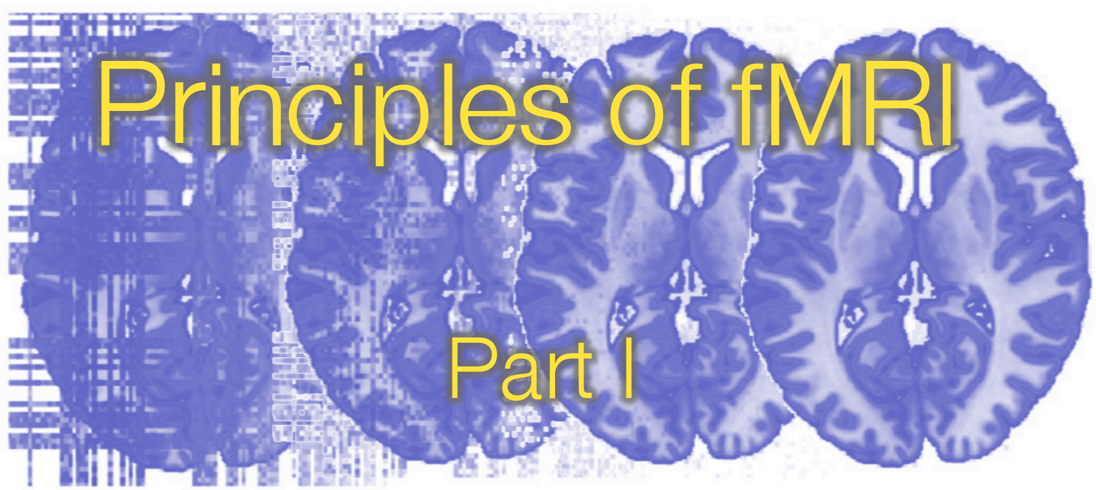
Principles of fMRI

Part I



Martin Lindquist
Department of Biostatistics
Johns Hopkins
Bloomberg School of Public Health

Tor Wager
Department of Psychology and
Neuroscience and the
Institute for Cognitive Science
University of Colorado, Boulder

@fMRIstats

Image Formation

Signal Formation

- The subject is placed into the MR scanner.
  - Nuclei of ^{1}H atoms align with the magnetic field.
  - The nuclei precess about the field at similar frequencies, but at a random phase.
  - Net longitudinal magnetization in the direction of field.

- Within a slice, a radio frequency (RF) pulse is used to align the phase and ‘tip over’ the nuclei.
  - Causes the longitudinal magnetization to decrease, and establishes a new transversal magnetization.

Signal Formation

- After the RF pulse is removed, the system seeks to return to equilibrium.
  - The transverse magnetization disappears (transversal relaxation), and the longitudinal magnetization grows back to its original size (longitudinal relaxation).
  - Longitudinal relaxation: exponential growth described by time constant T1.
  - Transverse relaxation: exponential decay described by time constant T2.

- During this process a signal is created that can be measured using a receiver coil.

Slice Selection

- Most structural MRI and fMRI scans involve the construction of a three dimensional image from a set of two-dimensional slices.

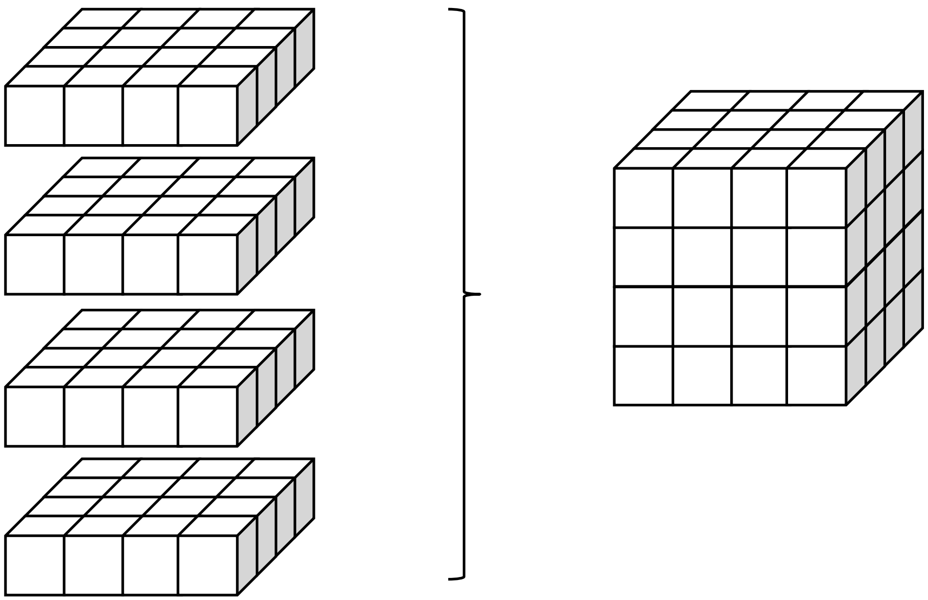
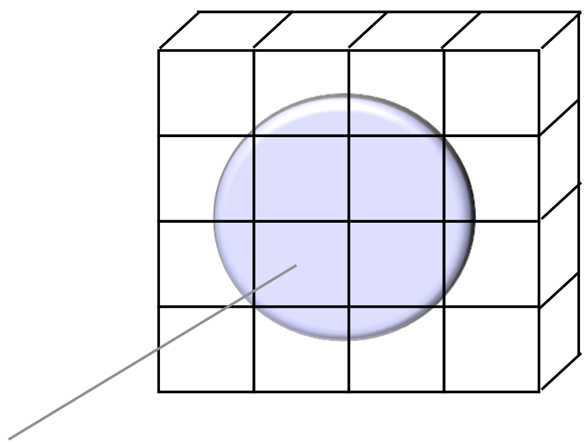
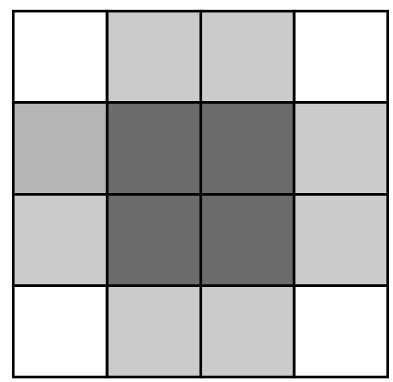


Image Formation

- Imagine a brain slice split into a number of equally sized volume elements or voxels.



$\rho(x,y)$



Gradients

- The measured signal combines information from the whole brain:

$$S(t) = \iint \rho(x,y)\,dx\,dy$$

- A magnetic field gradient is used to sequentially control the spatial inhomogeneity of the magnetic field, so each measurement can be expressed:

$$S(k_x,k_y) = \iint \rho(x,y)e^{-i2\pi(k_x x + k_y y)}\,dx\,dy$$

K-space

- The measurements are acquired in the frequency-domain (k-space).

- By making measurements for multiple values of (k_x, k_y) we can gain enough information to solve the inverse problem and reconstruct $\rho(x, y)$.

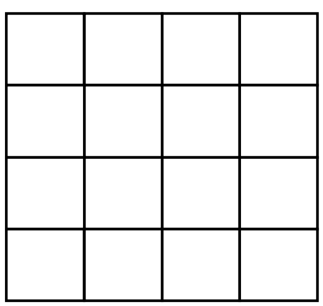
- We can use the inverse Fourier transform (IFT):

$$\rho(x,y) = \iint S(k_x, k_y) e^{i2\pi(k_x x + k_y y)} dk_x dk_y$$

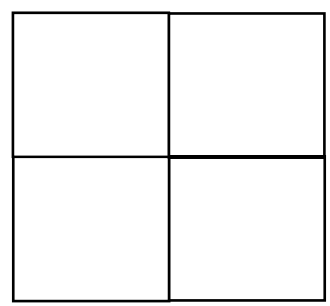
K-space Measurements

- In practice, data measurements are made discretely over a finite region.
  - Use discrete Fourier transforms.

- The number of k-space measurements we make influences the spatial resolution of the image.
  - Need enough measurements to solve inverse problem.

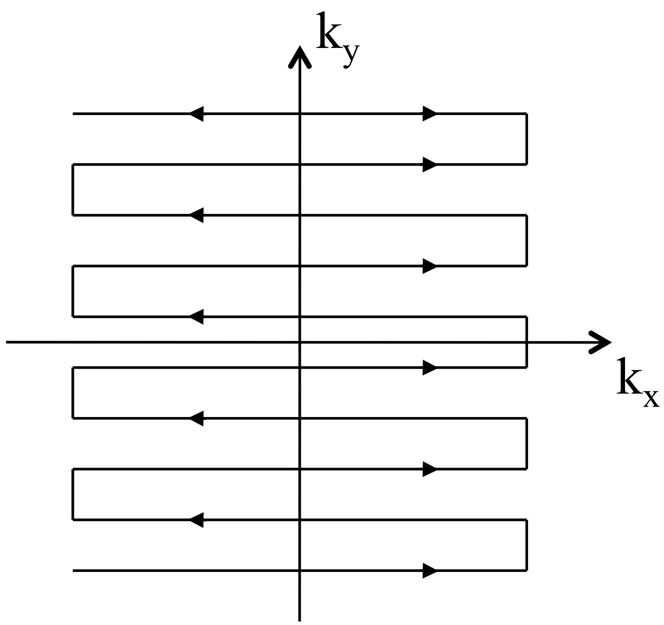


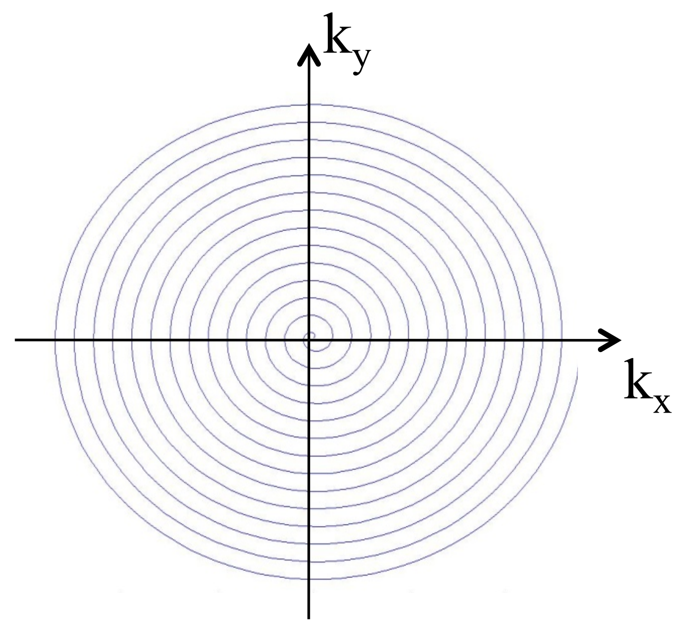
16 unknowns



4 unknowns

EPI and Spirals





Magnitude Images

- The measured k-space data is complex valued.
  - Hence, the measurement at each voxel is complex.

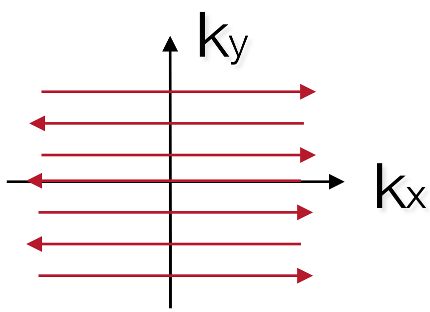
- We typically work with magnitude images, or

$$\left|\rho(x,y)\right| = \sqrt{\rho_R(x,y)^2 + \rho_I(x,y)^2}$$

where ρ_R and ρ_I are the real and imaginary parts of the k-space measurement.

Image Formation

k-space



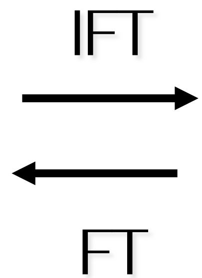
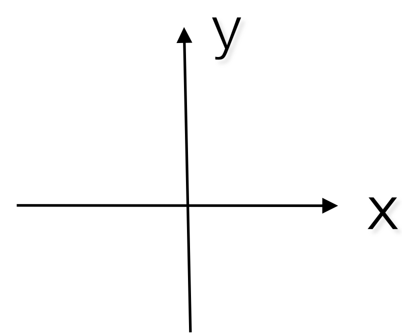
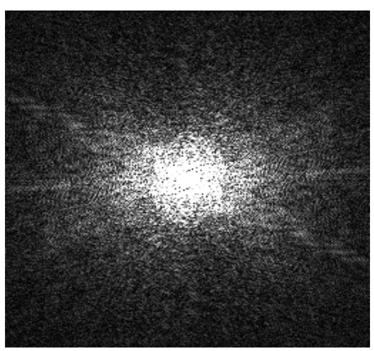
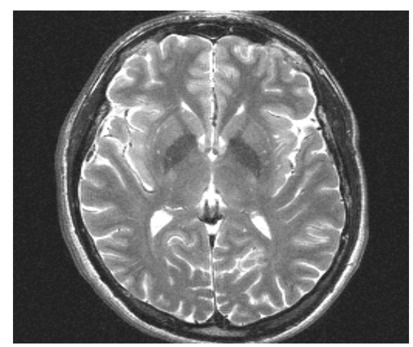


Image space







End of Module