3D High Resolution l1-SPIRiT Reconstruction on Gadgetron based Cloud

Hui Xue[1], Peter Kellman[1], Souheil Inati[2], Thomas Sorensen[3], and Michael Schacht Hansen[1]

[1]*Magnetic Resonance Technology Program, National Heart, Lung and Blood Institute, National Institutes of Health, Bethesda, Maryland, United States,* [2]*National Mental Health Institute, National Institutes of Health, Bethesda, Maryland, United States,* [3]*Department of Computer Science, Department of Clinical Medicine, Aarhus University, Aarhus, Denmark*

Introduction Non-linear and iterative reconstruction algorithms have been the subject of intense study in the MR imaging community. Very promising algorithms have been published in the literature, including image domain compressive sensing [1] and *k*-space SPIRiT and its regularized versions [2]. Given the lengthy acquisition time of high resolution 3D MRI imaging, it is of great interest to apply non-linear reconstruction to shorten the imaging. The robustness against subject movement or uncooperative pediatric patients can be improved. However, the clinical usage of these techniques is often prohibited by the high demand for computational power and very long reconstruction time. To achieve practical reconstruction times for clinical usage of non-linear reconstruction, we have extended the previously published Gadgetron framework [3] to support the distributed computing across multiple computers. This extension is named "Gadgetron Plus" or "GT-Plus". A cloud version of 3D l1-SPIRiT reconstruction was implemented on the GT-Plus cloud framework and applied to high-resolution 3D neuroimaging. With the use of the computational power of the cloud, we demonstrate that a 3mins reconstruction can be achieved for $1mm^3$ isotropic neuro scans using l1-SPIRiT. Compared to the linear reconstruction, the image quality was significantly improved.

Architecture and Implementation At least one Gadgetron process was started at every node. The inter-node communication was managed by a software module `GadgetCloudController` using TCP/IP sockets. A gateway node was connected to the scanner and received readout data. It then sent buffered data package to computing nodes for processing. Every computing node was responsible for processing the received job via its processing chain and forwarded results back to the gateway. With all expected results received on the gateway, images were sent back to the scanner.

Cloud version of 3D L1SPIRiT The gateway node was configured to receive the readouts for a 3D acquisition and perform *k*-space convolution kernel estimation. It then split the large 3D reconstruction problem by performing the 1D inverse FFT transform along the readout direction. Thus, the reconstruction was decoupled along the readout direction. Every chunk of data along the readout direction was sent to one computing node. The L1SPIRiT algorithm was running on every node. The redundant Harr wavelet transform was used in the regularization term.

Deployment on cloud systems Two cloud setups were tested. ***Amazon EC2 based cloud*** 19 nodes were launched on the Amazon Elastic Compute Cloud (Amazon EC2). All nodes had two eight-core Intel Xeon E5-2670 2.60GHz processers, running Ubuntu Server 13.10. The gateway node had 240GB RAM and others had 60GB. ***NIH Biowulf cluster*** 23 nodes were requested from the Biowulf cloud (http://biowulf.nih.gov) which is a linux based parallel computing system (Red Hat Server 5.10) and built at National Institutes of Health, USA. The gateway node had 16 CPU cores (two eight-core Intel Xeon E5-2670 2.60GHz processers) and 256GB RAM. All other nodes had two six-core Intel Xeon X5660 2.80GHz processers and 24GB RAM. For both cloud setups, "online" reconstruction was achieved. That is, the acquired readout data was sent to cloud while the scan was proceeding. The reconstructed images were directly sent back to the scanner and stored in the clinical PACS.

In-vivo test Cloud based reconstruction was performed for high resolution neuro acquisition. A healthy volunteer was scanned on a 3.0T clinical MRI system (MAGNETOM Skyra, Siemens, 20-channel head coil). Acquisition parameters were: GRE readout, TR = 7.0/TE = 3.07ms, acquired matrix size 256×256×192, flip angle 20°, $1mm^3$ isotropic spatial resolution, bandwidth 120 Hz/pixel, two dimension acceleration R=3×2 and 3×3 with a 32×32 fully sampled k-space center. The total acquisition time was 65s and 46s for two acceleration levels.

Results Figure 1 shows the reconstruction results generated on the GT-Plus based cloud for R=3×2. Figure 2 is for R=3×3. Both cases indicate non-linear reconstruction noticeably improved image quality, compared to the linear GRAPPA reconstruction. The reconstruction time (defined as the computing time to perform the reconstruction algorithms) was 171s for R=3×2 and 170s for R=3×3 on the described Amazon EC2 cloud. On the Biowulf system, the reconstruction time was 239s and 242s. If only a single node was used, much longer reconstruction time was experienced: for R=3×2 and 3×3, the Amazon EC2 cloud recorded 1002s and 1022s and for the Biowulf system, computation took 1279s and 1338s respectively.

Conclusions The GT-Plus extension for Gadgetron framework was developed to support distributed computing across multiple nodes. The 3D l1-SPIRiT algorithm was implemented on the Gadgetron based cloud, giving significantly reduced reconstruction time for high resolution neuro scans. This speedup can enable the clinical usage of advanced non-linear reconstruction algorithms on 3D MR applications.

References [1] Lustig M, et al., MRM 58:1182-1195 [2] Lustig M, et al., MRM 64:457-471 [3] Hansen MS, et al., MRM 69:1768-1776 (2013)

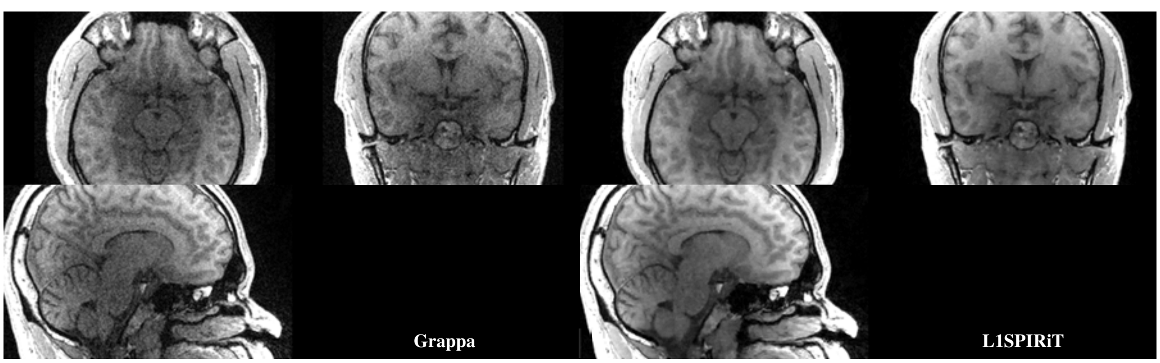

Figure 1. Reconstruction results of 3D neuro scan on the GT-Plus cloud for two dimensional acceleration R=3×2. Compared to the Grappa linear reconstruction on the left, non-linear reconstruction on the right gives noticeable improvement in signal to noise. For this $1mm^3$ protocol, the cloud version of non-linear reconstruction was completed within 3mins after the end of data acquisition, while on a single-node reconstruction took >15mins. This reduction of computing time could be crucial for clinical usage of advanced image reconstruction techniques.

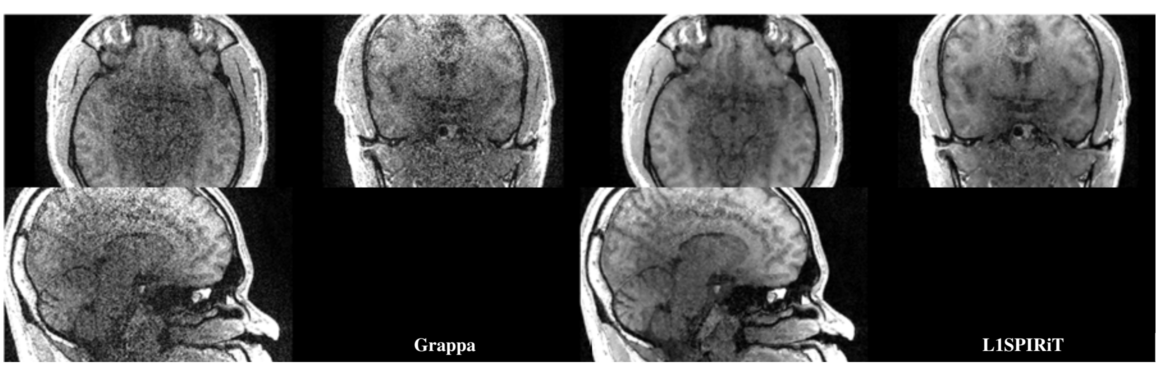

Figure 2. Reconstruction results of 3D neuro scan on the GT-Plus cloud for two dimensional acceleration R=3×3. Compared to the Grappa linear reconstruction shown on the left and results shown in Figure 1, the improvement in image quality is even more substantial for higher acceleration. Since the head coil used for this test has 20 channels, the R=3×3 acceleration severely degrades the Grappa reconstruction because of the elevated g-factor, while l1-SPIRiT reconstruction is much more robust in this case.