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Space and the Spaceball

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Abstract. The vast quantities of data produced by modern radio telescopes have outstripped conventional visualization techniques available to astronomers. ATNF staff have developed new visualization techniques to give astronomers a greater intuitive insight into their data. While visualization techniques in other areas find some application in astronomy, problems peculiar to the field require new techniques, such as methods for identifying three-dimensional regions. This paper presents an overview of some of the problems of visualization for astronomy and describes experiments with the Spaceball, a three-dimensional pointing device.

1. Volume Rendering

Visualization of three-dimensional data sets has already been researched and implemented in fields such medicine, for visualizing three-dimensional CAT scans. Great progress has been made through the use of volume rendering tools. These tools allow a three-dimensional data set to be displayed on a two-dimensional display (the computer monitor), with controls which the user can rotate and so obtain different views.

These techniques may also be applied to astronomy. While medical visualization deals with data which truly represent three spatial dimensions, radio astronomy spectral-line data sets represent two spatial dimensions and one frequency dimension. This does not prevent the data from being displayed as if they were a three-dimensional object, but the astronomer needs to be aware that the display is merely a representation of the data.

At the Australia Telescope, we have had considerable success using volume rendering. While we have experimented with both surface rendering as well as volumetric rendering tools, we have found the latter to be more successful. The focus of this technique is to make best use of the astronomers' spatial recognition functions. By presenting data three dimensionally, the astronomer may identify structure in the data which is not obvious when using conventional tools. Once this structure is identified, the astronomer may then proceed to further analysis.

1.1. Limitations of Standard Volume Renderers

Many existing volume-rendering tools are designed for visualization. The objects of interest are solids and fluids which are purely absorptive. In contrast, objects observed in radio astronomy contain regions of emission and absorption. Volume-rendering tools for radio astronomy need to take account of this fact.

Furthermore, most astronomical data contain noise, which further differentiates them from medical data. However, even simple shaders are far more effective in revealing structure than the techniques traditionally used by astronomers. While these techniques are suitable for revealing two-dimensional structure, the astronomer missed much of the three-dimensional structure. We find that a radiative transfer ("hot gas") shader is particularly helpful for volume-rendering of astronomical data.

Another limitation of standard volume renderers is the lack of analytical software. While in many cases medical specialists are content with a qualitative assessment and rely solely on visual inspection of images, the astronomer depends far more on quantitative analysis. Once a feature is identified in a multi-channel data set, quantitative measurements are required to determine the physical processes at work. Some of these measurements are simple (such as identifying the frequency extent of an emission), while others require complex processing to obtain a meaningful result.

1.2. Identifying Structure

Once the astronomer has visually identified a feature of interest in the data set, some means of defining that feature is required. Therefore, a way of identifying points in three-dimensional space is needed. Merely using a two-dimensional pointing device (e.g., a mouse) in conjunction with a two-dimensional projection (a "view") is insufficient. Some means of moving and displaying a three-dimensional cursor is required. Once this problem is solved, a visually identified feature may be related to the analysis software.

2. The Spaceball

The Spaceball is a three-dimensional pointing device, available from Spatial Systems, Inc. It is a force-sensing device which provides six parameters: three orthogonal forces and three orthogonal torques. I have coupled the Spaceball to a volume-rendering tool, allowing the user to rotate the volume in an intuitive manner. In addition, users can move a three-dimensional cursor through the volume, allowing them to identify three-dimensional regions of interest. While the positioning tools available in immersive virtual reality environments (such as a high-quality data glove) are far more advanced, they are also far more expensive. The Spaceball and similar devices provide a cost-effective means to position cursors in three-dimensional space.

When the user pushes the Spaceball in a particular direction, a three-dimensional cursor is seen to move inside the volume. From experiments, we have found that depth placement of the cursor is rather difficult. A simple solution is for the user to set the placement in the X and Y directions, then rotate the cube by 90° and set the placement in the remaining direction. Clearly, this is still a somewhat cumbersome interface. An improvement may be obtained by rendering the cursor as part of the data, rather than overlaying the cursor on top of the rendered volume. This method is particularly effective when moving the cursor behind thin opaque regions, as the placement is directly tied to the data, which is the ultimate goal. For placement relative to larger regions, other methods must be used to give depth cues to the user.

To assist the user, a wire frame is displayed, with color-coded lines projecting from the cursor (a simple three-dimensional crosshair) to the three orthogonal corner planes. By upgrading to a stereo display, we expect to provide the necessary depth cues to enable the cursor to be placed in three-dimensional space.

3. Applications of a Three-Dimensional Cursor

3.1. Extracting Quantitative Information

To address the problem of extracting quantitative information, the user must be able to define and extract sub-regions of the data set and process these with a wide variety of algorithms that provide measures of the physical processes in the observed astronomical object. Work is in progress to allow subsets of data to be passed seamlessly to the analysis tools (such as AIPS++).

3.2. Viewing Small-Scale Structure

To expose small-scale structure the astronomer needs to isolate a region of interest. One method is to integrate a "slicer" tool which allows the astronomer to view the three orthogonal slices which intersect at a specified position. While slicer tools have been available in some astronomical analysis packages for a few years, specifying the slices was done using three separate linear controls (knobs or sliders). To my knowledge, this is the first time an integrated input device such as the Spaceball has been used to control a slicer tool for analyzing astronomical data sets. Coupling this slicer tool with a volume-rendering tool allows the astronomer to specify a point in three-dimensional space relative to the overall structure while at the same time displaying small-scale structure.

3.3. Understanding Data

Most radio astronomy is not solely a matter of collecting, viewing and interpreting data. Many theoretical models exist which attempt to explain observed phenomena. Once an astronomer has identified structure in the data and proceeded to perform quantitative analysis, the data need to be compared with existing models. Various astronomical data analysis packages provide tools to do this. However, they are limited to one- or two-dimensional data sets.

A greater challenge will be to provide model-fitting tools for three-dimensional data sets using algorithms tuned to such data. New model-fitting algorithms need to be developed to take full advantage of emerging visualization technologies.

4. Results

The feedback we have obtained from astronomers indicates that they can extract more science from their data using the visualization tools we have developed than was previously possible. By taking advantage of the spatial recognition and integration powers of the brain (powers which are tuned for three-dimensional moving objects), features that would not appear using conventional techniques become readily apparent using volume-rendering tools. Objects that would appear as a number of faint, disjoint fuzzy patches in individual images appear as a clearly defined object in three dimensions. In a number of instances astronomers have found previously unknown features in their data when they used the new visualization tools.

Using the Spaceball to identify regions of interest is proving an effective means to extract quantitative information and focus on small-scale structure, especially when coupled with a slicer tool.

5. Future Work

Further into the future is the possibility of experimenting with fully immersive virtual reality environments. Virtual reality offers the potential to present far more information to the user's brain than current video display technology. With the capability to present more information will come the challenge to structure that information in a cohesive, meaningful way. For example, the current tools we are developing allow the user to view the data from the outside, using the controls to enhance and suppress regions of the data. Using virtual reality techniques, astronomers could walk through the data to regions of interest; this would give them more selectivity in viewing data.

6. Summary

Visualization of three-dimensional data sets for radio astronomy will continue to develop over the years. The field is currently in its infancy. While more-general visualization of three-dimensional data sets is at a slightly more advanced stage (but by no means mature), the problems unique to radio astronomy are challenging. Experiments with stereo displays, Spaceballs, analysis and modelling software may open up new vistas for the astronomer, and provide interesting and perhaps unexpected challenges for those developing visualization systems.

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