Spatial 3D EPR Imaging with Compressed Sensing Reconstruction

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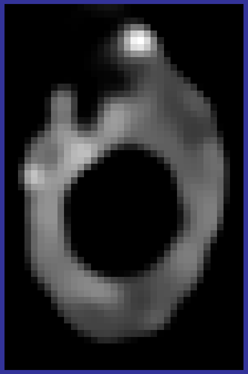
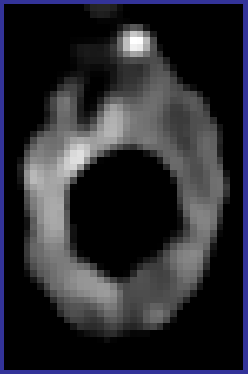
Isolated rat heart perfused with LiNc-BuO





Reconstructed from:

1,024 projections (4.3 min)

128 projections (33 seconds)

Background - Compressed Sensing

- CS is a data processing method which recovers an image from a small amount of data. 10-fold acceleration is common in MRI. Requirements:
  - Image sparsity (i.e., mostly zeros) in some domain
  - Incoherent noise from the acquisition
  - Nonlinear reconstruction (slower, more parameters)
- Previous limited applications of CS to EPRI:
  - Spectral-spatial with small, discrete implants
  - Some require analytical lineshape

Motivation – Spatial EPRI

- History of reconstruction algorithms: Filtered Back-Projection (FBP), Algebraic Reconstruction (ART), Maximum Entropy, l_1 minimization, and Bayesian estimation
- Spatial EPRI is useful for redox kinetics and probe development
  - Spectral-spatial EPRI can be too slow to capture rapidly changing signals
  - Does a newly developed probe enter the targeted tissue? Is it retained long enough to be useful?
  - Need to acquire enough projections with high temporal resolution, despite cardiac and respiratory motion
- Compressed Sensing (CS) provides a method to improve spatial EPRI experiments

Methods

Signal Model: $$y = CRx$$

Measured projections → y

spatial image → x

R: 3D Radon transform

C: convolution operator, with empirical spectrum (assumed to be spatially invariant)

Assumptions about the image (x):

- **x has many pixels with no signal** ⟶ $\min \|x\|_1$
- **x is piecewise constant** ⟶ $\min \|\mathrm{TV}(x)\|_1$

Implementation

$$x_{CS} = \arg\min_{x} \left\| CRx - y \right\|_2^2 + \lambda_1 \left\| x \right\|_1^1 + \lambda_2 \left\| \mathrm{TV}(x) \right\|_1^1$$

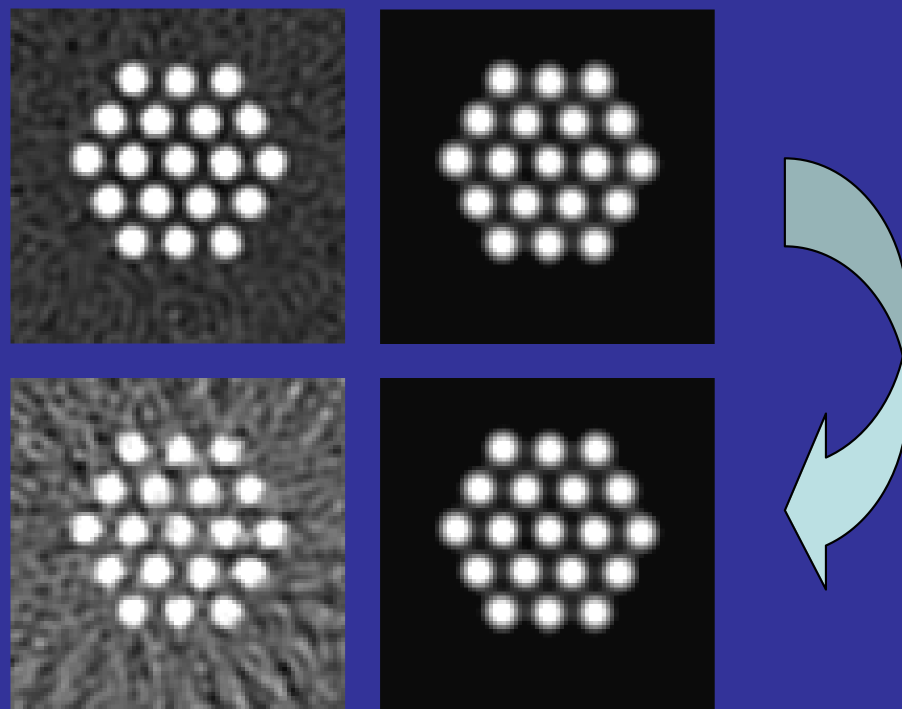
- No traditional filtering; no deconvolution
- CS reconstruction uses FISTA to solve the above minimization problem
- Split into sub-problems:
  - Enforce data consistency of the current estimate with the measured projections
  - Minimize the number of non-zero pixels
  - Minimize the Total Variation (TV) of the image
- Readily extendable to dynamic signals and spectral-spatial EPRI.

3D Phantom Experiment

FBP CS

1,764 projections

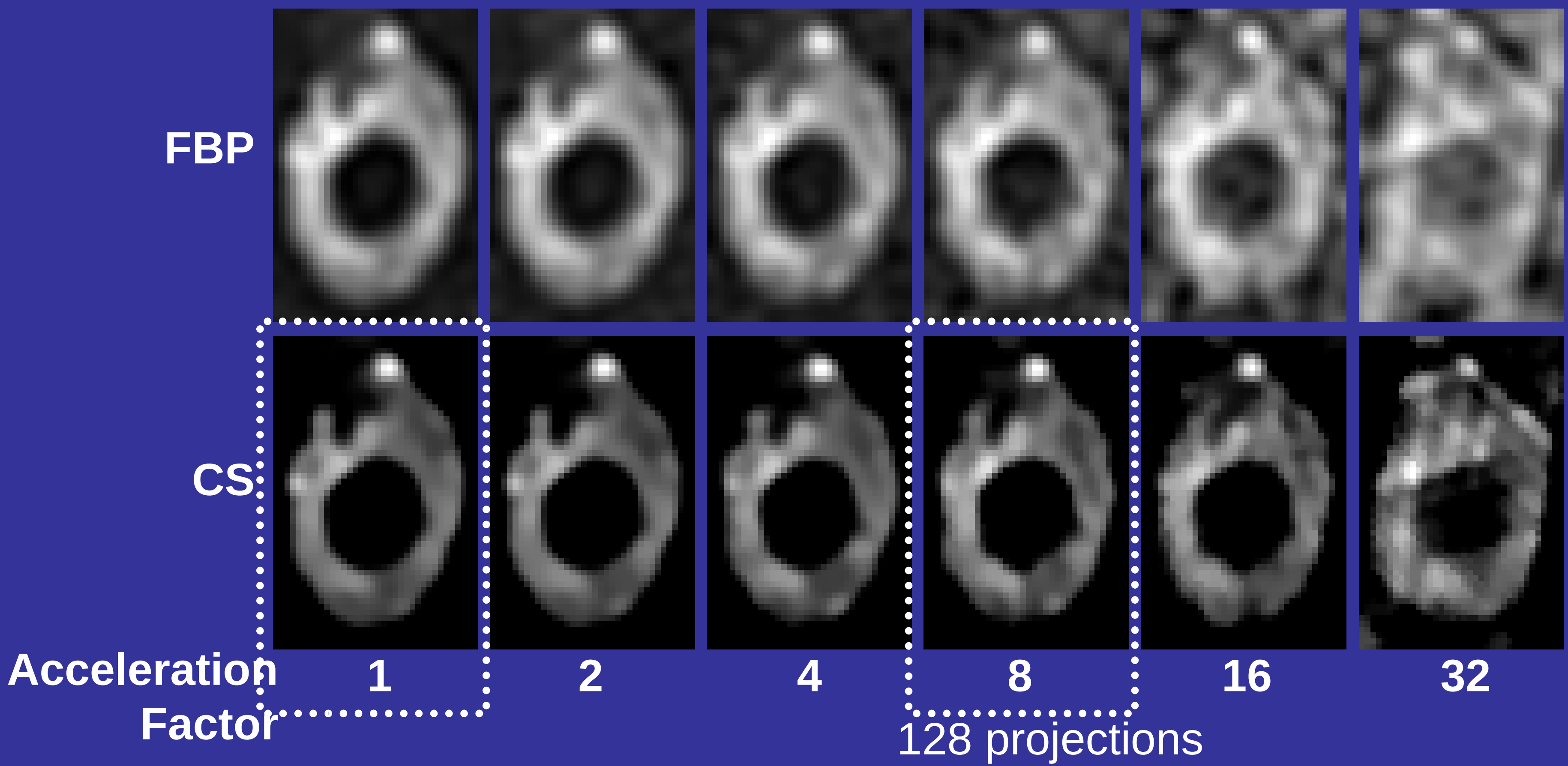
441 projections



4X faster!

A phantom of 19 tubes with 1 mM TAM radical were scanned in a 1.2 GHz EPR imaging system with 26.7 mT/m gradient amplitude and 5 s per projection.

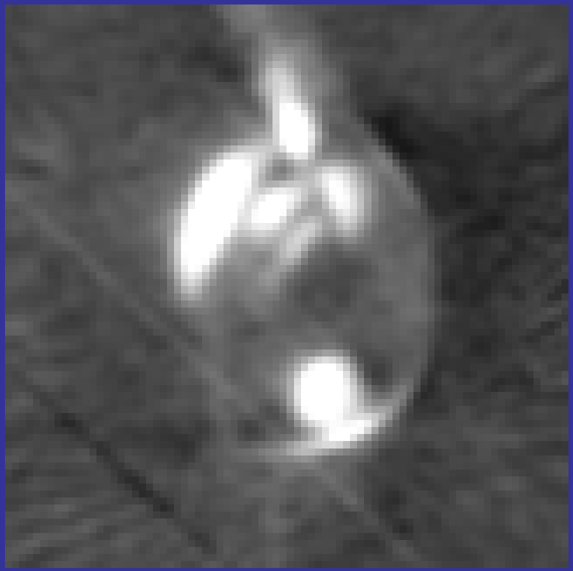
Cardiac Results



Comparison of Compressed Sensing (CS) and Filtered Backprojection (FBP) reconstructions in a LiNc-BuO isolated rat heart dataset. 4.5 min data acquisition on 1.2 GHz CW EPRI system (1,024 projections), but only 128 projections are really needed.

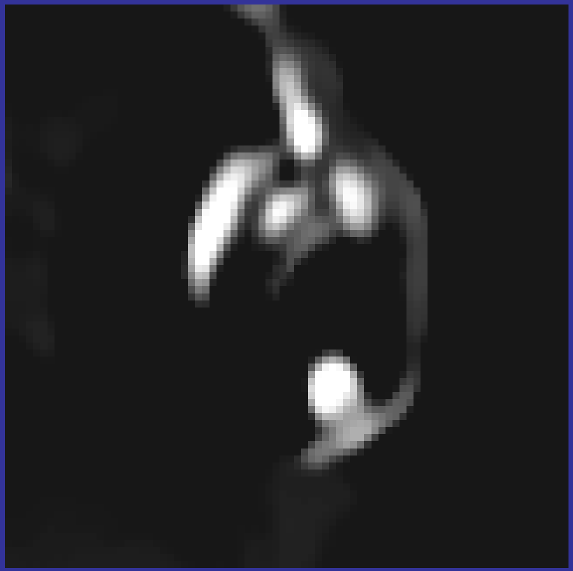
GI Tract Imaging Results

FBP



SNR 10.6

CS



SNR 20.7

Mice were fed activated charcoal, and GI tract imaging was performed (1,024 high SNR projections). Use of the CS reconstruction doubled the image SNR and suppressed streaking artifacts.

Conclusion

- New spatial EPRI reconstruction demonstrated
  - Works with diffuse probes, uses empirical spectra
  - Avoids deconvolution
  - Acceleration of 8X or more for static EPRI
- In vivo applications: cardiology, GI tract imaging
- Can be extended to redox kinetics experiments

Details available via: "Compressed Sensing of Spatial Electron Paramagnetic Resonance Imaging." Poster by piano.

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