Design Considerations for the Placement of Data Visualisations in Virtually Extended Desktop Environments

David Aigner[1], Judith Friedl-Knirsch[1,2] and Christoph Anthes[1]

[1]*University of Applied Sciences Upper Austria*

[2]*Technical University of Munich, Human-Centered Computing and Extended Reality Lab*

Abstract

As novel mixed reality devices are developed, the use case of augmented reality display extension becomes feasible. Especially, in a visual data analysis use case, users can then benefit from expanding the conventional screen space using augmented reality head-mounted displays. This opens up the discussion of suitable placement of user interface elements in this extended augmented reality space. This includes questions about customisability, interaction, and moving elements across the borders of a desktop screen. Therefore, we present design considerations on layout and interaction with augmented reality extended displays and propose a system that employs the discussed techniques to support the data analysis process.

Keywords

Extended Displays, Augmented/Mixed Reality, Cross Reality, Visual Data Analysis

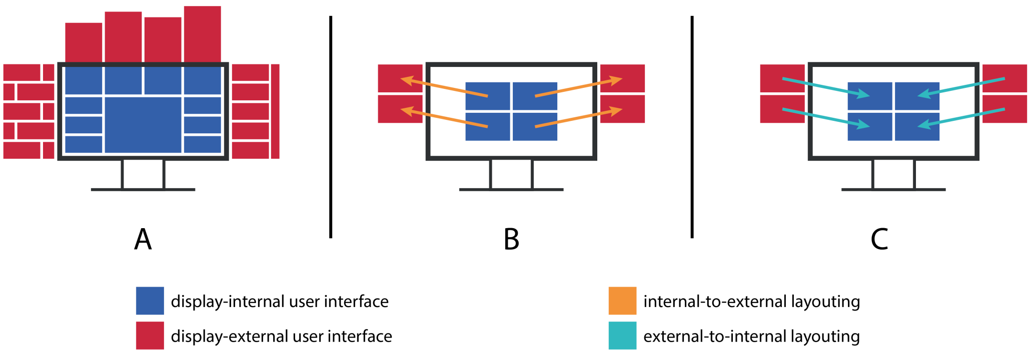

Figure 1: Virtually extended desktop environments feature display-internal elements displayed via desktop screen and display-external elements displayed via HMD (A). The process of creating a layout includes transitioning user interface elements from an origin position towards a destination position. In regards to the display, this transition can be internal-to-external (B) or external-to-internal (C).

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david.aigner@fh-hagenberg.at (D. Aigner); judith.friedl-knirsch@fh-hagenberg.at (J. Friedl-Knirsch); christoph.anthes@fh-hagenberg.at (C. Anthes)

1. Introduction

The development of novel devices that allow users to freely move along Milgrams's Reality Virtuality Continuum (RVC)[1] opens opportunities to extend conventional 2D systems into 3D space. Cross Reality systems can then allow users to switch between different stages on the RVC, depending on their preferences and the current requirements of their task, using transition techniques [2, 3, 4, 5]. This means that users can switch to an augmented reality (AR) perspective for collaboration with a collocated partner and switch further along the continuum towards virtual reality to be fully immersed in a digital environment.

There are numerous use cases that can benefit from this opportunity to move along the RVC. For example, in a data analysis process, immersive analytics allows users to experience and analyse data in a three-dimensional immersive environment [6]. Cross reality systems can extend this visual data analysis process to integrate multiple stages of the RVC [7].

However, most data analysis processes are still focused on 2D desktop environments. With users being familiar with this environment as well as its inherent benefits for text entry[8] and precise interaction [9], integrating this environment plays a vital role in employing immersive systems in data analysis. Therefore, a cross reality system could support the analysis process by extending the display space beyond the limitations of the physical screen. Users could then utilise the same interaction methods and analysis tools that are already part of their data analysis process and use the large display space as a dashboard to view multiple visual representations of their data at the same time and get an overview of all important information at a glance [10].

This use case then opens the discussion on how these additional visualisations can or should be placed. While the information layout in sensemaking tasks, where users arrange the information based on their needs, has been well explored in literature [11, 12, 13, 14], an automatic approach for this information layout has not yet been explored. We therefore propose design considerations and a concept for an immersive cross reality system that implements an automatic layout for a visual data analysis dashboard.

2. Related Work

In this section, we focus on the two most relevant fields for user interface layouts. First, we discuss methods for display extension with a focus on virtual display extensions using head-mounted displays (HMDs). Secondly, we elaborate on common placement strategies in 2D dashboards and 3D information layouts.

2.1. Extended display environments

When aiming to extend displays, there are multiple different approaches, starting with simply adding more displays [11] over cross-device interaction between multiple small devices [15, 16, 17] towards extending displays using immersive technology [18, 19].

There have been studies on different display types and sizes when using immersive display extensions, i.e. mobile devices [20, 21, 22, 23], desktop monitors [18, 24, 19, 25, 26], and large-scale displays [27, 28]. The display extension itself can then either be screen-aligned or utilise the entire three-dimensional space as a layout area. Within the area of utilising immersive technologies for display extension, the extended area is either connected to the display [18, 21, 20] or enables the free use of three-dimensional space [19].

In the research on screen-aligned display spaces for mobile devices, research focuses on interaction methods for the AR display extension [22, 29], as well as different sizes of extensions and their impact on spatial memory, workload, and user experience for smartwatches [20] and smartphones [21]. For both types of displays, researchers come to the conclusion that there is a limit on how large the extended display space should be to positively impact spatial memory, although the recommended sizes vary between the display types [20, 21]. Additionally, Biener et al. [23] explored the feasibility of using VR to extend a tablet display for knowledge work.

For desktop-based display extension, the display extension is used for a 3D perspective on objects [24, 18], for placing or extending controls into the screen-adjacent space [24, 18], or for free placement of data plots for visual data analysis [30]. Cools et al. [18] define a hybrid display space that is subdivided into screen space, screen border, a cylindrical space around the user and a desk surface space. Additionally, Pavanatto et al. [25] compared the physical and virtual monitors to a hybrid condition where the physical monitor was extended by two virtual ones in AR. They found that virtual displays can be used for knowledge work. Nevertheless, the discomfort of the HMD is still a problem. They also report that the hybrid condition represented a middle ground between the physical and virtual condition in terms of time and accuracy. This is similar to one of the findings of Pavanatto et al. [26] which found no significant difference in performance time between virtual displays and the combination of real and virtual screens. However, the relatively small field of view of the Microsoft HoloLens 2, which was used in both studies, might influence the results.

When looking at the extension of large scale displays, there is research in interaction techniques and visualisation techniques for transferring graph based data into the 3D space for exploration [28]. For screen-aligned display extension, Perelman et al. [27] have proposed to add an immersive personal view using AR HMDs to a shared space on a large interactive display. This personal view is then placed in an orthogonal manner to the large display. This allows users to decouple their own exploration from a collaborative analysis.

2.2. Layouts in 2D and 3D

For two-dimensional information layouts, Bach et al. [31] analysed 144 dashboards in order to identify design patterns that are being used when designing dashboard user interfaces. They distinguish between two different groups of patterns. A dashboard usually consists of multiple dashboard elements. Content design patterns describe different facets of the content of dashboard elements. Composition design patterns describe how these dashboard elements are combined and presented. Furthermore, they state that while there are some high-level design guidelines, there are still many open questions that have not been answered in research at this point.

In virtual environments, there are multiple studies that explore how users utilise the three-dimensional space around them, both in single-user scenarios [32, 14, 13], and collaborative user studies [33]. These studies focus on different sensemaking or clustering tasks with map data, including one larger map and several smaller multiples [32], as well as image data [33] and textual data [13, 14]. Overall, there are different layout patterns that were observed. For the planar layout, the items are mostly aligned flat, next to each other [32] and may be sorted into several planar clusters [13]. For a spherical layout, the items are clustered in a sphere around the user while for a spherical layout with cap, only a portion of this sphere is used [32]. Similar to the latter one, a semicircular layout was found in two other studies [13, 14]. The last common layout identified is the environmental layout where clusters are formed based on cues, such as objects, in the virtual environment [33, 13, 14]. Additionally, Lisle et al. [12] found, that an increase in available workspace also increases user satisfaction and decreases frustration.

In a different approach, based on visual data analysis with small multiples, Liu et al. [34] compared the performance and user experience of planar, semicircular and circular layouts. They found that planar is the most efficient layout while semicircular is the most preferred layout, as it provides a good compromise between walking distance and getting an overview of all plots. This was also later confirmed in two further studies, which also confirmed that there was no statistically significant benefit from the semicircular over the planar layout while users still preferred it [35]. Reipschlager et al. [36] also included a curved AR screen in their work to enable an overview of the whole screen while limiting distortion based on the viewing angle. For individual charts they included hinged visualisations that are connected by a hinge to the larger display while being angled towards the user to mitigate the perception distortion.

Liu et al. [37] consolidate the opportunities for visualisation view management in a design space, where thy consider four major topics concerning view presentation and user interaction. They include the spatial relationship between user and visualisation view, the coordinate system of the layout, the intent of the interaction and the input modality. When placing digital content in an AR environment, coupling information based on semantic meaning or based on geometric surfaces should also be considered [38]. Furthermore, Liu et al. [34] provide a design space for the layout of immersive small multiples including dimension, curvature, aspect ratio, and orientation. Daeijavad and Maurer [39] later add height and detail level and argue for the inclusion of interaction technique as an additional dimension.

3. Design Considerations and System Concept

This section presents our design considerations for display-external placement of user interface (UI) elements in a virtually extended display space and our concept for a respective system to support the visual data analysis process. First, we elaborate on the issues of customisability versus predetermination, external-to-internal versus internal-to-external transitions, and input methods. Then, we describe the architecture of our proposed virtually extended desktop environment in which we want to explore display-external UI placement.

3.1. Considerations for User Interface Layouts

One goal of UI placement is to provide users with an intuitive overview of the interface they are about to use. The suitability of a layout varies depending on the confronted user and the performed task [32].

3.1.1. Customisability versus Predetermination

The layout of UIs can either be predetermined by the developers, customised by the users or something in between (semi-customisability). This results in a dichotomy of two complementary states: *Customisability* and *predetermination*. While customising a layout is done by the application's users, predetermining a layout is a task done by the application's developers.

Customisability has the advantage of providing individual users with the ability to choose their own individual layout. This is valuable, as a predetermined layout might not be equally suitable for all users. It also leads to a higher level of complexity for the application, as the graphical user interface must therefore be designed more flexibly and allow the users to customise it. An extreme example of a customisable user interface provides its users with the ability to position and resize elements free-handedly.

Predetermination allows the developers to keep the application more simple, compared to an application with a user interface that is fully customisable. It also limits the user's flexibility in adjusting the interface to their needs. Predetermination must not imply limiting the user interface to a single layout. The developers may also predetermine a set of layouts the users can choose from but not customise. An extreme example of a predetermined user interface provides its users with a singular layout, which was defined by the developers.

Semi-customisable user interfaces might feature different mechanics in order to assist the users in customising the interface. A layout manager might allow users to save their customised layout as a template. This allows switching between different layouts without having to freshly customise them again when switching. User interface docks might allow users to assign a certain element to a predefined slot on the display space. These docks might have their own predetermined or customisable layout.

3.1.2. External-to-Internal versus Internal-to-External

The process of user interface placement involves moving elements of the user interface from an origin position to a destination position. In a virtually extended desktop environment, we distinguish between display-internal and display-external workspace. The origin and destination positions are in either of these two workspaces. Depending on which workspace these positions are located on, the transition of interface elements will be performed from one workspace to another or just within one workspace.

Transitions from display-internal to display-external workspace involve interface elements that are originally located on the display-internal workspace to transition to the display-external workspace. One possible example in the data analysis use case would be a "filter visualisations" mechanic, in which an overly crowded display-internal workspace is jammed with too many data visualisations. In order to reestablish an overview of the interface and reduce the number of visualisations on screen, the user decides on a filter configuration and triggers the transition of filtered visualisations from the internal to the external workspace. This results in a clearer and less jammed display-internal workspace and other visualisations being displayed on the display-external workspace in a sorted and organised layout.

Transitions from display-external to display-internal workspace involve interface elements that are originally located on the display-external workspace to transition to the display-internal workspace. One possible example in the data analysis use case would be a "thumbnail overview" mechanic, in which a set of data visualisations is aligned around the display-internal workspace in the form of small thumbnails. The resolution of these thumbnail visualisations is too small for actually analysing them. Clicking the thumbnails transitions them to the display-internal workspace, where they are displayed with a high resolution. This provides the users with an overview of all interface elements and the possibility to interchange them effortlessly.

Transitions within the display-internal workspace resemble the already well-established UI placement, which can also be found in graphical user interfaces like Microsoft Windows and Apple macOS.

Transitions within the display-external workspace do not involve the desktop display. Therefore, they can be performed without a virtually extended desktop environment only using a HMD. UI placement that exclusively takes place in the display-external workspace has been investigated in other articles [32, 12, 39, 35, 33, 40, 41].

3.1.3. Interaction with User Interface Elements

The controller input modality is established and often used in applications featuring a HMD. It provides the user with the ability to interact with the three-dimensional space. However, using it in combination with a desktop environment urges the user to frequently switch between controller and mouse or keyboard, causing a breach in input modalities.

Hand gestures do not require additional handheld hardware, but they are not available for every HMD. The front camera of the HMD may detect and track the user's hands' position, orientation and finger placement. This allows the user to perform certain hand gestures in order to interact with the application. Using hand gestures in combination with a desktop environment results in a smaller breach of input modalities compared to controllers. This is due to no hardware devices being involved in hand gestures. However, utilising hand gesture input in a large workspace may require a certain proximity between the user's hands and the points of interest in the workspace with which the user wants to interact. This might result in a decrease in comfort for the user.

An alternative to the previous options is the traditional mouse and keyboard input modalities. These are established in desktop environments. They offer benefits in terms of precision [9] and text entry [8]. Additionally, this input modality is strongly associated with desktop environments, which our architecture extends virtually. Given such a virtual workspace extension of the planar desktop environment, the pointer associated with the mouse input modality can traverse both the display-internal and the display-external workspace.

Additionally, there is the option of including different input technologies for the desktop interaction and the AR space. Cools et al. [18] argue in favour of employing mixed input modalities, using traditional keyboard and mouse interaction for the desktop system in combination with hand gesture interaction in the AR space. The integration of a touchscreen input modality should also be considered, as the hand gesture input modality already involves hand input in front of the desktop screen. Therefore, these input modalities are rather similar in this scenario. On the other hand, Seraji et al. [30] found in their user study, where participants also used mouse and keyboard interaction for desktop, but a tracked controller for AR interaction, that this mixed interaction led to a mental context-switching effort. Thus, they suggest that interaction methods should be as similar as possible to enhance user performance. Both of these approaches allow participants to place items far away from their screen, making interaction in the extended space difficult to achieve with a 2D device such as the mouse. Our proposed data analysis system, on the other hand, is mainly desktop based with the display extension only concerning the space in close proximity to the screen. Therefore, we suggest only using traditional mouse and keyboard input modalities for this system.

3.2. Proposed Architecture

Out of many possible use cases, we decided to use a data analysis use case that is performed on a desktop computer system in an office environment in order to illustrate the different facets of display-external UI placement. Our setup is similar to the one proposed by Cools et al. [18]. It includes a desktop computer with one monitor that provides the user with keyboard and mouse input modalities. Diverging from the usual office equipment, a HMD and a tracking device are needed in order to virtually extend this setup. While being seated in front of the desktop system, the user is wearing the HMD and therefore viewing the contents of the monitor as well as the rest of the desktop system and their environments via the HMD. In addition, the HMD tracks the position and orientation of the user's head, while performing the data analysis task. Additionally, a tracking device is attached to the monitor in order to track its position and orientation.

Via the HMD, the user can view both the contents situated inside the desktop display (*display-internal workspace*) as well as the contents situated outside the desktop display (*display-external workspace*). Due to the shape of the monitor hardware, the shape of the display-internal workspace must remain planar. The shape of the display-external workspace can be altered, though. Although a planar surface seems reasonable as it mimics the shape of the display-internal workspace, previous work [32, 33, 34, 35] has documented improved performance when working on tasks in cylindrically or spherically shaped virtual workspaces contrary to planar workspaces. Following the WIMP design schematic [**?**], we nest the data of our analysis task in windows. This creates logically separable entities in our user interface. These user interface elements can be portrayed both on the display-internal and the display-external workspace.

4. Conclusion and Future Work

In this work, we presented design considerations for the layout of data visualisations on a generic architecture for a system in which user interface placement can be investigated. This system combines a conventional desktop environment with an HMD to extend the planar desktop environment by a virtual surface around the display. This results in the division of a display-internal and a display-external workspace.

In the design considerations we discuss the topic of layouts being either customisable by the user or rather predetermined by the developer. Furthermore, the transition of user interface elements from an origin position to a destination position needs to be thought out during the design of the virtually extended display. Based on the location of these positions in regards to the display, the transition can be external-to-internal or internal-to-external. Other directionalities like internal-to-internal or external-to-external are not unique to virtually extended desktop environments. Furthermore, we argue for conventional mouse and keyboard input modality, because they are more precise, well established and strongly associated with desktop environments.

As part of our future work, we suggest implementing a prototype that features a virtually extended desktop environment. This prototype should be capable of simulating a user interface and enable the user to create and experience the effects of different user interface layouts. Additionally, a user study is required to evaluate the effects of different user interface layouts on performance, spatial memory and user experience.

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