

On Collaboration in Distributed Virtual Environments

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ABSTRACT

Today's advances in telecommunications stimulate a change in the way business is carried out, making it a globally distributed process. The challenge in collaborative virtual environments is to provide distributed teams with a virtual space where they could communicate as if face-to-face, while manipulating shared virtual data. Our approach moves beyond mere integration of video-conferencing and scientific visualization, to create a design framework for CVEs where issues of human-to-computer and human-to-human interaction in projection-based systems are addressed. The approach is exemplified by the design and implementation of the Collaborative Medical Workbench used by two Surgical Departments.

Keywords Distributed VEs, Immersive Telepresence.

INTRODUCTION

Scientific visualization in Teleimmersive environments has been used in many application areas and has proven a powerful tool in understanding complex data. In teleimmersive environments, audio and video conferencing is integrated with collaborative virtual environments to provide collaborators at remote sites with a greater sense of presence in the shared space[13].

Our approach focuses on projection-based systems and is moving beyond mere integration of video avatars by focusing on the issues of designing CVEs taking into account human to human communication and collaboration in such high-end collaborative systems. The vision is to provide distributed collaborative teams with a virtual

space where they could meet as if face-to-face, coexist and collaborate while being immersed and manipulating in real-time the set of virtual data of interest.

The need for such a high-end collaborative virtual environment is becoming more pressing due to the globalized nature of today's market. Distributed businesses require support for effective collaboration over distance in order to minimize time and travel costs[6]. Businesses that require high-end visualization of raw data gathered from remote sites [7] [8], as well as remote medical consultation [10] and tele-education, are examples where scientific visualization has been combined with video-conferencing to provide support for collaborative work [12].

In our approach for the design of such an environment, principles developed in the field of human computer interaction and computer supported collaborative work (CSCW) are complemented by techniques for facilitating human to human interaction within a virtual space, for users physically at the same place or for remote collaboration. Design issues involve ways of natural interaction with the virtual data as well as with the remote participants, while preserving shared data consistency.

The background section of the paper provides an overview of projection-based virtual environments and their use in scientific visualization. In the same section Immersive Telepresence and the first approach towards a collaborative virtual environment that incorporates real-time stereo video of remote participants in projection based VE is briefly described. The issues and requirements involved in designing a virtual space for remote collaboration of virtual teams and our design approach are presented in section *TEAM WORK IN VIRTUAL ENVIRONMENTS*. The approach is exemplified by a medical application, and the last section concludes this paper.

BACKGROUND

Projective Display Systems are the state of the art in high end Virtual Environments. They release the user from the heavy load and inconvenience related to head-mounted displays, and capitalize on the increased resolution and rendering speed of the available hardware[4]. Currently desk and room size installations include the Responsive Workbench¹ [11], the Collaborative Responsive Workbench Figure 1, the CyberStage and CAVE² [3] or the Teleport[1]. The virtual 3D objects can be directly manipulated via a stylus or data glove or other input devices such as the Cube[8]. In addition, localized sound and acoustic floors can be used to enhance the sense of immersion in such installations [5].

This type of projection-based VR installations allow collaboration between small groups on the same loca-

¹RWB is a registered Trademark of the German National Research Center for Information Technology.

²CAVE is a registered Trademark of the University of Illinois.

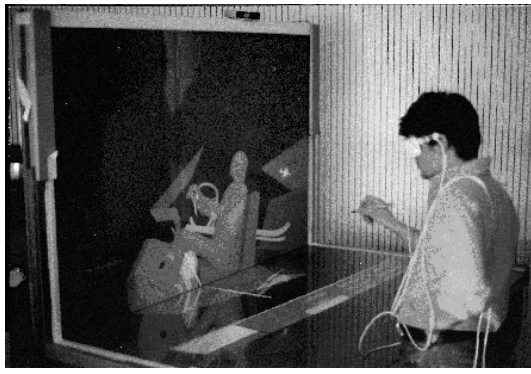


Figure 1: One user at the Responsive Workbench working with a virtual car model.

tion without the need for avatar representation and use of real-time video of remote participants for Immersive Telepresence. Our first approach in Immersive Telepresence uses live stereo-video, chroma-keying and texture mapping in order to integrate the live video into any virtual environment projected in these installations[12]. In addition, an approach for adjusting the left and right images generated from a static stereo-camera has been implemented to accommodate movement of participants within such an installation[12].

A distributed Virtual Environment Software Framework is the main requirement for supporting collaboration in Virtual Spaces. Users should be able to share and manipulate the same virtual data. During this process the consistency of the virtual data at each site should be guaranteed. Several toolkits have been in recent years extended to support distributed VE applications(e.g. DIVE[2], WTK[15]). The software framework we are using is AVANGO and it combines the familiar programming model of existing stand-alone toolkits with built-in support for data distribution that is almost transparent to the application developer. A detailed description of the toolkit and the way distribution is implemented can be found in [16].

TEAM WORK IN VIRTUAL ENVIRONMENTS

In this paper, we focus more on supporting communication and interaction between remote users of projection-based VEs and between the users and the shared data in distributed virtual environments. In this section we discuss the issues and the design of such a working environment. We separate the various issues by categorizing them as issues concerning the:

- operations
- metaphors
- interaction techniques

Operations defined in our virtual environment provide the means for supporting manipulation of virtual data

and shared manipulation between remote participants. They describe what can be done with the virtual data in terms of how the data can be explored. They can be data independent (i.e. basic operations such as selecting), or data dependent (i.e. slice through a 3D volume of data). Metaphors for interaction and collaboration make use of everyday interaction and collaboration paradigms to provide intuitive ways of interaction in virtual environments (i.e the metaphor of working around a table). Finally, interaction techniques are dealing with the way operations are implemented.

This categorization can be used for single interaction with the virtual environment, as well as collaborative interaction with a remote partner and is independent of the type of virtual data sets used. Stand alone does not mean that there is no connectivity at all to the outer world. Remote data servers and clients can extend the used VE but do not affect the interaction[10]. The Collaborative Interaction we like to introduce here goes a step further. It includes at least one remote person also working in a projection-based VE and video/audio connection extends each participating site by the possibility of hearing, talking and seeing the remote partners. To create such a team working environment operation metaphors and techniques are extended to the distributed multi-user mode.

Operations

Three categories of operations have been identified, generic operations and content specific operations and collaborative operations.

Generic Operations

Generic operations are used to manipulate virtual data sets of different kinds. There exist a lot of generic operations and to mention only a few:

- translation, rotation, zooming, dragging, pushing, deleting, grabbing, highlighting, selecting

Though in our approach selecting data is a generic operation, selection is the basis for all kinds of generic operations listed above.

Content Specific Operations

The other category of essential operations is content specific. The virtual data sets determine additional operations that are meaningful depending on their features and nature. We categorize them as follows:

- change the mode of visualization
- change the appearance of the data (i.e. color and material attributes including textures, highlighting parts)
- change the geometrical shape of the data (i.e. deformation, cutting, clipping, slicing)
- change the relationship (i.e. between different data sets or parts of the same)

- start/stop/pause of sequences of any kind (i.e. videos, simulation loops, animations)
- reading and editing describing text
- sonification of actions, events or text
- connecting/disconnecting with remote data servers or clients
- others

In the application example, content specific operations related to the medical data are defined.

Collaborative Operations

All of the generic and content specific operations for the single user mode can be extended to allow collaborative operations. Virtual data sets also have to be translated, rotated, zoomed in or out and so on. However, the operations on virtual data sets need to be extended to include shared manipulation. Furthermore, additional operations are needed to establish and control the collaborative session.

In the first category are operations for:

- sharing of virtual data sets
- sharing different views of data sets
- sharing of operations

The objects and data sets of common interest as well as the operations have to be distributed. A global operations box, similar to a tool-box, is the basis for sharing common operations in addition to the local operations at each site. Sharing different views of the data is important, for example when participants would like to concentrate on different aspects of the data set requiring different visualization modes.

Additional operations are needed for:

- establishing a session
- controlling positioning
- controlling conversation between participants
- terminating a session

More specifically calling, hanging up, muting a video and audio connection at any time are generic operations dealing with the audio/video communication of remote participants. Also switching between different remote partners or seeing and hearing them all at once is possible. Positioning of the remote participants' video in one's working environment allows control over the team's positions and support team dynamics.

Metaphors

Metaphors specify the different paradigms that can be used to interact with data sets, and collaborate in Virtual Environments. The metaphors are implemented by combining one or more of the generic, content specific and collaborative operations.

Stand-alone Metaphors

In this subgroup metaphors such as walk, fly and teleport, directly use or extend real-life paradigms to allow navigation through a virtual environment. Content specific metaphors that allow the user for focus on the part of data set of interest, look closer, hear/touch interesting subpart, as well as additional ones like play video/TV, search information library, can also be adapted from real-life paradigms.

However, there might be more than one ways of combining operations to implement a metaphor. The teleport metaphor, for example, can use the zoom operation to make the data set of interest appear bigger to the user or the translation operation to either change the user's position to be closer to the teleporting point, or to move the data part of interest closer to the user.

Depending on the application and the type of virtual data, one metaphor might be more intuitive than others. It can be very useful just to scale the object when observing interesting parts retaining the view on the surroundings. Moving closer to the object of interest could be useful for further operating on it. The metaphor that corresponds to Newton's law of action and reaction can use either the virtual data as point of reference or the user. Concerning the effect, it makes no semantic difference if the user moves around the object or the object rotates around its axis and the user's point of view is stationary. Both implementations have got their authority of existence. Our approach is to make the different metaphors transparent to the user and allow the user to choose the metaphor best suited to the task. These reflections show that the generic, as well as the content specific operations, can be used to implement metaphors. In the section *THE COLLABORATIVE MEDICAL WORKBENCH* we show how these metaphors are implemented for a specific application.

Collaborative Metaphors

We distinguish between metaphors for

- visual and verbal communication between users
- virtual/verbal/tactile manipulation and sharing of data sets
- sharing viewpoint of participants

Metaphors for visual and verbal communication include, working around a table, working next to each other, work at different "rooms" (parts of the data sets), walkie-talkie or turn-taking verbal communication. The verbal communication metaphors, especially when speech

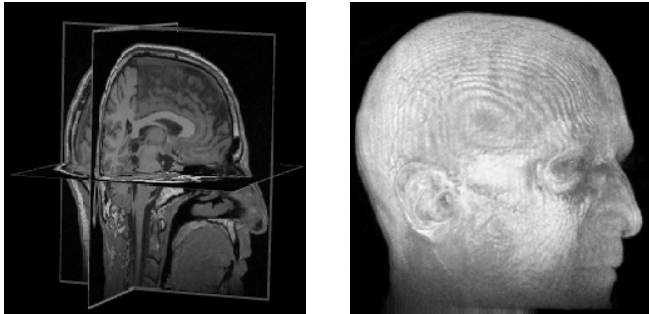


Figure 2: 3D textures rendered as volume or with slicing planes corresponding to the three main medical axes.

recognition is used, should distinguish between voice commands and audio communication addressed to other participant. The user may want to give commands to the computer and to share these commands, so that the remote site is aware of these commands. On the walkie-talkie metaphor the remote site cannot disturb the local user giving verbal commands to the system. In the turn-taking metaphor the computer does not have to listen during the user's verbal communication.

Also important in verbal communication is to simulate the real-life situation where the voice of a participant closer to us is louder. Attaching the audio stream on the position of the video-avatar of the remote participant using the localized sound feature of projection-based systems is a possible implementation of this real-life paradigm. Metaphors for sharing viewpoint involve:

- sharing each other's viewpoint (look over the other's shoulder)
- same viewpoint (look through one's eyes)
- mirrored viewpoint (opposite side of table situation)

Finally, metaphors used for collaborative manipulation of shared objects should provide the possibility of all users participating in the same session manipulating a shared object at the same time with the same or different operation. We call this the tug of war metaphor. An alternative metaphor that avoids deadlock situations is the tug of war without dead end metaphor. Each site receives two local versions of the shared object; one can be manipulated only by the local user and the other only by the remote user. This avoids conflicts but might require a bigger virtual space.

Interaction Techniques

In contrast to the metaphors the interaction techniques determine how to support and implement the different types of operations. It is clear that there are again many different ways to do this.

In order to make interaction in virtual environments richer and more intuitive we would like to provide interaction techniques that make use of more of our senses.

Some interaction techniques that have proved to be quite adequate in terms of intuition:

- speech recognition
- tactile feedback
- menus
- virtual pick-ray
- toolbar/toolbox
- body-centered interaction
- gesture recognition
- smell

Physical mnemonics and other senses have been successfully used to store and recall information relative to the body using hands, eyes, or even the whole body[14].

Depending on the available media and interaction devices, the defined operations can be implemented in different ways. For example, the selection operation can be implemented by recognising simple voice commands or by the use of an interaction device (i.e. stylus) and a virtual pick-ray. The perceived quality of interaction depends heavily on the interaction devices and their use. A plethora of interaction devices are used; to name a few tracked shutter glasses, 6DOF laser pointers, like the Polhemus stylus, button tools with location sensors or data-gloves, the cubic mouse[8], tactile and force feedback devices, such as the Phantom from Sensable, and joysticks with location sensors. The developer should carefully select the most appropriate ones according to the scientific application and VR installation. We recommend techniques that enable the user to concentrate on the task and not on steering through menus and toolboxes.

The collaborative interaction techniques are the same as in the single user mode. There is no need to develop new techniques in order to perform the collaborative tasks. When they are shared, menus, pickrays, voice recognition and other interaction techniques are used as in the single user mode.

THE COLLABORATIVE MEDICAL WORKBENCH

In this section, we give an example of an application making use of the theory and features mentioned above. The application is designed for preoperative surgery planning, training and education. The projection-based systems used are two Collaborative Responsive Workbenches and the resulting collaborative virtual environment is called Collaborative Medical Workbench (CMW).

The medical content for the application is real MR and CT data sets of the human brain, skull and liver. In addition, virtual models of the human skeleton, heart

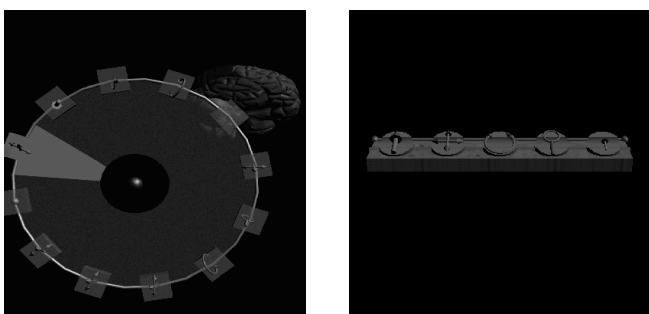


Figure 3: Toolbar for generic operations and object bound ring menu for content specific operations.

and brain are used. During the preoperative planning session as well as during the training the collaborating users work with real patient data. This data are visualized as volume rendered or as 3D textures.

In addition, deformation of the data and simulation of soft tissue behavior and collision detection is needed for the planing phase. In the case of a medical education session models of heart, skeleton and brain can also be used to show and explain physiological conditions and anatomical relationships.

Design of the Application

To design a collaborative virtual environment that supports the above requirements, we carefully studied all the issues mentioned in earlier sections of this paper in order to select the most appropriate metaphors, operations and interaction techniques.

Generic operations such as selecting, zooming, translating, pushing, dragging, grabbing, highlighting and content specific ones, such as labeling of parts of the data sets, cutting, slicing planes, deforming, starting/ending video sequences, were included in the design of such system.

We decided to use menus and virtual pick-rays as interaction technique to apply the desired operations to the data sets. Thereby the generic operations are applied using a fixed toolbar with a rotate tool, translate tool, zoom tool, drag and push tool.

The content specific operations allow slicing of the 3D representation of the patient's data, as shown in Figure 2. These operations are applied by calling an Object bound ring menu, as shown in Figure 3. The toolbar is fixed whereas the ring menu, bound to the object, disappears when an operation has been selected. Additional content specific operations for the real patient data sets are color lookup sliders, gray value windows, compass to obtain the orientation when slipping into the data set, deformation tools, slicing and clipping planes. For the heart, brain and skeleton model content specific operations for material change and fade, and wire-frame and gray value windows are available. Additional operations include viewing of labels bound to different bone

types and muscles, or of animation of the virtual heart model. The user is also able to visualize additional interesting medical information in their disposal. Rendering of video sequences in mono or stereo on virtual Screens is part of the system to allow video sequences of endoscopic recordings of the stomach or the esophagus to be played at will (see also Figure 4).

As interaction devices in our prototype we use tracked Crystal Eyes shutter glasses, a Polhemus stylus, and as we work two handed at the CMW, a three button tool also tracked by the Polhemus Fastrak system.

In order to enable teamwork we implemented the following metaphors:

- ring up the remote partner
- join a remote session
- share a tool
- face-to-face communication
- tug of war

The ring-up and join session metaphors were implemented by providing a session name. As soon as the user connects to a session a whole copy of the virtual scene provided by the others is transferred to the local site. In the same moment a video/audio connection to the other CMW is established. The video screen with the remote partner on it provides the content specific operation to mute or disconnect this video/audio conferencing depending on user's wish.

To enable collaborative manipulation of the data, the generic toolbar is distributed together with the patient data sets or models of heart, brain and skeleton. The content specific operations are also shared since there are bound to the shared medical data sets. The metaphors we make use of in the collaborative case are the face-to-face communication and mirrored viewpoint or sharing viewpoint (look through other's eyes and/or look over other's shoulder). Finally for the collaborative manipulation we used the tug of war metaphor (see Figure 4).

CONCLUSIONS

We presented our vision in creating Collaborative Virtual Environments to provide distributed collaborative teams with a virtual space where they could meet as if face-to-face, coexist and collaborate while sharing and manipulating in real time the set of virtual data of interest. We discussed the issues involved in bringing together Human Computer Interaction and Human to Human Communication, focusing on projection-based Virtual Environment systems. The issues were divided into three categories, namely issues concerned with the operations, the metaphors and interactions techniques needed to support communication and collaboration in a distributed virtual environment. We presented the design

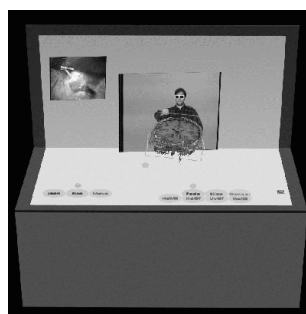


Figure 4: CMW used for remote medical training on virtual heart model and for a remote surgical planning session using additional endoscopic video sequences.

of such an environment according to the discussed issues and functional requirements and exemplified the approach with an application in the medical field. The Collaborative Medical Workbench was implemented according to the specified design and the prototype has been used for validating the approach. We are planning to carry out further tests and collaborative sessions in order to investigate the different metaphors used, and improve the theoretical approach and resolve some of the technical issues that would make the use of such an environment even more intuitive to the participants.

The prototype implementation of the CMW is been used by two of our collaboration partners, the Surgical Research Unit OP 2000 at Max-Dellbrück-Centre in Berlin and the Department of Maxillofacial Surgery and Radiology at the University of Technology Munich. The initial evaluation of the prototype was based on heuristic analysis [9] and we are planning to extend it to detailed user-task and ergonomic analysis [9].

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