Lessons Learned in Designing a 3D Interface for Collaborative Inquiry in Scientific Visualization

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Abstract

The paper specifies the design and evaluation of DocShow-VR's user interface. DocShow-VR is a software composite of data generator, dispatcher, and interactive displays for visualizing results of computational simulations over networks by means of animated 3D graphics in real time, used by researchers. 6 researchers, developers, and students evaluated the system informally over 10 months, collaboratively and alone. Results are specified. We improve the interface for network-distributed learning groups. A formal evaluation is due June 2003. Our improvements of the software in accordance to the evaluation results will aid students of the natural and technical sciences to use complex visualization.

1 Introduction

We report the development and informal evaluation of DocShow-VR's (DSVR's) user interface. DSVR is a software that visualizes data. Users interact by use of conventional (mouse, keyboard, monitor) and Virtual Reality (VR) devices.

Users carry out virtual experiments in DSVR's synthetic 3D space. For example, researchers at the University of Hannover investigate atmospheric convections (Jensen, Olbrich, Pralle, & Raasch, 2002). The parts of DSVR are distributed on networked computers:

- a graphic generator is called by a computer simulation and forwards the result,
- a 'Server' stores and replicates graphics to workstations, and
- a 'Viewer', on each workstation, displays graphics.

Users control the scene by use of a 2D graphical user interface (GUI). Augmented 3D graphics help them to mediate the actions of collaborative workers and learners (CSCW, CSCL).

The GUI must generate user acceptance, determined by quality defined by functionality, efficiency, and usability, compare Bevan (1999). 3D interfaces for collaborative work are not standardized (Kettner, 1995), in contrast to 2D GUIs for single users (Shneiderman, 1997). We encounter questions:

1. Differ 3D and 2D interaction from each other?
2. Are 2D metaphors directly applicable to 3D?
3. Does DSVR's CSCW interface support collaboration to a sufficient extent?
4. How must the CSCL interface differ from CSCW?

Section 2 specifies DSVR and related work. Section 3 describes our evaluation method, and Section 4 the results. We suggest answers in Section 5, and state future work.

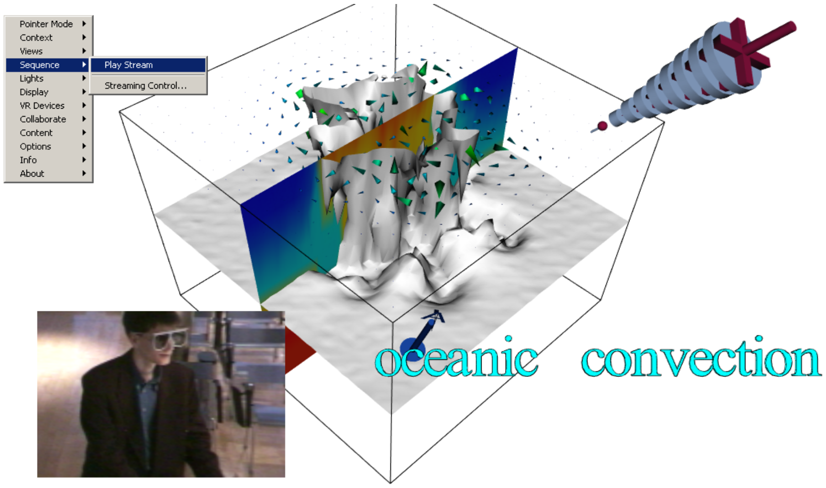

Figure 1: DocShow-VR with 2D menu and CSCW tools. Shown: oceanic convection.

2 Technology and the Evaluation of Collaborative Visualization

The Viewer is a plugin for web browsers that displays graphics in a resizable window (Figure 1). Data from remote computers are visualized by means of surfaces, geometric primitives, and compound shapes. Users control visible cues. The 2D GUI has a context menu, a mouse cursor, and windows. A workstation and conventional peripherals are used. Pushing the right mouse button opens the menu. A user selects an object and an action from the menu, for example 'move'. She moves the mouse while holding down the left button. The cursor indicates the selected action. DSVR differs to other systems because users visualize complex volumes, navigate a scene over interconnected Viewers synchronously, record ('capture') input and output, and use VR peripherals and CSCW tools:

- 3D stereoscopic display. Displays and glasses generate one view for each eye. Users reconstruct depth information that is not available through monoscopic display.
- Space mouse with 6 degrees of freedom (DOF) for 3D navigation. Mice have 2 DOF.
- Users synchronize their views and results of their actions to refer to the same things.
- A simulated video wall displays peers and their environment. The source is a teleconferencing hardware that mediates utterances over video and audio.
- A tele-pointer transports gesture, gaze, and pointing.
- Users place annotations to comment on a scene. Annotations are moved in relation to the object's coordinate system to which they are attached. Text is entered in a window.
- Clip planes extract portions of visible content. Planes are invisible and of unlimited extent. Up to six planes are displayed by means of identical symbols.

Related are 3D web browsers, visualization frameworks, and distributed virtual environments. Park, Kapoor, and Leigh (2000) evaluate CAVE6D, a tool for collaborative scientific visualization. They find students work independently over longer periods, converge their results, and synchronize their views. The number of collaborators is fixed, and their viewed data have at most 3 dimensions. Lindeman, Sibert, and Hahn (1999) study the use of 3D windows in synthetic environments. They observe: haptic feedback increases task performance, and windows must be in the same visual field as modified objects. They use 3D windows as mediators between objects and users, which we want to avoid because 3D objects can be addressed directly in a more intuitive way. A complementary strategy follow Dorohonceanu, Sletterink, and Marsic (2000) who specify an interface for collaboration in real time, similar to ours. Their system uses 3D views in 2D windows, the opposite of our approach of embedding 2D windows in 3D views. Jung, Gross, and Do (2002) describe a system, similar to our software, that helps users to annotate 3D elements in virtual space. Their ideas for improving their software could be adapted for DSVR, for example to structure discussion. They visualize architectures.

3 Method

6 people tested DSVR: 2 researchers in the natural sciences, 2 students in the engineering sciences, and 2 developers (the authors). Each had more than 5 years experience in computer use, 3 expertise in 3D graphics. 1 student used the Viewer for 3, others for 10 months. They viewed a virtual building, map, river flow, molecule set, and factory at their workplaces. 2 used Linux, 4 MS Windows. All used workstations, 2 with space mice. Developers used CSCW tools in a seminar room, and another room, each with 2 projectors and video wall. Also, we let ca. 10 colleagues and students from our department use the Phantom input device, a robotic arm to which a stylus was attached. Users translated and rotated a simulated box by means of a tele-pointer in a synthetic environment. The software that was tested in conjunction with the Phantom was delivered by the vendor.

4 Results

The 3D view attracted users. After 10 minutes they were ready to use the system.

Display: 2D elements occluded scenes. The mouse cursor appeared to hover in front of objects and generated eye strain in users that viewed stereoscopic scenes. Monoscopic display did not help us to track patterns in mostly unstructured data. Stereoscopic display mitigated, but did not eliminate the problem. We navigated the scene to display it from different viewpoints. 1 visitor could not see 3D images.

Workflow: **A researcher** suggested to keep selected windows and menus open to switch commands quickly. The researcher wanted to set which animation parts were skipped during ‘fast forward’ and ‘fast backward’. He switched between windows and set simulation parameters manually when he started DSVR. He felt hindered in working fluently, and did not want to repeat actions.

A student tried to pick 3D objects with the mouse before he noticed the context menu. He had difficulties to rotate an object when its rotation axis was separate from the object. The student and one of us moved objects out of the visible plane and set viewpoints to locations where we lost the orientation and restarted the scene.

CSCW tools: We wanted to share selected parts of a scene with remote collaborators. For example, we tried to move a pointer simultaneously and were not aware of each other’s actions. The situation required additional negotiation about who would use the object first because DSVR had no ‘floor control’ to regulate order of use. We wanted to show and hide tools during a session because they occluded other objects. Annoyed by that shortcoming, we often disabled tools before start.

To use the video wall we had to set the tele-conferencing hardware and video mode manually. Misconfigurations occurred. Video and audio were useful for presenting graphics and speech but did not indicate eye contact, necessary for 1-to-1 talk, between peers. A user could not determine if a peer watched her video screen and talked to her remote colleague or addressed her local physical surrounding. In one case there was no way to determine when one of us addressed his remote peer because audio transmission was distorted by a large group of visitors at the local site. The local peer switched attention to visitors without notice to his remote peer, who was unable to follow the discourse, which increased his uncertainty about when and how to reply to his partner.

Users moved tele-pointers with space mice, 2-DOF mice were too cumbersome. Users forgot or ignored the tele-pointer if they were detached from input devices or occupied by discussions with peers. One of us had difficulties to control the tele-pointer by means of a space mouse, and needed longer training (about 2 hours). The same user could move the stylus of the Phantom in a more accurate and faster way, which our evaluation of the Phantom verified for all testers.

Annotations were moved in relation to the selected camera, like tele-pointers, but after they were attached to an object they moved in relation to a different coordinate system, which made it hard for users to drag notes along the intended direction.

The state of a clip plane was not clear because its symbol, located above the plane, was symmetric around each axis. The use of identical symbols for up to six planes confused users.

5 Discussion

Differ 3D and 2D interaction from each other? Consistent with previous research, 3D interaction metaphors rely on tacit knowledge from everyday experience in reality. This is indicated by the attempts of users to grab 3D objects directly. Instant graphical feedback and VR devices helped them to carry out tasks. We assume movements in 3D must relate to the coordinate system of the viewer because actions slowed down on violation of the rule (compare our tests with annotations and space mice).

Stereoscopic viewing supplemented visual cues that eased users to perceive depth-cascaded elements. However, 2D windows interfered with stereopsis and occluded valuable space. They must be removed, which is no problem because users can control and view objects directly and instantly, as it is implemented partially in DSVR for the navigation of objects.

Are 2D metaphors directly applicable to 3D? 3D affects presentation and interaction. We observed that users got lost in complex scenes, and we noticed an increase of their arm activity while they used VR devices, which did not occur to that extent with conventional hardware. The higher burden on motor function, stamina, spatial perception, and visual memory leads to more errors of use. There are solutions:

- *Prevent*: **Ease motor function** by a context-dependent reduction of DOF, automated ‘way-finding’, and alignment. For example, just specify the target of an annotation by pointing and clicking at it, do not force the user to drag it to its place. **Clarify what is seen from where**. For example, make symbols indicate their orientation unambiguously, make them distinguishable from each other, and avoid abrupt changes of viewpoints and objects. **Prevent clutter**. Enforce stereopsis, and let the user navigate a scene to grasp ‘what’s in there’. Parameterize object transparency because clip planes may not suffice. **Indicate object states**, if they are unavoidable, to make subsequent actions predictable. When objects are manipulated, show the frame of reference (axis, coordinate, origin, boundary).
- *Guide*: Simulate landmarks that help users to navigate in 3D, e.g. haptic feedback.
- *Orient*: Provide an overview from which users recover orientation.
- *Reset*: Fix cameras, provide ‘undo’ and ‘redo’, and store settings.

Does DSVR’s CSCW interface support collaboration to a sufficient extent? 1-to-1, 1-to-many, and many-to-many communication is supported. Collaboration at the same time and different times (by way of recording sessions), and at the same place and different places is possible. We must improve computer-mediated 1-to-1 talk. We must help users to select objects they want to manipulate and use together. Users may request control over shared tools to make the previous owner release the tool, and stereotyped messages may supplement the video wall to indicate eye contact and posture to add missing nonverbal signs that guide a discussion.

How must the CSCL interface differ from CSCW? The differences will be small. Pea, Gomez, Edelson, Fishman, Gordin, and O'Neill (1997) suggest that experts and novices share the same tools, and learn from each other. Tools must expose the tacit knowledge of experts to students by way of mediating communication between and among tutors and students, and direct novices in search for relevant data and actions. Helpful could be an integrated synthetic desktop for retrieving and viewing web content without disabling stereoscopic viewing.

A controlled experiment is due June '03. We will improve DSVR, test it in universities, and add multimodal interfaces. Tailored versions can attract schools and 'virtual teams' from industry.

Acknowledgements

We thank all participants for their valuable comments and suggestions. The pilot study is part of the VASE 3 project at the Learning Lab Lower Saxony.

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