Diffusion Imaging Workshop

Day 1
MRI Physics and Diffusion Principles

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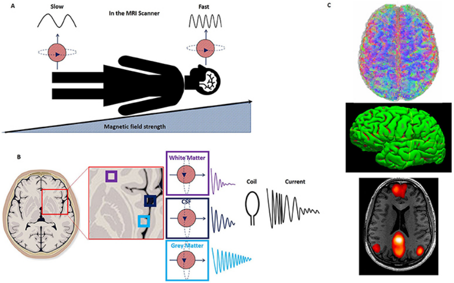


Overview

Background: MRI Physics

- Protons (hydrogen nuclei) tend to align with an externally applied magnetic field

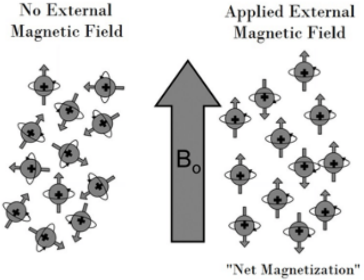


Figure: Pooley, R. A. (2005) RSNA RadioGraphics

Background: MRI Physics

- Protons (hydrogen nuclei) tend to align with an externally applied magnetic field
- If "pushed" away from alignment ("excited" from ground state), protons will being to spin (resonance)

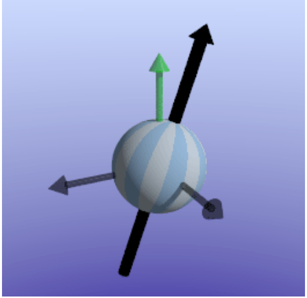


Figure: `http://xrayphysics.com/proton3d.gif`

Background: MRI Physics

- Protons (hydrogen nuclei) tend to align with an externally applied magnetic field
- If "pushed" away from alignment ("excited" from ground state), protons will being to spin (resonance)
- Any movement of charged particles creates a current, which in turn creates a new magnetic field
  - Measured by our coils

Signal Relaxation

- Two mechanisms of energy loss for the excited proton:
  - T_1: Thermal Relaxation

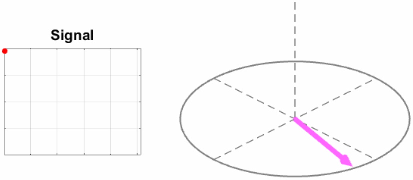


Figure: `http://mriphysics.github.io/images/FID_lab.gif`

Signal Relaxation

- Two mechanisms of energy loss for the excited proton:
  - T_1: Thermal Relaxation
  - T_2: Transverse Relaxation

(a) http://mriphysics.github.io/images/M_bloch_t2.gif

(b) http://mriphysics.github.io/images/M_bloch_t2prime.gif

Signal Relaxation

- Two mechanisms of energy loss for the excited proton:
  - T_1: Thermal Relaxation
  - T_2: Transverse Relaxation

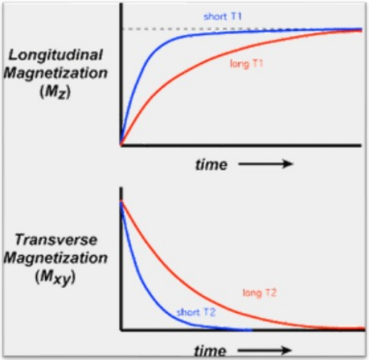


Figure:
https://mriquestions.com/uploads/3/4/5/7/34572113/3534010.gif

Signal Relaxation - Images

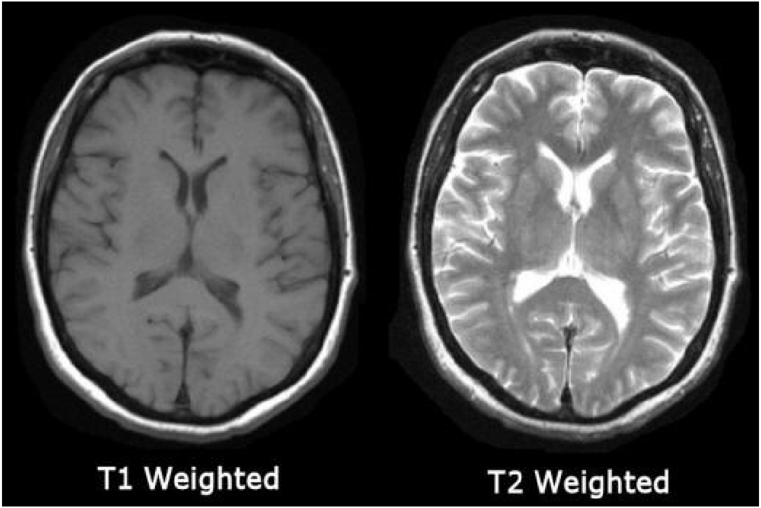


Figure: `http://syllabus.cwru.edu/YearThree/neuroscience/NeurLrngObjectives/MRI.htm`

Background: MR Imaging

- Preparation portion: How are we going to image these spins?
  - What biologic/physical properties do we want to weight?
- Imaging portion: How are we going to look at the spin properties?
  - What biologic/physical properties do we want to see?

Simple Example: Spin Echo

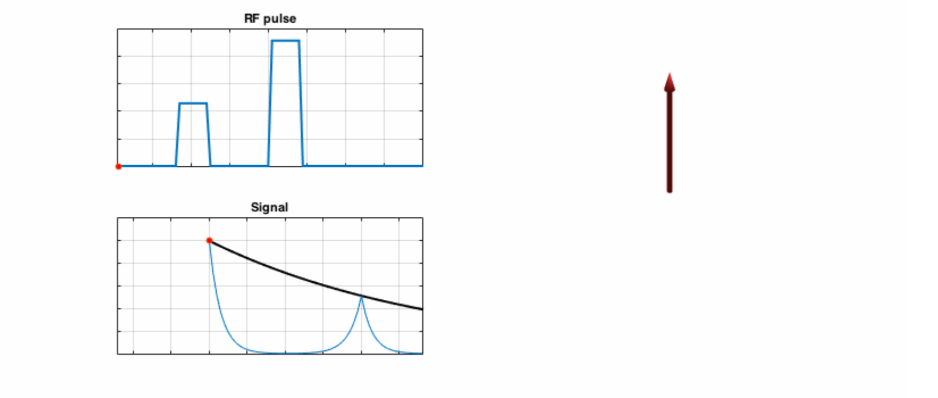


Figure: http://mriphysics.github.io/images/M_spin_echo.gif

What is Diffusion MRI?

DW-MRI is a method to probe the molecular motion of water in biological tissues as a result of random collisions between molecules.

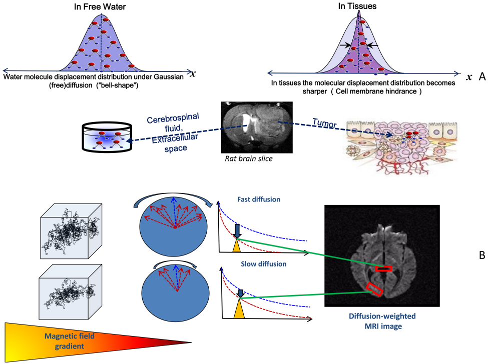


Figure: Le Bihan, D., Iima, M. (2015). Diffusion magnetic resonance imaging: what water tells us about biological tissues. PLoS biology, 13(7), e1002203.

How do we encode diffusion?

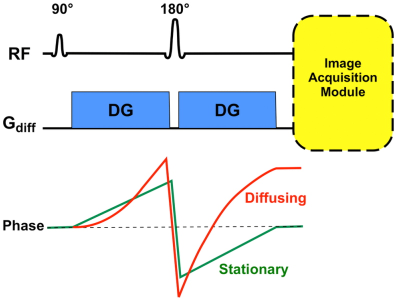
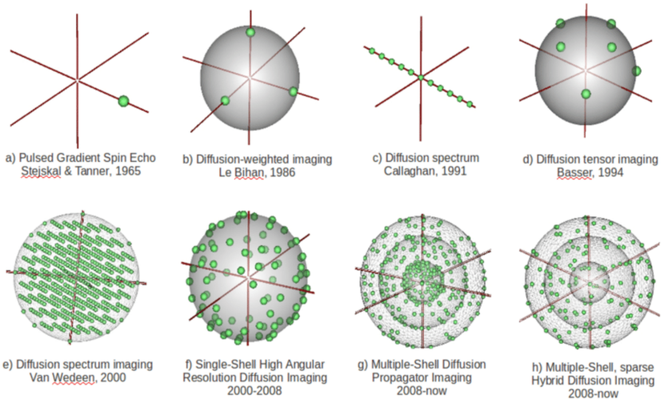


Figure: Overview of pulse gradient spin echo (PGSE), Stejskal and Tanner (1965)

$$b = \gamma^2 G^2 \delta^2 (\Delta - \delta/3) \tag{1}$$

What does this look like in q-space?



$$b = \gamma^2 G^2 \delta^2 (\Delta - \delta/3) \tag{2}$$

Q-Space Trajectory Imaging

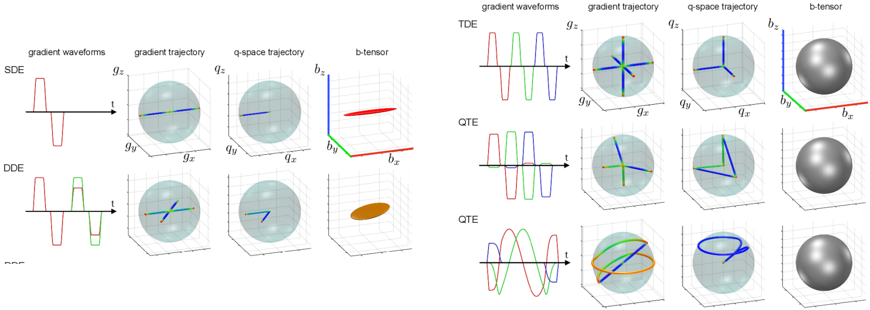
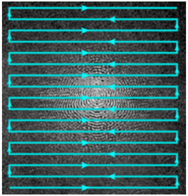
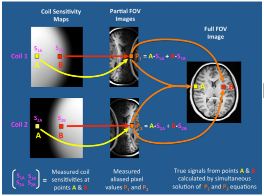


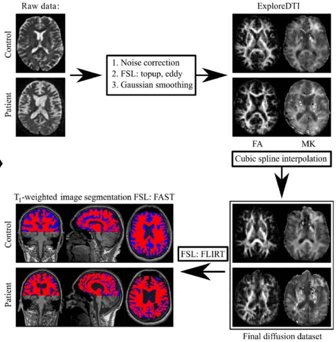
Figure: Overview of DDE, TDE, and QTE

There are many ways to encode diffusion, and you may come across these terms in various papers. Each has their advantages and disadvantages.

What is Reconstruction?

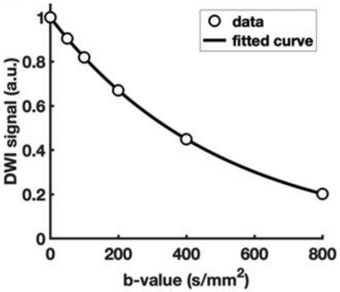


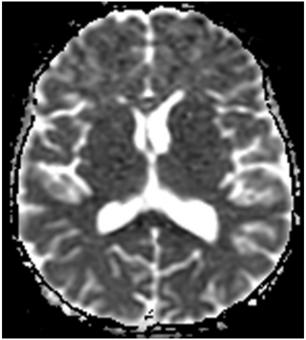




Reconstruction is a general processing of converting raw data to image data for further analysis. This may include coil combination for multi-channel data, gridding and NUFFT for non-cartesian data, and compressed sensing among others.

What can we do with our data?





Data can be represented as a monoexponential fit.

$$S/S_0 = e^{-bD} \tag{3}$$

Apparent Diffusion Coefficient

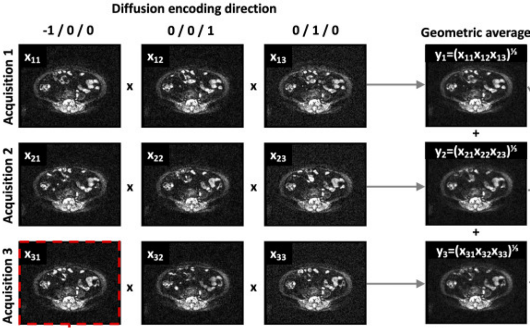


Figure: Zormpas-Petridis, K., Tunariu, N., Curcean, A., Messiou, C., Curcean, S., Collins, D. J., ... Blackledge, M. D. (2021). Accelerating Whole-Body Diffusion-weighted MRI with Deep Learning–based Denoising Image Filters. Radiology: Artificial Intelligence, 3(5).

$$S_{DWI} = S_0 e^{-b(D_{xx}+Dyy+D_{zz})/3}$$

$$S_{DWI} = S_0 e^{-b(D_{trace})/3}$$

$$S_{DWI} = S_0 e^{-bADC}$$

Reconstruction Overview

1. Diffusion Encoding Methods
    1. Diffusion Weighted Imaging (DWI)
    2. Diffusion Tensor Imaging (DTI)
    3. High Angular Diffusion Imaging (HARDI) - 65 q space vectors (single or 2 shells)
    4. Q ball Imaging (QBI) - 515 vectors (single shell)
    5. Diffusion Spectrum Imaging (DSI) - many qspae vectors
    6. Q-space Trajectory Imaging (QTI) - Time varying q space vectors
    7. B-tensor Encoding - LTE and STE.
    8. Tractography
2. Advanced Models
    1. NODDI
    2. FBA
    3. IVIM
    4. DKI
    5. IVIM
    6. CSD

General Overview

DWI and DTI

Software

1. Primary
    1. FSL
    2. ANTS
    3. Mrtrix3
    4. DIPY
    5. Camino
    6. TrackVis
2. Ancillary
    1. Nibabel
    2. Brain Connectivity Toolbox

What does our data look like?

1. Nifti converted data will be composed of a .bvec, .bval, and .nii data. You will likely have a B0 image, with PA for susceptibility correction. Single shell data will be labeled b1000, and multishell data will consist of multiple b-values.
2. bvec and bval files are text files that provide the gradient directions and their corresponding b-values, respectively.
3. The DWI data is a 4D data structure, composed of 3D volumes for multiple gradient directions at multiple b-values.

.bval and .bvec

Text files with b-values and gradient directions.

Additional Files

1. acquisition parameters
2. index

References