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# Symmetric and Asymmetric Action Integration During Cooperative Object Manipulation in Virtual Environments

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Collaborative virtual environments (CVEs) have been proposed for a wide range of applications, including design reviews in manufacturing industry, the training of astronauts, simulating the ergonomic aspects of handling materials in a factory, and visualizing and interpreting data in the oil and gas industry. Cooperation between multiple users in CVEs can take place at one of three levels. In the first, users co-exist in the CVE, and can perceive and communicate with each other. In the second, each user can individually modify the contents of a scene, but it is only in the third (Level 3) that users can simultaneously act on the same object and jointly perform operations such as changing objects' position and orientation that we take for granted in the real world. Thus Level 3 cooperation is highly desirable for many CVE applications.

To implement cooperative manipulation, a CVE's interface software must integrate the inputs of different users according to some predefined rules of interaction, resolve any conflicts that occur, and ensure that the resultant manipulations are reflected in the scenes that are rendered to each user's display. The situation is complicated by the fact that many CVEs will only provide visual information to users, with haptic feedback being unavailable because of technological constraints (e.g., the need for a large working volume) or cost.

This paper describes a behavioral experiment that investigated the effect of two substantially different rules of interaction when pairs of participants performed a general purpose cooperative manipulation task that is known as the piano movers' problem and involved the manipulation of a bulky object through doorways and along corridors in CVEs (see Figure 1). One of the rules only allowed the synchronized component of participants' actions to take place, but the other manipulated the object according to the mean of participants' actions and allowed them to interact in an asynchronous manner.

The most important findings were as follows. In terms of the total time participants took to complete the tasks neither rule was superior, but that did not tell the whole story. Detailed analysis of the data showed that parts of the task that required participants to perform similar actions were performed quickest if the interface only allowed synchronized movement to take place. However, if participants needed to perform different types of movement (e.g., one maneuver the object through a door while the other traveled down the corridor) then the asynchronous rule of interaction was superior. In the real-world people switch between synchronous and asynchronous interaction at a largely subconscious level. This research indicates the benefits that could accrue if CVE interfaces implement both types of action integration and allow users to switch between them as required. Simple versions of the piano movers' task were performed almost as quickly in a CVE as individual users did on their own, but the most difficult task that was studied took 50% longer in a CVE. This represents a substantial cooperation overhead (the reduction in performance caused by having to cooperate with another person, compared with doing something by oneself) and indicates the large improvements that could be made to CVE interfaces if force feedback can be implemented over a large working volume.

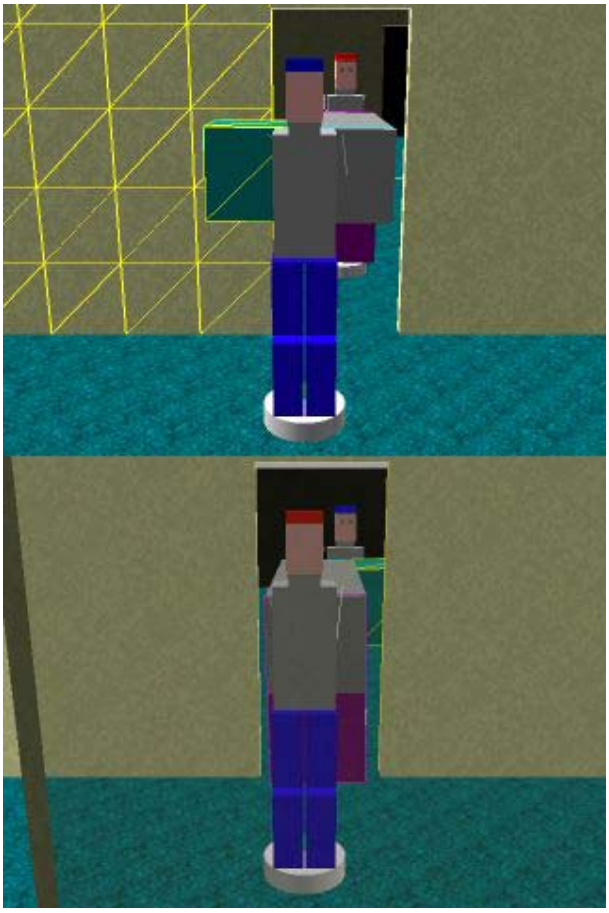

Figure 1. A view inside one of the CVEs used in the study, showing the view seen by one participant on top, and the other participant below. The participants interacted with the object via two virtual humans, which were their embodiments in the CVE. The wireline highlighting indicates that the object is currently in collision with one of the walls.

**For more detailed information on this research, see:**

Ruddle, R. A., Savage, J. C., & Jones, D. M. (2002). Symmetric and asymmetric action integration during cooperative object manipulation in virtual environments. *ACM Transactions on Computer-Human Interaction, 9*, 285-308