Design Considerations for Cross-Virtuality Applications

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In this publication potential challenges and aspects which are to be considered when designing cross-virtuality applications are highlighted. Current state of the art is presented and novel thoughts are introduced. Technical considerations like visual displays, tracking and network are discussed as well as conceptual considerations. Here we take a brief look at topics like visual transitions, interaction, visual coherence evaluation and locality.

CCS Concepts: • **Human-centered computing → Collaborative and social computing**.

Additional Key Words and Phrases: cross-virtuality, technical design, conceptual design

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1 INTRODUCTION

Although different stages of Milgrams' reality-virtuality continuum (RVC) [20, 21] have been extensively explored individually only few applications and experiments exist which make use of multiple locations of the continuum simultaneously or interconnect them dynamically. These systems are known as Cross-Reality (CR) [34] or Cross-Virtuality [28] (XV).

The desire for such applications is high, since the different locations can have diverse exclusive advantages and disadvantages when compared to each other. For example in the area of information visualisation large scale planar displays are often used for data analysis providing a clear and tangible overview. They could be extended with the help of augmented reality (AR) to offer a stereoscopic 3D view on the data set while interconnecting it with the display, a setup known as augmented display [27]. Ideally these systems could be extended to virtual reality (VR) hardware in the area of immersive analytics (IA) [6] providing a nearly infinite layout space [22]. XV would allow such a setup being able to transition seamlessly through the RVC stages and as Roo et al. demand to allow the users "to create unified mental models out of heterogeneous representations" [30].

Capable visual displays realising the desired transitions between all stages of the RVC were not available until recently, due to the availability of the required hardware. The rising interest is documented by two workshops on XV which have been held at ACM ISS '20 and '21 [13, 34], a recent journal article providing an overview on cross-virtuality analytics [11].

In this position paper, we identify technical and conceptual design considerations for the creation of such XV applications. We focus here on the aspects which become relevant when moving along the RVC but of course of the existing design aspects of the individual stages like AR and VR are still valid and have to be considered.

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2 RELATED WORK

Only a few examples for true XV applications exist, allowing transitions between the different stages of the RVC. One of the early XV examples is the Magic Book by Billinghurst et al. [3, 4]. Here users are able to experience augmentations registered with a tracked book, but they can also fully dive into an egocentric VR version of the scene, and perceive the book as a regular real physical object.

In another early experiment Kiyokawa et al. allow view mode switching between AR and VR to analyse collaboration between two participants [15].

Benko et al. use the combination of different technologies, like display surfaces, touch interaction and HMDs [2]. The are able to perceive data either in AR or in an egocentric VR mode.

Different combinations of spatial AR (SAR), see-through HMDs and VR are presented by Roo et al.[30, 31]. In one experiment they combine SAR and exocentric views with VR and egocentric views. In this setup they examine accuracy during selection tasks [30]. The other closely related publication by Roo et al. deals conceptual aspects separating the RVC in 6 stages between which fluent change should be possible [31].

The demand for moving between the stages of the RVC in smart production is documented by eissele et al. [8].

An extensive discussion on different types of XV in the context of IA was recently published by Fröhler et al. [11].

3 TECHNICAL DESIGN CONSIDERATIONS

The most relevant aspects of an XV setup from a technical point of view are the visual displays, a coherent tracking space, and a network to interconnect different displays and input devices. Other displays like audio and haptic are considered relevant but the focus of this publication is limited to visual displays.

3.1 Display Hardware

In terms of display hardware the current technology which seams ideal to implement XV are video-based see-through Head-Mounted Displays (HMDs) if full flexibility is desired. These HMDs are the only displays which can deliver full isolation from the real world when they are used in a VR mode allow with their see-though capabilities a view on the real world with an adequate field of view.

For augmented displays combining 2D displays with augmentations approaches using optical see-though displays is sufficient if a large field-of view is not negligible. A classic but still valid comparison between the two technological approaches is provided by Rolland et al. [29].

3.2 Tracking

For displaying a 3D environment using an HMD 6 degree-of-freedom (6DOF) head tracking is required. Typically also tracking for the standard input controllers is provided. In XV scenarios it would be desirable to have additional information about the real environment. For example when displays are to be augmented they have to be co-registered in the tracking space of the HMDs. With large displays the position and orientation might be hard coded but with mobile displays either the same tracking environment has to be used or multiple tracking environments have to be fused.

The more mobile physical objects are involved the more sophisticated the tracking has to be. For user tracking Time-of-Flight (TOF) sensors like the Kinect might be used. Optical markers could be included or lighthouse tracking is incorporated which supports most of the video-based see-through HMDs. Sensor fusion might be challenging, since different resolutions and runtimes would have to be considered. Ideally physical artefacts like documents could be scanned and digital replicas would have to be created.

3.3 Network and Software

In case multiple input devices have to be used often communication via Bluetooth is sufficient but when multiple displays are used network communication is mandatory. If collaboration over distance is a potential scenario network is also required. Generic low-level protocols will have to be designed, to be cross-application, cross-device and cross-platform, but they also need to be highly efficient to fulfil the needs of immersive real-time communication.

Since a plethora of potential devices can be involved cross-device and cross-platform development tools like Unity might act as a foundation for development. A generic software approach considering the previously mentioned aspects has been suggested by Pointecker et al. [26].

4 CONCEPTUAL DESIGN CONSIDERATIONS

Besides the technical challenges noted in the previous section many application design aspects which occur only when moving along the RVC or interconnecting different locations of it have to be considered.

4.1 Visual Transitions

The most obvious aspect to be taken into account are the visual transitions between the different RVC stages. A variety of visual transition techniques (fading, cutting plane, teleport and portal) has already been presented by Pointecker et al. [25].

Approaches for moving from the fully real world with additional 2D displays into an augmented space are also required. Here extrusion from 2D displays [36] even with transformation of data during the extrusion process [32] is desirable. An alternative would be the extension of displays [18]. Also the appearance of augmentations in the real world should be discussed and analysed, many alternatives to simple popping-up, like for example fading-in or upscaling would be thinkable.

Similar considerations would have to be taken for the inverse approach of AR, when real world content is displayed in VR in case of augmented virtually applications [35]. In case the camera resolution is good enough, it could be helpful displaying input devices like keyboards or displays from laptops or other mobile devices in the VR space. Here the real world window appearance can for example be triggered when close to the devices. In case the camera resolution of the HMD is too low the displayed content could be rendered redundantly in VR space, but also providing an indicator like an outline showing that a real world display is interconnected with the virtual displayed content.

Interconnecting these approaches and consideration could lead to a fully transitional interface covering all stages of the RVC and allowing a fluent movement between them.

4.2 Interaction

Throughout XV the interaction should ideally stay consistent, or follow at least the same interaction metaphors. This can become challenging if different technologies are combined for example 2D touch interfaces with augmented displays and 3D controllers in VR scenarios.

When controllers are used this will hinder touch interaction on 2D surfaces on the other hand interaction without controller will be beneficial for touch interaction but will pose problems in the spatial domain, since mid-air gestures will lead to problems like the gorilla arm [5, 19].

Approaches using mobile devices like tablets or smart phones [37] for 3D interaction need to be investigated further. Additional tangible devices could be integrated.

To allow for changing from controllers to touch interfaces it could be beneficial, to make use of the real environment for passive haptics feedback [16]. Here the controllers could be placed on real surfaces if not in use. Real world objects like tables, walls, displays could either be integrated with pre-calibration (if static), tracking or depth sensing hardware. If a high degree of Extend of World Knowledge (EWK) [20] is available aspects like substitutional reality [33] could be realised to provide a virtual environment with similar geometrical properties like the real environment. This might help orientation, spatial consistency, and allow for additional interaction possibilities.

4.3 Visual Coherence

When moving from VR to AR and vice versa a level of visual coherence between the different environments should be used. This problem is well researched in the field of AR for creating a coherence between the real world content and the augmentations. Aspects to be considered are lighting [7] and shadows [12] and occlusion [9].

4.4 Evaluation Methodology

MR applications in general have a set of techniques and tools used for evaluation. A discussion on the evaluation specifically of transitional interfaces in the area of XV is provided by Friedl et al. [10]. They suggest to look at the four aspects presence, physical discomfort, spatial orientation and cognitive load.

Related to the technology of video-based see-through HMDs a Simulator Sickness Questionnaire (SSQ) [14] or similar approaches would have to be used to verify that users do not encounter a significant degree of cybersickness which can be caused easily by the lag of the displayed real world video stream.

Since observation is challenging during XV advanced mechanisms for logging and replay are required. The users behaviour can be observed partially from the outside by using traditional video recording, but the face is still occluded by the HMD. Video streams can be captured and also eye tracking might be logged. A systematic review on logging in MR environments is provided by Lutoto [17]. Here applicable mechanisms could be analysed and adapted for XV logging and replay.

In general it would be helpful to create a novel set of tools targeting the unique aspects when transitioning between the stages of the RVC or interconnecting these stages. New or adapted questionnaires designed for XV would be desirable.

4.5 Locality and Collaboration

Often collaborative scenarios are interesting. In AR collaborating users are commonly co-located, while collaborating VR users are often dis-located. When both worlds are combined we have to deal with partially co-located and partially dis-located user groups which should be able interact through the different realities.

The main challenges opening up in such scenarios are communication and user representation.

User representation has been analysed extensively in VR looking at self- representation and also the representation of remote users. Integrating remote participants in AR environments has been explored for example in Holoportation [23]. Both approaches would have to be merged, but also transitions of user representations (self and remote, e.g. changing from AR to VR) are to be investigated.

To allow interaction visual hints and communication cues like gaze vctor, object highlighting, pointing line have to be provided [1, 24]. They might change depending on used stage of the RVC.

5 CONCLUSIONS AND FUTURE WORK

We have briefly introduced our thoughts on the general design of XV applications from a technical and conceptual level. The application areas of such approaches are endless. Much research is still to be done in this rather novel research area and we are happy to discuss potential solutions at the workshop.

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