AdapTables: Using Conformal Mapping for Collaboration on Tables in Asymmetric Mixed Reality

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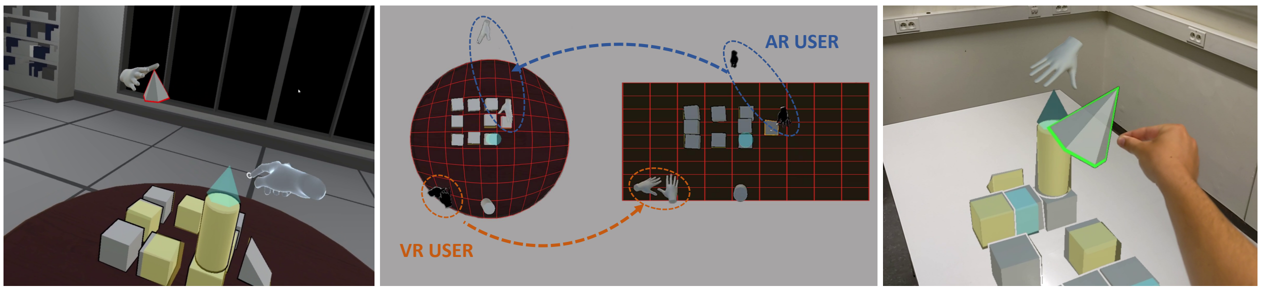

Figure 1: The *AdapTables* system allows a VR (a) and an AR user (c) to collaborate on tables with different shapes. *AdapTables* uses conformal mapping to transform coordinates of objects and the user avatar's hands, and supports inner and outer maps to allow seamless transition between the area on the table and the surrounding room.

ABSTRACT

Remote meeting applications are becoming more immersive by supporting virtual reality, however, support for augmented reality devices is still lingering. For augmented reality to be integrated, the asymmetry between the local spaces of the users needs to be solved, to which we contribute by focusing on the mismatch between tables. We present the AdapTables system, which maps a virtual reality user's virtual meeting table onto an augmented reality user's differently shaped physical table. By creating conformal maps between these tables, remote users can be transported to the environment of the other user. Additionally, shared virtual objects are also mapped to adapt to each user's table. We tested the system with 32 participants in pairs of two.

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1 INTRODUCTION & RELATED WORK

As Mixed Reality (MR) has become more commonplace, it has been adopted as a solution for remote meetings. Especially Virtual Reality (VR) has gained wide support in meeting platforms, allowing multiple users to immerse themselves in a shared virtual meeting room and manipulate objects within it.

Contrary to VR, Augmented Reality (AR) is less well supported in online meeting platforms. Integrating this technology in virtual meetings will make remote meetings even closer to reality, but the adoption is limited by the asymmetry of the user spaces. A possible solution in the current state-of-the-art, is to impose that AR users joining the virtual meeting should be present in a room with the same dimensions as the meeting room for the virtual projection to coincide with the real environment of the user, which does not scale properly to multiple users.

In this paper we present the *AdapTables* system, which allows VR and AR users to connect to a virtual meeting while accommodating differences between their table surfaces using conformal mapping. This solution has the advantage that the virtual table shape is not constrained by the physical table shape, allowing for multiple AR users with different tables to join the virtual meeting room. We tested the *AdapTables* system on 32 participants in pairs of two.

Collaboration between VR and AR users has been investigated with co-located or remote users. Examples of co-located VR and AR collaboration include the work of Grandi et al. [3], where both users perform a docking task collaboratively. The workspace in this paper was a table with the same shape in both the augmented and virtual environment. Further work on visualising a VE to an AR user includes SelectVisAR [2] which investigates methods for filtering a VE to visualise it to a local AR user. Conversely, VR has also been used to enable remote collaboration with an AR user.

Research into remote collaboration between VR and AR users mainly centres around the VR user entering the AR user's space remotely. Mini-me [5] is an adaptive avatar for presenting a remote VR user to a local AR user. Loki [4] allows bi-directional telepresence, where users can enter each other's space remotely.

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Conversely our goal is not to allow remote users to access each other's environment, but for them to join a shared meeting room that adapts to the AR users' physical environment.

AdapTables uses conformal maps to transform the boundaries of tables to adapt to each other, which have already been employed in previous research on locomotion [6]. Our system uses earlier work by Trefethen [7], who provides a numerical algorithm to calculate a map from a simple polygon to a unit circle using the Schwarz-Christoffel transformation. Our scenario requires not one but two conformal maps, one for the table surface and one for the rest of the room, which means that the implementation of the conformal mapping algorithm needs to create maps for points inside and outside of the polygon. Moreover, the algorithm has to be sufficiently performant, to allow real time calculation.

2 ADAPTABLES

AdapTables enables remote VR and AR users to be telepresent around a virtual meeting room table, even though the AR user's available physical table has a different shape. They can manipulate shared objects and see the hands of the other user. Both *Meta Quest 2* and *HoloLens 2* are supported, for VR and AR users, respectively. The system is implemented using *Unity (2020.3.0f1)*, and consists of the following three parts: networking, conformal maps, and VE.

The **networking** is based on a client-server model using Unity's *Netcode for GameObjects*. The VR user can host a virtual meeting room to which the AR user's client instance can connect. Because tables on each client can have a different shape, the objects on them have different coordinates from those on the server, which prevents us from using a network transform to synchronise their positions. To accommodate this asymmetry, we use proxy network objects rather than networking the objects directly. This allows the server coordinates to be transmitted to each client, where they are then transformed to be applied to the object's local counterpart. These proxy network objects are invisible during operation of the system.

AdapTables uses **conformal maps** to transform an object's coordinate from one table to another. Chebfun [1] was used for constructing and evaluating the maps. By using the Schwarz-Christoffel transformation, every table can be represented in the circular domain. This means that any two tables can be used for this setup as long as they can be represented by a polygon, and as such poses no limits on the scalability of this system to multiple AR users.

The conformal maps between the table shapes (circle, rectangle, and square) in the study are precomputed using the Chebfun MATLAB library. The inner and outer map for the square table were created with Chebfun. The calculations required for the evaluation of the maps were ported to C# so that MATLAB is no longer required for the operation of the system.

As the scenario to evaluate *AdapTables* we created a **VE** depicting an office in which the meeting could take place. This virtual office is populated with interactable objects, avatar hand visualisations, and one of three different tables. The interactable objects can be translated and rotated by users using their hands. We use MRTK for hand tracking on both HoloLens 2 and Quest 2, which provides users with symmetric input modalities (except for device-dependent performance differences). Each interactable object has a corresponding target where it needs to be placed. This target is initially blue and turns yellow to indicate correct placement. The hands of the other user are visualised by means of a static hand model and mapped to obtain the correct positioning. The AR user is presented with a physical rectangular table of size 0.9 m x 1.8 m, the same shape as its virtual counterpart, which means that no mapping is applied. The square (1.27 m x 1.27 m) and circular (1.44 m diameter) are shaped to have the same surface area.

We tested the *AdapTables* system in a within-subjects user study with 32 participants in pairs of two, during which we found no significant differences between participants having the same table, and thus no mapping being applied, and participants having differently shaped tables. During this study none of the participants noticed that they were collaborating on differently shaped tables, or noticed the effects of the mapping being applied.

3 CONCLUSION & FUTURE WORK

In this paper we introduce the *AdapTables* system, which enables VR and AR users to join a shared virtual meeting room while fitting the virtual table the shape of the AR user's physical table using a conformal map. As a result, remote users feel as if they are co-located. *AdapTables* was tested in a user study with 32 participants in pairs, one as VR user and one as AR user.

Our results indicate significant differences between VR and AR users, with AR users being slower and reporting a higher workload, mainly caused by technical limitations. No negative effects of the conformal mapping were found, with none of the users reporting that they noticed the mapping. As such, the *AdapTables* system allows VR and AR users to meet and collaborate on a table surface, without imposing restrictions to the shape of the table.

As future work, we are interested in the scalability of the system, both in terms of table shapes and amount of tables. As meeting room tables are often larger than tables available at home, this would most likely require a mapping that scales down the coordinates and is required to scale down objects as well. Additionally, we will also investigate transforming the objects themselves, in order to avoid collisions between objects caused by the mapping.

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