Display Invasion

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ABSTRACT
In this seminar paper we describe the challenge to overcome problems with multiple display systems. The first part focuses on the evaluation of how people perceive and use multiple displays and how they behave and interact in multi-display environments. Furthermore, we illustrate challenges that occur for dealing with multiple displays and provide an overview of techniques that are designed to bridge the gulfs of standard solutions.

INTRODUCTION
The topic Display Invasion might evoke the thought of displays that are threatening or harming us. Displays appear in our everyday life, in form of our personal computers, TVs, mobile phones, or even as touch screen displays in our home appliances. They are getting more, larger and available with still higher resolution. Several displays are trying to grab the attention of the user all the time. Some user might say that the displays are getting control over them and they would call it a Display Invasion. One central question is how to help the user to get control back.

From a scientific view the problem seems to be clear. The number of displays is increasing but communication between them (e.g. sharing information) often does not exist. So our challenge should be to develop new techniques that easily connect one or more displays and moving artefacts between them. For this, we have to understand the users to then develop new techniques that fit to their requirements and improve the interaction between multiple displays.

TECHNOLOGICAL TREND AND "UBICOMP"
Since the amount and complexity of information are increasing by and by, there is a permanent need for new technologies. Technology trends are always changing and new developments are constantly improving. Spotting those new technologies and obtaining immediately experience and knowledge of newly developed technologies can make most people's life easier and more comfortable. Since displays are important interfaces - not only working as output presenting information on many devices but even as input (e.g., touch screens) - they follow the same rules. Computing and multimedia technologies are permanently becoming more widely available and more cheaply priced. In the industrialized countries the standard for technological equipment that supports people's personal and business activities has reached a level that justifies the statement: We are surrounded by a host of electrical and computing devices in our everyday

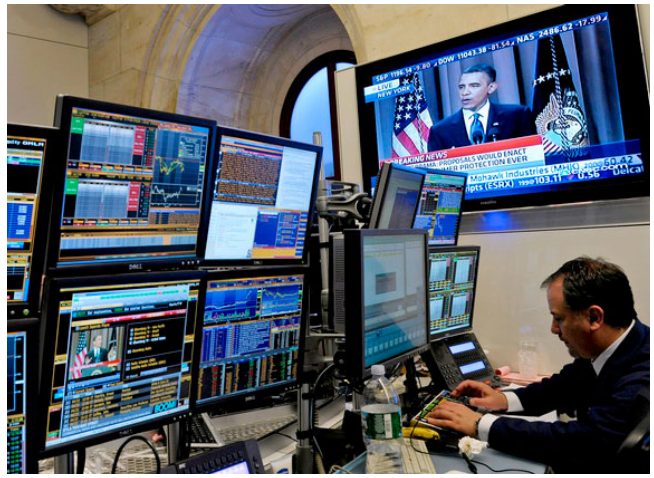

Figure 1. Increasing number of displays at today's workplaces [1].

The *mpfs*, a research association for media education, demonstrates this fact in their annual study [13]. In 2009 they interviewed 1200 young people at the age of 12-19 years about their habits for dealing with media. The result for the device equipment of those young person's households (that means including the parents equipment as well) confirmed their assumption of a high supply (figure 2). If we focus on the devices that are types of displays or have displays integrated, we can see that there is a total supply of computers (including laptops) and mobile phones. 97% of the households had at least one TV, 93% digital cameras and 91% MP3 players. In 2009 58% of the households had flat screen TVs, compared to the result of 2008 this is an increase of 17% after one year. Since the *mpfs* is researching multimedia behavior of young people they only list the types but not the number of devices. It can be assumed that in many cases there are multiple devices of same types, increasing the amount of displays surrounding people.

The Technological Trend is a characteristic of our society. Mark Weiser, who worked at the Xerox PARC, was quite aware of this development and initialized in 1991 with his foundational article "The computer for the 21st century" [23] a new field of research: Ubiquitous Computing (ubicomp). Ubiquitous computing means that computers (or technologies in general) disappear in fabric of everyday life. The goal is to activate the world, putting computers into everything. People then are using those technologies for their everyday activities without consciously thinking about using

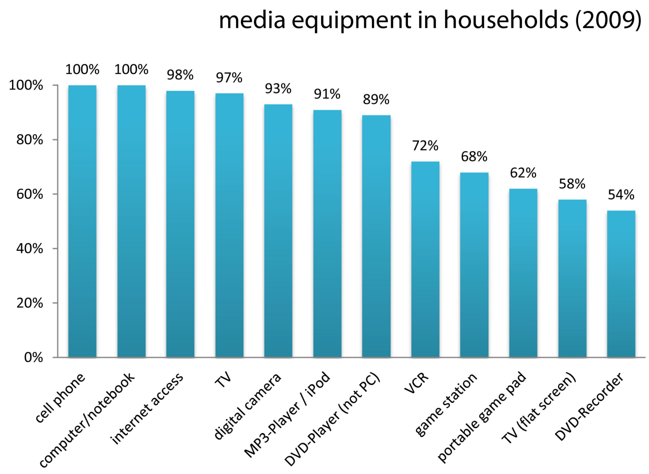

Figure 2. The *JIM-Study 2009* shows which types of multimedia devices exist in young peoples households[13].

computers. Weiser says: "Such a disappearance is a fundamental consequence not of technology but of human psychology. Whenever people learn something sufficiently well, they cease to be aware of it". Weiser illustrates this with the example of writing. It can be seen as the first information technology. So once it was a rather unusual technique, requiring a high level of skills. Today it is a ubiquitous technology: writing can be seen everywhere, labeling our world. Since displays can function as written media but provide additional possibilities compared to their analog equivalents, a similar trend can be expected. Weiser and his colleagues at the Xerox PARC developed so called "tabs", "pads" and "boards". These are inch-scale, foot-scale and yard-scale devices behaving like active Post-it notes, sheets of papers or blackboards. This technology was developed for a usage within the research center. Today similar technologies are in use of peoples everyday life, for example smartphones or the Apple iPad. Multimedia as used today (providing video and audio) is not that typical for ubiquitous computing since it is grabbing attention instead of disappearing. Nevertheless, people are starting to use it for everyday tasks (e.g., reading ebooks on the iPad) and get common with it. By and by the focus shifts from technology to task, using several displays for different purposes becomes a standard situation.

AFFORDANCES AND FUNCTIONALITIES

The rising amount of multiple devices with displays has more concrete and practical factors as well. They are used in many different ways and for different purposes. Each device provides a set of affordances that suggest how it can be used and constraints that limit the possibilities. Due to these affordances and constraints some devices are better suited for certain tasks than others, as explained in [16].

In their study [4], David Dearman and Jeffery S. Pierce interviewed 27 people from academia and industry to find out about why and how those people are using multiple devices. Using multiple devices was no pre-condition for the participants but nevertheless, there was not a single one using only a single device. The first factor Dearman and Pierce worked out is the form factor. The way a device is used always depends on its physical design. For example: the smaller a device is, the better is its portability. Since a modern 9.7 inch tablet (e.g., the iPad) is lighter than a 17 inch laptop and can be more flexibly arranged (just like a book), people could prefer it for reading an ebook. The second aspect for using multiple devices is the task completion time. Due to speed and configuration, on some devices tasks can be completed faster than on others. Furthermore, people desire to separate devices that are used for work and those for private purposes because the requirements strongly differ. However, the boundaries between home and work are diminishing in many cases. People often bring their work and the corresponding equipment home. Because of speed factors and comfort they use their home computer in addition to the laptop from work and end up in a multi-display environment, mixing private and business activities. Another reason for multiple devices Dearman and Pierce found out about and that is valid for displays, is the transition from old to new devices. People tend to repurpose old devices instead of replacing them completely by new ones. For example, they want to switch from a 19 inch 4:3 monitor to a 22 inch widescreen display. Instead of replacing the old display they keep it as a secondary device to enlarge their desktop to a multi-display system.

It is not only depending on objectively observable factors like the physical design or the functionality whether a device is suitable for certain activities or not. Further, people have individual conceptual models and cognitive structures for working with computing devices [16]. Different devices of a similar type can meet personal needs and likings in a different way. We will discuss this aspect later on in detail.

COLLABORATION

Collaboration is a central element for the efficiency of enterprises, research or in general for a collective that is pursuing the same goal. The organization of problem-solving tasks as well as the support of information technology are significant factors for the success of collaboration. It is serving to support the participants within their different tasks.

In collaborative environments displays are used to present and share information. Using large scale displays for a group of people provides the distribution and enables the participants to refer to information and to start discussions. The way people collaborate using displays depends on several factors. Inkpen et al. investigated some of these factors in their exploratory study [12]. Besides size, the display angle and arrangement of users have a high impact on the possibilities for working together. A horizontal setup allows the group to sit around the display having eye-to-eye contact; a vertical display provides the same visibility for all users but forces them to stand or sit in front of it and reduces by this the attention to others. A further important factor is the number of displays. A single display leads people to gather around or in front of it and provides working in a group. Giving access to multiple displays means offering the ability for each user to work independently and meets their preference

(a) (b)

Figure 3. Two pictures showing (a) wall-based and (b) table-based setups for large scale displays in collaborative environments. The physical orientation (vertical vs. horizontal) of the displays influences the participants collaborative behavior and the ways of interaction[20].

for personal workspaces. Furthermore multiple displays allow parallel working in a more efficient way.

Focusing on the physical orientation of displays, Yvonne Rogers and Siân Lindley describe in [20] how the way of collaboration changes for different types of interactive large scale displays. First they compare a horizontal, table-based display and a vertical, wall-based display (figure 3). Their thesis: “The physical affordances are quite different, resulting in the setting up of different social affordances”. Testing both setups for several groups by devising problem-solving tasks, involving decision making and planning they made significant findings. A horizontal surface makes it easier for people to participate in the process of active collaboration. The number of suggestions expressed by all members as well as the rate of role changing is higher. Since the group is sitting around the display, there is an equal accessibility for each member. Furthermore, the level of awareness about others and their work is higher because the interaction with the display can be seen by all persons. In contrast, the roles of the participants using a wall-based display mostly remain fixed. The person standing nearest to the display often becomes the interactor for at least a longer period. The other members remain at their positions and only take part in discussions by commenting. Also it is harder to see everything when somebody is standing in front of the display. However, there are not only advantages for using the horizontal variant. Permanently changing roles can “easily lead to uncertainty and even chaos” while remaining in a certain setup keeps a kind of structure. The solution for this dilemma is providing both, horizontal and vertical displays. This enables multiple ways of interaction within the same environment and provides task division. Groups can build depending on the kind of collaboration that is most suitable for the task. It allows parallel workflows and leads - as mentioned before - to higher efficiency. So providing a multi-display environment involving interactive large screen devices in both, horizontal and vertical orientation seems to be the preferable solution to meet the circumstances and

Figure 4. The NASA Mission Control Room provides a maximally amount of displays. Several personal displays for each person working there and common large scale displays are necessary to provide all required information simultaneously[8].

MULTI-TASKING

Talking about the technological trend, we already stated that more and more people use information technology, especially at work. Due to a higher complexity of information they are facing highly demanding tasks. An extreme example for a workspace where tasks require a great amount of information is the NASA Mission Control Room in Houston, Texas. This workplace is maximally crowded with displays (figure 4). This is necessary because each person working there has to coordinate several tasks and to provide continuously changing information to the others. The grade of interaction is significant and details have to be visible at a glance. This is only possible by providing all information simultaneously. Concerning multi-tasking, accessibility to greater amounts of information maybe is the most obvious reason for multiple displays, but not the only one.

Victor M. Gonzlez and Gloria Mark observed analysts, developers and managers to get a better understanding of how those peoples work is structured and which criteria lead to multi-tasking [7]. The result is an overview for the time span each person is spending on single tasks. They have to switch from task to task very frequently. One reason is the rate of interruption. Interruptions can occur when people have to communicate. Furthermore, tasks interrupt other tasks. Depending on the urgency, the incoming task will either become done immediately - and the older task will be resumed later or delayed. Tasks themselves include subtasks and each requires different documents, reference materials, software or hardware. The whole set of technological support can reduce the overhead that arises while managing several, parallel activities. In many cases one single device is not enough to handle this. Most devices are conceptualized in terms of special or general purpose [4] [7]. They provide either a small broadness of functionality, focusing on a specific task, or they realize multiple, primary functions to serve several needs. But providing multiple functions does not necessarily mean that devices match the conceptual models of task organization users have. Since each person differs in its cognitive structures from others, it is impossible to provide one universal solution that achieves such an aim. There are several fields of research that try to provide approaches for comprehending topics of human cognition and human computer interaction but also of organizational behavior and management science. Nevertheless, it "is left up to people to integrate their information into cohesive task structures that make sense to them." [7]

Tasks can be conceptually linked to displays, machines, applications, operating systems or several other entities. Users who work with multiple displays as well as with multiple computers allocate tasks and separate devices differently, depending on several factors [3]. Some of these factors base on simple, practical reasons, but some of them are attributable to structures that help to reduce the cognitive load for each user while handling multi-tasking. The fundamental idea is to enable parallel activities on separated devices. This for example enables users to avoid interruptions between several tasks, not only in terms of threads and processes but also in focusing on a certain task. "This helps them maintain task focus, since their visual field does not contain information from the other screen - separating other tasks out of sight also takes them, at least temporarily, out of mind" [3]. Depending on the level of separation that is preferred (for some users distractions can be welcome), this effect can be in-or decreased by altering the physical separation (distance of input devices or displays). Priorities can be provided by using primary devices for tasks that occur frequently and, for example, require a better performance.

Some participants mentioned another factor: multiple carets. For most people it is easier to switch the keyboard or mouse than switching applications. Those people create links between specific tasks and the combination of physically existing input devices and separate displays. Shifting the attention to another task then only means to change the input device and looking at another display. In the meantime the caret on each device remains at its position. It is not required to search for the needed application among several minimized windows, to activate it and to return the caret to the previous position. Handling a task becomes quicker while the cognitive load is reduced [3]. This solution also provides separated histories. Users can move backwards and forwards in multiple threads. In addition to the physical design and the portability of their devices (see also Dearman and Pierce, mentioned before) the interviewed persons mentioned platform differences as one important aspect. They use a mixture of applications that are only running on specific operating systems. As a consequence, at least they have to use multiple displays (e.g., running a virtual machine) or even multiple computers, if they want to use them in parallel.

We can see that multi-display environments provide a great support for multi-tasking. Each solution of course has a certain tradeoff, but this is accepted by most people since it is a requirement for handling parallel activities. Nevertheless, this point – the problems that can occur – has to beconsidered in more detail.

CHALLENGES OF MULTI-DISPLAY ENVIRONMENTS

Interacting with different devices, as they appear in our every day multi-display environment, brings us the need for sharing information between them, especially in collaborative work or in public places. This sharing among different devices should be easy as moving a pen or paper from one table to another. For this we have metaphors like "cut and paste" or "drag and drop" on most common systems today. But for different multiple devices this is not so obvious and simple implemented. For example pasting a mail address from PDA to PC is often still done "by hand". Also every system has its own input device, like a mouse or keyboard that can not be shared consistently to another. So today, in our ubiquitous computer environment, there is not one universal device (like the finger of the user) for all systems and the user has to distinguish the right one to use. Now - after we understand the user - we like to develop or design a new interaction technique. As described in [10] we should focus on the following points and their according design questions.

- **Connection** "How is a connection established?"

  A connection, also called system link, between the devices has to be established. This can be done by the user through gestures or interaction with the system. Referring to the just mentioned example of pasting a mail address from PDA to PC, creating a connection today is often to complex and difficult for the user (e.g. setting up a network configuration manually). For our new interaction technique this means we should keep it simple.

- **Command** "What type of connection is required?"

  Depending on the selected command by the user a different kind of connection is needed. For example the user could copy large files or only an URL. Back to our PDA to PC example, this means, if the user likes to transfer only a short URL, it is not appropriate to synchronized all data from the PDA when connected to the PC, because of the taken time. So we should keep it fast.

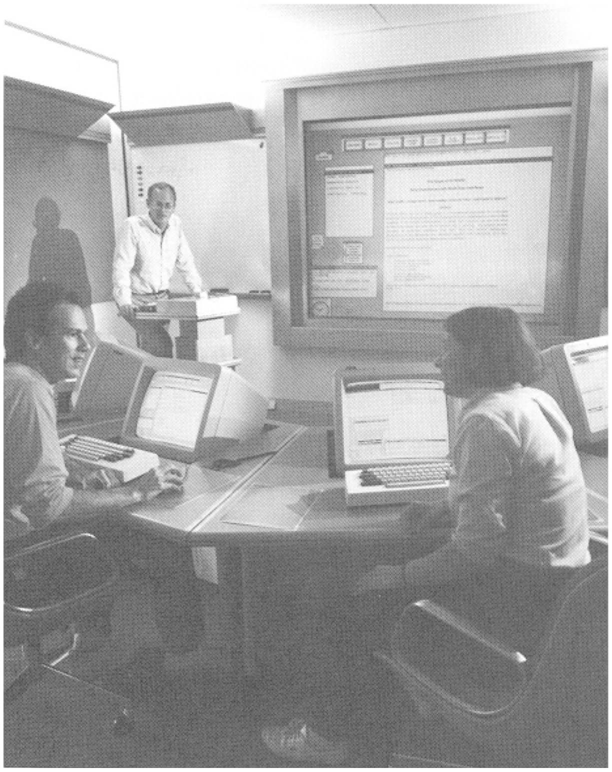

Figure 5. CoLab [21]

- **Operands** "What information is shared?"

  The user may share only one artefact at one time or a large collection.

- **Geometry** "What is the spatial relationship between the devices?"

  The system should know about the physical arrangement between the affected devices. This is important for example to move the pointer accordingly over the different displays.

- **Coexistence** "How do connection gestures coexist with traditional interactions or naturally occurring user behaviors?"

  Gestures and interaction techniques that are used for synchronisation and moving information between different devices should coexist without interdependency. This also includes to offer this special interaction techniques only if a system is connected to another.

- **Proxemics** "How do users share physical space?"

  If our new interaction technique is used in collaboration we should respect the social distance between the users. This also means that our technique is physical available in the common system setup.

MULTI-DISPLAY ENVIRONMENT SYSTEMS

One approach to overcome the problems of synchronizing multiple displays output and input by different users, is to build a complete system for a specific task. One example for such a task can be a meeting between users that have ideas in their mind and would like to collaborative bring them together in one paper. In the following section we present three of the most important systems that are able to do this.

CoLab Project

Parcs CoLab project [21] was one of the first system, that was used for a collaborative purpose and therefore need to exchange information between different devices and displays, like it is required in the case of a scientific meeting. The system consists of one large video projection screen and several PCs, one for each participant, around it as seen in figure 5. The flow of a meeting is given and restricted by the system. So every meeting has a "brainstorming stage", than an "organisation stage" and last but not least an "evaluation stage". Depending on these stages the user is working more and more collaboratively. So at brainstorming everyone is working independent and later in the evaluation part they work together on one document. For this, every computer is running the same distributed software that will collect and synchronize the information between them.

Roomware (i-Land)

The Roomware [22] concept comprises the "DynaWall", the "InteracTable" and the "CommChairs". "PassageConecept" is used for interaction between them. The "DynaWall" is a large display wall consists of several single or collaborative usable displays. Each display can be used by one person and collaborative interaction between them is enabled by techniques like "Take and Put" or Shuffle" as we will discuss later on. The "CommChairs" are combining a PC with furniture and can be used by a single person to work on. More people at the same time can work on a tabletop called the "InteracTable" and can position text and pictures freely on it. "PassageConecept" is a metaphor for transferring information between the different displays. For this, a physical object is placed on a defined place, e.g., on the "Interact-Table" and the user get the illusion to store objects on the table to it. If the user placed this object on, e.g., the "DynaWall", the information stored on it gets available.

iRoom

The iRoom [5] consist of 3 SmartBoards with touchscreens, a tapletop and one projection wall. The interaction is realized over mice and keyboards as they belong to the devices, but also over PDAs brought by the user. Goal of this approach is also to make the system more flexible and not focusing to much on a specific task. Also different kind of new devices should be easily integrated in this room. For this the user is interacting with HTML sites, which can easily developed and expand to different tasks.

INTERACTION TECHNIQUES FOR MULTIPLE DISPLAYS

For single systems with only one or two displays we appreciate metaphors like "Cut and Paste" or "Drag and Drop". But it is evident that these common interaction techniques used for one single display systems are not suitable for multi-display interaction. The "Cut and Paste" gesture will only work in the boundary of one system with one user. But what is about many users work on many displays and want to "cut

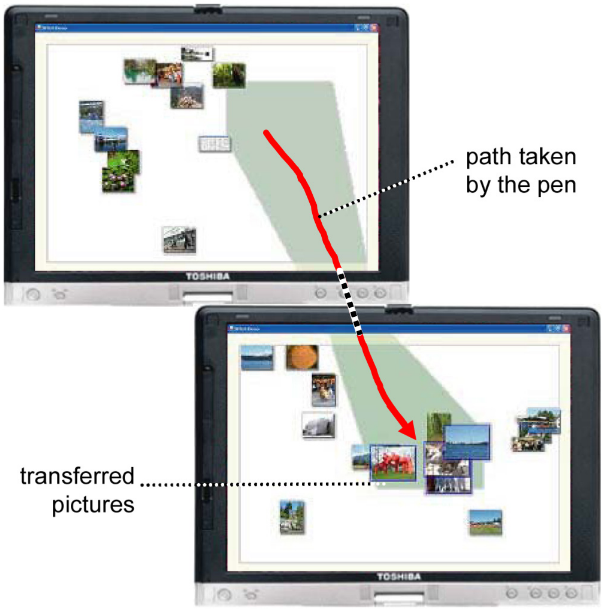

Figure 6. Stitching [10]

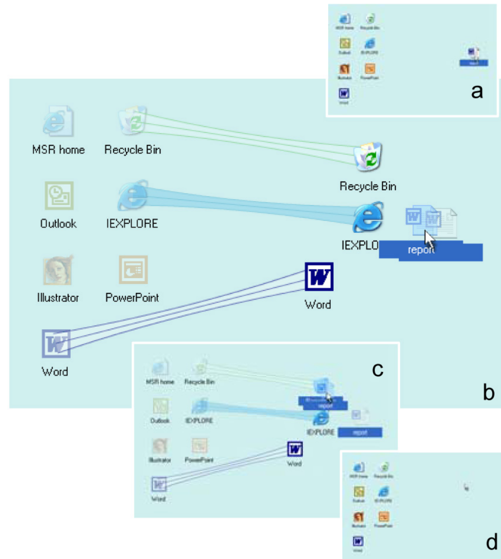

Figure 7. Drag-and-Pop [2]

and paste" simultaneously. With "Drag and Drop" we get problems like moving things over a long distance and if we use a pen as input device the "Drag and Drop" operation will end at the edge of the display. So in this section we present some of the most valuable and needed interaction techniques for multiple displays founded by the last years. We put these interaction techniques in the three groups "Synchronisation", "Moving Information" and "Perception".

Synchronisation

Synchronisation means techniques to couple different displays together and establish a connection between them.

Shaking

As described in Smart-Its Friends [11] a shaking gesture can be used to establishes a connection between different devices. The user hold the devices together and shake them, sensor boards mount to each device are going to apply the connection between the devices. A "beep" sound from the sensor boards will indicate the connection or disconnection when a device is out of reach.

Bumping

Bumping [9] is a gesture that is primary used to enlarge many single displays to one large wall. The user bumps one display to another and both displays get a connection on the affected edge. But as shaking, bumping as well is only suitable for small displays that can be hand held.

SyncTap

SyncTap [18] is a technique for pairing two devices together to transfer information between them. For this, each device has a "sync button" and by pressing and holding it, these devices are going to connect each other. This can be used, e.g., sharing icons on a desktop to another and also for sending pictures to a printer. To offer this technique, all devices have to be connected to a network. The synchronisation process itself is then realized over broadcast. This means whenever a sync button was pressed, all devices in the network gets a broadcast message containing the timestamp, duration and target of the pressed sync button. Compared with the state of its own sync button, the device can determine to which devices it has to connect.

Stitching

Stitching [10] accommodates the benefits of coupling two devices together and moving information between them. By moving a physical input device from one display to another, the displays get stitched together according to the taken path as seen in figure 6. Compared to "Pick and Drop" the input device is identified only by the taken path and allows to use other input devices than a pen (e.g., a finger). This technique also overcomes the problem of stitching more than one device together as it occurs by "SyncTap". If a connection between devices is established, the user decides about the content to be shared.

Moving Information

The techniques presented in this section helps the user to interact among different displays and exchange information between them after a connection is established.

Throwing

Throwing [6] is a technique that is based on the metaphor of accelerating and moving objects over a table. An artefact on the screen can be taken by an input device and is first dragged to the opposite of the final direction and then forward. The longer the taken reverse path the faster and far away the final position of the thrown artefact.

In [14] a similar technique called "Slingshot is evaluated.

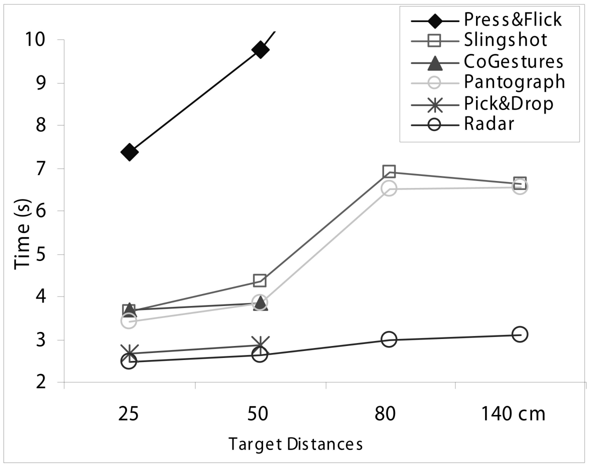

Figure 8. A Comparision of Techniques for Multi-Display Reaching [14]

The different to "Throwing is that the user only drag backwards to accelerate. Slingshot as seen in figure 8 performs worse then Pick and Drop within hand reach, but it is able to interact with displays far away.

Pick and Drop

"Pick and Drop" introduced by Rikimoto et al. [17] is a technique that tries to adapt the "Drag and Drop" gesture, as we know from our desktop computers, to multiple displays and devices. Goal of this technique is to simplify the exchange of information parts between different devices. By pushing a physical pen on to the display it will pick up an artefact underneath it (e.g., an icon on the desktop) and give the user the illusion of storing them into the pen. Pushing the pen on to another display will release the artefact on it. Different to "Drag and Drop", the user does not have to drag the content and therefore avoids sliding the pen over the displays. So "Pick and Drop" is an easy and fast to use technique to interact within multi-display environments.

Implementing this technique requires a connection (e.g., wifi, cable) among all devices and a server, called the "pen manager", that is storing the data picked up by the pen. This server can distinguish each pen by a unique identifier and is responsible for transferring the needed information between the affected devices.

Corresponding to the comparison of multi-display reaching techniques in [14] "Pick and Drop" is one of the fastest techniques within hand reach (figure 8). Targets with more then 50cm distance were not tested in this comparison because then the user has to stand up and walk to the specific target.

Drag-and-Pop and Drag-and-Pick

As mentioned in [2] these are techniques for accessing artefacts that are far away from user and hard to reach like icons on another display. The user drags with a pen like shown in figure 7a into the direction of the icons she tries to reach. Then all icons figure 7b, in a specific angle of the taken direction, will move a temporal copy of them close to the pens position so that the user is able to interact with them on her screen. In this example (figure 7c) the user put a document into the trash. After the user release the pen, the copied icons disappear (figure 7d). This technqiue also allows interacting with displays that do not support a pen based input device.

In a user study Baudisch et al. found out that "drag and pop" is significantly faster then the common "drag and drop", especially when the user need to cross the bezel between two displays. And in [14] it is the technique that performs best with and beyond hand's reach. In figure 8 it is called "Radar View" because in the evaluation they implement this technique so that a miniature map, representing the spatial arrangement of the artefacts appears, whenever the user moves the pen over the display.

Perception

In this section we present techniques helping the user to understand the status of the system and improve the work with it.

Perspective Cursor

A perspective cursor [15] enhances the use of pointing devices in multi-display environments. The goal is to approach the pointing device to the natural behaviour of a laser pointer. This means to detect the physical position of the user and move the cursor according to this position over the displays. Hence the cursor does not appear on a display if it is overlapped with another display from the users point of view. Also the "control resolution" is depending on distance to the active display.

Hyperdragging and Anchored Cursor

We take a look on hyperdragging and anchored cursor as they are implemented in the "Augmented Surfaces" [19]. Here the users can put their personal devices (e.g., notebook tagged with QR-Code) somewhere in a meeting room or public place and the system detects its position and orientation by a camera. Now the user can use the hyperdragging technique, which means to drag the cursor outside of the notebook to the shared displays according to the physical position of the notebook. To identify the cursor, which belongs to the current device, it is anchored to the device by a visible line, called the "anchored cursor". In conclusion this technique offers the use of collaborative display spaces as they appear in meeting rooms or public places by using the input device known by the user.

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