Study of 3D Visualization Software for Geo-Science Applications

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The aim of this study was to assess how certain tools in 3D volume visualization software aid physical scientists in their visual analysis of 3D data sets. The KeckCaves collaboration has lead to continuing development of a 3D volume visualization software package called **Visualizer**, which is built on the Virtual Reality User Interface (**VRUI**) Toolkit designed by Oliver Kreylos. Visualizer can be used to explore Geoscience data generated from seismic tomography models and mantle convection simulations to neutron imaging of ancient microbial communities preserved in rocks. In this study we compared Visualizer to a common commercial software package, called TecPlot [*TecPlot*], which was designed for visualizing 2D and 3D data on a desktop.

In the first part of the study, both software packages are compared in their native environments: Visualizer in a CAVE (Cave Automatic Virtual Environment) and TecPlot on a desktop computer. In the second part of the study, Visualizer was also used on a desktop computer. (TecPlot does not run in a CAVE). Comparison of the two software packages used in a desktop environment provides information that allows one to assess how specific tools aid researchers in navigating through and identifying features in 3D data using a 2D viewing environment. Comparison of Visualizer on the desktop and in the CAVE provides further information concerning appropriate transfer of design patterns for VR environments to a desktop environment.

Background

Geoscience Research Motivation

Due to the irregular shape of many geologic structures it can be challenging to define structures on a regular grid of 3D points used for finite element (FE) models. However, for a computer simulation of a subducting tectonic plate, for example, the initial structure must meet certain conditions:

1. Features must be smooth, without steps or faceted surfaces.

2. Features must be continuous, without holes or protruding structures.

Models that do not meet these conditions will often fail to produce a physically realistic solution or will take an extremely long time to find a solution. Therefore, visual inspection of input structures for FE models is required to insure that the input is appropriately defined on the model grid points. This inspection requires the use of 3D volume visualization software.

Software Designed for VR Environments

The Visualizer software has been specifically designed for highly interactive 3D virtual reality (VR) environments and therefore includes software design principles different from those for a desktop environment. Examples are: 1) Navigating (picking up, rotating and translating a slice or isosurface) in a VR environment is simply done by moving a tracked input device, such as a wand, while pushing a button; 2) all menus and dialogue boxes are dynamic, that is they appear anywhere in space when the user presses a button on the wand; and 3) iso-surfaces or slices are created in real-time as the user moves the wand through the data set.

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In a 2D desktop environment, this same interaction is implemented by assigning functions to mouse buttons and keys on the keyboard. For example, the left mouse button might control rotation, while the right mouse button controls translation, while pressing the Ctrl-key and right mouse button together might be used to create colored slices. Navigating in 3D space is achieved by adding a dollying operation, which allows the data to be translated in front of or behind cross-hairs that define the screen-plane. Menus and dialogue boxes still appear on demand, but always appear on the screen-plane.

In contrast, TecPlot has a more traditional desktop appearance with a menu bar across the top of a window, which opens up menus to dialogue boxes, and buttons for navigating and other actions displayed on the side of a window. TecPlot primarily uses one mouse button to do all navigation by changing the action assigned to the mouse button, while slices and iso-surfaces are created by entering positions or values in a dialogue box.

Format of the Study

Each participant was asked to use two different software packages on a desktop computer (Visualizer and TecPlot) and one software package in the CAVE (Visualizer) in order to assess whether a given model input data-set is appropriate for use in a FE model calculation based on the criteria listed above. The goals (as stated in the Background section) and format of the study were first explained to each participant and were outlined on a handout for the participant to read. Before using any of the software, each participant was asked to complete a pre-experiemnt questionnaire with five questions:

1. Have you used the software package TecPlot? Yes No

2. Have you used the Visualizer software on a desktop? Yes No

3. Have you used the Visualizer software in a CAVE? Yes No

4. Have you used a virtual reality (VR) environment for more than one hour? Yes No
   If yes, explain type and level of familiarity.

5. Do you have stereo vision? Yes No

Before using the CAVE, all participants were also given a simple vision test to determine whether they had stereo vision. For each software package, the core of the study included three steps:

1. **Introduction and familiarization of a participant with the 3D Visualization software**
   In the desktop session, each participant was given a sheet of instructions for the software (TecPlot, Visualizer). One of the project researchers guided each participant through the exploration of an example data set until he/she felt reasonably comfortable with the use of each tool needed to analyze the data set. This step usually took about 15 minutes. In the CAVE session all instructions were given orally because the participants were wearing head-tracking stereo glasses, which make it difficult to read something while using the CAVE.

2. **Analysis of target data set by a particpant using the 3D Visualization software**
   Each participant was asked to explore a target data set for 30 minutes, while locating and writing down coordinates and values of features that appeared to violate the conditions for an appropriate input structure (Figure 1). In the CAVE, where participant wore head-tracking glasses, a project researcher wrote down feature information as each participant spoke the findings out loud.
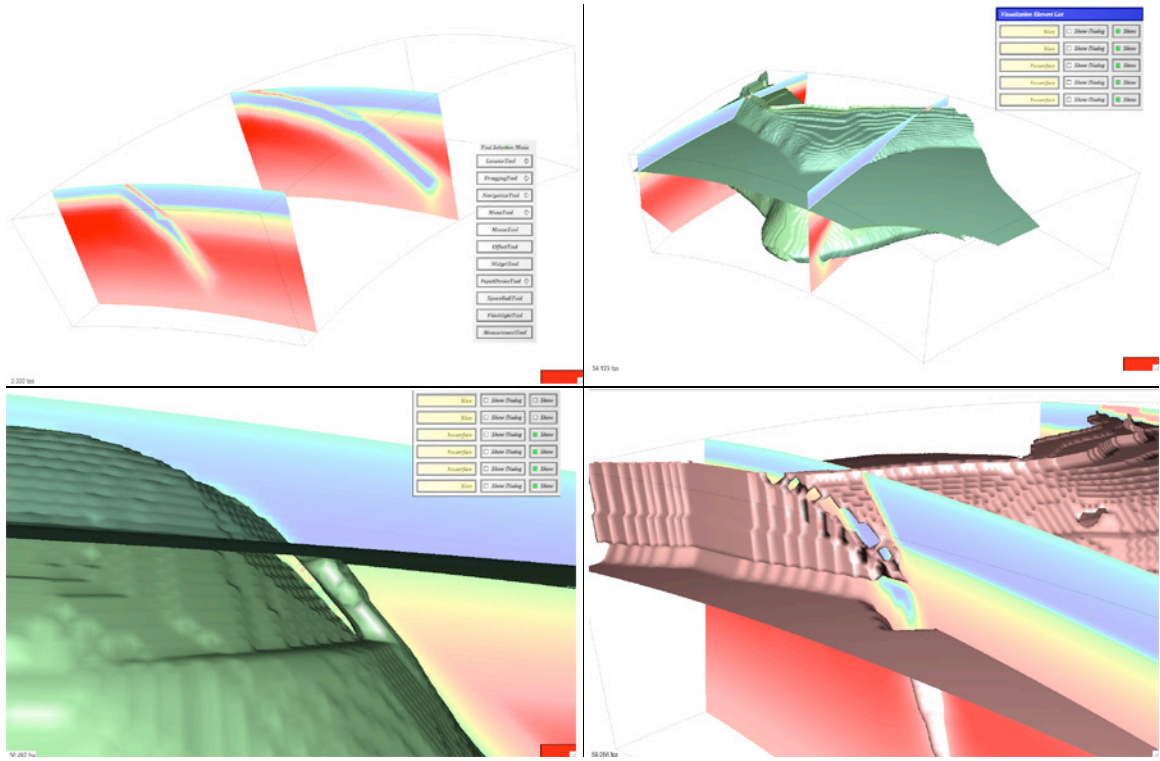
Figure 1: Snapshots from target data set exploration. a) Colored slices initially used to locate problem features. b) Iso-surface providing 3D view of subducting tectonic plate structure. c) Zoom-in on problem feature protruding from slab surface. d) Zoom-in on a second problem feature: holes in the iso-surface.

3. **Individual Software Questionnaire**

   Each participant was asked to answer a few questions about ease-of-use of certain tasks, such as navigating, and identifying and locating features. In addition, each participant was given the opportunity make comments about the software for the prescribed tasks.

After each participant completed the study in both environments using both software packages, he/she was ask to complete a post-experiment questionnaire that asked him/her to rate each software package in terms of ease or difficulty for five tasks: learning to use the software, navigating, identifying features, locating features, and overall use. Each participant spent about three hours to complete the study. Each CAVE session included one participant and one project researcher. Desktop sessions included between one and five participants at a time using the same software package on a laptop computer (MacBook). The order of use of each software package was varied: six participants used Visualizer in the CAVE first, six participants used Visualizer on a desktop first and seven participants used TecPlot first. We found no systematic variation in the results based on the order of use of the software (see next section).

Results

A total of 19 participants took part in the study over the course of one week. The participants included seven women and twelve men, of which three were faculty, eleven were graduate students

and five were undergraduates. All but one participant was engaged in geoscience study and/or research at the time of the experiment.

Pre-Experiment Questionnaire

Only one participant had previously used TecPlot and two participants had previously used Visualizer in a CAVE, although all of these participants had limited experience with these software packages and the CAVE. All participants had stereo vision.

Feature Identification while Using Software

Successful identification of features varied among users and with the software being used. The number of features identified ranged from zero to 16, with the same number of features identified for both software packages on the desktop (Tecplot: 5.9 ± 4.3; Visualizer-Desk: 5.5 ± 3.5) and slightly more listed for Visualizer in the CAVE (8.5 ± 3.2). There are no order effects in the data: for example, participants who used the CAVE first did not list more or less features than participants who used either Tecplot or Visualizer on the desktop first. This result suggests that it might be easier to find features in a CAVE. However, it is also possible that a side effect of having a project researcher waiting for the participant to give the locations of features, caused the users to stay more focused on this task in the CAVE.

Individual Software Questionnaire

The individual software questionnaire consisted of seven questions:

1. Which tool did you find *most* useful for navigating through the data set?

2. Which tool did you find *least* useful for navigating through the data set?

3. Which tool did you find *most* useful for identifying features in the data set?

4. Which tool did you find *least* useful for identifying features in the data set?

5. Identify any tasks you found particularly *difficult* to carry out and explain why you found it difficult?

6. Identify any tasks you found particularly *easy* to carry out and explain why you found it easy?

7. Describe your overall impression of the software.

The main results for questions 1–6 are summarized Table 1. While there was an overall pattern in the specific responses received to certain questions (e.g., rotating the data set was most useful for navigating in Visualizer on the desktop), others were highly variable. These results show that simple manipulation of the data set by rotating to gain new views is most useful for navigating in all software environment combinations. Most of the users found all available tools useful for this task in Visualizer. Iso-surfaces were most useful for identifying features in all software environments, but users found creating 2D colored slices cutting through 3D data to be less useful. Some participants included comments that colored slices were not at all helpful in TecPlot. About half the participants did not find any of the tasks to be difficult in the CAVE and found it particularly easy to identify features. However, assigning tools within Visualizer on the desktop environment was found to be

	Visualizer-CAVE	**Visualizer-Desk**	**TecPlot**
Navigation			
1. Most Useful	Rotating/Translating (14) Slices (4) Zoom (1)	Rotation (13) Zoom (2) Dollying (1)	Rotation (18) All (1)
2. Least Useful	None (9) Zoom (5) Iso-Surface (3) Slices (1) Rotating (1)	None (8) Dolly In/Out (4) Translating (3) Zooming (2) Rotating (2)	Zooming (8) Translating (2) Slices (2)
Identifying Features			
3. Most Useful	Iso-surfaces (13) Slices (2) Zoom (2) None (2)	Iso-surfaces (11) Slices (3) Dolly In/Out (3) Zooming (2)	Iso-surfaces (9) Zooming (4) Slices (2)
4. Least Useful	Slices (12) Iso-surfaces (2) Rotating (2)	None (8) Slices (6) Iso-surfaces (3) Translating (1)	Slices (6) Zooming (4) Iso-surface (2)
Tasks			
5. Most Difficult Task	None (9) Choosing Iso-surfaces (5) Assigning Tools (4) Navigating (1)	Assigning Tools (13) Locating (2) Navigating (1) Identifying (1)	ID Features (7) Locating (6) Navigating (1)
6. Easiest Task	ID Features (6) Navigating (5) Locating (4) All Tasks (4)	ID Features (9) Navigating (8) Locating (2)	Navigating (10) Identifying (3)

Table 1: Summary of individual software questionnaire responses. Total responses for each question may not sum to 19 (total number of participants) because some responses were left blank.

particularly difficult, although identifying features was still listed as particularly easy. On the other hand, identifying features was listed as the most difficult task in TecPlot.

The result that tool assignment in Visualizer was found to be difficult to learn by most users was anticipated because multiple actions are assigned to a limited number of mouse buttons and most participants are not used to using multiple buttons on a mouse. Tool assignment includes two steps: 1) deciding what one wants the program to do (e.g., create iso-surfaces) and choosing this from the main pop-up menu and 2) assigning the desired action to a mouse button and key combination on the desktop or a button on the wand in the CAVE. In the CAVE, button assignment involves pushing an unassigned button, which causes a Tool Selection pop-up menu to appear and to select the tool type (e.g., Locator).

On the desktop, two factors make this two-step tool-assignment process more difficult to learn. First, because the mouse buttons are also being used to rotate and translate the image a modifier key is required to assign the mouse button to create an iso-surface. Second, the tool selection menu must be accessed twice in succession: once to tell the software that the action should be attached to

the mouse and a second time to select the tool type. Many participants found it initially confusing to keep track of the different mouse button and mouse-key combination actions. However, even with this steep learning curve, the participants commented that by the end of the 30-minute time period they felt that their ability to use the software had greatly improved. Based on this feedback, we plan to add an optional fixed button menu to Visualizer that can be used when introducing new users to the software, but can be turned off once mouse-key combinations are learned, because these are faster to use.

Post-Experiment Questionnaire

The post-experiment questionnaire provided quantitative feedback on each software package and environment. The questionnaire ask the participant to rate ease-of use for each software environment combination concerning five tasks on a scale from "Easy" to "Difficult" by placing an X on an un-marked line for each software-environment combination. To obtain quantitative measure of the responses, the position of the X was measured, with a distance of 100 indicating the task was easy and distance of zero indicating the task was difficult. The results are summarized in Figure 2 and show that Visualizer in the CAVE was rated easiest for all tasks (navigating, identifying features, locating features, learning to use and overall use). Visualizer was also rated as easier to use for data exploration tasks on the desktop, even though it was more difficult to learn the mouse-key combinations in this environment.

Comments from the Participants

The open-form nature of the questionnaires provided opportunities for the participants to provide feedback concerning their experience, opinions and suggestions for the software. Some of the comments were:

- *I was convinced that being in the CAVE and being able to manually run a viscosity slice through the data set was the best way to catch any problems with the data.*

- *Visualizer allowed the user to scan through the iso-surfaces in real time and stop when features were observed.*

- *Hands down, the Visualizer-CAVE software version is the best as far as being simple and effective.*

- *Visualizer-desktop was difficult to use at first, but once I figured out the commands and how to assign commands to keys it was straight forward.*

- *The hand unit in the CAVE is much easier to use then a mouse and key combination... the usage of pop up menus in the Visualizer-desktop should be improved.*

- *The CAVE was by far the most useful program for carrying out the desired tasks. Being able to physically walk around and "fly" into the data was incredibly effective.*

- *The Visualizer-CAVE was by far the easiest to work with. All the features stood out very clearly and it is incredibly easy to navigate.*

- *Visualizer-desktop: The greatest difficulty is probably the initial complexity of click and key combinations (and understanding what dollying was good for), but even in 30 minutes I became pretty efficient with what I learned and can see getting use to it very quickly.*

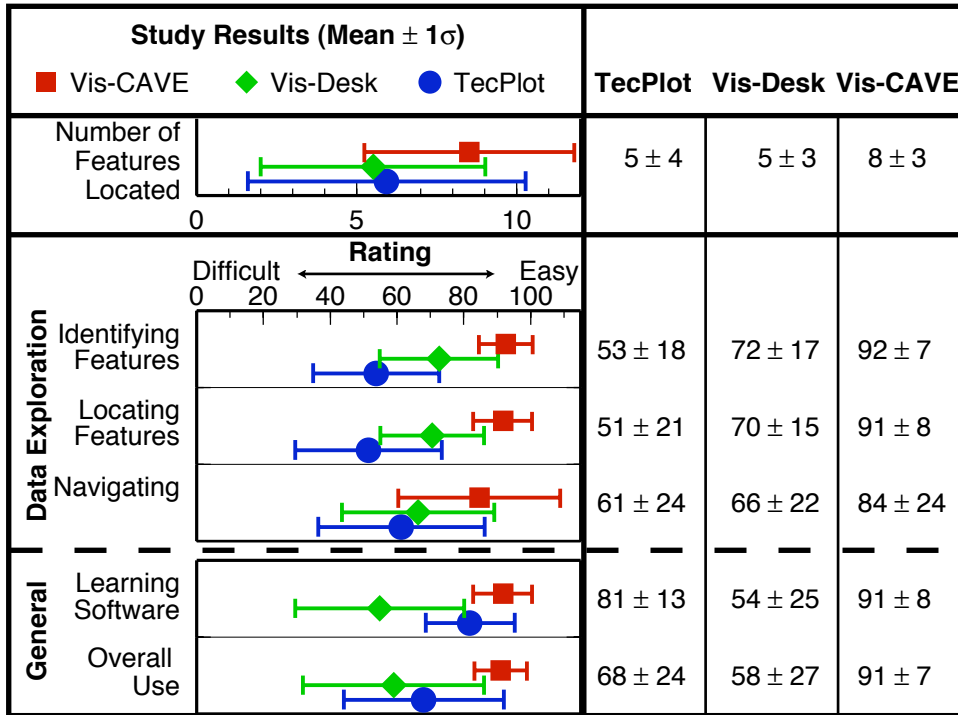| Study Results (Mean ± 1σ)			TecPlot	Vis-Desk	Vis-CAVE
■ Vis-CAVE ◆ Vis-Desk ● TecPlot					
Number of Features Located			5 ± 4	5 ± 3	8 ± 3
Data Exploration	Identifying Features		53 ± 18	72 ± 17	92 ± 7
	Locating Features		51 ± 21	70 ± 15	91 ± 8
	Navigating		61 ± 24	66 ± 22	84 ± 24
General	Learning Software		81 ± 13	54 ± 25	91 ± 8
	Overall Use		68 ± 24	58 ± 27	91 ± 7

Figure 2: Summary of feature identification and post-experiment questionnaire results. Participant responses given as mean and standard deviation. Top: Number of features successfully identified by participant. Bottom: Rating responses for data exploration tasks (navigating, identifying and locating features) and general use (learning software and overall use). The results show that participants found that using the Visualizer in a CAVE made data exploration easy and that the software was easy to learn and use overall. Visualizer on the desktop was also better for data exploration, but was more difficult to learn because the tool assignment process is more cumbersome on the desktop.

- *The button navigation in Visualizer-desktop has a steep learning curve, but works itself out with time.*

- *Visualizer-CAVE: The software is amazing and easy to use. It allows the user to examine every aspect of the data set.*

- *Visualizer-CAVE: It is really great to be able to really move around the slices and surfaces as you are choosing one to display.*

- *Visualizer-CAVE: Amazing program, 3D visualization made understanding the data incredibly efficient and effective.*

Conclusions

The goal of this study was to evaluate how well Visualizer, designed for visualization of 3D data in VR environments (like CAVEs) enables geoscientists to analyse structures within 3D volume data sets. The results show that Visualizer used in a CAVE makes data exploration very easy and allows geoscientists to efficiently analyze 3D volume data sets. In addition, the software is

easy to learn and use overall. Visualizer on the desktop is also better for data exploration than a desk-top software package commonly used by geoscientists (TecPlot), even though it is more difficult to learn how to use Visualizer on the desktop. The comments provided by the participants provide insightful feedback on how to improve Visualizer for desktop use and make it a completely environment-independent software package.

References

[*TecPlot*] TecPlot, http://www.tecplot.com/.