Quantitative Evaluation of Two Dimensional Vector Field Visualization Techniques

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Introduction

Arguably, one goal of scientific visualization is to represent physical quantities for interpretation without biasing what is inferred from the data by the particular choice of the visualization method. In experimental sciences, great care is taken when determining where data is to be sampled so that incorrect inferences are not made concerning the nature of the data. Must these same types of considerations be made in visualization? Questions of this type have been brought up in the works of Tufte [1], Cleveland [2] and more recently Ware [3]. In all three cases, much advice is given from a qualitative, or anecdotal perspective; user-studies pertaining to the questions raised are still very limited in both their number and their scope.

Problem Statement

The goal of this project was to quantify the results of one particular visualization question: If given a vector field, which distribution of vector icon placement is optimal for visualization? We have focused on two particular vector visualization methods: a regularly-spaced vector icon distribution and a jittered grid distribution as proposed by Dippe and Wong [4].

Because regular-grid distributions are common in computational settings, visualizations which use regular-grid distributions are common. However, as is pointed out by the study of Field et al. [5], perceived continuity play an important role in a human perception of a visualization, and thus, as is further interpreted by Ware icon placement which preserves continuity may lead to more effective visualizations. Ware points out, in an anecdotal fashion, that vectors placed on a regular-grid are less effective than vectors placed in a streamline-like fashion which preserves the continuity of motion perceived from the vector field. Based on these initial statements, we chose to evaluate the two vector icon placement strategies by accomplishing a user-study which attempts to resolve the following problem: The user is presented with a vector field visualization which has, in addition to the vector icons, a red dot placed randomly on the image, and contains a circle centered about the red dot. The user was asked the question: If a particle were to be placed on the red dot and were to be advected along by the vector field, where on the circle would the particle first intersect the circle?

Experiment

A user-study was performed in which a collection of four users were presented with two visualization types with two different vector icon densities. Example visualizations are presented in Figure 1.

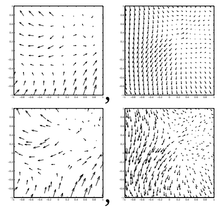

Figure 1: Sample visualizations. Top: Low and High Resolution Regular Grid. Bottom: Low and High Resolution Jittered Grid

For each user, four tests were run. An enumeration of the tests is as follows:

1. Test 1: Regular Grid - Low Resolution (100 vectors)
2. Test 2: Regular Grid - High Resolution (400 vectors)
3. Test 3: Jittered Grid - Low Resolution (100 vectors)
4. Test 4: Jittered Grid - High Resolution (400 vectors)

In each test, the user was shown 19 visualizations. For each visualization, the user was presented with a circle and a dot at the center of the circle, and was asked the question of where would a particle placed on the dot and advected along by the underlying vector field intersect the circle. Mean angular error and standard deviation from the true advected position were computed.

Results

In Figure 2 we present the mean absolute angular error and standard deviation for each user.

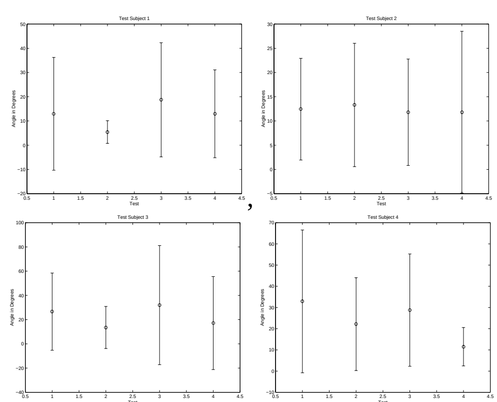

Figure 2: Mean absolute angular error and standard deviation for each user. The tests are as enumerated above.

[1]Tufte, Edward. *The Visual Display of Quantitative Information"*. Graphics Press, Cheshire, CT (1983).

[2]Cleveland, William S. "*The Elements of Graphing Data"*. Wadsworth & Brooks/Cole, Pacific Grove, CA (1985).

[3]Ware, Colin. "*Information Visualization: Perception for Design"*. Morgan Kaufmann, NY (2000).

[4]Dippe, Mark A.Z. and Erling Henry Wold. "Antialiasing Through Stochastic Sampling", SIGGRAPH '85.

[5]Field, David J. Anthony Hayes, and Robert T. Hess. "Contour Integration by the Human Visual System: Evidence for a Local 'Association Field'", *Vision Res.*, Vol 33 No 2, pp. 173-193, 1993.

Summary of Results

The results contained some non-surprising and some surprising trends. First, it is clear from the data that user performance increases as a function of resolution - as to be expected. What is surprising is that in some cases users do a better job using jitter at low resolution than regular grid at low resolution; however, when the resolution is increased, the regular grid is better. These trends will require future study.

Data Visualization for a Teaching Radio Telescope

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Introduction

Energy from space is constantly passing through us. Just as optical telescopes extend our visual sense, radio telescope allow us to extend the spectrum which we can perceive to include these frequencies. Just as some flowers have patterns visible only in the UV range, many celestial objects and phenomenon are only visible in the RF range. Hydrogen gas clouds make up the bulk of interstellar space in our own galaxy, but are visually opaque. Recently, an undergraduate-led team constructed an instrument designed to collect energy at 1.4GHz, which is the “hydrogen line” RF frequency emitted from these clouds. By examining the Doppler shift around this hydrogen line, red- and blue-shift can be extracted, and relative velocity between the earth and the cloud can be inferred. Output from the existing setup was a two-dimensional FFT graph of frequencies from an observation at a point in the sky (Fig. 1.)

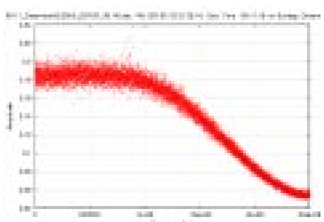

Figure 1: original output from student telescope

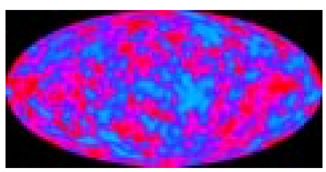

Figure 2: NASA’s COBE sky survey

Visualization

Although this instrument was designed as a teaching tool for astronomy courses, it is difficult to construct a mental understanding of the actual process behind the data– the shape and motion of the Milky Way– from a sequence of hundreds of these graphs. The state of the art has been elliptical projections, which reduce a complex, three dimensional map to a 2D image which many people find confusing and unintuitive (Fig. 2.) This method shows the entire sky distorted into an ellipse. A viewer’s first impression may be that they are looking at an ellipsoidal data set from the outside, when in reality they are viewing a spherical data set from the inside. Recognizing the clear need for an improved visualization, the investigators have created an interactive system for viewing the radio telescope data in an intuitive, realistic fashion. The data, after reduction, is projected onto a sphere which represents the sky surrounding the earth. Amplitude of the signal is mapped to visual brightness, and frequency shift is mapped from red to blue. The viewpoint can be changed so that one can rotate around this sphere and thus get an overall sense of the data. Constellations are overlayed for orientation. In the “planetarium view” (Fig. 3), a section of the data is viewed as from the surface of the earth. The combination of these two views allows description the overall data while showing how this is related to a more human-centered observation. A second novel visualization (Fig. 4) was created in which velocity data is represented as streams of points moving towards or away from the sphere; motion and direction are proportional to magnitude and direction of frequency shift.

Figure 3: interactive planetarium view

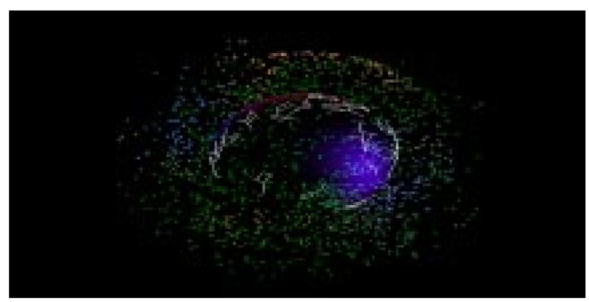

Figure 4: Still image from the animated visualization

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[2] Imaging the Universe at radio wavelengths. Crutcher, Richard M. IEEE Computational Science & Engineering v 1 n 2 Summer 1994 Publ by IEEE p 39-49 1070-9924

[3] Hands-on universe: bringing astronomical explorations to the classroom. Refling, John P.; Pennypacker, Carl R. IEEE International Conference on Image Processing 2 Oct 23-26 1995 1996 Sponsored by: IEEE IEEE p 312-314

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Introduction

One obstacle that scientific visualization researchers encounter is the difficulty of representing physical quantities in a coherent manner without adding bias specific to the visualization method. There exists relationships between the perceptual quality of the visualization, the difficulty of creating a visualization, and the accuracy of the technique in representing the given data. Obviously, it is advantageous to minimize misrepresentation. Recent studies on this subject have been addressed in the works of Tufte (1983), Cleveland (1985), and Ware (2000). Much of this research is anecdotal and qualitative; in comparision, very little research has documented quantitative information.

Problem Statement

Our goal in this project was to present quantitative data to answer the following visualization question: what is the optimal vector icon placement distribution for a given vector field? For this test, we employ two of the most common vector field display techniques, a regularly spaced grid distribution, and a jittered grid distribution, first presented by Dippe and Hayes (Dippe and Wong, 1985). Regular grid distributions, due to their ease of implementation and widespread use in computational software, are often used by researchers. However, there are several drawbacks to this method. Percieved continuity plays an important role in human vision, as noted by Field et. al. (Field et all., 1993). Therefore, the visualization method should strive to preserve continuity between icons (Ware, 2000). Ware states that vectors placed on a regular grid are not as useful as those placed on a more streamline based vector field, although he does not provide quantitative support for this assertion. Our task was to ask users the following question: given a vector field visualization with a randomly placed red dot, with a surrounding circle, judge from the visualization where a particle would intercept the bounding circle when placed on the red dot?

Experiment

A user study was presented to four users, in which four different visualization methods were tested for their effectivness- the regular grid and jittered grid visualizations, and two vector icon placement densities for each. A 4x4 latin square was utilized to decide a distinct random order between visualization task for each subject tested. Each user was presented 19 images. Given a starting point and a bounding circle, the user was asked to mark the point on the circle perimeter a particle would flow through according to the vector field. Error analysis was computed using the angle from the true advected location. The experiments were developed using HTML, Java, and Javascript, and were run on a Sun workstation.

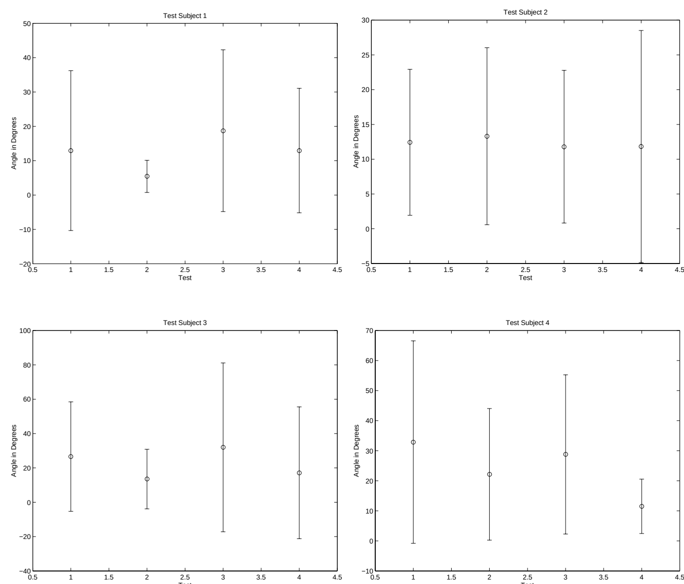
Results

The mean angular error for each task is shown for each user in figure 1. From these results, it can be inferred that a higher image resolution reduced error. However, statistically significant results were not obtained with respect to the grid layout type. This could be attributed to the small number of participants in the study.

Conclusions

We have provided evidence that vector icon resolution increases error in visualizations. A strong foundation for future work has be developed. This work will be extended to several other visualization methods in hope of developing a rubric for researchers utilizing vector field visualization.

Fig. 1- error data, in degrees away from target advection point, for each user. The four tests are aligned on the x-axis as follows: Regular grid/low resolution, Regular/high, Jittered/low, Jittered/high.



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[1] Cleveland, William S. ”The Elements of Graphing Data”. Wadsworths and Brooks/Cole, Pacific Grove, CA (1985).

[2] Dippe, Mark A.Z. and WErling Henry Wold. ”Antiailiasing Through Stochastic Sampling”. SIGGRAPH ’85.

[3] Field, David J. Anthony Hayes, and Robert T. Hess. ”Contour Integration by the Human Visual System: Evidence for a Local Association Field”. Vision Res. Vol 33 No 2, pp. 173-193, 1993.

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[5] Ware, Colin. ”Information Visualization: Perception for Design”. Morgan Kaufmann, NY (2000).

Visualizing Radio Astronomy Velocity Data in an Intuitive Manner

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Introduction

This project explored a more inuitive visualization of galactic hydrogen data. Radio telescopes produce two scalar values at all observed points: amplitude and radial velocity (from Doppler shifted frequency measurements) of the source. Velocity data has traditionally been shown as color variation across the observed sky. However, humans have no everyday experience with the Doppler shifting of visual light, so color variation in the visual spectrum is not an intuitive manner in which to represent velocity.

Data

Data from a small radio telescope (constructed in part by the PI as an undergraduate project) was used. The target source is hydrogen, emitting at 1.42 GHz (a good choice due to its abundance in our galaxy). The radial velocity of this hydrogen is correlated with the spiral motion of the Milky Way. Fourier analysis of the incident radio waves yields the frequency of the received signal. The shift in the signal from the known rest frequency of hydrogen is proportional to the radial velocity of the observed gas clouds.

Challenge

The difficulty in visualizing this information is that there is no distance information. Therefore, Earth is the only position for which the data can be accurately projected. However, this causes all radial information to be obscured. Hence, the standard technique is to use colors. We hypothesized that a person seeing an uncentered data visualization could easily compensate, and gain better understanding of the data than from an Earth centered image. We chose to represent the data as moving particles in a shell around the Earth. This can only be seen from a non-Earth position, allows velocity data to be represented intuitively: as velocity.

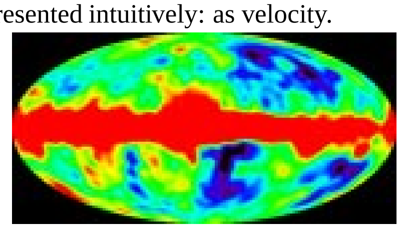

Fig. 1 A 2D projection of NASA COBE microwave data.

Results

This first step in visualizing the data was to make a 3D representation of the data. The usual image style used by NASA **(Fig. 1)** is an oval representing the entire sky. While displaying a great deal of information in a single image, the format is not intuitive. Position in the sky is very hard to interpret, especially near the edges of the image. We created a program in OpenGL to map obtained data onto a spherical sky **(Fig. 2)**. Constellations are given for positional reference. This visualization is navigable, allowing the user to explore the radio data.. However, it still has the limitation of showing velocity as color. **Fig. 3** is a still frame from the final visualization. The constellation sphere is now viewed from the outside so that the radial motion of the hydrogen clouds (small dots) can be observed.

Fig. 2 A 3D projection of Brown Univ. 1.42GHz data, with constellations for reference.

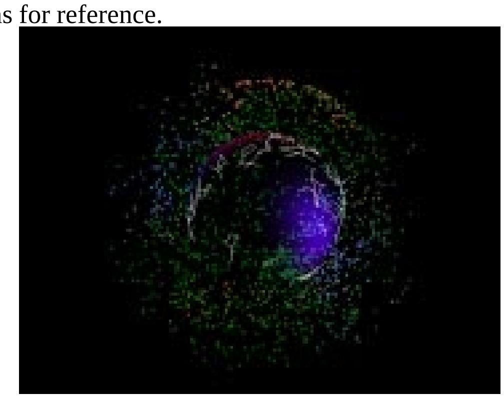

Fig. 3 A still frame of moving particles calculated from the dataset in Fig. 3..

Conclusions

Informal comparison of our visualizations with previous methods shows many trade offs. Displaying the data in 3D is unquestionably much more inuitive than in an awkward 2D projection. However, the field of view possible without image distortion is small, and navigation is tedious. The animated particle visualization is promising, but users must recall that the constellation sphere is fictitious. The particles behave in large groups, making it easy to see the hydrogen motion in one area. The problem with this visualization is that the particle motion is highly exaggerated. Just as color does not directly correspond to hydrogen behavior, neither do these high speeds. Differential rotaion of the galaxy is ignored in this model, and so the presence of radial motion without rotational motion creates a false galactic behavior. Further improvement to the particle visualization may be possible through assuming a model for galactic rotation and incorporating that into the particle motion.

References

[1] Crutcher, R. M., Imaging the Universe at radio wavelengths. IEEE Computational Science & Engineering v 1 n 2 Summer 1994

[2] Refling, J. P., Pennypacker, C. R., Hands-on universe: bringing astronomical explorations to the classroom. IEEE International Conference on Image Processing 2 Oct 23-26 1995 1996 p 312-314