Chapter V
Cluster-Based Multi-Dimensional Visualization: Harnessing Computational Resources for Real-Time Visualization

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ABSTRACT

There is a growing need for high-frame-rate low-latency visualization solutions as medical practice moves toward interventional procedures. We present a cost-effective visualization system well suited for off-line visualization and interventional procedures. Users can view large time-resolved multi-dimensional datasets in real time with GPU cluster visualization. In addition, computational pre-processing can be hidden by rendering across distributed graphics cards, leading to improved frame-rates over a single graphics card solution. Finally, rendering on graphics cards offloads CPU cycles for generating the next time frame in the visualization. We have developed a network arbitration protocol for GPU cluster visualization called "token scheduling." Our protocol reduces communication latency, which in turn lowers visualization latency and improves system stability and scalability. In addition, we evaluate GPU cluster behavior and performance through a timing analysis. This analysis leads to a better understanding of cluster size needed to achieve the desired frame rate of a given problem.

INTRODUCTION

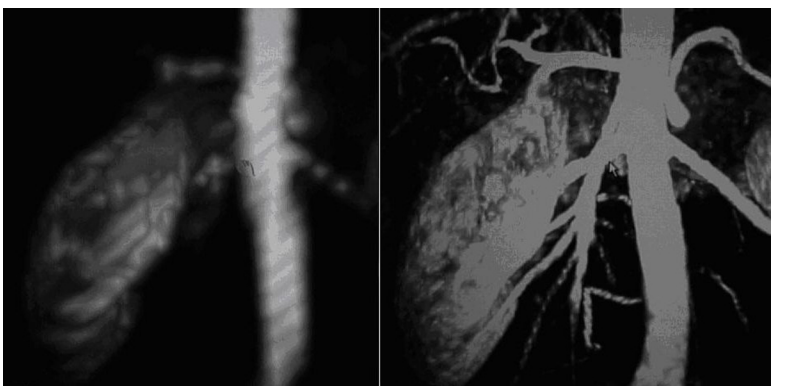
In the current medical clinical imaging paradigm, referring physicians usually order a diagnostic procedure to answer a clinical question. Technologists perform a set of prescribed scans that are specified and designed in advance to answer the specific question. Images are reconstructed and stored before being reviewed later by a radiologist at a Picture Archiving and Communication System (PACS). A PACS can post-process images from many modalities and enhance images when viewing off-line. Although these off-line still images are successfully used to diagnose many ailments, there is a growing need to interactively render multiple dimension image volumes, often containing time-varying information. These capabilities are necessary as imaging expands beyond anatomical diagnostic imaging to address functional clinical questions and interventional procedures, where processing must be performed in real time.

In addition to interventional procedures, interactive visualization of high-resolution images can convey additional information through motion. High resolution and motion are a large part of human perception and can naturally enhance insight provided by visualization; enabling the user to observe behavior not easily seen in still images. For example, viewing 3D medical images in real time can enable or enhance many interventional medical procedures. In contrast-enhanced MR angiography of the chest and abdomen, real-time imaging enables technologist to coach the patient to initiate a breath-hold as intravenous contrast arrives in the chest. Later, interactive visualization of the flow patterns in the MR exam can inform the radiologist about complex pathology such as dissections and abnormal vascular networks.

Currently, only top medical centers have access to real-time visualization of 3D medical image volumes. Very little interventional MRI is being performed outside research centers for several reasons, with visualization being one of the chief reasons. The remaining facilities view low-resolution time-resolved visualization (Figure 1) on PACS systems off-line, often with poorly responsive interaction when the number of dimensions of data grows. If the tools are not responsive or are not easy to use, the radiologists will not utilize them. Thus, new visualization solutions are needed to help overcome these problems.

One such visualization solution, called graphics processing unit (GPU) Cluster Multi-dimen-

Figure 1. Current clinical solutions have reduced resolution and cinematic rate (right), the full resolution image as seen on a PACS system (left)



When playing back time-resolved image volumes on a commercial PACS system, resolution is reduced. Cines using images similar to the left image can deliver a vague indication of contrast flow in the body, but lacks detail for precise control in an interventional system.