From Focus to Context and Back: Combining Mobile Projectors and Stationary Displays

[1,2]Martin Weigel, [1,3]Sebastian Boring, [1]Nicolai Marquardt, [2]Jürgen Steimle, [1]Saul Greenberg & [1]Anthony Tang

[1]Department of Computer Science
University of Calgary
2500 University Drive NW
Calgary, Alberta Canada T2N 1N4

[2]Max Planck Institute for Informatics
Cluster of Excellence MMCI
Campus E 1.7
66123 Saarbrücken, Germany

[3]Department of Computer Science
University of Copenhagen
Njalsgade 128, Bldg. 24, 5th floor
2300 Copenhagen S, Denmark

[mweigel, jsteimle]@mpi-inf.mpg.de, sebastian.boring@diku.dk, [nicolai.marquardt,saul,tonyt]@ucalgary.ca

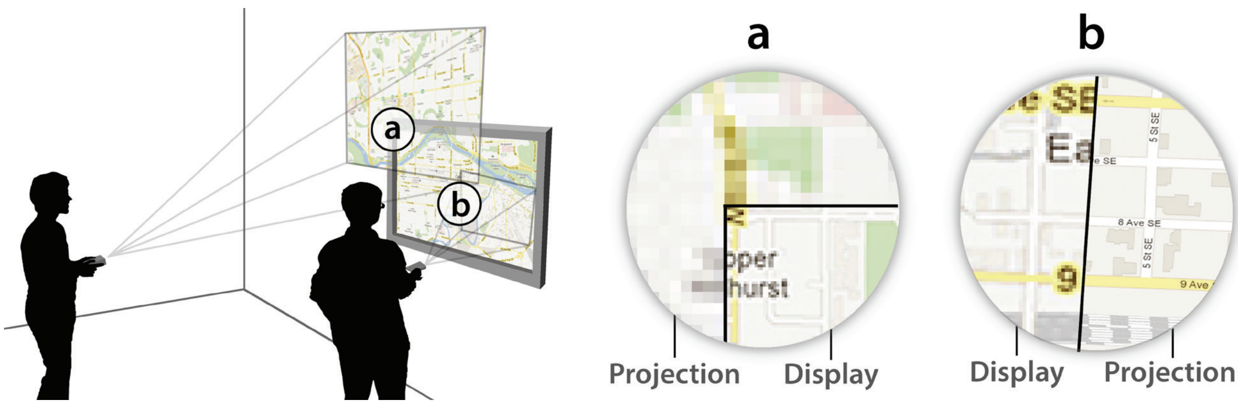

Figure 1: Mobile projections add focus and context areas on a display. The projection automatically adjusts to the needed size and level of detail by the distance of the user to the display. In (a) the mobile projector provides context, while in (b) it provides focus.

ABSTRACT

Focus plus context displays combine high-resolution detail and lower-resolution overview using displays of different pixel densities. Historically, they employed two fixed-size displays of different resolutions, one embedded within the other. In this paper, we explore focus plus context displays using one or more mobile projectors in combination with a stationary display. The portability of mobile projectors as applied to focus plus context displays contributes in three ways. First, the projector's projection on the stationary display can transition dynamically from being the focus of one's interest (i.e. providing a high resolution view when close to the display) to providing context around it (i.e. providing a low resolution view beyond the display's borders when further away from it). Second, users can dynamically reposition and resize a focal area that matches their interest rather than repositioning all content into a fixed high-resolution area. Third, multiple users can manipulate multiple foci or context areas without interfering with one other. A proof-of-concept implementation illustrates these contributions.

AUTHOR KEYWORDS

Focus plus context, portable projectors, multiple users, multiple displays.

GRAND 2013, May 14-16, 2013, Toronto, ON, Canada

1. INTRODUCTION

When people work with a large amount of information, they commonly apply *multi-scale interfaces* to view, navigate, and understand the data [8]. These interfaces facilitate (1) detail views, which allow exploration of the information at scale, and (2) context views, which provide an understanding of the information's overall structure. Interfaces that allow focus and context generally employ four different mechanisms [7]: spatially separated interfaces, zoomable interfaces, cue-based selective highlighting, and focus plus context interfaces [2]. Most of these approaches do not maximize the use of the resolution (in terms of dots-per-inch) offered by the display. The exception is *focus plus context displays* (F+C displays). Baudisch originally built these by embedding a high-resolution LCD screen within a cut out of a projection screen [2]. F+C displays trade off display space and resolution (and thus cost per pixel) to best match a user's conceptual "field of interest". The primary focal area (the *focus*) area is displayed in detail on the high-resolution LCD screen. The surrounding *context* is provided through the larger, low-resolution projection on the screen surrounding the LCD. The two are calibrated, where the projected region that aligns with the LCD screen is blanked out to reduce visual interference.

Although the particular F+C display described above optimizes the use of all the pixels in the display, it has limitations. First, the physical focus area is in a fixed location, meaning users have to shift or pan content into the focus area, instead of shifting the viewport containing the focus to the interest area seen in the surrounding context. Second, the focus and context areas have a fixed size and resolution. These can only be changed by physically altering the setup and equipment. Several recent systems explored the use of mobile devices as high-resolution magic lenses (see §Related Work), these still retain some restrictions on the spatial placement of a focus area within the context, as well as how they are used in collaborative, multi-user scenarios.

Our goal is to explore how the notions of a "focus" and "context" can be decoupled both conceptually and perceptually from particular displays. Our approach is to construct an F+C display using *mobile projectors* and a wall-mounted *stationary display* (see Figure 1). The visuals of both dynamically change their behavior based on the user's (and thus the projector's) proximity to a stationary display. In particular, (1) the projector provides higher pixel density and thus provides focus when close to the display, as the projected area is small in size (Fig. 1a), and (2) when further away, the projector acts as large, low-resolution context that extend the visuals and thus the context beyond the fixed boundaries of the wall display (Fig. 1b). We contribute over prior work by having both devices continuously transition between these two states as a function of proximity, where the role of each display inversely and smoothly changes between focus and context. Our approach further contributes support for multi-user interaction: we provide mutually visible multiple focus and context areas, which enhances workspace awareness [9].

2. RELATED WORK

Our work builds on F+C displays, applications of mobile projectors in focus plus context, and proxemic interaction.

Focus plus Context Displays. As mentioned, Baudisch presented a small fixed high-resolution display and a surrounding larger and fixed low-resolution projection around that display – simultaneously showing a focus area and undistorted context [2]. Eschewing a fixed focus area, Benko et al. showed how tablets on a stationary tabletop display can act as mobile focus-lenses with the tabletop providing common context [3]. Lin et al. further applied this concept to non-planar displays [11]. Thus we see how F+C displays still relied on a large display with fixed size and resolution to show context, but evolved to have a moveable focus area atop the context.

Mobile Projectors for Focus plus Context. Cao et al. [5] provide an alternative through the use of multiple handheld projectors, which allows for moving the context area as well. Here, the overlapping projections allow for a *mobile* focus plus context display when one projector is closer to the non-digital surface than the other. Our approach is similar, but works over a digital display to provide greater powers. Similarly, Bonfire [10] shows content on a laptop display, while using a mobile projector to project other information on the surfaces around the notebook. Chan et al. use moveable projectors with a flashlight metaphor to create dynamic high-resolution focus areas atop the stationary display [6]. Employing mobile projectors for focus plus context displays opens a wide range of possibilities. However, in these systems the projectors are used mainly for focus *or* context by projecting on or around a stationary display. We extend this idea by using mobile projections to provide *both* focus and context depending on the location of the user.

Proximity-based Interaction. Mobile projections physically change the projected image size and pixel density − and therefore its suitability as a focus or context display – as a function of their distance from the projection surface. Proxemic Interactions explores the relationship between people and their devices as a function of proxemic measures including distance and orientation [1,12]. It explores how content dynamically changes its appearance based on a user's proximity, where more detail is digitally added as one approaches the display. Cao et al. [4] showed how a mobile projector can reveal different information granularities, depending on the distance to the projection surface. Similarly, *SideBySide* [13] changes projected content of two handheld projectors based on the proximity of the two projected canvases. In our work, we smoothly transition between focus and context (and the level of detail displayed) between the projected and stationary display as a function of proximity.

3. FOCUS PLUS CONTEXT WITH MOBILE PROJECTORS

Our approach combines mobile projectors with a stationary display to create a dynamic, multi-user focus plus context display (Figure 1). However, instead of seeing one device as *either* focus *or* context, we use the proxemic relationships between the devices to dynamically change a device's behavior on a per-user basis. That is, a projector may provide a dynamic focus area within the context of the stationary display (when close to the display), or provide additional context to the stationary display (when further away). We first discuss each of these general behaviors, before describing how they apply to multi-user interaction. We also show how these work in two example applications: one that allows multiple users to explore a map (sketched in Figure 1; shown in Figure 2), and the other that allows them to lay out magazine spreads by viewing and manipulating articles and images (Figure 3). While both work the same way, the map illustrates a single continuous object while the layout tool illustrates multiple digital objects on the virtual canvas that comprises the working area.

4. MOBILE FOCUS PLUS CONTEXT

The stationary wall display anchors information, and all projector activity occurs relative to it. We consider the mobile projector as an indicator of interest. One projects *on* the stationary display if one is interested in exploring detail on it, or *around* that display if one is interested in context beyond its edges. The projector's mobility further empowers users to project from arbitrary distances, locations and angles. In doing so, people affect the resulting projected area's shape and size (e.g., the skewed but correct area in Figure 2, left side; the larger off-screen areas in Figure 3). Of significance is that the projector's pixel density (i.e., dots per inch) changes with its distance from the projected surface: when the projector is far from the surface, its pixel density is low; when it is close, its pixel density is high as the projection decreases in size. We exploit this behavior to dynamically change which device acts as *focus* and which acts as *context* as described below.

Mobile Projection as Focus. In real life, people move closer to see details of an object of interest. As they get closer, the resolution of their vision increases and the field of view decreases. Optical projectors behave in the same way: the image is smaller, but the pixel density is higher. However, because stationary displays have a fixed resolution, its perceived pixel density decreases when users get closer (e.g., actual pixels are distinguishable). This means, that when being closer than a certain distance, the pixel density of the projector will exceed that of the display. If this is the case, the projector can provide more detail than the large display. If the stationary display blanks out the overlapping projection area by displaying a black area instead of the application's content, the

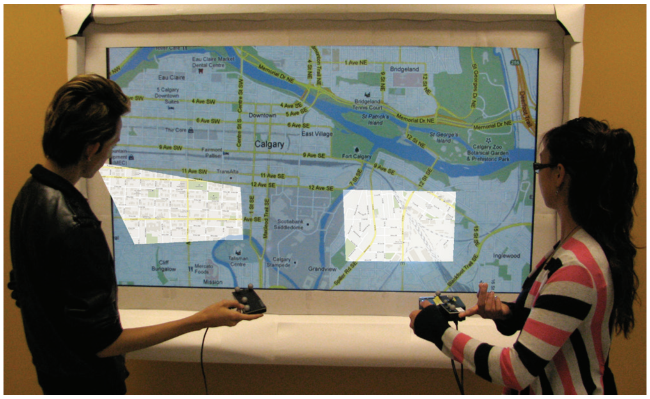

Figure 2: The map application. Two more detailed focus areas (one per user) are projected onto the stationary display. Projections are enhanced due to lighting issues.

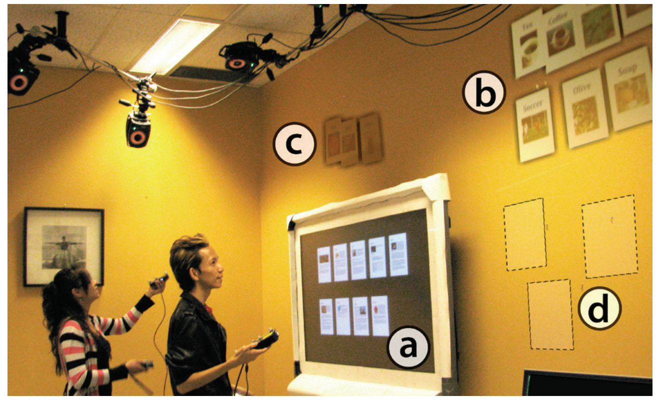

Figure 3: The layout application. The stationary display (a) is a permanent view into the digital space. Context outside the display (b-d) is invisible (as in d) unless revealed by the users projecting onto that area from afar (e.g., b, c). Projections are enhanced due to lighting issues.

projection's higher pixel density will show its content. This also means that the stationary display becomes (implicitly) the *context* area to the projection's *focus* area. The person on the right hand side in Figure 1 is in this situation. The projected image 'b' on the right not only has a higher resolution, but displays added semantic detail because the resolution allows for it. Figure 2 shows our map application in use, where two users are focusing on two map sub-areas by projecting atop of it. The layout application works the same way, but shows details of individual pages.

Mobile Projection as Context. In contrast, when people are interested in seeing the bigger picture, they move away from their point of interest, increasing their field of vision to see the context around it. Here, the resolution of content is less relevant, while the overview is more important. Again, optical projectors behave in exactly the same way: as the projection's size increases, its pixel density drops. At a certain distance, the stationary display's pixel density will exceed that of the projector. Depending on the distance, the projected area may even be larger than the stationary display, thus providing additional screen space around that display. In this case, the projector blanks out the overlapping area with the display and acts as *context* to the stationary display's *focus*. This context around the display is revealed on-demand by the mobile projectors. The left person in Figure 1 is in this situation, where the large projected image 'a' is of lower resolution, where that image has less semantic detail to match its limited resolution. Figure 3 shows the layout application in use, where two users are using their projectors to reveal groups of objects 'b' and 'c' in the context surrounding the focus display 'a'. Context 'd' will become visible when one points one's projectors atop of it. The map application works similarly, except it shows the off-screen parts of the continuous map.

5. MOBILE FOCUS PLUS CONTEXT WITH MULTIPLE USERS

Baudisch's F+C display has one focus and one context area [2]. While multiple users can work over that, they are limited to this single viewpoint. Benko's application of mobile devices (e.g., tablets) mitigates this, as each person's device holds their personal focus [3]. However, because the two foci are on separate screens, it is more difficult for one person to see what the other person is looking at, and thus collaboration is hindered [9]. In contrast, mobile projectors empower users to have their own focus/context areas that are still visible to others. Here, the projected focus and/or context areas do not interfere with one another, and can co-exist peacefully: when projections with different pixel densities intersect, the projection with the higher pixel density is shown in that intersection. As shown in all the Figures, users can view content at different distances, treating the stationary display as individual focus or context depending on their needs. We explore three specific scenarios below.

Multiple Projected Focus Areas. As illustrated in Figure 2, focus areas can be created on demand by people close to the display or the projection surface around the display. Here, the display provides a common context for all users. Separate focus areas can either be used for independent activity, where people have separate interests, or for collaborative work on the display. They also support workspace awareness [10], as each can see what the other is engaged in. Focus areas also serve as a highlighting mechanism, where one person can draw the attention of others to a specific focus area on the stationary display by pointing his or her projector on that area.

Multiple Projected Context Areas. As illustrated in Figure 3, multiple projections from a distance reveal larger portions of the context around the stationary display. These projections reveal different parts of the context, yet still provide all with a "multiple flashlight"-like experience of the context surrounding the focus area of the stationary display. Here, the focus area of the stationary display acts as common anchor for collaboration. People can also drag content from the context into the fixed area of the stationary display to see it in greater detail.

Mixing Focus and Context Areas. The stationary display acts as a mediator between the people to move information from coarse tasks (e.g., roughly organizing it) that relate to the context around the stationary display to focus tasks (e.g., precise content alignment), which occur within the stationary display. Since transitioning between focus and context is as smooth as moving one's projection, the environment promotes fluid transitions between coarse and fine interaction on a per-user basis.

6. IMPLEMENTATION

Our implementation uses the *Proximity Toolkit* [12] (which in turn uses Vicon's motion capture technology: www.vicon.com) to track the projectors' positions and orientations with respect to a stationary display. Because of projector limitations, each is connected to a laptop, which communicates with the display through a wireless network. The computer of the stationary display continuously informs all projectors of their spatial relationship to the display, so that they can appropriately distort their content or blank out the overlapping area when they are considered as *context* device. The display itself blanks out the areas where projectors act as *focus* device.

Our system holds a three-dimensional model of the physical environment and how content is distributed on the wall the stationary display is mounted on. Both display and the projectors render the scene in 3D, but use an orthographic projection, as it is parallel to the wall. Each projector (and its driving laptop) corrects for keystone effects and handles jitter. Since displays and projectors are rendering the same scene, content is seamlessly continued outside the display. The result is that content seems fixed in space (albeit at varying resolutions) even as a projector moves over it.

Our implementation is itself a toolkit that makes developing such applications relatively straightforward. For example, it performs all the mathematical operations and all blanking. Our map and layout applications were built atop of it.

Overlapped Regions. The system has to recognize potential overlaps to avoid interference of displayed *vs.* projected content. Our implementation does this by intersecting the projector's frustum (defined by four rays) with the display plane. We then use the resulting intersection polygon to blank out content depending on the distance of the projector (i.e., either blanking out parts of the projection, or parts of the display) to avoid interference. To do so, each device renders a black polygon atop the actual scene to black out that specific area. If the projector is further away than a certain threshold, it blanks out the respective overlapping projected area since the display has higher resolution. If it is closer, the display will do this instead. To avoid flickering of either projected or displayed content, we chose to use a cross-fade within a short range as opposed to switching between focus and context behavior once that threshold is passed.

Limitations. Our current implementation requires high-end external tracking hardware to track the positions and orientations of mobile projectors. This is sufficient for prototyping and testing such applications, but does not allow for real-world deployment. In the future, handheld devices may include some tracking mechanism that reduces the necessity external tracking hardware. Our mobile projectors also have a ways to go. They are not yet bright enough to be used from large distances, and most do not have sufficient processing power to be used as an independent computer. We used two different handheld projectors: a Dell M110 DLP (300 lumens) and a MicroVision ShowWX+ laser projector (15 lumens). The Dell projector provides a brighter projection, but requires manual focus and is too large to be embedded into mobile devices. Laser projectors overcome these issues, but are currently not bright enough to be used on dimmed stationary displays. This will change.

In summary, we contribute over prior work by having projected and stationary devices smoothly transition between focus and context as a function of proximity, where our approach supports multi-user interaction by these mutually visible multiple focus and context areas.

7. ACKNOWLEDGEMENTS

Funding provided by the NSERC SURFNET Networks grant, by NSERC/AITF/Smart Technologies Research Chair, and by the NSERC Discovery Grants program.

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