Low Latency Interventional MRI Visualization using a GPU Cluster

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Introduction: Fast, responsive, MRI systems may allow interventionalists to visualize flow patterns in vascular networks during intra-arterial contrast administration. We previously have described a system to interactively target and render large time-resolved sets of 3D image volumes using a GPU cluster [1][2]. Modern graphics cards (GPUs) are well-suited to interactive visualization of 3D MR data. With hardware support for geometry transforms, texture mapping, MIPS, and other pixel blending modes, well-developed volume rendering techniques can allow for interactive manipulation of large volumes. We have made significant developments to increase frame-rate, versatility, robustness, and dynamic range while reducing latency.

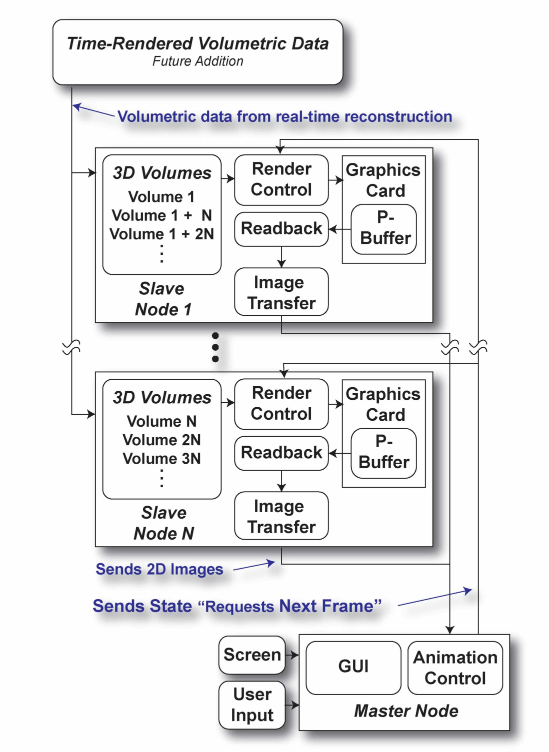

Figure 1: GPU Visualization Cluster Block Diagram. This Visualization platform has been developed to render volumetric MRI images, immediately following real-time reconstruction. The slave's CPUs are free for image reconstruction [3], as rendering is performed on the graphics cards.

Methods: A GPU Cluster Visualization system is implemented on a rack-mounted U1 server cluster with commodity graphics cards, Cg, OpenGL, sockets, Qt, and token-scheduling (Fig. 1). Distributed graphics cards managed by Token Scheduling are used to lower latency (Fig. 2) and offload CPU and network resources, necessary for real-time image reconstruction. Token Scheduling and sockets makes communication much more robust than our previous implementation with cumbersome NFS locked files. The number of time-frames that can be processed is increased by processing several frames per node. New techniques allow 16-bit depth, which provides increased dynamic range over our previously available 8-bit depth. We have made the system publicly available.

Results and Discussion: The system can generate targeted MIP images of 20 time-resolved 256^3 image volumes at a frame-rate of 14 fps when rendering thick MIP images covering the entire slab thickness. Speed is increased using hardware supported 3D textures, which also reduce artifacts (Fig. 3). The system latency to interventionalist changes in slab thickness, orientation, window/leveling and viewing angle of targeted MIPs is only 70 ms, adequate for interactive manipulation by untrained users[2]. The natural compression of data from 2D rendering of 3D volumes is also exploited to reduce system latency by lowering transmission times.

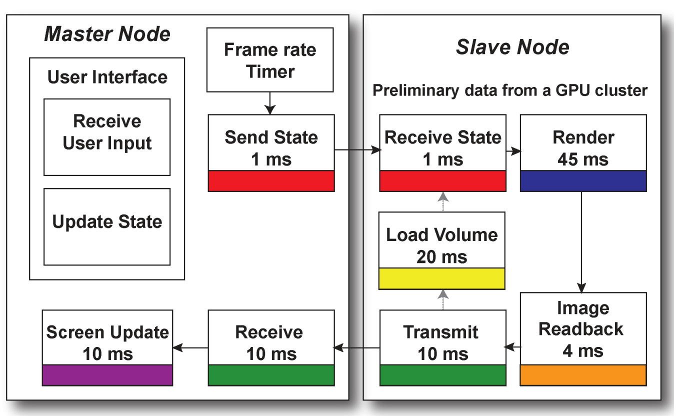

Figure 2: GPU Cluster Timing Diagram. Latency, critical in real-time interventional systems for providing fast feedback to the Interventionalist, is only 70 ms when rendering time-resolved 256X256X256 volumetric datasets.

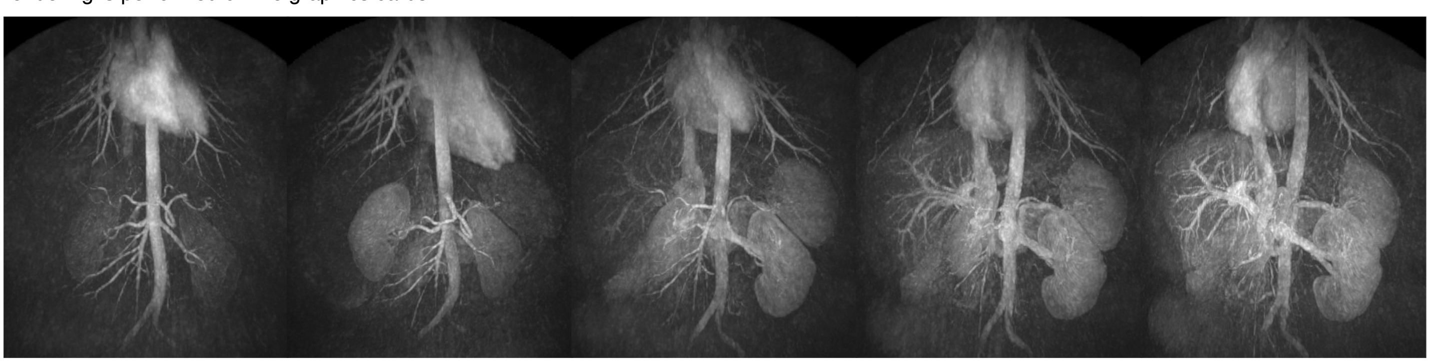

Figure 3: MIP from Oblique Angles. Commodity graphics cards generated time-series of MIPs of CE-MRA exam at varying viewing angles. GPU Cluster Visualization uses 16-bit 3D textures to reduce MIP artifacts at oblique angles.

Conclusion: A visualization system capable of fast, responsive rendering of 4D data, suitable for interventional viewing of flow patterns in 3D vascular networks, has been developed. Use of GPU cards free CPU resources for reconstruction or other types of processing.

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[2] M.J. Redmond et al. (2004). Proceedings of the SPIE medical imaging: Visualization, image-guided procedures, and display, vol. 5367, pp. 28-38.
[3] J. Liu et al. (2006), IEEE Transactions on Medical Imaging, vol. 25, no. 2, 148-157.