A Proposed Experiment for Evaluating 3D Vector Visualization Methods

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ABSTRACT
We present an experiment design for comparing multiple 3D vector field visualization methods. Decades of research have produced many visualization methods, but relatively few evaluations have been done to compare the techniques head-to-head for relevant tasks and on relevant data. Results from an effective experiment could not only discover the “best” methods, but also guide future research by helping identify shortcomings in methods and the experiment to perhaps more efficiently advance the state-of-the-art. The contribution of this work is a specific experimental design for comparing 3D vector field visualization methods.

KEYWORDS: 3D Vector Visualization Methods, Evaluation.

INDEX TERMS: I.3.8 [Computer Graphics]: Applications

1 INTRODUCTION
In general, quantitative studies of visualization methods are insufficient and the community’s methods are too ad hoc [1]. Our hypothesis is that comparing relevant 3D vector field visualization methods “head-to-head” will reveal subtle and important differences and reveals differences between techniques and will help guide the research community. There are many challenges to designing and executing an experiment evaluating 3D vector visualization methods—most notably, identifying tasks that are of general interest; identifying and creating relevant vector fields; selecting interesting visualization methods and tuning method parameters for the tasks; and appropriately training subjects.

2 RELATED WORK
[2] investigated 2D Vector Visualization methods. Laramee investigated swirl and tumble but not other flow analysis tasks and with engine design as a driving application [3]. Ware conducted a study to evaluate the importance of 3D cues in perceiving the orientation of curved contours [4] and motivated the tube-based visualization method in our study. Ware’s study used different data, different numbers of streamlines, and a plane-matching task while we used tasks motivated by interviews with flow scientists.

3 EXPERIMENTAL DESIGN
We describe below the key elements of our experimental design.

3.1 Tasks
Our tasks are aimed at testing how well subjects understand “chunks of 3D flow”. Informally, understanding “chunks of 3D flow” is the commonality we have noted after discussing for multiple years 3D flow tasks and developing visualization methods in collaboration with fluids researchers. While the flow experts are often searching for different scientific features from each other and often only answer what they look for given a statement of “what is the problem”, our best general explanation of a flow scientist’s task when visualizing 3D flow fields is to varying degrees they all explore or study a localized point itself often in considering the neighborhood around a region of interest. Finding and describing many common flow features fit this categorization including swirling flow, stagnation points, vortices, flow separation, flow reversal, high-residence time, and horseshoe-vortices. 3D flow scientists sometimes reduce their problems to 2D visualization or quantitative analysis, and in the context of this paper we consider that is a different problem from 3D flow visualization.

The six tasks we will use in the study are: 1) Verify if a given point is a critical point (CP), 2) Identify the type of a CP, 3) Verify if point A advects to point B, 4) Verify if a given point is in swirling flow, 5) Decide if the flow is moving faster at point A or B, 6) Report the number of critical points.

3.2 Task Design

Figure 1. Examples of each of the tasks. a) Does point A advect to B? b) Is the marker at a CP? c) What type of CP is at the marker? d) Is the marker in swirling flow? e) Is the flow faster at point A or B?

While these are not a complete set of vector visualization tasks (e.g., they do not include any test of the important flow property vorticity), they do cover an important range of vector field analysis tasks. Expert flow scientists who have piloted our study agreed they are relevant tasks. Pilot studies have revealed these tasks are challenging for both novice and flow experts.
3.2 Number of trials
We expect subjects will perform 80 trials (5 tasks x 4 methods x 4 iterations). The exact visualization methods and parameters we will use are still being investigated, but for practical reasons we expect to use 4 methods in the initial version of the experiment.

3.3 Datasets
For each trial we pre-compute a randomly generated dataset. Each 3D vector field consists of 20 x 20 x 20 vectors and is generated using a radial basis function. Detection and classification of CPs is conducted using Newton’s method and eigenanalysis. Eight types (2 node types, 2 saddle types, and 4 spiral types—see Figure 4) of first-order critical points are found. The vector field is relatively complex and the number of CPs ranges from 3 to 5. To prevent degenerate vector fields we filter out datasets where CP’s are too close together.

3.4 Visualization methods
Figure 3 illustrates a set of visualization methods we are considering for the experiment. We are including a streamline method as a baseline because it is often used in popular visualization tools like TecPlot. We initially planned to use a textured, lit, tube representation motivated by [4], but preliminary pilot studies have shown that adjusting that technique should lead to improvements—e.g., coloring streamlines by similarity [5] (see Figure 3c) has helped in analyzing the visualizations. Streamlines and streamtubes rendered with a gradient texture indicating flow direction have not performed well in pilot studies because interpreting the coded direction of flow is difficult (see Figures 3d and 3e). Preliminary studies indicate stereo viewing will outperform monoscopic viewing for these tasks.

To help control the visual stimulus, we will either oscillate the view as in [4] or allow user-controlled rotation about only the Y-axis. Pilot studies indicate static viewpoint is inferior to a dynamic viewpoint, even in the stereo viewing condition.

3.5 User Interface
Many cues help humans see in 3D. While many studies will be needed for a thorough investigation, in our initial study we want to minimize interactive adjustments to methods and evaluate the set of visualization methods we have tuned through pilot studies and “wedges” (visual galleries where individual parameters are varied and votes for the “best” parameter are recorded) which help us find effective parameterizations for the tasks. Subjects can use the four cursor keys to rotate the visualization about the screen’s X and Y axes. A text prompt on the display describes the current task to subjects. Subjects pressed “Y” or “N” to indicate yes or no responses. For CP identification, responses were a number from 1 to 8 corresponding to the eight CP types on a cheat sheet. Subjects rate their confidence using a Likert scale from 1-5.

3.6 Training
Subjects will learn to perform each task including how to identify the types of critical points in an interactive tutorial where subjects must both complete 10 trials and gotten 3 trials correct in a row. During training, visual feedback will tell subjects if their responses were correct and help illustrate the correct answer.

3.7 Data Analysis
We will process the trial data and questionnaire data using ANOVA. We will summarize information gathered during a debriefing session following the study. Currently, we expect to run 16 or more subjects to achieve statistically significant results.

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REFERENCES