Medical Applications of Signal Processing Research

COORDINATED SCIENCE LABORATORY

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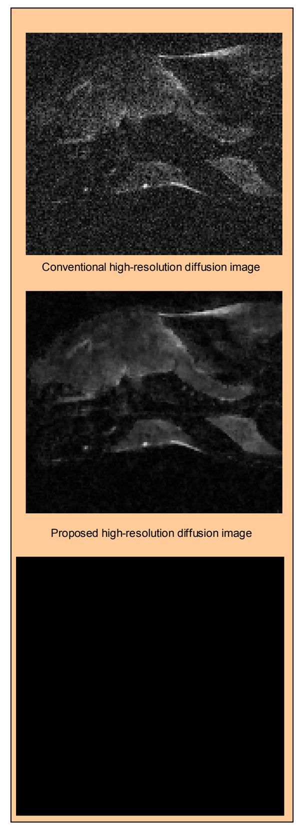
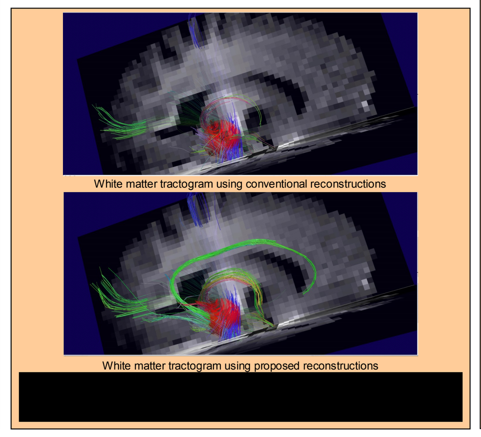
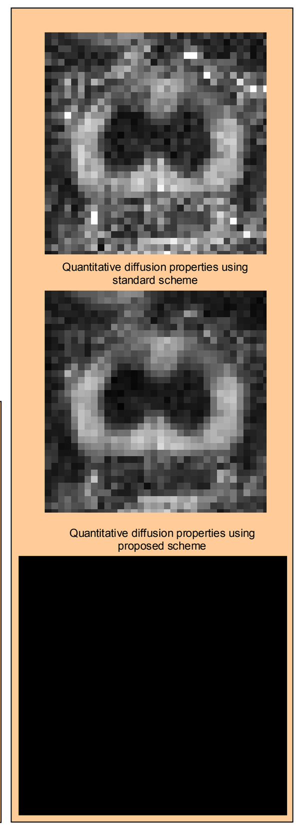
High-Resolution Diffusion MRI

Diffusion magnetic resonance imaging (MRI) reveals quantitative tissue microstructure and organization. However, the technique is limited by high-levels of noise.

Our algorithm permits higher resolution diffusion MRI by using the joint properties of diffusion images to uncover structure that was previously obscured by noise using conventional reconstruction.



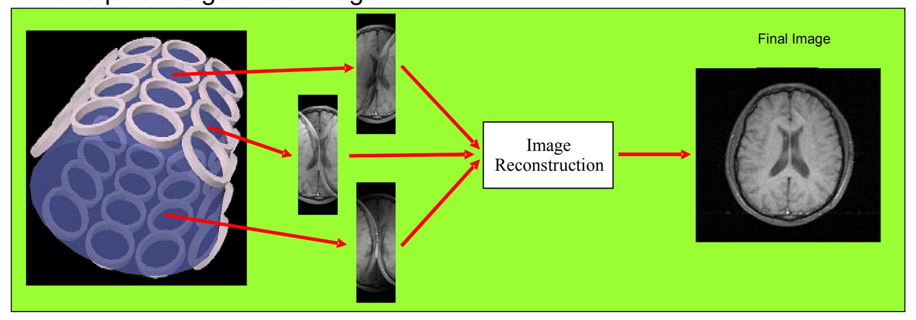




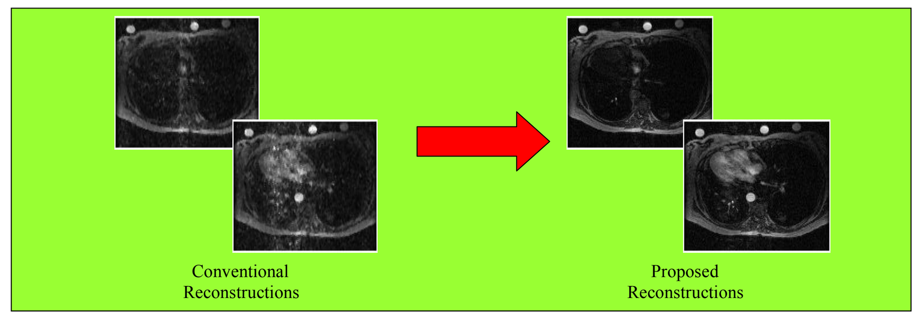
From the research group of Zhi-Pei Liang

Parallel MRI with Phased - Array Coils

Parallel MRI utilizes multiple sensors to greatly reduce the amo unt of imaging time required to generate images.



However, the speed of parallel MRI comes at the expense of incre ased noise sensitivity. We have developed techniques to stabilize parallel MRI, coming closer to achieving the theoretical limits of the technique.

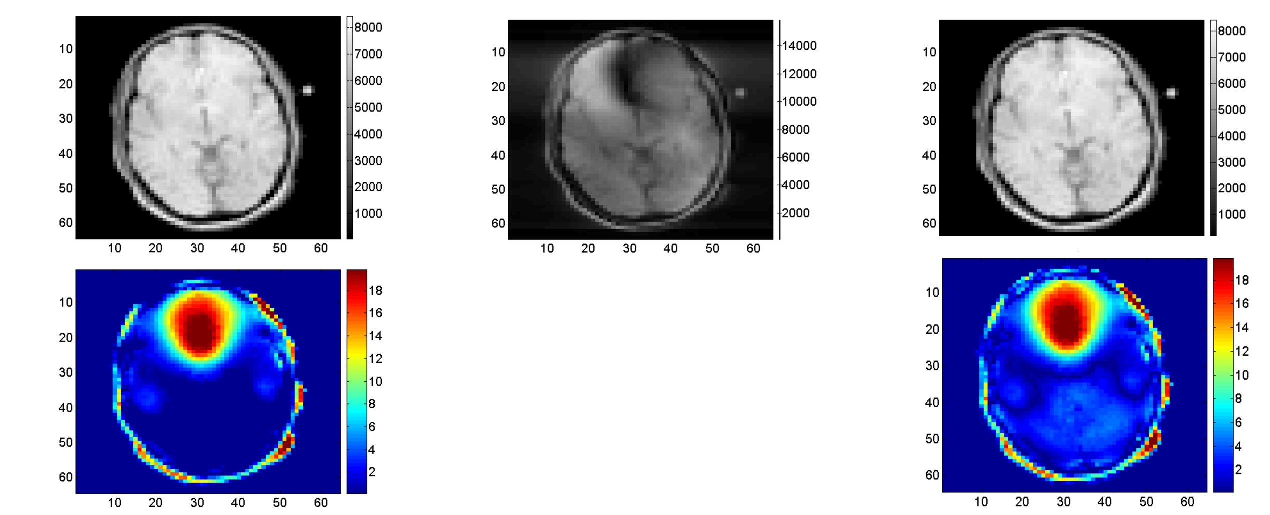


From the research group of Zhi- Pei Liang

Joint Image Reconstruction and Field Map Estimation in MRI

H.M. Nguyen, B.P. Sutton, R.L. Morrison, and M.N. Do

- Field inhomogeneity is a key factor affecting MRI image reconstruction
- We developed an efficient method to jointly recover image and field map



Dynamic Contrast-Enhanced MRI: Cardiac Imaging

What? Perform 3-D imaging on a live heart pumping a contrast agent.

Why? Detect early signs of heart transplant rejection.

Benefits: Tailor immune suppression therapy for each patient.

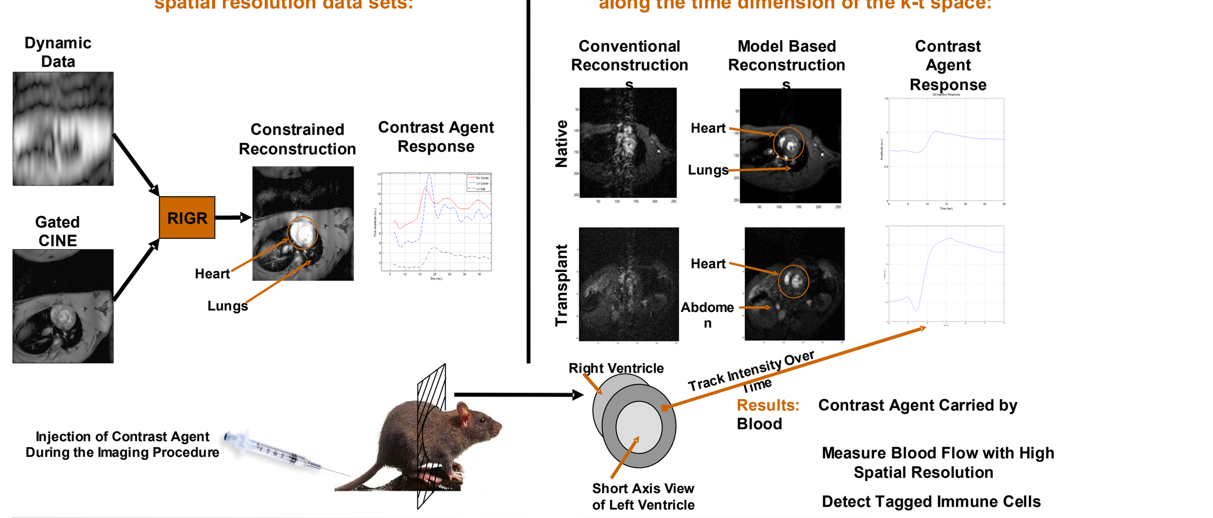
Technique can be developed into a general tool for 3-D perfusion imaging.

Accomplishments:

Two non-gated, non-breath-held, 2-D methods developed capable of 256 x 256 resolution over a 5 x 5 cm FOV in the 30 to 60 frames per second range for a heart rate around 330 beats per minute.

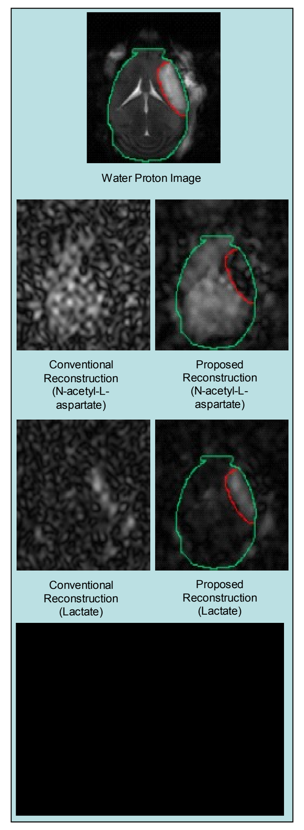
Use a priori geometric information to reconstruct low spatial resolution data sets:

Reduce the number of unknowns using a mathematical model to overcome undersampling along the time dimension of the k-t space:



From the research group of Zhi-Pei Liang

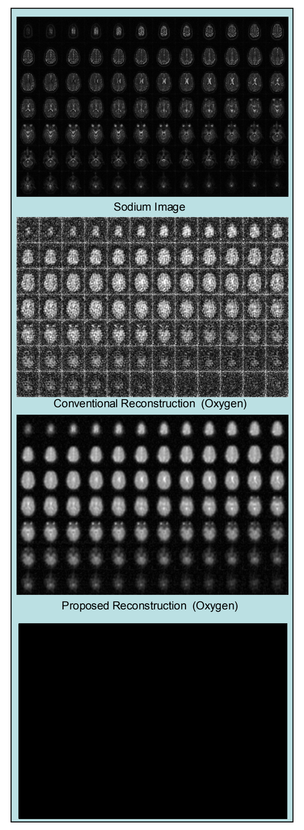
High-Resolution MR Metabolic Imaging



Magnetic resonance (MR) provides mechanisms for imaging biochemicals *in vivo*. These images provide important biological information not available using other methods. However, practical applications of these experiments is limited by low-sensitivity and long acquisition times.

Our research has shown that, in contrast to conventional wisdom, it can be more beneficial to acquire high-resolution data with large noise corruption than to spend time averaging low-resolution data. Prior information, available from anatomical reference images, can be used to reduce the effects of noise while mostly preserving resolution.

The technique is demonstrated for two important metabolic imaging scenarios.



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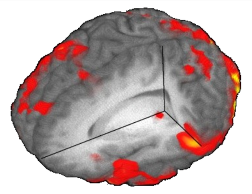
Functional MRI: Robust Detection of low CNR BOLD Signals



F. Kamalabadi, I. Atkinson, D. Jones, and K. Thulborn

Problem: Accurate Detection of Neural Activity in BOLD fMRI is Often Complicated By:

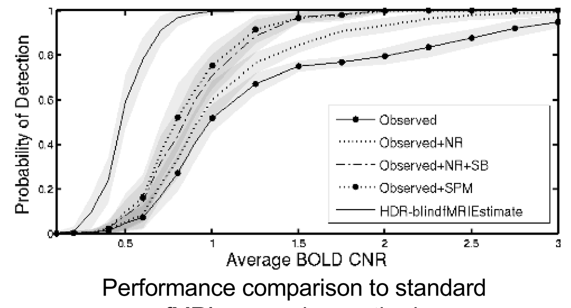
- Low Contrast-to-Noise Ratio
- Small region of activation
- Examples: Hippocampus (memory), Broca's area (Language)

Proposed Solution: HDR-BlindfMRIEstimate

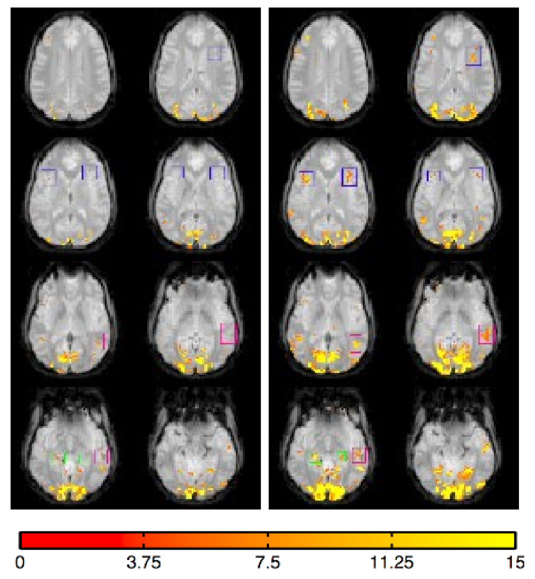
" Blind estimation framework designed for small activation regions with low CNR

" Improves detectibly of low CNR BOLD signals

Applications: Pre-surgical planning, clinical diagnosis, cognitive research



Performance comparison to standard fMRI processing methods



Application to real fMRI data for language paradigm. Increased activation detected in Broca's area (blue), Wernicke's area (pink) and the hippocampus (green)

Cardiac Magnetic Resonance Imaging

N. Aggarwal, B. Sharif, Y. Bresler

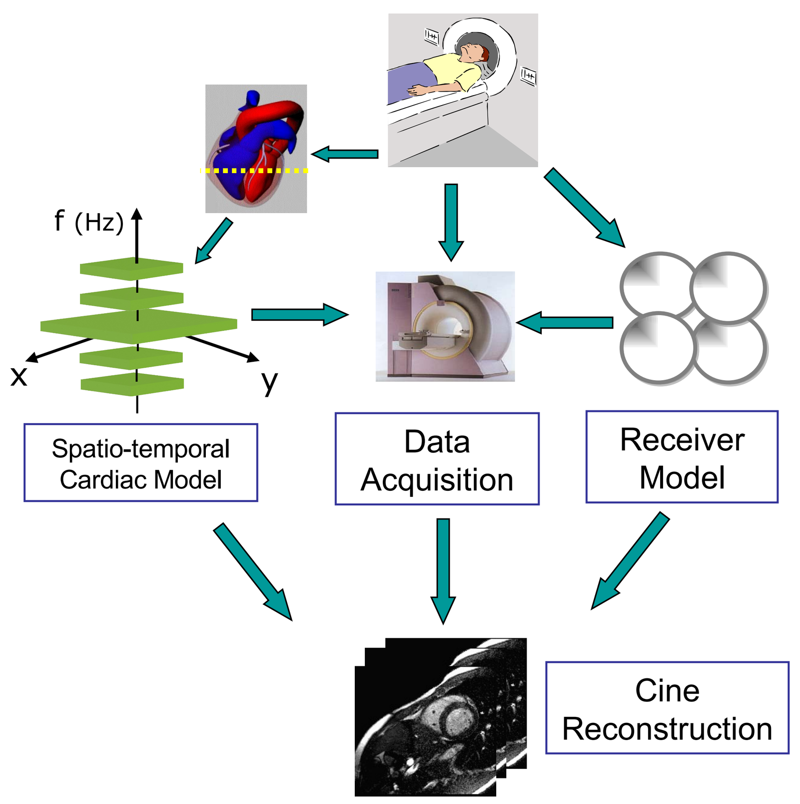
Problem: Dynamic imaging of the human heart with no cardiac synchronization (ungated)

Challenge: Simultaneous high spatial and temporal resolutions due to inherent MR sampling limitations

Approach: Patient-adaptive imaging (*PARADIGM* and *PARADISE*);

- Method optimizes:
  - MR data acquisition
  - Cine reconstruction

  based on:
  - Model adapted to patient
  - Model of scanner hardware
- Method based on time-sequential sampling theory and provides performance guarantees



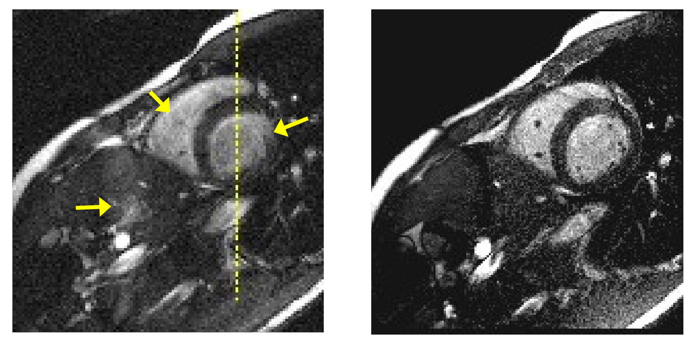
- Method tested in simulation and *in-vivo* (right panel). Features include:
- Providing artifact-free motion movies
- Capturing true dynamics of cardiac motion including beat-to-beat variability
- 10-25x enhancement in temporal/spatial resolution and/or SNR, or reduced scan time

Potential Clinical Impact:

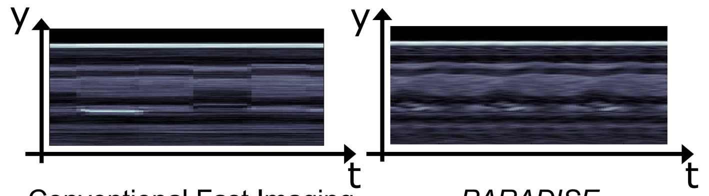
- Expand feasibility of MRI scans to a larger patient population
- Improved diagnosis, e.g., valvular heart disease and impairment of wall function
- Extend diagnostic capabilities of MRI to previously infeasible applications

In-vivo MRI Experiment

End-diastolic Snapshot

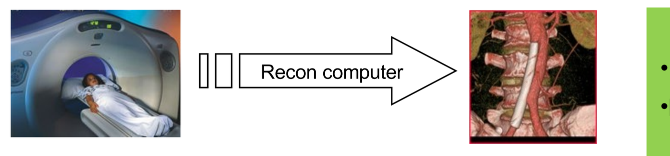


Time-evolution of the heart wall



Fast Image Reconstruction in Tomography (CT)

Y. Bresler and A. K. George



The Reconstruction Speed Barrier to Enabling the CT Revolution

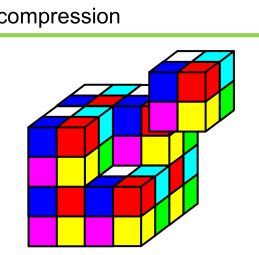
Feature	Benefit	Computational Need
Real-time recon	Emergency room, image-guided surgery	20x-40x
Double resolution	Better diagnosis	16x (computation is O(N^4))
Iterative recon	X-ray dose reduction–reduced cancer risk	50x

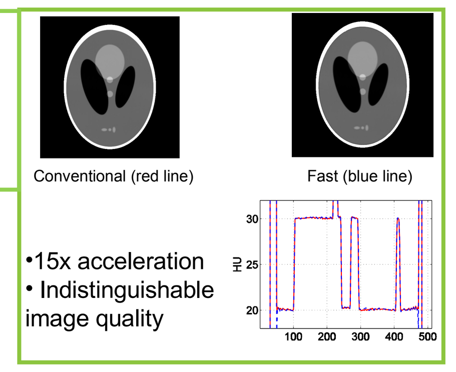
- Need huge accelerations: 20x – 32,000x
- Scaling hardware is expensive ($, power)!

Solution: Algorithmic acceleration of CT recon

- Has been an open problem for the past 30 years.
- Reduces computational complexity from the traditional $O(N^4)$ to $O(N^3 \log N)$ for an $N \times N \times N$ voxel volume.
- For typical image sizes, speedup is 10X to 50X
- Larger speedup for larger images
- Applicable to both hardware and software solutions
- Applicable to all scanning geometries: parallel-beam, fan-beam, conebeam, helical conebeam, multi-source.

- Two completely different divide & conquer schemes:
  - decimation in space
  - decimation in angle
- Both use recursive data compression





- 15x acceleration
- Indistinguishable image quality

Global Infotech: Pathways to the Future with Global Partnerships

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