Sparse MRI – The Application of Compressed Sensing in Rapid MRI

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Outline

• Recap Compresses Sensing (CS)
• Introduction to MRI (Motivation)
• Framework of Using CS in MRI
• Examples
Recap CS (Compressed Sensing)

- Three key ingredients:
  - Sparsity
  - Incoherence of Measurements
  - Non-linear Reconstruction
Redundancy: Compression

Most images are compressible
Standard approach: First collect, then compress

Shannon-Nyquist

N >> K

Compression
Instead: Compressed Sensing (CS)
First Compress, then reconstruct.

Compressed Sensing

Shannon-Nyquist

Donoho
IEEE TIF ’06

Candes et al.
IEEE TIF ’06

101001101000
1001101001000
1001110101010011
0100010001010110
101010101011
101000110100
1101011

M. Lustig, EECS UC Berkeley
Intuitive example of CS
Intuitive example of CS

Nyquist
Intuitive example of CS

equispaced → sub-Nyquist

M. Lustig, EECS UC Berkeley
Intuitive example of CS

random

sub-Nyquist
Intuitive example of CS

Looks like “random noise”

sub-Nyquist
Intuitive example of CS

But it’s not noise!

sub-Nyquist

M. Lustig, EECS UC Berkeley
Intuitive example of CS

Example inspired by Donoho et. Al, 2007
Similar to CLEAN algorithm

M. Lustig, EECS UC Berkeley
Intro to MRI
Neuro Examples of MRI

Many different contrasts available

Image courtesy: K. Pauly, G. Gold
Stanford Rad 220
MR Imaging

k-space (Raw Data)  Image

Fourier transform
Key MRI Idea

• MR scanner makes your body put out a signal that is its own Fourier Transform (k-space)

• Data is acquired directly in spatial frequency space (**coded nature of MRI**)

• Limits to how fast this can be done
Motivation: The Need for Speed

• MRI data collection is inherently slow!!

• Rapid MR imaging would
  ➢ Decrease scan time
  ➢ Reduce image artifacts
  ➢ Increase spatial/temporal resolution
  ➢ Increase coverage
Recall Example of CS

Example inspired by Donoho et. al., 2007
Similar to CLEAN algorithm
Recap CS (Compressed Sensing)

- Three key ingredients:
  - Sparsity
  - Incoherence of Measurements
  - Non-linear Reconstruction
Compressed Sensing MRI

Randomly throw away 84% of samples

Surprising Experiments!
Implications...

Randomly throw away 66% of samples

MRI data are obtained in the frequency domain

Potential for significant scan time reduction

Fourier transform

standard recon

compressed sensing

frequency domain

scan time reduction
Domains in Compressed Sensing

Signal

Sparse Domain

Sparse!

Not Sparse!

Sampling Domain

incoherent
Three Key Ingredients of CS also works in MRI!

• Sparse Representation (compressibility)
• Incoherent Measurement
• Recovery with non-linear convex optimization
Framework on Compresses Sensing in MRI

• Sparse Representation of Signals
• Incoherent Measurement
• Recovery with non-linear convex optimization
MR Images – difference applications

T2 weighted brain image

Brain angiogram

T2 spinal cord image

Image courtesy: K. Pauly, G. Gold
And google images
Sparsifying Transform

• Real-life images known to be sparse in discrete cosine transform (DCT) and wavelet transform domains
  ✓ DCT is central to JPEG image compression and MPGE
  ✓ Wavelet transform is used for JPEG-2000 compression standard

• Finite-difference Transform (not always work for MR images)
Compare Sparse Transforms

The images were reconstructed from a subset of 5, 10 and 20% of the largest transform coefficients.
Framework of Compresses Sensing in MRI

• Sparse Representation of Signals
• Incoherent Measurement
• Recovery with non-linear convex optimization
Compresses Sensing MRI- Incoherence

“randomness is too important to be left to chance*”

*R. Conveyo, Oak Ridge National Laboratory
Incoherent Measurement (sampling)

To create noise-like interference
Incoherence Analysis

Incoherent aliasing interference in the sparse transform domain is an essential ingredients for CS
Framework of Compresses Sensing in MRI

• Sparse Representation of Signals
• Incoherent Measurement
• Recovery with non-linear convex optimization
Reconstruction Model

\[ \min \| \psi m \|_1 \]
\[ \text{s.t. } \| F_u m - y \|_2 \leq \epsilon \]

\( m \) is the reconstructed image, \( \psi \) is the sparsifying transform, \( F_u \) is the undersampled Fourier Transform, \( y \) is the measurements.
Domains in CS MRI

- **Signal domain**
- **Wavelet domain**
- **k-space** (measurement domain)
- Incoherent
CS works very well in MRI

(Left) Nyquist sampled image; (right) CS reconstructed image with 2.4-fold acceleration
CS works very well in MRI

(left) Nyquist sampled image; (right) CS reconstructed image with 5-fold acceleration
Conclusions and General Comments

• MRI acquisition is slow
• Can be accelerated by collecting less data
• Compressed sensing exploits sparsity
• Many avenues for research:
  – Applications, Applications, Applications, and: signal representation, algorithms, computation, .....
To play with that

http://www.eecs.berkeley.edu/~mlustig/CS.html

Thanks for your attention!