Collaborative Visualization in Augmented Reality

Anton Fuhrmann,
Michael Gervautz,
Helwig Löffelmann,
Dieter Schmalstieg
Vienna University of Technology

STUDIERSTUBE is an augmented reality system that has several advantages over conventional desktop and other virtual reality environments, including true stereoscopy, 3D-interaction, individual viewpoints and customized views for multiple users, unhindered natural collaboration and low cost. We demonstrate the application of this concept for the interaction of multiple users and illustrate it with several visualizations of dynamical systems in DynSys3D, a visualization system running on top of AVS. We also show how the integration of AR into a commercial visualization system can be achieved. Several examples constructed in DynSys3D - developed for the visualization of complex dynamical systems in AVS - will complement the presentation.

Augmented Reality and Collaboration

Augmented reality (AR) combines a familiar physical surrounding with the visualization of synthetic data. As a highly interdisciplinary field, scientific visualization frequently requires experts with different background to cooperate closely. Many valuable insights only occur in face-to-face discussions over the relevant data. The intrinsic advantage of AR, namely the superposition of computer-generated images over the users view of reality enables unique combinations of real and virtual objects and the unhindered cooperation of different users viewing the same visualization.

Related Work

Early adopters of virtual reality (VR) systems soon realized that one of the immediately useful applications comes from the field of scientific visualization, where scientists try to understand complex data sets and can benefit from true 3D, stereoscopy, and interactive exploration, e.g. in the virtual Windtunnel[1]. The need to support collaboration of human users lead in two directions: geographically remote collaboration and collaborative virtual environments (VEs) where users gather in one place, and can interact and communicate in a natural way.

In the latter category, two very successful approaches have been developed: The CAVE[2], and the workbench, with two variants - Responsive Workbench[3] and Virtual Workbench[4]. Both systems present stereoscopic images to the user via large display screens and LCD shutter glasses, and both systems support multiple users.

The CAVE is a small room composed of three projection walls and a projection floor, on which computer-generated images are displayed. Among the CAVE's advantages are high resolution, wide field of view, insensitivity towards lag for rotational head movements, and a strong feeling of immersion.

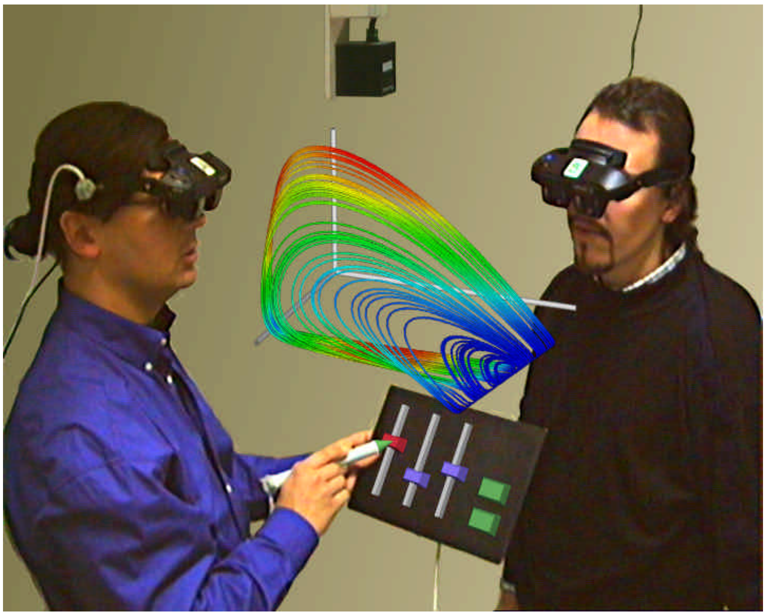
The Workbench is essentially a table on which computer generated images are projected, resulting in a typical setup used by e.g. surgeons, engineers and architects. The resource requirements are less demanding than those of the CAVE, and the horizontal workspace is very useful for manipulation with hand-held tools.

Both systems suffer from the drawback that true stereoscopic images can only be rendered for one „leading" user wearing the head tracker - the users have to remain close to the leading user, because distortions increase proportional to their distance to the tracked point of view. Applications in which users surround an object do not work in the CAVE and are only possible for two participants in the latest version of the workbench[1]. However, the authors state that their approach - unlike the one presented in this paper - does not easily scale beyond two users because of inherent limitations of the display hardware.

System Design

We propose a system that allows multiple collaborating users to simultaneously study three-dimensional scientific visualizations in a „study room" - German: „STUDIERSTUBE" (inspired by the classic play „Faust"). Each participant wears an individually head-tracked see-through HMD providing a stereoscopic real-time display.

The use of individual displays and head-tracking for each participant allows stereoscopic, undistorted images to be presented to everyone.



1 typical setup: Dynastic Cycle in Studierstube

There are no constraints regarding the viewpoint, unlike the Workbench, users may sit on opposite sides of the table, which in combination with the see-through property of the HMDs allow users to see each other. This also avoids the fear of bumping into obstacles which often limits the freedom of movement in purely immersive setups. The HMDs we use - Virtual I-O i-glasses - are very lightweight and unobtrusive, but only of limited resolution and small (30°) field of view. Rendering separate images for each user gives great flexibility in the choice of the presented image, but also makes the rendering effort proportional to the number of users, whereas CAVE and (single-user) Workbench require only a constant rendering effort.

The defining features of STUDIERSTUBE are:

Augmented props: We exploit the capabilities of AR to construct a three-dimensional user interface needed for controlling the presentation and possibly the simulation by introducing tracked real-world objects that combine physical items and overlaid computer graphics, such as the Personal Interaction Panel (PIP) [Szal97]. The PIP is used as an input device for visualization parameters, system commands and as a 3D manipulation device.

Customized views: In addition to individual choice of viewpoint, customized views of the data are possible, for example one user may want to see stream lines added to the basic image, while another may not. Two users in the same room may see different aspects of the same object at the same time.

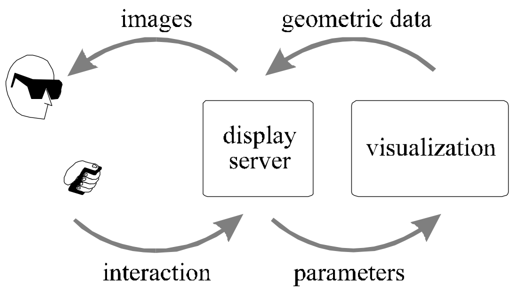
Usage of space: The space in STUDIERSTUBE can be used similarly to a CAVE (multiple users standing around), but also allows a workbench setup (users gathering round a desk).

Organizational advantages: While the cost of STUDIERSTUBE's hardware components are certainly higher than a conventional desktop visualization station consisting of only a graphics workstation, they are very conservative compared to a setup like the CAVE. This is particularly important as the potential users of STUDIERSTUBE - research groups - are typically operating on a tight budget. Furthermore, the setup consumes little space and is relatively easy transportable.

Personal Interaction Panel

One of the advantages of a VE is the ease of manipulation in 3D space. Positioning of objects with six degrees of freedom and indicating of starting points for visualization methods (figure 3) are readily accomplished by dragging or clicking with the 3D-mouse. Changing your point of view is done by simply moving your head the virtual object.

STUDIERSTUBE is controlled with a two-handed interface, the Personal Interaction Panel[5] (PIP) (figure 4). The PIP allows both intuitive three-dimensional manipulation such as placement of objects and the input of numerical data or commands – historically one of the weak points of VEs. For that purpose, we simply use traditional 2D desktop interaction on the PIP's surface with conventional input elements like slider, dial and buttons, that were easily understood by our users without any specific introduction.



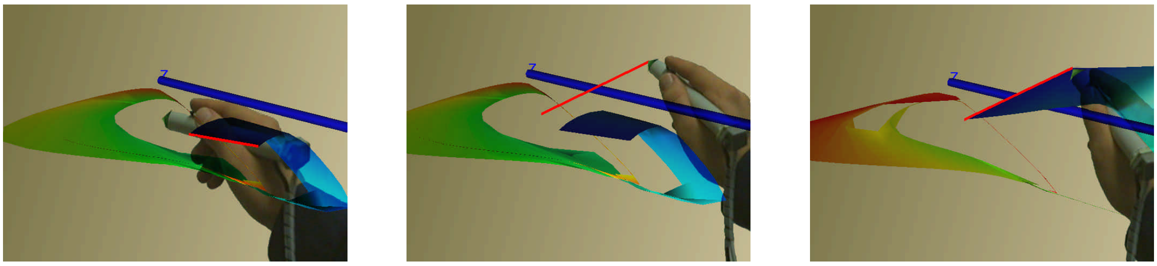
2 **decoupled simulation model**

Visualization in Studierstube

To combine augmented reality and scientific visualization, a new integrated solution could be developed, but employing an existing, general-purpose scientific visualization system (in our case, AVS) allows a wider range of applications and eases development. Since this desktop-based system is not designed for the real-time requirements of AR, we use *decoupled simulation*: The visualization system and the AR user interface (called *display server* in an analogy to X-Windows) run as completely independent processes, typically executing on separate machines and communicating with each other over a network.

As shown in figure 2, the system is composed of two loops: the display loop, a tightly coupled human-in-the-loop component, where real-time response is essential, and a loose coupling between display server and visualization application for the exchange of visual information. The display server continues to serve real-time graphics to the user while the application may work in background, delays of several seconds for recomputation are quite acceptable.

The display server is a multi-threaded



3 **mixed-mode oscillations: starting a new streamsurface**

from left: mouse click, drag and release

application: Rendering the HMD images from the geometry database and transferring data to and from AVS execute simultaneously. Local interaction such as positioning and rotating the virtual objects is done by interacting with the display server, and does not affect the visualization system. Input from the HMDs and interaction devices is delivered to the display server by a dedicated tracker demon, which runs on a separate machine. The display server in figure 3 also forwards user commands to AVS and receives updates to the geometry database.

Interface to DynSys3D

DynSys3D is a multi-purpose workbench for the rapid development of advanced visualization techniques[6] in the field of three-dimensional dynamical systems. It is based on AVS, a commercial general purpose visualization system based on the data flow paradigm.

One design guideline of DynSys3D, namely that all of its modules have to produce standard AVS output (geometry), enables the integration of DynSys3D and STUDIERSTUBE: A simple module which converts AVS geometry into STUDIERSTUBE's format (Open Inventor) was sufficient to export geometry. Interaction messages from the VE are converted to applicable AVS input data: 3D mouse click and drag events are delivered as points and lines, slider or dial changes on the PIP as real values and button events as booleans.

Governed by the data flow paradigm underlying AVS, the user's commands are routed via the display server to the input ports of an AVS net, while the resulting geometry is sent to the output modules, and from there further to the display server (figure 4). Due to the decoupled simulation model, the user is able to adjust parameters on the PIP or start additional calculations while AVS is still busy processing former input.

One design objective of the AVS/STUDIERSTUBE interface was to give the user complete freedom in the planning stage: The AVS net can be developed as it would be for a conventional visualization. All links to the VE behave like standard AVS modules and initialize their network connections to the display server transparently for the user.

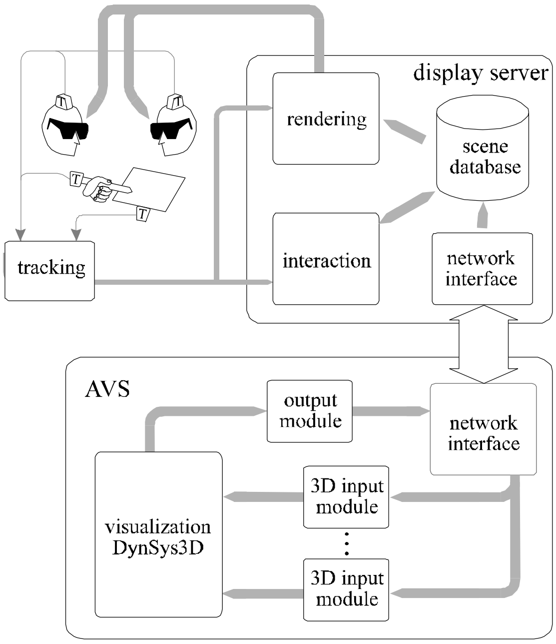
Therefore we can reconfigure the visualization while the VE is in use. Changes to the net are reflected instantly in augmented reality. For example adding a slider module in AVS instantly displays the slider on the PIP, allowing to adapt the interaction capabilities of the setup on the fly.

Applications

The following DynSys3D applications were selected as representative examples for the evaluation of our concept.

Mixed-mode Oscillations

A model we investigated together with colleagues from our econometrics department is the 3D autocatalator[7]. It is a simple 3D dynamical system which exhibits mixed-mode oscillations. These are phenomena often encountered in real world



4 dataflow in Studierstube

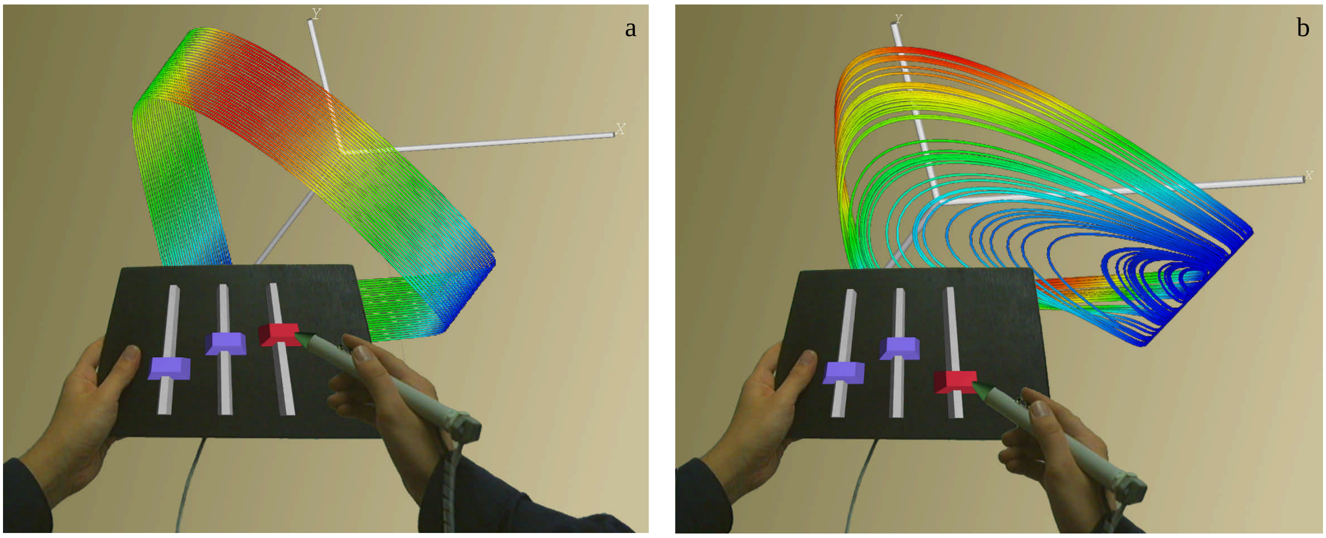
systems, for example in chemical systems. Depending on the parameters of this system either periodic or quasiperiodic (chaotic) solutions can be found. Direct immersion in the 3D phase space provided a useful tool for the investigation of its behavior. Structure and relations of visualization icons that are produced by the visualization system can be better investigated through 3D interaction in augmented reality.

Dynastic Cycle

This model deals with the visualization of the "Dynastic Cycle"[8], a three-dimensional dynamical system, that was modeled as an explanation for the rise and fall of dynasties in ancient China, given as alternating periods of anarchy and despotism. The three system variables X, Y , and Z express the amount of farmers, bandits, and soldiers, respectively. The model defines their interactions similarly to well-known food-chains (prey, predator, and superpredator). The evolution induced by the Dynastic Cycle is governed by slow-fast dynamics. Two of the system variables (X, Y) are fast variables that change rapidly in comparison to the last one (Z). The knowledge about this slow-fast characteristics simplifies the analysis and must be considered during visualization.

Animating the length of the streamline in the virtual environment proved to be an efficient way of visualizing this behavior and was accomplished by simply inserting an animated float parameter – a standard feature of AVS – to the dataflow network.

Since this system exhibits vastly different behaviors, we used sliders on the PIP to adjust the most important parameters. By using these sliders and the insertion of animated streamlines we were able to obtain the visualizations in figure 5.



5 streamline visualizations of dynastic cycle (a) periodic and (b) chaotic behavior

Conclusion

By connecting the AR system STUDIERSTUBE and the visualization system DynSys3D we have initiated a synergistic effect: Researchers who investigate dynamical systems profit from the intuitive interaction techniques available for 3D phase space in STUDIERSTUBE, and also from the collaborative setting. From an AR researcher's perspective, the behavior and demands of „real“ users (designers of dynamical systems) supported the development of STUDIERSTUBE as a practical tool, and also permitted us to verify that useful work can be done in such a setup.

The main advantages of STUDIERSTUBE are:

Rapid feedback for visualization mapping. It has been seen that the fast feedback loop allowing to trigger new calculations of the visualization mapping, e.g., the integration of a streamsurface from within the AR setup, speeds up and enhances the visualization and understanding process. The process of choosing an initial visualization mapping, then refining it converges much faster as researcher are better able to estimate their requirements.

Reduced abstraction. Abstract mathematical constructs such as phase space, attractors etc. can be deterring in their complexity even for experts. The intuitive 3D user interface of STUDIERSTUBE greatly simplifies the exploration of these structures and allows the user to get familiar with the 3D representation of the dynamical systems much faster than via a 2D display.

Educational settings. The collaborative setting of STUDIERSTUBE is of great utility for explaining dynamical systems. Tutorial situations are strongly supported by the capability to freely choose ones viewpoint and the unhindered natural communication. The very concrete, true 3D representation especially benefits students that are unfamiliar with complex mathematical structures.

Customized views. When multiple researchers investigate dynamical systems together, STUDIERSTUBE's capability of separating customized views allows individual markers and visualization icons to be added. These icons can be kept private to avoid display clutter, or they can be shared with others.

Enhanced interaction capabilities. We have verified that true three-dimensional viewing and manipulation is indeed superior to screen-and-mouse based interaction of complex 3D models. The tedious work of positioning, orienting, and zooming, typical for conventional systems, can be reduced significantly. Alternatives in the operation make exploration less computer-centric and are easy to learn for inexperienced users. The use of 2D interaction methods on the PIP is easy to learn and is a useful extension of the functionality of the VE.

Future directions

Currently we are developing new visualization icons and interaction methods specifically for AR. These will include animating textures locally on the display server and input events with 6 degrees of freedom.

Acknowledgments

This work has been supported by the Austrian Science Foundation (FWF) under project no. P-12074-MAT. Special thanks to Zsolt Szalavári for providing the PIP and to M. Eduard Gröller, without whom this paper would have been impossible.

Authors

Anton Fuhrmann is a research assistant at the Institute of Computer Graphics, Vienna U. of Technology.

He graduated in computer science in 1993 and is currently working towards his PhD thesis on STUDIERSTUBE. His other research interests include distributed virtual environments, computer animation and human interaction.

Helwig Löffelmann is research assistant at the Institute of Computer Graphics, Vienna U. of Technology. He finished his studies of computer science in 1995 and is currently working on his PhD thesis about advanced visualization techniques of complex dynamical systems.

Dieter Schmalstieg is a research assistant at the Institute of Computer Graphics of the Vienna U. of Technology. In 1997 he completed his PhD thesis entitled "The Remote Rendering Pipeline", which deals with efficient distributed 3-D graphics. His current research interests include virtual environments, augmented reality and interactive graphics.

Michael Gervautz received his MS degree and his Ph.D. degree in computer science from the Technical University of Vienna, Vienna, Austria in 1984 and 1989 respectively. He is currently professor of computer science at the Institute of Computer Graphics at the Technical University of Vienna. His research interests are virtual reality, computer animation, realistic image generation and solid modeling. He is member of EUROGRAPHICS, ACM and VRS.

References

[1] S. Bryson: The Virtual Wind Tunnel. Proceedings of IEEE Visualization 91, 17-25, 1991.

[2] C. Cruz-Neira, D. Sandin, T. DeFanti: Surround-Screen Projection-Based Virtual Reality: The Design and Implementation of the CAVE. Proc. of SIGGRAPH 93, 135-142, 1993.

[3] W. Krüger et al: The Responsive Workbench: A Virtual Work Environment. IEEE Computer 28(7): 42-48, 1995.

[4] M. Agrawala et al: The Two-User Responsive Workbench: Support for Collaboration Through Individual Views of a Shared Space, Proc. of SIGGRAPH 97, 927-332, 1997.

[5] Zs. Szalavári, M. Gervautz: The Personal Interaction Panel - A Two-handed Interface for Augmented Reality. Proc. EUROGRAPHICS 97, Budapest, Hungary, 335-346, 1997.

[6] Löffelmann H., Gröller E.: DynSys3D: A workbench for developing advanced visualization techniques in the field of three-dimensional dynamical systems. WSCG 97, Plzen, Czech Republic, 301-310, 1997.

[7] A. Milik: Dynamics of Mixed-mode Oscillations. PhD thesis, Vienna U. of Technology, Austria, 1996.

[8] G. Feichtinger et al: Despotism and Anarchy in Ancient China: Visualizing the Dynastic Cycle. Jahrbuch für Wirtschaftswissenschaften 47/1, publisher Vandenhoeck & Ruprecht, Goettingen, Germany: 1-13, 1996.