The Effectiveness of Multiscale Collaboration in Virtual Environments

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ABSTRACT
Adding multiscale capabilities to collaborative virtual environments can potentially help people work on very large electronic worlds. Our experiment shows that user performance on cross-scale tasks is indeed improved.

Keywords
Collaborative virtual environment, multiscale, virtual reality

INTRODUCTION
A multiscale collaborative virtual environment (mCVE) is a 3D world where users can control a set of interaction size parameters, such as viewing distance, eye separation (in stereo views), eye-level (if there is a ground plane), moving speed, and reaching distance. It gives multiple users the capability to work together with different interaction scales, allowing each to perceive different characteristics of objects and act with different action domains at different scales. Metaphorically, users can work together as giants and ants in the virtual world. Such a virtual environment could be a useful tool to support cross-scale collaboration in scientific research, such as the analysis of synthesized materials at different length scales, from the atomic details to the macroscopic structural design, and the management of large-scale information structures expanding towards the tera- or even peta-byte range (e.g., the whole Internet, the human-genome project, and satellite image GIS).

This paper first introduces the implications and design of mCVE systems, and then focuses on a study of the effectiveness of an mCVE in supporting a cross-scale task.

IMPLICATION AND DESIGN OF mCVE
Our ability to observe objects is limited in ways described by two measurements: *grain*, the size of the smallest observable structures, and *extent,* the largest. This limit on attention resources leads to competition for attention between a fine grain and a broad extent[1]. We use tools to adjust the working range of our perceptual system: microscopes push down the grain, and satellite photos shift up the extent. Multiscale technology is a similar scale-shifting tool, already in use for 2D worlds as Zoomable User Interfaces[2]. Collaboration techniques also help people deal with attention competition by dividing a large problem into smaller ones, with individuals focused on jobs at specific scale ranges, but working collaboratively.

An mCVE brings multiscale and collaboration techniques into one integrated system for virtual worlds. It creates a world inside which people can alter their working scales easily, and control the grain and extent of their observation and manipulation capabilities as they work together.

The design of an mCVE involves interactions between users and multiscale space (e.g., how to present virtual worlds at different scales) as well as cross-scale collaboration challenges (e.g., how can ants and giants work together?). Addressed issues include scaling models, rescaling effects on static views, scale-sensitive object representations, cross-scale social presence, cross-scale context sharing, cross-scale action interference, and so on[5].

EXPERIMENTAL EVALUATION
Based on a desktop mCVE implemented with Java3D and Java Shared Data Toolkit (JSDT), an experiment was designed to evaluate the effectiveness of an mCVE in supporting a cross-scale task.

Design The 3D-game style task involved searching for a "bomb" on a square ground plane (2000x2000m^2), with a distinctly shaped building in each corner (square, hexagon, octagon, and circle as seen from above). Each had a height of 12m and a base of about 80x80m^2. On the ground behind each building was a unit cube (1m^3) containing a unique text name and smiley face (about 0.5x0.5m^2). The "bomb" was inside one of these four cubes. In the test, subjects were placed in the middle of the square plane. They had a default eye-level of 1.68m and a default moving step of 1m in the virtual environment. The shape of the building that the bomb was nearby was known in advance, and subjects needed to find that building, locate the bomb box, and key in the name of the box to defuse the bomb.

Procedure A 2x2+2 factorial design was adopted (Table 1).

Table 1: 2x2+2 Design

	Non-collaboration	Collaboration
Non-multiscale	VE	CVE
Multiscale	M-VE	NR GUIDE MOVE

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For the two non-collaboration treatments, VE is just a conventional 3D virtual environment, and M-VE is a VE enhanced by multiscale tools, specifically it allows users to change their interaction scales, eye-level and speed. Among four collaboration treatments, CVE, a conventional collaborative virtual environment, is the only one without multiscale tools. The other three treatments, all equipped with multiscale tools, differ in the assignment of subjects' task roles (being a giant or an ant) and in the way subjects affect each other's work across scales. In one treatment, subjects do not have pre-defined roles of being giants or ants, and they can choose their own eye-levels and speeds as desired. This environment is labeled as NR (No Role). The other two mCVEs both assign one subject to be a giant and the other an ant so that subjects can only change their eye-levels and speeds within a limited scale range. In one such environment, the giant is permitted to move the ant directly, and this treatment is labeled as MOVE. Another condition only allows the giant to guide the movement of the ant verbally, and is denoted as GUIDE.

Subjects Recruited through email, twenty-four UM students paired in twelve groups participated in the experiment. In non-collaboration treatments, they worked on their own, and in collaboration treatments, they communicated through an audio channel. The performances were measured by task completion time.

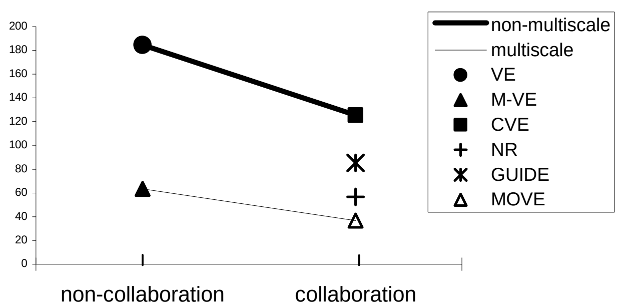

Figure 1: Time (in seconds) for the six treatments

Results: An ANOVA analysis of data from four treatments (VE, M-VE, CVE, and MOVE) shows main effects of both collaboration ($F_{1,70}=12.98$, $p<0.001$) and multiscale ($F_{1,70}=70.90$, $p<0.0001$). Interaction is not significant ($F_{1,70}=1.87$, $p=0.176$). (Figure 1) Subjects performed best in MOVE, where they could take full advantage of multiscale and collaboration, and they did worst in VE, where there was no help at all.

Subjects used different strategies in the different conditions. Without multiscale tools, subjects had to go around and count the number of sides of all four buildings to find the target, a very time-consuming process. With multiscale, subjects can increase their sizes to see building shapes from above and approach the "bomb" quickly, so the time required can be reduced significantly.

The performance difference among the three mCVEs also indicates the importance of different collaboration supports. In the NR treatment, subjects needed to negotiate their roles, an expensive process[4]. In the GUIDE treatment, the giant subject could see the building shape, but must coordinate verbally with the ant about the navigation orientation and the shape and color attributes of buildings, a costly grounding process [3]. In MOVE, however, the all-seeing giant could actually move the ant to the destination quickly, and the above grounding process could be by-passed.

DISCUSSION

The experiment result indicates that multiscale and collaboration can indeed help people in tasks requiring cross-scale perception and actions. Moreover, it implies that to allow users to better use the perceptual and action advantages in a collaborative multiscale way, simply assembling multiscale and collaboration technologies together may not suffice. It is also necessary to consider how to tailor interaction tools and choose the right collaboration styles in the design to facilitate people's work. To let users take full advantage of multiscale collaboration in a cross-scale task, in addition to having multiscale and collaborative tools available to every user, a better design should also make it clear who should use what tools and at what scales. Otherwise, overheads to coordinate cross-scale collaboration could be very expensive.

This research largely focused on the impact of multiscale and collaborative technologies on navigation activities, and how they could affect activities like object manipulation is not studied. Thus, future research efforts can be made to the investigation of cross-scale object manipulation at the individual level (e.g., how could a user be able to control a very large or a very small object without changing her interaction scale?) and at the collaborative level (e.g., how could a giant and an ant work on objects together?). In addition, it is expected that mCVEs can be used to build new tools to help people work on large structures. Therefore, besides general interaction issues like navigation and object manipulation, research can also be extended to domain-related interaction issues (e.g., what specific tools would biologists need to use mCVEs in their work?)

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