# A 3-D Interface for Cooperative Work


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## 1. Abstract

We present a new graphical three-dimensional user interface for synchronous cooperative work, called *Spin*, designed for multi-user real-time applications to be used in, for example, meetings and learning situations.

We have designed an interface, for an office environment, which recreates the three-dimensional elements needed during a meeting and increases the user's scope of interaction in comparison to a real-life situation. In order to accomplish these objectives, animation and three-dimensional interaction in real time are used to enhance the feeling of collaboration within the three-dimensional workspace and keep visible a maximum of information. This workspace is created using artificial geometry — as opposed to true three-dimensional geometry — and spatial distortion, a technique which allows all the documents and information to be displayed simultaneously while centering the user's focus of attention. Users interact with each other via their respective clone, a three-dimensional representation, displayed in each interlocutor interface, and animated with user action on shared documents. An appropriate object manipulation system is used to point out and manipulate 3D documents, through direct manipulation, using 3D device and some interaction metaphors.



**Keywords:** Synchronous CSCW, three-dimensional interface, 3D interaction.


## 2. Introduction

Technological progress has given us access to fields which previously only existed in our imaginations. Progress made in computers and in communications networks has benefited computer-supported cooperative work (CSCW), an area where many technical and human obstacles have to be overcome if it is to be considered a valid tool. We need to bear in mind the difficulties inherent in cooperative work and in the user's ability to perceive a third dimension.

### 2.1 The shortcomings of two-dimensional interfaces

Current WIMP (Windows Icon Mouse Pointer) office interfaces have considerable ergonomic limitations. Two-dimensional space is not effective when it comes to displaying massive amounts of data; this results in shortcomings such as window overlapping and the need for iconic representation of information. Window display systems, be they Xll or Windows, do not make the distinction between applications, and information is displayed in identical windows regardless of the user's task.

Until recently, network technology only allowed for asynchronous sessions; and because the hardware being used was not powerful enough, interfaces could only use two-dimensional representations of the workspace. This created many problems: moving within the simulated three-dimensional space was limited, metaphors were not realistic, there were difficulties representing users and their relation to the interface. Moreover, because graphical interaction was low (proprioception was not exploited) users had difficulties to get themselves involved in the outstanding task.

### 2.2 Interfaces: New Scope

We are putting forward a new interface concept, based on computer animation in real time. Widespread use of 3D graphics cards for personal computers has made real-time animation possible on low-cost computers. The introduction of a new dimension (depth) changes the user's role within the interface. The user now has new ways of navigating in, of interacting with and of organizing his workspace.

In this paper we discuss the various concepts inherent in simultaneous cooperative work (synchronous CSCW), in representation and interaction within a three-dimensional interface. We also describe our own interface model and how the basic concept behind it was developed. We conclude with a description of the various current and upcoming developments directly related to the prototype and to its assessment.

## 3. Concepts

When designing a three-dimensional interface several fields are taken into consideration. We have already mentioned real-time computer animation and computer-supported cooperative work, which are the foundation of our project. Certain areas in the field of human sciences have directly contributed to project development. Ergonomics and sociology contribute to our knowledge of the way in which the user behaves within the interface, both as an individual and as a member of a group. Synthesized analysis of these fields allows us to put forward general concepts for the development of a three-dimensional interface for cooperative work.

## 3.1 Synchronous Cooperative Work

The interface must support synchronous cooperative work. This entails supporting applications where the users have to communicate in order to make decisions, exchange views or find solutions, as would be the case with teleconferencing or learning situations. The degree of realism is crucial; the user needs to have an immediate feeling that he is with other people. Experiments such as *Hydra Units* [Buxton 92] and *MAJIC* [Okada 94] have allowed us to isolate some of the aspects which are essential to multi-media interactive meetings.

*eye contact* - a participant should be able to see that he is being looked at, and should be able to make eye contact;

*gaze awareness* - being able to establish a participant's visual focus of attention;

*facial expressions* - these provide information concerning the participants' reactions, their acquiescence, their annoyance and so on;

*gestures* - play an important role in pointing and in three-dimensional interfaces which use a determined set of gestures as commands, and are also used as a mean of expression during verbal interaction.

## 3.2 Group Activity

Speech is far from being the sole means of expression during verbal interaction [Cassel 94]. In addition to facilitating communication, gestures (voluntary or involuntary) and facial expression contribute as much information as speech. Moreover, collaborative work entails the need to identify other people's points of view as well as their actions [Shu 94] [Kuzuoka 94]. This requires defining the metaphors which will enable users involved in collaborative work to understand what other users are doing and to interact with them. Users may be represented in the interface by a fixed or animated image (video) or in three dimensions; semantic content increments from one form to the next, a fixed image (its only purpose being to visually identify a user) being the poorest in semantic content. [Benford 95] have defined various communication criteria for representing a user in a virtual environment. They lay down rules for each characteristic and apply them to their own system, [Benford 93] (Distributed Interactive Virtual Environment). Their work points out the advantages of using a clone, a realistic three-dimensional representation of a human, to represent the user: eye contact (it is possible to control the eye movements of a clone) as well as gestures and facial expressions can be controlled.

Along with his representation, every user must have a telepointer, a device used to designate objects which can be seen on other users displays. Cooperation can be improved by developing a more complex telepointer which is able to do more than simply designate objects, thereby enabling the various users to interact.

## 3.3 Task-oriented Interaction

Users attending a meeting must be able to work on one or several shared. It is therefore preferable to place the documents in a central position in the user's field of vision, this increases his feeling of participation in a collaborative task. This concept, which consists of positioning the documents so as to focus user attention, was developed in the Xerox *Rooms* project [Henderson 86]; the underlying principle is to prevent windows from overlapping or becoming too numerous by classifying them according to specific tasks and placing them in virtual offices so that a single window is displayed at any one (given) time.

## 3.4 The Conference Table Metaphor

Visually displaying the separation of tasks seems logical — an open and continuous space is not suitable. The concept of "room", in the visual and in the semantic sense, is frequently encountered in the literature. It is defined as a closed space which has been assigned a single task. This type of model does not allow the user to view, subjectively or otherwise, the other activities taking place concurrently. A three-dimensional representation of this "room" is ideal because the user finds himself in a situation that he is familiar with, and the resulting interfaces are friendlier and more intuitive.

## 3.5 Perception and Support of Shared Awareness.

Some tasks entail focusing attention on a specific issue while others call for a more global view. Generally speaking, over a given period of time, our attention shifts back and forth between these two types of activities. CSCW requires each user to know what is being done, what is being changed, where and by whom; consequently the interface has to be able to support shared awareness. Ideally the user would be able to see everything going on in the room at all times (an 'everything visible' situation). Nonetheless, there are limits to the amount of information that can be displayed on the screen at any time. Improvements can be made by drawing upon (and adapting to) certain aspects of human perception, namely, a field of vision with a central zone where images are extremely clear, and a peripheral vision zone, where objects are not well defined, but where movements and other types of change are perceived. Our model simulates this aspect of human perception by placing the main document in the center of the screen while continuing to display all the other documents. Thus, by reducing the space taken up by less important objects, an 'everything perceivable' situation is obtained and, although the objects are not clear, they are visible and all the information is available on the screen.

## 3.6 Interactive Computer Animation

Interactive computer animation allows for two things: firstly, the amount of information displayed can be increased, and secondly, only a small amount of this information can be made legible, see [Mackinlay 91] and [Robertson 91]. The remainder of the information continues to be displayed but is less legible (the user only has a rough view of the contents). The use of interactive computer animation to display each application enables the user to visually analyze the data quickly and correctly. The implementation of this concept allows us to subsequently implement the "everything perceivable" concept.

Interactive computer animation is also used for the interface itself. The interface needs to be seamless. We want to avoid abstract breaks in the continuity of the scene, which would increase the user's cognitive load. Unnecessary cognitive load is lessened when visual information is eloquent. Certain graphical systems, for example, reduce a window to its iconic representation in a linear animated sequence. In our model, we do not abruptly suppress objects and create a new icon; consequently, the user no longer has to strive to establish a mental link between two different representations of the same object. Hence, visual recognition decreases cognitive load.

## 3.7 Navigation

We define navigation as the user's movements within a three-dimensional environment; this means changes in user perspective. Interaction, on the other hand, refers to how the user acts in the scene: the user manipulates objects without changing his overall perspective of the scene.

Navigation and interaction are correlated; in order to interact with the interface, the user has to be able to move within the interface. Unfortunately, the existence of a third dimension creates new problems with positioning and with user orientation; these need to be dealt with in order to avoid disorienting the user, see [Gomez 94]. This is especially true for our interface, where the main objective is not navigation within the interface, but rather the work being carried out in the interface.

In a cooperative work context, the user is physically in the interface, and also has a position relative to the group. Each user has a role, e.g. the user presiding over the meeting and other participants do not do the same things. Having a role to play can entail limits. The user needs to have an instance of the interface which is adapted to his role and which translates his perspective. The user can then better integrate the workspace and should not be disoriented when moving about in the interface. This entails designing a coordinate frame where navigation within a restricted space is adequate and easy.

## 3.8 Manipulation

While navigation is restricted, the execution of an action is not. Our model is based on direct object manipulation. The user can interact with the interface and manipulate objects directly. By enhancing the user's ability to move around within the interface we come closer to realistic interaction. We are working towards a model where representation, navigation and interaction are three-dimensional (the link between the virtual work environment and the real work environment is reinforced by the interface), with two-handed interactions. [Kabbash 94]'s research points out the type of applications where bimanual interaction can be implemented without increasing the user's cognitive load. He goes on to explain that from his observations the use of two hands can be less productive than the use of one hand in cases where the application assigns an independant task to each hand. In certain cases, however, the use of two hands enables the user to adapt more quickly, to retrieve information faster, and to manipulate the interface with greater ease. In order to design applications which are suitable for bimanual interaction we try to implement constraints such as keeping the left hand (in this case, for right-handers) as a spatial reference, as a task initiator, or as the hand with the easiest task to perform.

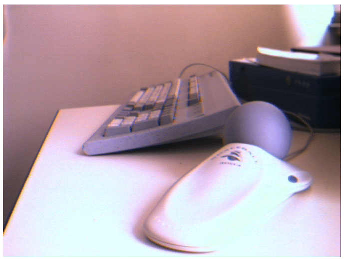
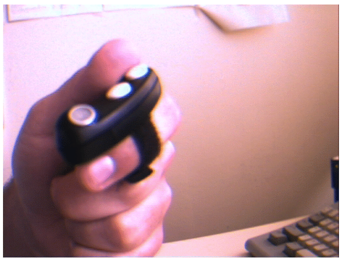
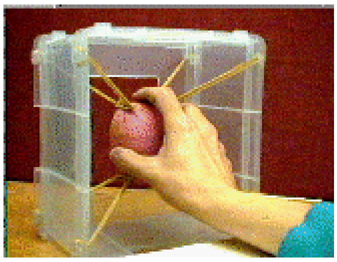
## 3.9 Deictic Gesturing

Increased scope for gestures also increases the incidence of problems related to hand position, namely, the perception of movement in real space and how it corresponds to movement in virtual space [Venolia 93]. Interaction within the interface (mode) should correspond to the devices used to navigate (means). Research should look at the mode and the means of interaction concurrently.

With this in mind, we have decided to use 3D input devices [Fuchs 95] such as Spaceballs™ and acoustic input devices attached to the finger which return three dimensions of input data (the typical "mouse" device only returns two dimensions of input data). These devices provide input which indicates their position. When the input device provides information relative to movement along three axes (translations on the x, y, and z axes) it is said to have three degrees of freedom; if it is also able to provide information concerning rotation about all of the axes, it is said to have six degrees of freedom (translation along the x ,y, and z axes and rotation about each of these axes). Three-dimensional input devices can be put into three categories: isometric input devices, isotonic input devices and elastic input devices (those which, once released, return to their original position automatically).

*Isometric Input Devices*

Their resistance is infinite and they are stationary. They translate movement by measuring force and couple. The amount of force applied to the device is used to translate movement and the hand itself barely moves, so there is no direct correlation between what the hand does and what goes on in the interface. Another drawback is the lack of touch feedback (the user's sense of proprioception is not exploited); this calls for extra adaptation time when performing complex tasks. 3D Trackballs are an example of this type of input device (fig. 1a).

la: isometric figure 1b: isotonic device 1c: elastic device

*Isotonic Input Devices*

Isotonic input devices move with the user, and have no resistance. The data-glove is an example of isotonic device. Their drawbacks are possible user fatigue following prolonged use, and the fact that the space they can be used in is too limited for certain types of applications. This, however, is not the case with our model, where the user remains seated in front of his computer. One of their advantages is that they can return up to six dimensions of input data. Acoustic devices are an example of isotonic input devices (fig. lb).

*Elastic Input Devices*

This type of input device is midway between the previous two. Movement is translated by the amount of pressure applied**,** once released, they automatically return to their position in equilibrium. They are believed to correspond more to user proprioception and are thus easier to manipulate (fig. 1c).

Opinions differ as to what type of input device obtains the best performance, see [Zhai 94]. Isometric devices perform best for rate control (as is the case in robotics), whereas isotonic ones perform best for position control (in situations where there is a direct relation between hand and pointer movement).

# 4. Our Model

In this presentation we describe our interface model by expounding the aforementioned concepts, by defining spatial organization, and finally, by explaining how the user works and collaborates with others through the interface.

## 4.1 Spatial Organization

*The Workspace*

While certain aspects of our model are directly connected to virtual reality, we have decided that as our model is aimed at an office environment, the use of cumbersome helmets or gloves is, therefore, not desirable. Our model's working environment is non-immersive. Frequently, immersive virtual reality environments lack precision and hinder perception. We try to eliminate many of the gestures which are linked to natural constraints and which are not necessary during a meeting. Our workspace has been designed to resolve navigation problems by reducing the number of superfluous gestures which perturb the user. In a real life situation, for example, people sitting around a table could not easily read the same document at the same time. To create a simple and convenient workspace, situations are analyzed and informations which are not indispensable are discarded [Saugis 97].

There are two types of basic objects in our workspace: the actors and the artefacts. The actors are the representations of the remote users or of artificial assistants. The artefacts are the applications and the interaction tools.

*The Conference Table*

The metaphor used by the interface is the conference table. It corresponds to a single activity, divided spatially and semantically into two parts. The first is a simulated panoramic screen on which actors and shared applications are displayed. Secondly, within this screen there is a workspace located near the center of the simulated panoramic screen, where user can easily manipulate a particular document.


figure 2: objects placed around our virtual table

The actors and the shared applications (2D and 3D) are placed side by side around the table (fig. 2), and in the interest of comfort, there is one document or actor per "wall". As many applications as desired may be placed in a semi-circle so that all of the applications remain visible. The user can adjust the screen so that the focus of his attention is in the centre; this type of motion resembles head-turning. The workspace is seamless and intuitive, and simulates a real meeting where there are several people seated around a table. Participants joining the meeting and additional applications are on an equal footing with those already present.

*Distortion*

If the number of objects around the table increases, they become too thin to be useful. To resolve this problem we have defined a focus-of-attention zone at the centre of the screen. Documents on either side of this zone are distorted (fig. 3).

Distortion is symmetrical in relation to the coordinate frame x=0. Each object is uniformly scaled with the following formula (where x is the abscissa of the object center):

$$x' = \left(1 - \left(\frac{S - x}{S}\right)^{\alpha}\right) \times S$$

where S is half of the width of the parallelepiped and $\alpha$ is the deformation factor. When $\alpha=1$ the scene is not distorted. When $\alpha>1$, points are drawn closer to the edge; this results in centrally-positioned objects being stretched out, while those which are in the periphery are squeezed towards the edge.

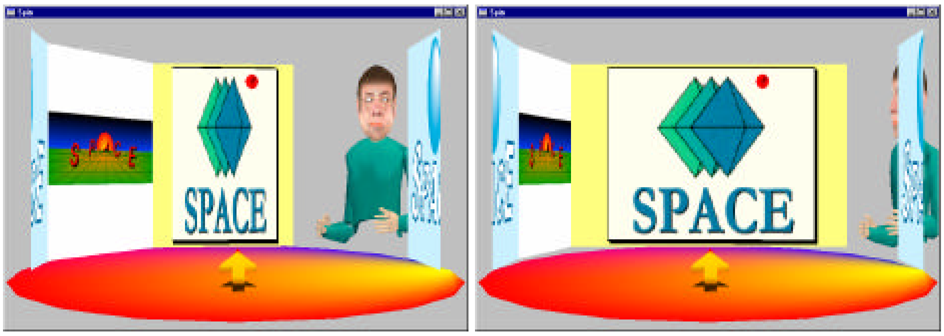



figure 3: Two examples of interface distortion

*Everything Visible*

With this type of distortion the important applications remain entirely legible, while all others are still part of the environment. When the simulated panoramic screen is reoriented, what disappears on one side immediately reappears on the other (the other elements present in the scene do not move). This allows the user to have all applications visible in the interface. In CSCW it is crucial that each and every actor and artefact taking part in a task are displayed on the screen.

*A Focus-of-Attention Area*

When the workspace is distorted in this fashion the user intuitively places the application on which he is working in the center. The participants see clones of other users, their head movements follow the focus information of their owner. So, it gives users the impression of establishing eye contact and reinforces gaze awareness without the use of special devices.

In front of the simulated panoramic screen is the workspace where the user can place (and enlarge) the applications (2D or 3D) he is working on, he can edit or manipulate them. Navigation is therefore limited to rotating the screen and zooming in on the applications in the focus-of-attention zone.

## 4.2 Interaction

*The Pointer*

Our model uses bimanual interaction, so that the user can best exploit three-dimensional techniques and the fact that they simulate reality. The user has an input device which controls a pointer, the pointer's movements indicate changes in the user's hand position**.**

The isotonic input device used to control the pointer returns 3 dimensions of input data (x, y, and z). The interaction system is complemented by an isometric input device placed in the other hand and which is used for object manipulation and navigation, an easy and immediate manipulation (rotation and zoom) of the simulated panoramic screen. The use of an isometric input device such as the 3D trackball in the non-dominant hand, should reduce hand movement and thus increase precision and decrease arm synchronization problems stemming from hand movement. With the use of an isotonic input device (Polhemus™ trackers, for example) in the dominant hand, we have an heterogenous approach, where the interface profits by the advantages of the two sorts of device (isotonic and isometric).

The translation in the context of the "room" of the dominant hand's movement is immediately reflected in the interface (by the pointer). Even though the appropriate input devices are available to the user he may still lose his pointer when moving around in the interface. There are several ways of dealing with this problem. First of all, pointer orientation is used to indicate any change in direction and to enhance the impression of movement. Secondly, we use shading effects and the pointer's shadow is projected onto the floor. So as to maintain a constant size-intensity ratio, the shadow's intensity varies in relation to the cursor's distance from the floor. This helps the user to perceive meeting room depth accurately and to get his bearings quickly and easily. Lastly, to make it easier to perceive the meeting room in 3D, we could add markers at regular intervals (a grid design, for example) on the interface conference table. This would add perspective. However a study [Plenacoste 98] to see influence of different visual cues, has shown that artefacts other than shadows have a negligible influence on user depth perception, in the special context of our interface.

*3D Interaction*

The user should be able to interact in the interface by using the pointer. With the pointer, the user is able to select all of the graphical objects. Selecting an object must be simple. Our model uses visual cues to show that the object has been selected or that it can be selected: a graphical representation of a box appears progressively around the object. The closer the pointer is from the object, the more the surrounding box is visible. This progressive bounding box system greatly simplifies the manipulation of the pointer. Once an object has been selected, the commands which can be applied to it, appear around it as explicit symbols ( open, move, etc.). Some other options may appear depending on the application being used.

After having selected an object, the user may want to manipulate it (fig. 4). In order to keep direct manipulation concept and to avoid widgets, we use the isometric device to rotate or to move accurately the object. This entails facilitating the work carried out on the interface by using the possibilities afforded by bimanual interaction whenever the application and the situation allow for it.

To access to objects special functions, we currently use 3D circular menus with icons located around the object.

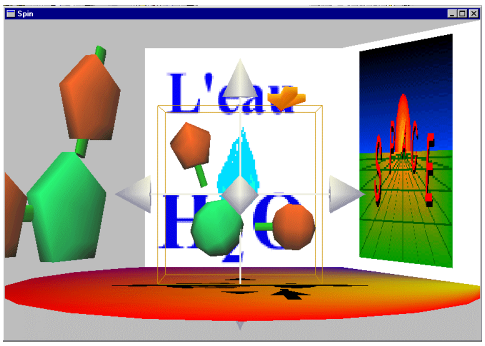


figure 4: selection/translation of an $H_2O$ molecule (without other participant connected)

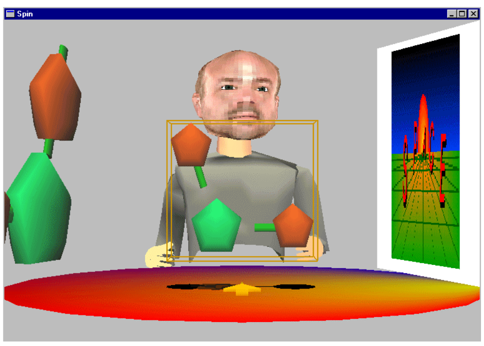


figure 5: clone of a distant user (so two participants are connected)

*Actors and Artefacts*

There are many ways of representing the user; while video technology allows us to see participants, it requires high-performance networks and the data are almost impossible to manipulate (e.g to show where the participant is looking at). Moreover, depending on the camera angle, users' gestures and attitudes can be interpreted differently. This type of problem does not arise when clones are used as representations because they are more functional.

A clone is a synthesized three-dimensional representation of the user (fig. 5). We use two photographs (front and side views) to obtain a three-dimensional model of the face as well as a complete texture of the head. These are then mapped onto a 3D model of the face, see the [Televirtuality] project. The clone closely resembles the user and can be used as a means of identifying him. The clone's role is to show the remote participants' actions in an intuitive, coherent, and precise manner. The main reasons we use clones is that head and eye movement —amongst other things— can be controlled, and can be used to indicate the focus-of-attention area; the arms can be used for remote manipulation. There are more intuitive reasons: the clone is a visual representation of the user and of his gestures. The clone can be used to translate facial expressions, as well as head and arm movement [Viaud 95]. A clone can be used for the translation of gestures and can even be used for elicit gestures during a conversation.

From a technical perspective, use of clones implies that pictures are no longer transmitted in their "raw" (video) format; instead, only the data which are relevant to the clone's actions across time are transmitted. As there are fewer data, narrow-bandwidth networks can be used for transmission. Clones, however, are not sufficient when it comes to identifying remote users’actions. To deal with this, we have introduced a telepointer.

*The Telepointer*

A telepointer is a remote pointer which can be identified in a user's workspace as being that of another user. Its position is controlled with an input device and its use is limited to shared applications. The telepointer's field of action is restricted, it is defined by the shared application. The pointer's representation is directly related to that of its user (in the case of a clone it is an arm); its primary functions are designating objects and annotation; in these cases the arm can also be used in nearby applications. When the telepointer is out of the shared object zone it is no longer visible on the other users' displays.

*Implementation*

The pictures and diagrams which appear in this paper were taken from our interface prototype. This working model implements all of the concepts mentioned in this paper. The prototype was developed on a PC using Windows NT™. Our objective was to design our model using inexpensive equipment and for this reason we intentionally avoided high-end equipment. As a graphical library we used Open GL.

# 5. Conclusion

We have presented *Spin*, a new 3D interface for synchronous CSCW. Its task-oriented architecture is in keeping with the concept that everything should remain visible at all times. The metaphor used in the interface is the conference table. The actors and the applications are positioned around the table without overlapping. The field of vision (in the interface) is distorted so that it resembles a human being's field of vision, namely, the central part of the screen is used as a focus-of-attention zone, and the user cannot clearly see the peripheral zone, where he is only able to perceive changes. The interaction is supported by a bimanual system, that allows users to interact easily with the interface through a progressive bounding-box selection system. It decreases user reaction time compared to a gesture command approach. We use an heterogenous system of three dimensional devices, isometric and isotonic, that are complementary for 3D selection and manipulation tasks.

We have started evaluation for manipulation tasks, and the whole prototype will be used in future studies to assess our interface.

## Acknowledgements

The research reported here was supported by the National Center of Telecom Studies CNET, the National Institute of Audiovisual (INA) and the regional council of Nord-Pas de Calais region (France).

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