Collaboration around Shared Objects in Immersive Virtual Environments

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Abstract

Many teamwork tasks in the real world require the shared manipulation of objects, both sequentially and concurrently. Collaborative virtual environments (CVE) bring remote people together in an interactive, spatial social and information context that is distributed over a network. Supporting highly collaborative tasks in a natural manner requires a thorough understanding of event traffic as distinct forms of shared object manipulation are bound to diverse real-time and consistency constraints.

This position paper summarises our findings during user trials around the shared manipulation of objects within linked immersive displays and introduce a CVE system with a flexible event-handling framework that allows task-oriented consistency control.

1. Introduction

Collaborative Virtual Environments (CVE) allow remote people to share the experience of interactive virtual worlds and it's inhabiting entities (objects). The effective use of collaborative applications requires intuitive, responsive and consistent interaction. In interactive environments, responsiveness is of prime importance. While centralised simulations enable highest consistency and safety, local responsiveness may be increased through distribution of the shared simulation to local clients. Changes in state at the local simulation are communicated in form of events, which contain update information of replicas on the remote sites (figure 1).

The event-handling layer of a CVE system is responsible for transmitting events, as well as maintaining a sufficient consistent shared state of all replicas. Many mechanisms have been developed to maintain consistency, such as reliable transmissions, mutual exclusion and causality. Increasing the effort for assuring consistency often decreases the responsiveness of system. This is known as consistency – through put trade-off [10].

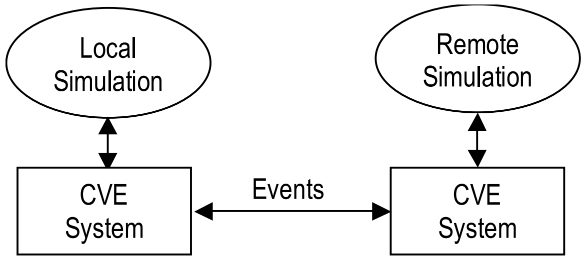

Figure 1. Distributed simulations.

1.1. Shared Object Manipulation

Over the last few years the levels of cooperation within CVEs have been categorised by a number of research groups but yet in similar ways. Ruddle described the different level of cooperation as co-existence and shared perception; individual modification of the scene; and simultaneous interactions with an object [7]. A similar taxonomy was presented for haptic collaboration [1] that describes the respective levels as Static, Collaborative and Cooperative. We defined a taxonomy according to the order of cooperative manipulation of an object, which can be manipulated sequentially and concurrently through the same and distinct object attributes [4], as summarised in table 1.

Table 1. Types of shared object manipulation.

Timing	Manipulated Attributes	
Sequentially	Distinct	Same
Concurrently		

1.2. Immersive Display Devices

The collaboration of people always requires communication between the participants. The communication can occur in different forms (verbal, non-verbal, through an object or the environment) [3]. Immersive displays lend themselves well to supporting these four forms of communication, as they firstly surround the user in the information context and secondly, enable natural and intuitive interaction between remote users through motion tracking. The wide field of view encourages natural head and body movement for both focussed and general observation. Spatial sound may be mapped to correlate with the relative position of remote users and objects. With the advantage of supporting natural, intuitive and subconscious interaction comes the disadvantage of the increased event stream caused by the high the update rate of user input due to the motion tracking.

2. Benchmark Application

In order to design a consistency management scheme it is vital to have a detailed understanding of the requirements for interaction and collaboration and the kind of event traffic that is likely to be generated while supporting these between particular interfaces.

We have developed a benchmark application that involves distinct forms of shared object manipulation within a CVE [4]. Remote users collaborate in the construction of a gazebo from cooperative manipulations and fixing together of beams and joiners, as illustrated in figure 2.

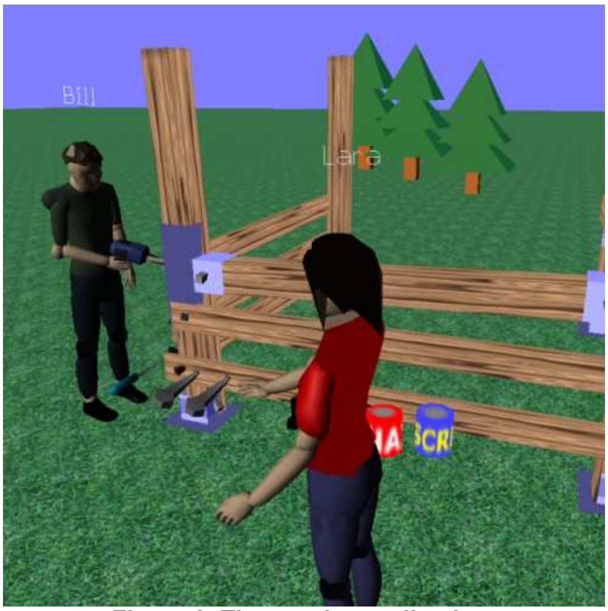

Figure 2. The gazebo application.

Constraints within the application, such as the simulation of gravity, force the users to work in a team.

The main features of our benchmark include:

- Highly collaborative and structured task
- First to link-up immersive displays for shared manipulation of objects
- Involves distinct forms of shared manipulation of objects
- Combines non-verbal communication with shared manipulation of objects

The application has been built on top of the established CVE platform DIVE [2] and its immersive extension Spelunk [8] for linking immersive displays. DIVE provides loose consistency in which events are sent via fast but unreliable multicast messages, relying on eventual convergence of the replicas. Although DIVE provides scalable reliable multicast (SRM) functionality, we found that insuring reliable transfer of events caused unacceptable delays [5].

The benchmark application includes various forms of shared object manipulation, such as moving objects sequentially or concurrently, as well as holding objects in place while another fixes them. Table 2 shows a summary of the supported forms of shared object manipulation in our construction site application.

Table 2. Supported shared object manipulations.

Task	Type of Sharing
A user passes a tool to another	Sequential, same attributes
One user drills a hole, another inserts a screw afterwards	Sequential, distinct attributes
Two users carrying a beam	Concurrent, same attributes
Two users hold a beam, while a third fixes it	Concurrent, distinct attributes

To successfully support concurrent object manipulations the CVE's consistency mechanisms had to be extended via the application layer in form of object behaviour scripts. For example, intermediate objects have been introduced that control the manipulation on the shared object. These helped to workaround the default ownership constraints by the system, which did not allow concurrent object manipulation. Further, sequential manipulations on objects were made operational only when applied in a certain order, thus steering causality of manipulations. Such application-layer extensions to consistency control however resulted in additional events that had to be communicated between remote sites.

3. Results

We have undertaken several user trials within our benchmark with linked immersive and desktop displays within Europe [4,5,6,9]. During these trials we collected data sets of event frequency and compared the effect of the form of object sharing and the impact of the display device with the overall event traffic.

A main outcome was that linking several immersive displays increases the communicated event traffic considerably and thus creates a high load for the event-handling layer. Analysing the event traffic we found that event bursts occurred during shared object manipulation that often resulted in events queuing-up before being processed. For example, this was apparent through the jumping around of the shared object, the magnitude of discontinuity depending on a combination of interface and type of object sharing. The bursts were exacerbated by events generated to ensure consistency of shared objects by bringing them to an objective state. We found also that the characteristics of event traffic are task dependent [5,9]. In our application, concurrent object manipulation resulted in more traffic than sequential manipulation, whereas concurrent manipulation of the same attribute impacts more than distinct attributes [9]. Erroneous representation of the shared objects arose from the delay or loss of vital events, such as those that change the hierarchy of the scene graph. Vital events were rare but tended to coincide or bound bursts of non-vital events.

The magnitude and importance of movements depends on the kind of collaborative scenario. Within further trails [6], we have seen that the frequency of avatar movement events is fairly continuous and constitutes up to 60% of event throughput. Object movement events only occur during or shortly following interaction. The highest peaks in frequency of events come from shared object attribute manipulation and are caused by the added effect of the consistency mechanism. However, vital events bound the manipulation of a shared object attribute but seldom coincide with it.

4. Adaptive Event Handling

Supporting applications around the shared manipulation of objects across walk-in displays is made difficult without unnaturally constraining the application and laboriously tuning event passing [5]. ICE (Immersive Collaborative Environment) is our current approach to provide a CVE system to better support a wide range of highly collaborative applications. This is achieved by enabling higher flexibility in optimising consistency control than conventional systems offer. ICE is built on top of FLOW, an event-handling framework, that allows the task-oriented re-configuration of applied consistency strategies directly through the application layer. The basic idea is to provide a number of customised event-handling pipes, which process events according to a particular consistency strategy. The actual consistency strategy can be re-configured on a per-event basis at run-time.

ICE is still under development and is designed to investigate the impact of adaptive consistency control in immersive collaborative applications. System testing between a variety of immersive displays in various cities is coming to an end and we are about to start user trails.

5. Conclusion

We conclude that, although it is possible to successfully support the shared manipulation of objects within immersive virtual environments, the impact of the display and the form of object sharing vary dramatically. Distinct collaborative tasks have specific influences on the characteristics of event communication between remote simulations. We believe that task-oriented consistency control may help to optimise event handling in further CVE systems.

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