calculation of the movement of items on the Current. Therefor, the value between the start and end point of the pen movement is calculated
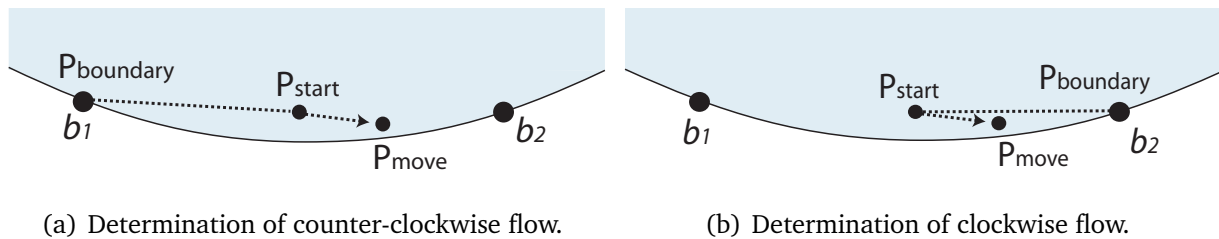
(a) Determination of counter-clockwise flow.   (b) Determination of clockwise flow.

Figure 4.22: Determination of different directions for the same interaction.

and, depending on this value, the velocity list is chosen. The further the pen is moved, the faster information items flow on the Current. For the slowest velocity, the velocity list with 1024 points is applied, for the fastest, the velocity list with 256 points. In that way the user can control the speed of items moving on a Current.

The next section describes how awareness, a very important factor during co-located collaborative work (see Sections 2.1.5 and 2.2.5), was taken into account in the design and development of Interface Currents.

Awareness

One constraint of Interface Currents is that they can only be manipulated by one user at a time. This seems appropriate because, otherwise, conflicting interactions could happen that could lead to system instabilities. For instance, one user could try to enlarge the Current and another one could try to make it smaller at the same time. Alternatively, one user could change the direction of the flow to clockwise, while the other one tries to make the Current flow counterclockwise. Thus, the system determines who has started an interaction with the Current first and an Interface Current does not react to other manipulations until the first interaction is finished. However, this leads to difficulties when several people are collaborating in the workspace as described in the following.

Awareness is an important factor during collaboration (see Sections 2.1 and 2.2.5). However, people often are not aware what other group members are actually doing when they are concentrating on their own activities. During pilot tests, it was often observed that one participant was trying to manipulate a Current in any way while the partner was already interacting with it. Of course, the Interface Current did not react on these attempts due to the "one-user-interaction" constraint. This was causing frustration and anger because the participant could not see the reason why the interaction attempts were not working. This is in particular problematic when users are interacting with systems that are new and unfamiliar to them because they think they are incapable to use the system which increases the frustration. Although pilot groups were told that they could not interact at the same time with the same Interface Current, people tend to forget this during the actual work. Thus, a simple function was applied to all Currents to help people to recognize if somebody is currently manipulating the Current they want to interact

with: Every time somebody starts an interaction with a Current the fuzzy border of the concerned Current turns orange as shown in Figures 4.12, 4.13, 4.14, 4.15, 4.16, 4.17, and 4.20(d). This happens every time somebody manipulates the Current's shape, location or flow. Further pilot tests revealed that this function seemed to be very helpful to people. Sometimes conflicting actions still happened but people immediately remembered what could cause the problems when they saw the orange border and started to communicate with their partner to solve the conflict.

Creating and Deleting Interface Currents

Since the evaluation of the concept of Interface Currents should show for which purposes people would use Interface Currents, an interaction technique was developed that would enable users to create their own Currents. Three buttons were designed—one for each of the basic types of Interface Currents: a button for creating pool-shaped Currents, one for stream-shaped Currents with the control points on the inside, and one button for stream-shaped Currents with the control points on the outside boundary. Touching such a button invokes the desired type of Interface Current which then can be moved to the desired location in the workspace (see Figure 4.23). Furthermore, it seemed

Figure 4.23: Creating a new Interface Current.

appropriate to provide a function for deleting Interface Currents just in case people want to get rid of Currents they have created. Thus, a trash can for Currents was developed in form of a "local tool" [BHD+96]. The trash can for Interface Currents has nearly the same characteristics as an Interface Object: It is movable and rotatable and can be tossed across the workspace. Furthermore, it provides the concept of RNT described in Section 2.2.4. Due to these characteristics, people can easily share the trash can and only one trash can needs to be provided in the workspace. For deleting an Interface Current, the user has to move the Current over the trash can by dragging it on its fuzzy border as described above. When the touch point of the pen or finger is within the area of the trash can, the whole Current turns orange in order to indicate that it is ready for deleting. When the user releases the pen from the table surface, while the Current is orange, the Current will be deleted (see Figure 4.24). Note, that only the Current is deleted but not the information that was floating on it. Information items are brought back into the normal workspace when the relating Current is deleted. This design decision was made
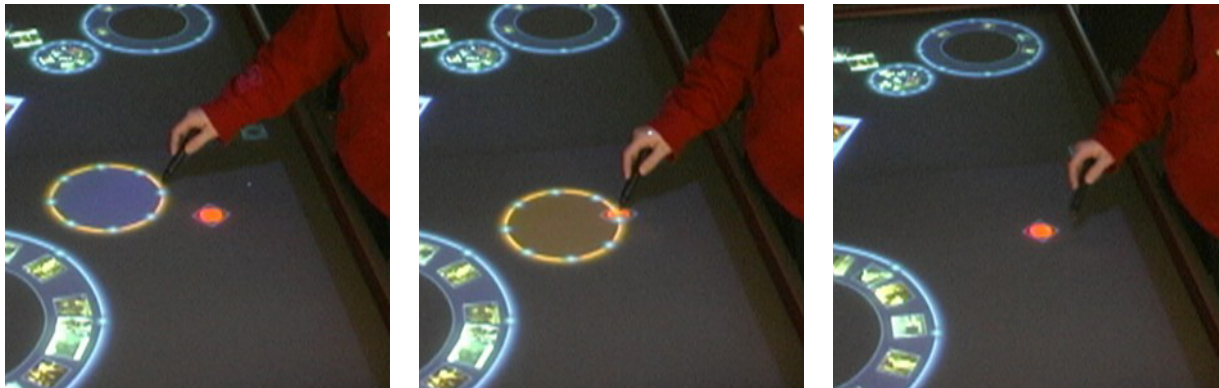
Figure 4.24: Deleting an Interface Current.

especially for the user study to prevent participants form deleting information items that they could want to have back later. For other purposes one could allow that the whole Current together with floating information will be deleted and design a function for recovering deleted content.

The next section describes an extension of the concept of Interface Currents, the so-called *Interface Folder*, that was developed in order to enhance the possibilities of working with Interface Currents.

4.3 Extending Interface Currents to Interface Folders

Interface Folders form an extension of the concept of Interface Currents by providing a source of information that can be spread out on an Interface Current. The motivation for Interface Folders, the concept and the relating interaction techniques are described in the following.

4.3.1 Motivation for Interface Folders

Folders form the basis for our everyday work with personal computers. People usually make use of folders extensively, for instance, to store information in a structured and organized way. Tree structures are offered by most operating systems to give an overview of the organization of information. Features are offered that try to give users an overview of the content of folders. For instance, Microsoft Windows™' thumbnail view in the Windows Explorer, visualizes information in folders as small icons that mirror the content of a folder which is in particular useful for folders holding images (see Figure 4.25(a)).

Browsing through folders displayed in a thumbnail view enables the user to gain a visual overview of the content or to find certain images quickly.
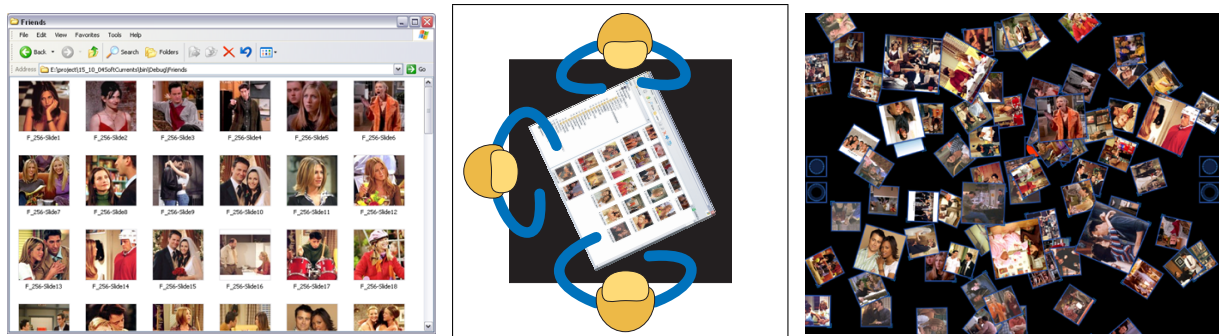
(a) Thumbnail view of the content of (b) Default window of Mi- (c) Information items spread out all
    a folder.   crosoft Windows™ on a   over the workspace.
                                     horizontal display.

Figure 4.25: Motivation for Interface Folders.

Folders in general could also have a supporting impact on co-located collaborative work that takes place on horizontal displays. Often, when people get together to accomplish a task and they each bring their own set of information they want to share with each other. This is especially the case when group members come from different fields of interest (for instance, designer often work together with programmers or engineers). The problem is how to spread out different groups of information so that all group members can easily browse through them together. Applying the traditional concept of folders as it is presented by most operating systems for personal computers on group work on horizontal displays is problematic. Folders themselves have a specific orientation and so do windows displaying the content of a folder. Even if such windows would be rotatable, it would still be difficult to find a compromised angle that suits for all group members, in particular, when the group consists of more than two participants (see Figure 4.25(b)). In contrast, spreading out large amounts of information over the workspace, as illustrated in Figure 4.25(c), would make information reachable and sharable in a more natural and intuitive way but it would be very overwhelming and any structure or organization of information would get lost. Groups would have to spend lots of time to reorganize the information by themselves. Furthermore, this way of sharing information would require a lot of space that is needed for the actual task. The concept of Interface Folders makes use of the functionality of Interface Currents and traditional folders. It enables users to share information that are stored and organized in folders with other people around a large horizontal display as explained in the following section.

4.3.2 The Concept of Interface Folders

Interface Folders are items in the workspace that can hold several information items, such as other folders, documents, images, or another kind of data, without showing them directly. The developed prototype of an Interface Folder is limited to images but

extendable to almost any kind of data. To make Interface Folders distinguishable from Interface Objects, they have a yellowish color similar to folders known from Microsoft Windows™ and are labeled with text representing the content that they contain (see Figure 4.26). Similar to folders in common operating systems they can be opened or closed in order to access their content or pack it up. However, these common features are applied in conjunction to Interface Currents: by opening an Interface Folder, its content is spread out automatically to an Interface Current. In that way, the content of a folder can be shared between multiple users or users can browse through it individually. In terms of interaction, Interface Folders have very similar characteristics as Interface Objects: Using the RNT technique by KRUGER et al. [KCST05] (see Section 2.2.4), they are movable, rotatable and resizable. Similar to Interface Objects, they can be tossed across the surface of a table. These characteristics make them easy to share between multiple users.
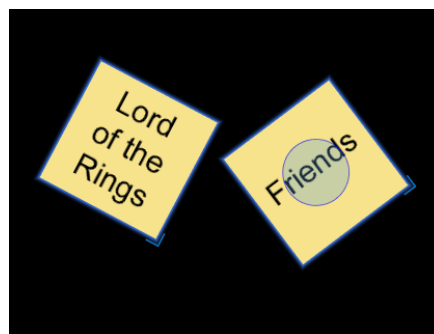
Figure 4.26: Interface Folders.

Interaction with Interface Folders

Since in most operating systems folders are opened by double-click, this interaction technique was taken over for Interface Folders as well. The double-click interaction technique was self-implemented. When one single touch on an Interface Folder is followed by another touch on the same Folder within a certain time the system handles this as a double-click. The threshold for the time in which both touches have to be performed is based on a timer. Interface Folders can be "opened" by a simple double-tap with the pen or finger. Double-tapping on a closed Interface Folder causes the folder to visually connect via a so-called *connection bridge* with the closest empty Interface Current (see Figure 4.27). The connection bridge is basically a blue triangle that is stretched from the center of the Interface Folder to the outer border of the Interface Current (see Figure 4.27(b) and 4.27(c)). The decision of implementing a visual connection between Interface Folder and Current and letting items move one by one out of the Folder onto the Current instead of spreading them all out on the Current in just one single step was motivated by the concept of *rapid serial visual presentation* (RSVP) developed by DE BRUIJN and SPENCE [dBS00] (see Section 2.3.4). The concept of Interface Currents on
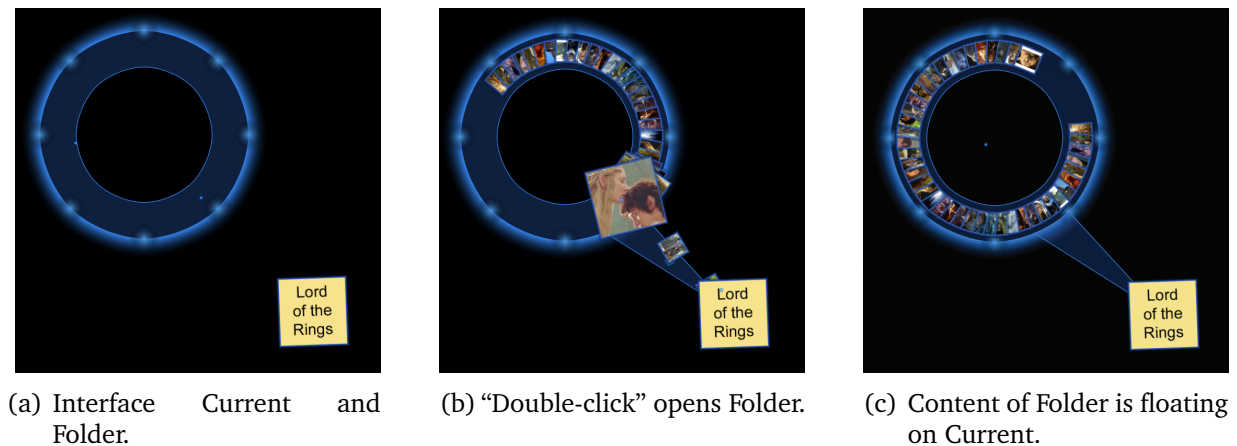
(a) Interface Current and Folder.

(b) "Double-click" opens Folder.

(c) Content of Folder is floating on Current.

Figure 4.27: Opening Interface Folder.

its own can be regarded as a technique for RSVP because information items are moving constantly one after another so that the user gets an idea about structure and organization of information. By letting items move separately over the connection bridge onto the Current, every single item is brought into foreground for a short time. In this way, according to the theory of RSVP, the user gets a spatial idea about how the content in an Interface Folder is structured, for example which images are stored adjacent to a certain image. Establishing such a structure in the users' brain makes it easier to find certain images later. Although this feature can only used by one or two users at a time due to visibility problems, in particular, when the group is working around a large table, it can be very helpful during phases of individual work. Furthermore, the connection bridge forms a smooth transition between the two component states "all information items are hidden in the folder" and "all information items are visibly spread out on a certain Interface Current". The development of such transitions is important to keep the user aware of such processes within the interactive workspace and make them understandable to the user [Bae90].

Once the Interface Folder is connected to an empty Current, the information items that the Folder contains, start to move separately out of the Folder over the connection bridge onto the connecting Interface Current and are distributed evenly until the Folder is empty (see Figure 4.27(b)). The celerity of this process depends on the flow velocity on the Current. Thus, it can be influenced by the user. When all items of the Folder are on the Current, they are floating depending on the velocity and direction of the Current's flow just like normal items that were added to the Current. The bridge between Folder and Current always stays visible. Despite of that, an Interface Current that is connected to an Interface Folder can be adjusted and relocated just like a normal Interface Current. The bridge will be stretched or compressed if necessary (see Figure 4.28).

The prototype of Interface Folders only provides the connection of an Interface Folder with a Current that is not yet connected to another Folder. Thus, only one Interface

Folder can be connected to an Interface Current at a time. If no empty Interface Current can be found in the workspace, the Folder cannot be opened. Of course, this constraint is not mandatory. Extensions of this concept are possible (see Chapter 8).

Adding and removing items to a Current that is connected to an Interface Folder works just as described in Section 4.2.3. When an item is added to a Current that is connected to a Folder, the item belongs automatically to the Folder as well. Vice versa, if it is removed from the Current, it does not belong the the Folder any more. Interface Folders
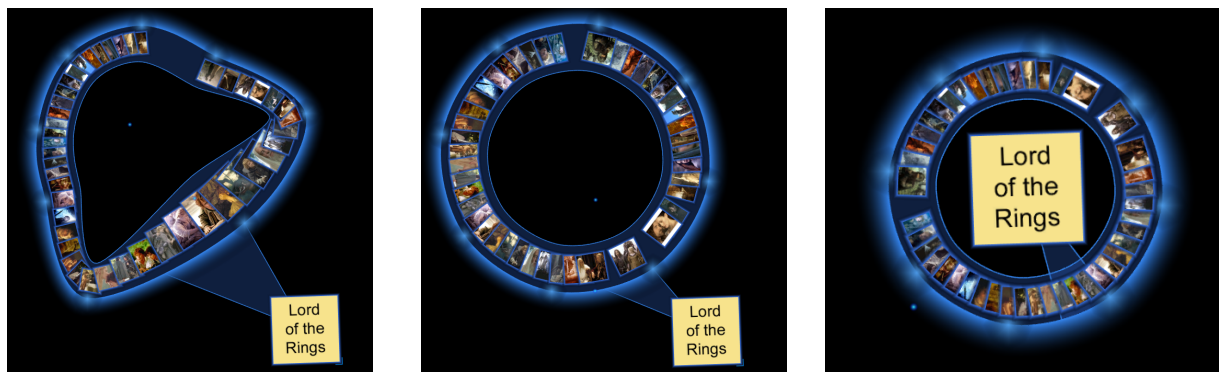
Figure 4.28: Bridge between Folders and Interface Currents reacts flexible to adjustments of the Current.

can also be closed. A double-tap on an open Folder causes all items to go over the bridge back into the Folder. When all items on the Current are back in the Interface Folder, the bridge between Interface Current and Folder disappears. Both processes, letting items move out of or back into the Folder can be slowed down or accelerated by controlling the velocity on the relating Interface Current. When the flow on the Current is strong (fast), items will flow fast on the bridge as well. Another possibility of closing an Interface Folder is to delete the connected Interface Current. If an Interface Current that is connected to a Folder is deleted, all information items floating on it go automatically back into the Interface Folder that is connected to the Current at once and the Current disappears.

A problem that was encountered during the design process of Interface Folders is that information on the Current start to overlap when the amount of information in an Interface Folder is too large to fit on the Current (see Figure 4.28(c)). Heavy overlapping of items makes it difficult to see the information they are holding and, thus, hinders interaction with them. Several potential approaches were developed for this problem and some of them were tested early in informal pilot tests. However, none of them was developed further due to time constraints so that none of them found its way into the actual user study because of their premature stadium and stability issues.

Approaches for Avoiding Overlapping Information on a Current

The probably most obvious way of dealing with the problem of overlapping items on a Current is to just increase the size of the Current the more items are floating on it. However, it has to be considered that a swelling of an Interface Current could affect the partition of the workspace quite seriously and, thus, interfere with users intentions. A swelling Current, could, for instance, cover an are where several specific items are piled up. For this reason, this approach was considered but not realized. In contrast, three other approaches were implemented and tested in form of some short pilot tests.

The first approach only allows a certain number of information items on an Interface Current so that they do not overlap. This was realized by letting each item to come out of the Folder and move on the Interface Current until it has reached the bridge to the Interface Folder again. If there are still information items inside the Folder by that time, the item goes back into the Folder to make space for new information items. Thus, this solution allows only items to move exactly one "round" on the Interface Current while the rest is invisible "waiting" in the Folder. This approach was found unsatisfying during pilot tests because not all information items are visible all the time which can be disturbing and confusing during a task because items are continuously disappearing although they could be needed for the task.
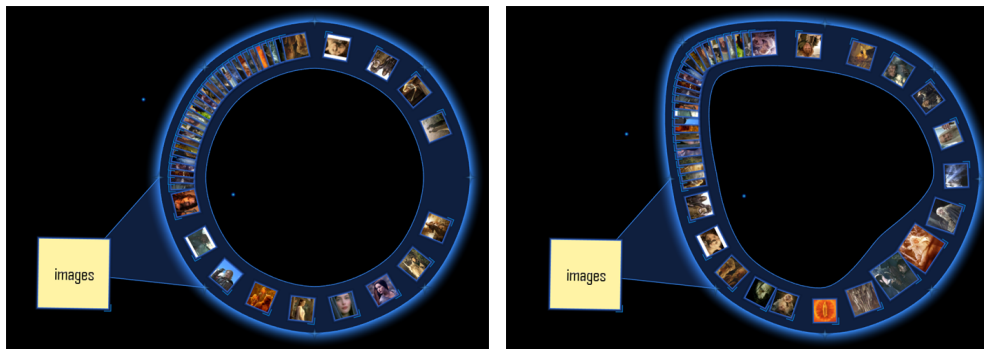

Figure 4.29: Items piling up on the Current right in front of the bridge.

In the second approach, items were piled up before they passed by the bridge between Folder and Interface Current again (see Figure 4.29(a) and 4.29(b)). When the Folder is empty and all items are on the Current the first item in the stack starts to move on the Current again while items still piling up at the end of the stack. In that way, all items of the Interface Folder are visible but only overlapping at one part of the Current. This approach has a lot of potential since items do not have to pile up but a bubble could appear on a the Current where items would slowly move around just like on a little pond that is fed by a creek or stream (see Figure 4.30(a)). Furthermore, the Current that is connected to the Interface Current could produce another Current if it becomes too crowded and let some information items drift into that new Current (see Figure 4.30(b)).

Findings from the study revealed that these ideas lead into the right direction (see Chapter 6). However, they are future work. For the study, a version of Interface Folders was used that spreads out information on an Interface Currents evenly, no matter, how much they are overlapping.
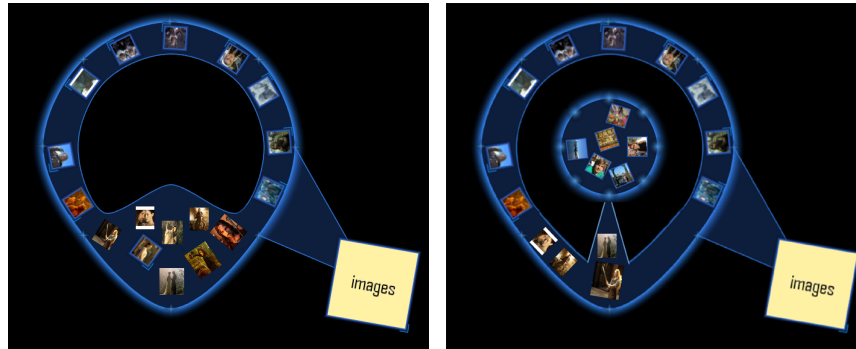
(a) Invoking a pond for supernumerous items

(b) Invoking a new pool for supernumerous items

Figure 4.30: Possible solutions for the problem of overlapping items on Currents.

4.4 Chapter Summary

This chapter described the single interface components of the workspace that were designed for the evaluation of Interface Currents. The workspace was designed in an user-centered iterative process, that is, short pilot tests were conducted during the development in order to discover interaction problems and solve them before the actual user study. Furthermore, the findings of SCOTT et al. [SCH05] that tested storage bins, an interface component that is visually similar and based on the prototype of Interface Currents by HINRICHS et al. [HCS05a], were taken into consideration.

The workspace basically consists of three interface components: Interface Objects, Interface Currents, and Interface Folders. Interface Objects, that are serving as information items form the basis for the tasks that participants had to perform during the user study. They are movable and rotatable using the concept of RNT by KRUGER et al. [KCST05]. Furthermore, Interface Objects can be tossed across the table, a technique that HABELSKI [Hab04] implemented in order to enable users to pass information between each other in an easy way. For the user study, Interface Objects holding images and words were designed. Page Objects have the same characteristics as Interface Objects but, in addition, Interface Object can sticked on top of them. In that way, they serve as containers for Interface Objects, a function that can be useful for doing collages or page layouts.

The design of Interface Currents, the component that was to be evaluated in the study, were partly adopted from the prototypes that HINRICHS et al. [HCS05a] introduced and partly renewed and enhanced. The new version of Interface Currents provides two new types of stream-shaped Currents: a stream whose control points are installed on the outer boundary and one with the control points installed on the inside border. The latter type seems to be in particular useful for peripheral Currents that are stretched along the edges of the workspace but the evaluation should show for which purposes these new types of stream-shaped Currents are used during co-located collaborative work. In addition, the number of control points is enhanced to 16 for the peripheral Current to make it easier to adjust in the desired way.

In general, the new version of Interface Currents provides three different velocities that can be manipulated by the user. Interacting with a Current in order to change the flow is possible from any position on the table. The functions for manipulating the shape of the Current were enhanced by a resizing function that allows the user to enlarge the Current itself and the items floating on it. The function for relocating the Current was outsourced from the menu due to the findings of SCOTT et al. [SCH05] and can now be performed by touching the Current directly on its fuzzy border. To avoid awareness problems that were observed during pilot tests, the fuzzy border of an Interface Current turns orange as soon as a user starts to interact with it in order to indicate other users that somebody else is manipulating the Current at the time. For the study, buttons for creating different types of Interface Currents were developed as well as a trash can for deleting unused Currents.

Interface Folders, as the last interface component introduced in this chapter, expand the concept of traditional folders for storing, organizing, and structuring content known from most operating systems, to horizontal displays. Interface Folders are yellowish items in the workspace with little name tags indicating their content. The interaction with Interface Folders is similar to the interaction with Interface Objects. A double-tap on a closed Interface Folder causes it to connect to the closest Interface Current, that is not yet connected to another Folder. The content of the folder is then spread out automatically onto the connected Current. Information items from the folder start floating on this Current immediately. The connection bridge between Interface Folder and Current remains until the Folder is closed and all items are back in the Folder again or the connected Current is deleted. While a Current is connected to an Interface Folder it remains fully adjustable. Spreading out the content of an Interface Folder automatically on an Interface Current enables people working around the table to share these information in an easy way. Different approaches were introduced for avoiding overlapping of information item on the Current. However, none of these approaches went into the study workspace because they all need further development.

The next chapter will explain the experimental methodology for the exploratory user study that was conducted for evaluating the concept of Interface Currents. The proce-

dure of the user study is explained more detailed concerning task description, technical setup, participants and so forth.

CHAPTER 5

Exploratory User Study

Within the scope of this thesis' research project, an exploratory user study as described in Chapter 3 was conducted to explore people's interaction with Interface Currents. The goal of this study was to find answers to the following questions:

- How would people interact with Interface Currents?

- How do Interface Currents influence collaboration?

- For what purposes would people use Interface Currents?

- How would people set up a workspace based on Interface Currents?

- Would people enjoy interacting with Interface Currents and if so, why?

The reason for conducting an *exploratory* user study using qualitative analysis was that Interface Currents are an entirely new approach to collaborative interfaces and interfaces in general. Since they do not have explicit functionality but rather create an environment, is was important to understand how this environment would influence collaboration. This requires observation with as many of the natural complexities of collaboration in place as possible. Since continuous flow has never been explored in a collaborative environment, it was appropriate to start with an exploratory study first.

While the general methodology for the user study was discussed in Chapter 3, this chapter describes details concerning the experimental methodology, that is, general information about the participants, the technical setup, the experimental design and tasks, the procedure, and, finally, the data collection and analysis.

5.1 Participants

Since the study was conducted to discover whether and in what way Interface Currents would support collaborative work as conducted by small groups, every study session involved groups of two people. The decision for working with pairs of participants was a technical one. The 4-camera SMART Board™ DViT 1810 interactive whiteboard is not able to handle more than two simultaneous inputs. A pilot test was conducted where three people were interacting in the workspace at the same time using two simultaneous inputs, but this caused serious interaction problems and negatively affected the stability of the system. Thus, groups of two people were recruited for the user study, through a recruitment notice e-mailed to all the undergraduate and graduate students of the University of Calgary (see Appendix A.1).

Eight pairs of participants, 16 people in total, took part in the exploratory study. However, only the data of six groups (12 participants) was used for the analysis due to technical difficulties that occurred during two study sessions[1]. The age of the participants ranged from 19 to 31 years. In total, seven male and five female participants took part in the study. They formed one female group, two male groups and three mixed groups. All pairs of participants except one knew each other before the experiment. From the 12 participants whose data was analyzed, all, except one, were students at the University of Calgary. Six participants were computer science students while the rest belonged to other departments, such as biology or English. One participant was a Professor of English at the University of Calgary. Since Interface Currents were developed to support a variety of collaborative tasks involving people with and without computer, creative and less creative people, this diversity of the participants' background is advantageous.

The vast majority of participants (10 out of 12) had been using computers for more than five years. Two participants had worked with computers for between one and five years. Thus, all the participants were experienced and familiar with the major functions of common single-user computers. Seven out of twelve participants had never used a tabletop display before the experiment, while three stated that they had used it "once". Only two participants had worked with tabletop displays more than one time. These tabletop displays were either part of a research project or were art pieces in a museum. This shows that tabletop displays are a highly innovative technology and people have very little, if any, experiences with them. Participants were also questioned about their level of experience in using computers with touch-sensitive surfaces. Half of the participants had used touch-sensitive displays at least five times, whereas only one participant had never interacted with touch-sensitive surfaces on a computer before.

---

1   Participants in inadvertently loosened the cable connecting the SMART Board™with the computer by accident which led to the loss of the detection of the second input. These two groups thus had to take turns while interacting in the workspace.

The next section deals with the technical setup of the user study, that is, what kind of hardware and software was used and how the equipment was arranged during the study.

5.2 Technical Setup

The exploratory study took place in the *Interactions Lab* at the University of Calgary. The tabletop display that was used for the user study is situated in a half-open part of the laboratory. The technical setup of the tabletop display and other equipment is described in the following section.

5.2.1 Apparatus

The participants were interacting pairwise with a large, high resolution tabletop display. For this tabletop system a 4-camera SMART Board™ DViT 1810 interactive whiteboard with a size of 72 inches in the diagonal is used. It supports simultaneous multi-user
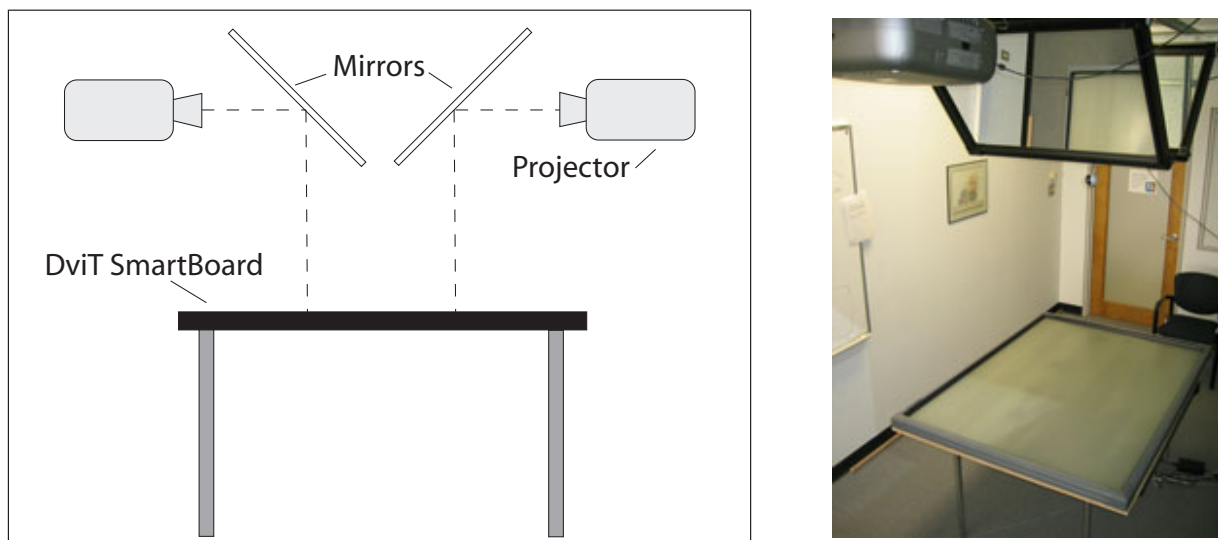
Figure 5.1: Tabletop display of the Interactions Lab.

touch interaction as described in Section 2.2.1. The SMART Board™ is placed on a regular table frame (see Figure 5.1). Above the table, two NEC GT 2150 projectors are placed—each with a resolution of 1280×1024 pixels and a GT 19ZL lens. They display the virtual workspace onto the surface of the SMART Board™using two first-surface mirrors—each with the size of 36×24 inches. The projected workspace has a resolution of 2048×1024 pixels at the size of ca. 55×37 inches. The experimental software

ran on a Xeon™ 2.80GHz computer that uses Windows XP Professional as the operating system. To enable simultaneous multi-user interaction Tse's DViTtoolkit (an extension of the SDGToolkit [TG04]) was used for the software. A video camera was installed in front of one of the shorter edges of the table for recording participants interacting in the workspace as well as the virtual workspace itself.

5.2.2 User Arrangement

Each group of participants were seated across from each other on the longer edges of the table (see Figure 5.2). This user arrangement was chosen to simulate a situation

Figure 5.2: Participants were seated face-to-face.

where people see the workspace from contrary perspectives, in order to discover if the environmental orientation of information items on Interface Currents (see Section 3.1) would ease the orientation problem and therefore, facilitate the sharing of items. Sitting shoulder-to-shoulder or right-angled, it is rather easy for pairs to find a compromised angle where they can both see orientation-dependent items in the workspace [MSI02] (see Section 2.2.3). However, this is only possible when there are two people interacting in the workspace. As soon as three or more people are collaborating, it is much more difficult to find a compromised angle because at least two group members sit across from each other. Since group work often involves more than two people, it is more realistic to consider the case that people sit across from each other, although in the actual study only pairs were interacting with each other.

At the beginning of each study session, participants sat on chairs that were adjustable in height, however, they were not forced to remain seated. Some pairs actually performed parts of the study tasks standing.

5.3 Experimental Design and Task Description

Each pair of participants performed two collaborative tasks, where the second task built on the first task. Thus, the order of the tasks was never changed. The following sections describe the tasks in detail.

5.3.1 Task 1—Building a Photo Story

For the first task, participants were given a set of images containing 80 photos of the TV show "Friends". For each group, all 80 photos were initially placed on a peripheral stream-shaped Current, with 16 control points on the inside border. On the longer edges of the workspace two small magnification areas on the right of each participant were predefined. In front of each participant, buttons for creating new Interface Currents were installed: one each for creating pool- and stream-shaped Currents with eight control points on the outside border. One single page object was provided, identifiable as bluish item with a text label. In addition, one trash can for deleting Interface Currents was available to the participants. The Page Object and trash can were arranged randomly in the workspace while the positions of the buttons for creating Currents were fixed. The initial start setup for the first task is shown in Figure 5.3. The task consisted of building
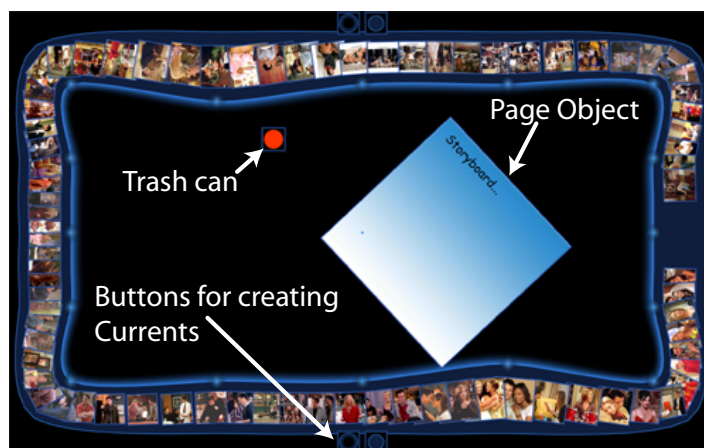
Figure 5.3: Initial setup of the first task.

a photo story by arranging at least ten of the provided photos on the Page Object. Since pilot sessions revealed that people had difficulties coming up with a theme for a story all on their own, participants were offered four predefined topics:

- The big fight
- The wedding
- A new passion

- With a little help from a friend

Participants were asked to choose one of these topics and build the corresponding photo story. They were given 20 minutes to finish the task but could finish earlier if they wanted to.

In this first task, participants had to deal with a large amount of unknown images in the workspace. They were forced to get a certain overview of these images in order to be able to choose the appropriate ones for their story. The purpose of this first task was to explore how people would use Interface Currents to accomplish the task. For instance, it was unclear whether they would use the peripheral Current for browsing through the pictures, if they would change the shape of the peripheral Current in any way, or if they would create new Interface Currents for certain purposes. At the same time, information about the interactions of participants with Interface Currents could be gained, for instance, whether the realization of Interface Currents holds serious usability issues. Furthermore, and this is the reason why the order of tasks is not alterable, the first task should allow participants to become familiar with Interface Currents so that they can use their experiences from the first task for the second task.

5.3.2 Task 2—Setting Up a Workspace Based on Interface Currents

For the second task, participants were given a nearly empty workspace that consisted of three buttons, one each for creating a pool-shaped Current, a stream-shaped Current with eight control points on the inside, or a stream-shaped Current with eight control points on the outside, each installed right in front of the participants. In addition, one trash can was provided, as well as three folders, one containing pictures of the TV show "Friends", one containing pictures of the movie trilogy "The Lord of the Rings", and one containing small word icons, similar to the small word magnets of Magnetic Poetry®[2] (see Figure 5.4). Participants were given the following scenario: They should imagine that after they finish their own study session, the next group of participants would come into the lab to take part in the study. The task of the new group would be to create a photo story as well, except that they would also have to support the meaning of the pictures with little word tags. The task of the existing group was to set up the workspace for the following group so that this new group could immediately start on their task by using a workspace which helps them to find the appropriate photos and words easily. In other words, the current group should spread out photos and words in the workspace in an appropriate way using the experiences with Interface Currents that they gained in the previous task.

In this second task, participants were forced to create Interface Currents on their own and arrange them in the desired and appropriate way. While in the first task, the setup of
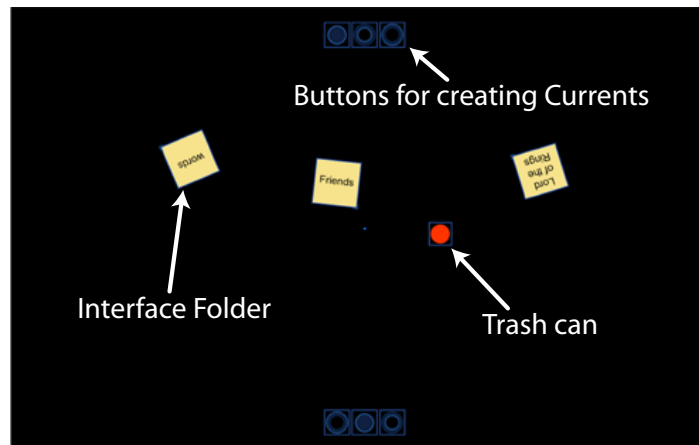
---

2 http://www.magneticpoetry.com

Figure 5.4: Initial setup of the second task.

the workspace was initially predefined in a broader sense with the pre-installed periph-eral Current, the purpose of this task was to show how people would set up a workspace based on Currents of their own choosing. The second task forced participants to use the reshaping and relocating functions of the Current, as well as the functionality of Interface Folders, so that the usability of these functions could be examined very nicely. Since Interface Folders are a very new idea that is not fully developed yet, this task should bring new ideas and insights about how participants would adopt the concept of Interface Folders.

These two tasks were embedded in a procedure that involved the introduction of partic-ipants to the study session, a practice task, a semistructured interview and a debriefing at the end as described in the following section.

5.4 Procedure

Each study session began with a short introduction of the experimenter and the research project in general (see Appendix A.2). Participants were informed that their participa-tion in the user study would be strictly voluntary and that they could quit at any time if they should feel uncomfortable. After this, each participant was handed a consent form to fill out. This consent form briefed participants about the kind of activities the study would involve, approximately how long the study would take, and what kind of data would be collected. For instance, they were informed that their physical and verbal activities would be videotaped (see Appendix A.3). After participants had signed the consent form, they were asked to fill out a background questionnaire in order to col-lect demographic information about the gender and age of the participants, as well as their computer experience and experiences with tabletop or touch-sensitive displays (for more details see Appendix A.4). Next, the participants were asked to put on the micro-
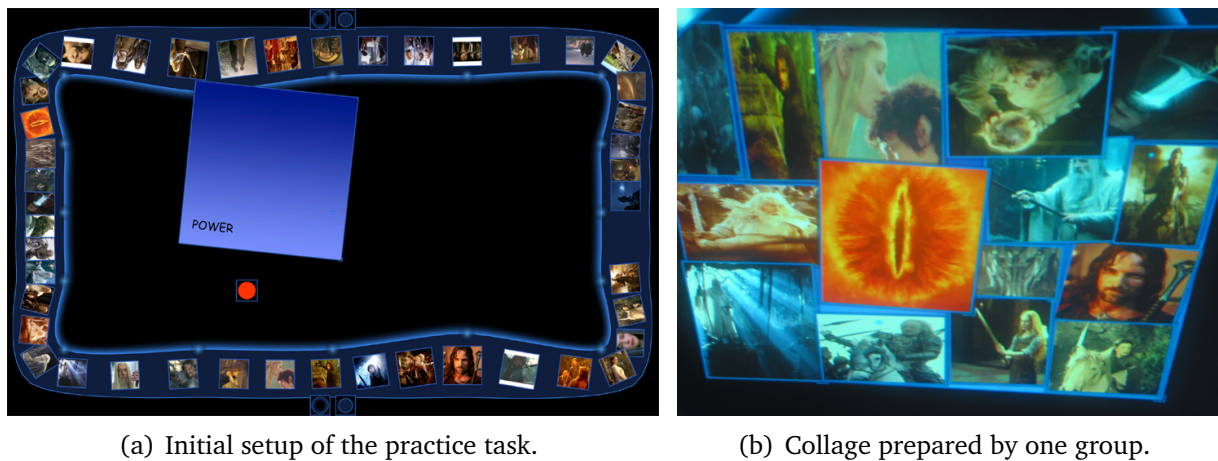
(a) Initial setup of the practice task.

(b) Collage prepared by one group.

Figure 5.5: Practice task.

phones, and the video camera was started. The actual user then study began. First, the experimenter explained the functionality of the tabletop display and exemplified every single component in the workspace (see Chapter 4). After a component was introduced, the participants were invited to play around with it in order to become familiar with the relevant interaction techniques. Following the introduction of the study workspace, participants were asked to perform a practice task in order to internalize the interaction techniques and to clarify anything that was unclear to them. The setup of the practice task was similar to the initial setup of the first task (see Section 5.3) except that a smaller set of different photos was provided, and the task was slightly modified: 45 pictures of the movie trilogy "Lord of the Rings" were arranged evenly on a peripheral Current (see Figure 5.5(a)). Participants were asked to collect an optional amount of pictures that represented "power" to them, in any form or way. These pictures were to be arranged in the form of a collage on the provided Page Object (see Figure 5.5(b)). Participants were given 10 minutes to perform the practice task and they were allowed to ask questions concerning the task or any of the interaction techniques. After the practice task, participants performed the first task as described in Section 5.3. When the task was completed, they were interrogated in the form of a semi-structured interview. This interview was based on predefined questions concerning their interaction with the system (for more details see Appendix A.5). However, when the experimenter observed certain interesting interactions or behaviors of participants during the task, she would ask the participants about these as well, and vary the interview questions accordingly.

The interview was followed by a short introduction session where participants learned how to interact with Interface Folders. After this, they performed the second and last task of the user study. During the second task, participants were ask to *think aloud*, that is, they should say out loud what they intended to do, and why. That way, the experimenter could get a better understanding of the participants' activities and potential problems. While the experimenter stayed in the background most of the time during the first task,

she interacted more with participants during the second task. For instance, when participants expressed problems or frustration, the experimenter tried to find out how they would improve the system in order to avoid these problems. In this way, participants were able to express interesting ideas that could influence further enhancements of the system (see Chapter 6). The second task often ended in a discussion with participants about the system in general and possible enhancements that could be made on it.

At the end of each study session, participants were debriefed (see Appendix A.6), thanked, and paid for their participation. Every study session took about 90 minutes. During each session, data was collected in different ways as explained in the following section.

5.5 Data Collection

As explained in Chapter 3.3, most of the data collected during the study was qualitative data, such as field notes. The activities of the participants within the workspace, as well as their verbal comments and expressions, were recorded by a video camera, starting from the practice task to the end of the second task. In addition, each participant's interactions were logged to a data file. As described above, after the first task, participants' opinions and preferences about the system were collected in the form of a semi-structured interview. During the second task, participants were questioned whenever it was regarded as necessary or important by the experimenter. This data was analyzed according to the research questions described in Chapter 3.2. The analysis was based on techniques that are typically used for analyzing qualitative data, as described in the following section.

5.6 Data Analysis

The data analysis was based on the goal of interpreting the participants' interactions in order to find specific collaboration patterns that could have been caused by the availability of Interface Currents, and to gain more insight into the purpose and usability of Interface Currents. That is, the field notes and, in particular, the video data was analyzed based on *what* interactions were happening in the workspace, and *why* the interactions were happening. After structuring the field notes, the videos from each study session were watched several times in order to find general patterns of interactions, and to get an overview of general usability issues. Furthermore, the video data was transcribed, so that every interaction and verbal expression of each participant were written down in detail (see Appendix B). This helped to reveal similarities in interactions between groups, and showed interesting phenomena that were not visible through shallow video observations. In particular, transcriptions were useful in order to analyze and compare participants statements gained from the interview after the first task.

In addition to this, interactions of particular interest were visualized by plotting data collected in the log files. This was in particular helpful because the technology of the DViT surface of the SMART Board™ is able to identify two different inputs at the same time, but cannot distinguish between different users. Thus, the log files alone can only give information about the various interactions performed, but not *who* performed certain activities. Visualizations of the data, however, can offer valuable clues in identifying of the initiator of various interactions. Furthermore, in contrast to the video data, the visualizations of the log data offered the possibility of concentrating on specific interactions (for instance, interactions concerning the shape of a Current, such as reshaping, changing the width, resizing, and relocating) and plotting them sequentially over time in order to reveal interesting interaction patterns and to compare the data of various groups.

5.7 Chapter Summary

This Chapter described the experimental methodology of the exploratory user study that was conducted to evaluate the concept of Interface Currents. In total, the data of six pairs of participants provided the basis for the data analysis. The six groups consisted of two male, one female, and three mixed pairs.

Every group performed two tasks on a tabletop display. The first task was creative in nature and involved building a photo story out of several pictures floating on an Interface Current. The workspace for this task was predefined but modifiable by users. In the second task, participants were asked to build a workspace for a similar task, by themselves. The purpose of the two tasks was to reveal how people would use Interface Currents during co-located collaborative tasks. The collection of qualitative data occurred in the form of field notes, video recordings, and a semi-structured interview. Interactions and activities in the workspace were stored in a log file. The analysis consisted of structuring and analyzing the field notes, closely watching the video recordings several times, transcribing the video data, and visualizing particular data from the log files. The findings revealed from these analysis strategies are discussed in the following chapters.

CHAPTER 6

Usability Issues

After the user study was conducted according to the experimental methodology described in the last chapter, the analysis of the collected data was initiated. The findings of the study can be structured into two groups: findings regarding the usability of Interface Currents and Interface Folders and general findings concerning such things as the influence of Interface Currents on collaboration. In contrast to the general findings, that required a very detailed analysis of the various data, the usability issues were quite obvious, probably due to the prototypical nature of the underlying interactive workspace. With regard to research question *Q2* (see Section 3.2), this chapter discusses how participants generally interacted with Interface Currents and what issues in terms of usability could be found. The general findings of the study are described in Chapter 7.

During the various study sessions it became clear very quickly that participants enjoyed working with Interface Currents and found them quite helpful (see Chapter 7). They also adopted the different interaction techniques quickly and, in the broader sense, were able to accomplish the desired interactions. However, some usability issues became apparent clearly. Some were provoked by the technical setup of the tabletop display. Frequently, participants covered parts of the infrared arrays on the edges of the tabletop display, for instance, with their arms or sleeves. This was assessed as an adequate input by the system which was causing confusing by participants because the system did not react on point-and-touch gestures anymore. The usability problems caused by the setting of the hardware are not considered in this chapter. This chapter is about the usability issues that are related to the interactive workspace and, in particular, to the interaction with Interface Currents.

After structuring the field notes, watching the video recordings several times, and analyzing the statements participants gave during the interview, different categories of usability problems of Interface Currents and Interface Folders could be distinguished. These categories are discussed in the following sections, including the relating design implications that result directly from the findings of the user study. The implementation

of some of these design implications would have gone beyond the scope of this thesis' research project, because they require the redesign of the underlying structure of the whole workspace. Thus, some of them still remain future work. The goal of the study was to explore the general potential of the concept of Interface Currents and to identify future research directions. Since the actual implementation is only one possibility of realizing the concept of Interface Currents as pointed out in Chapter 4, this chapter will illustrate ideas and potential directions rather than new concepts of realization.

First, the usability issues concerning the manipulation of Interface Currents as found during the study are illustrated in this chapter. This is followed by a discussion about the usability of Interface Folders. At the end of this chapter, the design changes that were realized according to the usability issues revealed by the study are described. These design changes led to the enhanced version of Interface Currents and Interface Folders.

6.1 Usability Issues of Interface Currents

The usability issues concerning the manipulation of Interface Currents can be categorized into problems of relocating an Interface Current, problems concerning the flow of an Interface Current, and interaction problems of using the menu of a Current. These categories and the relating design implications are explained in the following sections. Usability issues that did not fit in any of these categories are described in Section 6.1.4.

6.1.1 Relocating Interface Currents

As explained in Section 4.2.3, the interaction technique for relocating Interface Currents in the workspace was changed according to findings of Scott et al. [SCH05]. The study revealed that this new interaction technique (touching the fuzzy border and moving the Current to the desired position, Section 4.2.3) seems be more intuitive than the one previously implemented as proposed in [HCS05a] (integrating the function into the control point menu, as described in Section 4.2.1). Nevertheless, participants needed some time to get familiar with this new interaction technique. Although the interaction technique was explained to participants and they were given time to practice it, it was observed several times that, similar as in the study that Scott et al. conducted, participants tried to move Interface Currents just like they would drag around an Interface Object. Addressing this problem, one participant stated during the interview: "I kept trying to move the Current by grabbing it. (...) Because that is kind of like the page and the images work. Just grab in the middle. So the Current works different.".

Furthermore, problems appeared when participants touched one of the control points by accident instead of the fuzzy border of the Current. Due to the inaccuracy of the input, some participants also had difficulties in selecting the fuzzy border. These observations

reveal, similar to SCOTT et al.'s findings, that it is much more intuitive to drag an Interface Current directly in order to relocate it. However, this would interfere with the interaction techniques for manipulating the flow of a Current which is why the process of learning this interaction technique has to be accepted. Nevertheless, one factor was found to complicate this learning process that can be eliminated as described in the following.

The confusion about how to relocate an Interface Current was increased by the form of interaction technique that was developed for creating new Interface Currents, as described in Section 4.2.3. For creating a new Interface Current the user has to touch the relating button and drag the new Interface Current to the desired location in the workspace. In the moment the pen or finger touches the button, the new Interface Current appears with its center right at the touch point. Thus, when creating a new Interface Current, the user is in fact able to just touch its area somewhere and drag it to the desired location (see Figure 6.1). Since the actual interaction technique for relocating an Interface Current

Figure 6.1: Creating new Interface Currents.

is slightly unintuitive although easy to learn, this inconsistency confused participants and inhibited the learning process. This problem can be eliminated by redesigning the interaction technique for creating new Interface Currents in that way that new Interface Currents appear with the fuzzy border under the actual touch point. Selecting the fuzzy border of an Interface Current can be facilitated by broaden it slightly. However, it has to be considered that this enlarges the area of the whole Current which decreases the actual workspace.

It becomes clear that a learning process is required to be able to relocate an Interface Current fluently. However, this learning process has to be accepted because an equivalent and more intuitive interaction technique that does not interfere with other manipulation functions is hard, not to say impossible, to find. Furthermore, it was observed that the longer participants worked with Interface Currents, the more familiar they got with the interaction technique for relocating them.

While the usability problems that occurred when participants tried to relocate an Interface Current are not that severe, the manipulation of the flow had a strong impact on the usability of Interface Currents as described in the following section.

6.1.2 Manipulating the Flow of an Interface Current

The flow, as one of the major characteristics of Interface Currents, was generally found very useful, in particular on the peripheral Current where participants used it frequently for browsing through information (see Chapter 7.1.2). The functionalities of manipulating the flow such as stopping and starting it and changing its velocity were often used while the direction of the flow was rarely changed on purpose. Being able to change the velocity of the flow and stop it completely seems to be much more important for users. The interaction technique for stopping the flow was adopted by participants very well. None of them had problems to apply it. Starting the flow and changing its velocity required some more practice because participants needed to get a feeling for how far they had to slide the stylus or finger on an Interface Current in order to achieve the desired velocity. When participants started the flow, they had often difficulties of adjusting the desired velocity immediately. Usually, it was faster than desired which made it necessary to readjust. Furthermore, participants were confused, in particular at the beginning of the first task if the slowest velocity setting was already applied on the Current or if there was a slower setting available.

While these problems seem to depend on practice and occurred less frequently after some time, some serious issues were found, in particular, with regard to the peripheral Current. Participants stated that there were phases when they perceived the flow on the peripheral Current as distracting. Furthermore, the manipulation of the flow on the peripheral Current was found to cause serious interferences between users. Other problems were caused by the fact that there is no indication on an empty Interface Current, what flow velocity is currently applied or if its flow is completely stopped. All these issues are described in detail the following sections.

Phases of Perceiving the Current's Flow as Distracting

Although continuous flow was successfully used for browsing through large amounts of photos, in particular on the peripheral Current, there were phases when participants perceived it as distracting. These phases occurred, for instance, when participants wanted to concentrate on other parts of the workspace rather than on the peripheral Current. The following statements by two different participants from different groups represent the opinion of all participants, in the broader sense: "Having the (peripheral) Current moving in the background seemed to me a little distracting unless I was actually looking for something (on the Current).", "(...) when we decided to finally go to do the collage on the storyboard we would stop it (the flow on the peripheral Current)". Participants perceived floating items as very attention catching. Thus, they stopped the flow on the peripheral Current from time to time, in particular, when they were not interacting with it.

Another reason for stopping the flow on the peripheral Current was the desire to increase the visibility of information items. Due to the algorithm that determines the flow of

Interface Objects on an Interface Current, the velocity of the flow increases the more the Current is stretched out, as described in Section 4.2.2. Thus, the flow on the peripheral Current in its slowest setting is faster than the flow on smaller Currents of the same velocity setting. Most participants perceived the speed of floating items on the peripheral Current as too fast, even in the slowest setting. They often quoted that the photos were hard to see due to the high velocity. Furthermore, the rather low resolution of the display and the fact that items appear increasingly blurry the closer they are positioned to the edges of the display degraded the visibility of items floating on the peripheral Current. One strategy of participants to cope with these problems was to stop the flow from time to time in order to have a closer look at groups of photos and to start the flow again after a short moment. Although this strategy was observed very frequently, the manipulation of the flow on the peripheral Current often led to severe interferences between users as illustrated in the following.

Interferences Between Users

In particular at the beginning of the first task, participants often worked independent from each other with information on the peripheral Current (see Chapter 7.1.1), that is, they were both concentrating on the part of the peripheral Current right in front of them. In these work phases they were not or little aware of what the partner was actually doing. Thus, it often occurred that one participant stopped or sped up the flow on the peripheral Current which distracted the partner seriously because he or she was not prepared for this change. Groups became aware of this problem quickly. One participant stated: "I would not stop it (the flow on the peripheral Current) for very long and if I changed the direction either back and forth I would impair his (the partner's) visibility. (...) whenever I made the interaction I knew that it could interfere with his (the partner's) activities." Such interferences between participants were observed in every single group that performed the study. Some groups were able to cope with this problem by communicating with each other as one participant exemplified: "I usually asked before I was going to speed it (the flow on the peripheral Current) up". However, this problem still required coordination among group members—coordination effort that could be cut down for the benefit of the actual task. Furthermore, not all groups were that communicative among each other and, thus, were distracted by the interference problem seriously.

Another problem concerning the flow on Interface Currents, in general, is that the flow on an empty Interface Current is not visible to users. This became a problem especially during the second task where participants had to interact with Interface Folders.

Visibility of a Current's Flow

The flow on an Interface Current is indicated by items floating on the Current. The velocity of floating items indicates the velocity setting that is applied to the Current. When items just stand on an Interface Current without floating, the user can deduce that the

flow on the Current is stopped completely. However, if no item is located on an Interface Current, all this information stays invisible to the user. In normal situations, this problem is not serious because a user can easily readjust the velocity setting when the added information item does not flow in the desired way. For the interaction with Interface Folders, the feedback an Interface Current gives in terms of its current flow setting was found to be very important. During the second task, participants often created a new Interface Current and manipulated its shape as desired before connecting it with an Interface Folder. During the manipulation of the Current's shape and location its flow sometimes was stopped by accident without being noticed by participants. This was causing serious problems when this Current was finally connected with an Interface Folder: Items of the Folder piled up on the Interface Current right after leaving the "bridge" between Folder and Current because the flow on the Current was stopped (see Figure 6.2). Participants often were confused by this phenomenon and only after the experimenter's intervention they could fix the problem by starting the flow on the Current.
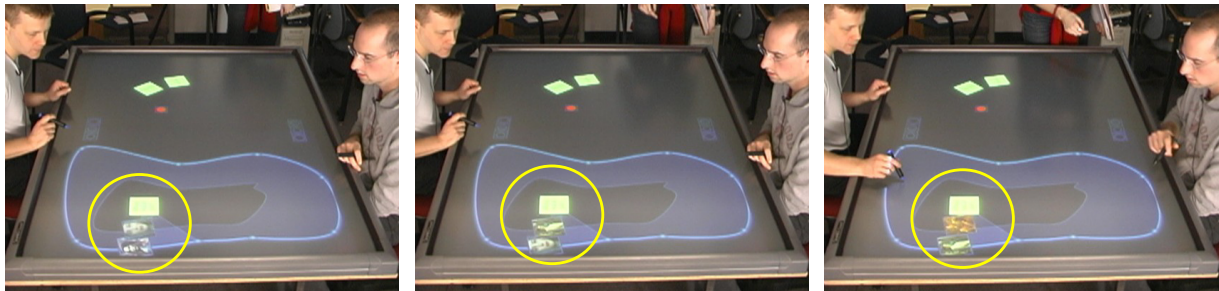
Figure 6.2: Items are piling up because flow on the Current is stopped.

On the one hand, these problems can be solved by a more mature design of Interface Folders. On the other hand, feedback about the flow settings on an Interface Current would be helpful and could also facilitate the adjustment of the velocity as pointed out at the beginning of this section.

Design Implications Concerning the Flow on Interface Currents

The usability issues discussed above lead to the following design implications. First of all, the color of the Current could indicate its current flow velocity: When the velocity of the flow is set to its fastest setting, the Current could turn into a very light blue (relating to a shallow river where the water streams very fast) while it could become darker the more the flow is slowed down (see Figure 6.3). Users could easily see if the flow can be adjusted to a slower velocity, for instance, or if it is completely stopped and in that way confusion and problems with Interface Folders could be avoided.

During the interview, several participants ask for the possibility of adjusting the velocity of the flow continuously instead of relying on three distinct velocities. In fact, the current algorithms that determine the movement of items on an Interface Current are of

| (a) Slow. | (b) Medium. | (c) Fast. | (d) Flow is stopped. |
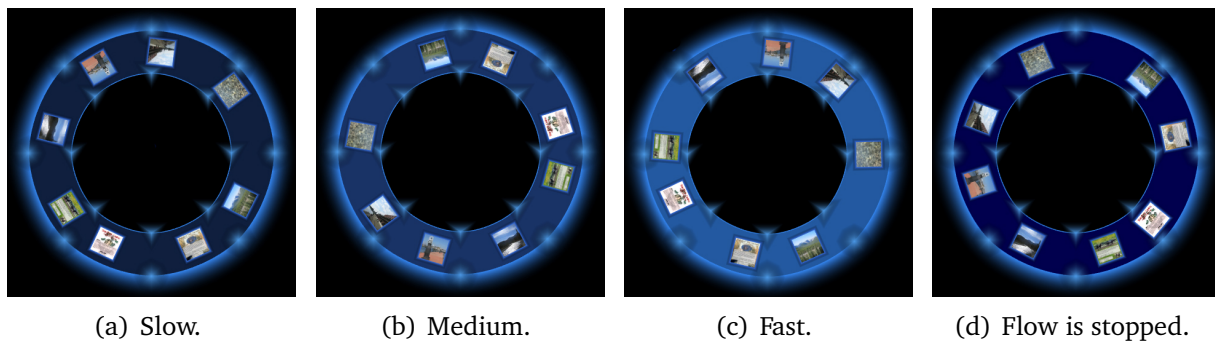
Figure 6.3: Color indicates the velocity setting on a Current.

prototypical character. Several improvements could be applied. For instance, the manipulation of the flow could be based on the behavior of a physical lazy Susan so that the velocity of floating items an Interface Current is based on the strength with which the user applies the relating interaction technique on the Current. In that way, the velocity could be changed continuously. A color scheme as mentioned above could support this technique visually. The interference problem that occurred, in particular, on the peripheral Current could be solved by applying independent velocities between the different control points. In that way, stopping the flow on one side of the Current would not affect the other side (see Figure 6.4). Observations revealed that participants never stopped the flow for a long time but just for a moment in order to look at photos more closely. Thus, information could pile up in front of the area on the Current where the flow is currently stopped and would start to distribute when the flow in that area is started again (see Figure 6.4). While applying a color scheme to Interface Currents in order to visualize the setting of its flow does not require many changes of the system, implementing continuous changing velocities between the different control points would requires a redesign of the algorithms that determine the flow on Interface Currents. Thus, these changes stay future work (see Chapter 8.2.1) and were not taken into consideration for the redesign of Interface Currents as described in Section 6.3. Severe usability problems were not only found with regard to the flow on Interface Currents but also in the interaction with the control point menu. They are discussed in the following.

6.1.3 Interacting with the Menu

The user study clearly revealed that participants had difficulties in performing the desired activities using the control point menu. Usability problems were observed already in the first task and outcropped even more obvious in the second task where participant had to interact more with the menu in order to adjust the shape of Interface Currents in the desired way. Despite of these problems, the majority of participants stated during the interview that the menu was "easy to use". This phenomenon shows strikingly that data collected during an interview or questionnaire is not necessarily reliable because
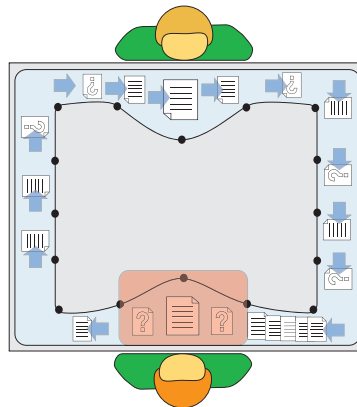
Figure 6.4: Independent flow between control points.

participants often try to pronounce statements they think the examiner wants to hear. The advantage of a semi-structured interview is that the examiner has the possibility to scrutinize answers of participant that do not match with the observations, as mentioned in Chapter 3. This technique was applied in particular concerning the usability issues of the control point menu. Since in every single group usability issues in relation to the control point menu were observed, participants were questioned very detailed about the sources of problems. Furthermore, the video data was analyzed focusing on this issue. This section will illustrate the reasons for the usability problems with the control point menu and discuss the impact these findings make on the design of Interface Currents.

Difficulties of Assigning Menu Icons to Desired Activities

The major reason for the usability problems that occurred in correlation with the control point menu was that participants had difficulties of choosing the appropriate menu icon for the desired activity. In the first task this problem occurred only from time to time because participants did not feel to change the shape of Interface Currents extensively. However, in the second task this problem occurred very frequently and was causing frustration among participants. Interaction sequences were observed where the participant selected all three menu icons one after another until he or she finally found the desired one. The analysis of observations and statements of participants revealed that although the icons in the menu differ from each other sufficiently it is not possible for an unexperienced user to assign them to the desired interaction technique without practicing. However, all participants stated that they would get used to the menu after some time. One participant stated in this regard: "I think even throughout this exercise I have learned it (using the menu) pretty much". Observations of participants performing the second task seem to confirm this assumption. At the end, they usually were able to identify the right item for the desired interaction immediately.

Another observed phenomena revealed that the basic concept of introducing a control point menu for controlling interactions with an Interface Current conflicts with the natural tendency of users to interact with Interface Currents. At the beginning of the study session, participants tended to point-and-touch on a control point and just try to move it directly in order to accomplish the desired adjustment on the Current. This happened frequently although participants were told to select the desired menu item first and practiced the interaction technique during the introduction session several times. This issue was pointed out by one participant in particular : "My initial feeling is that if I pull it (the control point), I just stretch it (the Interface Current) the way I want." This statement shows that it would be much more intuitive if adjusting an Interface Current would only require to adjust one control point directly. Observations of participants confirm this. Often, stream-shaped Currents were resized by accident before participants found the desired menu icon. This indicates that they first intended to move the control point directly which is why they selected the resizing icon by accident that is in the middle of the control point menu and, therefore, in the move direction of the particular control point that they intended to move.

These usability findings provoke the question if participants used all functions that are offered by the menu or if some of them are useless and, thus, could be eliminated in order to facilitate the use of the menu. During the first task the major number of participants only used the changing-the-width function on the peripheral Current and the resizing function for new created Currents in the middle of the workspace. The reshaping function was never used beside some exemptions when participants played around with the functionality of the menu in order to get a feeling for it. However, during the interview none of the groups stated that one of the functions in the menu should be eliminated. All participants could imagine situations for using one of the three functions. This was confirmed in the second task where all menu functions were used several times. Here, the reshaping function played a very important role because the Currents in the workspace were not arranged for participants but had to be adjusted by them. Thus, the different situations in which participants used particular functions for adjusting the Interface Current, were taken into careful consideration for the redesign of Interface Currents as described in Section 6.3.

Another reason for the difficulties with the control point menu was that the learning process of assigning the different menu icons to the underlying functions was complicated by the inconsistent design of the control point menus for pool- and stream-shaped Currents. This is explained more detailed in the following section.

Inconsistent Design of Different Menus

The differential arrangements of icons in the control point menus of pool- and stream-shaped Currents complicated and decelerated the learning process of participants that was required learn to identify the desired menu icon in the menu quickly. The menus for pool- and stream-shaped Currents are illustrated in Figure 6.5. On the pool-shaped

Figure 6.5: Menus on stream- and pool-shaped Currents.

Current, the menu icon for resizing is installed on the right side of the menu while it located in the middle of the control point menu of the stream-shaped Current. This inconsistency makes it difficult for users to learn the gesture for resizing an Interface Current. Whenever they invoke a menu on a pool- or stream-shaped Interface Current, they have to rethink how the menu icons are arranged instead of automatically applying the learned gesture. This problem was solved in the new realization of Interface Currents (see Section 6.3). A similar problem appeared when the shape of the Current was
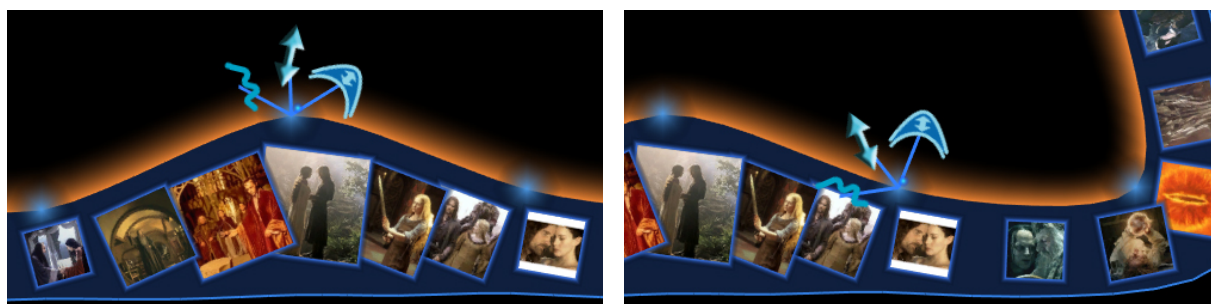
(a) Menu oriented in the right way.   (b) Menu occluding Interface Current.

Figure 6.6: Different orientations of the control point menus.

changed in a specific way. In general, the control point menu should always be oriented to the workspace that immediately surrounds of the corresponding Interface Current but never to the Current itself as illustrated in Figure 6.6(a) (see Section 4.2.3). However, when the control points are deferred in a certain way, the menu is not oriented into the expected direction but slightly displaced (see Figure 6.6(b)). Thus, the user, again, has to rethink where the desired menu icon is actually located instead of automatically applying the appropriate gesture. This problem is of algorithmic nature. As explained in Section 4.2.3, the orientation of the menu is determined by the direction of the vector between the corresponding control point and the center point of the Interface Current. When the Interface Current gets deformed in an irregular way this algorithm generates undesirable results as described above (see Figure 6.7(a)). Rather than basing the calculation of the menu's orientation on the vector between the corresponding control point

(a) Current algorithmic approach.   (b) Proposed approach.
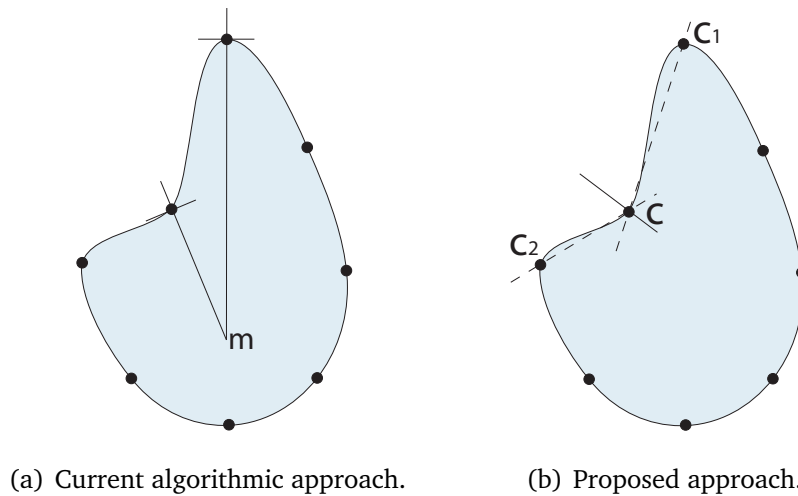
Figure 6.7: Approaches for determining the orientation of the menu.

and center point of the Current, it should be based on its adjacent control points (see Figure 6.7(b)). The orientation of the menu could be determined by calculating the angle between vector $\overrightarrow{CC_1}$ and $\overrightarrow{CC_2}$. The orientation angle of the menu would have to be half of the calculated angle α. Following this approach, the menu would always invoke in the expected orientation.

Inaccuracy of Input

The problems discussed in the sections above are aggravated by the inaccuracy of the input on the DViT SMART Board™. In particular, near the edges and corners of the SMART Board™ the determination of the touch point of a user's finger or stylus can be very inaccurate. Since the menu items are rather small and very close together, especially in the control-point-menu of stream-shaped Currents, this inaccuracy can have the result that the system determines the wrong menu item for selection. This case is frustrating, in particular, for the user because she intended to select the right icon and the system gives inexplicably the undesired feedback. However, this particular problem is hardware-based and can only be solved by improving the hardware. The the other usability problems of the control menu mentioned above were addressed in the new realization of Interface Currents (see Section 6.3).

The next section describes a general usability issue concerning the manipulation of the shape of Interface Currents. This issue is not necessarily related to the usability of the control point menu but it is important for understanding participant's problems with adjusting Interface Currents.

Indirect Manipulation of the Current's Boundaries

During the second task of the study it was found that participants often had difficulties to manipulate a stream-shaped Interface Current when its control points were installed on the inside border instead of on the outside. Participants often created a stream-shaped Current with the control points on the inside or on the outside without thinking about the consequences. When they started to adjust the Current for their purposes, "inside" stream-shaped Currents were often deleted again in support of an "outside" Current. The reason for this phenomenon is probably that new created Interface Currents are initially rather small and have to be made bigger either by resizing or reshaping them. The required interaction technique is a movement towards the edges of the workspace as illustrated in Figure 6.8(a). This technique seems to be more intuitive to apply when
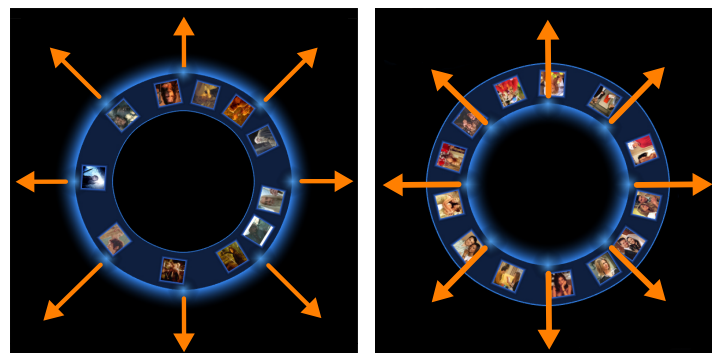
(a) Resizing of an outside stream. (b) Resizing of an inside stream.

Figure 6.8: Movement vectors on outside and inside Currents.

the control points are located on the outside of the Current because they can be moved towards the free space surrounding the Interface Current rather than towards the Current itself (see Figure 6.8(b)). On the other hand, participants had serious difficulties to manipulate the inner border of an stream-shaped Interface Current indirectly with the help of the outside control points, for instance, in order to establish a magnification area on the Current (see Figure 6.9). This was found difficult, in particular, when the Current was already near the edges of the workspace. For this reasons, it is not surprising that participants often ask for the possibility of manipulating both, inside and outside, border directly, for instance, by installing control points on both boundaries. This desire was realized in the redesign of Interface Currents (see Section 6.3).

In the following section, findings are discussed that could not be allocated to any of the categories discussed above. These findings are related to usability issues caused by overlapping information items, simultaneous user interaction and the buttons for creating new Currents.

Figure 6.9: Indirect manipulation of the inside boundary.

6.1.4 General Usability Issues

Apart from the usability issues explained above, the study revealed a couple of other problems that had impact on the usability of Interface Currents. These problems include overlapping of information items floating on a Current, the fact, that only one user at a time can interact with a Current, and some usability issues with regard to the buttons for creating new Interface Currents as discussed in the following sections.

Overlapping of Information Items

The space on an Interface Current is limited by its surrounding boundaries. Thus, when large amounts of information items are spread out on an Interface Current it cannot be avoided that they start to overlap each other. This decreases the usability of Interface Currents because the visibility of floating information is hampered. While the problem was already observed during pilot tests, it occurred in both tasks participants had to perform during the study. During the first task, information items overlapped primarily on the peripheral Current (see Figure 6.10).

This constrained participants while browsing through the pictures on the Current because they could not see sufficient details. Several statements during the interview addressed this problem: "That (overlapping of images) was something hard. (...) they (the images) were kind of one over another". Some participants applied a certain technique in such situations: They successively touched the pictures floating by in order to bring them into foreground (see Figure 6.10(b)). This technique was often combined with the establishing of a magnification area on the peripheral Current that lets pictures appear larger and clearer (see Figure 6.10(a)). Furthermore, participants sometimes just dragged items from a clustered part of the Current into the normal workspace in order to watch them more closely (see Figure 6.11). The functionality that lets items shift into foreground at a certain position on the Current, as described in Section 4.2.2, eased the problem a little bit as some statements show: "I did like that they come into focus. I mean, that they take the top position when they are in front of you". However, this functionality seems to be too restricting to really solve the problem. It does not allow users

(a) Creating a magnification area on the Current.   (b) Touching pictures successively.

Figure 6.10: Problem of overlapping pictures on the peripheral Current.

Figure 6.11: Taking a closer look on pictures.

to move around, for instance. Some groups did not even notice this feature at all. With regard to the problem of overlapping items, the first task revealed that users concentrate more on an whole area on the Current when they are browsing through information items floating on the Current rather than on a certain position. This has to be considered when designing solutions for this problem.

Similar problems occurred in the second task when participants were loading the content of Interface Folders on Currents. Overlapping items were perceived as even more distracting than in the fist task because word tags were involved among the information items. While the content of photos was at least partly visible, participants could not read the words at all when the word tags were overlapping each other (see Figure 6.12). On the stream-shaped Currents participants used similar techniques as in the first task for dealing with this problem: They were tapping on items to bring them in foreground and they established magnification areas on the Currents. Other strategies were applied

(a) Overlapping word tags on stream.

(b) Overlapping word tags on pool.
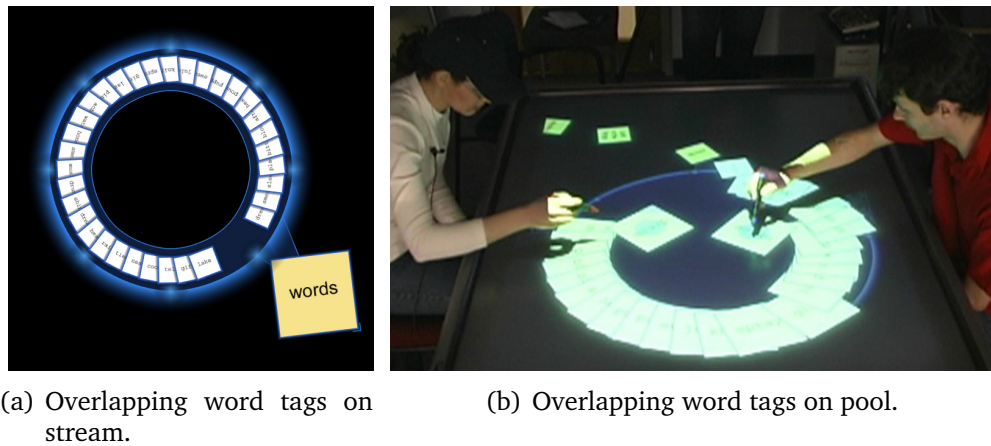
Figure 6.12: Overlapping word tags are hard to identify.

when participants were working with a pool-shaped Current. When connected to a pool-shaped Current, the content of an Interface Folder gets spread out along the peripheral of the Current, as shown in Figure 6.12(b). Some participants complained about this because items could be spread out more on this area in order to avoid overlapping. In contrast, some participants liked the possibility of selecting certain items from the periphery of the pool-shaped Current and bringing them into the middle (see Figures 6.13). Answering to the question of the examiner if it would be better to spread items out on a
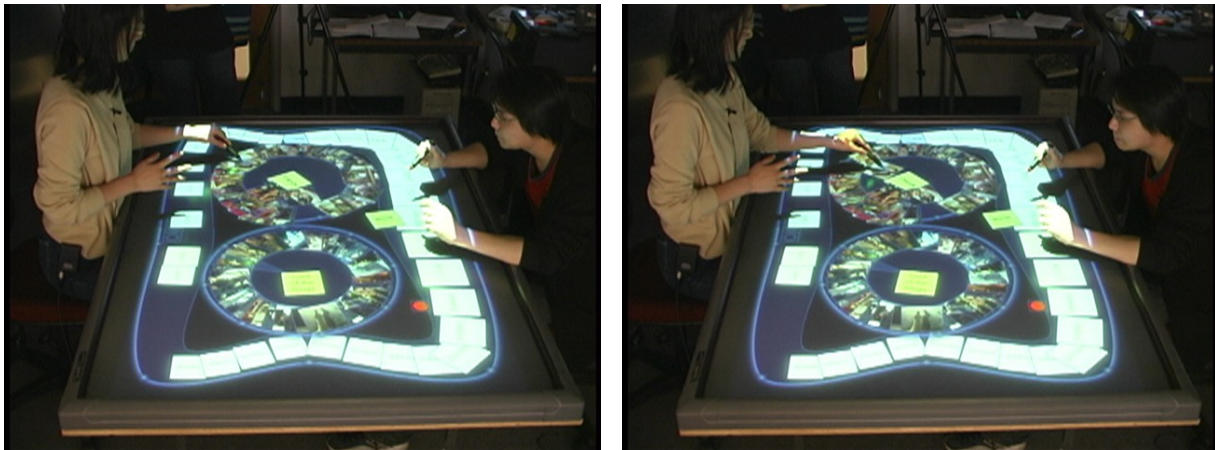
Figure 6.13: Hierarchical arranged items on a pool-shaped Current.

pool-shaped Current evenly, one participant stated: "Maybe not. Maybe we want everything on the base hierarchy (the periphery of the Current) and if we want something, maybe we can just pull it out. Or if we don't want it we can just drop it back into the base hierarchy.". This statement shows that the overlapping or piling, in particular on a pool-shaped Current, is not necessarily problematic but also can offer new strategies for using the Current. However, working with a pool-shaped Current in such a way requires

the items to be visible at least so that users can decide if a particular item is worth to be selected and watched more closely or not.

In Sections 4.2.2 and 4.3.2 some solutions were discussed that can be applied to avoid the problem of overlapping information items on Interface Currents. Although these solutions are only prototypical approaches they seem to have potential. Participants pronounced similar ideas during the study. The approach of letting information items come into foreground when they reach a certain position on the Current, for instance, could be enhanced by bringing items in foreground and spread them out as soon as they reach an area on a stream-shaped Current where the width exceeds a certain threshold (see Figure 6.14). This idea is motivated by the assumption that users enlarge the parts
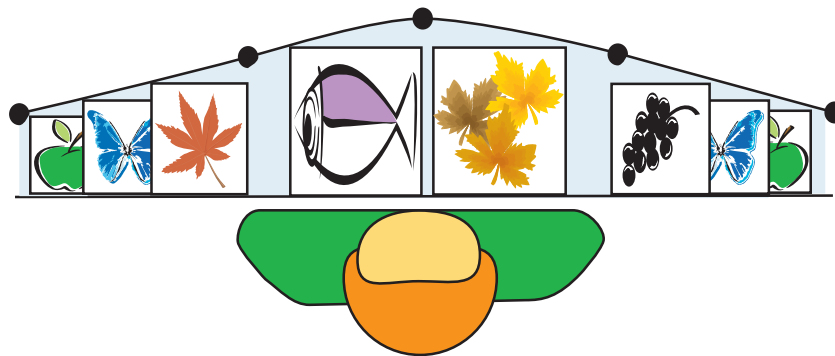
Figure 6.14: Bringing items into foreground based on a certain threshold.

on a stream-shaped Current that they are interested in. Other parts, at the same time, are left rather narrow in order to save space. Information items on narrow parts of a Current are hard to see anyway and, thus, it does not distract users if they are overlapping. In contrast, items in wider areas should be spread out nicely because it is very likely that users want to see items more detailed in these areas.

Another similar idea is to spread items out on certain parts of the Current that are directly defined by users. For instance, certain gestures could be developed that enable users to select groups of items on a Current that are to spread out (see Figure 6.15). Spreading out groups of items would cause other items to pile up more. In that way items on user-defined parts of the Current would be clearly visible whereas other parts would be more clustered.

Apart from the problem of overlapping items, the fact that participants could not interact simultaneously with Interface Current had a huge impact on their usability as described in the following section.
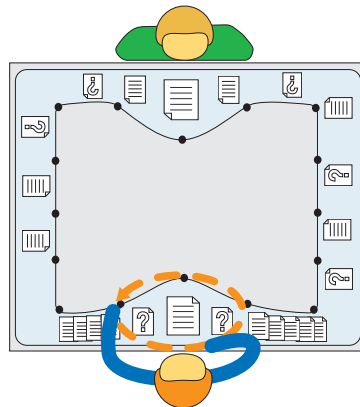
Figure 6.15: Using a gesture for spreading out items.

Simultaneous Manipulation of Interface Currents

In Section 2.2.2 the importance of simultaneous user interaction during co-located collaborative work was discussed. Simultaneous user interaction should be enabled in interactive workspaces that are developed to support collaborative work. In the interactive workspace that was provided to participants during the study, simultaneous user interaction was enabled. However, while users can interact simultaneously in the workspace, all interface components, such as Interface Objects, Interface Currents, and Interface Folders, can only be manipulated by one user at a time to avoid interferences between users caused by conflicting interactions. During the interaction with Interface Objects, participants did not feel constricted by this constraint because Interface Objects were usually used by one single participant at a time. In contrast, with regard to Interface Currents, this restriction was causing some problems because Interface Currents are rather large and are often utilized by multiple users, such as, the peripheral Current. In particular during the second task, both participants often tried to manipulate the Current at the same time. Due to the awareness function (see Section 4.2.3), participants quickly became aware of when they could not manipulate the Current because it was already adjusted by another user so their interactions did rarely conflict directly. Nevertheless, they had to wait until the partner had finished the interaction with the Current. This was often found very frustrating. In the first task, this problem occurred mostly on the peripheral Current, for instance, when both participants wanted to establish a magnification area on the Current. The second task exposed the problem even clearer. Participants often worked together very closely during this task. Usually, they first debated how the different Interface Currents should be arranged in the workspace and, after this, started to manipulate them in the desired way. Nearly every group tried to stretch Currents across the workspace in order to make them available to both users. This required moving several control points of a Current. Several groups wanted to divide up this work

in a way that each participant would manipulate the points that are easy to reach (see Figure 6.16). Since participants could not interact with the Current both at the the same

Figure 6.16: Reshaping the same Current together is difficult.

time, this strategy did not lead to a saving of time but forced one participant to wait until the other had finished the interaction with the Current.

Simultaneous interaction with an Interface Current was disabled for the study system because it can cause conflicts when contradictory interactions are performed by users, for instance, when both users try to interact with the same control point or when they try to use the same function (for instance *resizing* or *relocating*) in a contradictory way. The first case never happened during the study probably because of the chosen user arrangement. Participants did not really share the same control points on an Interface Current and they could not reach the control points on the partner's side easily. Furthermore, if those kind of conflicts would have happened, they would be noticed by users and could be corrected immediately. Thus, for critical functions such as resizing and relocating, simultaneous user interaction should be disabled. In contrast, *reshaping* and *changing the width* of a Current are functions that involve only one single control point. When these functions are performed on different control points, simultaneous user interaction should be enabled. This would avoid frustrating waiting periods for users and, in fact, enable groups to work together when establishing a workspace.

Another usability issue found during the study was caused by the buttons for creating new Currents as described in the following section.

Hindering Buttons for Creating New Interface Currents

The buttons for creating new Interface Currents were installed fixated in front of each user. This chosen position was causing problems as the study revealed. In every single study session it was observed that participants touched the buttons accidentally and, thus, produced new Interface Currents that they actually did not want to create (see Figures 6.17). While this inconvenience was relatively easy to fix by just deleting accidentally created Currents, the position of buttons was, in addition, preventing participants from using the space in front of them for other purposes, for instance, as a personal

Figure 6.17: Participants sometimes created Currents accidentally.

working area, as pronounced by one participant: "It would also be nice to be able to manipulate the position of the buttons. (...) The buttons are actually sitting right in front of me in a place where I would be inclined to actually do work.".

For these reasons, the position of buttons for creating new Interface Currents should be more flexible and adjustable by users. One way would be to design these buttons, similar the trash can, as local tools [BHD+96] (see Section 4.2.3). This would enable users to move the buttons wherever they want. However, it has to be considered that this could lead to complications because every user could potentially spread out his or her buttons everywhere in the workspace. This would increase the hazard that users would, again, produce new Interface Currents accidentally. Thus, another way of designing these buttons would be to build a bar in front of each user, where buttons can be moved horizontally. Similar to the taskbar of Microsoft Windows, this bar including all buttons would disappear when it is not used and invoke again when the user performs a certain gesture.

This completes the discussion about usability issues of Interface Currents. The next section deals with the usability issues of Interface Folders.

6.2 Usability Issues of Interface Folders

Generally, the concept of Interface Folders was adopted very well by participants. They appreciated the function of structuring the workspace with the help of Interface Folders and the fact that the content of an Interface Folder can be spread out automatically on an Interface Current. However, the study showed that the realization of the concept of Interface Folders has to be reconsidered and the relating interaction techniques have

to be enhanced in order to be really usable and supporting. This section introduces the two major usability issues of the current realization of Interface Folders the study revealed. The first is related to the general concept of Interface Folders: Participants had to literally wait for items to come out of an Interface Folder which was found to be increasingly frustrating. The second problem relates more to the interaction techniques that were designed for Interface Folders: It was often observed that participants opened or closed Interface Folders by accident which lead to some confusion. These issues and the design implications they reveal are explained detailed in the following.

6.2.1 Slow Process of Opening and Closing an Interface Folder

The mechanism of spreading out the content of an Interface Folder onto an Interface Current is invoked by two quick touches on the Folder (equivalent to a double-click with a common computer mouse), as explained in Section 4.3.2. Triggered by the "double-click", information items are floating one by one from the Interface Folder over the connection bridge between Folder and Current onto the connected Interface Current (see Section 4.3.2). While this process was sometimes complicated by the problem that the flow on the Interface Current was being stopped accidentally by users and items were piling up but not spreading out on the Current (see Section 6.1.2), the fact that participants had to wait some time for items to come out of the Interface Folder was perceived as much more frustrating. The feature of letting information items move over the connection bridge between Interface Current and Interface Folder was developed to offer a smooth transition between the different states of Interface Folders (closed and opened, disconnected and connected to an Interface Current). However, the study revealed that this transition was not necessary or, respectively, too pronounced and time consuming. Participants always used the fastest velocity setting on the Current in order to get items spread out as fast as possible and even in the fastest setting this process was taking too long. Furthermore, when participants closed a Folder, they always used the functionality of deleting the whole Current and getting all the relating items back into the connected Interface Folder at once (see Section 4.3.2), instead of double-clicking on the Interface Folder again in order to get items to move back into the Folder separately.

In addition to this problem, double-clicking as an important interaction technique for the interaction with Interface Folders was found to be problem-afflicted as explained in the following.

6.2.2 Interaction Problems

It was observed several times that Interface Folders were closed by accident, that is, participants' interactions caused information items to move from the Interface Current back into their relating Interface Folder. This was perceived as annoying although participants

were able to disrupt this process by opening the Folder again. This problem was particularly observed in situations where much computing power was demanded by the system, for example, when large amounts of items were moving on several Interface Currents. This problem was caused by the algorithm used for implementing the double-click event. When a user touches an Interface Folder, a timer is started whose value is used to acquire if a double-click was performed or not. The more computing power is used by the system, the slower this timer counts. Thus, the threshold, that indicates if the timer's value is within the double-click range or not, is reached later. In that way, the system is handling more consecutive touches as double-clicks as desired. The interaction problem of recognizing double-clicks where no double-clicks were performed has algorithmic character rather than ergonomic usability issues. It can be easily solved in conditioning the initiation of a double-click on the actual system time, that is based on seconds rather than on a timer.

After having discussed the usability issues that were found during the exploratory user study, the following section describes the redesign of Interface Currents that was conducted according to several usability issues discussed in the preceding sections.

6.3 The Redesign of Interface Currents and Interface Folders

The usability issues found during the exploratory user study revealed that a redesign of the current realization of the concept of Interface Currents is strongly required. Some of the usability problems arise from underlying algorithms, for instance, the problems of controlling the flow's velocity (see Section 6.1.2). However, most of them have to do with the actual realization of the the design concept of Interface Currents and Interface Folders in general and the design concepts of certain interaction techniques. Major algorithmic changes, as required for installing continuous flow on Interface Currents, were not considered for the redesign but remain future work. In contrast, conceptual design implications revealed by the study were taken as basis for a new realization of the concept of Interface Currents and Interface Folders as described in the following sections.

6.3.1 New Interaction Concepts for Interface Currents

The most usability issues of the realization of Interface Currents were found with regard to the control point menu as described in Section 6.1.3. These problems can be classified as very serious because they prevent users of making use of the flexibility of a Current. A Current's flexible shape, in particular, was found to be a very important factor during collaborative activities (see Chapter 7.3). However, when users are not able to control the shape of a Current, they cannot benefit from this generally supporting characteristic.

Thus, most changes in the realization of Interface Currents arose from revealed usability issues of the control point menu. In particular, the redesign of Interface Currents is conditioned by three goals:

- Conforming the menus of stream- and pool-shaped Currents in order to gain more consistency (see Section 6.1.3)

- Improving the selection design of menu icons to avoid mistakes caused by the inaccuracy of input devices (see Section 6.1.3)

- Making both borders manipulatable in order to avoid forcing the user to manipulate one of the borders of a stream-shaped Current indirectly (see Section 6.1.3).

The way to attain these goals was predetermined by the findings of the user study. As described in Section 6.1.3, the changing-the-width function was the only function that was frequently used on the peripheral stream-shaped Current. In addition, it was found that stream-shaped Currents with the control points on the inside border are hard to reshape or resize. In contrast, it seems to be more intuitive for users to control the shape of a stream-shaped Current by manipulating its outside border (see Section 6.1.3). These findings, together with the request of many participants of being able to control both boundaries of stream-shaped Currents directly, led to the following redesign of stream-shaped Interface Currents. The functionality of changing-the-width of a stream-

(a) Unhinging changing-the-width functionality from the menu.

(b) Menu on pool-shaped Current.

(c) New menu on stream-shaped Current.

Figure 6.18: Redesigning the menu of stream-shaped Currents.

shaped Current with the control points on the outside border was unhinged from the control point menu (see Figure 6.18(a)). The remaining menu icons were rearranged according to the menu icons of pool-shaped Currents. In that way the consistency of the menu design for pool- and stream-shaped Currents was highly improved: Both types of Interface Currents now have identical menus (see Figure 6.18) which facilitates the learning process that is required for being able to interact with them smoothly (see

Section 6.1.3). Furthermore, having only two different icons in the control point menu makes it much more concise and icons are easier to select because they are further apart from each other.

Since the functionality of changing-the-width was found to be very useful on stream-shaped Currents (see Section 6.1.4 and Chapter 7), it was not discarded without substitution. Instead, control points were installed on the inside boundaries of stream-shaped Currents that fulfill this functionality (see Figure 6.18(c)). In order to change the width of a stream-shaped Current the user has to touch one of these control points on the inside boundary of the Current and drag it directly to the desired position (see Figure 6.19). No menu is required for this interaction. The control points on the inside boundary have a different visual appearance than the ones on the outer boundary in order to help the user to distinguish between both. Based on this new realization of the concept of Inter-
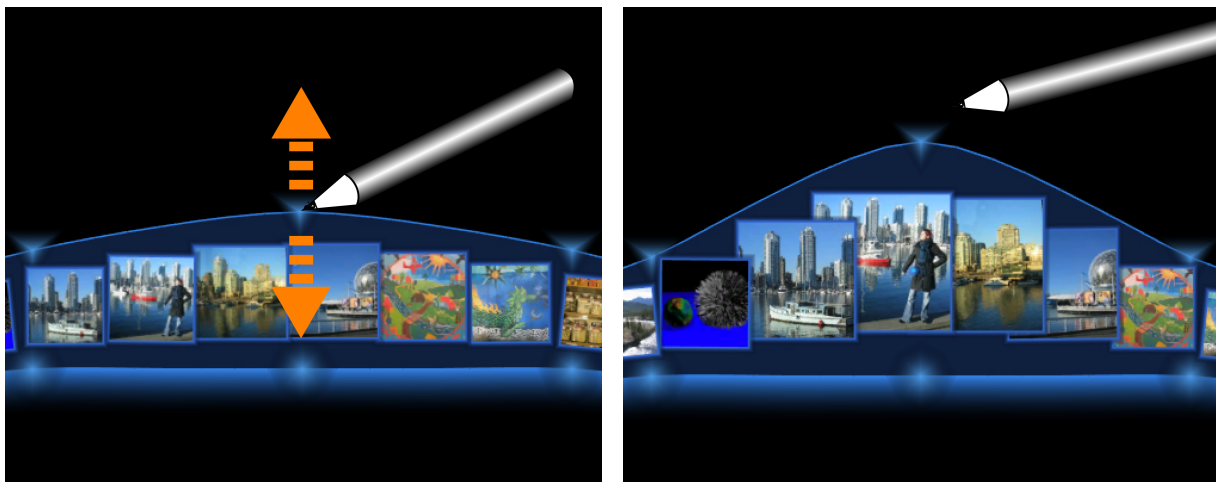
(a) Touching the control point by stylus or finger.   (b) Dragging control point to desired position.

Figure 6.19: New interaction technique for changing-the-width functionality.

face Currents only one type of stream-shaped Currents is required. The functionalities of reshaping and resizing are always located on the outside border which seems to be very intuitive to users. The functionality of changing the width, in contrast, is located on the inside border. Since changing-the-width is the only functionality that needs to be used frequently on peripheral Currents, it seems appropriate to design the relating interaction technique as direct and intuitive as possible while the other two functions are present but remain rather in the background (see Figure 6.20). The user is still able to use them but they cannot be activated accidentally.

In addition to these changes, a color scheme indicating the velocity setting of an Interface Current, as described in Section 6.1.2 (see Figure 6.3) was applied.

Informal tests with this new realization of Interface Currents revealed that users are able to interact with them much more intuitive. Based on this new design, other design

Figure 6.20: Revised peripheral and pool-shaped Currents.

implications that were mentioned in the sections above can be applied. The following section explains the redesign of Interface Folders based on the findings of the study.

6.3.2 New Interaction Concepts for Interface Folders

The main usability issue of the realization of Interface Folders is the slow process of opening and closing Folders as described in Section 6.2.1. In fact, once the content of an Interface Folder is spread out on the connected Current, the connection bridge between Current and Folder was perceived as rather disturbing than helpful or supporting. For this reason, the realization of Interface Folders was revised. This revision was strongly based on a comment one participant made during the second task: "You know what would be cool? If it (the concept of Interface Folders) would be like a window on the computer. If you click on the folder and the Current with all images comes up. (...) Like you double-click it and it just pops up just like on the PC." The observations of other groups during their interaction with Interface Currents confirmed the appropriateness of this idea. Transforming Interface Folders directly into an Interface Current is very much related to the concept that most operating systems apply when a user opens a folder: The folder "transforms" into a window that contains the content of the folder. Furthermore, in the cumbersome waiting times until all items are spread out on the Interface Current, as mentioned in Section 6.2.1, would be eliminated. The following describes how the participant's comment was realized.

When a user double-clicks on an Interface Folder, the Folder disappears and an Interface Current appears instead (see Figure 6.21). The content of the Interface Folder is spread out automatically and evenly on the Current and starts to flow immediately if the flow on the Current is enabled. The shape and the location of the Current can be manipulated just like on conventional Interface Currents. Items can be added to or removed from the folder-based Current. The Current can also be deleted by using the trash can. However, a
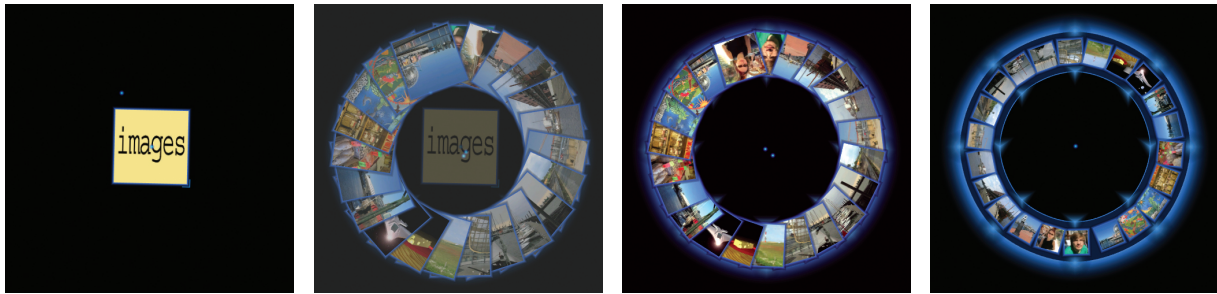
Figure 6.21: Transforming an Interface Folder into a Current.

folder-based Current is deleted, it transforms back into an Interface Folder. This feature gives users the opportunity to quickly collapse Interface Currents whose content is no longer needed and restore them later if necessary. In particular during collaborative work where large amounts of information are used, the ability to collapse content can be crucial. The name tag on the Interface Folder helps users to retrieve the collapsed content easily. When the Folder is opened again, the Current invokes in the same shape it had when it was collapsed.

Transforming Interface Folders into Currents seems to be a promising realization of the concept of Interface Folders. While it seems much more intuitive to use than the first realization, further user studies are required to prove usability.

6.4 Chapter Summary

In this chapter, the usability issues concerning Interface Currents and Interface Folders revealed by the exploratory user study were discussed. The first part of the chapter explained the actual usability issues and the resulting design implications while in the second part the redesign of Interface Currents and Folders was introduced. The usability issues of Interface Currents and Interface Folders are summarized in Table 6.1 and Table 6.2. The issues are classified on a scale from "1" to "3". Issues classified with "1" are minor issues whereas a "3" stands for major issues. With regard to Interface Currents, the major usability issues were found in the interaction with the menu and the interaction techniques for manipulating the flow on an Interface Current. In certain situations, the flow, in particular on the peripheral Current, was found to be distracting and participants tended to stop it. In addition, the interaction of users with the peripheral Current was sometimes interfering with the activities of other users.

Relocating a Current was found to require some customization. Overlapping of information items on a Current was revealed to be a serious problem that has to be solved in order to ensure that Interface Currents can be utilized for tasks that involve large amounts of information. Simultaneous user interaction with Interface Currents should

Usability Issues of Interface Currents	Classification	Resolved
Relocating a Current needs practice	1	no
Manipulating the flow of an Interface Current		
Perceiving the flow as distracting	1	no
Interference between users because the flow on the Current was manipulated by one user	3	no
No indicator for the velocity setting of a Current	2	yes
Interacting with the menu		
Assigning menu icons to the relating functions is difficult for unpracticed users	2	yes
Inconsistent menu design of pool- and stream-shaped Currents	2	yes
Indirect manipulation of the boundary of stream-shaped Currents that has no control points	3	yes
Other issues		
Overlapping of information items on Currents	3	no
Simultaneous manipulation of Currents is not possible	2	no
Buttons for creating new Current were sometimes hindering	1	no

Table 6.1: Summary of usability issues with regard to Interface Currents.

Usability Issues of Interface Folders	Classification	Dissolved
Slow process of opening and closing Interface Folders	3	yes
"Double-click" is often activated accidentally	2	no

Table 6.2: Summary of usability issues with regard to Interface Folders.

be enabled as well, at least for the *reshaping* and *changing-the-width* functions. In addition, but this was found to be a minor problem, the positions of buttons for creating new Interface Currents should be manipulatable rather than fixed in order to enable users to locate them individually on most convenient positions in the workspace.

In general, the concept of Interface Folders was found to be useful but its realization required some revision. Participants found it particularly frustrating to wait for the content of a Folder to spread out on the Current. Furthermore, the connection bridge between Current and Interface Folder was rather distracting than helpful.

For all usability issues the study revealed, design implications were presented that can be applied for future enhancements of the system. However, the most serious interaction problems were revisioned in the redesign of Interface Currents and Interface Folders that is introduced in the second part of the chapter. The redesign of Interface Currents

involves basically a new realization of the interaction techniques for manipulating the shape of a stream-shaped Current. The type of stream-shaped Currents with control points on the inside border was abolished. Instead, all stream-shaped Currents now have two interactive boundaries: The functionality of changing-the-width of a Current was eliminated from the control point menu and, in exchange, installed on the inside boundary. This improves the consistency of control point menus on stream- and pool-shaped Currents and facilitates the interactions with them.

The new realization of Interface Folders presents a new mechanism for spreading out content of Interface Folders on an Interface Current. Instead of connecting the Current visually with an Interface Folder and letting its content move onto the Current, opening an Interface Folder causes the Folder to transform into an Interface Current. During this process the content of the Folder is spread out on the Current directly. Deleting a Folder-based Current causes the Current to transform back into an Interface Folder. This feature supports collaborative tasks that involve large amounts of information very well because it allows users to quickly collapse Interface Currents that are not needed at the time and invoke them again if required. The new design of Interface Currents and Folders will be presented at SIGGRAPH 2005 [HCS05b] and SMART GRAPHICS 2005 [HCSP05].

While this chapter discussed the usability issues that the exploratory user study revealed, the following chapter will describe the general findings of the study, including for which purposes participants used the different types of Interface Currents and the general influence of Interface Currents on collaborative work.

CHAPTER 7

Findings

While a usability analysis of Interface Currents as described in the previous chapter gives information about the usability of the *realization* of Interface Currents, a qualitative analysis of participants' activities during the study tasks can reveal more about how users adopt the *general concept* of Interface Currents. However, it has to be considered that the realization greatly influences the acceptance of the general concept.

In this chapter, the general findings of the exploratory user study are discussed. The analysis of the qualitative data is based on the underlying research questions of the study (see Section 3.2). With these research questions in mind, the collected data is analyzed in terms of certain work patterns or other significant activities that could be instigated, influenced, or reinforced by Interface Currents. While for the usability analysis user statements during the interview and during the tasks are analyzed carefully, for the qualitative analysis, the logged data plays a more important role since it mirrors the users' activities directly and is capable of revealing more general patterns. An existing plotting program developed by SCOTT [Sco05] was modified for this particular study and is used to visualize relevant parts of the logged data automatically. On the basis of these visualizations the data from the different groups can be compared.

The chapter is structured as follows. First, the findings from the first study task are discussed. This task aimed at exploring what work strategies were applied during the task, for what purposes users would utilize Interface Currents in their collaborative task, and how Interface Currents as a concept fit into the design implications for interfaces on tabletop displays mentioned in Section 2.2.5. The second part of the chapter describes the findings the second study task revealed. This task provided rich information about how users would set up a workspace based on Interface Currents and often confirmed the findings discovered during the first task.

117

7.1 Findings from Task 1—Building a Photo Story

For the analysis of the first study task, the different work phases and work strategies participants applied are classified. This classification gives information about participants' purposes for using the different types of Interface Currents. The following section describes the different work phases observed during the first task that all groups went through. Based on these phases, the general characteristics of the different types of Interface Currents are explained.

Some of the work phases, observed in the video recordings, can be clearly identified in the visualizations of activity sequences produced by the plotting program. Based on the logged data the sequences visualize the movements and manipulations of interface items (Interface Currents, Interface Objects (pictures), and the Page Object) during the first study task. Each visualization shows the activity in the workspace during a passage of time selected to demonstrate the typical activities during each work phase. The timestamp displayed in the upper left corner of each visualization (see Figure 7.1(a)) marks the end time of each passage. The triangles in the activity sequences represent pictures that were moved by participants either onto a Current (green triangle), into the normal workspace (blue triangle), or onto the Page Object (pink triangle) (see Figure 7.1(a)). The yellow-red strokes that each terminates at a triangle demonstrates the Interface Objects' movement vector. The yellow end of a stroke represents the initial point of the movement while the red end marks the point at which the movement stops. In particular at the beginning of the first task when participants were moving pictures from the peripheral Current into the surrounded workspace the direction of this movement vector can sometimes indicate which participant was interacting with a picture, information that cannot be given by the tabletop system automatically (see Section 5.6).

(a)   (b)
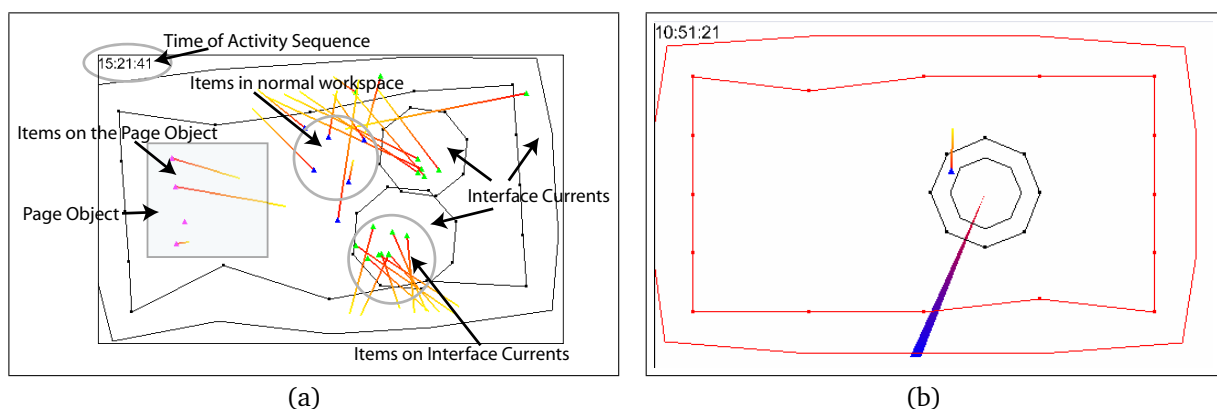
Figure 7.1: Visualization of an activity sequence.

Also, the visualizations show the silhouettes of Interface Currents. When an Interface Current is moved, this is shown by a red-blue triangle, where the red head of the triangle points into the direction the Current was moved (see Figure 7.1(b)). Due to incomplete logging data, the position of the Page Object could not be determined automatically so that the Page Object was added to the visualizations by hand making use of the video data for confirmation. The blue square represents the approximate position of the Page Object.

7.1.1 Work Phases

During the practice task and first task, certain work phases were found to be applied by all groups that participated in the study. All six groups structured the tasks into four work phases, which are described in the following.

Phase 1—Identifying Available Information

During the first phase, groups tried to gain an overview of all available pictures in the workspace in order to decide what kind of photo story they could make. Some groups (4 out of 6) chose the title for the story immediately while the two others first glanced at the pictures floating on the peripheral Current in order to find an appropriate title with regard to the available pictures. After choosing a title for the story, most groups (4 out of 6) established a magnification area on the peripheral Current for each group member (see Figure 7.2). The moment they started to collect pictures for their photo story was taken to indicate the beginning of Phase 2. For most groups, this first phase took approximately one minute while some started to collect pictures so soon that they passed to Phase 2 after a few seconds. In these groups, Phase 1 was brief enough to require attention to be noticed.

Figure 7.2: Example of two magnification areas on the peripheral Current, one for each participant.

The peripheral Current (see Section 4.2.2) played a very important role during this first phase. All pictures that were provided for the first task were initially floating on this

Current (see Section 5.3.1). Thus, the peripheral Current enabled participants to quickly get a general idea of the amount and the content of available pictures. This is indicated by statements such as: "I see a bunch of wedding pictures!", only a few seconds after the task was started. Participants could quickly classify pictures that were floating by on the peripheral Current and decide if they would be suitable for the story or not. Here, it was found that the peripheral Current supported discussion and creative story building.

While participants mostly concentrated on the peripheral Current during the first phase, additional Currents became increasingly important during Phase 2.

Phase 2—Collecting Pictures

The second phase of the first study task was characterized by collecting the appropriate pictures for the photo story. Analyzing the video recordings, three different strategies were observed:

Strategy A: Gathering Pictures in the Normal Workspace Strategy A consisted of dragging interesting pictures directly from the peripheral Current into the workspace surrounded by the Current. This strategy could be observed occasionally in every single group. While many groups used it in combination with Strategy B, described in the following paragraph, one group embarked on it exclusively.

Strategy B: Gathering Pictures on an Interface Current Strategy B consisted of creating pool- and stream-shaped Currents additionally to the peripheral Current and positioning them in the workspace surrounded by the peripheral Current. Suitable pictures were collected on these *additional* Currents (see Section 7.1.2). This strategy was often combined with Strategy A.

Strategy C: Gathering Pictures on the Page Object Some participants gathered pictures directly on the Page Object (see Figure 7.3). This strategy sometimes led to problems because of the limited space on the Page Object so that participants had to remove pictures from the Page Object again and rearrange them. This method was only observed during the practice tasks. For this reason, it can be assumed that participants experimented with this strategy during the practice task but did not find it very helpful and, thus, did not apply it during the following tasks.

To illustrate the following discussion about Phase 2, a series of figures is included. For Groups 1, 4, 5, 6, and 8 there is a pair of figures with the visualization of the activity sequences during Phase 2 on the left and an example screen shot on the right. For Group 7 it was not possible to summarize Phase 2 in one single visualization. Thus, the figures for Group 7 contain four activity sequences and one example screen shot. The

Figure 7.3: Group 7 using Strategy C during the practice task.

| (a) | (b) |
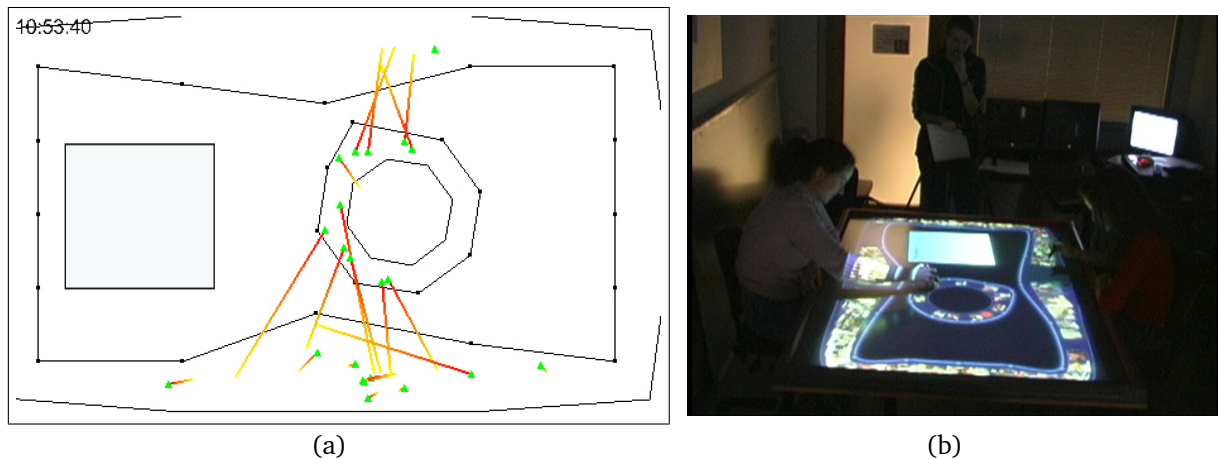
Figure 7.4: Phase 2 of Group 1: Applying Strategy B using one stream-shaped Current.

figures are placed consecutively for Group 1, 4, 5, 6, 7, and 8, and will be referenced as appropriate in the text explanation.

Analyzing Phase 2 of each group using the video recordings, it was found that, except for one group, groups never applied Strategy A and B solely but combined them. However, as the activity sequences shown in Figures 7.4, 7.5, 7.6, 7.7, 7.8, and 7.9 illustrate, every group chose a "major" collection strategy during the second phase of the first task as explained in detail in the following. The Figures show the major activity sequences of the groups during Phase 2 (see Appendix C for more detailed sequences). As illustrated in Figure 7.4, Group 1 chose to use Strategy B as their major strategy for gathering pictures. They hardly collected pictures in the normal workspace. Group 4 (see Figure 7.5) used the normal workspace in combination with a stream-shaped Current for gathering pictures. However, their major strategy for collecting pictures was Strategy B as well. In contrast, Group 5 (see Figure 7.6), as mentioned above, used Strategy A exclusively. Group 6 (see Figure 7.7) chose Strategy B using a pool-shaped Current. However, this
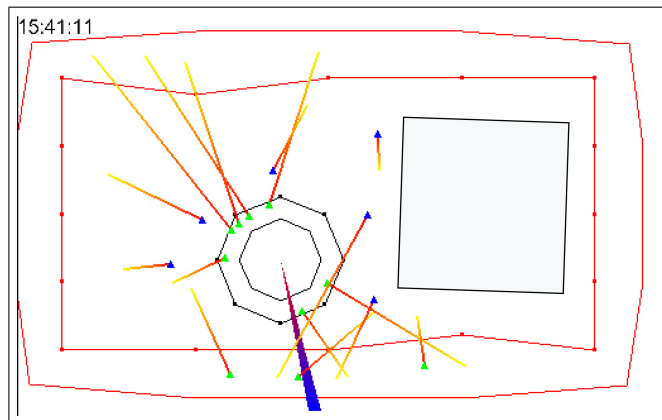
Figure 7.5: Phase 2 of Group 4: Applying Strategy B as a major strategy using one stream-shaped Current.
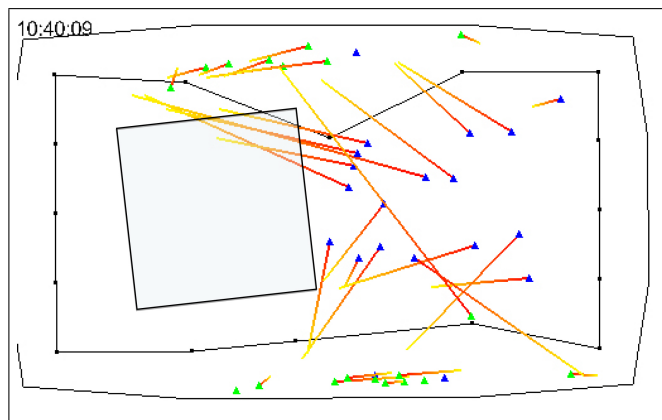
Figure 7.6: Phase 2 of Group 5: Applying Strategy A.
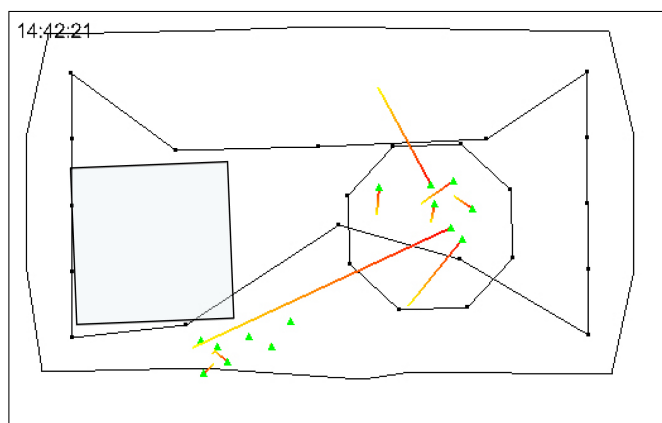
Figure 7.7: Phase 2 of Group 6: Applying (involuntarily) Strategy B using one pool-shaped Current.

(a)

(b)

(c)

(d)

(e)
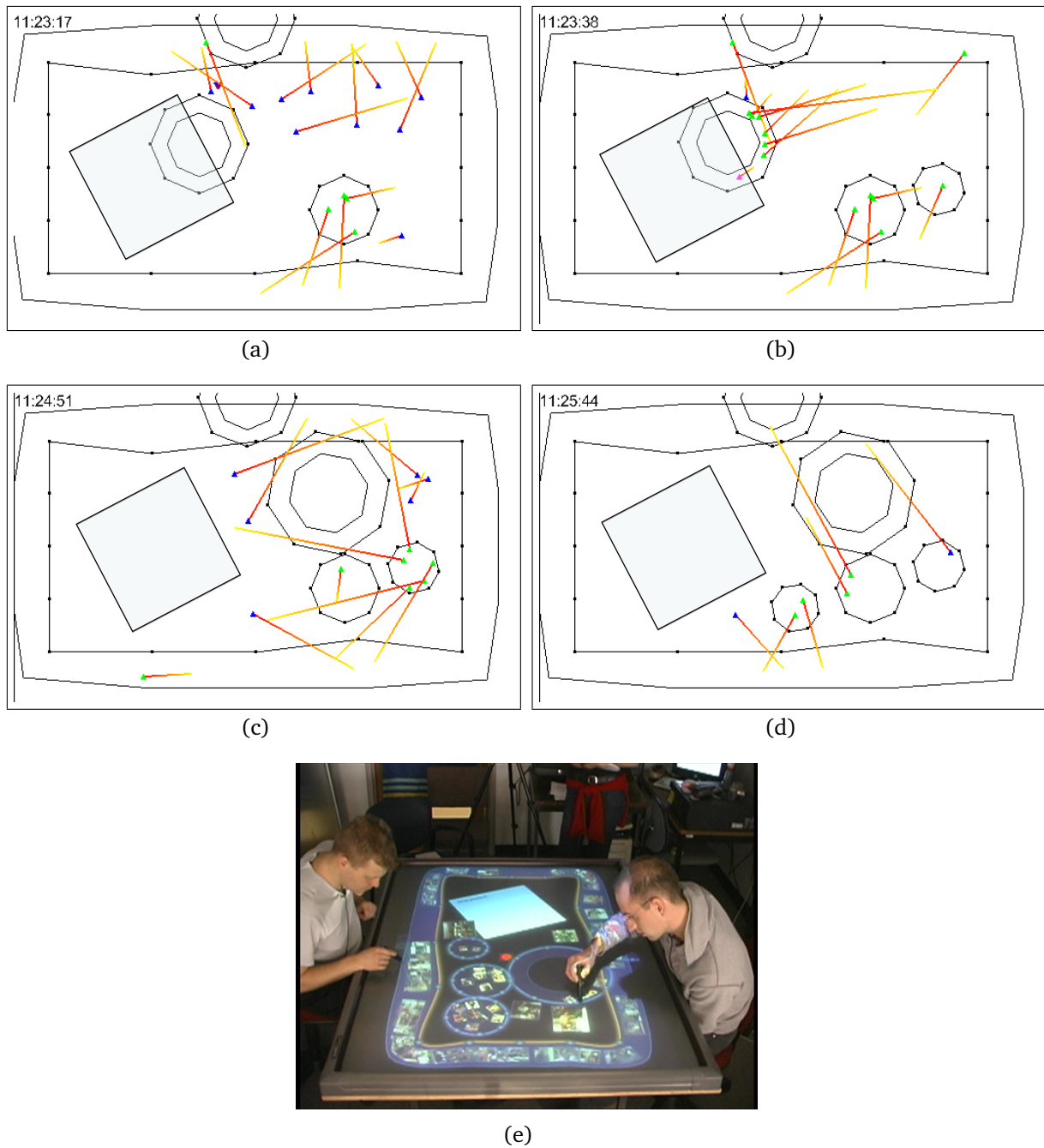
Figure 7.8: Phase 2 of Group 7: Applying Strategy B as a major strategy using one stream- and several pool-shaped Currents.
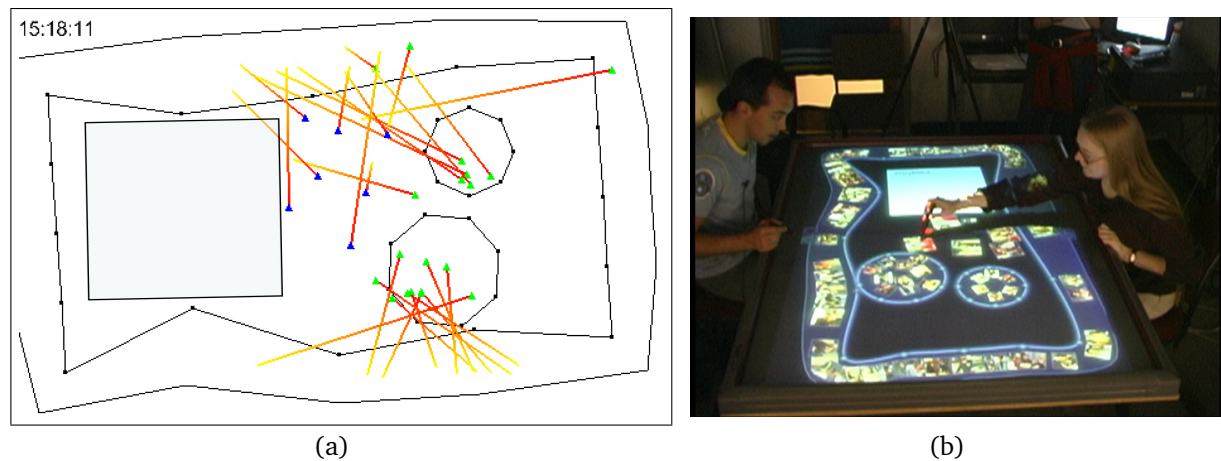
Figure 7.9: Phase 2 of Group 8: Applying Strategy B as a major strategy using two pool-shaped Currents.

group seemed to feel forced to work with an additional Current for collecting pictures. Later, during in the interview they stated that they would have found it more comfortable to apply Strategy A. For clarity reasons, the major activity sequences of Group 7 could not be illustrated in one single sequence, as mentioned above. Thus, their major interactions during Phase 2 are illustrated in four visualizations (see Figure 7.8). As shown in Figure 7.8(a), one participant of this group started collecting pictures using Strategy A but then decided to move them all onto a stream-shaped Current (see Figure 7.8(b)). Thus, it was found that Group 7 applied Strategy B as their main strategy for gathering pictures. Group 8 (see Figure 7.9) clearly decided for Strategy B using two pool-shaped Currents.

The second phase was generally characterized by independent work. Usually, both participants in one group concentrated on the part of the peripheral Current right in front of them and collected pictures independently. During this process, participants of some groups were working completely independently. Group members preserved awareness of their partner's activities by commenting on pictures that they were collecting. Some groups even discussed the story line for the photo story while collecting pictures.

Except for one group, all groups that produced additional Currents for collecting pictures, decided either on stream- *or* on pool-shaped Currents but did not mix the two types of Currents. In this regard, it could be observed that groups used stream-shaped Currents in a different way than pool-shaped Currents. This is discussed in more detail in Section 7.1.2.

Another important aspect observed during Phase 2 is the workspace partitioning. All groups divided the workspace surrounded by the peripheral Current into two parts. One part was dedicated to the Page Object that took approximately half of the workspace, the other part, the *collection area*, was dedicated to the collected pictures and/or additional Currents. This workspace division could be observed, no matter what collecting strat-

egy groups were embarking on. During the second phase, all workspace activity took place mostly in the collection area and on the peripheral Current, which is illustrated in Figures 7.4, 7.5, 7.6, 7.7, 7.8, and 7.9. However, during Phase 3, the activity on the peripheral Current decreased more and more in support of the activity on the Page Object.

Phase 3—Defining a Story Line

After groups had collected pictures either in the workspace or on additional Interface Currents, they started discussing the story line for the photo story. Figures 7.10 to 7.14 illustrate the main activity sequences of each group during Phase 3 (see Appendix C for more detail). As noted above, the workspace activity slowly shifted from the peripheral Current to the collection area and the Page Object which is shown in particular in Figures 7.10, 7.12, 7.13, and 7.15. Participants stopped collecting new pictures from the peripheral Currents and started working with the collected ones. Pictures were increasingly moved from the "collecting Currents" or the normal workspace onto the Page Object. Groups often stopped the flow on the peripheral Current in this third phase because they perceived it as distracting when concentrating on the middle of the workspace (see Section 6.1.2). Some groups enlarged the additional Currents holding collected pictures or spread out the pictures in the middle of the workspace more (see Figures 7.15(a) and 7.12(a)). Group 4 created a new stream-shaped Current and used it to develop a story line (see Figure 7.11(b)). Hence, this group did not interact with the Page Object but actively worked with the "story line Current". The activity sequences of all other groups show that the activity on the Page Object increased the more the story developed (see Figures 7.10(b), 7.12(b), 7.13(b), 7.15(b) and Figure 7.14(c) and 7.14(d)).

(a) Moving pictures to the Page Object.   (b) Roughly arranging pictures on the Page Object.
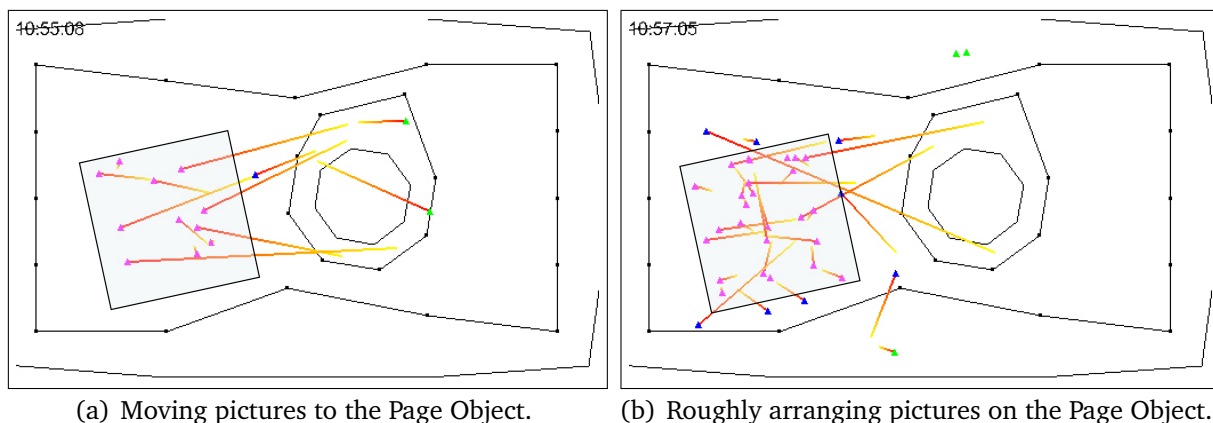
Figure 7.10: Phase 3 of Group 1.

While participants mostly worked independently during the second phase, they started collaborating increasingly during Phase 3. They discussed certain pictures with each other and suggested ideas for the story line to their partners.

(a) Creating a "story line Current".

(b) Arranging pictures on the "story line Current".
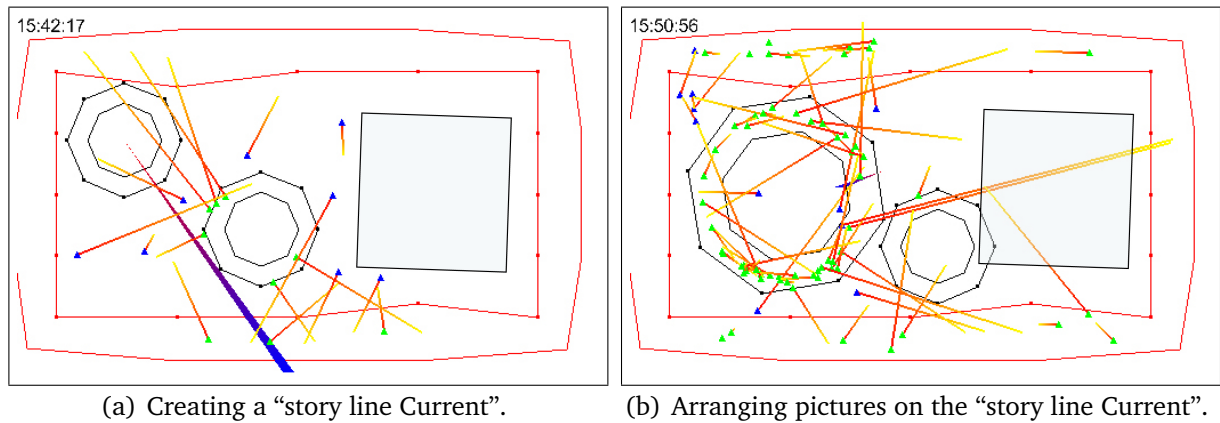
Figure 7.11: Phase 3 of Group 4.

(a) Spreading out pictures in the workspace.

(b) Moving pictures to the Page Object.
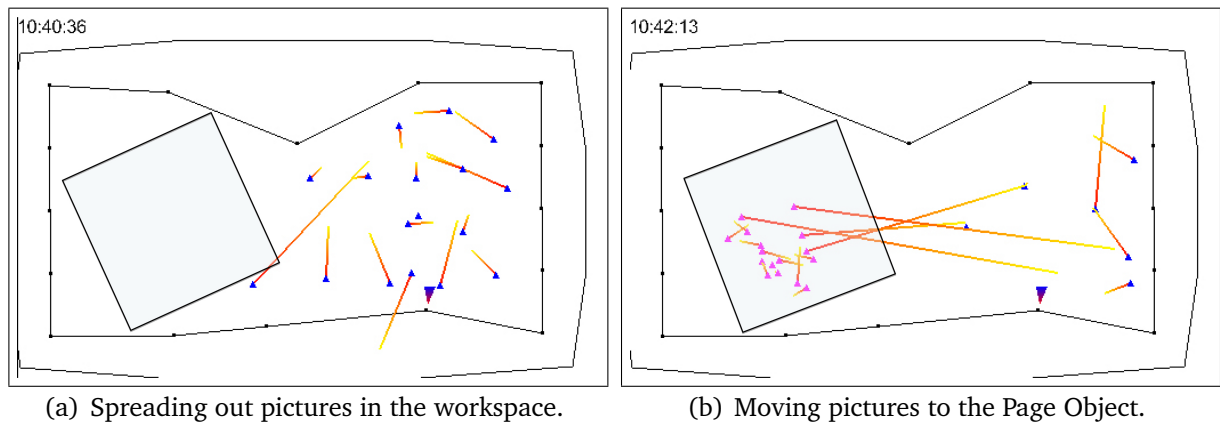
Figure 7.12: Phase 3 of Group 5.

(a) Moving pictures to the Page Object.

(b) Roughly arranging pictures on the Page Object.
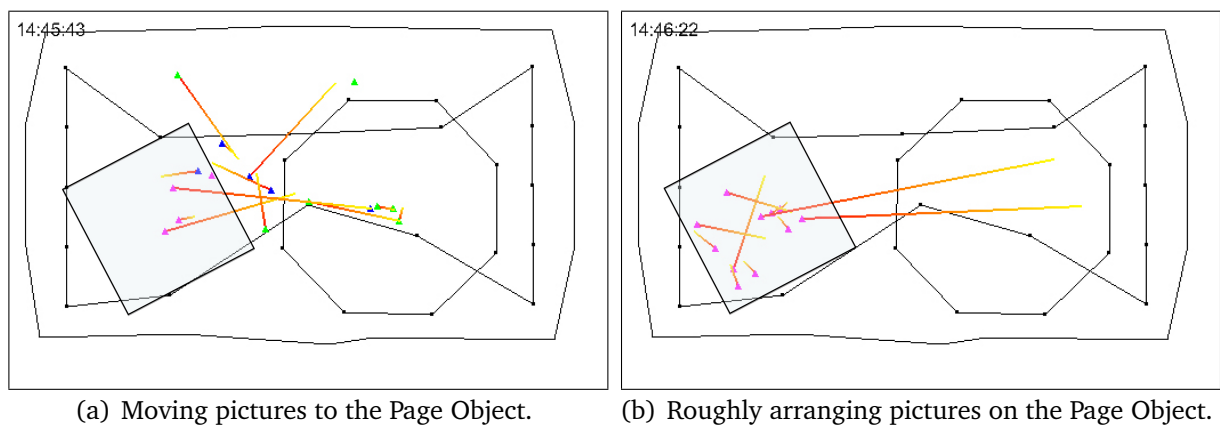
Figure 7.13: Phase 3 of Group 6.

(a) Moving some pictures to the Page Object.

(b) Looking for certain pictures.

(c) Roughly arranging pictures on the Page Object.

(d) Looking for certain pictures.
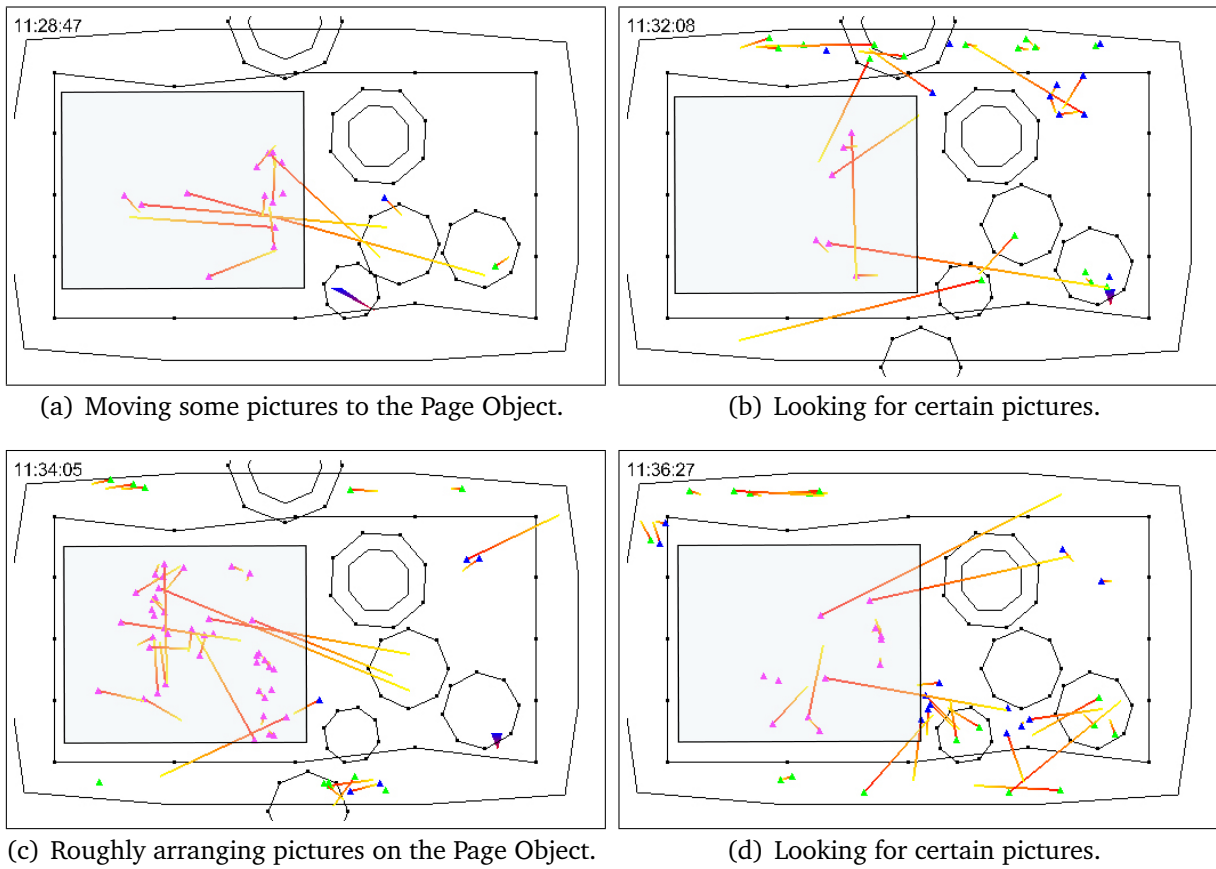
Figure 7.14: Phase 3 of Group 7.

(a) Enlarging pools.

(b) Roughly arranging pictures on the Page Object.
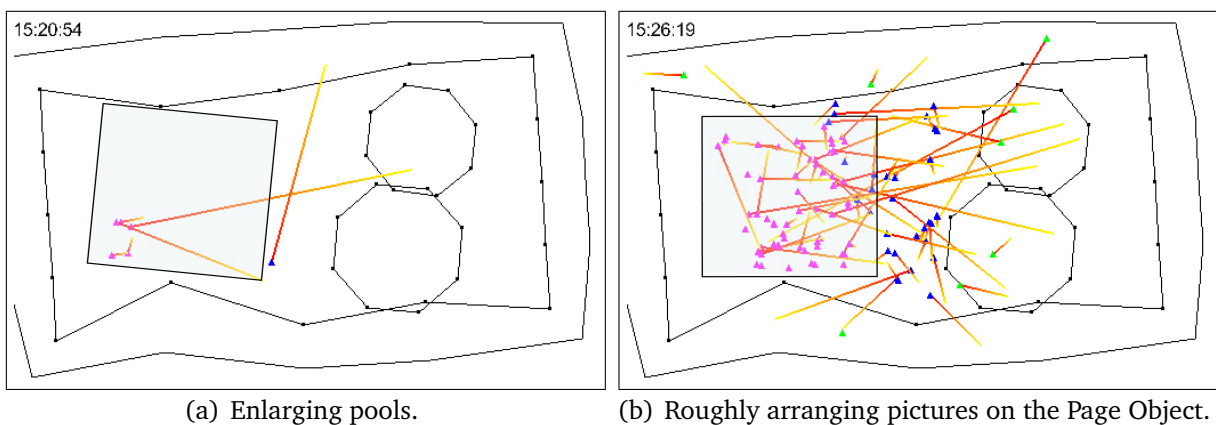
Figure 7.15: Phase 3 of Group 8.

The more the story line developed, the more often participants went back to the peripheral Current to look for certain pictures that would fit into the photo story (see Figure 7.14(b), 7.14(c), and 7.14(d)). Here it could be observed that the flow on the peripheral Current supported the search for particular information. Pictures that were remembered by participants from previous work on the peripheral Current could be found quickly and without much effort. This observation leads to the conclusion that the peripheral Current is appropriate to support the shifts from independent to collaborative work and vice versa. When it is not used (for instance, in phases of collaborative work), it stays in the background but can be activated easily. The same applies to the additional Currents that were used for collecting and categorizing information: they can be stretched out when groups need to focus on the collected information but can be collapsed easily if space for other activities is needed.

Phase 4—Arranging Pictures for the Photo Story

During the last phase, participants concentrated mostly on arranging the pictures for the photo story on the Page Object. Pictures were brought into the right order or were just arranged evenly. Figure 7.16 shows an example for this. The peripheral Current

(a) (b)
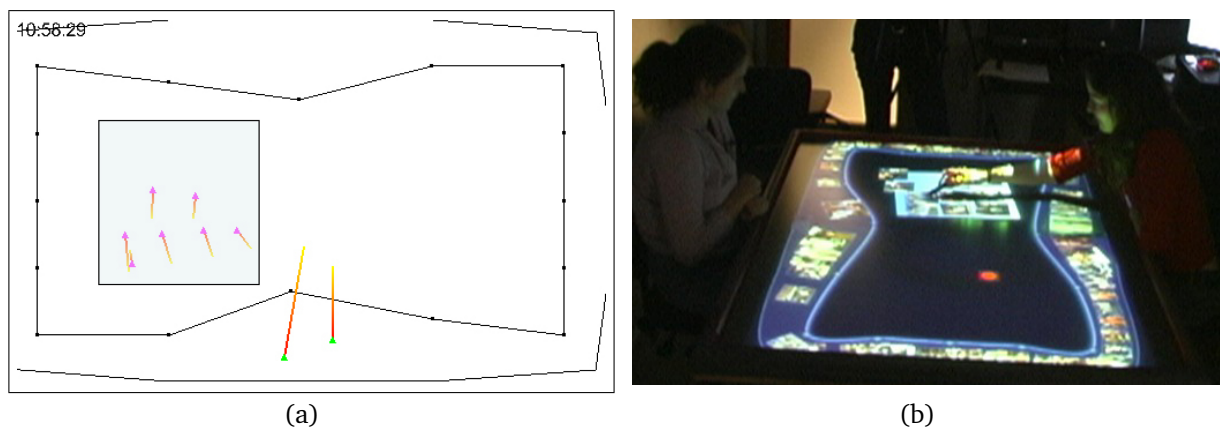
Figure 7.16: Phase 4 of Group 1.

and the collecting Currents were not used in this phase any more. Some groups deleted their additional Currents in order to clean up the workspace. Leftover pictures in the workspace were brought back onto the peripheral Current.

The analysis of the different work phases revealed that groups used different forms of Interface Currents depending on the work phase they were at. Based on this, the characteristics of the different types of Interface Currents can be defined as described in the following.

7.1.2 Characteristics of Interface Currents

During the work phases of the first study task, three different types of Interface Currents could be classified on the basis of the purposes they served: the peripheral Current and additional Currents, including pool- and stream-shaped Interface Currents, that were created by participants in addition to the peripheral Current. These three different types of Currents have different characteristics.

The Use of the Peripheral Current

In the first two work phases of Task 1, the peripheral Current was used for gaining an overview of the large amounts of pictures that were provided to participants and browsing through them (see Section 7.1.1).

Large amounts of information can be perceived as overwhelming when they are spread out all over the workspace and users have to manipulate them manually in order to see them as revealed in the exploratory user study of SCOTT et al. [SCH05, Sco05]. In contrast, using a peripheral Current, users just have to glance at the items floating by and whenever they see something interesting they can drag it into the normal workspace. While doing this they can discuss the actual task. It can be strongly assumed that providing a peripheral Current for this kind of task, demands less cognitive effort from participants and, thus, is perceived as more convenient.

Furthermore, the peripheral Current enables groups to share the same set of information at the same time. Information that is dismissed by one group member can still be taken into consideration by other users. This can be a reason for the fact that, in contrast to the study of SCOTT et al. [SCH05], participants rarely used the tossing function of Interface Objects, Page Objects, Interface Folders, and the trash can (see Section 4.1) for passing items to each other. Apparently, the peripheral Current takes on the functionality of sorting and sharing information so that tossing is not as important as previously. These observations are confirmed by statements that participants made when they were asked why they perceived the peripheral Current as supporting: "There is no way we could have seen all these tons and tons of pictures." "The peripheral Current was definitely useful. Because there are so many pictures I don't think I could have just shuffled them otherwise." "(...)Particularly in a situation like this where it is a large screen and we have to share images, the constant cycling is really helpful just because it gives everybody maximum visibility for a certain amount of time."

Once they had gained an overview of the available pictures and developed a general idea for their photo story, participants often went back to the peripheral Current in order to search for certain pictures that would fit into the story. Thus, as one result of this user study, it was found that participants perceived the flow on the peripheral Current as supporting.

In particular, the flexibility of the peripheral Current's width was perceived as helpful. In order to see pictures better, the participants of four groups broadened the part of the peripheral Current right in front of them (see Figures 7.4, 7.6, 7.7, and 7.9). This technique of establishing magnification areas on the Current seems to ease the problem of overlapping pictures (see Section 6.1.4). All groups that used this technique stated that they found it supporting for the task. They also made use of it during the second task (see Section 7.2). According to the statements of the two other groups that did not make use of this functionality, it just did not occur to them that they could do this. When they were shown the magnification effect on the peripheral Current during the interview they all stated that it would have been helpful. Thus, the flexibility of the peripheral Current's width is an important and supporting functionality and needs to be easy to control (see Section 6.3.1).

In terms of territoriality [Sco05] (see Section 2.2.4), the peripheral Current seems to be a mix of both, personal storage territory and public territory. On the one hand, information items on the peripheral Current are accessible by all group members in the same way. Every group member can reach at least one part of the peripheral Current easily and, furthermore, every group member can control the flow on the whole peripheral Current. For these reasons it can be interpreted as a public territory in the broader sense. On the other hand, the part of the peripheral Current that is located directly in front of each group member can be characterized as a personal storage territory because of its position in the workspace. Personal territories are usually located near the person they belong to. No other group member would access the part of the peripheral Current that is directly located in front of a person because this would be socially awkward [SCI04]. The territorial aspects of peripheral Currents need more exploration. It is not clear to what extent its public characteristics are useful and supporting. For example, the fact that all group members are able to control the flow on the peripheral Current led to disturbing interferences (see Section 6.1.2). If independent flow velocities would be applied between the different control points, the flow on the peripheral Current could be controlled for certain areas individually as explained in Section 6.1.2. This would make it more and more similar to a personal storage territory. Future studies have to explore how users adopt such changes.

Generally, Phase 1 and 2 revealed that the peripheral Current supports browsing through large amounts of unknown information in a convenient way. It offers a good opportunity to share information within a group of people. Users can start quickly with the actual task without having to manually sort through information. Furthermore, a peripheral Current facilitates searching for certain pictures. Although this requires further investigation, it can be conjectured that the peripheral Current provides a form of rapid serial visual presentation (RSVP) [dBS00] (see Section 2.3.4).

During the observations of groups, the experimenter often got the impression that the continuous flow of pictures on the peripheral Current was inspiring the creativity of

participants. However, this observation has to be investigated in future studies (see Section 8.2).

With regard to the positive perception of the peripheral Current, it has to be considered that groups were forced to use it because all pictures were located on the peripheral Current in the study setup at the beginning of the task. However, participants really seemed to find this condition useful since all groups established at least one peripheral Current in the workspace during the second task where they were asked to set up a workspace based on Interface Currents on their own (see Section 7.2).

In contrast to the interaction with the peripheral Current, participants could make use of additional Currents at will. Several groups worked actively with additional Currents. The usage of stream- and pool-shaped Currents differed quite a lot between groups as described in the following section.

The Use of Additional Interface Currents

Table 7.1 shows the amount and type of additional Currents, that groups created during the first task. Five out of six groups created additional pool- or stream-shaped Currents. Two groups solely used stream-shaped Currents for structuring and organizing pictures (Group 1 and 4) while two groups used pool-shaped Currents (Group 6 and 8). However, as mentioned above, Group 6 did not make use of the pool they created. They stopped the flow on this Current and enlarged it in order to magnify items in this area sufficiently. It can be assumed that the participants of this particular group felt forced to create a new Interface Current since the functionality of the buttons for creating new Interface Currents was explained to them. They used the pool of necessity because it was covering most of their normal workspace. Based on the observations during the study session and the interview statements it was found that they perceived the pool as distracting. It stays unclear why they did not delete it. Therefore, Group 6 is not taken into consideration in this analysis of the use of additional Interface Currents.

| Group | Current Type | | Comments |
	stream	pool	
1	1	x	
4	2	x	One stream for collecting items(Phase 2) and one stream for organizing items (Phase 3).
5	x	x	
6	x	1	Group did not really made use of the pool Current.
7	1	3	Stream was created for experimental purposes and mainly used just like a pool.
8	x	2	One pool for each group member.

Table 7.1: Additional Currents used by the specific groups.

Considering all groups that made use of additional Currents, Table 7.1 reveals that all except for one, created either pool-shaped *or* stream-shaped Currents but never mixed both types.

The mix of both types of Interface Currents in Group 7 can be considered as participants personal experiments rather than serving an important function in the task. It can be assumed that this particular participant did not decide consciously to produce a stream-shaped Current rather than a pool-shaped Current because he first started collecting pictures directly in the workspace before he saw his partner collecting pictures in pool-shaped Currents. It is very likely that he produced the stream-shaped Current because he wanted to give it a try and/or because his partner was doing so. He actually stated in the interview after the first task that he found the additional Interface Currents "not necessarily useful". This participant actually used the stream-shaped Current in the way other participants used pool-shaped Currents.

The decision of groups to use a certain type of Interface Currents beside the peripheral Current seems to have influenced their work strategies during the first task. For those groups that made active use of additional Currents, both pool- and stream-shaped Currents were basically used for collecting the appropriate pictures for their story. However, some interesting differences could be observed as described in the following.

Stream-shaped Currents Groups that used stream-shaped Currents for collecting pictures, only worked with one single stream. That is, both group members were collecting pictures onto the same Current (see Figures 7.4 and 7.5). The stream-shaped Current was placed in the middle of the workspace so that both group members could access it. In fact, the stream-shaped Current was used as a *public territory* [Sco05] (see Section 2.2.4). Members of Group 1 and 4 worked independently during Phase 2 such as all other groups. Despite of this, they seemed to be more aware of what kind of pictures the partner was collecting because of the public location of the Current. Due to the flow on the stream-shaped Current pictures were transported into the field of view of participants automatically. The sharing character of stream-shaped Currents was confirmed by groups that used pool-shaped Currents. For instance, when Group 7 was asked, why they used pool-shaped Currents for collecting pictures, one participant answered: "I would not use these ones (stream-shaped Currents) personally but actually trying to share images. (...) I would not see much reason to actually use it (a stream-shaped Current) as for personal storage." Furthermore, stream-shaped Currents have a structuring and organizing character. One group even used a stream-shaped Current not only for collecting pictures but also as a time line for the photo story (see Figures 7.11(b) and 7.17). After Group 4 had collected all pictures on the one stream-shaped Current, they created a new one and started to arrange pictures on it as if it was a story board. The continuous movement of pictures on the Current helped them to share and access the pictures in the same way so that all participants could actively take part in this activity. The linearity of the stream-shaped Current helped them to bring pictures into the right order.

Figure 7.17: Stream-shaped Current as time line for story.

Pool-shaped Currents   Pool-shaped Currents, in contrast, serve as containers for loose categorization of information. Several groups organized pictures on pool-shaped Currents depending on the themes they showed such as "love", "happy end", or "fighting". Collecting pictures on different pool-shaped Currents was found to be more of an unstructured process: Pictures that seemed appropriate were just dragged from the peripheral Current onto a pool-shaped Current in order to look at them more closely at another point in time. Participants that used pool-shaped Currents for collecting pictures did not pay attention to the arrangement of items within the pool as long as the items were all visible clearly. However, it seemed important to participants that items within the same pool-shaped Current roughly covered the same topic.

Group 4 was asked why they did not use a pool-shaped Current for collecting pictures. They stated: "We should have used it (a pool-shaped Current) when we were collecting all those images.(...) Because I think we used this one (the "story board Current") because it rotates in time line versus the pool is sort of like random, massive thing. So yes, when we were collecting those images we could have used just the pool because that were just random images going in there". This shows that, after all, they perceived pool-shaped Currents as more appropriate for collecting pictures.

In contrast to groups that established stream-shaped Currents in the workspace for collecting pictures (Groups 1 and 4), groups that used pools usually created several of them (Group 7 and 8). These pool-shaped Currents were not positioned in the middle of the workspace but near the participant who created them (see Figure 7.8 and 7.9. They were used as personal storage territories [Sco05] (see Section 2.2.4). The pools were exclusively used by their "creator" unless the creator "invited" the partner to use them as well. This is very clearly in the activity sequences in Figures 7.8 and 7.9. The strict ownership of pools was usually softened during the shift from Phase 2 to Phase 3. In the sequences shown in Figures 7.8(c) and 7.8(d) this shift is illustrated: At the end of Phase 2, the "owner" of the pool-shaped Currents had made an inviting gesture (see Figure 7.18) to

Figure 7.18: P1 (left) invites P2 (right) to use "his" pool-shaped Currents.

his partner. From this moment on, the partner made use of the pool-shaped Currents as well.

In Group 8, the shift to collaborative work could be observed at the beginning of Phase 3. Group 8 enlarged the pool-shaped Currents, so that the floating pictures were easy visible and accessible by all group members (see Figure 7.19). This shows how easily pool-shaped Currents can be turned into public territories. Therefore, these Currents support the transition between collaborative and individual work well, a requirement for systems that support collaborative work, as discussed in Section 2.2.5.

Figure 7.19: At the beginning of Phase 3, Group 8 enlarged their pools.

The purposes of the different types of Interface Currents are summarized in Table 7.2. In general, the first study task revealed that different types of Currents serve different purposes. Peripheral Currents are used for browsing through large amounts of information or searching for certain information. Their advantage is the continuous flow that enables groups to share the same set of information at the same time. Furthermore, users do not have to sort through information manually but just have to passively watch them on the

Current and can collect the ones that seem appropriate. In terms of territoriality, periph-

Current Type	Purposes
peripheral	browsing through information gaining an overview of information searching for certain information
stream-shaped	collecting information structuring information (by time) putting information in a certain order sharing information (public territory)
pool-shaped	collecting information categorizing information personal storage territory (Phase 2) group territory (Phase 3)

Table 7.2: Purposes of Interface Currents.

eral Currents cannot be assigned to one particular type of territory. They seem to be a mix of both, personal storage and public territory.

As Phase 2 revealed, pool- and stream-shaped Currents support collecting pictures. Pool-shaped Current are appropriate for loosely categorizing information while stream-shaped Currents, in contrast, have a more structured character so that they can serve as a container in the workspace where information can be arranged in order, for instance, by time.

These findings provide answers to the questions *Q1* and *Q3* (see Section 3.2). However, it has to be considered that they are not generalizable to tasks of different character. This issue is discussed in more detail in Section 7.3. Before that, however, the findings of the second study task are discussed.

7.2 Findings from Task 2—Setting Up a Workspace Based on Currents

During the second task of the study, groups were ask to design a workspace based on Currents (see Section 5.3.2). They were given three different Interface Folders filled with pictures and word tags, as well as buttons for creating different types of Currents. Some groups created three different Interface Currents first and connected each of these Currents with the Interface Folders in the workspace in order to get an overview of the amount and content of information. After that, they started to arrange the Currents in the desired way. Other groups created one single Current first, connected it with a Folder, and arranged it before continuing with the next Current and Folder. During these

activities, participants worked together very closely. Phases of individual work occurred rarely and only when participants were forced to do so because it was not possible to work together on the same Interface Current (see Section 6.1.4).

The results of the second task are shown in Figure 7.20. There are some similarities in the workspace designs that emerged from the different groups. Four out of six groups used three Currents to structure the workspace. In general, the results can be classified into two groups: workspaces that are based on concentric, peripheral Interface Currents as defined by Group 1 and 6 (see Figure 7.20(a) and 7.20(d)), and workspaces that contain three parallel Interface Currents stretched from one side of the table to the other as defined by Group 4, 7, and 8 (see Figure 7.20(b), 7.20(e), and 7.20(f)). Only the workspace setup of one group does not really fit in one of these two categories. Group 5 sorted the pictures of the two Interface Folders containing pictures onto one single stream-shaped Current and arranged this Current together with a Current containing the word tags concentrically in the workspace (see Figure 7.20(c)).

It is very likely that the similar design of workspaces has a technical reason. Due to the prototypical realization of the concept of Interface Folders, only one Current at a time can be connected to an Interface Folder (see Section 4.3.2). In addition, it was not possible to mix the content of two Folders or, respectively, Currents automatically. Since three different Folders were provided to participants, most groups decided to just establish one Interface Current for each Folder in the workspace. It was the easiest and fastest way to solve the task. However, it can be assumed that groups would have decreased the number of Currents if it had been easier to mix the content of different Folders because several participants asked for this possibility. Furthermore, after finishing the task, many groups noticed that they provided no or only little amount of space for collecting information items. Group 4, in particular, restructured the workspace after this was questioned by the experimenter. While they first had installed two large pool-shaped Currents surrounded by a peripheral Current containing word tags (see Figure 7.21), they shrank all Currents and positioned them adjacent to each other, very similar to Group 7 (see Figure 7.20(b) and 7.20(e)).

With regard to this, Group 5, again, was an exception. They established an extra (empty) pool-shaped Current in the workspace for collecting pictures. Since they installed only two Currents, their workspace provided enough amount of space for accumulating information items.

Except for Group 5, groups mostly had the first phase of the Task 1 in mind when they were structuring the workspace. They tried to install the Currents so that users could easily browse through information. This could be a reason, why most groups used stream-shaped Currents rather than pool-shaped Currents. Only Group 1, 4, and 5 used pool-shaped Currents at all. In fact, as explained above, the pool-shaped Current that Group 5 installed was an empty Current meant as a container for collecting images. Furthermore, Group 1 stated that they installed the pool-shaped Current more for aesthetic rather than practical reasons. Thus, it can be concluded that only one single group in-

(a) Group 1.

(b) Group 4.

(c) Group 5.

(d) Group 6.

(e) Group 7.

(f) Group 8.

Figure 7.20: Results of Task 2.
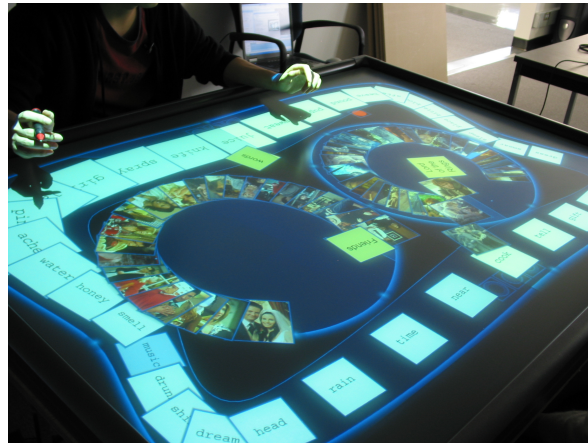
Figure 7.21: First result of Group 4.

tentionally decided to use pool-shaped Currents for browsing through information. This conclusion confirms the findings of Task 1 that revealed that stream-shaped Currents were perceived as better ordered and structured than pool-shaped Currents (see Section 7.1.2). For this reason, they are more appropriate for browsing through and getting a general idea of unfamiliar information.

The second task of the study also revealed very clearly what types of Currents participants really found useful during Task 1. During Task 2, all groups established at least one Current in the workspace that can be assigned to the class of peripheral Currents. Since all groups had experienced the peripheral Current during the first task it can be strongly assumed that even the groups that did not use additional Currents for collecting pictures perceived at least this type of Interface Current as supporting and, thus, used it during the second task. Groups also tried to establish magnification areas on the peripheral Currents. However, due to the usability issues described in Section 6.1.3, they often were not able to realize this satisfactory.

The following section concludes this chapter with a summary of the results that arose from the study.

7.3 Conclusion: Interface Currents and Collaboration

In general, the study revealed that Interface Currents support co-located collaborative work around tabletop displays for tasks that involve large amounts of visual information that needs to be shared between users. Currents support providing a method for overviewing information, browsing through information, and collecting, structuring and organizing information (see Question *Q3*, Section 3.2). The flow, in particular on the peripheral Current, enables groups to share information in a smooth and convenient

way. Although the continuous movement of items was sometimes found distracting participants were able to solve this problem by stopping the flow on the Current. All groups seemed to enjoy working with Interface Currents (see Question *Q5*, Section 3.2). Despite of some usability issues discussed in Chapter 6, they adopted the concept of Interface Currents and its interaction techniques very well (see Question *Q3*, Section 3.2).

The study has shown that the concept of Interface Currents supports the application of people's collaborative work habits as practiced on traditional tables to digital tables. For instance, they support territoriality and smooth transitions between parallel and collaborative work.

For these reasons, the question if Interface Currents support co-located collaborative work around tabletop displays (see Question *Q1*, Section 3.2) can be answered positively. However, as mentioned in the previous section, it has to be considered that the study explored the concept of Interface Currents only for a certain kind of task. This kind of task is characterized by involving creativity and mostly visual information items. The type of task was designed to be open ended to give groups a lot of liberty in solving it. In the real world, such tasks can be found in advertising agencies that produce magazine layouts or posters. However, future studies should be conducted to explore further fields where Interface Currents could be helpful (see Section 8.2).

In addition, the question of how people would set up a workspace based on Currents (see Question *Q4*, Section 3.2) has to be explored further and cannot be answered clearly at this time. As mentioned above, it has to be assumed that the realization of the concept of Interface Folders strongly biased the results of the second study task. It is very likely that the workspace designs would have turned out differently if participants would have been able to mix the content of Interface Folders. However, it can be assumed that participants would have used at least one peripheral Current since every group perceived this type of Current as very supporting and applied it in the workspace design.

Several questions were raised by the study that will have to be explored in future studies. The following chapter will conclude this thesis and give an outlook of future research.

CHAPTER 8

Conclusion

Developing interfaces that support co-located collaborative work on tabletop displays is still a challenge. People tend to interact very intuitively with such large displays because of their extensive experiences with collaborating on traditional tables. However, interfaces for tabletop displays have to compensate problems that are caused by their angle and size and, furthermore, they have to provide intuitive and lightweight interaction techniques to support phases of collaborative and independent work.

The concept of Interface Currents as proposed by HINRICHS et al. [HCS05a] has the potential to fulfill these criteria. However, its potential benefits had never been evaluated in a user study before. Within the scope of this thesis an exploratory user study was conducted to explore whether Interface Currents support co-located collaborative work around tabletop displays. This chapter summarizes contributions of the thesis. In addition, possible directions of future work are discussed with regard to the realization of the system, design ideas, and further user studies.

8.1 Summary of Contributions

This thesis describes the background, the realization, and the findings of an exploratory user study that was conducted to explore the influence of Interface Currents on co-located collaborative work around tabletop displays. Based on this study, for the first time, information can be gained about:

- how Interface Currents support collaborative work around a tabletop display,
- how people interact with Interface Currents in general,
- for what purposes Interface Currents are used,
- how people would set up a workspace based on Currents, and

- how people perceive the interaction with Interface Currents

Furthermore, the current realization of Interface Currents was explored with regard to usability issues.

The contributions of this thesis also include improvements on the realization and the concept of Interface Currents that were applied during the study design process and according to the study's usability findings.

Developing an Interactive Workspace Based on Interface Currents and Enhancing the Realization of Interface Currents

For the study, the realization of Interface Currents according to HINRICHS et al. [HCS05a] extended an interactive workspace developed by HABELSKI [Hab04]. Several new features were included: Three velocity settings were implemented for the flow on Interface Currents. Furthermore, a peripheral Current as a new type of Interface Current and a new type of stream-shaped Current were developed. A new interaction technique for relocating the Current was implemented and the spectrum of functions for manipulating the Current was enhanced by a resizing function.

Extending the Concept of Interface Currents to Interface Folders

In addition to the improvements of the realization of Interface Currents, the concept of Interface Currents was extended to Interface Folders enabling users to bring information stored and organized in folders directly onto an Interface Current in order to share them with other people. A "double-click" on an Interface Folder causes its content to automatically move over a connection bridge onto the closest Interface Current. In that way, the content of a Folder can be spread out on a Current and becomes visible to everybody working on the tabletop display.

Identifying Usability Issues of the Realization of Interface Currents

The analysis of the observed interactions with Interface Currents and Interface Folders revealed that both realizations had several usability issues. With regard to Interface Currents, the most issues were found concerning the control of the flow on a Current and the interaction with the control point menu. In addition, the overlapping of information items on a Current was perceived as distracting.

With regard to Interface Folders, participants perceived the connection bridge between Interface Folders and Currents as frustrating because it required them to wait for items to come out of the Folder.

Improving the Realization of Interface Currents and Interface Folders

Considering found usability issues, a redesign of Interface Currents and Interface Folders was conducted. This redesign involved the establishment of control points on both

boundaries of stream-shaped Currents so that the function for changing the width of a Current was deleted from the control point menu and established on the inside border of the Current. This improves the consistency of the control point menu of stream-shaped Currents compared with the one on pool-shaped Currents and increases its clearness.

The design of Interface Folders was changed so that on a "double-click" Folders directly transform into Interface Currents. Deleting such folder-based Interface Currents causes them to transform back into an Interface Folder. This enables users to quickly expand Currents in order to work with them and collapse them when they are not needed momentarily.

Exploring the Capability of Interface Currents to Support Collaborative Work

The study revealed that Interface Currents support collaborative tasks involving large amounts of visual information that need to be shared between users. The peripheral Current was found to be particularly helpful for browsing through information items, that is, gaining an overview of unknown information or searching for particular information items. Smaller stream- and pool-shaped Currents were used for collecting, structuring, and organizing information, whereas stream-shaped Currents were perceived as more appropriate for structuring. In contrast, pool-shaped Currents were usually used for loosely categorizing information. Furthermore, stream-shaped Currents were used for sharing information while pools were utilized as personal storage territories.

In addition, Interface Currents support the smooth transition between phases of collaboration and independent work that often occur during collaborative work.

It can be summarized that, despite of some usability issues, participants enjoyed interacting with Interface Currents and perceived them as supporting for their task. Thus, future research on the concept of Interface Current is highly recommended. The following section illustrates some possible directions of future work.

8.2 Future Work

The concept of Interface Currents opens several directions of future work. These directions involve the optimization of the realization of Interface Currents, design ideas, and ideas for future user studies.

8.2.1 Optimizing the Realization of Interface Currents

Chapter 6 refers to several design implications that would highly improve the usability of Interface Currents. For instance, the flow velocity on Interface Currents should be continuously changeable rather than depend on three distinct values. Furthermore, in

order to avoid interferences between users when the flow on a shared Current is changed, independent velocity settings should be applied between control points as mentioned in Section 6.1.2. In general, the velocity of a Current's flow should not depend on its size. To optimize interaction speed for several hundreds of interaction items the whole interactive workspace could be based on image buffers holding information about different areas in the workspace. Such an image buffer could contain information about direction and velocity of an Interface Current's flow.

Apart from such improvements of the implementation, several design ideas would improve the use of Interface Currents and Folders as described in the following.

8.2.2 Design Ideas

The study revealed that participants perceived the overlapping of information on an Interface Currents as very distracting. Thus, interaction techniques as proposed in Section 6.1.4 should be realized as summarized below.

With regard to Interface Folders, users should be offered an opportunity of mixing the content of several Folders on one Current. For instance, a gesture could be implemented that causes two overlapping Currents to melt into one single Current. In this way, the information floating on them would be automatically mixed. Using such a technique, Interface Currents could be enlarged by "docking" empty Currents on existing ones. For instance, an empty pool-shaped Current could be connected to a crowded stream-shaped Current in order to spread out information more, as mentioned in Section 4.3.2.

When introduced to the concept of Interface Currents, several groups asked for the possibility of bringing Interface Currents onto other Interface Currents. This idea could be realized in the future as well, although the new realization of Interface Folders partially enables this since Interface Folders can flow on Interface Currents and can be transformed into Interface Currents as well.

Beside these design ideas, the study brought up several questions that could be explored in future studies as described in the following.

8.2.3 User Studies

First of all, the new realization of Interface Currents and Interface Folders should be assessed in a study to make sure that the applied changes improve the interaction with both interface components as informal tests revealed. For such a study, groups of more than two people could be recruited in order to explore if the group size influences the interaction with Currents and the purposes they are used for. Based on such a study, the influence of Interface Currents could be explored further as explained in the following.

Do Interface Currents Support Creativity?

As mentioned in Section 7.1.2, the observation of participants led to the assumption that the flow on Interface Currents could support creative processes. A comparative study based on the hypothesis *"Interface Currents invoke creative processes."* could be conducted where participants are offered two different interactive workspaces on a tabletop display, one with and the other without Currents. The task for participants could be to create words out of little letters just like in a scrabble game. In one setting, these letters would float on an Interface Current, in the other, they would lay still in the workspace. It could be measured, how many different words participant create in a certain period of time. Such a comparative study could show if participants' creativity is activated stronger if they are supported by Interface Currents.

Interface Currents and Storage Bins

Similar to Interface Currents, storage bins as proposed by SCOTT et al. [SCH05] can be used to collect, structure, and categorize information. Indeed, pool-shaped Currents and storage bins only differ from each other with regard to the continuous flow that is installed on Interface Currents but not on storage bins and the automatic orientation of information located on an Interface Current. A study could be conducted to explore when users would make use of Currents and for what purposes they would use storage bins. Such a study could also be comparative comparing one system providing Interface Currents with another system providing storage bins.

What other forms of tasks do Interface Currents Support?

The exploratory user study described in this thesis can only give information about how Interface Currents were used in a certain type of task, as explained in Section 7.3. Thus, the benefit of Interface Currents in other forms of tasks should be explored. For instance, a study involving groups of children as participants could be conducted in order to discover whether Interface Currents support educational group tasks and playful learning.

Bibliography

[AEF⁺00]   Ernesto Arias, Hal Eden, Gerhard Fischer, Andrew Gorman, and Eric Scharff. Transcending the Individual Human Mind—Creating Shared Understanding Through Collaborative Design. *Transactions on Human-Computer Interaction (TOCHI)*, 7(1):84–113, 2000.

[Bae90]   R. Baecker. Animation at the Interface. In B. Laurel, editor, *The Art of Human-Computer Interface Design*. Addison-Wesley Pub. Co., Inc, 1990.

[BCR⁺03]   Patrick Baudisch, Edward Cutrell, Dan Robbins, Mary Czerwinski, Peter Tandler, Benjamin Bederson, and Alex Zierlinger. Drag-and-Pop and Drag-and-Pick: Techniques for Accessing Remote Screen Content on Touch- and Pen-Operated Systems. In *Proceedings of the International Conference on Human-Computer Human-Computer Interaction (Interact)*, pages 57–64, 2003.

[BFBK00]   William Buxton, George Fitzmaurice, Ravin Balakrishnan, and Gordon Kurtenbach. Large Displays in Automotive Design. *IEEE Computer Graphics and Applications*, 20(4):68–75, 2000.

[BHD⁺96]   Benjamin B. Bederson, James D. Hollan, Allison Druin, Jason Stewart, David Rogers, and David Proft. Local Tools: An Alternative to Tool palettes. In *Proceedings on the 9th Annual ACM Symposium on User Interface Software and Technology*, pages 169–170. ACM Press, 1996.

[BIF⁺04]   Harry Brignull, Shahram Izadi, Geraldine Fitzpatrick, Yvonne Rogers, and Tom Rodden. The Introduction of a Shared Interactive Surface into a Communal Space. In *Proceedings of the 2004 ACM Conference on Computer Supported Cooperative Work*, pages 49–58, 2004.

[BOO95]   Mathilde M. Bekker, Judith S. Olson, and Gary M. Olson. Analysis of Gestures in Face-to-Face Design Teams Provides Guidance for How to Use Groupware in Design. In *Proceedings of the Conference in Designing Interactive Systems: Processes, Practices, Methods, & Techniques*. 1995.

[Cla96]   Herbert H. Clark. *Using Language*. Cambridge University Press, 1996.

Bibliography

[Cre98]   John W. Creswell. *Qualitative Inquiry and Research Design: Choosing Among Five Traditions*. Sage Publications, 1998.

[dBS00]   Oscar de Bruijn and Robert Spence. Rapid Serial Visual Presentation: A Space-Time Trade-Off in Information Presentation. In *Proceedings of Advanced Visual Interfaces*, pages 189–192. ACM Press, 2000.

[dBS01]   Oskar de Bruijn and Robert Spence. Serendipity within a Ubiquitous Computing Environment: A Case for Opportunistic Browsing. In *Proceedings of the 3rd International Conference on Ubiquitous Computing*, pages 362–370. Springer-Verlag, 2001.

[DL01]   Paul Dietz and Darren Leigh. Diamondtouch: A Multi-User Technology. In *Proceedings of the 14th Annual ACM Symposium on User Interface Software and Technology*, pages 219–226. ACM Press, 2001.

[DLG87]   Nira Dyn, David Levin, and John A. Gregory. A Four-Point Interpolatory Subdivision Scheme for Curve Design. *Computer Aided Geometric Design*, 4(4):257–338, 1987.

[Gei98]   Jörg Geißler. Shuffle, Throw or Take It! Working Efficiently with an Interactive Wall. CHI '98 Conference Summary on Human Factors in Computing Systems, 1998.

[GG00]   Carl Gutwin and Saul Greenberg. The Mechanics of Collaboration: Developing Low Cost Usability Evaluation Methods for Shared Workspaces. In *Proceedings of the 9th IEEE International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises*, pages 98–103, 2000.

[Gru88]   Jonathan Grudin. Why CSCW Applications Fail: Problems in the Design and Evaluation of Organization of Organizational Interfaces. In *Proceedings of the 1988 ACM Conference on Computer-Supported Cooperative Work*, pages 85–93. ACM Press, 1988.

[Hab04]   Stefan Habelski. Realisation of Territory-Based Interaction Techniques for Supporting Tabletop Collaboration. Internship Thesis, December 2004.

[Hal66]   Edward T. Hall. *Distances in Man: The Hidden Dimension*. Double Day, Garden City NY, 1966.

[HCS05a]   Uta Hinrichs, Sheelagh Carpendale, and Stacey D. Scott. Interface Currents: Supporting Co-Located Collaborative Work on Tabletop Displays. Technical Report 2005-773-04, University of Calgary, 2005.

[HCS05b]   Uta Hinrichs, Sheelagh Carpendale, and Stacey D. Scott. Interface Currents: Supporting Fluent Face-to-Face Collaboration. Sketch Presenation at The 32nd International Conference on Computer Graphics and Interactive Techniques (SIGGRAPH), August 2005.

[HCSP05]   Uta Hinrichs, Sheelagh Carpendale, Stacey D. Scott, and Eric Pattison. Interface Currents: Supporting Fluent Collaboration on Tabletop Displays. In *Proceedings of the 5th International Symposium on Smart Graphics (Smart Graphics)*. ACM Press, 2005. In Press.

[Hit04]   Popgadget: Personal Tech for Women, 2004. `http://www.popgadget.net/2004/11/hitachi-table-top-display.html`, as of June 29ᵗʰ, 2005.

[IBR⁺03]   Shahram Izadi, Harry Brignull, Tom Rodden, Yvonne Rogers, and Mia Underwood. Dynamo: A Public Interactive Surface Supporting the Cooperative Sharing and Exchange of Media. In *Proceedings of the 16th Annual ACM Symposium on User Interface Software and Technology*, pages 159–168. ACM Press, 2003.

[IHMS01]   Kori M. Inkpen, Mark S. Hancock, Regan L. Mandryk, and Stacey D. Scott. Collaboration Around a Tabletop Display: Supporting Interpersonal Interactions. Technical report, Simon Fraser Universtiy, 2001.

[JA01]   Elizabeth J. Jewell and Frank R. Abate, editors. *New Oxford American Dictionary*. Oxford University Press, 2001.

[JH95]   Brigitte Jordan and Austin Henderson. Interaction Analysis: Foundations and Practice. *The Journal of the Learning Science*, 4(1):39–103, 1995.

[KCSG03]   Russell Kruger, Sheelagh Carpendale, Stacey D. Scott, and Saul Greenberg. How People Use Orientation on Tables: Comprehension, Coordination and Communication. In *Proceedings of the 2003 international ACM SIGGROUP conference on Supporting group work*, pages 369–378. ACM Press, 2003.

[KCST05]   Russell Kruger, Sheelagh Carpendale, Stacey D. Scott, and Anthony Tang. Fluid Integration of Rotation and Translation. In *Proceedings of the Conference on Human Factors in Computing Systems (CHI)*, pages 601–610. ACM Press, 2005.

[LHG92]   Paul Luff, Christian Heath, and David Greatbatch. Task-in-Interaction: Paper and Screen Based Documentation in Collaborative Activity. In *Proceedings of the ACM Conference on Computer-Supported Cooperative work*, pages 163–170. ACM Press, 1992.

[McG94]   Joseph E. McGrath. *Methodology Matters: Doing Research in the Behavioral and Social Sciences*, chapter Methodology Matters: Doing Research in the Behavioral and Social Sciences, pages 152–169. CA: Morgan-Kaufman Publishers, 1994.

[MH94]   Matthew B. Miles and A. Michael Huberman. *Qualitative Data Analysis - An Expanded Sourcebook*. SAGE Publications, Inc., Thousand Oaks, California, 1994.

[MIEL99]   Elizabeth D. Mynatt, Takeo Igarashi, W. Keith Edwards, and Anthony LaMarca. Flatland: New Dimensions in Office Whiteboards. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 346–353. ACM Press, 1999.

[MLO+04]   Mitsunori Matsushita, Makoto Lida, Takeshi Ohguro, Yoshinari Shirai, Yasuaki Kakehi, and Takeshi Naemura. Lumisight Table: A Face-to-Face Collaboration Support System that Optimizes Direction of Projected Information to Each Stakeholder. In *Proceedings of the 2004 ACM Conference of Computer Supported Cooperative Work*, pages 274–283. ACM Press, 2004.

[MO94]   Munir Mandviwalla and Lorne Olfman. What Do Groups Need? A Proposed Set of Generic Groupware Requirements. *ACM Transactions on Computer-Human Interaction*, 1(3):245–268, 1994.

[MRS+04]   Meredith Ringel Morris, Kathy Ryall, Chia Shen, Clifton Forlines, and Frederic Vernier. Beyond "Social Protocols": Multi-User Coordination Policies for Co-located Groupware. In *Proceedings of the 2004 ACM Conference on Computer Supported Cooperative Work*, pages 262–265. ACM Press, 2004.

[MSI02]   Regan L. Mandryk, Stacey D. Scott, and Kori M. Inkpen. Display Factors Influencing Co-Located Collaboration. (Poster Presentation Paper) in Conference Supplement to Computer Supported Cooperative Work, 2002.

[MSP03]   Carsten Magerkurth, Richard Stenzel, and Thorstan Prante. STARS—A Ubiquitous Computing Platform for Computer Augmented Tabletop Games. In *Extended Abstract of UbiComp'03*, pages 267–268. Springer, 2003.

[NCR04]   Dennis C. Neale, John M. Carroll, and Mary Beth Rosson. Evaluating Computer-Supported Cooperative Work: Models and Frameworks. In *Proceedings of the 2004 ACM Conference on Computer Supported Cooperative Work*, pages 112–121. ACM Press, 2004.

[N.V04]   Koninklijke Philips Electronics N.V. Living Memory Project (1997), 2004. `http://www.design.philips.com/about/design/section-13617/index.html`, as of June 30th, 2005.

[OOCS92]   Gary M. Olson, Judith S. Olson, Mark R. Carter, and Marianne Storrosten. Small Group Design Meetings: An Analysis of Collaboration. *Human-Computer Interaction*, 7(4):347–374, 1992.

[OPH+00]   Olufemi Omojola, E. Rehmi Post, Matthew D. Hancher, Yael Maguire, Ravikanth Pappu, Bernd Schoner, Peter R. Russo, Richard Fletcher, and Neil Gershenfeld. An Installation of Interactive Furniture. *IBM Systems JOURNAL*, 39(3&4):861–878, 2000.

[Pre05]   Oxford University Press. Ask Oxford, 2005. `http://www.askoxford.com`, as of June 29th, 2005.

[RFSM04] Kathy Ryall, Clifton Forlines, Chia Shen, and Meredith Ringel Morris. Exploring the Effects of Group Size and Table Size on Interactions with Tabletop Shared-Display Groupware. In *Proceedings of the 2004 ACM Conference on Computer Supported Cooperative Work*, pages 284–293. ACM Press, 2004.

[RL04] Yvonne Rogers and Sian Lindley. Collaborating Around Large Interactive Displays: Which Way is Best to Meet? *Interacting with Computers*, 16(6):1133–1152, 2004.

[RRHT03] Tom Rodden, Yvonne Rogers, John Halloran, and Ian Taylor. Designing Novel Interactional Workspaces to Support Face-to-Face Consultations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 57–64. ACM Press, 2003.

[RRS$^+$04] Meredith Ringel, Kathy Ryall, Chia Shen, Clifton Forelines, and Frederic Vernier. Release, Relocate, Reorient, Resize: Fluid Techniques for Document Sharing on Mulit-User Interactive Tables. In *Conference on Human Factors in Computing Systems CHI'04 Extended Abstracts on Human Factors and Computing Systems*, pages 1441–1444. ACM Press, 2004.

[RS99] Jun Rekimoto and Masanori Saitoh. Augmented Surfaces: A Spacially Continuous Work Space for Hybrid Computing Environments. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI)*, pages 378–385. ACM Press, 1999.

[SBD99] Jason Stewart, Benjamin B. Bederson, and Allison Druin. Single Display Groupware: A Model for Co-Present Collaboration. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 286–293. ACM Press, 1999.

[SCH05] Stacey Scott, Sheelagh Carpendale, and Stefan Habelski. Storage Bins: Mobile Storage for Collaborative Tabletop Displays. *Computer Graphics & Applications: Special Issue on Large Displays*, 58–64, 2005.

[SCI04] Stacey D. Scott, M. Sheelagh T. Carpendale, and Kori M. Inkpen. Territoriality in Collaborative Tabletop Workspaces. In *Proceedings of the ACM Conference on Computer-Supported Cooperative Work (CSCW)*, pages 294–303. ACM Press, 2004.

[Sco05] Stacey D. Scott. *Territoriality in Collaborative Workspaces*. PhD thesis, University of Calgary, 2005.

[SER03] Chia Shen, Katherine M. Everitt, and Kathleen Ryall. Ubitable: Impromptu Face-to-Face Collaboration on Horizontal Interactive Surfaces. Technical Report TR-2003-49, MERL - A Mitsubishi Electronic Research Laboratory, 2003.

[SGH⁺99]   Norbert A. Streitz, Joerg Geiszler, Torsten Holmer, Shin'chi Konomi, Christian Mueller-Tomfelde, Wolfgang Reischl, Petra Rexroth, Peter Seitz, and Ralf Steinmetz. i-Land: An Interactive Landscape for Creativity and Innovation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 120–127. ACM Press, 1999.

[SGM03]   Stacey D. Scott, Karen D. Grant, and Regan L. Mandryk. System Guidelines for Co-Located Collaborative Work on a Tabletop Display. In *Proceedings of European Conference Computer-supported cooperative work (ECSCW)*. Kluwer Academic Publishers, 2003.

[SLK02]   Stacey D. Scott, Neal Lesh, and Gunnar W. Klau. Investigating Human-Computer Optimization. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 155–162. ACM Press, 2002.

[SLV03]   Chia Shen, Neal Lesh, and Frederic Vernier. Personal Digital Historian: Story Sharing Around the Table. *ACM Interactions*, 10(2):15–22, 2003.

[SMI03]   Stacey D. Scott, Regan L. Mandryk, and Kori M. Inkpen. Understanding Children's Collaborative Interactions in Shared Environments. *Journal of Computer Assisted Learning*, 19(2):220–228, 2003.

[Som69]   Robert Sommer. *Personal space: The Behavioural Basis of Design*. Prentice-Hall, 1969.

[Spe02]   Robert Spence. Rapid, Serial and Visual: A Presentation Technique with Potential. *Information Visualization*, 1(1):13–19, 2002.

[SVFR04]   Chia Shen, Frederic D. Vernier, Clifton Forlines, and Meredith Ringel. Diamondspin: An Extensible Toolkit for Around-the-Table Interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 167–174. ACM Press, 2004.

[SWH⁺02]   Olov Ståhl, Anders Wallberg, Jan Humble, Lennart E. Fahlen, Adrian Bullock, and Jenny Lundberg. Information Exploration Using the Pond. In *Proceedings of the 4th International Conference on Collaborative Virtual Environments*, pages 72–79. ACM Press, 2002.

[Tan91]   John C. Tang. Findings form Observational Studies of Collaborative Work. *International Journal of Man-Machine Studies*, 34(2):143–160, 1991.

[TFB91]   Deborah G. Tatar, Gregg Foster, and Daniel Bobrow. Design for Conversation: Lessons from Cognoter. *International Journal of Man-Machine Studies*, 34(2):185–209, 1991.

[TG04]   Edward Tse and Saul Greenberg. Rapidly Prototyping Single Display Groupware Through the SDGToolkit. In *Proceedings of the 5th Conference on Aus-*

tralasian User Interface, volume 28, pages 101–110. Australian Computer Society Inc., 2004.

[TK95]   Mark A. Tapia and Gordon Kurtenbach. Some Design Refinements and Principles on the Appearence and Behaviour of Marking Menus. In *Proceedings of the 8th annual ACM symposium on User Interface and Software Technology*, pages 189–195. ACM Press, 1995.

[TPMT⁺01] Peter Tandler, Thorsten Prante, Christian Müller-Tomfelde, Norbert Streitz, and Ralf Steinmetz. ConnecTables: Dynamic Coupling of Displays for the Flexible Creation of Shared Workspaces. In *Proceedings of the 14th Annual ACM Symposium on User Interface Software and Technology (UIST'01)*, pages 11–20. ACM Press, 2001.

[Wel93]   Pierre Wellner. Interacting with Paper on the DigitalDesk. *Communications of the ACM*, 36(7):86–96, 1993.

List of Figures

List of Tables

APPENDIX A

Study Materials

In the following all materials are listed that were used during the exploratory user study, including the recruitment notice, a written form of the introduction that were given all participants before the actual study session, the consent form, the prequestionnaire, the semi-structured interview and the debriefing form.

A.1 Recruitment Notice

Our research group is currently investigating how people interact on large displays, in particular, how collaboration between people working on large horizontal displays can be supported. Interfaces for large horizontal displays have different requirements than those for small vertical displays. To support collaboration on large horizontal displays we developed a new interface component. To better understand how people interact with this new component we will be conducting a usability study. You will get two collaborative tasks that involve interaction with virtual images in a virtual environment. Your time commitment will be less than two hours in total, and you will be remunerated for your help. Your involvement in this study will remain strictly confidential. If you are interested in taking part in this study, please contact one of the people listed below to set up a time and date for your participation.

Uta Hinrichs	Sheelagh Carpendale
Dept. of Computer Science	Dept. of Computer Science
2500 University Dr NW	2500 University Dr NW
T2N 1N4	T2N 1N4
hinrichu@cpsc.ucalgary.ca	sheelagh@cpsc.ucalgary.ca
(403) 210-9501	(403) 220-6055

A.2 Introduction

My name is Uta Hinrichs and I will be giving you instructions on what to do and will answer your questions. I am a visiting student from Germany and I am doing my diploma thesis here. I am interested in Human Computer Interaction, in particular how people can collaborate on large displays like this tabletop display.

This study will involve two tasks which will both take part on this tabletop display. In both tasks you have to interact with virtual images in an virtual workspace. Before the tasks begin I will give you an introduction in how you can interact in the workspace and you will get time to practice and get used to the interaction techniques. Both tasks involve the interaction with a new interface component called Interface Current. You are helping us to find out how Interface Currents can improve and facilitate collaboration on tabletop displays. I will explain later what an Interface Current is. We are especially interested in which task scenarios they are appropriate and how they can be arranged appropriately in workspace. If you have trouble performing the tasks it is the fault of the interaction techniques and the program. Do not feel bad. That is exactly what we are looking for. Remember, we want to test the interaction techniques not you. If you feel uncomfortable, you are free to quit at any time. Do you have any questions at this point?

A.3 Consent Form

Department of Computer Science

Title of Investigation: Evaluation of Interface Currents as an Interface Component on Tabletop Displays
Investigators: Uta Hinrichs, Sheelagh Carpendale
This consent form, a copy of which has been given to you, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Please take the time to read this form carefully and to understand any accompanying information.

Description of Research Project:
We are currently investigating how people interact on large horizontal displays, in particular how collaboration between people working on tabletop displays can be supported. Therefore, we developed a new interface component called Interface Current. The two tasks you will be performing during the study involve interaction with these Interface Currents. In the first task you will be given a large amount of virtual images in a virtual environment that includes an Interface Current.

You will be asked to perform a collaborative task based on these images. In the second task you will be asked to create a virtual environment (workspace, interface) yourself with the help of some tools. We want to find out how people interact with Interface Currents, for which tasks they are appropriated and how we can improve them. After the first task, you will be questioned about your experiences with the interface. You will be recorded while performing the tasks and during the interview. You will also be asked to complete a pre-session questionnaire to further our investigation. After the study we will also ask you about your preferences or problems with the interaction on the tabletop display. It is estimated that your involvement will take approximately one and a half hour.

There are no known harms associated with your participation in this research. No information that discloses your identity will be released or published without your specific consent to disclosure. All data received from this study will be stored in a locked cabinet and such information that will be stored on a computer will only be accessible through the use of a password. All data will be stored for a period of time no longer than three years. Information will be carefully disposed of (shredding for hard copies and deleting for electronic copies) when this investigation is complete.

You will be able to withdraw from this study at any point. If this occurs, any data collected up to that point about you will be discarded. You are also able to refuse to answer whatever questions you prefer to omit.

Uta Hinrichs, Department of Computer Science, University of Calgary
Phone: (403) 210-9501, hinrichu@cpsc.ucalgary.ca

Sheelagh Carpendale, Department of Computer Science, University of Calgary
Phone: (403) 220-6055, sheelagh@cpsc.ucalgary.ca

Informed Consent: Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in this research project and agree to participate as a participant. In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal professional responsibilities. You are free to not answer specific items or questions in interviews or on questionnaires. You are free to withdraw from the study at any time without penalty. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. If you have further questions concerning matters related to this research, contact:

If you have any questions not satisfactorily answered by the primary researchers concerning your participation in this project, you may contact the Research Services Office, University of Calgary, and ask for Pat Evans, (403) 220-3782.

	Please circle one	**Please Initial Your Choice**
I agree to participate in the activities explained above	YES | NO	
I agree to be videotaped, photographed, and audiotaped	YES | NO	
I agree to let my conversation during the study be directly quoted, anonymously, in presentation of the research results	YES | NO	
I agree to let the videotapes/photographs/audiotapes be used for presentation of the research results	YES | NO	

_____   _____
Participant's Name (please print legibly)   Participant's Signature

_____   _____
Investigator/Witness   Date

A copy of this consent form will be given to you to keep for your records if you request it. This research has the ethical approval of the Department of Computer Science and the University of Calgary.

A.4 Prequestionnaire

Interfaces for organizing and sharing information

A. Circle the number that best indicates how long you have used computers for:

1	2	3	4	5
no experience	less than a month	less than a year	1 to 5 years	more than 5 years

Comments:_____

B. Circle the number that best indicates how often you have worked with a tabletop display:

1	2	3	4	5
never	once	2-5 times	5-20 times	>20 times

Comments:_____

C. Circle the number that best indicates your experience with computers with touch-sensitive surfaces (input device hand or stylus):

1	2	3	4	5
never	once	2-5 times	5-20 times	>20 times

Comments:_____

D. In this study you are solving collaborative tasks in a group of two people. Did you know your collaborator before this experiment?
( ) YES ( ) NO

E. Are you currently a student at the University of Calgary?
( ) YES ( ) NO

If yes, answer Questions E.1 through E.3.

E.1 In what year of university are you currently enrolled?

1	2	3	4	5 or higher

Comments:_____

E.2 What is your major (or intended major) field of study?

E.3 What is your minor (or intended minor) field of study (if applicable)?

F. What is your gender (for statistical purposes)?
 ( )   Male   ( )   Female

G. How old are you?

A.5 Semi-structured Interview

Interviewquestions

What did you use the Currents for during the task?

- Browsing through images
- Collecting images
- Passing

Did you find Currents supported your task?

- If yes, in which situations specifically?

Was the Current ever distracting?

- If so, where?

Were there times when you wanted to use the Current but could not?

- If so in which situation and why?
- Was it maybe because of its functionality?

Did you find the Interface Currents easy to use?

- Using the menu?
- Changing the flow?
- Changing the position?

Do you have any suggestions for additional functions you would have found useful during the task?

How satisfied are you with the result of your task?

- Is there something, that could have made the result better?
- Is there something that could have made the task easier/better to solve?

A.6 Debriefing Form

Department of Computer Science
Debriefing Form

Thank you for the time you have taken to participate in our study. The experiment that you have just completed was aimed at discovering more about how people interact with Interface Currents on tabletop displays. The purpose of this study was to understand how people use Interface Currents and which kind of tasks Interface Currents can support. With the data we have collected, we will endeavor to determine how best to enhance the concept of Interface Currents. At this point please feel free to ask us for additional explanations of any detail of the study that you would like to know more about.

If you have any further questions concerning matters related to this research, please feel free to contact:

Uta Hinrichs	Sheelagh Carpendale
Dept. of Computer Science	Dept. of Computer Science
2500 University Dr NW	2500 University Dr NW
T2N 1N4	T2N 1N4
hinrichu@cpsc.ucalgary.ca	sheelagh@cpsc.ucalgary.ca
(403) 210-9501	(403) 220-6055

APPENDIX B

Transcriptions

The video recordings from each group were transcribed in order to gain more insight in particular interactions and verbal statements of the participants. As an example, the transcriptions that were taken from the video recordings of Group 1 are listed in the following.

B.1 Group 1

B.1.1 Task 1

(14:56) **Note:** P_r Strategy B
(14:59) **P_r:** Yes. This is the slowest setting.
(15:07) **Note:** P_l is trying to bridge a vacancy of images on the Current with a gesture but with the gesture she speeds up the flow on the Current.
(15:09) **P_l:** UAAAAA
(15:09) **Note:** P_l is stopping the flow again. And starts it into the slowest mode again.
(15:10) **P_l:** Sorry.
(15:17) **Note:** P_l resizes the peripheral Current (accidentally)
(15:18) **P_l:** Ups, sorry.
(15:21) **P_l:** I wanted to do that (she changes the width of the Current (magnification area)). So I could see them bigger.
(15:26) **Note:** P_r Strategy B
(15:33) **Note:** P_l Strategy B
(15:37) **Note:** P_r shortly stops the flow than she starts it again.
(15:39) **Note:** P_l tries to spread images out a bit more.
(15:53) **Note:** P_r changes the width on the collecting Current (wider)
(15:53) **P_r:** What do we have in here?

(15:56) **Note:** P_l shortly stops the flow and starts it again.

(15:00) **P_r:** Hey, do that again.

(16:02) **Note:** They recognize that stopping the peripheral Current speeds up the collecting Current because more calculation power goes into the only Current.

(16:06) **P_l:** Oh, we discovered the frame rate is better.

(16:18) **Note:** They are quite happy with that.

(16:23) **P_r:** So I am seeing a story emerge.

(16:27) **Note:** She is explaining her idea

(16:38) **Note:** P_r tries to make the movement on the collecting Current slower. but she already has the slowest velocity.

(16:44) **Note:** P_l is moving an image to the page object.

(16:50) **Note:** P_r is starring at the moving collecting Current and gets some ideas.

(16:57) **Note:** She is pointing on an image and P_l moves the image onto the page object.

(17:03) **Note:** P_r drags an image onto the page object.

(17:08) **Note:** P_r again drags an image onto the page object. In both cases she comments the image and for what it is good for.

(17:11) **Note:** P_l is dragging an image onto the page object.

(17:16) **Note:** P_r drags an image onto the page object.

(17:20) **Note:** P_l starts to arrange the images on the page object.

(17:31) **Note:** P_r drags an image onto the page object.

(17:41) **Note:** P_r also arranges an image on the page object.

(17:56) **Note:** She than goes back to the collecting Current.

(17:56) **P_r:** Ok what is left here?

(17:59) **Note:** P_l slows the collecting Current down.

(18:01) **P_r:** Oh it DOES slow down.

(18:07) **P_r:** Ok, we need ten and right now we have seven.

(18:07) **Note:** P_l goes back to the peripheral Current.

(18:09) **Note:** P_l Strategy A

(18:10) **Note:** She starts the flow (accidentally) on the peripheral Current again.

(18:10) **Note:** P_r (accidentally) stops the flow on the Current. (maybe with her hair).

(18:13) **Note:** P_r drags an image onto the page object.

(18:17) **Note:** P_r resizes the image she dragged into the workspace (bigger)

(18:21) **Note:** She passes the image to P_r. She rotates it in her direction.

(18:34) **Note:** P_l explains P_r how to use the image for the story.

(18:34) **Note:** P_r drags the image to the page object.

(18:34) **Note:** the page object is all the time oriented towards P_r.

(18:36) **Note:** P_r arranges some images on the page object.

(18:58) **Note:** P_r drags an image from the collecting Current to the page object where is no space for the image any more.

(19:01) **P_l:** Now we have to kind of squeeze here.

(19:08) **Note:** P_l starts to rearrange images on the page object.

(19:10) **Note:** When P_r touches the page object again, an image goes under the page

object.

(19:12) **P_r:** I shouldn't have done that, sorry.

(19:28) **Note:** P_l has arranged the images in her space (on her side of the page).

(19:28) **P_l:** Ok, you do the rest.

(19:43) **Note:** They are again discussing the story.

(20:05) **Note:** They have brought the story into the right order.

(20:05) **Note:** Now they are arranging them a bit better.

(20:17) **Note:** P_l deletes the collecting Current.

(20:19) **Note:** Then she brings the remaining images back onto the peripheral Current.

(20:23) **P_l:** These are the once that we decided against using.

(20:33) **P_r:** It would be great if there was some automatic orient function.

(20:34) **P_l:** Align or snap to grid function.

(20:43) **Note:** They are finished.

B.1.2 Interview

(21:40) **Note:** Interview starts.

(21:44) **Instructor:** What did you use the Currents for during the task?

(21:59) **P_r:** For viewing images as they went by and for sharing or a separate kind of container for the ones that we selected.

(22:00) **P_l:** Or potential selection.
Passing them back and forth.

(22:07) **Instructor:** Passing them to each other?

(22:07) **P_l:** Yes.

(22:15) **P_l:** Because if I put it on here (the collecting Current) it spins around to you eventually. And you can decide.

(22:15) **P_r:** Yes.

(22:25) **Instructor:** I've seen that you choose a donut shaped Current for collecting images. Why did you choose that?
Why didn't you choose the pool Current?

(22:38) **P_r:** Actually I thought about choosing the pool Current but one thing about the donut Current was that you can widen just a section of it so that it magnifies in front of you and small again as it goes around.

(22:43) **P_l:** It also has a linearity to it and since we are making a storyboard I think we could put it in order.

(22:44) **P_r:** Yes that is true.

(22:46) **P_l:** But we ended up not doing it (what has maybe to do with the fast flow on the Current)

(22:55) **Instructor:** Did you have the feeling that the Current supported your task in any kind of way?

(22:59) **P_r:** Yes. For sure.

(23:01) **Instructor:** In which situations?

(23:14) **P_r:** There is no way we could have seen all these tons and tons of pictures. Both of us seeing each one individually unless it was circulating or we had to physically move around and bump into each other and stuff. So I think this is a lot better than that.

(23:27) **P_l:** It is also confusing. I mean the tossing thing is nice but if I had to toss her all the images that I thought might be good they would kind of get metaled with the images in the Current so having the second Current was good, too.

(23:34) **Instructor:** So basically for browsing through images and collecting them.

(23:34) **Both:** Yes.

(23:36) **P_l:** And the fact that we could use it in the way we wanted to. Like in whatever format we want to.

Make it large for example.

(23:47) **Instructor:** Was the Current ever distracting?

(23:59) **P_r:** Just the way the frame rate was so slow. And I think, well I don't know if this is the answer to the right question but I wished there was an even slower setting.

(24:00) **P_l:** Yes. Me too.

(24:03) **Instructor:** So the velocity was too fast?

(24:04) **Both:** Yes.

(24:23) **Instructor:** And I saw you after you collected images on the collecting Current you stopped the flow on the peripheral Current. Was there any reason for that?

(24:28) **P_l:** It made the smaller Current smoother.

(24:31) **P_r:** But it also was faster.

(24:34) **P_l:** But easier to see. Because it wasn't jerking.

(24:46) **P_r:** Yes. But it is nice that you can like even though that it was too fast and sometimes jerky you could still stop it and then look at something carefully and then keep moving it or whatever. And I liked the changing direction too. Because if I just miss something I could come back.

(24:58) **Instructor:** So you didn't liked the fast velocity but there was a way to solve this problem.

(24:59) **Both:** Yes.

(25:06) **Instructor:** Did you found it distracting that if you changed the velocity (P_l) it will also change on your side?

So did you have the feeling that there was an interference?

(25:09) **P_l:** A couple of times.

(25:09) **P_r:** Yes.

(25:14) **P_l:** More in the practice one actually. I was looking for an image and you (P_r) changed direction. Oh well I looked at it again.

(25:28) **Instructor:** Were there ever times where you wanted to use the Current in some kind of way but couldn't?

(25:39) **P_l:** Yes I wanted to open up the space in front of me but I couldn't do it because she (P_r) was using it.

(25:51) **Instructor:** Oh because somebody else was using the Current at the same time.

(25:59) **Instructor:** How did you liked the menu of the Current?

(26:00) **P_l:** It is so pretty. I liked it.

(26:00) **P_r:** Yes.

(26:02) **Instructor:** Did you find it easy to use?

(26:03) **P_l:** Yes.

(26:26) **P_r:** I had a little trouble with it. So my initial feeling is that if I pull it, I mean I understand that there are three things I can choose, that this motion could mean three different things but still in my mind I sometimes think, Oh just stretch and go this way (as if it was only one point). So it is just getting used to the fact that there are three options for that motion and I have to pick which one.

(26:32) **Instructor:** So it would be easier for you if you just would move this (control point) and it would stretch.

(26:44) **P_r:** But then...if my mind was thinking differently and I meant reshape than... you know. So I don't know if there is anything you could do about that but it was a little tricky picking the right icon.

(26:47) **Instructor:** Do you have the feeling that you could learn that?

(26:51) **P_r:** Yes definitely. I think even throughout this exercise I've learned it pretty much.

(26:00) **Instructor:** And do you have the feeling that any of the menu items are totally useless?

(26:00) **Both:** No.

(27:06) **P_l:** I am not sure what the difference between reshape and the two side ones is (she means the changing width icon).

(27:11) **P_r:** One curves the whole thing. And the other one stretches.

(27:14) **P_l:** I probably get used to it with more practice.

(27:20) **P_r:** I wouldn't use the curve the whole thing too much but I might if I wanted to make a little space for myself (she points in front of her).

(27:25) **Instructor:** And how was changing the flow, so the manipulation of the flow, was that easy or more harder?

(27:34) **P_l:** It happened by accident a couple of times. When I didn't mean to. When I was grabbing a picture I accidentally accelerated the flow.

(27:39) **P_r:** Yes.

(27:46) **Instructor:** And how did you liked the interaction with the borders for changing the position? Was that easy or was it causing problems?

(28:04) **P_r:** Maybe a tiny bit of problems because I know there is some highlighted kind of stars where you get the menu and then the rest is moving it but it could be maybe a little bit more obvious. Sometimes I would try to move the whole thing and I accidentally hit a star. But it wasn't a big problem.

(28:18) **P_l:** I kept trying to move it by grabbing the Current. And then I accelerate it (accidentally).

(28:18) **P_r:** Yes.

(28:26) **P_l:** Because that is kind of like the page and the images work just grab in the middle. So the Current works differently.

(28:26) **P_r:** Yes true.

(28:28) **Instructor:** Yes that is a bit inconsistent. That is right.

(28:40) **Instructor:** Do you have any suggestions for additional functions you would have found useful during the task?

(28:42) **P_l:** Slower speed.

(28:52) **P_r:** The kind of the grid lock or snap to grid function.

(29:12) **P_r:** And also sometimes images kind of like - especially if you are stretching it - kind of clumped. Like right here (pointing on a free space on the peripheral Current) there is no image and here there is a clumping of them. Maybe some kind of snap to grid thing on the Current as well. Like I don't know if it is possible but just as equally distributed as possible so all of sudden you could just redistribute everything.

(29:30) **P_l:** I wouldn't even say necessary snap to grid but when I open that up because I want to see the images maybe when an image comes here push the other ones to the side so when I get the one here I can see that and it is not (overlapping).

(29:32) **Instructor:** So that images are not overlapping right in front of you.

(29:32) **P_l:** Yes. So that if I open it wide I could have ...

(29:35) **P_r:** Yes, that is a good one.

(29:43) **P_r:** I did like that they come into focus. I mean that they take the top position when they are in front of you.

(29:49) **P_l:** In front of you being on the line. It is a little bit awkward. What if you moved.

(29:56) **P_r:** Is it at the biggest position?

(30:06) **Instructor:** It is snapping right in front of you at the moment. But I am working on a different function. So whenever you make it really big it snaps in front of you.

(30:12) **P_l:** So when the gradient is...when the derivative changes.

(30:23) **Instructor:** So how satisfied are you with the result of your task?

(30:28) **P_l:** I think we got a good story.

(30:28) **P_r:** Yes.

(30:34) **Instructor:** Ok and did you have the feeling that it was also caused by the Currents? Or do you think that you could have done a similar task just without them?

(30:44) **P_l:** I don't think so at least not in that amount of time.

(30:45) **P_r:** Yes.

(30:47) **Instructor:** So you think you were faster?

(30:48) **P_l:** Yes. It would have taken a lot longer. To go through all those images.

(30:48) **P_r:** Definitely faster.

(30:58) **P_r:** It was also a lot more fun. To just be able to just go by.

(31:01) **P_l:** Yes.

(31:07) **Instructor:** Ok, so you didn't have to concentrate on searching for images but they just came by.

(31:10) **P_l:** Yes. But less exercise.

(31:13) **P_r:** That is true.

(31:17) **Instructor:** So the flow is kind of a thing you have to get used to?

(31:42) **P_r:** Well I like it but I think ... The amount of images would have been over-

whelming unless I could just like this - this is good - because I can just focus on one section of groups of images. If they were all laid out on a section of the table and I had to look at them all it would have been like an overwhelming task.

B.1.3 Task 2

(32:12) **Note:** Design Task starts. (32:25) **P_r:** So I liked the really big Current (the peripheral one). But I think it makes sense to divide words and pictures, right? So that they can choose words separately and stuff? (32:25) **Note:** P_l is creating a stream-shaped outside Current and places it in the middle of the workspace.
(32:31) **Note:** P_l resizes the stream (bigger) (32:36) **P_l:** I like the idea of and I don't know if that works but that they have things to choose from.
(32:36) **Note:** P_l creates another stream-shaped inside Current and places it so that it is surrounded by the outside Current.
(32:39) **P_l:** Put one inside the other and have one going in one direction and one into the other.
(32:39) **P_r:** Uh, I like that.
(32:46) **P_l:** And we could put all lord of the rings pictures on one and all the other pictures on the other one.
(32:46) **P_r:** Awesome.
(32:53) **P_l:** For the words I don't know. We have to have a third one. But there is no space for it.
(32:55) **P_r:** We could put it in the middle again.
(33:02) **P_l:** Which direction with the things. I mean this one (the outside Current) you can expand (she shows it) and this one (the inside Current) you can expand that way (towards the inside). But if you put an extra words one ...
(33:14) **P_r:** I guess, well we could have one of those pool ones in the very center but we have to leave room to resize the middle one. Well whatever... (33:18) **P_l:** So we could do this for pictures around the outside.
(33:21) **P_r:** Pictures around the outside and words in the middle? And not divide up pictures? (33:23) **P_r:** Oh we could do that, too. Oh we can't do that though because we can't expand two folders on one Current. But we could put one set of images on half the board and one half on the other half but ....
(33:47) **P_r:** You mean two different Currents?
(33:48) **P_r:** Do we want a big surrounding Current?
(33:51) **P_l:** That is probably a good idea. But for what? For working?
(33:59) **P_r:** I think it is better to have a smaller thing for working.
(33:59) **P_l:** Yes I think you are right. But then what do we want to put in the big surrounding Current?
(34:04) **Note:** P_r moves the outside stream away from the inside stream. She moves it more to one side of the table.

(34:08) **P_r:** Oh, we could do these two as the big surrounding Current. Flowing both ways.

(34:11) **P_l:** And then doing something else with the words?

(34:12) **P_r:** Yes.

(34:12) **Note:** They are starting to set up the Current.

(34:15) **Note:** P_l resizes the Current. Then she changes the shape (accidentally??)

(34:22) **Note:** Because they can not work on the same Current at the same time P_l is working on the inside Current and P_r is working on the outside one.

(34:26) **Note:** P_r moves the outside Current back to the middle of the workspace.

(34:26) **P_l:** Oh oh, that is bad. (she means the wide width on one side of the Current.)

(34:32) **Note:** She makes the outside Current more narrow again.

(34:34) **P_l:** Because you don't want it to be that wide. We need to get the outside of this (outside Current)

(34:41) **P_r:** Lets resize first.

(34:46) **Note:** P_l reshapes the Current ("Like that?")

(34:46) **P_r:** Oh sure, yes.

(34:54) **Note:** P_r resizes the Current (bigger)

(34:54) **P_r:** When you resize it stretches the inside also. That is actually no good.

(34:56) **P_l:** That is actually good. So let me put mine back.

(34:57) **Note:** P_l wants to reshape again but produces accidentally a pool Current because the buttons are right in front of her.

(35:00) **Note:** She deletes the pool Current. She that reshapes the outside Current back into its circular shape.

(35:08) **Note:** P_r resizes the outside Current (bigger).

(35:20) **Note:** She then reshapes the outside Current (to the edges of the workspace)

(35:20) **Note:** P_l reshapes the inside Current.

(35:35) **Note:** P_r can't reach all corners in the workspace so she asks P_l to do that.

(35:37) **Note:** P_l accidentally choses the wrong icon (changing width instead of reshaping).

(35:40) **Note:** P_r helps her.

(35:48) **P_l:** We need to be able to add more control points.

(35:52) **P_r:** Yes, actually!

(36:07) **Note:** P_l adjusts the inside Current. On ends where she cannot reach, P_r helps her.

(36:34) **Note:** P_l makes the outside Current on the short edges of the table more narrow.

(36:35) **P_l:** Because it doesn't need to be so so wide at the edges.

(36:35) **Note:** She (accidentally) resizes the Current (bigger)

(36:56) **Note:** P_l makes the Current narrower in the corners as well.

(36:56) **Note:** P_r continues to adjust the inside Current.

(37:26) **Note:** P_l has difficulties in the corner of the workspace to adjust the Current. She obviously knows which icon to choose but the input isn't tracked very well.

(37:37) **Note:** When she is using her finger it works better.

(37:37) **P_r:** Oh oh, we are not good at this.
(37:50) **Note:** Again P_ls actions are interfering with the buttons for creating a Current.
(38:00) **Note:** She accidentally creates a new Current.
(38:00) **Note:** She tries to remove it but has difficulties in moving it
(38:26) **P_l:** Corners are hard.
(38:37) **Note:** P_r has learned how to use the menu.
(38:54) **Note:** P_l is often resizing accidentally but she knows how to correct her actions.
(39:03) **Note:** They have pretty much arranged the outside Current how they want it.
(39:27) **Note:** They are adjusting the inside Current a bit.
(39:35) **P_r:** Ok, so we got the two outer rings. Should we have ....Lets just use the pool for words.
(39:38) **Note:** P_r creates a pool Current and drags it into the middle of the workspace.
(39:43) **Note:** She brings the word folder near to the pool Current and opens it.
(39:50) **Note:** She makes the flow on the pool go faster.
(39:50) **P_l:** You can't read them at all.
(39:52) **P_r:** There's lots. Ok. So we need a big one for words too.
(39:00) **P_l:** What if we had two for words.
(40:06) **P_r:** Could we have two?
(40:06) **Instructor:** Yes, but you would have to divide it by hand.
(40:26) **P_r:** Can we create new folders?
(40:28) **Instructor:** No.
(40:34) **Note:** P_l connects (accidentally) one of the image folder with the inside Current (friends)
(40:34) **Note:** P_r connects the other image folder with the outside Current.
(40:35) **Note:** The flow on the outside Current is stopped which is why the images are not spreading out.
(40:35) **Note:** They are waiting for all the images to come out of the Current.
(40:39) **Note:** P_r recognizes that the flow is stopped and starts it.
(40:40) **Note:** P_r changes the direction of the flow on the outside Current and makes it really fast.
(40:43) **P_r:** So it piles them up if this guy (the outside Current) isn't moving?
(40:48) **Note:** P_l changes the direction on the Current again. (not sure if she tries to speed up the spreading out of the images).
(41:08) **P_l:** We didn't intend to let them overlap. We just wanted them going in different directions so that it was clear that they are different.
(41:32) **Note:** P_l wants to let the image go back into the folder to make the overlap going away but accidentally she has added the folder to the inside Current.
(41:45) **Note:** She fixes it and tries to get the images back into the folder.
(41:53) **Note:** It doesn't work.
(42:03) **P_r:** So are we done?
(42:03) **P_l:** I think so. We have this work area in the middle.
(42:18) **P_r:** I think if it was easier to control, resizing it and stuff we probably make it thinner and more exact.

(42:19) **P_l:** Yes more like you had it for the first task. That was nice.

(42:28) **Instructor:** On which side would you have made it thinner?

(42:32) **P_r:** I would stretch it in front but be thinner along the edges.

(42:34) **P_l:** I would make the whole band actually the same size as this middle one (the inside Current). The middle one is really good. Because then if we leave a little space they can stretch it themselves. But right now there is all this wasted space over here because we couldn't get it right...

(42:59) **Instructor:** So basically you have one Current for friends, one for lord of the rings and they are moving in opposite directions and you have two Currents for words.

(43:01) **P_l:** Because they are hard to read when they are stacked.

(43:06) **Instructor:** So you would have liked to divide the words by folder?

(43:06) **Both:** Yes.

(43:12) **P_l:** Create own folder like words one and words two. Also if she wants to look at these words, I can pull these words (dividing up the work)

(43:45) **P_r:** And we could divide the work, I could stretch the one Current right in front of me and you could stretch the other one.

(43:48) **P_l:** Just so that the control was here when we are working we can make that decision.

(43:56) **Instructor:** Why did you choose the outer Current to have the control points on the outside? Did you decide that or did it just happen?

(44:07) **P_l:** We decided it on purpose so that it is opposite on this one (the inner Current) so that the controls of this (outer) you can move in this direction and the controls for the inner one go in the opposite direction. So they don't interfere with each other.

(44:10) **P_r:** You can stretch them both. But it does make it a bit awkward like (she cannot reach the controls any more because they are outside of the workspace). It would have definitely been easier to stretch an stuff like that if it were up (on the inside).

(44:24) **P_l:** But I think if we got it placed initially it would be easy to work with.

(44:32) **P_r:** But if the stretching point is right at the bottom of the screen I can't... (she means changing the width)

(44:33) **P_l:** Why does it have to be right at the bottom of the screen?

(44:34) **P_r:** I guess it doesn't but it is just a better use of space.

(44:43) **P_l:** Well mine isn't right at the bottom. But it does interfere with the menu.(for creating Currents).

(44:50) **Instructor:** Would you have placed the buttons on another position in the workspace?

(44:52) **P_l:** yes.

(44:54) **Instructor:** Where?

(44:54) **P_l:** Bottom right.

(44:57) **P_r:** Yes, me too. Because you pretty much want your main working area kind of to be there so it is like a start menu

(45:10) **P_l:** Yes, so it is there if you need it but it is not something you are going to permanently focus on or working on.

(45:14) **P_r:** And it is mostly for getting rid of stuff or forgetting stuff not what you are

working on right now.

(45:24) **Instructor:** Ok, and you would like to be able to create new folders.

(45:27) **Both:** Yes.

(45:53) **P_r:** Not so much for splitting one folder into two to view easier. I think for that it would be nice to be able to connect directly to two. But that is not so important...Like onces the select the images that they want to use, images and words, they should be able to have a working folder or something like that so the can put selected things into a folder and close it if they want.

(45:59) **Instructor:** Why did you choose to use pool Currents for the words? Why didn't you choose donut shaped Currents?

(46:14) **P_r:** I only did it because there were so many donuts already. I don't know just to make it look a little different.

(46:22) **Instructor:** If you think of it now would you rather use donut shaped Currents?

(46:31) **P_r:** I would leave it just for visual purposes.

(46:31) **P_l:** I would leave it just like that because than you could spread things out (on the inside of the pool Current)

(46:34) **Instructor:** You could use the middle?

(46:46) **P_r:** But it probably would make it easier especially on a stack like that to view (them on a stream??). There is more possibilities for viewing if it is a donut. There is a magnifying something.

(46:50) **P_l:** That is true.

(47:02) **Instructor:** Did you choose to make a peripheral Current because you liked in the first task?

(47:04) **P_l:** Yes, it was really nice.

(48:40) **Instructor:** Do you have any ideas for tasks that you would like to use Currents for?

(48:40) **P_r:** If P_l and I would work together on a program. Visual checking in and out of files. Or planning a task. Storyboarding was a good thing too.

APPENDIX C

Activity Sequences

Group 1—Task 1

Table C.1: Activity sequences of Group 1—Task 1.

Group 4—Task 1

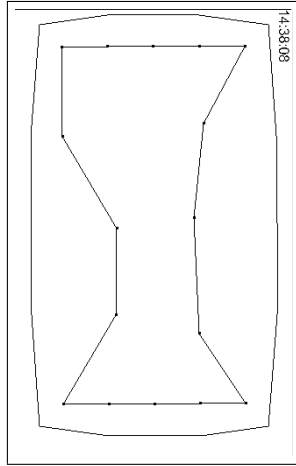**Table C.2:** Activity sequences of Group 4—Task 1.
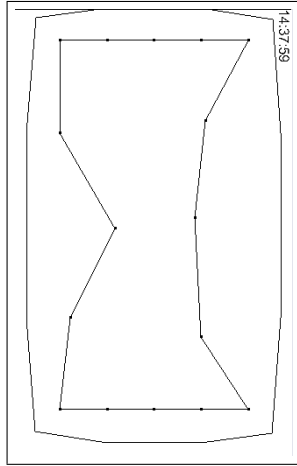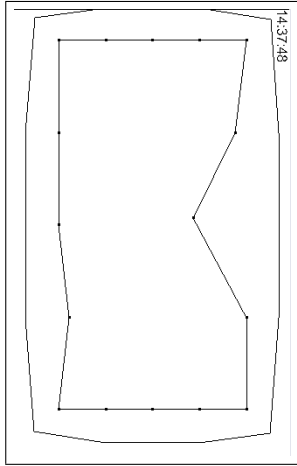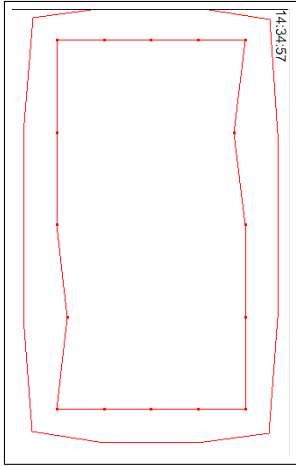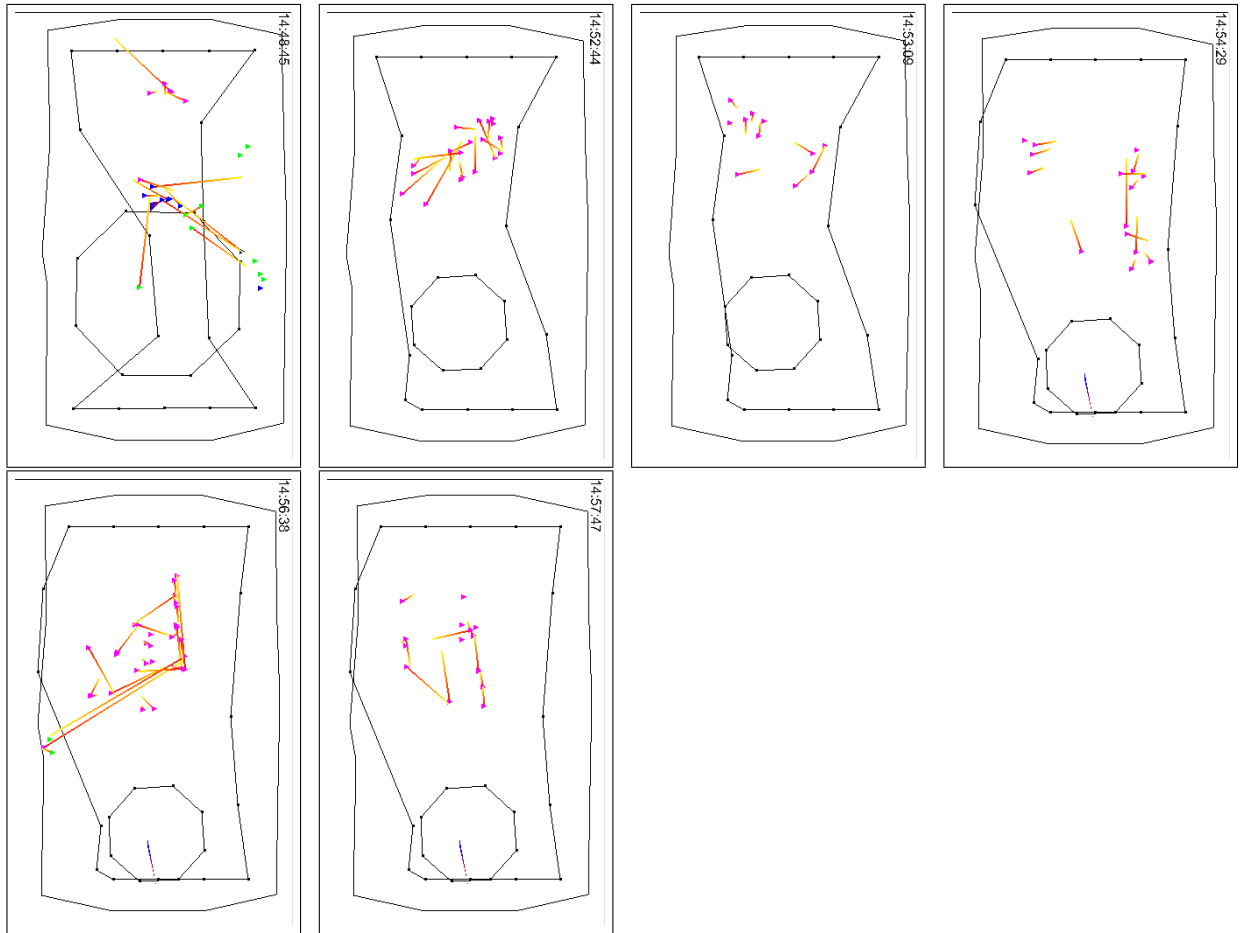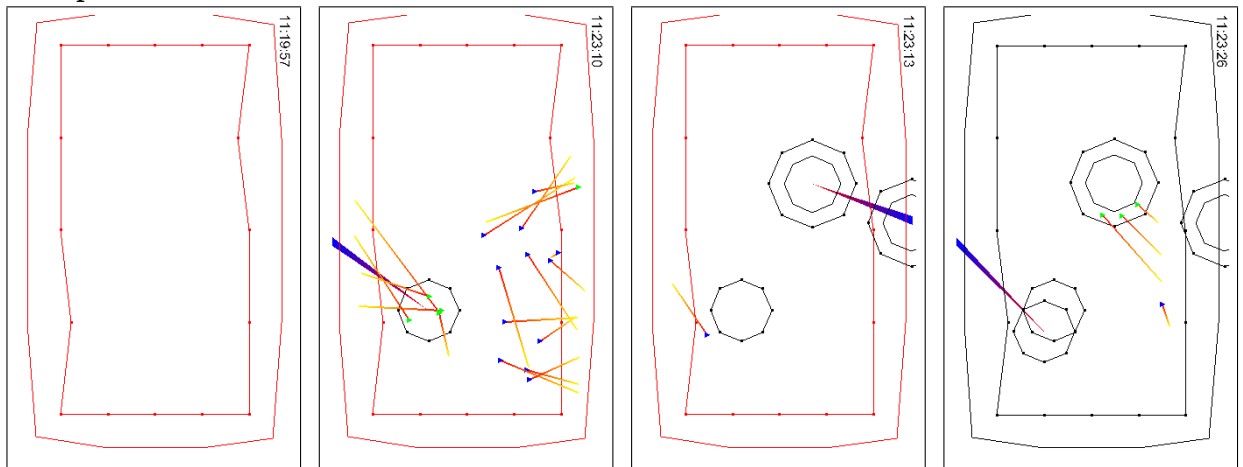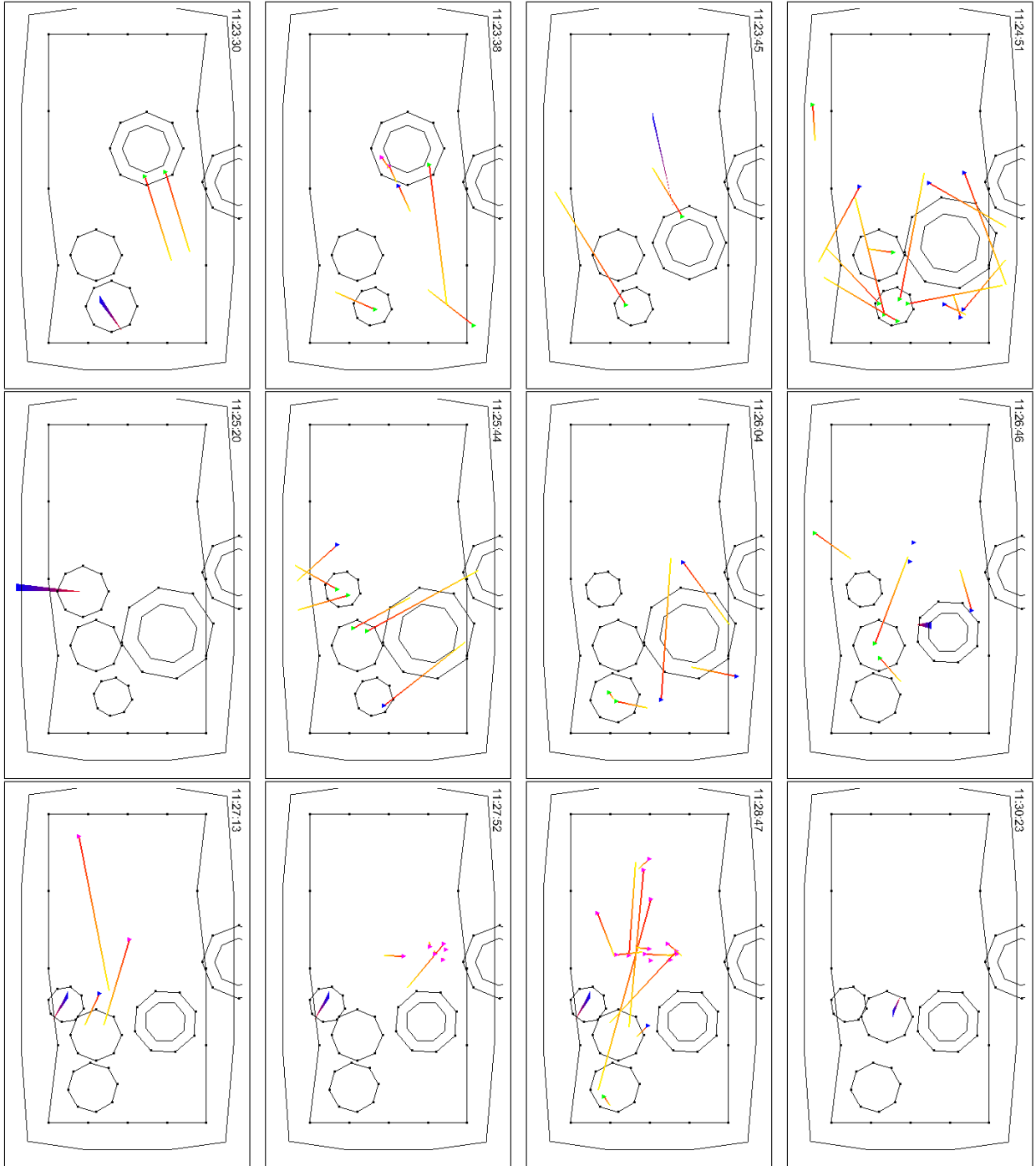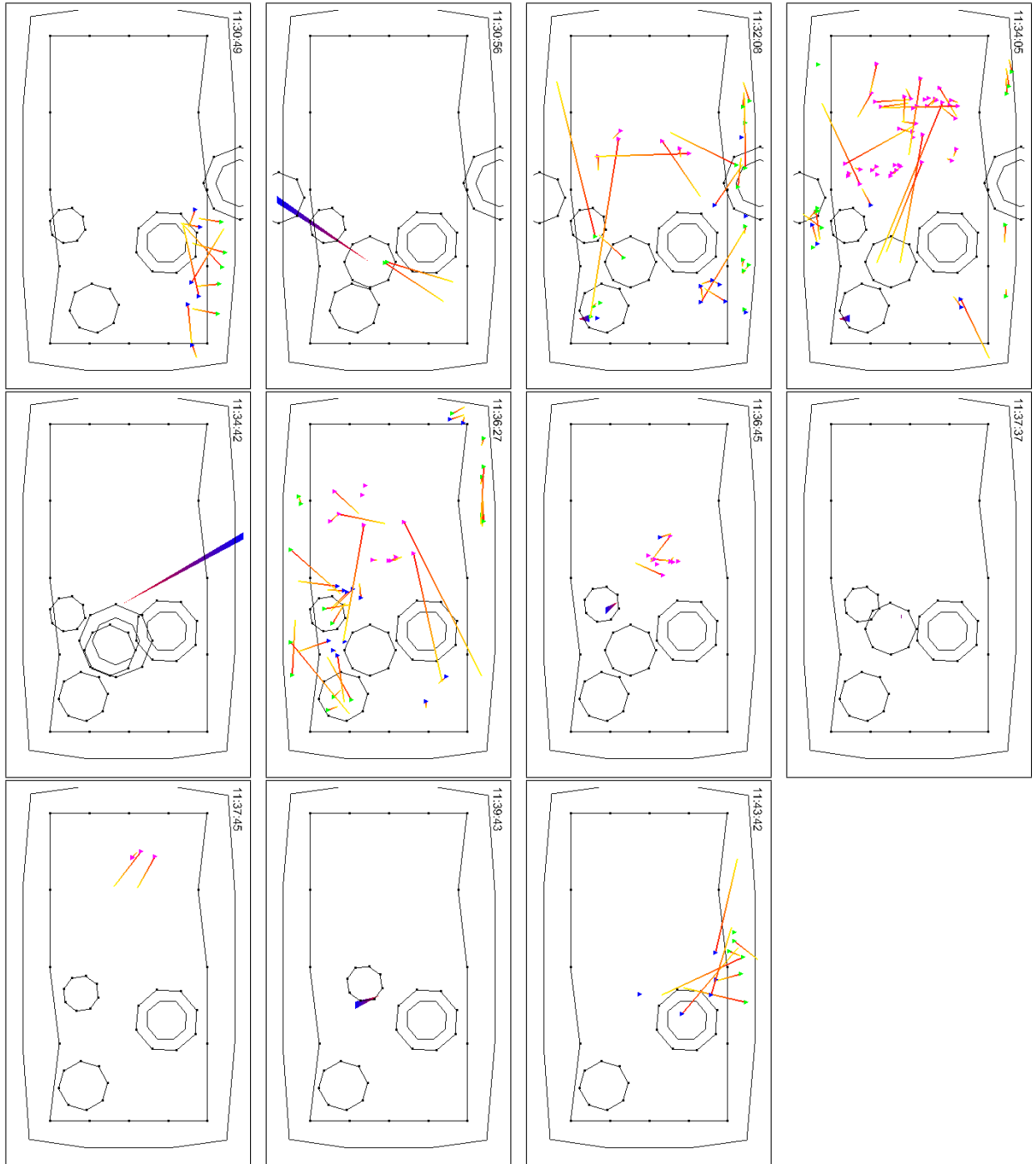
Group 5—Task 1

Table C.3: Activity sequences of Group 5—Task 1.

Group 6—Task 1

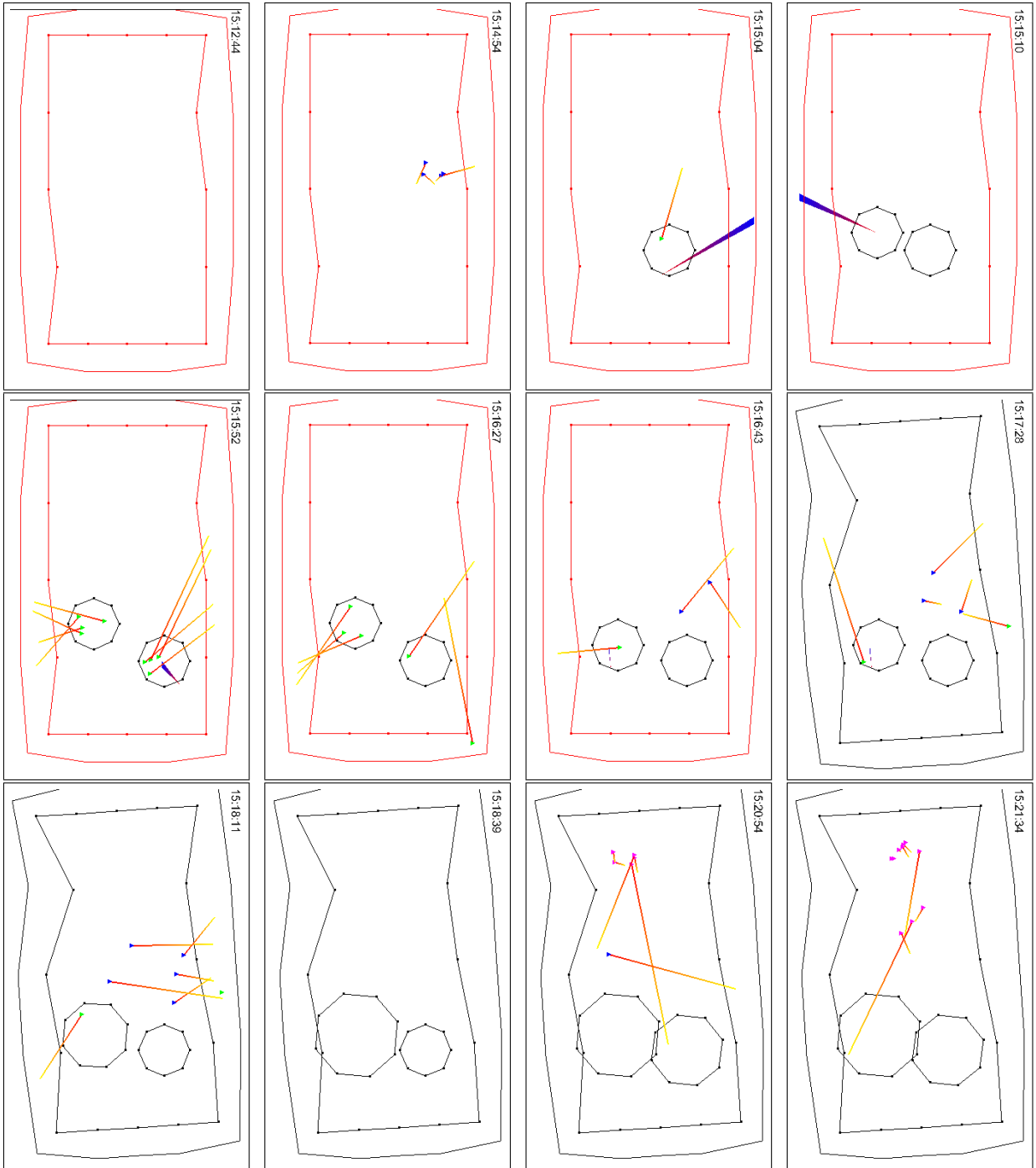**Table C.4:** Activity sequences of Group 6—Task 1.

Group 7—Task 1

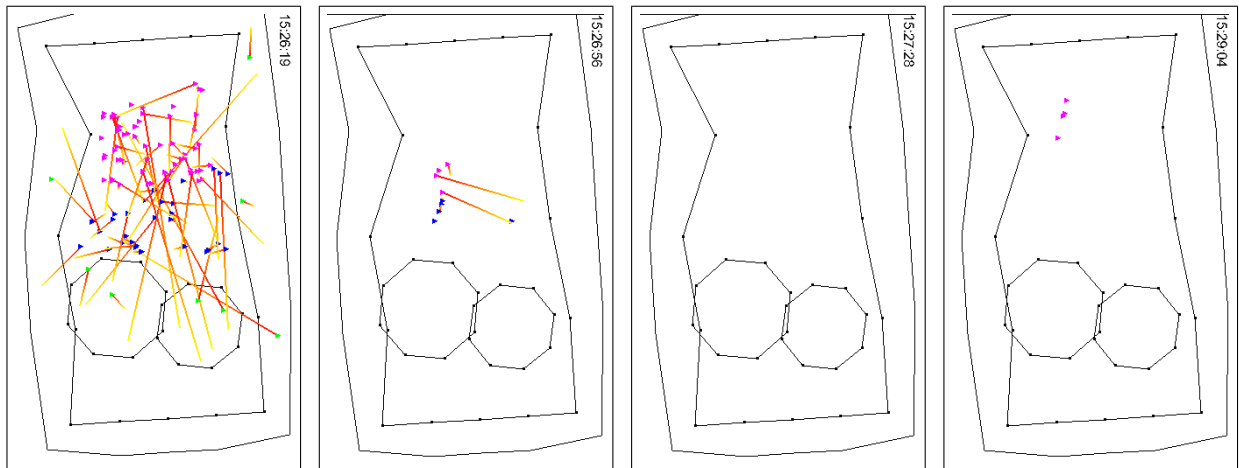**Table C.5:** Activity sequences of Group 7—Task 1.

Group 8—Task 1

Table C.6: Activity sequences of Group 8—Task 1.

Independence Statement

Herewith I declare that I have completed this work solely and with only the help of the mentioned references.

Magdeburg, July 6, 2005

Uta Hinrichs