3D Astronomy Visualization

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ABSTRACT

Last few years, scientists developed many more advanced telescopes to see what we could not see before in space. These modern telescopes collect huge data sets from space, which allows huge advancements in Astronomy.

Visualizing these data sets is key to understanding the information that is gathered. However, we find 3D visualization tools are incapable of rendering ever-growing data sets effectively. In this paper, we will focus on the importance of 3D visualization, different astronomical data file formats, different visualization tools, and their techniques, and what these tools are missing.

CCS Concepts

Applied computing - Physical sciences and engineering (Astronomy)

Keywords Astronomy, 3D-Visualization, Visualization tools

1 INTRODUCTION

Scientific visualization has been applied in many different branches of science in an effort to support the knowledge discovery process, and one of the branches is astronomy [4]. Visualizing data sets that are gathered by modern telescopes is necessary for astronomers. Without current visualization tools, astronomers will have a hard time when observing data sets.

Astronomy is a data-intensive science, and already petabytes of observational data are stored in archives [1, 12]. Rendering and interacting with these data sets are very hardware intensive. One of the big challenges astronomers face is trying to use 3D visualization tools that are incapable of processing these large amounts of multi-dimensional data efficiently.

Some of the 2D visualization tools can process huge data sets efficiently and certainly are very useful for astronomers, but obviously having 3D renders will give astronomers a different and better understanding of the astronomical data sets. Current 3D visualization tools fail to render these data sets effectively because these tools are not designed to deal with the huge data sets that are gigabytes in size. Besides memory and speed issues, there are other issues that are required to be dealt with when developing a good modern 3D visualization tool like being real-time interactive with render, accurate and fast 3D rendering, a good user interface.

2 CHARACTERISTICS OF ASTRONOMICAL DATA

Space is usually observed as electro-magnetic radiation within some range of the electromagnetic spectrum. There is a lot to observe and many wavelengths to observe it in [14]. The Astronomical data contains a range of wavelength values and the presence or absence of these wavelengths provides us different information such as the chemical formation of astronomical objects, velocity of the astronomical objects, etc. A visualization tool becomes necessary to understand such data.

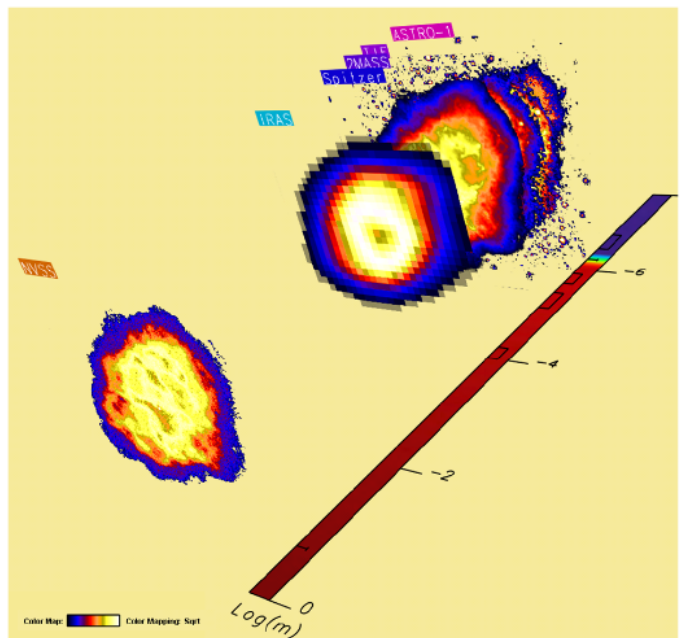

Figure 1: Visualization of the Crab Nebula as slices depicting different wavelengths of light from radio, infrared, to ultraviolet [14].

Astronomical data is stored in different formats such as FITS, HDF, ASDF, etc. Around one billion astronomical data that is gathered by astronomical instruments worldwide are stored in FITS format [10]. There are already some tools that convert FITS to other standardized data formats. If another data format needs to be used in a new modern visualization tool because of its speed, concurrency, and other benefits, it should not be an issue as long as FITS files can be converted to such format.

2.1 FITS

The Flexible Image Transport System (FITS) format is a very generic format and is used to represent a large amount of different data types. The strengths of the FITS format are being widely used, easily understood serialization, and good documentation of the format [13]. Petabytes of astronomical data are archived in FITS format [6]. One of the biggest weaknesses of FITS is being serial only. FITS does not support parallel read/write operations and large data sets require parallel read/write operations to be processed on parallel computers [13]. Parallelization has a huge speed advantage over serialization especially with today's modern computers that are optimized to parallelism.

2.2 HDF5

Hierarchical Data Format version 5 (HDF5) file format is complex structured, can be used to archive large data sets, and supports various types of data sets. HDF5 format has more capabilities and potentially higher performance over FITS format. HDF5 datasets with a contiguous layout strategy, nearly constant access time to any element in the array, and zero overhead for locating elements in the dataset is assured [5]. HDF5 format can stream sections of files across multiple spindles and has a very high read/write speed [10]. Some Astronomers are tending to use the HDF5 format these days. The Low-Frequency Array (LOFAR) has been archiving its astronomical data in the HDF5 format because of its speed advantages [2].

3 VOLUME RENDERING

Volume Rendering used in scientific visualization to create 2D projection from a 3D data set. For instance, a series of 2D slice images of astronomical objects can be assembled to render 3D volume rendered images using a volume rendering algorithm.

3.1 Indirect Volume Rendering

The goal of indirect volume rendering is to create a surface with constant density from a 3D data set [9]. These surfaces then create geometric shapes which are rendered. This type of rendering is usually used for medical purposes, games, etc. Indirect volume rendering produces lower-quality renders compared to what direct volume rendering produces. Some data sets are not suitable for this type of rendering and astronomical data sets are one of them. Astronomical data does not contain well-defined object surfaces, making this type of rendering produce inaccurate results [9].

3.2 Direct Volume Rendering

Direct Volume rendering is creating a projected image from multi-dimensional data. Only simple algorithms and no approximations are applied to the data. This type of rendering is best suited to visualize astronomical data. Geometric structures are not created in this type of rendering which results in renders as natural and accurate as possible. Volume ray casting, splatting, shear warp are the well-known techniques used in direct volume rendering. Ray casting is preferred over other techniques in astronomy because of its higher quality and more accurate render results.

3.2.1 ***Volume Ray Casting.*** Volume ray casting is widely used when volume rendering scientific data because of its high-quality results. This technique of rendering also allows parallelization and good user interactivity [15]. Volume ray casting is an intensive process and a single general-purpose CPU is not sufficient to achieve interactivity or even real-time for large data sets [8]. There are certain optimization algorithms that are used to achieve better speeds like empty space skipping, early ray termination. Visualizing big multi-dimensional data sets with the help of a high-end GPU and also using parallel algorithms may achieve fast render speeds.

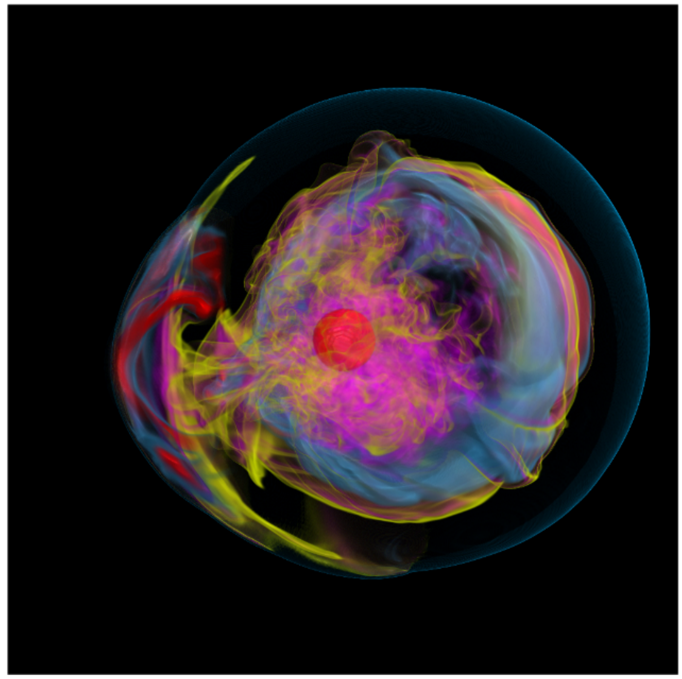

Figure 2: Direct volume rendering of a single time step of the scalar field of entropy values from a core collapse supernova simulation. GPU accelerated volume ray casting with high precision transfer function classification and compositing were used [14].

4 CURRENT 2D AND 3D VISUALIZATION TOOLS

Most of the current astronomical visualization tools focus on 2D visualization. These tools render images in 2D and display them as slices. Astronomers have to go through slices one by one to observe the data sets. This sometimes can overwhelm astronomers. 3D visualization tools do exist like Karma, SAOImage DS9, etc that are used in astronomy. There is also a 2D visualization tool called CARTA with very efficient processing speed times that could be also focused on techniques.

4.1 KARMA

Karma is firstly designed to visualize data sets in 2D, slice by slice. It is widely used by astronomers today. There are packages that allow Karma to read different astronomical data formats like FITS and Miriad. This tool lacks a good user interface, even doing small tasks on this tool may require high technical knowledge. Karma developers have introduced a 3D visualization package called Karma XRAY. This package was not astronomers' preference because its rendering speed limited the tool's interactiveness and had memory problems with big data sets [3].

4.2 SAOImage DS9

This is another widely used tool by astronomers around the world. This tool has a better user interface compared to KARMA. SAOImage DS9 supports FITS and many other data formats [7]. This tool has 2D visualization that renders data sets slice by slice and has 3D visualization that allows users to interact with the 3D render. However, this tool suffers performance problems when it comes to rendering 3D visualization because rendering with Graphics Processing Unit (GPU) acceleration is not supported [7].

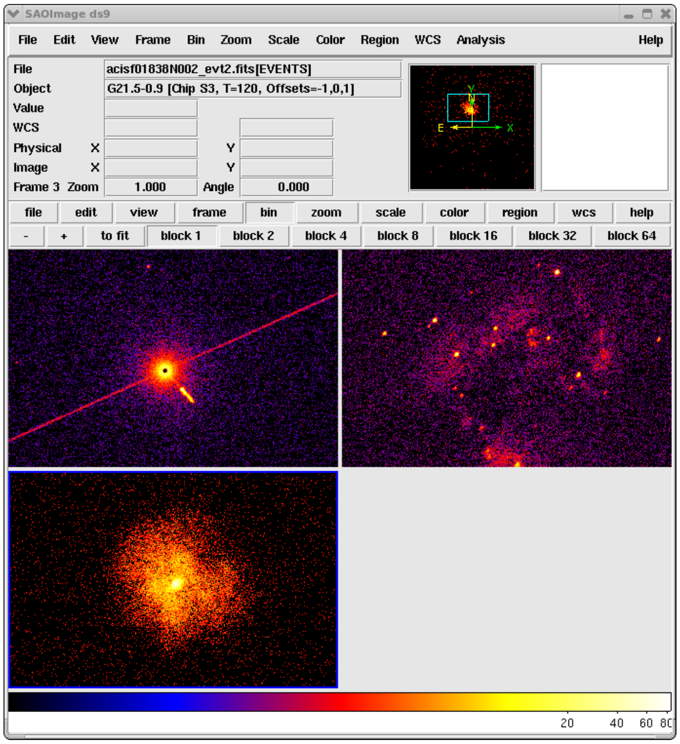

Figure 3: The user interface of the SAOImage DS9 [7].

4.3 CARTA

CARTA is a modern 2D visualization tool that offers a very good user interface and very good rendering speeds. CARTA functions as a server-client system where CARTA is installed on a high-end server and astronomers connect to this server from their typical workstations. After all the processing gets done on the server, render data is sent to the client where the render gets processed preferably by GPU and displayed to the user. This means having a GPU on the client's workstation increases the rendering performance of this tool. Server-client interaction created a lot of advantages on this tool and this same type of technique could be used for 3D visualization.

Astronomers do not always have good access to sufficient computational power or data-storage capacity to deal with large data sets. Dealing with large data sets effectively and efficiently requires a higher level of computing knowledge relating to the choice and use of appropriate data structures, techniques for scheduling, and so on. Therefore using server-client presents an opportunity to provide the wider astronomy community with a very good visualization

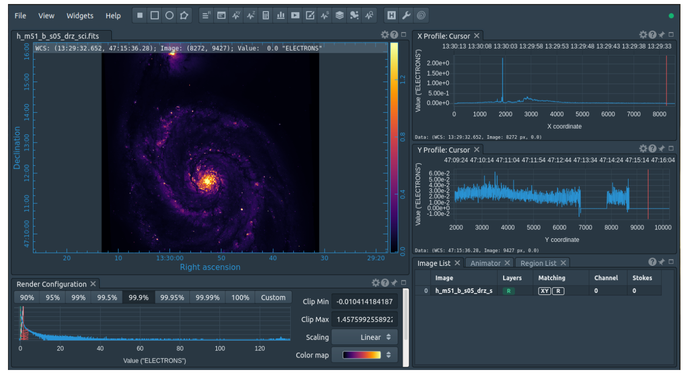

Figure 4: Carta's user-friendly interface..

service with potentially lower cost, less administrative effort, and a reduced need to transfer data [11, 16].

5 ISSUES WITH EXISTING 3D VISUALIZATION TOOLS

Today's 3D visualization tools lack a good user interface, parallelization when reading/writing astronomical data files, parallelization when processing data, GPU accelerated rendering and using memory efficiently.

5.1 Not being user-friendly

Visualization tools are developed mostly to do the job and not much time is spent on making it more user-friendly. New modern tools must provide a better user experience to astronomers so they can spend more time observing data instead of trying to understand how to use the tool. All the different characteristics of the data must be easily accessible to the users.

5.2 No parallelization

Most visualization tools do not use parallelization when reading/writing data sets. These data sets can be gigabytes in size and reading these files serially is not an efficient way to do it. A modern 3D visualization tool should be able to read/write data sets with concurrency.

5.3 Not capable of rendering with GPU

3D visualization tools do not use GPU for rendering data sets. GPUs are far more superior compared to Central Processing Units (CPUs) when it comes to rendering images. A good 3D visualization tool must be able to use GPUs to render data sets.

5.4 Memory inefficiency

Current 3D visualization tools try to store all of the data set into memory. This is a huge flaw because data files in astronomy can be tens of gigabytes. Therefore a modern 3D visualization tool should not store the whole data set in the memory and must use memory more efficiently.

6 DISCUSSION

Current 3D visualization tools are lacking very important features like parallelization, GPU accelerated rendering, User-friendliness, performance issues, and memory efficiency.

However, CARTA supports HDF5 file format, it is very user-friendly, has GPU accelerated rendering, and good memory efficiency. The server-client approach also seems to solve performance issues. However, CARTA does not support 3D visualization.

When developing a modern 3D visualization tool, developers should take similar approaches CARTA developers did. Having CARTA's advanced features is a must in the modern day.

7 CONCLUSION

In this paper different astronomical data file formats, different types of volume rendering, and 3D visualization tools are reviewed. Issues of current 3D visualization tools have been reviewed and solution approaches were provided. Many existing visualization tools have interesting features and techniques that could bring insight. However, a new good modern 3D visualization tool is required.

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