Asymmetric Collaboration in Augmented / Virtual Reality and its Applications

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1 Introduction

Asymmetric collaboration in augmented reality and virtual reality is a key topic in the field of Human Computer Interaction[6][20]. The asymmetry in the collaboration can refer to the different means of visualization and interaction in the virtual environment taken by users during the process of collaboration[18][46]. These asymmetries can be further refined to the following aspects, namely, 1) the asymmetry in scales and point of view (PoV) between users[28], 2) the asymmetry in the users' geometric space and environmental settings[2], 3) the asymmetry in users' devices and visualization hardware[19], and 4) the asymmetry in users' role or level of AR/VR[34].
This essay will explore the asymmetry in the above four aspects and summarize the potential application of asymmetry collaboration settings in different industrial areas.

2 Aspects of Asymmetric Collaboration

Generally, asymmetry in Augmented Reality and Virtual Reality can vary in scale and Point-of-View (PoV), space, devices and roles and depending on the design these aspects are connected and affect each others[18].

2.1 Asymmetry in scales and PoV

The most common and well studied asymmetry in the field of AR/VR is the asymmetry in the scale of points of view of users[26]. As shown by[28][38], allowing multi-scale asymmetry in the collaboration of AR/VR is crucial in the task of navigation. Due to the inherent property of multi-scale environment in the real world, asymmetry in the collaborating scales and points of view between users provides a powerful support for the exploring users to deal with lack of comprehensive knowledge in large-scale and complex virtual environment[28].

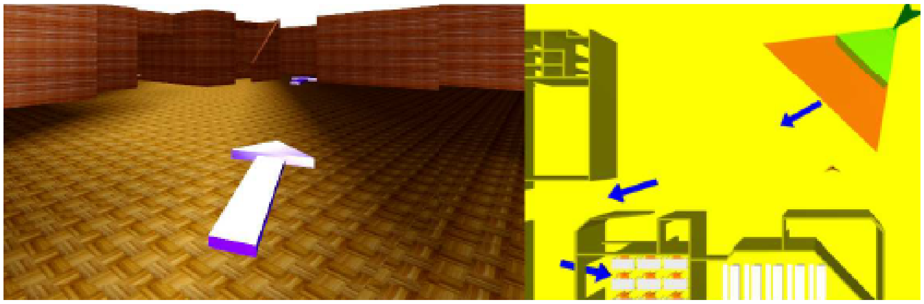

Figure 1: Asymmetry in the scales and PoV between the helping user and the exploring user in the navigation task.[28]

Apart from the navigation, this type of asymmetry also shows great potential in the manipulation tasks[26]. The manipulation of 3D objects can benefit from the asymmetry in scales and PoV, since this kind of asymmetric setting benefits users from suited points of views[26]. This type of collaboration setting can be utilized in factories, where giant objects must be carried by several different collaborators at different angles and different distances to the 3D object. The flexibility in the asymmetric setting in scales and PoV adapts the users to their own applications and thus improves the efficiency in the tasks of manipulation[26].

2.2 Asymmetry in users' geometric space and environment

Virtual Reality has made the rapid prototyping and designing involving multiple stakeholders possible. However, the asymmetry in different users' geometric space and environment settings could be a problem for creating a seamless collaborative environment[10]. Thus, the synchronization between different users' geometric environment is crucial[18]. As proposed in[18], during an interaction, AR/VR user can scan their local environment and share the space with the other user, which increases the awareness of space and improves the fidelity as well as the quality of collaboration. The potential benefits brought by the allowing asymmetry in space and environment is promising, as shown in Figure 2, remote users can collaborate as if they are face-to-face regardless of the environment difference between ends, which speeds up the industrial process and saves the cost of potential transportation of users[5].

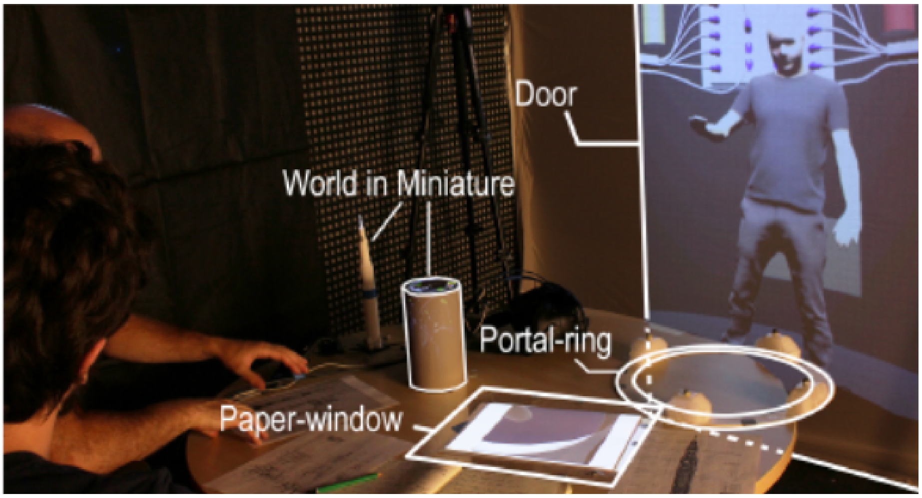

Figure 2: A remote meeting example under the asymmetric space and environment settings[10]

2.3 Asymmetry in devices and visualization

Another notable aspect of asymmetry is in the different devices and visualization methods utilized by different users. AR/VR technologies evolve and advance rapidly nowadays, creating potential difference in the devices and visualization methods between different users. Compatible platform is therefore needed for the collaboration under this kind of asymmetric setting. ShareVR[19] connects HMD users with non-HMD users using a spatial AR/VR environment. Co-located users can therefore utilize this prototype to resolve the asymmetric issue. Reports indicate that a increasing level of enjoyment and social interaction emerged in this asymmetric setting of HMD and Non-HMD collaboration compare with the pure non-HMD interaction[19]. Similar approach has been taken by CoVAR[2], which enable collaboration between remote AR/VR system. This kind of asymmetry is actually a 'blessing in disguise', according to [18], the mixed mode collaboration between AR and VR users significantly improves the effectiveness of solving complex manipulation tasks, such as locating a certain object accurately. The potential of this aspect of asymmetry is obvious: it adds the potential to integrate users with different devices and visualization approach into a single coherent mixed reality space, where users can cooperate and collaborate in a shared asymmetric experience.

2.4 Asymmetry in users' role and levels of AR/VR

The different role of users and level of AR/VR is another type of asymmetry in collaboration. In general, the roles of collaborators are usually different. Take

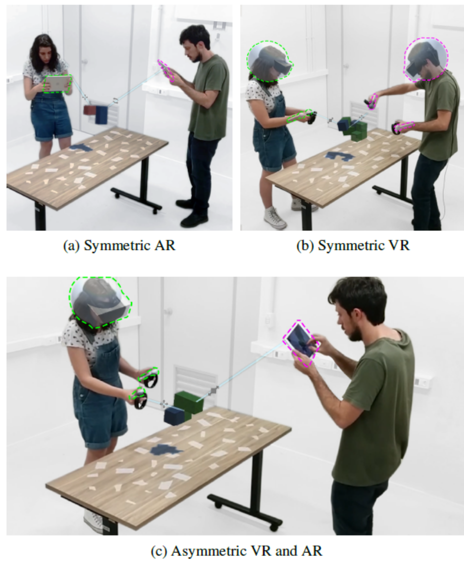

Figure 3: illustration of symmetric and asymmetric device and visualization setting[18].

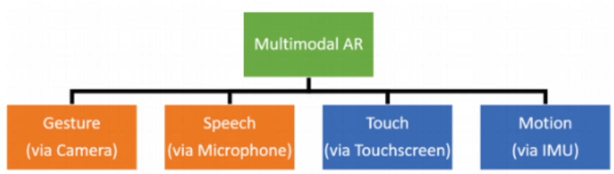

Figure 4: multi-modal collaboration under the asymmetry of roles.

apprentice process as an example[30], the students and experts take up different roles in the collaboration and the mode they utilize in their interaction would be totally different. Multi-modal collaboration has been investigated in this type of asymmetry[22], different modes of collaboration have been enhanced in the respective collaboration roles of users. As demonstrated in One Reality, different levels of AR/VR would also be an asymmetry in the collaboration[34], users in different collaboration roles would be in different levels of AR/VR, focusing on different aspects of the virtual environment, thus improves the overall collaboration performance. This type of asymmetry demonstrate a more realistic scenario happens in the physical world, users have asymmetric roles in the collaboration, which has great meaning for applying AR/VR technologies in the real life.

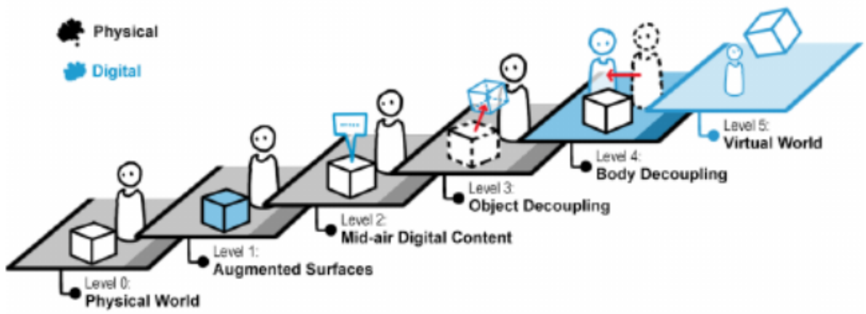

Figure 5: Demonstration of 6-level of augmentation in a cascading order[34].

3 Application of asymmetric collaboration

3.1 Surgical Application

The great potential of the augmented reality application in surgical training and treatment has been uncovered by various surgeons[11][36][47]. However, the asymmetric collaboration has not drawn much attention in this research field, most designs utilize the better understanding of the geometric structure of patients but do not focus on the collaboration between surgeons in the surgery[13][36]. A remote asymmetric collaboration system is proposed in 2016[32], focusing on the remote collaboration between surgeons, which provides more possibilities for the development of AR surgery. This system actually focuses on the asymmetry in the scales and space of the users. It resolved the potential inconsistent between different users' space and scales by a sophisticated mentor-trainee collaboration system, allowing the local trainee to benefit from the instructions and annotations provided by a remote mentor, without shifting his focus of operations[32].

3.2 Architectural Design

The application of Augmented Reality in the field of urban planning and architectural design has a promising future[8][35]. Assigning asymmetry in architectural design is also a potential research field. CDPP[17], a protocol which synchronise the virtual worlds between two AR/VR peers has been proposed to enhance the discussion of architectural ideas between professions and laypeople. It reveals the dilemma that in the physical world, the architectural plans and models which are well-understood by the professionals are inconceivable to those untrained customers[39][40]. Thus a system that can resolve the asymmetry in roles of participants is required.
Another concrete design of asymmetry relating to the architectural field is Dollhouse VR[21]. This system focuses on resolving the asymmetric scale issue in

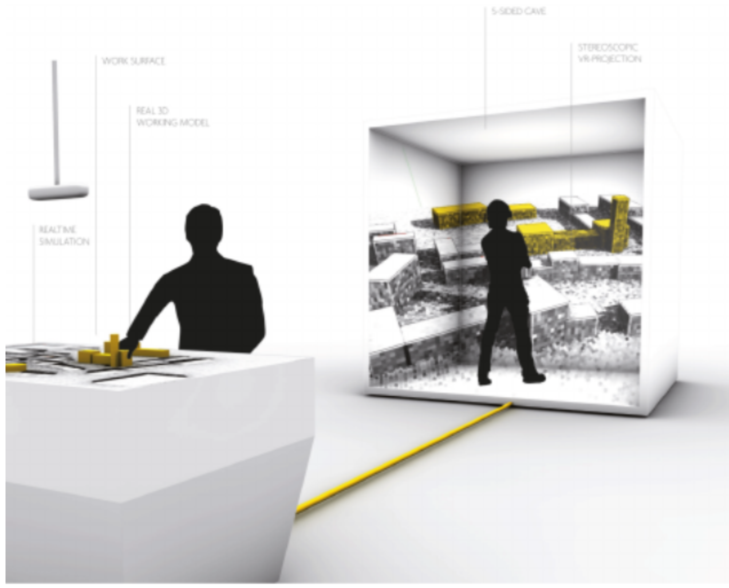

Figure 6: Conceptual design displayed with the help of AR in the architectural field[17].

the VR architectural design. Both internal and external view-points are enabled for the users to better understand the geometric layout and structure of the architectural ideas. As shown in Fig 7, designer utilizes the external view to gain a whole sight of the overall architectural structure, while the occupants adopt the internal view to attain an immersive understanding of the proposed architectural idea by the designers. This kind of collaboration resolved the potential obstacles between the communications between an experienced designer and a non-professional occupant, thus empower the architectural design process.

Figure 7: Different view points are adopted by designers and occupants[21].

Figure 8: Asymmetric collaboration between climbers and bystanders[43].

3.3 Sports

AR has shown great potential in enhancing the users' experience in the field of sports[15]. Collaboration is crucial in the application filed of sports[29][42]. A Substitutional Reality system provided by[43] has focused on the asymmetry in roles and devices between the climber and bystander in a wall-climbing activity. This projection-based VR system involves the bystanders to play an active part in the collaboration of wall-climbing sports. In order to resolve the potential asymmetry in the roles of users, it provides the climbers with a immersive projection environmental setting, while provides a semi-immersive interface for the bystanders. In this way, the VR information gained by the climbers can be displayed to the bystanders and the projection clues given by the bystanders will be understood fully by the climbers. As a result, this Substitutional Reality system get users involved in a sports activity, enjoyment and interest of the users have been greatly improved compared to the physical wall-climbing settings[33].

4 Experiment of Asymmetry in Spatial Scales and Geometric Space of Users

4.1 Background

Previous works have revealed the importance of Asymmetry Collaboration in the fields of surgical training. Thus, we want to conduct a experiment resembling the surgical application scenario about the asymmetry in scales and view points as well as the geometric space and environment (refer to the first and the

Table 1: Spatial Scales Defined by Barba *et al.*[4]

Types	Description
Figural	Small and manipulable space, Experienced without locomotion
Vista	Small space and non-manipulable, As large or slightly larger than human body
Panoramic	Small to large space, non-manipulable, Experienced through rotation without locomotion
Environmental	Large space that requires locomotion to experience
Geographic	Giant, non-manipulable space, Cannot be experienced through locomotion
Map	Project a space with large scale into small scale Use symbolic representation to show the information

second aspects of asymmetry in Chapter 2) to further explore the influence of asymmetry in collaboration with the help of HoloLens[12].

4.2 Motivation

The actual goal of setting up different roles of participants is to resemble the surgical application scenario, where a experienced expert is teaching an untrained apprentice to accomplish tasks through AR/VR asymmetric collaboration. We use cubes to represent the object to be manipulated in a surgical training and design selection, rotation and translation task for the cubes to represent the essential operations conducted in a surgical training. The factors to be considered in this experiment are: the asymmetry in the spatial scales of the users and the asymmetry in the geometric difference of the users.

4.3 Overview

Inspired by Barba *et al.*[4] and Whitlock *et al.*[41], we decided to define the scales in our experiment as spatial scales, which are defined by Barba *et al.*[4]. The scales have been classified into six types, which are shown in Table 1. For the ease of designing our experiment we take Figural and Vista Spatial scales to set up the experiment.
Another set of Independent Variable we want to use is co-location/remote. We want to examine the effect of the co-location in the process of collaboration. The reason why this is a point worth considering is that AR/VR gives rise to the remote instructions, thus the evaluation in both co-locate and remote settings is important when examine the effect of asymmetry in collaboration.

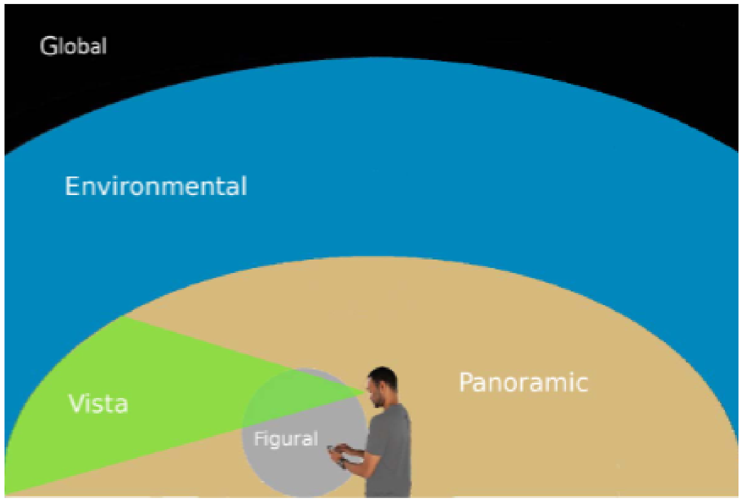

Figure 9: A vivid illustration of different types of spatial scales[4]

4.4 Methods

We decided to conduct our experiment in three tasks: selection, rotation and translation (docking). The selection and rotation tasks[24] are the fundamental set of interactions as pointed out by Kaiser *et al.*[23], Piumsomboon *et al.*[31] and Whitlock *et al.*[41], while translation (docking) task is the fundamental building block of 3D interaction[16], typical 3D environment requires docking[14]. Besides, people can always agree if the translation positions match with each others[44], thus would be a useful task for the evaluation of the experimental results. Two participants will take part in these tasks as operator and instructor, with operator always takes up figural scale while instructor takes up either figural or vista scale. Each set of three tasks will be conducted in both co-locate and remote settings as shown in Figure 10. In the co-locate setting, participants can communicate through speech as well as gesture, while in the remote setting, participants communicate through speech and shared anchor. The performance in each tasks will be measured by the time to complete. The time of completing this task will be marked in different experiment settings: Co-locate with both participants in figural scale; Remote with both participants in figural scale; Co-locate with operator in figural and instructor in vista; Remote with operator in figural and instructor in vista.

4.4.1 Task 1: Selection

In this task, there would be five to ten virtual cubes stacked on a plain. Small number are marked on each cube, audio hint of the desired condition (eg. the cube with the largest number etc.) of the cubes will be given to the instructor

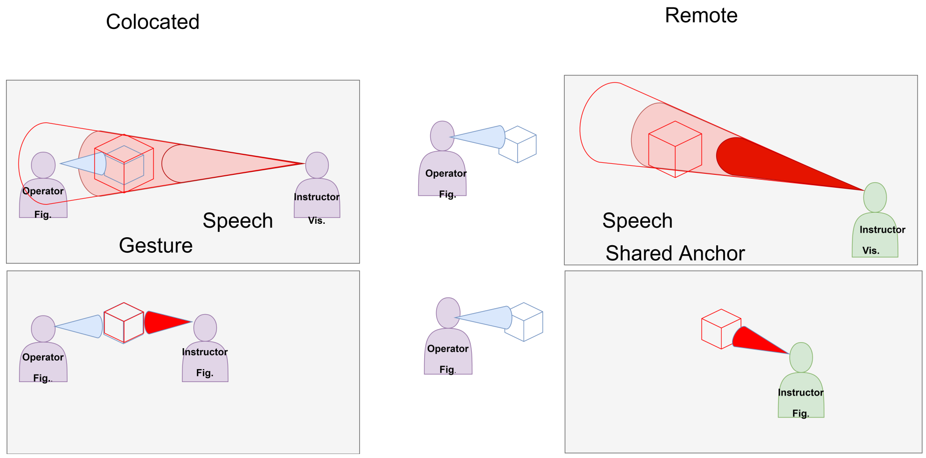

Figure 10: An illustration of the experiment set-up

and the instructor will help the operator to select the right cube.

4.4.2 Task 2: Rotation

In this task, a single virtual cube will be manipulated by the operator. Instructions of the degrees to rotate will be given by the instructor, while the total time used for the operator rotate the cube at correct orientation will be recorded.

4.4.3 Task 3: Translation (Docking)

In this task, a single virtual cube will be used by the operator. Instructor can see the virtual marks given by the system, while the operator cannot, thus instructor would like to give hints to the operator to help him translate the cube and dock it at the right place. Similar experiments have been carried out by[18].

4.5 Hypothesis

H1a: Under co-located setting, in the mode of both participants taking figural scale, gesture would be the main communication channel.
When both participants are in the co-located space with same spatial scale. There is no asymmetry in spatial scale and geometric environment between operator and instructor. Thus, we hypothesized that gesture would be the main and efficient communication method used between participants[3][9][31].
H1b: Under co-located setting, in the mode of operator taking figural scale and instructor taking vista scale, speech would be the main communication channel.
When one in figural the other in vista scale. The asymmetry in spatial scale between operator and instructor would lead to misunderstanding of the gesture.

Thus, we hypothesized that speech would be a more reliable and efficient way for participants to communicate[7][27].

H1c: Under remote setting, regardless of the spatial scale settings between participants, speech would be the main communication channel.

Since under remote setting, there would be inherent difficulty of coordinating different spatial scales in different geometric environment[10], both participants would take speech as the main communication media instead of shared anchor.

H2: The locomotion for instructor under remote setting would be less frequent than that under co-located setting.

When participants under the co-located setting, there would be more chance for them to switch between face-to-face and side-by-side collaboration. Thus, the locomotion of the instructor would be more frequent. Another perspective is that the co-located setting provides the participants with much more sense of interaction, thus the locomotion of the instructor would be more active. Under the remote setting, the instructor would tend to stay at a point and giving verbal instructions to the operator, instead of moving around, since locomotion in this case would not help reducing the distance and geometric asymmetry between the two participants. Therefore, we hypothesized that the locomotion of the instructor under remote setting would be less frequent than that under co-located setting

H3a: The task performance for operator under remote setting would be worse than that under co-located setting.

Since the fig-vis configuration under remote setting has inherent difficulty of coordinating different spatial scales in different geometric environment[10], the difference in spatial views under remote setting would cause inaccuracy for object positioning and selecting. Thus, we hypothesized that the configuration of both participants in figural scales would have better performance under the remote setting.

H3b: The task performance for operator when both participants taking figural scale would be worse than that under figural-vista configuration.

The asymmetry of the spatial scales between participants provides the collaboration with a more comprehensive understanding of the space they shared, which may enhance the performance in selection and translation tasks. The configuration that both participants in figural scale, on the other hand, limited participants view space to a small range, thus would present potential drawbacks in the experiment tasks. Thus, we hypothesized that the configuration of one participant in figural the other one in vista scale would have better performance under the co-located setting.

4.6 Measures

When measuring the main channel of communication, as pointed out by Buchmann *et al.* [9] and Piumsomboon *et al.* [31], using ARToolKit to record the gestures and Grasp-Shell to record the speech of users would be a good measurement of communication channels. Thus, we record the amount of gestures and

words used in each trial and analyze the changing behaviour between different trails.
As for the locomotion, acceleration and time spent at each position would be great factors to measure the locomotion of users as pointed out by Kourogi *et al.* [25]. Thus, we would like to use heatmap to measure the time spent by the instructor at different position of the space[37]. We would also measure the total length the instructor move during each trial.
We take two objective measures to denote the performance of each trial: the time to complete each task and the accuracy of positioning in each task. These factors have been justified by Whitlock *et al.* [41], who used time and accuracy to analyse the performance of each task. We measure the completion time as the duration between the 'Start' and 'End' button pressed by the instructor for each tasks. We measure the accuracy as the Intersection over Union loss between the object and the target[45] in the task of rotation and translation (docking). Tukey's honest significant difference test would be conducted after the experiment[1].

5 Discussion & Future Work

Due to time limit, we do not have chance to conduct the experiment so I write about the possible future work we planned to do in order to push this project forward. Firstly we will complete the technical implementation of these designed tasks in HoloLens. As described in the three tasks, we will implement a virtual plane for participants to place their virtual cubes. For the ease of time measurement and accuracy measurement, a timer and an IoU calculator will also be implemented in the virtual view of HoloLens. Besides, ARToolKit should be implemented in our project to help record the gestures, a word measurement tool and a position recorder are also needed for the measurement of speech channel and locomotion of the users.
Apart from technical implementation, we decided to call for a group of volunteers to participate in the experiment tasks. The gender and age distributions of the participants should be balanced and all of them should be native Chinese speakers to avoid difficulties caused by language.
Besides, currently we used cubes to represent the complicated structures and objects utilized in the surgical training. As a future extension, we would like to generate more objects with different morphology that can better represent the real objects such as scalpels, forceps and medicine etc. used in a surgical training. Besides, the current tasks we designed are selection, rotation and translation of cubes. As a future work, we would like to extend these into a wider range to further accommodate the need in a virtual surgical training scenario.

6 Summary

This report examined the asymmetry in the collaboration of VR/AR. We reviewed the existing work about the asymmetric collaboration in four aspects: scale, space, device and users' role. We also studied about the application of asymmetric collaboration in the industry. The applications in surgical training, architectural design and sports revealed a great view of applying asymmetry collaboration with VR/AR technology. The practical experiment we designed further combines the asymmetric collaboration with the novel definition of spatial scales and explores the possible relationship between performance and the asymmetry in spatial scales as well as geometric space. Provided further experiments and evaluation of the results, we believe that a more meaningful and valuable result will be generated and contribute to the development of HCI field.

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