Validation of SplitVector Encoding and Stereoscopy for Quantitative Visualization of Quantum Physics Data in Virtual Environments

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Abstract

We designed and evaluated SplitVector, a new vector field display approach to help scientists perform new discrimination tasks on scientific data shown in virtual environments (VEs). Our empirical study compared the SplitVector approach with three other approaches of direct linear representation, log, and text display common in information-rich VEs or IRVEs. Our results suggest the following: (1) SplitVectors improve the accuracy by about 10 times compared to the linear mapping and by 4 times to log in discrimination tasks; (2) SplitVectors lead to no significant differences from the IRVE text display approach, yet reduce the clutter; and (3) SplitVector improved task performance in both mono and stereoscopy conditions.

1 Introduction

Quantum physics produces data with large ranges: the differences between the largest and the smallest numbers can reach 10^9 or more. Linear mappings of the numerical values to a vector in a virtual environment (VE) lead to small nonzero-data that are invisible and to large data too large to be seen. The information-rich virtual environment (IRVE) [1] approach can successfully display numerical values as text attached to each vector location; however, for dense scientific data, displaying more than a few hundred labels can be prohibitive. The logarithmic approach is common in engineering and science. Logs, however, are not linear and require some mental calculations of the real values, which may produce a greater mental workload.

The goal of this research is to explore new encoding approaches to reduce clutter and to support real world discrimination tasks in both stereo and mono conditions. We investigate whether designing a new vector field visualization can lead to more accurate feature analysis in complex physics simulation results in VEs. More specifically, we consider: are there differences in accuracy and efficiency when novel encodings are used compared to the classical linear, log and textural IRVE approach? Can the encoding work equally well in stereoscopic conditions. Answering these questions will have implications for using encoding and cues in dense data simulation visualizations in VEs.

Our research contributes to the following: (1) New design to let scientists perform change detection and discrimination tasks for more precise numerical data measurement; (2) Statistical and anecdotal evidence on the performance of encoding styles and stereoscopy that is useful in designing future visualization algorithms for the accurate measurement of complex spatial structures; and (3) A first look into the broader issues of clutter management for displaying explicit numerical values and task performance in VEs.

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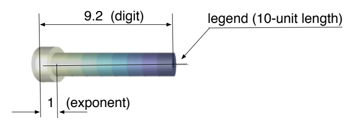


Figure 1: SplitVector Design: Representation of 92 ($= 9.2x10^1$). Here 9.2 and 1 are represented by two cylinders.

2 SplitVector Design

SplitVector is an encoding method for showing large range data (Fig. 1). SplitVectors split a vector representation into two parts: the digits and the exponent, using scientific notation. The orientation is simply expressed by the orientation of the line segment, as in the existing approach. Here, the digits term can be any real number in the range [1, 10) and exponents are always integers. We also used a gray-scale blue colors from light to dark blues to double-encode the length, where the darker the blue, the higher the values. Each different color on that cylinder represents one one unit length.

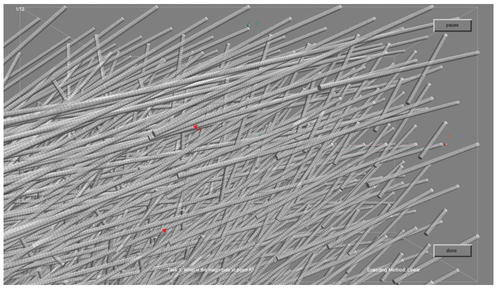
3 Evaluation

We ran an experiment on determining quantitatively how effective this new type of visualization is. Our experiment used a $4 \times 2 \times 3$ within-subject design with three independent variables: visual encoding method (linear, log, text, and SplitVector), display conditions (mono and stereo), and tasks (three types). Dependent variables include error and accuracy, task completion time, confidence, and subjective ratings.

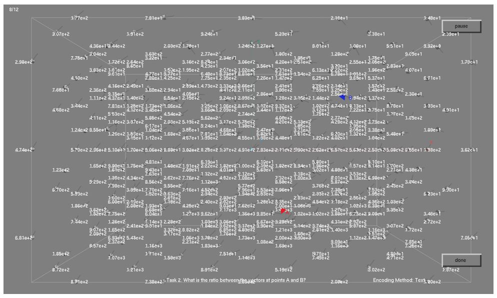
We hypothesize that SplitVector can lead to more accurate readings than linear and log approaches, especially for large values in discrimination tasks. Text may perform better than SplitVector. And for detection tasks of comparison for a binary answer, all visualizations will perform equally well regardless of rendering or stereo conditions.

Participants performed three tasks (Fig. 2): the first two tasks being discrimination and the last being detection. We carefully selected the task-related point(s) for each data sample.

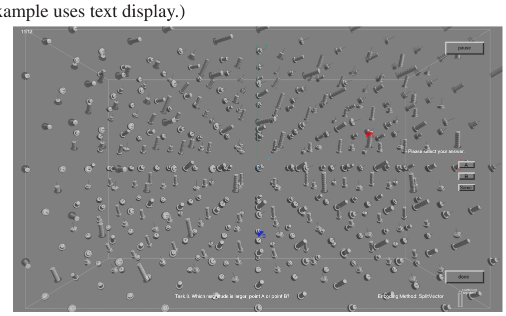
Task 1 (MAG, Fig. 2a): Magnitude reading at A.We used four instances per visualization method for each of the two display conditions, either stereo or mono ($4 \times 4 \times 2 = 32$ trials).



(a) Task 1 (MAG): What is the spin magnitude at A? (This example uses direct visualization.)



(b) Task 2 (RATIO): What is the magnitude differences at A and B? (This example uses text display.)



(c) Task 3 (COMP): Which point has the large vector magnitude, A and B? (This example uses SplitVector.)

Figure 2: The three tasks used in this study.

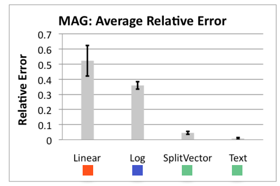
Task 2 (RATIO, Fig. 2b): Magnitude differences at A and B. Four instances per visualization method ($4 \times 4 \times 2 = 32$ trials), difference in speed between query points in range $[1.1 \times Min_{magnitude}, 0.9 \times Max_{magnitude}]$.

Task 3 (COMP, Fig. 2c): Which magnitude is greater? Four instances per visualization method ($4 \times 4 \times 2 = 32$ trials), differences in speed between query points in range $Max_{magnitude} \times [0.2, 0.5]$ (where $Max_{magnitude}$ is the maximum speed for that specific dataset.)

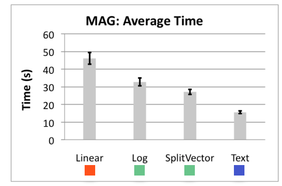
Twenty participants (16 male and 4 female) with mean age 25.2 (standard deviation = 5.0) participated in the study. The room had natural light and the display was a BenQ GTG XL 2720Z 27" stereoscopic, gamma-corrected, VE display (resolution 1920×1080). The stereo rendering was implemented using OpenGL quad-buffered stereo viewed with NVIDIA nVision 2. Participants can rotate the data; Zoom in-out was also supported.

4 Results

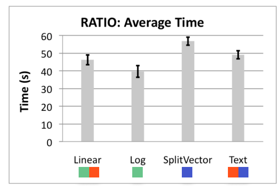
We collected 1920 data points (96 from each of the 20 participants). There are 640 data points from each of the three tasks. Our hypotheses were supported which clearly demonstrated the benefits of using our new design in both mono and stereo conditions. Statistical significance is computed with SAS's general linear model (GLM) procedure. Tukey pairwise comparisons among dependent variables (e.g., stereo, visualization, and ranking) are computed in post-hoc analysis. All error bars represent standard error. The relative error measurement is expressed as a ratio $RE = |CorrectAnswer - ParticipantAnswer|/CorrectAnswer$ and is a unit-less number.



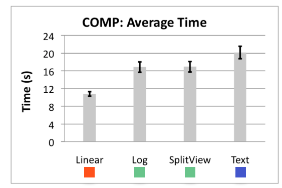
(a) Task1 (MAG): Encoding vs. Error



(b) Task1 (MAG): Encoding vs. Time



(c) Task2 (RATIO): Encoding vs. Time



(d) Task 3 (COMP): Encoding vs. Time

Figure 3: Study Results. Error bars represent standard error. Same colors represent same Tukey group.

We observed the significant main effect of encoding on relative errors for the discrimination tasks of "magnitude reading" ($F(3,639) = 22.5$, $p < 0.0001$). In the MAG tasks, SplitVector improved accuracy about tenfold over linear and sevenfold compared to log (Fig. 3a). SplitVector and text were in the same accuracy group, tested by Tukey post-hoc analysis. For task completion time, the encoding approach was a significant mean effect in all three tasks (MAG: $F(3,639) = 35$, $p < 0.0001$; RATIO: $F(3,639) = 6.98$, $p < 0.0001$; COMP: $F(3,639) = 12.2$, $p < 0.0001$). For the "magnitude reading" task, each of linear and log was in separate Tukey group compared to splitVectors and text in terms of task completion time (Fig. 3b). In "ratio" task, splitVector and text led to longer reading time (Fig. 3c. For detection of "which one is larger", linear required the least amount of time due to its intuitiveness; Log and splitVector were about the same; and text took the longest perhaps due to reading (Fig. 3d). Stereo and mono worked about equally well in the first "magnitude" task, with stereo marginally better than mono. The stereo effect was significant only in the detection task COMP of determining which one is larger. Stereo doubled accuracy for the relatively difficult RATIO task.

5 Conclusion

A clear take-home message is that for future IRVE design, perhaps consider new and efficient encoding to compensate current text display approach. For discrimination tasks of reading large-range data, use SplitVector if possible especially for very large data, and avoid the linear and log methods which lead to large errors.

Acknowledgements

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References

[1] D. A. Bowman, C. North, J. Chen, N. F. Polys, P. S. Pyla, and U. Yilmaz. Information-rich virtual environments: theory, tools, and research agenda. In *Proceedings of the ACM VRST*, pages 81–90, 2003.