Scaling Distributed Collaboration in Mixed Reality

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ABSTRACT

Distributed collaboration in Mixed Reality (MR) promises to revolutionise how people connect across different physical environments, offering experiences akin to face-to-face interactions. However, previous work has mostly focused on enabling this vision in overly simplified settings such as with only two users interacting in identical distributed environments. Scaling current systems to work with large groups and for common real-life scenarios is a persistent challenge that requires addressing multiple tensions. We identified six challenges: 1) supporting locally congruent actions from heterogeneous remote spaces, 2) communicating accurate user behaviours through virtual representation instead of physical bodies, 3) facilitating organic group interactions within limited physical space, 4) maintaining conversational dynamics even in asynchronous exchanges, 5) providing equal access to physical objects for all participants, and 6) enabling efficient task switching within a complex ecology of applications, devices, and accessibility needs. This workshop aims to gather researchers and practitioners to explore actionable strategies for resolving these challenges. Through a mix of presentations, hands-on activities, and group discussions, participants will generate new ideas and develop a research agenda to articulate the future of MR collaboration systems. The workshop outcomes will include a list of concrete next steps for the community to bring distributed MR collaboration at scale.

CCS CONCEPTS

• **Human-centered computing** → **Mixed / augmented reality**; **Collaborative interaction**.

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KEYWORDS

Mixed Reality, Collaboration, Human-Computer Interaction, Distributed Systems

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1 MOTIVATION

Collaboration is essential for solving complex problems. It becomes especially critical when tackling large-scale scientific challenges, where diverse expertise is needed and different people contribute in various ways. However, as our world becomes increasingly distributed, these collaboration efforts face new hurdles. Software solutions such as videoconferencing tools have become instrumental in maintaining connections despite distance and fostering new global collaborations that might have been impossible otherwise. Yet, these tools require us to adapt our communication styles and often fall short of providing an effective collaborative environment: they struggle with conveying body language, nonverbal cues, and eye contact, while also encouraging multitasking, reducing engagement, and increasing cognitive strain [1].

MR offers the potential to create collaborative experiences that preserve the nuances of face-to-face communication while leveraging the digital capabilities of modern technology. By blending the virtual and physical worlds, MR can create co-presence illusions–the impression that remote collaborators are present in the same physical space [11, 14]– and bring back the real world's physicality, which the computer-supported collaborative work (CSCW) and proxemics literature highlighted as key to effective collaboration [2]. This includes key elements like contextual understanding, rapid turn-taking, interaction with physical

objects, and maintaining personal space and spatial awareness [5]. However, in practice, achieving this vision in MR has proven challenging, as it requires solutions that address both the technical constraints and the human-centred aspects of designing such applications [4, 5, 16].

In an effort to derive and define these challenges, we previously organised a workshop with the goal of bringing face-to-face-like experiences into distributed MR. Experts from various universities, including some of the authors of this paper, were invited. However, not all of us could attend the workshop in person, which necessitated a hybrid setup. We initially opted for a videoconferencing platform, but time zone differences would have prevented some participants from joining. Other remote attendants able to join would also not have been able to fully engage in the activities we had planned. For instance, "body storming" where participants simulate collaborative scenarios using the space makes it impossible to include remote attendants. Spontaneous cues and non-verbal actions are also highly diminished during conversations, preventing the same degree of involvement.

While time zone differences could not be solved, we considered conducting the workshop using MR to enable the embodied presence of at least some remote participants. Given that many of us had access to headsets, this was also a chance to "dogfood" the technology and learn from our own experiences. As such, we attempted commercially available MR solutions, such as Arkio [1] or Wooorld [2]. However, the many discrepancies and complications we experienced made us quickly give up on the idea of using these to run our workshop. For instance, the non-verbal cues of in-person attendees, such as pointing to a whiteboard in the workshop venues, were not meaningful. It also took us a while to recognise who was who, as our avatars were highly cartoonish. Even verbal communication with the collaborative MR application presented challenges, as talking in a low voice to specific collaborators in the MR space was impossible without disrupting other conversations. Like on Zoom, participants repeatedly tried speaking at the same time and had to negotiate who was to go first. In-person attendees suffered additional problems as co-located participants' positions did not match their real-world location and it was impossible to disable their avatar representation or mute them individually. Finally, we abandoned hybrid efforts altogether and continued the workshop in-person only.

Despite the often-touted potential of MR to transform remote meetings, this previous workshop highlighted how far we still are from reaching this point. Nevertheless, our failed attempt to conduct it in MR led to insightful discussions about what to do next to bring us closer. We notably identified a set of grand challenges, deeply rooted in both the technical and human-centred aspects of collaborative MR. Therefore, **the motivation of the present workshop is to push the reflection to the next step by identifying immediately actionable items towards addressing these challenges.** Bringing together world experts from diverse disciplines, CHI is the ideal venue to conduct this second iteration. We expect this will bring actionable items to the collaborative MR research agenda and accelerate research on breaking the barriers towards the vision of distributed MR. We detail the six challenges we curated for this workshop in the next section.

1.1 Challenges

For MR to be adopted as a *de facto* distributed communication tool in the modern world of hybrid work, it must **scale** to the various real-life contexts of users. To illustrate this tension, consider the following scenario: you are a University academic leading a tutorial in MR with 20 students from your 6-seat home dinner table.

The first challenge is that your physical space *cannot easily be aligned* with 20 other physical spaces. These environments will inevitably have different fixed (e.g., walls, doors) and semi-fixed (e.g., tables, chairs) features, dimensions, shapes, and objects (e.g., task-relevant tools). For example, while you might see students sitting around a large dinner table, students attending from their dorm room desks will have a much smaller work surface for activities. These disparities also create challenges for nonverbal and verbal communication that must be reconciled: someone's "on my right side" might be "behind me" for another user, depending on how they are arranged in their available space.

The second challenge is that *virtual representations can be limited in representing the user's behaviour*. While the fidelity of virtual avatars is steadily increasing with avatar personalisation options, live reconstruction, body tracking, and even facial expressions, this is greatly dependent on the capabilities of the employed technology. Importantly, not all students may have access to identical technology: each will be limited in expressing only what their virtual representation affords to communicate, which can vary broadly. In worst cases, this can make it hard to quickly identify users, what they are looking at, and what they are intending to do. Catching non-behavioural cues such as a leaning body posture or eyebrows raising becomes difficult. Irrespective of the used technology, the user's abilities may also differ from what they appear to be: while modern avatar creators support cultural and racial diversity to some degree, further dimensions, such as visible and invisible differences in ability, may not be perceivable.

The third challenge is that your physical space *does not accommodate the whole group* at once. You could render avatars of students on each seat and around the table, but the rest would have to appear beyond walls or overlap with the furniture, diminishing the co-presence illusion. This becomes even more of a problem when wanting to implement dynamic group formations: switching to break-out groups, you might not be able to physically walk around and monitor the overall progress easily.

The fourth challenge is that some students *may not be able to attend synchronously* but would still like to feel like they had been there. For example, when viewing a 'replay' of the class in MR, they might want to be asked questions and respond as if the class was happening right now. This would require the teacher to have interacted with them while they were away as if they were there, or AI-driven simulated

[1] https://www.arkio.is/
[2] https://www.wooorld.io/

interactivity. However, how to support such interactions and create the feeling of being present with others is unclear.

The fifth challenge is that *the benefits of physical interactions with props and other objects cannot be shared by all.* MR can facilitate the spontaneous use of local physical objects in collaboration, allowing users to incorporate their surroundings into discussions. However, the physical differences between objects, their locations, and their very availability, can hinder remote users from engaging equally. For instance, while co-located students might discuss and manipulate detailed physical models, remote users might have to rely on nearby everyday items as proxies. This disparity can limit remote users' interaction richness and tacit participation, revealing key gaps that must be addressed to enable seamless physical participation in MR settings.

Lastly, the sixth challenge is that collaboration may become inefficient when *not supporting dynamic tool-switching, diverse user needs, and multitasking*. While participating in a "real world" tutorial, a student might be taking notes on their laptop or tablet, doing a quick search for a particular concept, putting the homework deadline in their calendar, checking the time on their watch, and raising their hands to ask a question. These diverse tasks often involve short interactions with multiple devices and materials, which vary with the user's habits, needs, and impairments. This is poorly supported in immersive collaboration applications, where it is frequently not even possible to check the time without accessing the main menu.

Prior work has started addressing these challenges. Heterogeneous spaces [4, 5, 9], expressive human avatars [13, 15], scalable group collaborations [16], asynchronous work [3, 10], distributed task spaces [6, 8, 9], and integration with existing physical and digital tools [7, 8, 12] have been increasingly explored topics in recent years. However, significant progress toward realising the full potential of MR collaboration will require more than isolated advancements. It demands articulated, joint efforts across research and practice to integrate these developments into cohesive systems that support the richness and fluidity of in-person collaboration, even when participants are physically apart. To move closer to this vision, our workshop aims to identify actionable strategies and foster collaboration among experts, ensuring that future MR systems can truly enhance remote collaborative experiences.

1.2 Workshop Goals

The goal of this workshop is to gather an interdisciplinary group of researchers and practitioners to collaboratively address the previously described challenges. While we focus on these six key challenges, this list is not exhaustive. Many other barriers and complexities exist in the realm of distributed MR collaboration, which will inevitably need to be addressed as the field evolves. We use these six challenges as a starting point, recognising that they will need to be refined and expanded upon in the future as new insights emerge. By focusing on these, the workshop aims to:

- Identify concrete research questions to overcome the identified tensions in terms of technical progress, fundamental research, and infrastructure needs.
- Draft a detailed agenda to answer these questions with immediate actionable items, articulating the community's efforts.
- Create a "living lab" gathering the diverse expertise of the CHI community, regularly meeting to share insights and collaborating to implement the agenda.

Through a combination of discussions, hands-on activities, and collaborative ideation, this workshop seeks to move from understanding the mission to defining the actions needed for to scale distributed MR collaboration to real-life needs. The following list of questions will drive the session:

- **Spatial Congruency in Heterogeneous Environments:** How can we create congruent MR interaction spaces across diverse physical environments?
- **Embodied Interactions through User Representations:** How can MR systems accurately portray embodied interactions across diverse distributed teams?
- **Organic Group Formation within Distributed Teams:** How can we support dynamic and fluid group interactions within large, distributed MR settings?
- **Asynchronous MR Collaboration:** How can MR enable embodied conversations across different times to facilitate effective asynchronous collaboration?
- **Tangible Interactions Across Locations:** How can MR systems support shared interactions with tangible objects across distributed locations?
- **Fluid Task Switching in Distributed MR Collaboration:** How can distributed MR environments support seamless transitions between collaborative tasks?

Focusing on these questions will enable a deeper understanding of how MR systems can scale up to the 'messiness' of real-life collaboration while supporting flexible, fluid interactions and a strong sense of co-presence.

2 ORGANISERS

Adélaïde Genay is a Lecturer in computer graphics and visualisation at the University of Melbourne, Australia. Her main expertise is avatar embodiment in MR and Human-computer Interaction (HCI). Her research interests include avatar perception, remote collaboration, and immersive visualisation for decision-making. She defended her PhD on avatar embodiment in Augmented Reality (AR) in 2022, at Inria Bordeaux within the Potioc team. Then, she worked as a postdoctoral researcher at Monash University and at the University of Melbourne (2023-2024) where she later joined the HCI group. Adelaide has published in HCI and graphics venues, such as ISMAR, IEEE VR, and TVCG.

Brandon Victor Syiem is a Postdoctoral Research Associate at the University of Sydney, Australia. His research interests lie in the intersection of eXtended reality, artificial intelligence, and cognitive psychology. Brandon received his PhD from the University of Melbourne in 2023 where his work focused on the cognitive and perceptual effects of AR. He has worked as a postdoctoral research fellow at the University of Melbourne, Queensland University of Technology, and currently at the University of Sydney. Brandon has

published work related to XR in top HCI venues, including CHI, ISMAR, and IJHCS.

Emily Wong is a Research Fellow at the University of Melbourne, undertaking a Master of Philosophy in HCI at the University of Sydney. With a background in systems thinking and co-design, her research focuses on HCI and collaboration in MR. Creating spaces and facilitating activities that help people collaborate is a central theme of her previous work. Emily has previously published in top HCI venues including CHI and DIS.

Tiare Feuchtner is a Tenure-Track Professor at the University of Konstanz, where she co-leads the HCI group. She is also an associated researcher at Aarhus University, where she completed her PhD in computer science. Her main research interests are embodiment and novel user interfaces for mixed reality technologies to enable multi-user interaction and asymmetric collaboration. Tiare has mainly published in HCI-related venues, such as CHI, ISMAR, UIST, IEEE VR, and ISS.

Jarrod Knibbe is a Senior Lecturer in HCI at the University of Queensland. His research interests include perception, haptics, wearables, and XR. His work has proposed new haptic theories for VR, explored the user experience of novel interactive technologies, revealed VR insights from YouTube videos, and developed interactions that are now embedded into the latest Samsung smartphones. He has published across HCI, including at CHI, UIST, ISMAR, TEI, and ISS.

Jens Emil Grønbæk is an Assistant Professor at Aarhus University, Denmark. He received his Ph.D. from Aarhus University supported by Microsoft Research. His current research explores proxemics and flexible interfaces for distributed team collaboration, with the invention of new adaptive interfaces for video conferencing, telepresence, and MR collaboration. Jens Emil has several publications at CHI, UIST, DIS and ISS, and regularly serves as an AC for CHI.

Eduardo Velloso is a Professor of Computer Science at the University of Sydney. He is interested in the novel user experiences that are enabled by the combination of novel input and sensing modalities, the design of new interaction devices and techniques, and the use of artificial intelligence and machine learning in interactive systems. His work has received awards at the top HCI venues, including CHI, TOCHI, UIST, TEI and DIS, and has been covered by media outlets like New Scientist, the BBC, and Wired.

3 PLANS TO PUBLISH WORKSHOP PROCEEDING

We will encourage all participants to submit their proposals on arXiv in addition to making them available on the workshop's website we developed (http://blendedrealities.org/). Furthermore, we plan to co-author a joint publication capturing key insights and research directions. targetting top peer-reviewed venues.

4 IN-PERSON OR HYBRID

The workshop will be conducted in person only. Ideally, our vision for the workshop would require a hybrid mode of operation, leveraging MR to let remote participants join us. However, as outlined in subsection 1.1, current MR systems poorly support distributed collaboration in such settings, and it is precisely our goal to determine how to solve these limitations.

Videoconferencing systems are also incompatible with some of the activities we plan to run. For example, our afternoon activity will involve brainstorming on whiteboards or easels, sketching and annotating ideas in break-out groups. We also want to encourage participants to "bodystorm" by simulating situations with their bodies and using the space around them. Running these tasks in hybrid mode would require trading physical props for digital tools even for locally present attendants, hence reducing the advantage of physically attending this workshop and leveraging embodied cognition and physicality.

The workshop will also be run synchronously to ensure the best experience possible. Nevertheless, recognising the global nature of our audience, all the materials will be made available for asynchronous viewing, as detailed in section 5.

5 ACCESSIBILITY AND ASYNCHRONOUS MATERIALS

We will set up a discussion forum (e.g., Slack or Discord) to facilitate pre- and post-workshop engagement. This space will allow participants to introduce themselves, share their initial thoughts on the workshop themes, and engage with fellow attendees. This asynchronous engagement will help create a sense of community among participants and enable them to start forming connections before the event, making the in-person discussions more effective.

Presentations and discussions will be recorded and made available for participants to review at their convenience. We will also assign a member of the organising team or a volunteer to document the workshop activities through notes, photos, and recordings, ensuring that these materials are accessible to all participants afterwards. Material made available before the workshop will meet SIGCHI accessibility standards by including descriptions for images, subtitles for videos, and correctly tagged PDFs.

6 PRE-WORKSHOP PLANS

The workshop's website (http://blendedrealities.org/) will provide the participants with the needed information to write their proposals and prepare for the workshop, including:

- The objectives and workshop organisers. To clarify the scope of our goals, a manifesto will describe the vision of distributed collaboration in MR that we will be aiming for.
- A summary of the six tensions in distributed MR collaboration, with links to relevant academic papers and articles.
- Short videos and demos illustrating some of the current challenges and potential solutions in MR collaboration.
- A curated list of key questions and scenarios to consider before the workshop, aimed at stimulating thought and discussion around the workshop themes.

Participants will be encouraged to review these materials before attending. We will promote the workshop widely within the HCI and MR communities through relevant mailing lists (e.g., CHI, ISMAR, IEEE VR), social media platforms like Twitter and LinkedIn, and targeted outreach to research groups and industry professionals in related fields. Additionally, we will reach out to previous workshop participants at CHI and similar conferences to encourage a diverse mix of academic, industry, and practitioner attendees.

Interested participants will be asked to submit a position paper (3-4 pages) detailing their perspectives on one or more of the workshop themes. Submissions should include a brief description of their research background, motivation, and ideas for future work in MR collaboration. We will review the submissions based on relevance, quality, and diversity of perspectives. Selected participants will represent a broad range of expertise, ensuring an interdisciplinary dialogue. Selected participants will be asked which challenge they would like to focus on during the workshop in order to accommodate their interests to the best we can.

7 WORKSHOP ACTIVITIES

The morning will start with a kick-off and getting to know each other. The afternoon will be focused on meeting the workshop's goal through a whiteboard exercise. The schedule is planned as follows:

Time	Activity
09:00 - 09:30	**Welcome and Introduction**: The workshop will begin with a brief introduction from the organisers, outlining the goals and structure of the day.
09:30 - 10:15	**Opening Talk / Panel**: A keynote or panel will provide an overview of the six tensions in MR collaboration, emphasising the need for collective exploration of solutions.
10:15 - 10:30	**Break**
10:30 - 11:30	**Presentation of Participants**: Participants will form 6 groups and introduce themselves to each other. A volunteer from each group will make a lightning talk presenting their group to others.
11:30 - 12:30	**Whiteboard Exercise**: Each group will be assigned one of the six questions and a scenario imagined by the organisers. They will brainstorm action plans (e.g., studies to run, prototypes to build, theory to create) to answer their question within the scope of their scenario.
12:30 - 13:30	**Lunch**
13:30 - 14:30	**Whiteboard Exercise (continued)**
14:30 - 15:00	**Break**
15:00 - 16:30	**Round-table Discussion**: Participants will present their action plans, followed by a discussion on how it will bring us closer to running this kind of workshop in distributed MR.
16:30 - 17:00	**Wrap-up**: A summary of key takeaways and next steps.
19:00	**Dinner**: A social gathering for further discussions and networking.

Table 1: Workshop Schedule

8 POST-WORKSHOP PLANS

After the workshop, the proposed action plans will be summarised on the workshop's webpage. We will maintain a communication space (e.g., Slack or Discord) for participants to continue sharing ideas, resources, and progress on collaborative projects. Recordings of key sessions and supplementary materials will also be provided to ensure participants can revisit discussions or catch up on missed content.

We will encourage participants to develop their ideas into extended papers for submission to venues such as CHI, IEEE VR, and ISMAR, supported by follow-up virtual meetings to foster collaboration. If there is sufficient interest, we plan to propose a special interest group at a future conference, aimed at building a dedicated community around advancing MR-supported distributed collaboration. This will help maintain momentum and create a lasting impact from the workshop.

9 EXPECTED SIZE OF ATTENDANCE

We anticipate 18-24 participants. This will enable us to form groups of 3-4 participants to address each challenge.

10 CALL FOR PARTICIPATION

Mixed Reality (MR) has the potential to transform distributed collaboration, enabling teams to work together as if they were face-to-face. However, there are fundamental challenges still preventing MR from fully supporting the requirements of modern distributed work.

This workshop aims to articulate and address these challenges by exploring solutions to the tensions between the properties of face-to-face collaboration and the demands of distributed work.

Workshop Topics: We invite contributors from Human-Computer Interaction, Computer-Supported Collaborative Work, Virtual/Augmented/Extended Reality, and related fields to submit papers addressing, but not limited to, the following topics:

(1) **Spatial Congruency in Heterogeneous Environments:** How can we create congruent MR interaction spaces across diverse physical environments?
(2) **Embodied Interactions through User Representations:** How can MR accurately portray embodied interactions across diverse distributed teams?
(3) **Organic Group Formation within Distributed Teams:** How can we support dynamic and fluid group interactions within distributed MR settings?
(4) **Asynchronous MR Collaboration:** How can MR enable live conversations during asynchronous collaboration?

(5) **Tangible Interactions Across Locations:** How can MR systems support shared interactions with tangible objects across distributed locations?
(6) **Fluid Task Switching in Distributed MR Collaboration:** How can distributed MR environments support seamless transitions between collaborative tasks?

Submission Guidelines: We welcome submissions of position papers (3-4 pages) that present research challenges, potential solutions, case studies, or visions related to any of the workshop topics. Submissions should adhere to the ACM Master Article Template. Selected authors will be invited to participate in the workshop at CHI 2025.

Contact: For more information or questions, please contact **Adélaïde Genay**: adelaide.genay@unimelb.edu.au.

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