

Challenges of Single-User Cross Reality Applications

NANJIA WANG, University of Calgary, Canada

FRANK MAURER, University of Calgary, Canada

Cross-reality (CR) is defined as "the transition between or concurrent usage of multiple systems on the RV continuum."^[1] Our work aims to develop the guidelines and processes to create the single-user CR application. In this position paper, we present three scenarios derived from the definition of CR, focusing on single-user CR applications. For each scenario, we discuss some challenges that need to be considered in order to enhance the single-user CR experience.

Additional Key Words and Phrases: cross reality, augmented reality, virtual reality, mixed reality

1 INTRODUCTION

For decades, researchers have been conducting studies and designing applications to exploit the benefits and define the limits of Extended Reality (XR) on different points along Milgram's RV continuum (RVC)^[14]. Given available technologies, different points on the spectrum are more or less suitable for different tasks. Standard 2D monitors have higher resolution and readability than head-mounted displays (HMDs) and currently seem to be more suitable for analytical tasks that require accurate and precise viewing^[10, 18, 21]. Compared with a standard monitor, immersive technologies such as virtual reality (VR) and augmented reality (AR) are expected to increase performance for analytics tasks that involve 3D visualizations^[9]. Bowman and McMahan point out that VR supports stereopsis, head tracking, motion tracking and provides depth cues that are not available with a standard monitor. These advantages of VR lead to better spatial understanding and reduce information clutter^[4]. However, VR HMDs isolate the user from the real physical environment, so the user can only perceive information from virtual content rendered on the VR display. AR HMDs allow the user to perceive information from the physical world while preserving functionality such as stereoscopic visualization and body motion tracking. Nevertheless, disadvantages such as low contrast and a narrow field of view (FoV) remain unsolved, which are barriers between the user and a fully immersive experience^[3, 20]

With the advancement in head-mounted displays (HMDs), multi-sensory rendering, computational capability, and enhanced networking technologies, applications are no longer restricted to a single space on the RVC. Therefore, researchers have started exploiting the potential benefit of a system that connects multiple points or spaces on the Milgram spectrum. CR applications naturally utilize systems or devices in different spaces along RVC. Thus researchers have proposed research ideas and started conducting studies focusing on CR collaboration.^[2] However, the potential benefits brought by single-user CR should not be neglected. Single-user CR applications can enable users to transit to the space along RVC most suitable to the specific task. In addition, the user could use the device in one space on RVC to enhance the user experience with the device in another space on RVC.^[13] Our work targets state-of-the-art personal technologies that are commercially available and accessible by daily users, such as AR HMD, VR HMD, desktops, laptops, and tablets. Our work aims to develop single-user CR applications that bridge different points of RVC to integrate the advantages, overcome the drawbacks, and gain more insights into developing the processes and guidelines for implementing single-user CR applications that allow easily and effectively moving between different points of the spectrum, enabling users to utilize the capabilities of extended reality technologies when suitable. In this position paper,

Authors' addresses: Nanjia Wang, nanjia.wang1@ucalgary.ca, University of Calgary, Calgary, Canada; Frank Maurer, frank.maurer@ucalgary.ca, University of Calgary, Calgary, Canada.



Fig. 1. Single-user CR prototype for reservoir engineering data visualization. The user performing analytical work on a laptop transit 3D reservoir model from standard monitor to VR space to increase working space and improve spatial perception.

we present three single-user CR applications scenarios derived from the definition of CR. We suggest these scenarios as the scope of a dimension so that all single-user CR applications can be described by at least one of the scenarios.

2 SINGLE-USER CROSS REALITY TRANSITIONS

A key usability challenge for cross-reality applications is allowing a user to transition seamlessly between different points of the spectrum while bringing the state of the work and corresponding documents along. This section presents three scenarios for single-user CR applications that are derived from the definition with challenges associated with each scenario. Derived from the definition of CR, single-user CR applications should support at least one of the following three scenarios.

2.1 Transition of the environment along the RVC

The first scenario is transitioning between the space with different degrees of immersion along the RVC (i.e., user transit from real physical space to virtual space). An example is a user doing analytical work, putting on a XR headset for the tasks on 3D visualizations, and continuing working in a fully immersive environment. This transition from the real physical environment to the virtual environment changes the level of immersion. In addition, the transition removes the limitation of space for showing virtual content due to the physical dimension of the standard monitor. Thus the transition from the real physical environment to the virtual environment can increase the information bandwidth. In this position paper, we define information bandwidth as the amount of information perceived by the user at a given time. Following are challenges for single-user CR applications that fall into this scenario:

- **The seamless transition across the RVC**

Although the action "put on VR HMD" would transition the user from the physical environment to the virtual environment, the move is not seamless since the real environment and the virtual environment are separate each other and the action "put on headset" distracts the user from her tasks. A seamless transition should be easier to achieve between points closer to each other on RVC (i.e., transition between real environment and AR environment, transition between AR and VR environment). An optical see-through HMD has the potential to support the seamless transition between the real and AR environment[15, 20]. However, state-of-the-art video pass-through HMD that renders live captured video supports cross-environment transition

between all points along the RVC, including the real and VR environment transition[11][16]. Therefore it is essential to investigate utilizing these techniques to provide a seamless transition across the whole Milgram spectrum.

- **Consistency across graphic user interfaces (GUI) along the RVC?**

For a seamless transition, GUIs need to be consistent across the RVC while taking advantage of the platform-specific capabilities[6–8]. The physical size of the screen limits traditional GUIs on the standard monitor. Therefore, the developer needs to decrease the clutter of GUI elements within the 2D plane so that important content is not occluded. Meanwhile, XR GUIs are not restricted by the 2D physical boundary of the standard monitor so that developers can take advantage of the 3D room/virtual space for GUI placement. Input devices for different points of the RVC have different strengths and weaknesses. For example, the mouse is a fast point device that is suitable for precise selection in the 2D plane. On the other hand, the XR controller performs well at 3D space selection but is hard to use to pinpoint the small virtual object. The single-user CR application should maintain aspects of windows, icons, menus, and pointer (WIMP) for GUIs along RVC to make engaging with the applications at different points along RVC easier. Meanwhile, enabling users to move workflows into the best-suited point of the RVC, utilizing the strengths of the interwoven devices.

2.2 Transition of the virtual objects along the RVC

The single-user CR application should allow users to move virtual objects from one point on RVC to another. This transition should be bi-directional. The system should enable users to seamlessly move 3D virtual objects to the environment with a greater degree of immersion (i.e., move virtual objects from the standard monitor to the virtual environment). Therefore users can gain more depth cues such as motion parallax, perspective, occlusion, and stereopsis[4]. Another use case is moving virtual objects from the immersed environment to a standard monitor when viewing the detail of 2D virtual objects or continuing analytical work on the standard monitor while taking a break from a XR session.

- **The seamless transition of visualization**

The seamless transition allows the user to effortlessly move visualization along the RVC while focusing on the task. Many factors can affect the seamlessness of the transition. The prototype implemented by SCHWAJDA et al. creates an illusion for the user during user transit graph-based visualization from a standard monitor to an AR environment which appears to the user that the visualization is moving out from the standard monitor into 3D space[19]. In addition, the transition should be triggered by natural and effortless interaction. The gesture that grabs and pulls the visualization is an example of natural interaction. The transition of visualization from a standard monitor to an immersive environment can be triggered by clicking a 2D button using a mouse or hitting a key on a keyboard since a mouse and keyboard are conventional input devices. Since the transition started from a standard monitor, triggering the transition using input devices that the user familiarizes with can be effortless. Other input modalities that can offer seamless and effortless transition include but are not limited to voice input and eye gazing.

2.3 Interacting with multiple systems located at different points along RVC concurrently

A typical example of concurrent usage of CR applications is multiple users collaborating using systems at different points of RVC. A single user usually is present at a specific point of the RVC. However, a single user interacting with multiple devices with different levels of immersion can be considered "self-collaborating." Standard monitors, AR HMDs, and VR HMDs have advantages in viewing and interacting with different types of visualizations. A user could not wear AR and VR HMDs simultaneously. However, the system that utilizes concurrent usage of the standard monitor and VR/AR HMD has the potential to enhance the immersive experience.

- **Enhance the user experience with device located at different point on RVC**

Concurrent usage of multiple devices along RVC can enhance the user experience in different ways. For example, a few studies use AR HMDs to generate 3D visualizations to augment 2D graphs displayed on the standard monitor[12][17]. The standard monitor can be used to augment 3D visualizations rendered on AR HMDs. Cartwright et al. proposed rendering 3D reservoir visualization on AR HMD while using the standard monitor to display 2D charts related to the reservoir model to support reservoir engineering workflows[5]. Concurrent usage of single-user CR applications is not limited to augmenting visualization. Personal devices along RVC, such as a tablet, smartphone, or XR HMD, can be used as peripheral devices to interact with the system at a different point on RVC. Mayer et al. proposed a prototype that uses a tablet as a handheld device (HHD) to interact with visualizations generated on VR/AR devices[13].

- **Unify ways of interaction**

Since the user can interact with multiple devices concurrently, it is essential to utilize a unified input modality so that the user is not distracted from the task by frequent input method switching. The unified input modality can be realized by connecting a single input device to multiple CR devices. For example, the prototype proposed by Mayer et al. uses a tablet as the primary input method for the application[13]. In addition, the user can interact with both XR HMD and standard monitor using the built-in hand tracking in the XR HMD or using an external hand tracking device such as the Leap Motion sensor.

3 CONCLUSION

This paper presents three single-user CR scenarios with challenges associated with each scenario. We hope this paper will be a minnow being thrown out to catch a whale at the workshop, which can lead to a better understanding of single-user CR that contributes to a concrete guideline for developing single-user CR applications.

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