Designing Viewpoint Awareness for 3D Collaborative Virtual Environment Focused on Real-Time Manipulation of Multiple Shared Objects

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Abstract. In some collaborative manipulation activities – for example, medical experts making a diagnosis based on a 3D reconstruction of a human organ – remote participants may tailor their views on the shared object to their particular needs and task. This implies that each user has her viewpoint on the object. Awareness of viewpoint is then necessary both to coordinate each other and to understand remote users' activities. This work investigates how to provide the remote viewpoint awareness in a 3D collaborative desktop in which multiple shared objects can be independently positioned and manipulated to accomplish a common single activity. Preliminary results of ergonomic evaluations of the proposed metaphors are also provided.

Keywords: viewpoint, 3D virtual desktop, manipulation of 3D objects.

1 Introduction

In real life collaborative activities, some tasks are performed focusing on a specific aspect, and others require an overview of all participants' activity. Therefore, over a give period of time user attention is engaged in both individual and shared efforts [12], [13]. Consequently, Collaborative Virtual Environments (CVEs) have to manage subjective views on the shared data, independently navigation in common virtual space, shared and private mode of working, in order to actually support people's ability to collaborate [15]. In these workspaces, maintaining awareness of others – where partners are located, what they can see, what they are currently focused on, and what they are doing [1] – is an important factor for smooth and natural collaborations [2]. Particularly, in CVEs where distant users collaborate being concentrated on different parts of the shared data, the viewpoint awareness is necessary to coordinate each other and to understand remote users' activities.

Our research topic focuses on collaborative applications concerning the manipulation of multiple 3D shared objects. There are a lot of examples of possible collaborative activities that require distant users to manipulate shared objects. Let us consider for instance the following scenario. A group of mechanical engineers, geographically distant, is collaborating to design a new car. They could be discussing the engine

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structure and so they are concentrated on the same part (the engine), or be involved in individual tasks that may require to work on different parts of the car (for example, an engineer works on the front wheels and the other on the windscreen). So, the mechanical engineers might have different viewpoints on the same shared object (that is the car). Another example is given by three distant physicians (a radiologist, a surgeon and an oncologist) who make a diagnosis of a tumor by simultaneously analyzing a 3D reconstruction of a real patient's liver and the X-ray image. We can suppose that the radiologist examines the x-ray image, while the surgeon and the oncologist use the 3D model. The surgeon studies how to cut the liver (to extract the tumor) and the oncologist measures the tumor size. The three physicians cooperate to carry out the common activity (the diagnosis) but being concentrated on different objects and from distinct viewpoints, depending on their skills.

These and similar manipulation activities share three common features. The manipulated objects are the focus of the collaboration and so they are the only things that have to be shared among distant participants. There is no spatial relation among the manipulable objects. Finally, each user may have a different viewpoint on the shared objects, depending on the task she has to accomplish. Multiple perspectives can provide more insight into the task and might enable a group to accomplish it more efficiently. On the other hand, it is difficult to discuss and to coordinate each other since different viewpoints are employed [7], [16]. In a real context, a person working in a group can easily and naturally infer other partners' viewpoints because she can see them and their spatial position according to the common object.

This work deals with this specific problem: how to provide viewpoint awareness during a collaborative manipulation in a 3D virtual workspace in which distant users can not see one another and the manipulable objects can be independently positioned and oriented?

In this paper, we exploit two viewpoint metaphors: the "remote user's viewpoint" metaphor, which aims to provide any user with a global sense of where the other person's viewpoint is relative to a shared object, and the "local viewpoint" metaphor, which allows to share remote user's view on the common object. Our overall research hypothesis is that "local" viewpoint is more effective and useful than "global" viewpoint during a collaborative manipulation activity.

This paper first reviews the related research concerning the viewpoint awareness. It describes the experiment we conducted. Finally, it presents some of the observations, lessons learned and ideas for future explorations.

2 Related Work

The viewpoint is considered one of the main factors to maintain awareness in CVEs and it is widely exploited to reveal "what the remote users are looking at" both in navigation and visualization activities. A lot of techniques have been implemented to represent the viewpoint in CVEs.

In navigation activities, where users can independently move in the 3D shared workspace, the remote viewpoint is necessary to determine what a co-participant is referring to when she is out of view, distant or facing away. Dyck et al. [2] propose a number of embodiment enhancements, like the explicit representation of field of view, to support awareness of collaborators in their 3D collaborative workspace called Groupspace. In particular, the view cone approximates the viewable area of other users making it easier to see what is in their fields of view. A similar implementation is found in Hindmarsh et al. [6]. In their study of object-focused CVEs, also extend the embodiment's view by representing it as a semitransparent frustum, in order to provide action awareness. Park et al. [17] employ avatars with long pointing rays emanating from their hands to point at 3D model's features in a collaborative CAVE-based visualization tool for exploring multivariate oceanographic data sets. Schafer et al. [7] investigate egocentric/exocentric view combinations in a 3D collaborative virtual environment which represents the spatial problem the collaborators are working to resolve. The egocentric actor, who restricts the user to a first-person view of the space, is represented by a floating head avatar which shows her position and orientation. The exocentric view is restricted to an external view of the space.

On the other hand, the main issue for the collaborative visualisation of data is to provide collaborators with the remote user's focus of attention since each user can visualize data from different viewpoints. In CSpray [3], a collaborative 3D visualization application, the viewpoint concept is implemented by two techniques: eye cones and shared views. An eye cone is a simple embodiment in the form of a white eyeball placed at the camera position of a distant user and oriented towards the view direction of that camera. It represents the remote user's focus of attention. Shared views enable to share the viewpoint of any participant, by clicking over an eyeball, providing an "over the shoulder" viewpoint. Valin et al. [5] also exploit shared views to request another user's view or to send their view to the other users. Moreover, they use a 3D telepointer, positioned at the location of the user it represents, to point to remote user's focus of attention. Sonnenwald et al. [4] use multiple pointers – each showing the focus of attention and interaction state for one collaborator – to support mutual awareness when working in shared mode with their nanoManipulator Collaboratory System. The system also allows users to work independently in private mode. Finally, alternative views like radar views are common in 3D games, but do not show perspectives. 3D versions of the radar view have been developed, an example is the Grand Tour [2], to overcome problems in the 2D radar representation arising when users can move vertically and horizontally in the virtual space.

Our research differs from previous work for two main reasons: the collaborative activity we want to support is a synchronous and real-time manipulation of different parts of the same shared object and/or of multiple objects; the workspace is a non-immersive 3D virtual environment in which direct manipulation is applied in order to interact with the 3D objects in the environment. A detailed description is given in the following paragraph. In particular, the common objects can be independently positioned and oriented. Consequently, the viewpoint metaphors can not concern the 3D workspace as whole, since it is typical to each user, but they have to refer to every shared object.

3 Setting the Scene

There are bounds on the collaborative activities that we are trying to support in this research. Our boundaries involve the kinds of groups we are trying to support, the workspace environment where collaboration takes place, and the kinds of tasks that groups will undertake.

Small groups and mixed-focus collaboration. Small groups of between two and five people that work together but from different places. These groups often engage in mixed-focus collaboration, where people shift frequently between individual and shared activities during a work session.

Workspace environment. Many real-time groupware systems provide a bounded space where people can see and manipulate artifacts related to their activities. We concentrate on user-activity oriented desktop implemented as a closed space in which distant users cooperate to carry out a common single activity, by working on multiple shared objects. The shared objects are always kept visible and they can be privately placed and manipulated. Furthermore, each participant can arrange her own workspace to her liking, so that the workspace organization and the common objects arrangement are specific to each user. In these spaces, the focus of the activity is on the manipulable objects through which the task is carried out.

Tasks. Performance of physical manipulation on the existing shared objects.

4 The Remote User's Viewpoint Metaphor

This metaphor provides a global sense of where the other person's viewpoint is relative to a particular shared object, in order to have a roughly idea of what the others are looking at.

Specifically, we aim to reproduce the real situation in which a person working in a group knows other collaborators' perspective on the common object because she can see them. Let us consider this explanatory example. During a painting course, a group of students is asked to draw a statue placed in the centre of the room. Each student, owing to her physical position in the room, looks at it differently from the others and so she sees and draws different "aspects" of it. In particular, let us suppose that student A and student B are looking respectively at the front and back side of the statue. Even if the student B can not see the front side of the statue, because she is in the opposite position, she can have an idea of how student A perceives of it.

To this aim, our proposal is a wire sphere with a number of semicircles, one for each distant collaborator. The idea is that the sphere can be thought as the local user's virtual space surrounding the common object, and the semicircle as the representation of the remote user's viewpoint according to the local and remote object orientations. So this metaphor provides an egocentric representation of the remote perspectives since viewpoints are represented according to the local user's orientation of the common object.

The following figure (Fig. 1) shows the implementation of the remote user's viewpoint metaphor. The red semicircle placed on the left side of the wire sphere reveals the remote red user's viewpoint dependently on the local object orientation. So, the

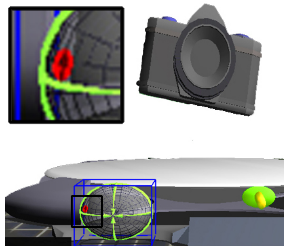

Fig. 1. The remote user's viewpoint metaphor

local green user can infer that the red user is looking at the left side of the camera (the camera on the table is the shared object).

We chose the semicircle shape to represent the remote user's viewpoint to correctly visualize the gaze orientation (the semicircle is a smiling mouth). The semicircle on the wire sphere does not reveal the physical distance between the object and the user, unlike the traditional radar map. Moreover, we use a wire sphere to enable to see the semicircle placed on its hidden surface. We implemented this metaphor like a 3D map, that is separately from the manipulated object, for two main reasons: to avoid surcharging the space around the object, and to keep the remote viewpoint always visible.

5 The Local Viewpoint Metaphor

The local viewpoint metaphor provides an "over the shoulder" [8] view on the shared object. The idea is to allow a user to instantaneously synchronize her viewpoint with that of a remote partner, seeing exactly what the other partner is looking at. In the painting course example, this metaphor corresponds to the teacher which takes one student's place in order to verify her painting. In fact, it is necessary for the teacher to share the student's viewpoint on the statue to understand if the drawing is correct.

The following figures show the implementation of this metaphor in our 3D collaborative workspace. Two users (the green and the blue) are collaborating in order to learn to use a camera (the object placed on the table), but every participant has a different viewpoint on the shared object (Fig. 2). At a certain point, the green user switches to the blue user's viewpoint (Fig. 3). So, the two users are now looking at the camera from the same viewpoint (the blue user's viewpoint).

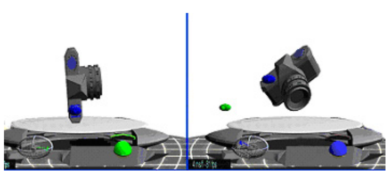

Fig. 2. The blue and green users' desktops, respectively on the left and the right

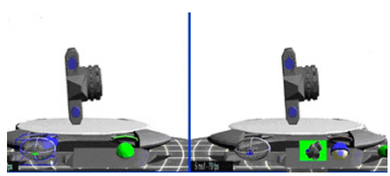

Fig. 3. The green user (on the right) switches to the blue user's viewpoint

If the green user wants to continue working privately, she selects the camera in miniature displayed beside the eye icon. This action causes the camera to be positioned according to her last orientation before sharing the other user's viewpoint (Fig. 4).

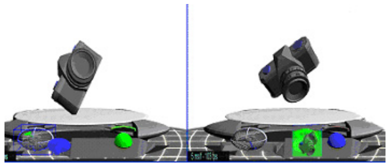

Fig. 4. Both users work privately, so the object orientation is local

6 Preliminary Usability Study

To test the understandability of our viewpoint metaphors we performed two experimentations, one for each metaphor. Our research hypothesis is that the "local viewpoint" is more intuitive and useful than the "global viewpoint" for a collaborative manipulation activity within our bounds.

Procedure
The experimental task, carried out in both the experiments, was a collaborative manipulation activity consisting in taking eight pictures, using a virtual Pentax camera, of a virtual person who was skiing. Participants were asked to set the virtual camera and to push on the shutter release button to take the photos. They manipulated the speed deal, the zoom ring and the aperture ring in order to choose the optimal settings to take good photos. The captured images could be viewed. Participants were asked questions such as: "in your opinion, how do I look at the camera?", "what is my camera orientation? (Could you rotate your camera according to my camera orientation?)", "my camera lens is in front of me, and the yours?". Each pair completed eight tasks corresponding to eight pictures taken according to different camera settings. They were seated back to back, so as not to be able to see each other's screen, and participants were asked to talk freely about the task.

Each trial took about an hour and consisted of a brief presentation to provide background information on the experiment, about 5 minutes for participants to get used to the system (individual practice), approximately half an hour to perform the given tasks, and about ten minutes for the participant to reply to a questionnaire about her experience of using the system. Finally, an informal debriefing discussion (approximately 15 minutes) was conducted before the participant left.

A VCR was used to record each participant's on-screen activities and audio from their perspective. Eight trials were performed for each metaphor validation.

Subjects
People participated in the experiments were divided into two homogeneous groups, each of them composed of 8 persons, 4 females and 4 males. Only one person was a computer scientist but the most had experienced a computer. Three persons knew 3D

virtual spaces, and five subjects played video games. None of them had a background in CVE technology. The average age of the participants was 32, with the youngest person being 24 years old and the oldest being 40 years old.

Workspace settings
The 3D workspace used for the experiments consisted of:

- a pointer, associated with the local user, to interact in the environment. So, the user selected an object in the scene and, once selected, she could manipulate it exploiting direct object manipulation [11];
- a telepointer (that is the local representation of the pointer associated with a distant user) to represent the remote user's focus of attention;
- colour changes of the public object subparts to show the remote user's action point ([9], [10], [11]);
- a clone representing the distant user in order to reinforce the co-presence during the collaborative activity;
- the virtual camera, that is the shared object, placed on the table;

The following figures (Fig. 5 and 6) show the 3D workspaces used to test out the remote user's viewpoint and the local viewpoint metaphors respectively.

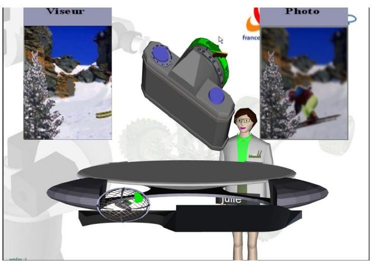

Fig. 5. 3D workspace used to study the "remote user's viewpoint" metaphor

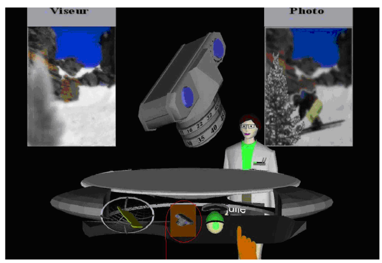

Fig. 6. 3D workspace used to study the "local viewpoint" metaphor

The experiments were conducted in the Virtual Reality Room of the GRAPHIX Laboratory, University of Lille 1, France. A Barco monitor displayed the 3D workspace used for the experiments. Each participant was provided with polarized glasses, a mouse and a space-mouse for the interactions.

Discussion
Our observations of the videos and debriefing discussions led us to the following interesting findings:

- during a manipulation activity, subjects are completely concentrated on the manipulated object so that they ignore the surrounding environment;
- the 3D virtual environment we proposed is perceived in two different ways: some users think that all participants share the same view on the common object, others think that the remote user looks at the object through the clone's eyes. Consequently, questions concerning the remote user's camera orientation, such as "how

do I look at the camera?", got the participants lost so that they thought they were wrongly accomplishing their task. This implies that participants did not understand that object orientation is local to each user.

These findings explain away the preliminary results we obtained:

- the local user's viewpoint metaphor is well-understood and efficiently used;
- subjects understand that the remote user's viewpoint metaphor represents the distant user's view on the shared object even if they find pretty difficult to infer how the distant partner is actually looking at it.

The eye metaphor has been correctly perceived by the most of the participants. The subjects immediately realised that the eye could be used to look at the object like the other user did. In fact, the answer to the question "what does it happen when clicking on the eye?" was often "I look at the camera from your viewpoint". Moreover, the subjects intuitively understood as well that, when sharing a distant user's viewpoint, their local orientation of the camera was piloted by the remote user. In other words, sharing the viewpoint causes the camera orientation to become public. Similarly, the miniature of the camera beside the eye was easily perceived as being "the local camera orientation before sharing the remote user's viewpoint".

Examining answers about the semicircle (for example, "what is the semicircle used for?"), we observed that at the beginning of the experimentation the semicircle had not been understood by the most of participants, even if somebody unconsciously replied "would the semicircle be your (the other participant) representation?". After accomplishing the whole task (eight photos), the most of participants (five persons) understood that the semicircle revealed the remote user's viewpoint on the shared camera. Specifically, two persons realised it after taking the first two photos, a participant at the fourth photo, and two at the seventh photo. One possibility is that these users were familiar with video games and so they applied their knowledge and experience to understand this metaphor. In fact, participants that did not understand the semicircle metaphor after completing the whole activity were not used to play video games and had never experienced 3D virtual spaces. Nevertheless, only one person among the last three replied that the semicircle is very hard to understand.

On the contrary, the percentage of correct camera orientations (31.25%) describes a different conclusion. Even if the semicircle revealed the remote viewpoint, it certainly required some real cognitive processing to understand what the other user was actually looking at. This may be because this metaphor is "statically" used by the subjects. In fact, we observed that the participants exploited this metaphor only when they were asked questions about the camera orientation. This is most likely due to the fact that the manipulated object (the virtual camera) was familiar and the activity to accomplish were relatively straightforward so that participants did not really need to know other viewpoint on the object to correctly attain their objective. These remarks are supported by the comments "the remote user's viewpoint awareness was not necessary for this specific manipulation task" and "the task was relatively straightforward to accomplish". Another possible explanation is that the remote user's viewpoint metaphor is separated from the manipulated object from the graphical point of view (in fact, the sphere is placed in the left bottom corner of the scene). Since the user is concentrated on the object during the collaborative manipulation she does not exploit this information because "it is not part of her focus".

In our opinion, people involved in a collaborative object manipulation need to know the collaborators' viewpoint only in the case of misunderstandings that hinder the activity. Also it could be most likely that the information required concerns "see exactly what the collaborator is looking at", rather than having a global idea. Sharing views, in this case, is more effective and efficient and allows users to quickly get the information needed to continue collaboration, without interrupting their main activity (the manipulation).

7 Conclusions and Future Work

This research investigated what kind of viewpoint awareness is more appropriate in a 3D collaborative desktop in which a group of persons, from different places, work together while they manipulate multiple shared objects in order to accomplish a common single activity. To this aim, each participant can position and orient the common objects to her liking to facilitate her manipulation task. So, different viewpoints on the shared objects can be employed.

We proposed two viewpoint metaphors: the remote user's viewpoint metaphor and the local viewpoint metaphor. The former aims to provide every user with the other person's viewpoint relative to the public object; the latter provides an "over the shoulder" viewpoint. We think that during a collaborative activity focused on the physical manipulation of existing objects, users need to share views rather than have a rough idea of what the distant partners are looking at. In fact, an "over the shoulder" viewpoint provides quickly the information necessary to solve a misunderstanding, without interrupting one person's private manipulation. Moreover, sharing views allow users to be involved in shared manipulation tasks, achieving therefore the mixed-focus collaboration [10], [12], [13], [7].

The preliminary results corroborate our hypothesis. The eye metaphor is more intuitive and pertinent to convey the awareness of viewpoint for collaborative manipulation activities within our bounds (paragraph "Setting the scene").

But having a global sense of where the other persons' viewpoints are relative to a shared object provides the implicit awareness of viewpoint that is typical of face-to-face collaborations. Is it therefore important to provide this kind of viewpoint awareness? To answer this question it should be necessary to experiment with a more difficult activity involving the manipulation of more complex objects.

Anyway, our preliminary study provides us with an important insight concerning how to design this kind of viewpoint awareness. So the global viewpoint awareness has to be strictly "linked" to the manipulable objects. This means that global viewpoint cues have to be graphically represented in the space which surrounds closely the focused object to be efficiently exploited. In fact, during a manipulation activity, persons are completely concentrated on the object to accomplish precisely their task. So everything outside this space is not considered.

A possible proposal is to exploit the telepointer to convey awareness of viewpoint. In fact, all subjects thought that the telepointer is very intuitive and helpful for helping collaboration. To this aim, it is necessary to add orientation to the telepointer to represent gaze direction. Moreover, a solution should be found to keep the "oriented" telepointer always visible.

Finally, we are investigating "rich telepointers" [14] to exploit telepointers in order to provide awareness of presence to avoid using clones.

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