Bridging the Gap Across Realities: Visual Transitions Between Virtual and Augmented Reality

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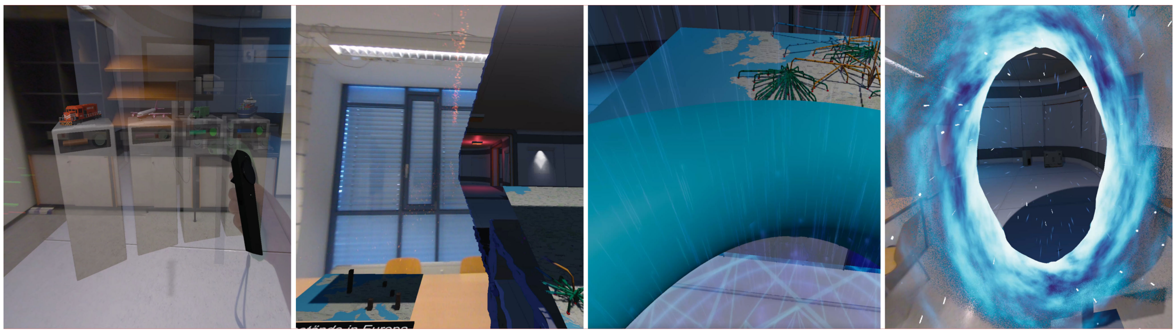

Figure 1: Four transition techniques from the user's perspective during the transition between augmented and virtual reality in the context of data visualisation. From left to right, *Fade*, *SimpleCut*, *TeleportBeam* and *Portal*.

Abstract

Cross-Virtuality applications enabling users to move between different stages of Milgram's reality-virtuality continuum are a rapidly growing field of research. Modern video see-through head-mounted displays allow users to switch between augmented and virtual reality without removing the headset. This enables for the first time a fluent transition between augmented and virtual reality. Based on insights from literature and preliminary experiments we designed and implemented four transitions: *Fade*, *SimpleCut*, *TeleportBeam* and *Portal*. These techniques were expected to represent the best suitable concepts for transitioning seamlessly between augmented and virtual reality. After incorporating results from a pre-study, the transition techniques were evaluated in a qualitative user study regarding user experience, simulator sickness, continuity and applicability. Participants were able to freely move between both realities during the study in an immersive analytics scenario for logistics data.

In the user study, users preferred *Fade* in a workplace setting due to its efficiency and simplicity when transitioning frequently between realities. The *Portal* technique was deemed visually exciting and suitable for infrequent transitions between realities that differ greatly.

Index Terms: Human-centered computing—Mixed / augmented reality; Human-centered computing—Virtual reality; Human-centered computing—User studies;

1 Introduction

Cross-Virtuality applications that interweave entities at different stages of Milgram's reality-virtuality (RV) continuum [34] develop increasing interest in the research community, as multiple recent workshops in this area indicate [23, 32, 44]. We can already observe a rising number of prototypes interconnecting heterogeneous devices and their users at different stages of the RV continuum [18]. However, many optical see-through head-mounted displays (HMDs) have a limited mobility along the RV continuum as their displays do not cover the whole field-of-view (FoV) and are not able to fully isolate the user so that they cannot be used for virtual reality (VR) [42].

Yet, there are scenarios where the combination of augmented reality (AR) and VR might be desirable, for instance in analytical tasks to exploit the higher level of immersion [29] and unlimited workspace [35] in VR, and to switch back to AR if a closer coupling with the real environment is required [5, 15, 26, 27]. Such a combination, consisting of a video see-through AR mode, together with VR became a hot topic in recent years, after more and more consumer-grade HMDs are equipped with high-resolution front-facing cameras with a large FoV and acceptable latency. Users are able to move freely along the RV continuum without having to remove the HMD.

The possibility of switching between different realities within one application raises a wide range of design questions that potentially influence how fluent and seamless these transitions are perceived. Beside the composition of adequate metaphors and interactions, additional cues guiding users through the transition such as visual, acoustic and haptic feedback have to be considered.

As central element in the design of the transition between AR, VR and vice versa we identified the visual aspect of the transition which is able to guide the user during the transition process. However, it is an open question what an ideal implementation of this sequence could look like when taking user comfort into account. This may also vary depending on the context and application area. In principle, it might be desirable to avoid excessive visual distraction during the transition, to help users stay focused on their original task. In contrast, strongly differing source and target environments might require a certain level of distraction to ensure that users do not experience discomfort due to an abrupt visual change.

To draw qualified conclusions about how transition techniques influence user experience, continuity, and overall enjoyment in different contexts, we designed and implemented four different transition

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techniques with varying visual animation and playfulness, based on our literature research: *Fade*, *SimpleCut*, *TeleportBeam* and *Portal* (see Figure 1). In the conception of those techniques, we followed a multisensory approach that considers not only visual aspects of the transition, but is also supported by acoustic and haptic feedback. These techniques were subsequently evaluated in a qualitative user study in which users were asked to analyse a logistics network in an immersive analytics [10] scenario.

2 Related Work

Visualisation approaches that combine VR, AR, and desktop without switching HMDs show an early need for transitions along Milgram's RV Continuum [34], to combine the benefits of the different realities [2, 5, 15, 26, 27]. In addition, the emerging research field of Cross-Virtuality Analytics (XVA) [41] enables seamless integration between traditional 2D visualisations, AR, and VR. To support this seamless transition metaphor along different realities, transition techniques are required and potential challenges and recommendations were identified recently [18]. However, out of these five approaches, Billinghurst et al. [5] is the only one that uses more than a simple switch to change between different realities. In their MagicBook, they use a flight metaphor where the user perceives the transition as a flight from an exocentric AR view to an egocentric VR environment. In contrast, Kiyokawa et al. [27], Benko et al. [2], and Eissele et al. [15] immediately switch between AR and VR, changing the environment instantly and without any additional visual guidance. Kijima and Ojika [26] examined the transition between the desktop and AR environment. They use the position and orientation of the HMD to trigger an immediate switch between the environments.

Visual transitions are a common technique to change location or time in three-dimensional applications with stereoscopic HMDs (e.g. Portal [50]) as well as for non-interactive time-dependent media such as films (e.g. Star Wars trilogy [31]). Based on research in film editing, a distinction can be made between hidden transitions, which preserve a sense of continuity, and more visible transitions, which actively disrupt continuity [3, 12, 13, 24]. Men et al. [33] analysed this impact in the context of scene changes in VR by comparing the following four visual transition techniques. *Fade* gradually changes the transparency of objects, *SimpleCut* uses a cutting plane to cut the environment, FastMovement uses a fast camera movement, and Vortex creates the illusion of a rapidly spinning vortex that absorbs and teleports the user. Their study confirms that less visible transitions, such as *Fade* and *SimpleCut*, increase consistency of presence, while more visible transitions, such as FastMovement and Vortex, break the continuity.

Scene transitions in VR were also evaluated in terms of presence, continuity, and usability by Husung and Langbehn [21]. The concept behind an immediate change, fading to black and fading to the target environment was inspired by well-known film transitions, while Orb, *Portal* and Transformation are based on popular VR-specific applications. The user study revealed that Orb and *Portal* received the highest overall ratings and should be used as techniques in settings where high presence, continuity, and user acceptance are required. To break continuity, fast and sudden transitions such as Cut should be considered.

Sisto et al. [45] evaluated six visual transition techniques regarding continuity and perceptibility to change the virtual environment in VR without the user noticing. They transitioned gradually from a quiet starting environment to an intermediate environment and to the target workplace environment. The combination of object-based transition techniques and selected environment settings caused only 22 percent of the participants to perceive the transition.

Slater et al. [47] and Steinicke et al. [49] investigated how a transitional environment in combination with a portal metaphor can affect the assessment of the user's sense of presence in VR. This involves starting the VR experience in a virtual replica of the physical environment and switching to the target scene using the portal as a transition technique. The idea of passing through a portal to a new environment is an easily understandable concept which is inspired by film (e.g. MGM's Stargate [16]) and video games (e.g. Portal [50]). The portal provides a preview from the target environment and can be shaped in different ways, making it a commonly used technique to move between different scenes and relocate the user [9, 11, 17].

To assist the user in leaving a VR experience, Horst et al. [20] implemented several exit sequences where *TeleportBeam*, Wipe, and *Fade* could be adapted for a transition between AR and VR. In contrast to leaving the experience, Valkov and Flagge [51] explored several ways to smoothly immerse the user in an HMD-based VR experience. They morph objects from a replica of the real environment into objects from the target scene. To support a continuous transition process, only objects outside the field of view are morphed.

George et al. [19] evaluated two interaction concepts to connect the virtual environment with the real environment and presented design considerations. The sky portal provides a continuous window to another environment, and a virtual phone acts as a user-triggered tangible window. Their user study concluded that the virtual phone has the potential to assist HMD users in micro interactions between different realities. In contrast, our work provides not only a glimpse into the other environment, but actually performs and supports the transition between realities using a transition technique.

There is not yet any work on the attitude of users towards switching between different stages on the RV continuum. However, research in outside awareness in VR suggests that this is highly relevant [37]. The option to switch between AR and VR could therefore mitigate the negative aspects of being isolated in VR.

3 Comparison of Transition Techniques

Out of 18 provided references in the area of transitions, we identified 13 different transition techniques which can be used or adapted for transitions between AR and VR. Based on the findings and analysis of our literature research we classified all techniques according to the following five criteria:

- Visibility: Indicates how noticeable the transition is. Berthouzoz et al. [3] addressed this topic in films where a distinction can be made between hidden and visible transitions. Men et al. [33] recommend visible or invisible transitions depending on the purpose. If the visibility is low, only a few visual effects are used to display the transition. In contrast, intense visual effects lead to high visibility.
- Distraction: Describes how easily the user might be distracted from the current workflow. A high level of distraction indicates that the user is pulled away from the current task. Low visibility leads to a continuous workflow, without distraction from the main task.
- Plausibility: Indicates how plausible the transition metaphor appears in the given setting. In this context, Slater et al. [46] observed in an experiment that the appearance of the virtual environment influences the plausibility of the whole scenario. High plausibility provides therefore an easier understanding of the metaphor or reasoning behind the transition. In contrast, low plausibility implies an unreal and unfamiliar transition experience.
- Interactivity: Indicates the degree of engagement between the user and the transition technique during the transition process. High engagement is achieved when the user has control over the transition to retrieve additional information or engage in the transition process [28]. Low interactivity isolates the user through the transition and prevents further action.
- Applicability: This parameter specifies the range of possible application scenarios with a given transition technique. High

applicability implies that the transition can be adopted in a variety of application areas. Low applicability refers to a technique that is applicable only to a specific context.

In Table 1 we compared all 13 transition techniques in relation to the above criteria and highlighted their references. This provides an overview of suitable transition techniques from multiple reality stages. These reality stages include transition between VR scenes, between AR and VR, and between VR and the real environment. We also include film transitions that are used in post-production and transitions that are directly involved in the plot of a film. For transition techniques that are additionally found in films, we included an example film reference in which the transition is easily identified.

3.1 Selection of Transition Techniques

We selected the following four techniques for transitioning between AR and VR based on the classification criteria and the scope of the reference list. To cover a wide range of potential application areas, we have considered transitions with high applicability and as many different characteristics as possible, such as high and low visibility, plausibility and distraction.

- *Fade* is a rather hidden transition with minimum visual effects, reducing the chance of any distraction. It lacks a comprehensible real-world metaphor, which reduces plausibility.
- *SimpleCut* has a plausible concept, as it looks like cutting objects. Visibility is depending on the transition process and the users viewing direction.
- *TeleportBeam* is a highly visible transition which could cause distraction. The concept is fairly plausible, as it is known from Film and can be used in any application. The beam around the user limits the user's interaction.
- *Portal* is a visible transition and the concept is often used in films and literature. It works similar to a real door resulting in higher plausibility and interactivity. Depending on the application additional walking space is required.

For each of the transition techniques we developed a concept and design which is described in more detail in the following chapter. We then implemented the transitions in a simulated real-world scenario of a logistics use case and evaluated them in a qualitative user study.

4 Concept and Design

Based on insights from literature, film and video games, we developed a concept on four distinct transition techniques in terms of visual design, audio design and haptic feedback. During the design process, we tried to ensure the suitability of all four techniques for a wide range of use cases without restricting possible application areas (for instance Immersive Analytics, Education, Medicine).

The transition process for each technique is user-triggered and can be initiated at any time. The focus is on the complete transition between AR and VR and the techniques are therefore not designed for system-related events, such as handling interruptions like notifications. Future work should investigate whether adapted versions are suitable for notifications from the respective other environment. During the transition process the user is in an intermediate state between the VR environment and the AR environment. Parts of the fully virtual environment as well as parts of the real surrounding can be perceived. Especially when using passive haptic feedback [30] it is common that virtual objects are visually replaced by real objects or vice versa. Imprecise alignment of those objects could cause discomfort or distraction, especially with large objects like the floor or a desk. This should be considered when developing the environments.

To pre-evaluate design decisions which are not addressed in literature and to obtain initial feedback, we conducted a pre-study. Participants noted that the transition start was often not noticed immediately, especially with *SimpleCut*. As most current hand controllers are equipped with a vibration motor, we included active haptic feedback in addition to the auditory feedback. Both hand controllers vibrate during the transition to signal the transition process.

Table 1: Transition techniques from literature and film in comparison. The rating represents Low as "-", Medium as "o", and High as "+".

Technique		Visibility	Distraction	Plausibility	Interactivity	Applicability
Portal		+	o	+	+	o
VR-VR	[9, 17, 21, 47, 49]					
VR-AR	[11, 19]					
Film	[16]					
Fade		-	-	-	-	+
VR-VR	[21, 33, 36, 45]					
VR-RE	[20]					
Film	[14]					
Appearance and Disappearance		-	-	-	o	-
VR-VR	[36, 45, 51]					
TeleportBeam		+	+	o	-	+
VR-VR	[20]					
Film	[53]					
Morphing		o	-	o	-	-
VR-VR	[45]					
Film	[48]					
SimpleCut		+	o	+	+	+
VR-VR	[33]					
Film	[31]					
Fly		+	+	+	+	-
VR-VR	[33]					
VR-AR	[5]					
Position Change		o	o	-	+	-
VR-VR	[45]					
Vortex		+	+	o	-	+
VR-VR	[33]					
Fragmentation		+	+	+	-	-
VR-VR	[45]					
Transformation		+	+	-	-	+
VR-VR	[21]					
Scale Change		+	o	-	-	o
VR-VR	[45]					
Wipe		+	+	o	+	+
VR-VR	[20]					

4.1 Fade

Instead of immediately switching between two environments, the *Fade* transition gradually changes the surrounding environments. When moving from VR to AR, the transparency of all VR-related objects is increased over time, while the transparency of AR-related objects is decreased at the same level. The real world video stream also appears slowly as the VR environment is no longer able to hide the real world. The transition from AR to VR works vice versa.

Visual Design: Figure 2 (top) demonstrates how the *Fade* transition directly blends into the target environment rather than into black or white, as it is common in films [38, 52]. This would have created an additional transition layer increasing transition duration. A black or white screen that covers the entire FoV could be distracting and cause discomfort. If the transition process is too fast, the effect is no longer noticeable. If the transition is too slow, the intermediate state in which both environments are visible to a similar extent will endure for a comparatively long time. Initial testing has

Figure 2: Time-dependent representation from the user's perspective during the transition from VR to AR. *Fade* (top) gradually increasing the transparency of VR-related objects and decreasing the transparency of AR-related objects. *SimpleCut* (bottom) cuts away the VR environment using the clipping plane, revealing the AR environment.

indicated that three seconds for the entire transition can be considered as comfortable. No additional visual effects were designed for *Fade*, as the transition already covers the entire FoV, drawing the user's attention immediately.

Audio Design: In addition to visual cues, auditory feedback is provided to signal the transition process. This is a slowly rising tone with a small final bang to notify about the completion of the transition.

4.2 SimpleCut

During the *SimpleCut* transition, the scene is cut with an invisible clipping plane that runs through the entire environment from one side to the other. Figure 2 (bottom) illustrates how the target environment is initiated behind the clipping plane and the source environment is cut off. In the pre-study, the start of the transition was often not perceived because users were facing in a different direction and not paying enough attention to the sound. To further increase awareness, the clipping plane starts along the user's view vector.

Visual Design: To support the cut metaphor, hatches are drawn on top of the sectional area, similar to an engineering drawing that provides information about the inside of an object. To clarify the transition process and draw the user's attention, small sparks are emitted at the cutting plane. These sparks help to easily identify where the dividing line between the VR and AR environment is located. They are generated with a particle system [40] to provide a dynamic spark representation. A spark visualisation was chosen as it seems natural that sparks occur when something is cut away and they are used in the popular VR game Beat Saber [22].

Audio Design: As the clipping plane moves from one side to the other, the visual effects may be out of the user's FoV. Therefore, the sound starts right at the beginning of the transition and is played until the transition is finished. The sound consists of grinding metal and sparks to further support the cutting metaphor. The audio source is positioned at the clipping plane to generate spatial audio cues.

4.3 TeleportBeam

The *TeleportBeam* technique uses the metaphor of teleportation which is known from sci-fi film series like Star Trek [6]. To represent this illusion, various visual effects are displayed. These effects allow the user to perceive the surroundings less and less as the effects increase over time. When the user is entirely inside the virtual teleportation tunnel, the user's view is fully obscured. At this point, the environment is changed from VR to AR or vice versa. As the visual effects slowly diminish, the user can see more of the target environment until all effects have vanished and the transition process is complete. A time-dependent representation can be seen in Figure 3 (top).

Visual Design Teleportation is a widely used technique for navigation in VR and usually contains no visual effects. However, studies show that teleportation can cause spatial disorientation [1, 8]. To address this effect, Bolte et al. [7] and Bhandari et al. [4] used visual effects during teleportation. This generates a visual flow that gives users the feeling of fast movements and supports spatial orientation. To imitate a fast visual flow for the *TeleportBeam* transition, small particles appear around the user and move upwards. These particles gradually move faster and should draw the user's attention. To restrict the user's view, a stack of solid, torus shaped objects appear and move upwards with the user standing in the middle of those objects. The number and speed of those objects increases, creating a teleportation tunnel and block the user's view of the surrounding. Then, the environment is changed and the visual effects are reduced, so that the target environment is slowly revealed and the transition is completed.

Participants in the pre-study noted that this transition took a long time compared to other techniques. This interrupted the workflow and was considered annoying after several changes. We have therefore accelerated the appearance of the torus-shaped objects, reducing the transition time by five seconds. We decided on 14 seconds as the best trade-off between duration and metaphor effect.

Audio Design The sound design is tied to the visual effects. The faster the particles and objects move, the more intense the sound gets. This is supposed to sound as if energy is being charged for the teleportation. At the peak, a small signal bang effect is played, indicating the transition to the other environment. Subsequently, the intensity of the sound decreases to signal a decreasing energy level.

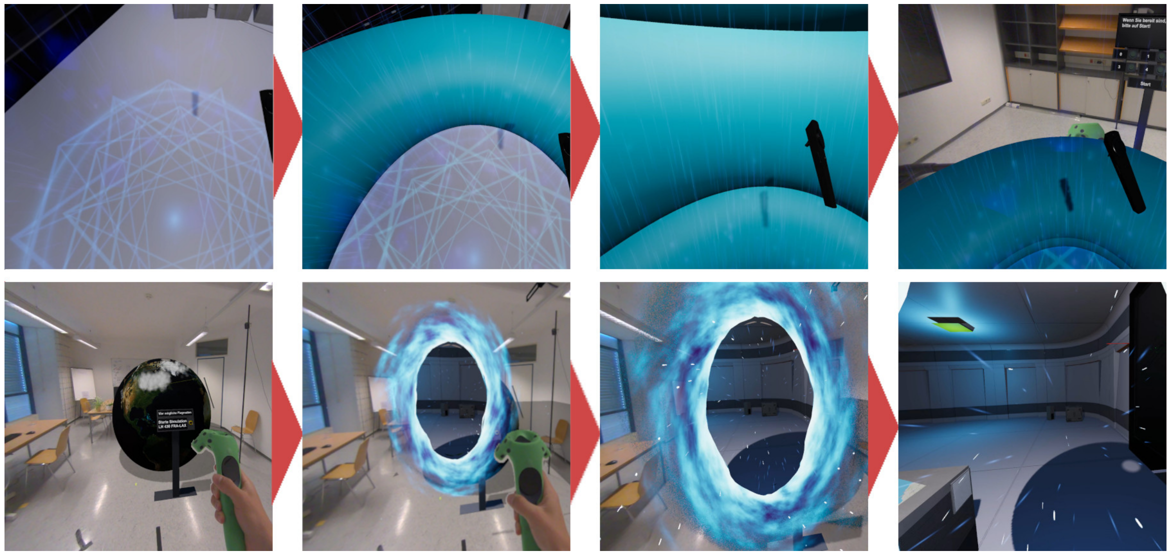

Figure 3: Time-dependent representation from the user's perspective during *TeleportBeam* (top) from VR to AR and *Portal* (bottom) from AR to VR. *TeleportBeam* gradually builds up a teleportation tunnel that blocks the user's view and slowly reveals the AR environment after switching reality. The portal opens in front of the user and provides a preview of the VR environment within the portal.

4.4 Portal

The portal metaphor imitates a gateway to another reality. In our first approach the portal could be positioned freely in space, depending on the position and orientation of controllers. Once the portal is open, the transition requires physically walking through the portal to switch between realities. After the user arrived in the target environment, the portal is closed. However, the pre-study indicated that real obstacles that are not visible in VR may cause problems during portal placement, for instance by placing the portal just before a wall or an obstacle in the real environment, preventing the user from passing through the portal. As a result, we changed placement by placing the portal in two predefined locations depending on the viewing direction of the HMD. This ensures that the portal cannot be opened unintentionally in front of an obstacle, similar to the concept of Freitag et al. [17], where the portal is automatically placed to guide the user to a safe position.

Visual Design The design was inspired by movies like MGM's Stargate [16], video games like Portal [50], or from literature [19, 21, 49], keeping it in line with the common vision of a portal. The portal is oval shaped (1.6m height and 0.4m width) and consists of an outer frame with visual effects circling the portal. This way, the sharp edge between the different realities is blended and the portal distinguishes itself from the surrounding environment. Particles are emitted from the outer frame into the inside of the portal to encourage the user to pass through. The inside of the portal displays the target environment to provide an immediate insight into the context of the other side of the portal. This allows to already perceive information about the target environment before changing. Rendering of the target environment is based on the viewing angle and is dynamically adjusted depending on the user's perspective. The portal is designed identically in VR and AR to support the idea of linking two realities. The entire transition process and visual effects are shown in Figure 3 (bottom).

Audio Design Unlike the other transition techniques, the *Portal* transition time is not predefined. It is actively controlled by the user and depends on how fast the portal is passed through. Therefore, there is a buzzing energy wave as a base tone to signal that the portal has been opened. Once the user has passed through the portal, a futuristic bang indicates that the portal is closed and the transition is complete.

5 User Study

We chose a qualitative approach and a within-subjects design to gain exploratory insights into user experience, workflow disruption and application areas of visual transition techniques in the context of immersive analytics. To address this research area, we stated the following two research questions:

- How did the transition techniques influence the users' perception of interruption in their workflow?
- What are the application areas of the respective transition techniques?

This user study was preceded by a pre-study with five participants to uncover basic usability issues for each technique.

5.1 Pre-Study

We used the feedback gathered in the pre-study to adapt the prototype for the main study to get exploratory insights into interaction without discussing usability issues of the prototype itself.

Participants: For the pre-study we recruited five participants, two of which were female, within an age range of 23 to 54.

Procedure: In a within-subjects design each participant tested each of the four transitions. With each transition, participants were asked to answer five questions by analysing data from interactive visualisations displaying logistic network data. To encourage transitioning between VR and AR, questions often required users to combine information from visualisations in different environments. At the end, a semi-structured interview was conducted where participants were questioned on the perceived transitions. Furthermore, participants were asked to elaborate on their subjective user experience and design issues of each transition.

Results: Participants reported problems with perceiving the start of the transition, especially with *SimpleCut* when participants were not facing the clipping plane at the very beginning. For *Teleport-Beam*, the duration was considered too long and therefore disrupted the workflow. Another issue we observed was the placement of the portal. Sometimes the *Portal* was placed too close to a real object in VR, causing difficulties when walking through it. Proposed and elaborated solutions were incorporated into the further concept and integrated into the prototype. A detailed explanation can be found in section 4, under the respective techniques.

5.2 Implementation

The transition techniques, virtual environments, data visualisations, and user study system were developed using Unity (2021.2.12f1). As HMD, we used a Varjo XR-3[1], featuring a dual display architecture per eye, with a total FoV of 115° at 90 Hz. The focus display has a resolution of 70 pixels per degree (27° x 27°) and the context display 30 pixels per degree. For the video pass-through mode, the built-in front cameras (dual 12-megapixel) were used. During the user study, the HMD was powered by a GeforceRTX 3090, an Intel Core i9-11900K, and 64 GB of RAM, resulting in an average of 80 frames per second. For input, we used the HTC Vive handheld controller, where all transitions were triggered by participants using the grip button on the side of the controller. To select virtual buttons, such as the filter buttons, or user study related buttons, we used position-based input from the virtual controller representation. Participants were able to move around a 4x4m tracking room with a table as passive haptic feedback.

5.3 Participants

For the main study 16 participants were recruited. Five participants were female and the average age was 31 years and ranged from 20 to 50. Participants were recruited on campus with twelve having a university degree. Eleven participants had no prior experience with visual data analysis and five participants had at least six months of experience. Nine participants had considerable experience with VR HMDs. The vision of the participants was normal or corrected to normal.

5.4 Study Design

We chose a within-subjects design for the user study with four conditions corresponding to the four transition techniques: *Fade*, *SimpleCut*, *TeleportBeam* and *Portal*. For counterbalancing we employed a balanced Latin square test design. Within each condition participants had to answer three questions by collecting information from data visualisations that were distributed over the VR and the AR environment, to encourage frequent transitions. This is also the reason why participants always had to return to AR to read and answer the questions. For the use case we chose a simple logistics use case which allowed us to derive simple subtasks that could be solved by users unfamiliar with visual data analysis. Furthermore, it allowed us to craft a fictional use case resembling reality where users would experience the different transition techniques in the context of solving a visual analytics task. The transition itself was therefore not the main attraction but rather a medium for switching between realities. A similar setup and an early generic design of the application used for the evaluation is given in our previous work on design approaches for IA [39].

In the first question, participants were asked to first check in VR which of the distribution centres in Europe was currently experiencing problems and then switch back to AR and determine the current stockpile of that centre. The second question asked participants about the total count of connections of a specific means of transportation in a specific area. This could be solved by looking at the visualisation on the global supply chain network in VR which could also be filtered by means of transportation. To answer the third question, users had to start the simulation of different flight routes on the globe in AR to determine the fastest route. Afterwards, users transitioned to VR to see how much fuel was consumed on this route and return to AR to answer the question.

[1]https://varjo.com/products/xr-3/

5.5 Procedure

At the start of the study, participants received a short introduction into the user study and filled out a standardised General Data Protection Regulation form. Then, they filled out the Simulator Sickness Questionnaire (SSQ) [25] to provide a pre-immersion baseline. Afterwards, users put on the HMD and received an introduction into every visualisation of the prototype, starting with the AR environment. When users confirmed that everything was clear to them, they were asked to initiate the first transition. The transition participants saw during this introduction was always the transition they would use in the first condition. Participants then received an introduction into all visualisations in the VR environment and then returned to AR. Subsequently, users started the first condition and answered the three questions in the task. Users were allowed to ask questions at any time during the study. After completing the condition users answered three short questionnaires. First they answered the SSQ, then the short version of the User Experience Questionnaire (UEQ-S) [43] and finally a three-item questionnaire on continuity [21]. Afterwards, we conducted a semi-structured interview including questions on workflow disruption and spatial orientation as well as questions on behaviour we noticed and comments made by users while interacting with the prototype. Then we continued with the next condition and repeated the process. After the semi-structured interview in the fourth condition, we continued with a semi-structured interview on all four transition techniques. Therefore, we first asked users to rank the four transition techniques form least pleasant to most pleasant. Then, we questioned participants on the reasoning behind their ranking and what was essential to them finding a transition technique pleasant. Finally, we asked participants about different application areas of the different conditions.

5.6 Results

In the data analysis we quantitatively analysed the SSQ, the UEQ-S and the questions on continuity using Microsoft Excel for data preprocessing and IBM SPSS for the statistical calculations. For the qualitative data analysis of the semi-structured interviews, two researchers analysed the interview notes as well as the recordings and categorised the findings.

Simulator Sickness Questionnaire

To compare the simulator sickness for the different transition types we calculated the three subscales for nausea, oculomotor and disorientation as well as the total score. A Shapiro-Wilk test suggests that the data is not normally distributed. In the Friedman test we found no significant result for any of the scales.

Continuity Metric

The continuity is calculated as a mean score of the three questions for continuity from Husung and Langbehn [21]. However, we reversed the third question before calculating the mean, since a high continuity would mean that users would give high ratings for the first and the second question but low ratings for the third question.

A Shapiro-Wilk test suggests that the data is not normally distributed (p=0.002). A Friedman test found a significant main effect ($\chi^2 = 16.678$, df=3, $p < 0.001$), and a pairwise comparison with Bonferroni correction revealed that *Fade* (Mdn_F=4.67, z=1.594, p=0.003) and *SimpleCut* (Mdn_S=3.83, z=1.375, p=0.016) were rated significantly higher than *TeleportBeam* (Mdn_T=3.17). There was no significant effect concerning *Portal* (Mdn_P=3.50). Figure 4 also depicts the overall scores for continuity.

User Experience Questionnaire

The UEQ-S provides us with an overall score for each transition technique as well as two subscales that allow for a more nuanced analysis of the results by providing a comprehensive score for pragmatic quality and hedonic quality. Overall the scores in the UEQ-S

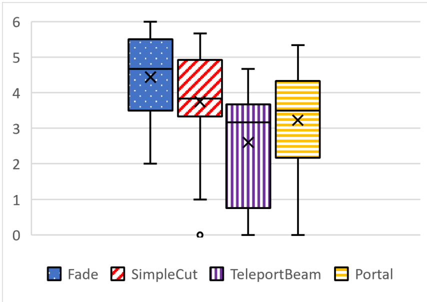

Figure 4: Boxplot visualisation of the scores for continuity showing the spread of the values

range from -3 to 3, however, values below -2 and above 2 are rare. Therefore, a score below 0.8 is considered a negative evaluation and a score above 0.8 is considered a positive evaluation.

As seen in Table 2 *SimpleCut* received the best overall rating and was rated positively in both subscales. *Fade* received the highest score in the pragmatic scale, while *Portal* received the highest score in the hedonic scale and both of the transition techniques received a positive overall rating. *TeleportBeam* received a positive rating in the hedonic subscale, however, it is the only transition technique that received a neutral overall score. Although the hedonic quality of the *Fade* technique was rated neutral, the ratings were more mixed on this subscale than on the pragmatic subscale, see Figure 5.

Table 2: UEQ-S Scores for each Transition Technique; light green markes positive evaluation scores and dark green marks the best score for each scale

	Overall	Pragmatic	Hedonic
Fade	0.922	1.922	-0.078
SimpleCut	1.289	0.922	1.656
TeleportBeam	0.680	0.156	1.203
Portal	0.953	-0.219	2.125

Qualitative Results

In the ranking from the most pleasant to the least pleasant transition technique, *Fade* came in first, followed by *SimpleCut*. *Portal* came in third place and *TeleportBeam* was most often ranked last, see Figure 6. When asked about the reason for their ranking, participants' answers can be categorised into four groups: efficiency, workflow, intuitiveness and playfulness. All participants, but one (P14), mentioned that perceived efficiency was crucial for their ranking. 13 participants mentioned aspects concerning a seamless workflow, such as little disruption, and ten participants found intuitiveness to be essential. Seven participants mentioned that playfulness, which was perceived either positively or negatively, was relevant in their decision. This was also the most important factor for P14, who did not consider efficiency to be relevant for pleasant transition techniques.

Fade This technique is suitable for daily use (15/16) with frequent transitions, specifically in a professional context, such as data analysis (10/16). It is especially useful for switching between similar environments that contain the same visual landmarks (6/16). The biggest benefit of the *Fade* technique is its speed (12/16) with only two users requesting slower (P10) or higher (P13) speed in our study. Moreover, this fast way for switching between realities may actively encourage frequent transitions (P12). *Fade* was perceived as the most efficient technique (9/16), which corresponds to the high ratings of the *Fade* technique in the pragmatic subscale of the UEQ-S, see Figure 5 and Table 2. In general, *Fade* is often barely noticed at all (8/16) and provides only little disruption of the workflow (11/16). However, *Fade* may come across as boring, which can be seen either positively (P7 & P16) or negatively (P14). However, users may miss a more noticeable visual transition (P10 & P14) with P14 describing the visual effect to resemble losing visual focus for a short while. For visually simple and fast techniques such as *Fade*, the auditory feedback is especially relevant (4/16).

SimpleCut When the transition itself needs to be emphasised, *SimpleCut* is a good choice (P15 & P16) for both professional (3/16) or playful (3/16) contexts. It is suitable for environments with shared visual landmarks (P7) as well as visually different realities (P16). However, users felt that *SimpleCut* was too slow (10/16) and may therefore distract users from their taks (P13). On the other hand, this slower visual transition may be helpful for maintaining spatial orientation (3/16). Moreover, the clear view and predictability of the transition progress can also be a benefit for novice users (4/16). Opinions on workflow disruption were mixed for this technique, with eight users feeling disrupted while five users disagreed with that. *SimpleCut* is visually exiting (3/16) which can also feel exhausting (P15) or over-the-top (3/16). Interestingly, for users it may seem like the audio effect is longer than the visual effect (4/16).

TeleportBeam The *TeleportBeam* is suitable for environments without shared visual landmarks (5/16) in playful settings (4/16). However, transitioning takes too long (16/16) for productive work (P10 & P16). Due to its long duration, users are interrupted in their workflow (12/16) which is amplified by the users being forced to stand still as soon as they trigger the transition (12/16). However, it may appear less disrupting than the *Portal* technique (P7). The prominent animation of the teleportation tunnel may affect the users focus on the task either negatively (4/10) or positively (P2 & P4). Nevertheless, being isolated in the tunnel may be visually exhausting (3/16) and make users feel uncomfortable (4/10). Furthermore, it may be detrimental to their spatial orientation (P10 & P13). Auditory feedback was mentioned to be unnecessary (P16) or not noticed at all (P4). P14 compared *TeleportBeam* to taking a lift. However, the animation may be received as over-the-top for frequent transitions (P2 & P10).

Portal For both, a professional (P13 & P14) and a playful (8/10) context, *Portal* is a good option to switch between realities without shared visual landmarks (6/16). It may also be suitable for more than two realities (P12 & P16) and it emphasises the transition (P15 & P16). Using *Portal* the total duration from triggering to finishing a transition may be too long as it requires users to actively step through the *Portal* (3/16). This additional physical action may also strongly interrupt the workflow (11/16), except when users are able to integrate it (3/16). However, looking for and stepping through the *Portal* may still be distracting users from their task (7/16) and exacerbate spatial orientation (P10 & P16). The peak view into the other reality, however, may mitigate this effect (P10 & P12). *Portal* is more visually appealing and more fun than *Fade* or *SimpleCut* (6/16) and may actively encourage interaction (P5 & P13). Moreover, users appreciate to be in control over the exact point and duration of the transition (4/16) and the *Portal* metaphor resembles walking into another room in the real world (P2 & P11).

6 Discussion

In the user study we found that user experience for transition techniques in AR and VR depends highly on the overall context as well as the specific use case. This is represented by the difference in scores for the UEQ-S subscales as well as by users' comments in the semi-structured interview. For example, the *Fade* technique reached the fairly good score of 1.922 in the pragmatic subscale of the UEQ-S and the neutral rating of -0.078 in the hedonic subscale. However, in the interviews participants appreciated that the transition was "boring", with P7 stating that "in the work context these negative attributes from the UEQ-S, like boring, usual and conventional, are

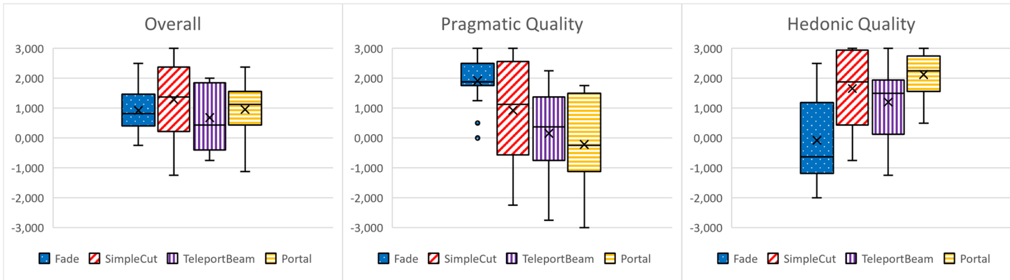

Figure 5: Boxplot visualisation of UEQ scores showing the spread of the values

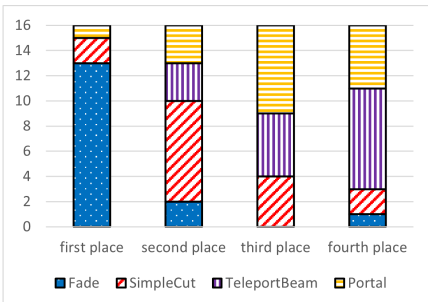

Figure 6: Scores in the Ranking showing the frequencies of which transitions were assigned to which rank.

actually positive". This is also reflected in participants disliking elaborate animations and in the ranking of the *Fade* technique in first place. *Fade* is inherently simple and quick and therefore most participants preferred this technique in the context of data analysis. In contrary, the *Portal* technique received very high results in the hedonic subscale (2.125) while it received only a neutral rating for the pragmatic subscale (-0.219). However, since the pragmatic aspects were more valued by the participants, *Portal* was mostly ranked in third place.

Additionally, efficiency was mentioned by all but one participant as the main reason for their ranking scores. In the case of our user study efficiency was mainly interpreted as speed but also in terms of disruption of the workflow. Therefore, this demand for efficiency is reflected in the users statements of preferring a certain technique because it was faster as well as in the high ratings in terms of continuity for the *Fade* technique. Although, participants could potentially transition even faster using *Portal*, it was received as more disruptive since it required an additional physical action and users were often not quite sure where the *Portal* would appear. Additionally, in our study users answered questions incorrectly more often when using *Fade*. However, this is not a statistically significant result and must be evaluated in a controlled quantitative experiment.

However, participants mentioned that *Fade* was only their first choice for the work context. In different application areas, such as playing games or attending a virtual concert, users preferred other techniques, such as *Portal*, chosen by eleven participants, *TeleportBeam* by four and *SimpleCut* by five participants. Nevertheless, *TeleportBeam* was not at all mentioned as an option for transitioning in a professional context while *Portal* and *SimpleCut* still received some support for professional use.

Nevertheless, the specific use case is also crucial in defining which transition technique is suitable. For use cases where the environments are similar to each other and share visual landmarks, participants preferred a more subtle transition technique such as *Fade* or *SimpleCut*. This is also the case for use cases where users transition frequently between realities. On the other hand, users mentioned that they would prefer *Portal* or *TeleportBeam* for transitions between environments that differ greatly and do not share visual landmarks.

Furthermore, users mentioned that a more prominent transition is useful when the user is unfamiliar with the target environment or with working across realities in general. A prominent transition is also crucial for scenarios where users need to be aware of their whereabouts in the realities. This could for example be the case in collaborative scenarios when users want to discuss specific content within one environment or for the simple reason of not bumping into one another.

7 Conclusion

In this work we conceptualised, implemented and analysed four techniques for transitioning across different stages on Milgram's reality-virtuality continuum: *Fade*, *SimpleCut*, *TeleportBeam* and *Portal*. In an exploratory qualitative user study we found that *Fade* is suitable for frequent transitions in a workplace setting when realities share visual landmarks. *SimpleCut* is useful if transitions occur less frequent and realities share visual landmarks. It is suitable for both professional and non-professional contexts and especially novice users benefit from its clear representation of the transition itself. For transitions between realities that do not share visual landmarks, *Portal* is a good fit. However, transitions should not be necessary too frequently. Finally, *TeleportBeam* is less suitable for a professional context or frequent transitions, but is an option for a playful environment with little shared visual landmarks.

Since the field of visual transitions between realities is relatively new, there is still much work to be done in future research. The techniques implemented in this work still need to be evaluated in a quantitative study. A quantitative experiment could further compare the implemented transition techniques to a baseline condition without visual support, such as the immediate switch implemented in the Oculus/Meta Quest series. Moreover, there is yet no research that considers the whole reality-virtuality continuum. This also includes transition techniques for more than two stages on the continuum and transitions from and to reality, as results could differ compared to our approach. Furthermore, at this point haptics and audio where only considered as support for awareness. However, when sounds differ in realities, not only the visual representation needs to transition but also the auditory representation.

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