Exploiting Spatial Memory and Navigation Performance in Dynamic Peephole Environments

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Abstract

One way to handle the representation of (and the navigation in) datasets that exceed the available display space is by provisioning movable viewports which display a subset of the entire space. Unlike static viewports, where the information space is moved (e.g. by panning), dynamic viewports – so-called dynamic peepholes – allow the user to move the viewport in physical space and thereby enable egocentric navigation in digital information spaces.

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In my research I investigate how information spaces and the navigation with peepholes need to be designed in order to exploit spatial memory and navigation performance. In particular I focus on the interplay between the physical and the digital aspects and how they affect user performance. For study purposes I use a tablet as a dynamic peephole. I will conduct controlled studies in our research lab, which is equipped with 24 infrared cameras and enable a precise tracking of the lab environment.

Author Keywords

Information spaces; Dynamic Peephole Navigation; Egocentric Navigation; Spatial Memory; Navigation Performance; Mobile computing

ACM Classification Keywords

H.5.2. User Interfaces: Interaction styles. Input devices and strategies. Evaluation/methodology.

Research Situation

I hold a Bachelor’s degree in Computer Science in Media (Furtwangen University) and a Master’s degree in Information Engineering (University of Konstanz). As part of a research project on the design of control rooms (see e.g. [1][10][14][15]) my master thesis

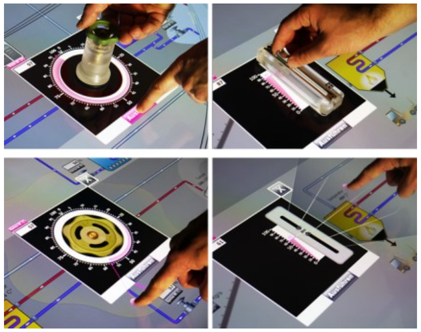

Figure 1. Two tangible concepts (top) and two touch concepts to control numeric process values [10].

Figure 2. Interactive display installation in the public library of Cologne. See [9] for the basic concept.

deals with the design of operator workplaces. For my thesis I designed and implemented several touch- and tangible concepts to manipulate numeric process values (see Figure 1) and compared them with traditional mouse- and keyboard input styles [10]. The design process was based on the Reality-Based Interaction (RBI) [5] framework. In the interim, two claims of RBI have influenced my way of thinking about interface design: First, exploit humans' preexisting skills and abilities to make interaction as natural as possible, and second, balance the interaction qualities of the analog world with the potentials of the digital world.

Since the beginning of my first year I have been affiliated with a public library project which is funded by the Ministry for Family, Youth, Culture and Sports of the Federal German State of North Rhine-Westphalia. The project investigates how new information technologies can contribute to providing appropriate access to both traditional analogue media and the expanding range of digital information and services. (See Figure 2 for the prototype in situ). I'm now in the middle of my second year.

Context and Motivation

My motivation for this proposal originates from the library project and evolved from three major observations that I made in a six-day contextual inquiry: *First*, library visitors, in particular knowledge workers, have to handle an expanding body of information – in constant physical space! *Second*, most visitors prefer seeking information by navigating in physical space (i.e. they browse the shelves) rather than using the online library catalog. And *thirdly*, the current search interface, the desktop-based online catalog, represents an isolated application which is experienced as an alternative to the physical browsing and searching process rather than complementing it.

At the same time I became familiar with *dynamic peephole navigation* [8] and learned about the potentials that spatially-aware mobile devices provide. Dynamic peephole navigation allows users to explore information spaces in an egocentric way, where the screen of a handheld device, such as a smartphone or a tablet, acts as a viewport on an information space. Instead of panning the screen content (e.g. a map), users can physically move to off-screen content (e.g. cities outside the viewport) as if it were situated in physical space. In a controlled lab experiment we [12] investigated the effect of three peephole sizes on users' navigation behavior, navigation performance, and task load (Figure 3).

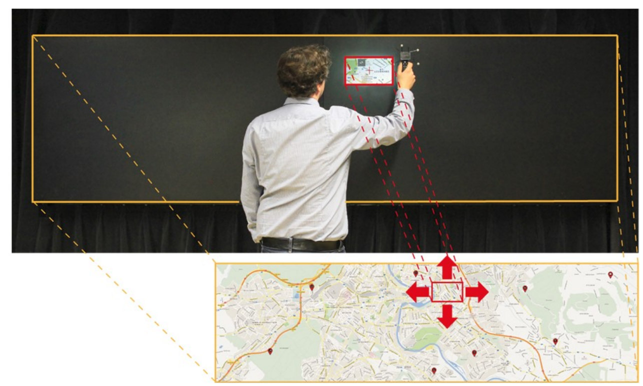

Figure 3. Map navigation using a (simulated) tablet sized peephole [12].

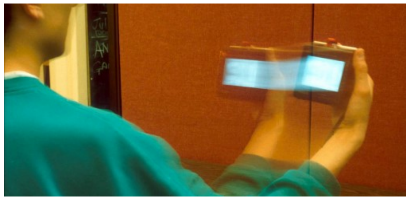

Figure 4. The Chameleon prototype by Fitzmaurice [2]. A spatially-aware palmtop serves as a viewport on a situated information space.

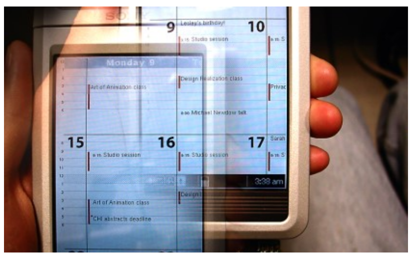

Figure 5. Yee's [17] Doodle Pad, a continuation of the Chameleon Prototype [2].

Figure 6. The PaperLens prototype [16] showing the skeleton layer above the tabletop.

My contact with dynamic peepholes as viewports on information spaces together with my prior observations in the library domain resulted in the following question:

"How can we use our physical environment (and our pre-existing knowledge and skills that refer to our environment) to create information spaces in which we can seamlessly navigate and interact with digital and physical content in a natural way?"

Referring to the RBI design trade-offs [5], I am particularly interested in the question which physical aspects of interaction should be preserved in such spaces and which aspects should be extended or even replaced by digital functionality.

Background and Related Work

This section provides an overview of both related interfaces and research on the cognitive aspects of egocentric navigation with peepholes.

Peephole Navigation Applications

In 1993 Fitzmaurice [2] presented the concept of situated information spaces – physical spaces which are semantically augmented with digital information. Spatially aware handheld devices, such as his Chameleon prototype, act as a viewport and can be used to access and navigate these spaces (Figure 4). He considered computer-augmented libraries and offices to be future application areas for situated information spaces.

In 2003 Yee [17] presented the Doodle Pad (Figure 5), a peephole prototype to create and manipulate objects that are larger than the display. He considered his work a direct descendant of Fitzmaurice's Chameleon [2]. Furthermore, he contributed a working implementation of multiple applications, arranged around the user in a personal information space. A usability test showed that the "peephole technique can be more effective than current methods for navigating information on handheld computers" [17]. He finally points out, however, that "the tracking hardware has a long way to go before it is truly robust" [17].

2009 Spindler et al. [16] presented PaperLens, a peephole prototype to navigate a virtual information space spanned above the tabletop (Figure 6) and contributed a classification of 3D spaces. Compared to the first peephole prototypes, which were based on digital displays, the image of the PaperLens [16] is generated via projection on a paper.

For a long time, study around dynamic peephole navigation has been subject to technological limitations. We now have the technology (for instance camera-based tracking systems and a variety of sensors inside our mobile devices) to design and evaluate information spaces that are accessible in an egocentric manner.

Research on Cognitive Aspects

In addition to the changes in technology, recent cognitive theories give special consideration to humans' structured environment. Distributed cognition [4] for instance assumes that our physical environment is an essential element in the cognitive system – externalizing information can, for instance, reduce memory load. Recent theories in this research area may serve as both a starting point for the design of digitally augmented environments (e.g. as in [3]) and also as a reference to explain observed effects.

Figure 7. Tabled-sized peephole within a controlled lab study on the impact of peephole size on navigation performance, spatial memory, and subjective workload [12].

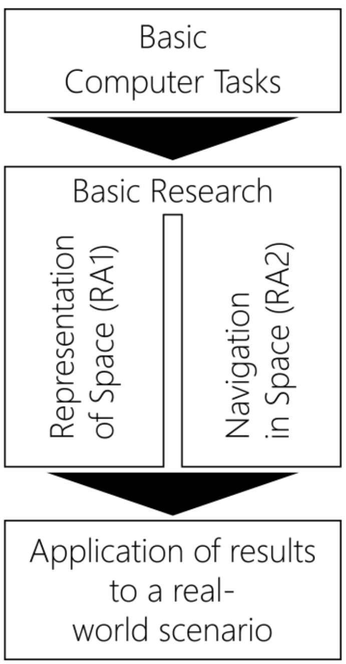

Figure 8. Anticipated research plan.

In several studies the cognitive benefits of egocentric peephole navigation has been proved, when compared to traditional interaction styles. In 2006 Mehra et al. [8] compared static peepholes (static viewport and pannable landscape) with dynamic peepholes (fixed landscape and movable viewport) and investigated the perception of line lengths on an information landscape. The study showed that dynamic peephole navigation results in a significantly better line length discrimination.

In 2012 Rädle et al. [11] compared egocentric navigation with traditional touch navigation in terms of navigation performance, spatial memory, and subjective workload. Their study revealed an effect on navigation performance and long term spatial memory in favor of egocentric navigation. For subjective workload, participants reported a significantly higher physical and a lower mental demand in the egocentric condition.

Kaufmann and Ahlström [6] investigated the impact of peephole size (projector phone vs. smartphone) on spatial memory and navigation performance. While there were no significant differences in navigation performance they showed that spatial memory performance was significantly better when participants navigated with the projector phone.

Similarly, Rädle et al. [12] investigated the effect of the peephole size on users' map navigation behavior, navigation performance, and task load. They simulated 4 peephole sizes: smartphone (4"), tablet (10.1"), projector phone (54.7"), and control condition (120", peephoe size equaled the size of the entire landscape). They identified the tablet condition as "sweet spot" in terms of peephole size and both user navigation performance and user task load.

A general overview on spatial memory in user interfaces is provided by Scarr et al. [13], who discuss the crucial role of the two spatial reference systems *landmarks* and *frame of reference*.

Thesis scope

In my research I focus on basic tasks such as navigating in digital information and organizing digital content, tools and associated activities. I assign the aspects that are relevant to these tasks to the two research areas *Representation of Space* and *Navigation in Space* (Figure 8). In the first part of my research I will do basic research in both areas in a controlled lab environment. In the second part I will apply the results of the basic research to a real-world scenario, e.g. such as the augmented library. Based on our prior study results ([12]) I will use a tablet computer as viewport.

- In the research area *Representation of Space* (RA1) I investigate the perceivable (i.e. the physical and virtual) properties of information spaces to support spatial memory and navigation performance. Critical parameters in this area refer to the effect of spatial reference systems such as *landmarks* and *frames of reference* [13] and whether their representation (e.g. virtual on screen vs. in the physical environment vs. hybrid as room-wide projection) has an impact on user performance, e.g. on spatial memory. Another aspect in this area refers to the layout of information spaces. Except for small-scale, table-based application such as the PaperLens prototype [16], research on dynamic peephole navigation refers to information spaces in

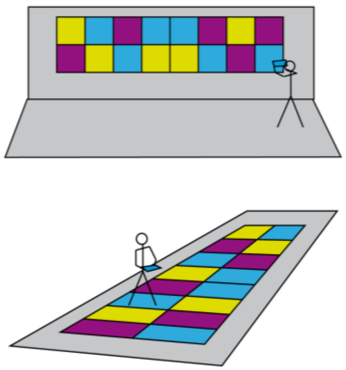

Figure 9. Sketch of a study to investigate the effects of two different orientations of the information space. (The colored rectangles are virtual, and thus can only be seen through the tablet.)

which information is laid out vertically, i.e. navigation is performed parallel to walls or large wall displays (see e.g. [6][11][12]). Little, however, is known on how well egocentric navigation works in larger, horizontally laid-out information spaces such as floors (see Figure 9). Considering our natural skills, it can be hypothesized that peephole navigation may be experienced even more natural if the information space is laid out horizontally. Additionally, this orientation provides more space accessible by the user, with which to lay out digital information. Finally, and referring to the classification of space by Spindler et al. [16], I will address the question how constant and limited physical space can be best used to layout arbitrarily large sets of data.

- In the research area *Navigation in Space* (RA2) I investigate the effects of different navigation properties and features such as modified control-display gain or (egocentric and non-egocentric) zooming on users' spatial memory and navigation performance. I will focus on the question whether yielding better results for navigation performance (e.g. by bypassing the naïve physics [5] through an increased control-display gain) are at the expense of spatial memory. Furthermore, I will design and evaluate navigation concepts that address the problem of limited physical space for the navigation of an arbitrarily large amount of digital information.

Accordingly, I will conduct studies under controlled conditions in our lab (Figure 10). For the study infrastructure I will use 24 infrared cameras and the proximity toolkit [7], a framework which provides proxemic relations, such as distance and orientation between the objects (persons, devices, and interior) within the lab infrastructure.

Dissertation Status

My current work focusses on the establishment of the study environment. The environment includes a 3D model of our lab and provides the opportunity to set up the studies for basic research associated with RA1 and RA2. The first study aims at investigating the layout of planar information spaces (Figure 9). In this study I will compare both layouts in terms of an egocentric study task, in which participants will need to navigate to virtual symbols on the information landscapes and reconstruct their position afterwards. Data referring to navigation performance and subjective workload will also be gathered.

Figure 10. Study lab equipped with 24 optitrack cameras connected to the proximity toolkit [7]. The setting allows for precise tracking and controlled lab studies.

Expected contributions

With my research I will contribute to a better understanding on how to use our physical environment and exploit the associated motor and spatial memory skills for dynamic peephole navigation. The findings of my research can then be applied to real-world problems to generate scenarios such as the digitally augmented library and the surrogate office envisioned by Fitzmaurice [2].

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