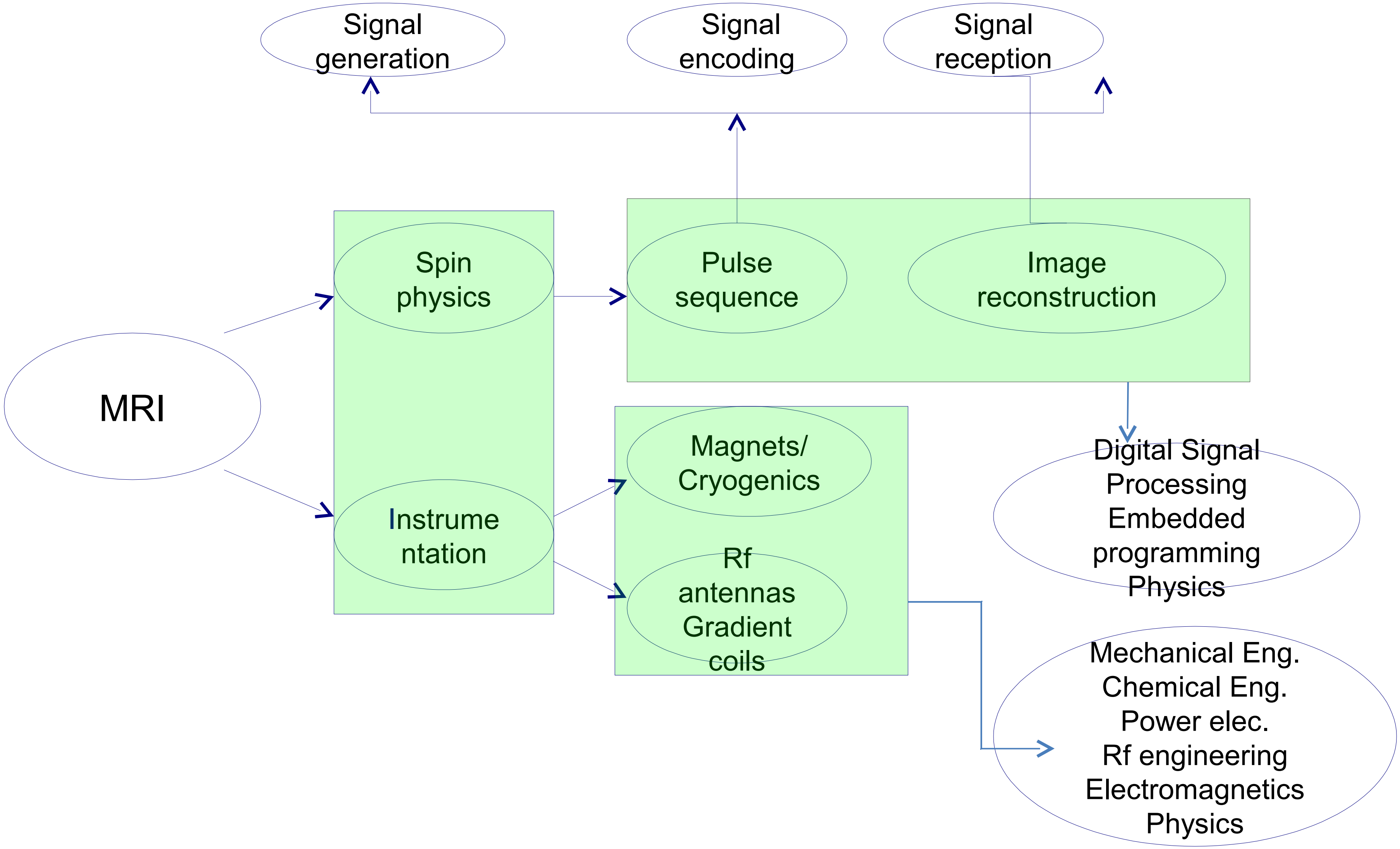
Non Fourier Encoding For Accelerated MRI

Arjun Arunachalam
Assistant Professor
Electrical engineering dept
IIT-Bombay

Outline of the Presentation

- An introduction to Magnetic Resonance Imaging (MRI)
- The need for speed in MRI
- Recent advances in accelerated MRI
- A current example of Compressed Sensing (CS) in MRI
- CS and Radio frequency encoding
- Simulations and Results
- Future work

MRI is an inter-disciplinary field



Magnetic Resonance Imaging Fundamentals

- Powerful non invasive imaging modality
- Superior soft-tissue contrast
- Imaging planes in an arbitrary orientation
- Applications
  - Diagnostic imaging studies of the CNS and musculoskeletal system
  - MR angiography, functional MRI, real time MR...
  - Emerging- Carbon 13 imaging etc..

MRI Fundamentals

- MRI Signal formed by localizing the NMR signal by frequency

- Medical MRI uses ^1H (the proton)

- Protons interact with
  - static magnetic field B_0
  - radiofrequency field B_1
  - linear gradient field G

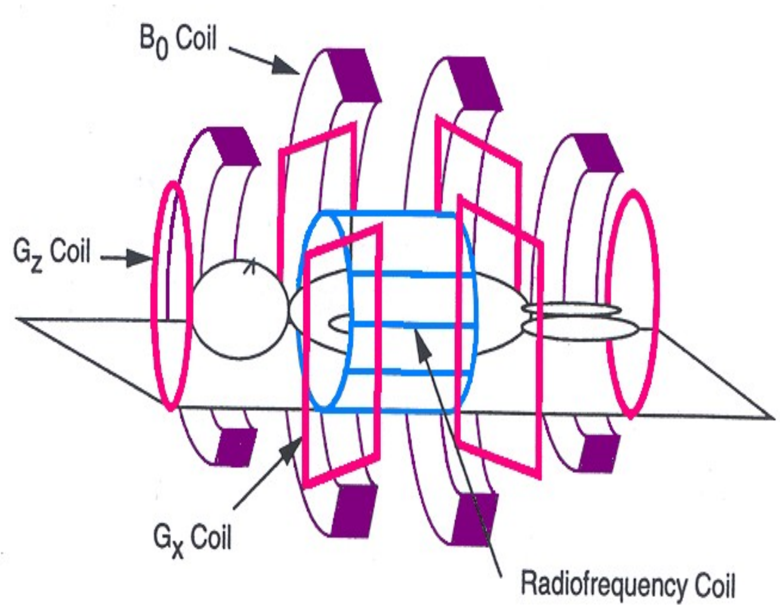
MRI Fundamentals

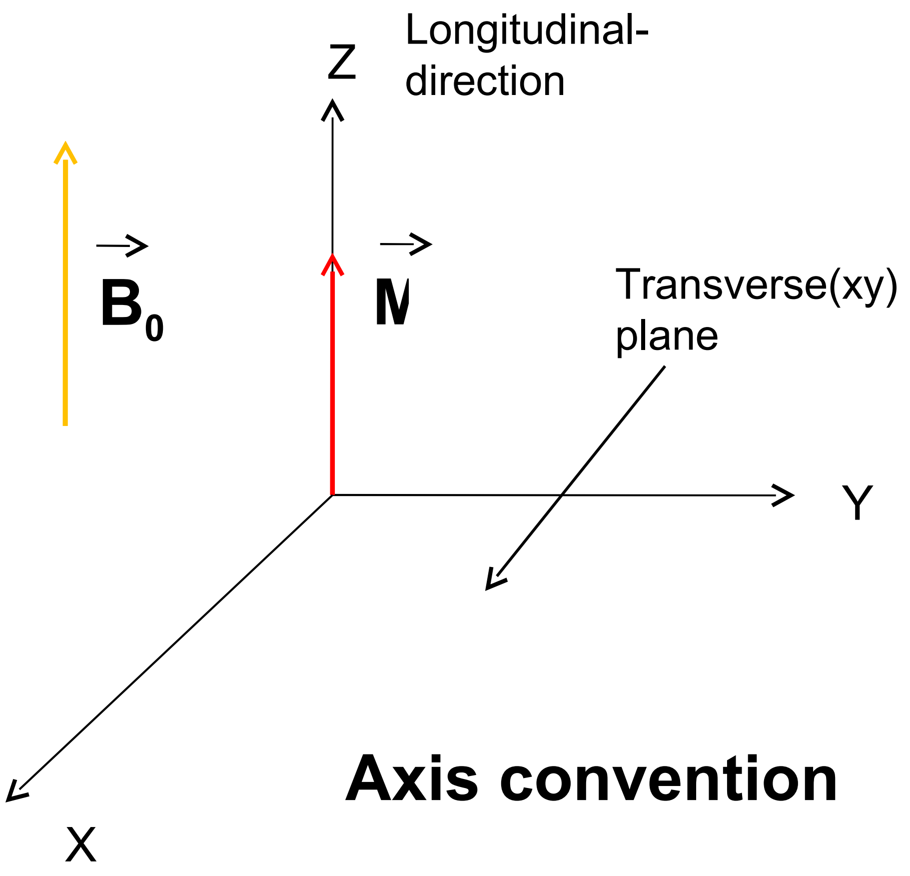
1. Static magnetic field B_0

Resonance at Larmor frequency

$$\omega = \gamma B \text{ rad/s}$$

$$f = \gamma / 2\pi B \text{ Hz}$$





Axis convention

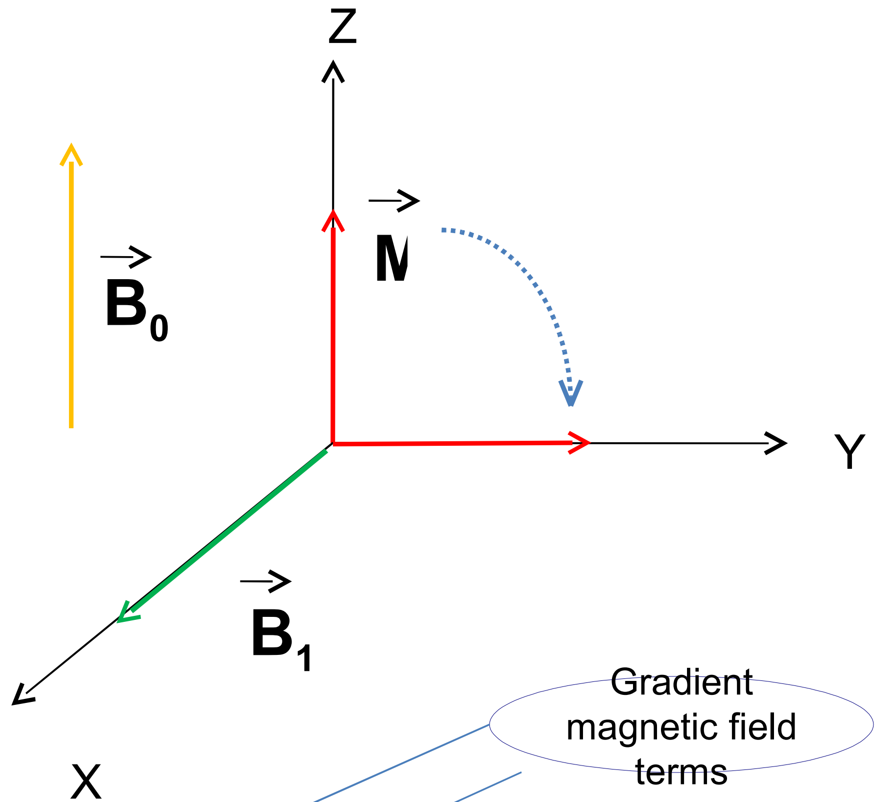
MRI Fundamentals

2. Radiofrequency (RF) Field B_1

- $\mathbf{M_{xy}}$ detected
by receiver coil
-Free Induction Decay(FID)

- Longitudinal relaxation time constant ($\mathbf{T_1}$)

- Transverse relaxation time constant ($\mathbf{T_2}$)

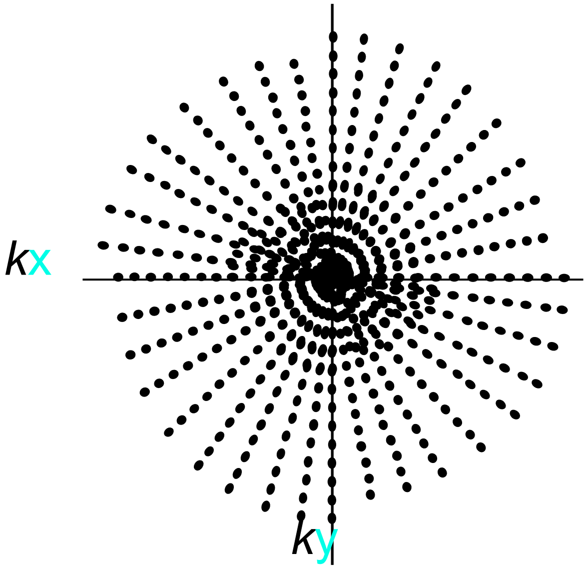


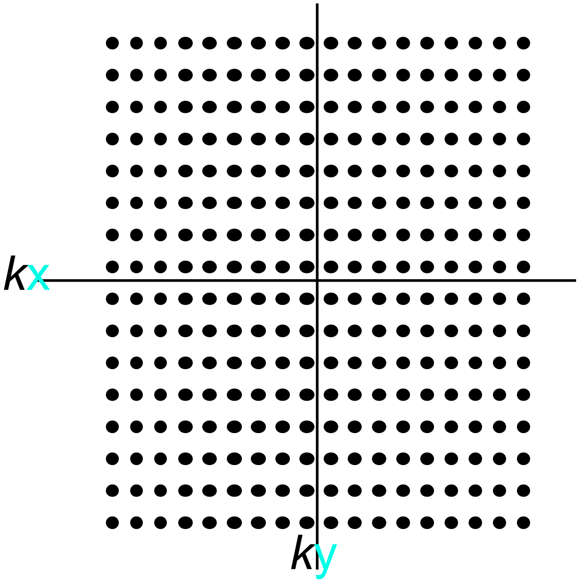
Introduced by Rf pulse

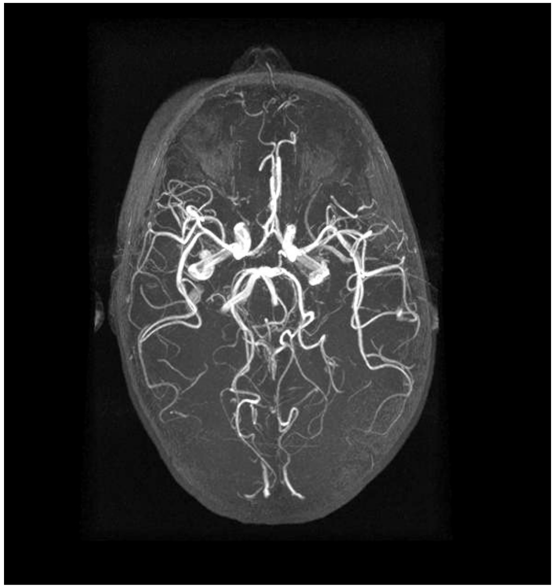
Gradient magnetic field terms

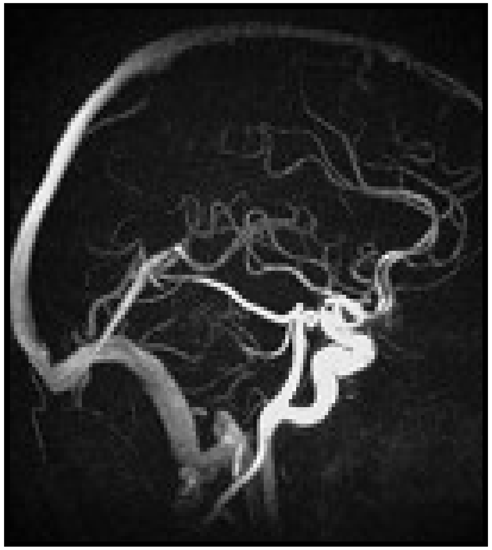
$$S(t) = \iint \vec{M}_z(x,y) Sin(\alpha(x,y)) e^{-j\gamma G_y y t_p} e^{-j\gamma G_x x t} dxdy$$

MRI sampling using gradients









The need for speed in MRI

Dynamic Imaging

Contrast enhanced MR angiography

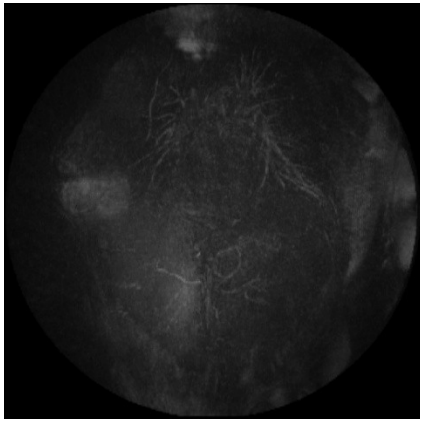
Cardiac Imaging

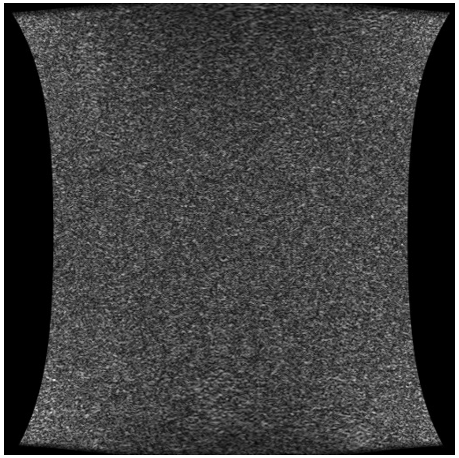
Trade off between spatial and temporal resolution

Acquire a series of 2D/3D images over time (*time frames*)

Temporal resolution: Rate of acquisition of time frames

Spatial resolution: Image resolution of each time frame



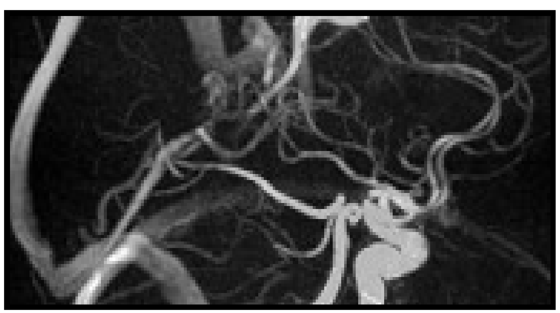


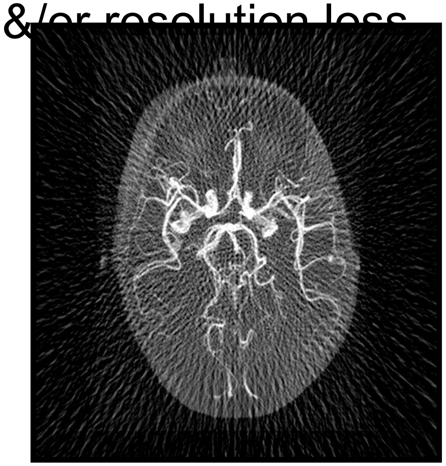
Problem Definition

Conventional MRI data acquisition speed is limited (physical and physiological constraints)

To speedup acquisition sub-sampling k-space is necessary

The consequence is aliasing &/or resolution loss





Need for better methods to speedup the acquisition without degrading the image quality

Parallel Imaging

•Spatially separated multiple RF receiver coils

•Independent spatial sensitivity profiles of the RF coils

•Coils must have some sensitivity difference in the sub-sampling direction

•Can be used for the primary in-plane phase encoding(2D scans) & secondary phase encoding(3D scans)

Parallel Imaging (PMRI)

Parallel Reconstruction Algorithms

Reconstruction algorithm	**Coil reference data**	**Sub-sampled target data**
	Image -based	
SENSE	image domain	image domain
	k-space based (Fourier space)	
SMASH	image domain	k-space
Generalised SMASH	k-space	k-space
AUTO-SMASH	K-space	K-space
GRAPPA	k-space	k-space

Parallel Reconstruction Algorithms

Example: Sensitivity Encoding (SENSE)

Receiver coil sensitivities encode the object in complementary way to Fourier encoding

Undersample k-space for every coil

Aliasing in object domain (for every coil)

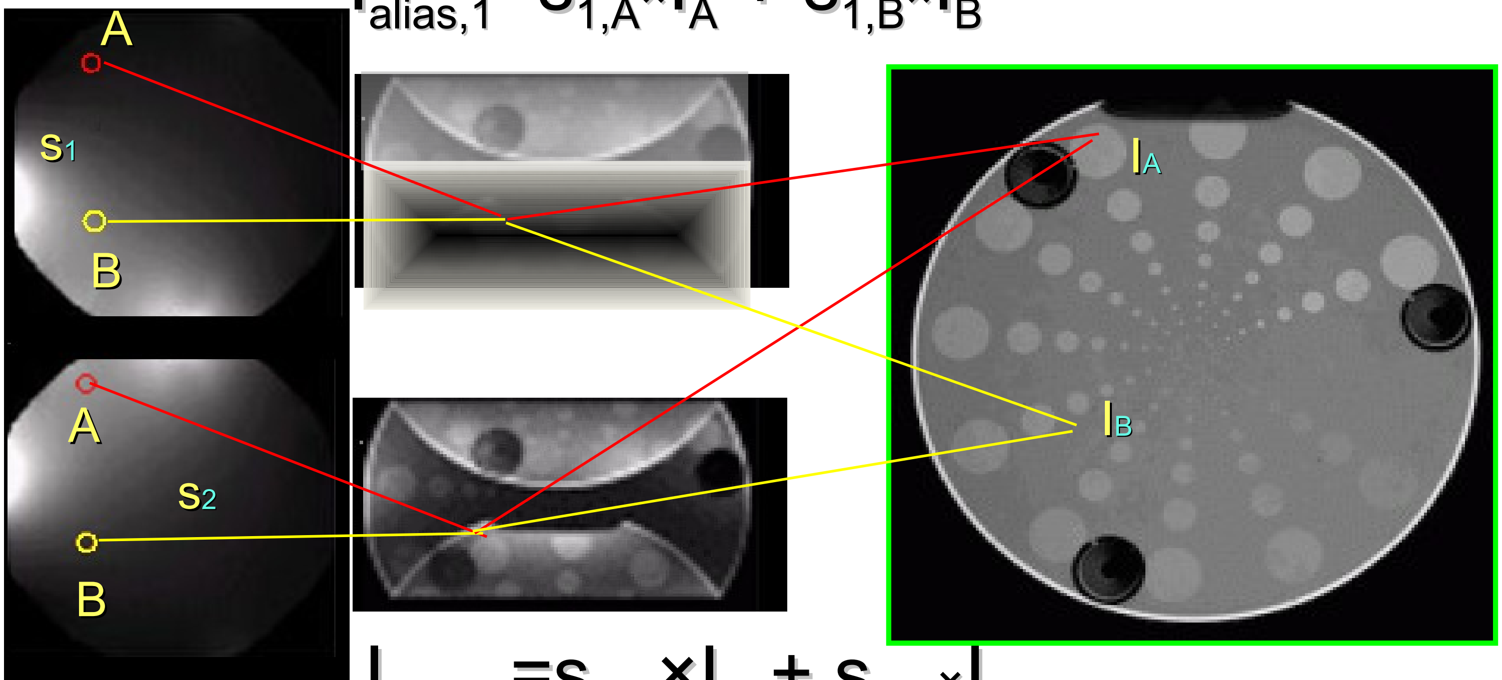
Use sensitivity information of the coils to & reconstruct the original image

Example-SENSE

step 1: create aliased reduced FOV image for each array element using DFT

step 2: create a full-FOV image from the set of intermediate images.

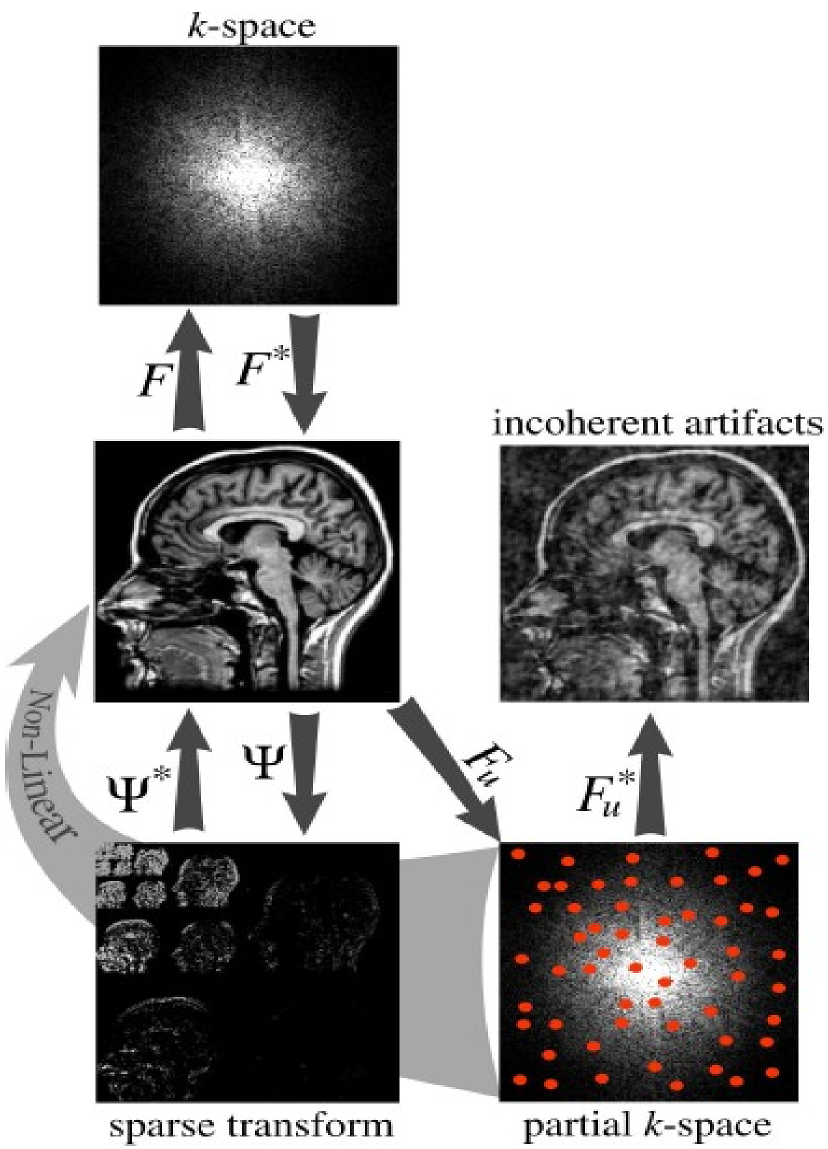
$$I_{alias,1} = s_{1,A} \times I_A + s_{1,B} \times I_B$$



$$I_{alias,2} = s_{2,A} \times I_A + s_{2,B} \times I_B$$

We know s_1, s_2 (sensitivity maps); we measure $I_{alias,1}$, $I_{alias,2}$; so we can calculate I_A, I_B

Example-Compressive Sensing



Again, gradients are used to perform random sampling

Sparse MRI: Lustig et al: Available on Rice university *CS* webpage

A Non Fourier encoding approach

Non-sinusoidal spatial encoding profiles induced via RF excitation

$$S(t) = \iint \vec{M}(x,y) Sin(\alpha(x,y)) e^{-j\gamma G_y y t_p} e^{-j\gamma G_x x t} dxdy$$

Can be
approximated as

$$S(t) = \iint \vec{M}(x,y) \alpha(x,y) e^{-j\gamma G_y y t_p} e^{-j\gamma G_x x t} dxdy$$

Can be derived from well known fixed mathematical basis sets: Wavelets, Noiselets etc

Non Fourier Encoding

$$S(t) = \iint \vec{M}(x,y)\alpha(x,y)e^{-j\gamma G_y y t_p} e^{-j\gamma G_x x t} dxdy$$

$$S(K_l, k_x) = \sum_{m=1}^{M} \alpha^l{}_m \iint \vec{M}(x,y)e^{-j2\pi k_m y} e^{-j2\pi k_x x} dxdy$$

$$K = (k_1, \ldots\ldots\ldots, k_M)$$

$$S(K_l, k_x) = \sum_{m=1}^{M} \alpha^l{}_m s(k_m, k_x)$$

$$l = (1 \ , \ldots\ldots\ldots, N \ )$$

The non-Fourier signal equation is a combination of the typical Fourier modes

Acquired through conventional means in MRI

MRI Images are compressible in the wavelet domain.

An appropriate measurement domain can be introduced during Rf excitation

The measurements are linear combinations of typical Fourier modes

Non-Fourier PMRI acceleration

When using multiple coils γ, the equation if the following:

$$S_\gamma(K_l, k_x) = \sum_{m=1}^{M} \alpha^{l}{}_{m} s_\gamma(k_m, k_x)$$

Haar Encoding

R=6

Random Encoding

R=6

Potential for compressive sensing and PMRI

- The measurement matrix is not restricted to Fourier domain alone
- Current CS approaches are unpredictable when applied on multi-sensor MRI data
- The solution can be in the image domain or the Fourier domain
- Non Fourier acceleration methods can exploit real time k-space data properties