A Highly Customizable MRI Reconstruction and Post-Processing Platform with Integrated High-Performance Computing for Cardiac MRI: A Basic Framework Description

THE UNIVERSITY OF CHICAGO DEPARTMENT OF MEDICINE

Keigo Kawaji, Ph.D. and Amit R. Patel, MD.

Department of Medicine - Section of Cardiology, The University of Chicago, Chicago, IL.

Background

- Cardiac Magnetic Resonance Imaging (MRI) offers a wide variety of clinically important diagnostic methods that can characterize the following:
  1) Geometric parameters and detection of defects (eg. size of vessels, presence of stenosis in arteries, cardiac muscle (myocardium) tissue scarring).
  2) Functional information (eg, myocardium motion, blood flow).
  3) Tissue characteristics that may correlate to specific physiologic defects (amyloids, myocarditis, sarcoidosis).
- Dedicated processing methods currently exist for each imaging approach, and these customized methods may vary in terms of the following steps:
  i) **Data acquisition** on the MRI scanner.
  ii) **Image reconstruction** from raw MRI k-space data.
  iii) **Clinical post-processing** methods for technique-dedicated assessments.
- For each technique, an approach requires ***multiple tasks on different hardware***; but these methods may become inefficient for a clinical MRI protocol with many techniques, and also difficult for the clinician to use.
- We outline a basic framework that integrates the MRI scanner, a local workstation and high-performance computing node for efficient reconstruction and post-processing accounting for computational overheads, and describe several applications that are currently in use.

Proposed System Description

Schematic of the Proposed MRI Processing Framework

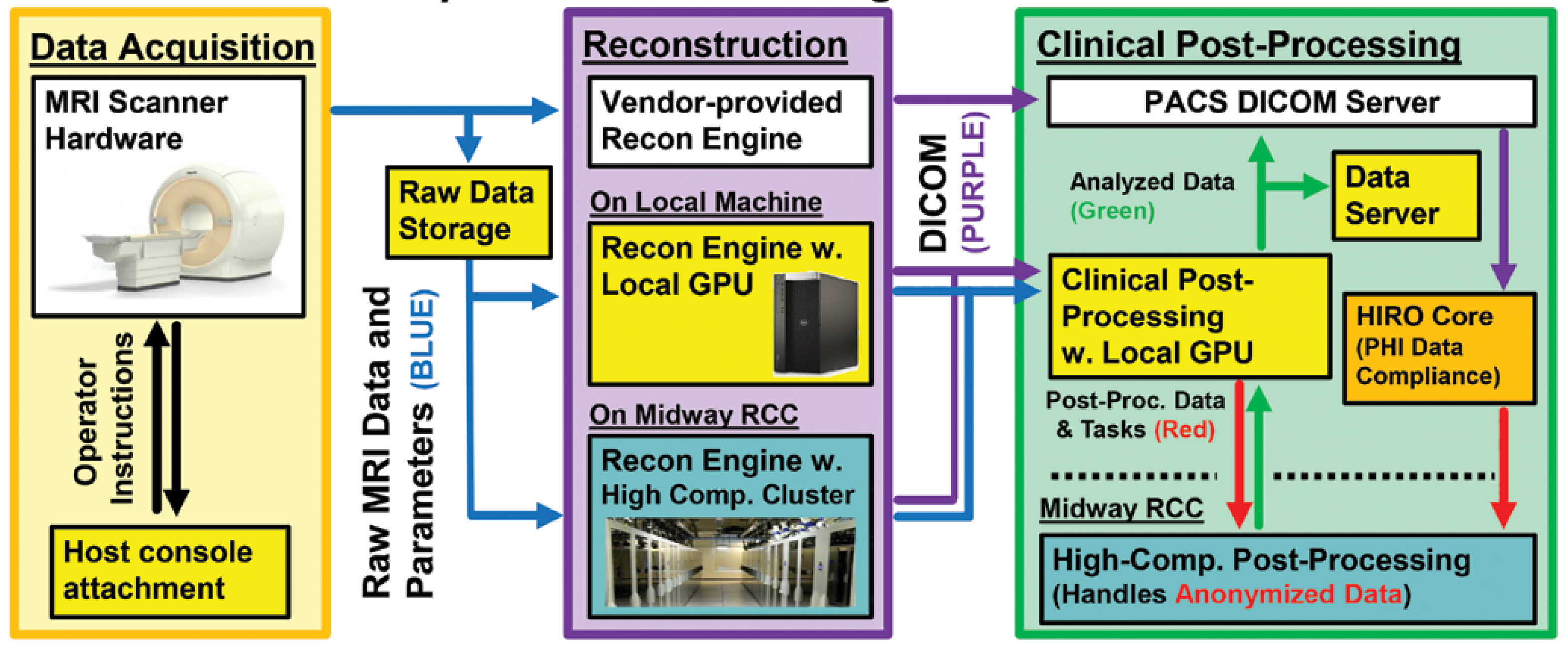

Figure 1. Schematic of the proposed framework architecture. Computationally expensive reconstruction or post-processing tasks can either run directly a local running Graphical Processing Unit (GPU) for time-critical tasks (0.1 – 60 sec processing times), or be delegated onto the high computation note (RCC) for large-volume/computationally expensive processes.

- During **Data Acquisition**, a dedicated extension (host console attachment) enables data export and handling raw MRI data in a format compatible with both vendor-provided (Philips, The Best, Netherlands) and in-house **reconstruction algorithms**.
- Reconstructions can use any of the processing (vendor/local machine/Midway RCC) and is also stored on a local network drive.
- Reconstructed images are exported as DICOM format to the hospital's PACS DICOM server, and can also be exported in any desired format to the clinical post-processing workstation with NVIDIA Quadro K4000 GPU.
- The local workstation handles assignment of both reconstruction and post-processing tasks, and communicates with the Midway RCC node to perform computationally expensive processes in parallel.

Local Workstation and Midway RCC Integration

- Data transfer protocol utilizes SAMBA to map the Midway RCC on the Windows-based Local Workstation, and are currently constrained to PHI-protected (ie. anonymized) MRI data processing.
- All tasks assigned for processing on Midway RCC are implemented as single-call MATLAB scripts (Ver. 2013b, The Mathworks Inc. Natick MA), and are called from the Local Workstation.
- This framework provides flexible and heavily customizable infrastructure for processing and analysis of acquired MRI data.

Example 1: Compressed Sensing Reconstruction for 3D High Resolution MRI Data

Background: Compressed Sensing reconstruction methods can be used to randomly undersample the raw MRI data and iteratively differentiate between noise and true signal in an iterative manner through the use of a sparsifying mathematical transform.

This approach allows MRI scans to complete within a fraction of the duration needed to collect the fully sampled data, but such approaches are computationally expensive, and is currently not available on the vendor-provided MRI processing.

Approach: An offline workflow is developed to enable the compressed sensing reconstructions in a clinically feasible amount of time using the Midway RCC.

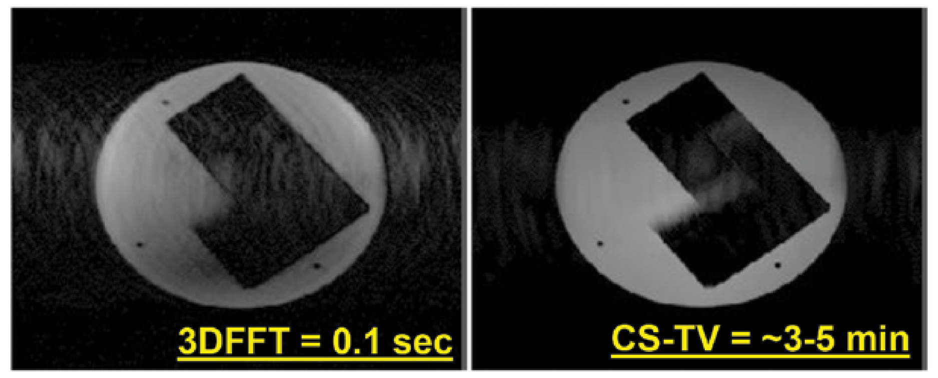

Table 1. CS-TV Tasks	Proc. Time
Data transfer to RCC	~20 sec
Load and Mount data	~20-60 sec
Run CS-TV Recon	175 sec
Save and Export	~20 sec

Figure 2. Example of two reconstructions of a phantom. a) zero-filled, and b) Compressed Sensing reconstruction using Total Variance (TV). Note the significant decrease in the incoherent artifact in the method right image. On the Midway RCC, we can perform this reconstruction in ~3-5 mins.

Example 2: Fast Assessment of Cardiac MR Images

Background: Techniques for analyzing Short-Axis Cardiac images can be beneficial for the clinical assessment of the Left Ventricle (LV).

Currently, there are numerous approaches that acquire these SA images, including Cine-CMR, Myocardial T1 mapping, and Cardiac Perfusion MRI. Each of these MRI methods require a dedicated analysis extract clinically useful parameters.

Approach: We have developed an in-house post-processing platform for versatile analysis of the acquired MRI data. This is incorporated into various parallelization schemes using both local workstation GPU and Midway RCC.

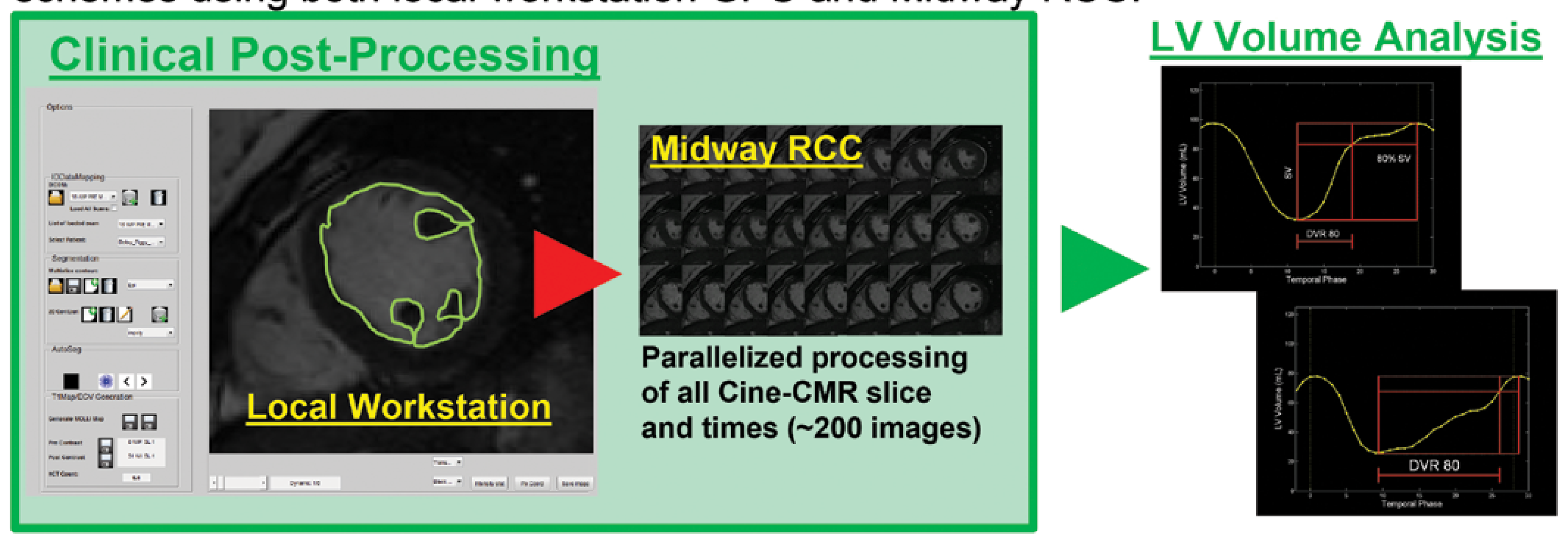

Figure 3. Representative schematic of parallelized LV endocardial border segmentation for short-axis Cine-CMR scans. This step is performed locally on the GPU hardware if it is time-critical. If the post-processing step is very large and is **non-time critical**, then it is assigned to Midway RCC for processing. This allows volumetric analysis of the LV for diastolic dysfunction.

Table 2. Time-Critical Computation Tasks	Processing Time
LV Segmentation Algorithm (160x160 pixels)	
Local Workstation CPU (MATLAB 2014a; no C/C++ w. mex)	0.4 sec / slice
Local Workstation GPU (CUDA 6.0 w. Matlab 2014a)	0.07 sec / 8 slices
T1 Map Curve Fitting	
Local Workstation CPU (MATLAB 2014a; no C/C++ w. mex)	4.8 ms / pixel
Local Workstation GPU (CUDA 6.0 w. Matlab 2014a)	81 μs / pixel

Note: GPU-MEX implementations reported here are currently tested and optimized for MATLAB 2014a on the local workstation. Migration to Midway RCC upon subsequent release in same version (R2014a) is underway.

The examples in this poster presentation represent several ongoing technology developments at the UofC's Cardiac MRI Research Group.

We thank the Research Computing Center (RCC) for providing us the necessary tools to enable many of these novel technologies.

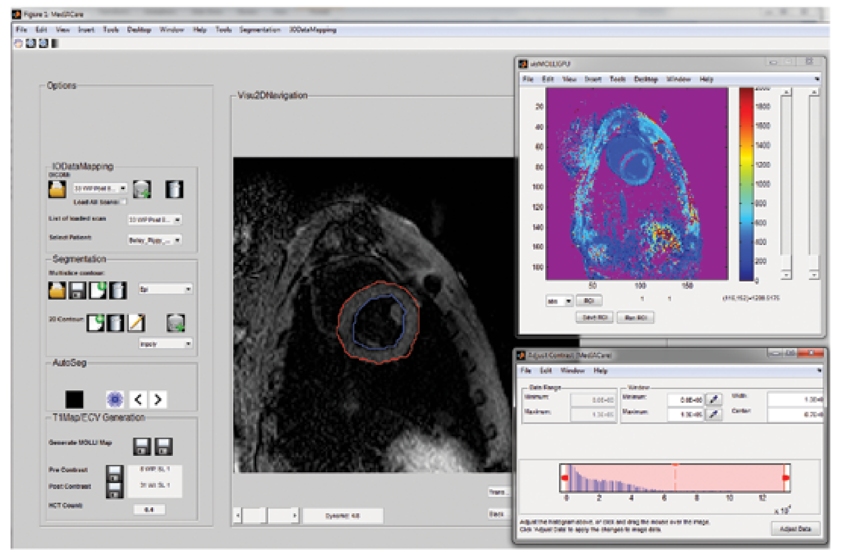

Figure 4. User-interface of the Local Workstation for analysis of various MRI data. Dedicated tools can be developed and customized as Plug-Ins.

Example here shows myocardial T1 mapping, which requires a rapid 3-point curve fitting from 8 values for each pixel, which is used clinically to characterize tissue and diagnose the amount of extracellular volume.

Example 3: Rapid Technology Development Demo: Current Work-in-Progress @ UofC Cardiac MR Research

Background: We have recently developed a highly customized MRI method to acquire coronary artery images in 4D (3D + time). We seek to develop novel technologies based on this MRI approach and extend to other CMR applications.

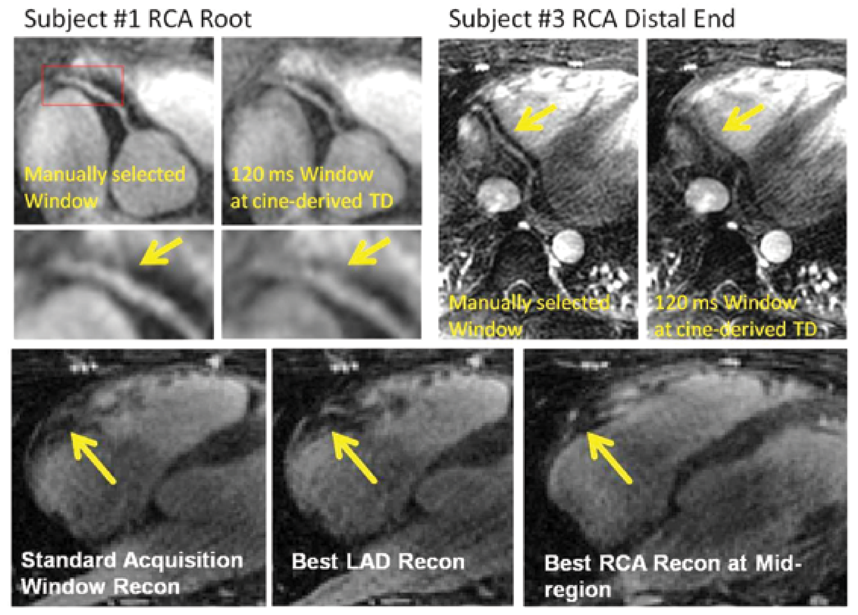

Figure 5. (Top row) Two Examples of image quality improvement achieved with the proposed method that allows interactive adjustment of the MRI temporal window for reconstruction.
(Bottom row) The mid-Right Coronary Artery region depicted from three different temporal windows. The RCA is not visualized with the temporal windows selected for both standard (left) and LAD-tailored reconstructions (middle), but is clearly visualized after a tailored window for best visualization of this region (right).
Figure from Kawaji et al. PLOS ONE 2014.

Proposed New Method: We incorporate a rapid MRI processing algorithms that was utilized in the above method. The key implementation requires an optimized implementation of gridding of radial MRI data.

- **This reconstruction is achieved rapidly within 0.4-0.6 seconds per image with GPU. Without GPU acceleration, this approach requires ~ 12 sec/image.**
- This post-processing algorithm will be integrated into the platform, and will be used to assess and analyze 3D cine-CMR acquisitions.
- Since the post-processing has already been developed, tested, and published
→ development time for this novel approach is feasible in a rapid manner.

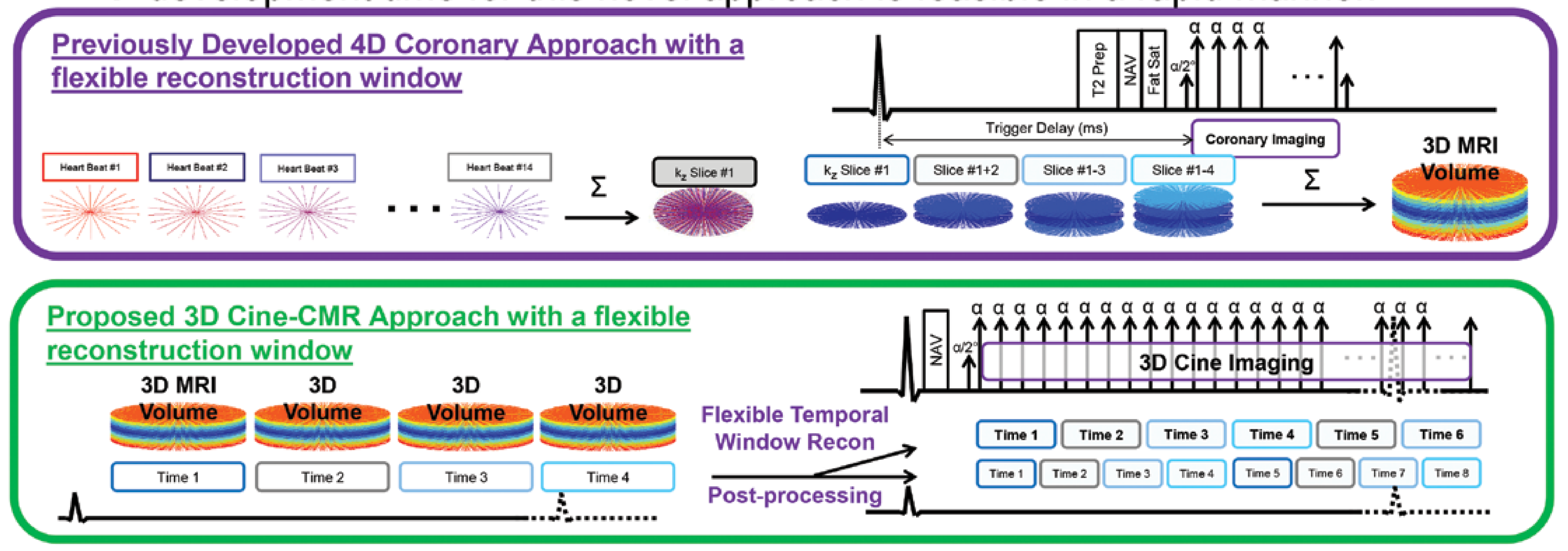

Figure 6. (Top) Schematic of the MRI data acquisition for a previously developed 4D coronary MRI with any flexible reconstruction windows. (Bottom) Extension of the same post-processing method for 3D Cine-CMR data acquisition. This can enable reconstruction of ***any flexible temporal window during post-processing from Cine-CMR images***. Previous cine methods have been acquired in *2D at a fixed temporal window, limiting both coverage and spatial resolution*.

Discussion

- We describe a general framework for MRI image reconstruction and post-processing that is integrated with clinical assessment on our local workstation.
- Access to both local GPU for time-sensitive tasks, and Midway RCC for processing of larger and computationally more expensive tasks can significantly improve throughput of MRI data post-processing at our site.
- Rapid development of customized MRI methods becomes feasible with this platform, significantly improving our research capabilities.