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INTERACTIVE VISUALIZATION OF LARGE-SCALE TIME-VARYING VOLUME DATA OVER NETWORKED COMPUTERS

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Abstract: Visualizing a time-varying multi-dimensional volume data is a computationally intensive process and it requires a large storage space. Parallel processing offers the potential for achieving the visualization in a reasonable time. This paper discusses how an appropriate parallel visualization approach for large-scale time-varying volume data sets over networked computers can improve overall system performance. Hence, parallel splatting is implemented for interactive volume rendering on the system. The targeted application is the Mandelbrot set in the quaternion using a large 4D unstructured mesh consisting of one hundred millions cells. Therefore, we are able to produce a large-scale experimental 4D data set as time-varying volume data. Progressive refinement offers the possibility of interactive visualization for large scale time-varying volume data streams. Our system is also quite effective in producing fly-through visualization of the volume data at high resolution in an acceptable time.

Keywords: volume rendering; splatting; time-varying volume data; scientific visualization; parallel volume visualization.

1. Introduction

Time-varying volume data set, which may be obtained from numerical simulations, physical phenomena or sensing instruments, allows scientists to understand the detailed *dynamics* of the phenomenon under study. Thus, volume visualization enables the viewer to extract meaningful and intuitive information from these four-dimensional time-varying volume data sets. Simulation of physical phenomena with very high temporal and spatial resolutions demands very high amount of computation power. A complete run of a time-varying simulation may also generate output consisting of hundreds of gigabytes or terabytes of data. Then, high performance parallel computing systems provide potential to such computational requirement. The ability to visualize these data sets interactively provides a powerful tool to scientists and engineers to examine a complex four dimensional time-varying volumes from a variety of orientations and to investigate its structure and complexity [1, 2, 7, 8].

The computational effort required to render a single image of a complex time-varying volume data set on a conventional machine is significant and may take many minutes, even hours. Parallel processing offers the potential of reducing this rendering time significantly. In this paper, scalable parallel visualization techniques are presented for rendering of large-scale time-varying volume data sets. The remainder of this paper is organized as follows. The related work of volume rendering and time-varying data visualization are briefly discussed in Section 2 and Section 3, respectively. The overview and details of parallel visualization schemes for time-varying volume data rendering are presented in Section 4. Results and conclusion are given in Section 5.

2. Volume visualization

Several techniques have been developed for volume visualization in the past studies. Most known of these techniques are splatting and ray casting. In this application, splatting is employed for volume visualization of each frame of time-varying volume data. Splatting has been described as assuming the volume data to be a stack of snowballs and the image plane to be a brick wall. The splatting process throws each snowball, one by one at the wall. As each snowball hits the wall it makes a noise that sounds like "splat" and spreads its contribution across the wall with each subsequent splat obscuring earlier ones. This method determines each sample's footprint on the image plane by accumulating the effect of each footprint. An image-space based footprint table for each volume sample is evaluated to spread the energy of each input sample onto the image plane during the reconstruction process.

3. Time-varying volume data visualization

A typical time-varying data set from a simulation can contain hundreds to thousands of time steps and each time step may have more than millions of voxels and gigabytes to terabytes of storage space to store a single data set. A time-varying volume data set can be most efficiently visualized while the data set is being generated. Then, the viewer receives immediate information about the data set under examination and the visualization results can be stored rather than the large volume data set. In the literature, many techniques have been developed to visualize time-varying volume data. These techniques allow users to explore the complex data from view points by generating the set of images. In the last few decades, a number of time-varying volume visualization algorithms have been developed to enable high interactivity and improve data understanding of the volumes. Splatting technique is employed to exploit the data coherency between consecutive time steps and it reduces rendering time and storage capacity required. Effective time-space partitioning with compressing techniques is used to exploit the temporal and spatial coherence in the time-varying volume data sets.

4. Parallel time-varying data visualization

In the application, parallel time-varying volume data visualization is performed in three-steps; distribution of 4D data by dividing it into sub-volumes, rendering of the sub-volumes and composting the partial images according to a view angle. A time-varying volume data is a temporally and spatially defined object. Therefore, three possible approaches may be defined for parallel time-varying volume visualization. The first approach, inter-volume parallelism, exploits the temporal coherence for the maximum speed-up so that each processing element on the parallel system renders one volume frame of the sequential volume frames of the time-varying data. The second approach, intra-volume parallelism, may benefit from the spatial coherence for minimum inter-frame delay. In this approach, all processing elements of the parallel system cooperate to render each individual volume frame of the data. The third approach, a hybrid approach, combines intra-volume and inter-volume parallelism to benefit from both approaches. This hybrid approach utilizes the temporal and spatial parallelisms for efficient and time critical volume visualization [3, 4, 5, 6, 9, 10].

4.1 Task Management

Three task management schemas are used to allocate task to processing elements. The first schema is the balanced data driven model. This static approach allocates all tasks to specific processing elements prior to computation proceeding. The second schema, the demand driven model, allocates tasks to specific processing elements on demand when it has completed a task. This approach is also known as dynamic task allocation model and tasks are allocated to the processing elements on demand. The third schema, the preferred bias task management method, is a way of allocating tasks to processing elements which combine the simplicity of a balanced data driven model with the flexibility of the demand driven approach [3, 4, 5].

4.2 Multi-threading

If an application process is not supplied with requested task or data item for certain period of time, the process will result in idle time unless the processing element can be kept busy doing some other useful computation. One solution is to have more than one concurrent computational process at each processing element. Each of these application processes is known as a separate thread of computation. Now, although one thread may be suspended awaiting a task or remote data item, the other threads may still be able to continue. If there are sufficient threads, then the processing element should always be performing useful computations. A simple illustration of the proposed parallel processing model with multi threading is given in Figure 1. Here, several threads are created on each processing element and each thread works on different volume along the sequential volume frames, where T stands for Thread.

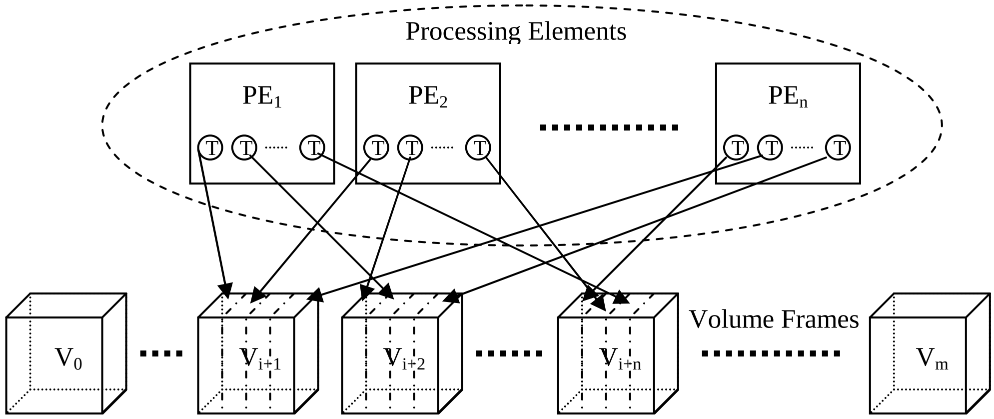

Figure 1. Parallel computing model for time-varying volume data visualization

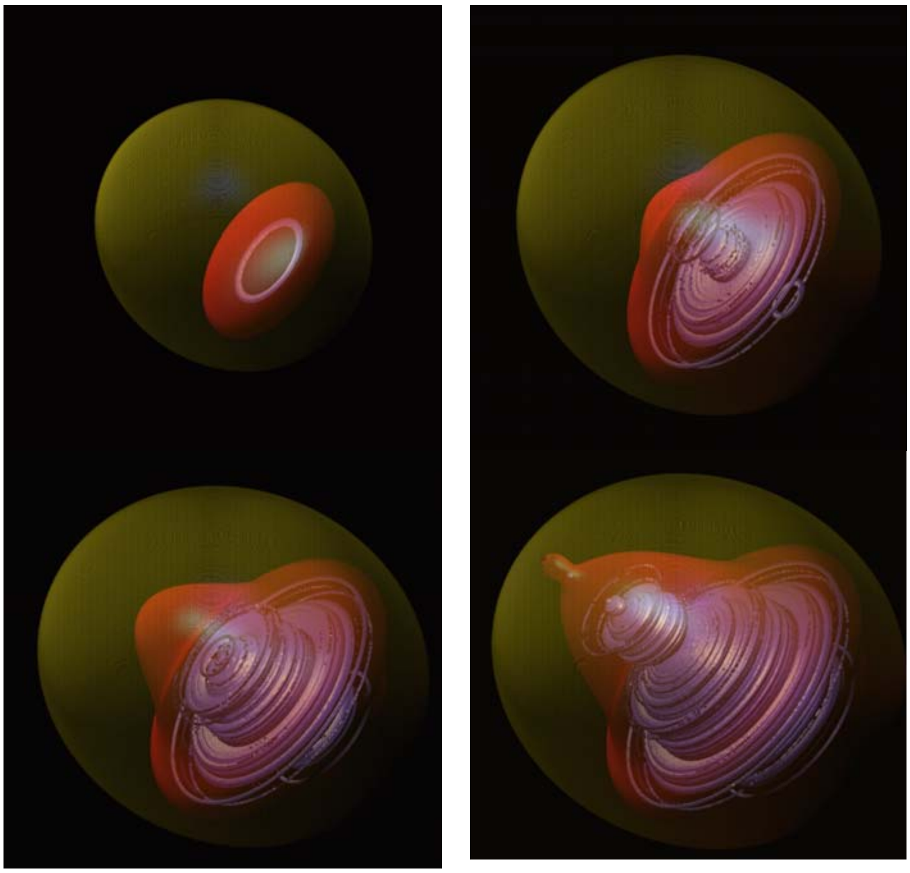

Figure 2. Several images of whole Mandelbrot set as the time-varying data set.

5. Results and Conclusion

Parallel processing offers the potential for achieving time-varying volume visualization in reasonable time. Higher performance networked PCs may be utilized for the visualization of time-varying volume data sets. Figure 2 display several images and sub-spaces of the data sets at some particular time steps. Progressive refinement offers the user a coarse approximation of the image from currently selected view points as initial image of the time varying volume data [5, 8, 9]. In this application, a rough approximation image for a time step is generated under 1 sec of time period. Figure 3 (a) and Figure 3 (b) show speed-ups of static and dynamic task management models with multiple threads, respectively. On 16 processors two threads and dynamic task management give a speed-up of 13.54, which is better compared to 12.51 using only a single thread. The overhead resulting from having many threads at each processing element are such that the system performance may be degraded as the number of threads grows beyond an optimum number. Thus, the system with four threads gives a speed-up of 12.95.

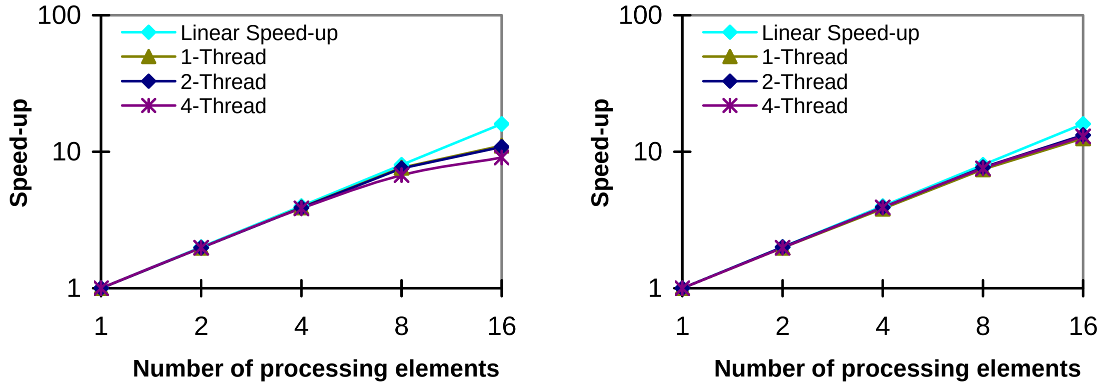

Figure 3. Performances of (a) static and (b) dynamic task managements with multi-threading

Visualization of time-varying volume data sets poses a different problem than rendering a single-volume data set and the demand for high-resolution visualization also increases as scientific data resolution continues to increase. Visualization approaches of parallel volume with multi-threading on networked computers overlaps the communication and computation but communication delay and overhead increase when rendering rates increase. Hence, more sophisticated task and data management techniques can be incorporated into the parallel visualization, and this would improve the overall system performance.

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