Exploring Large Data over Wide Area Networks

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ABSTRACT

Simulations running on the top supercomputers are routinely producing multi-terabyte data sets. Enabling scientists, at their home institutions, to analyze, visualize and interact with these data sets as they are produced is imperative to the scientific discovery process. We report on interactive visualizations of large simulations performed on Kraken at the National Institute for Computational Sciences using the parallel cosmology code Enzo, with grid sizes ranging from 1024^3 to 6400^3. In addition to the asynchronous rendering of over 570 timesteps of a 4096^3 simulation (150 TB in total), we developed the ability to stream the rendering result to multi-panel display walls, with full interactive control of the renderer(s).

Index Terms: I.3.2 [Computing Methodologies]: Computer Graphics—Graphics Systems: Distributed/network graphics; J.2 [Computer Applications]: Physical Sciences and Engineering—Physics; I.3.1 [Computer Methodologies]: Computer Graphics—Hardware Architecture: Parallel Processing; I.3.8 [Computer Applications]: Computer Graphics—Applications

1 FRAMEWORK

Enzo [2] is a parallel code for hydrodynamic simulations of astrophysics, and it is one of a few applications that consistently utilizes the largest supercomputers. Enzo's effectiveness at scaling to larger and larger simulations presents challenges at all stages of the analysis and visualization process; from simple data storage, to interpretation of the simulation results. As the raw datasets have grown in size from gigabytes to terabytes, and now to over a hundred terabytes, much of the data goes unexamined. Researchers are forced to ask very specific questions of the data, and opportunities for discovery through exploration are being lost. As we move toward exascale, facilitating such explorations is of paramount importance.

To enable the Enzo scientists to interactively explore their multi-terabyte simulation datasets, we have developed a flexible framework that couples our hybrid-parallel volume renderer, vl3, running on Eureka at Argonne National Laboratory, to parallel display software running on a tiled display wall at the San Diego Supercomputer Center, over dedicated high bandwidth dynamic virtual local area networks, using an AJAX-based Web client for control of the vl3 processes, (see Figure 1).

vl3 is a modular-design parallel volume rendering system, enabling various components to be easily swapped out and extended. It uses a ray casting method to implement direct volume rendering using OpenGL and the OpenGL Shading Language (GLSL). GLSL allows the system to run code on GPU hardware, if available, or in software using the Mesa 3D library. Parallelization is facilitated by using domain decomposition to subdivide the data across processes. The result of rendering the sub-volumes of the data in separate processes is many 2D images that need to be composited together. Several different compositing algorithms have been implemented in vl3, including binary swap, direct send, and parallel direct send. This compositing can be done on either the GPU or the CPU.

There are several possible end points for the final volume rendered images. They can be sent to a local display device, written to disk, or they can be streamed out over the network. When streamed, the rendered and composited image is divided up into rectangular pieces, which are sent as separate streams to the tiled display cluster. The picture is divided up because the display responsibilities in a cluster-based tiled display are divided between the computers in the cluster. We use the Celeritas library to facilitate high-throughput streaming of the raw pixel data over TCP. In order to manipulate the Enzo vl3 volume rendering, its controls are exposed through a control channel made available via web browser. This control is connectionless and has the advantages of being cross-platform and not requiring a client installation. The display responsibilities in a cluster-based tiled display are divided up among the computers in the cluster. Each computer is responsible for the pixels in a subsection of the tiled display. We have created flTile, a tiled display application that handles which machines show which parts of an image or movie so that they look correct on the full display. In addition to rendering, the application synchronizes state between machines to handle changes such as moving or adding images or changing movie frames. It uses simple OpenGL for rendering and MPI to handle the synchronization between machines. The source of the images to be displayed by flTile can come either from disk, as in the case of pre-rendered images or movies, or it can come in the form of encoded streams received over the network, such as those produced by vl3.

The utility of our end-to-end framework was showcased in several demonstrations. For the SC10 conference in November of 2010 OSCARS [1] was used for dynamically provisioning guaranteed bandwidth over secure circuits, both within ESnet, and between ESnet and other networks. The primary data set used in this demonstration came from a simulation that uses a flux-limited diffusion solver to explore the radiation hydrodynamics (rad-hydro) [3] of early galaxies, in particular, the ionizing radiation created by Population III stars. The simulation volume is 11.2 comoving megaparsecs, and has a uniform grid of 1024^3 cells, with over 1 billion dark matter and star particles, the largest calculation of this type known to date. The data set contained 13 variables from the simulation, 238GB for a single time step. Loading a single variable from the multi-variable 1024^3 data set requires substantially less memory than the 4096^3 data set used for our SC09 demonstration, and thus could be run on few nodes of Eureka. This enabled us to run multiple instances of the vl3 end-to-end framework using different variables from the same simulation and display all of them on the tiled display on the SC10 exhibit floor simultaneously for interactive exploration and comparison.

This demonstration provided the first opportunity for the researchers to visually explore the data from this simulation. The multi-variate rendering is particularly useful, because it shows both the baryonic matter ("normal") and dark matter, and the pressure and temperature variables are properties of only the baryonic mat-

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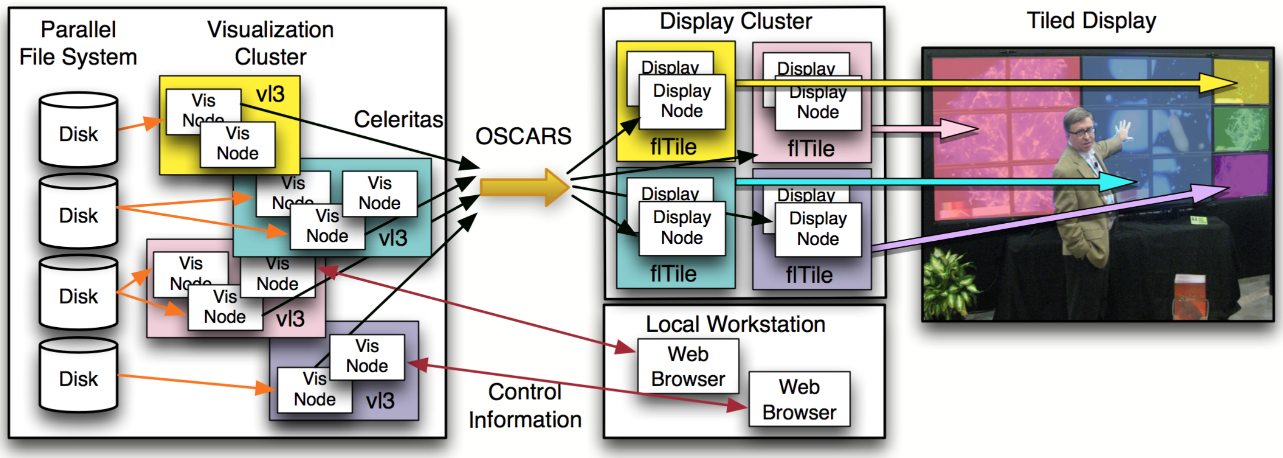

Figure 1: Architecture of end-to-end framework for interactive remote data exploration.

ter. Visible in the baryonic matter density are "bubbles", or shells, created by the radiation feedback from young stars. Seeing the bubbles from feedback provides confirmation of the physics model implemented. Features such as these are difficult to identify algorithmically, but easily found when viewing the volume rendering, (see Figure 2).

2 Discussion

While the Enzo astrophysics simulations have been the primary application driver for the end-to-end framework, vl3 has been used to visualize data from many different scientific domains, including life sciences, geosciences, and materials science. Its plug-in architecture also enables additional data readers to be easily added. This functionality was used to read the Enzo HDF5 data sets. This project had the specific goal of utilizing large format, high resolution tiled displays to enable users with such resources to leverage them effectively. In addition, users without access to such resources can make use of a stand-alone, Python-based client to remotely explore their data from their desktop or laptop. While what we have described is focused on a somewhat specific type of visualization (i.e., volume rendering), we have made significant progress in providing scientists direct access to their data. Beyond the occasional high profile demonstration, the Enzo researchers at SDSC can now utilize this framework to perform real data exploration.

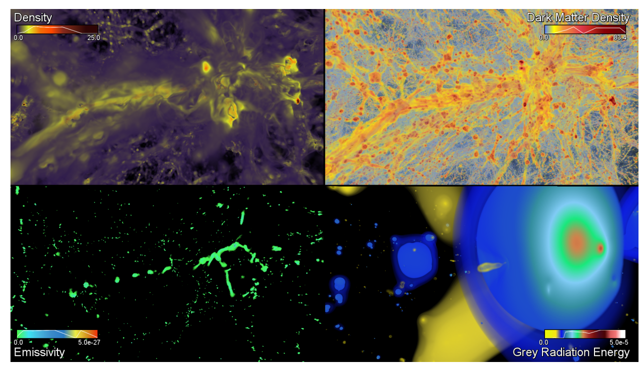

Figure 2: This figure shows a close-up of (*clockwise from top left*) the gas density, dark matter density, radiation energy and emissivity from a 1024^3 simulation of cosmological radiation hydrodynamics. The rendering of the gas density clearly shows features difficult to find algorithmically.

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References

[1] C. Guok, D. Robertson, M. Thompson, J. Lee, B. Tierney, and W. Johnston. Intra and interdomain circuit provisioning using the oscars reservation system. In *Broadband Communications, Networks and Systems, 2006. BROADNETS 2006. 3rd International Conference on*, pages 1 –8, oct. 2006.

[2] M. L. Norman, G. L. Bryan, R. Harkness, J. Bordner, D. Reynolds, B. O'Shea, and R. Wagner. Simulating Cosmological Evolution with Enzo. *ArXiv e-prints*, May 2007.

[3] D. R. Reynolds, J. C. Hayes, P. Paschos, and M. L. Norman. Self-consistent solution of cosmological radiation-hydrodynamics and chemical ionization. *Journal of Computational Physics*, 228:6833–6854, Oct. 2009.