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[DC] Towards Understanding, Alleviating, and Exploiting the Effects of Asymmetry in Collaborative Mixed Reality

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Abstract

Mixed reality (MR) has the potential to transform the way we communicate and collaborate. However, there is a lack of knowledge about the collaborative use of different MR devices, such as collaboration between local augmented reality (AR) and remote virtual reality (VR) users. This position paper outlines research focused on deepening our understanding of the impact of asymmetry on collaboration and to use this knowledge to mitigate its negative effects and leverage its positive potential, leading to improved collaboration in MR environments. The findings of this research are expected to be valuable for the design of systems that support a diverse range of collaborative scenarios.

Index Terms: Human-centered computing—Collaborative and social computing systems and tools;

1 Introduction

Personal computing devices have become the backbone of modern communication and collaboration. However, the ongoing evolution of technology capabilities and form factors makes it challenging to design effective systems for collaboration between different types of devices [1]. Mixed-reality (MR) technologies, such as virtual reality (VR) and augmented reality (AR), present similar challenges in their integration into collaboration. While MR is at the forefront of the future of communication and collaboration, little is known about the collaborative use of different MR devices. Asymmetric collaborative MR (CMR), where different users collaborate using different MR devices (e.g. AR and VR), presents numerous challenges in the creation of collaborative virtual environments (CVEs) where remote and local users can work together seamlessly [4]. This asymmetry obstructs the ability to send and receive awareness cues, hindering the ability to establish a shared understanding of the environment and tasks, and reducing the effectiveness of collaboration [3]. Alleviating these barriers could not only improve productivity and ease of use, but could also help ensure that every user is able to collaborate effectively regardless of the devices they are able to access.

However, asymmetry in CMR can also be a valuable asset when used properly [13]. For example, through subjective views, which enable users to have a customised view of a CVE to display private or role-specific information [10]. In addition, asymmetry can also be useful in scenarios where specific tasks are more easily carried out with a specific MR device (e.g. remote assistance).

The objective of my research is twofold. First, to *understand* the effect of asymmetric factors on CMR, and second, to develop new techniques and guidelines based on these insights to *alleviate* and *exploit* these effects to create effective and inclusive CMR experiences. This research will involve: (1) evaluating the effect of asymmetric factors on CMR; (2) developing techniques and systems to alleviate and exploit the effects of asymmetry; (3) and leveraging the findings to propose guidelines for the design of asymmetric CMR systems.

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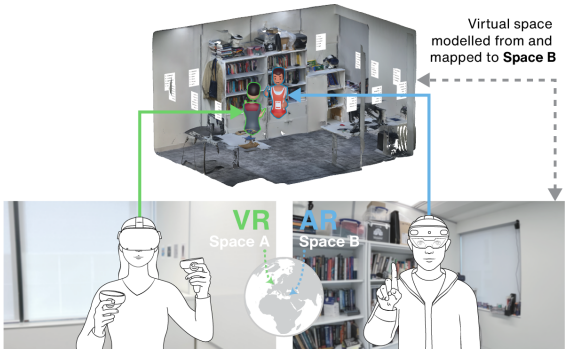

Figure 1: Conceptual overview of the CMR system, including a 3D model of the AR user's physical space (Space B) and user avatars. Line illustrations by Suhyun Park (artist).

In conclusion, this research aims to address the challenges faced in asymmetric CMR in terms of awareness and explore the potential benefits of asymmetry for improved collaboration. By developing techniques and guidelines based on the insights gained from the research, this work aims to pave the way for the creation of more inclusive and effective MR systems for collaboration in a variety of asymmetric scenarios.

2 Current Research

An exploratory pilot study was conducted to understand user behaviour in collaborative tasks within an asymmetric MR setting [7]. The study utilised a system developed in Unity with Ubiq [2], as shown in Figure 1. This work focused on the behaviour of collaborating dyads, in which one user used an AR head-mounted display (HMD) and the other user used a VR HMD to solve a puzzle task. This study was based on previous research that has found evidence suggesting that immersion confers leadership emergence [8, 9, 12].

The CVE consisted of a 3D model of the AR user's physical environment and depicted users as cartoon-like avatars. The puzzle task involved identifying and ordering words with matching numbers displayed on virtual posters throughout the (virtual) room. Each trial consisted of two periods of fifteen minutes. Participants were randomly assigned to the AR or VR condition for the first trial period and then switched conditions for the second trial period. Motion and audio data of the participants were recorded during the trial using the *record and replay* module of the Ubiq-Exp toolkit [11]. Following each trial period, participants completed a questionnaire assessing their experience in terms of sense of presence, co-presence, and accord. Additionally, participants rated their own and the other participant's leadership and talkativeness.

The subjective responses collected showed that the AR or VR condition did not have a significant effect on the distribution of leadership and talkativeness within dyads. However, objective data revealed that AR users tended to be more talkative than VR users, which could suggest a higher level of activity. Post hoc analysis revealed statistically significant relationships including co-presence and presence, head rotation velocity and leadership, and talkativeness and leadership.

In addition to the pilot study, the described system was applied within an outdoor scenario, combined with a large-scale photorealistic model of a street in Nicosia, Cyprus. A paper describing design considerations, lessons learnt, and future work areas will be presented at the ReDigiTS workshop at IEEE VR 2023 [6].

Lastly, to support the development and evaluation of future systems, an extension of the Ubiq platform was developed for server-assisted CMR applications, titled Ubiq-Genie [5]. This modular system enables the decoupling of applications into a server-client structure, enabling the offloading of computationally intensive processes to support applications that are not possible with current untethered MR devices.

3 Planned Research

Upcoming research will carry out a more in-depth examination of the three objectives discussed: understanding, alleviating, and exploiting the effects of asymmetry in CMR.

To gain a deeper understanding of the effect of asymmetry on CMR processes, the next phase of this research will build upon the findings and limitations of the previous pilot study. The upcoming studies will examine the challenges of collaboration in asymmetrical setups, such as issues regarding inconsistent environmental representations, technical glitches (e.g. registration errors), and other conflicting information. These studies will feature domain-specific tasks and involve interactions between virtual and real spaces, which could emphasise the impacts of asymmetry. Furthermore, user behaviour will be evaluated using a wider range of objective measures to obtain more comprehensive insights. Additionally, video see-through HMDs will be used to equalise the field of view of AR and VR users, reducing the chance of unintended device-related bias.

To alleviate awareness-related issues caused by asymmetry in AR-to-VR collaboration, I am exploring the design of systems that enhance users' awareness of the CVE and others' interactions with it [3]. Technical and practical limitations prevent virtual replicas of physical spaces to be kept up-to-date continuously, which obstructs remote users' sense of awareness. To address this, I am investigating alternative ways of virtually representing physical environments. For example, by using vision-based algorithms or sensors that gather, interpret, and represent environmental information dynamically, simplified virtual representations of spaces that maintain similar semantic and spatial properties and constraints as their physical counterparts may be created. The potential benefits of these representations could include reduced bandwidth usage, real-time changes, and protection of local users' privacy. User studies will be conducted using a mixed methods approach to assess the effectiveness of these alternative representations for successful collaboration.

To exploit the effects of asymmetry in CMR, my objective is to investigate how asymmetric user roles and views can enhance collaboration efficiency. For instance, in the context of city planning, different stakeholders may desire to view and interact with distinct information layers of a virtual replica of a city. A crucial challenge in this regard will be to effectively coordinate the actions and perspectives of all users involved.

As a concluding contribution, my goal is to establish a comprehensive set of guidelines for the design and implementation of asymmetric CMR systems. With this research effort, I seek to contribute to making CMR more effective and accessible for all to help realise its full potential. I am eager to receive any form of feedback on my research during the Doctoral Consortium at the IEEE VR 2023 conference. I would appreciate any reflections or suggestions regarding the following questions in particular.

- What are the main effects of asymmetry and how can they be addressed?
- What are the best proxy tasks for asymmetric interaction to ensure generalisability?

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