Interactive Visualization of Diffusion Image Data and its Models

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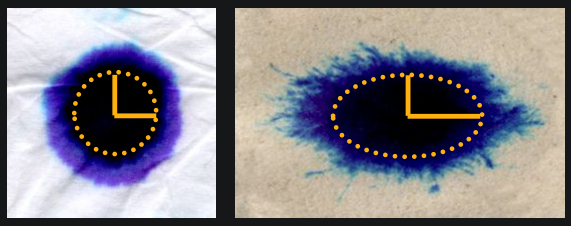
Outline

- Intro to modality
- Single tensor parameters, applications
- Beyond single tensor fit
- Visualization of DWI and model

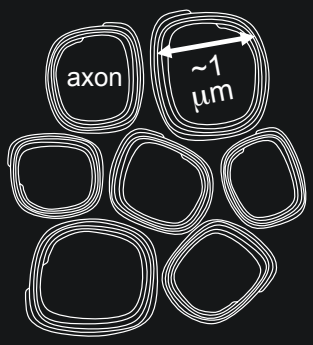
Diffusion imaging detects anisotropy



Kleenex newspaper

Anisotropy: directional variation in diffusivity

White Matter fiber bundle Cross-section:

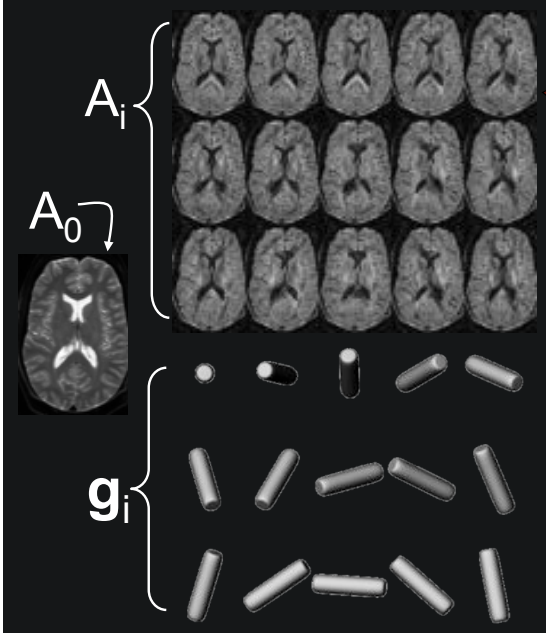


Microstructure of bundles directionally constrains water diffusion along fiber direction (LeBihan et al. 1985)

Diffusion-weighted MRI measures "apparent diffusion coefficient" (ADC) along many directions

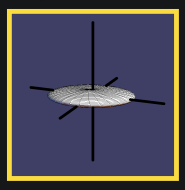
Tensors from diffusion-weighted images

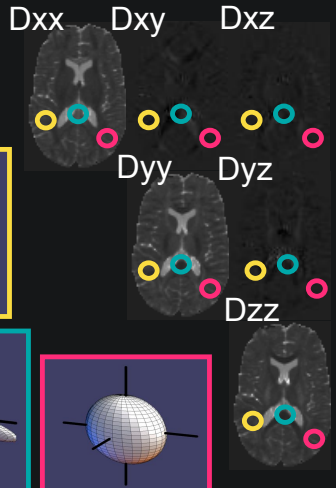
Single Tensor Model (Basser 1994) $A_i(b, \mathbf{g}) = A_0 e^{-b\mathbf{g}_i^T \mathbf{D} \mathbf{g}_i}$



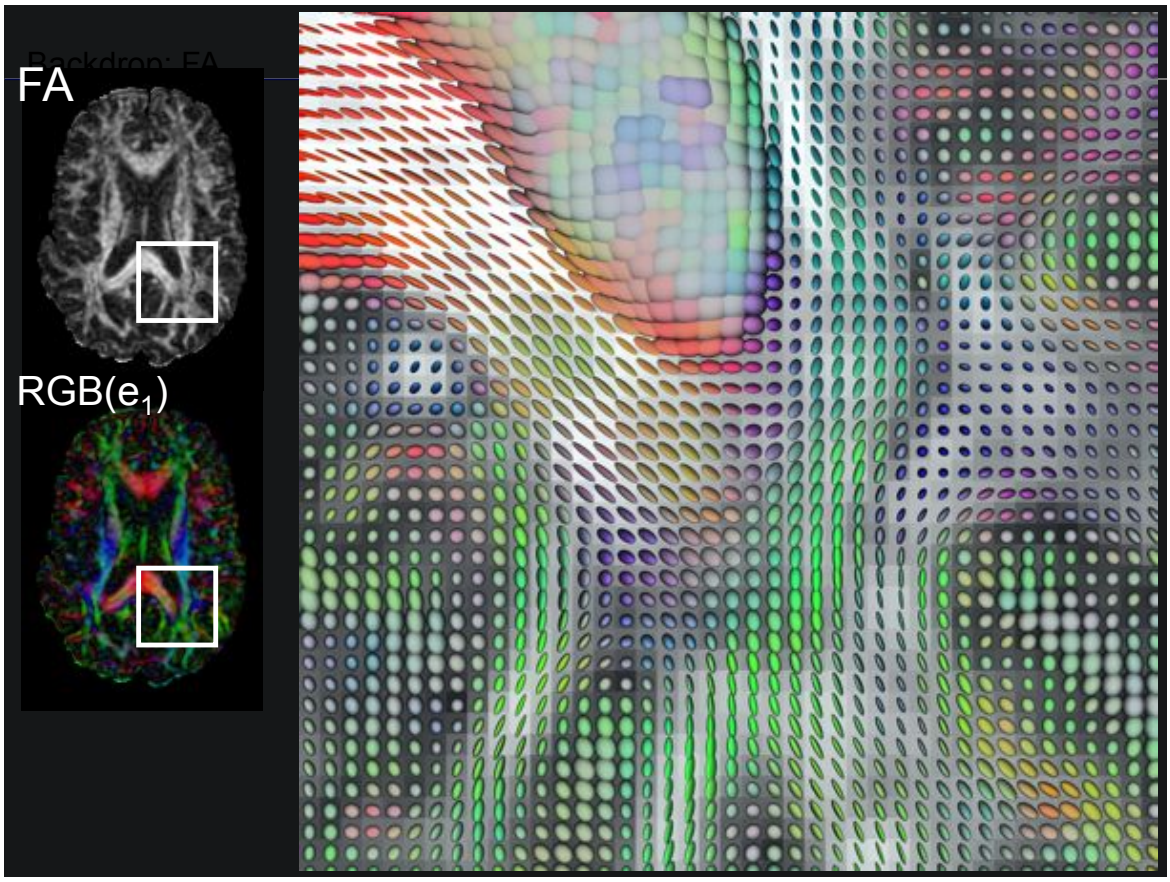
Linear regression

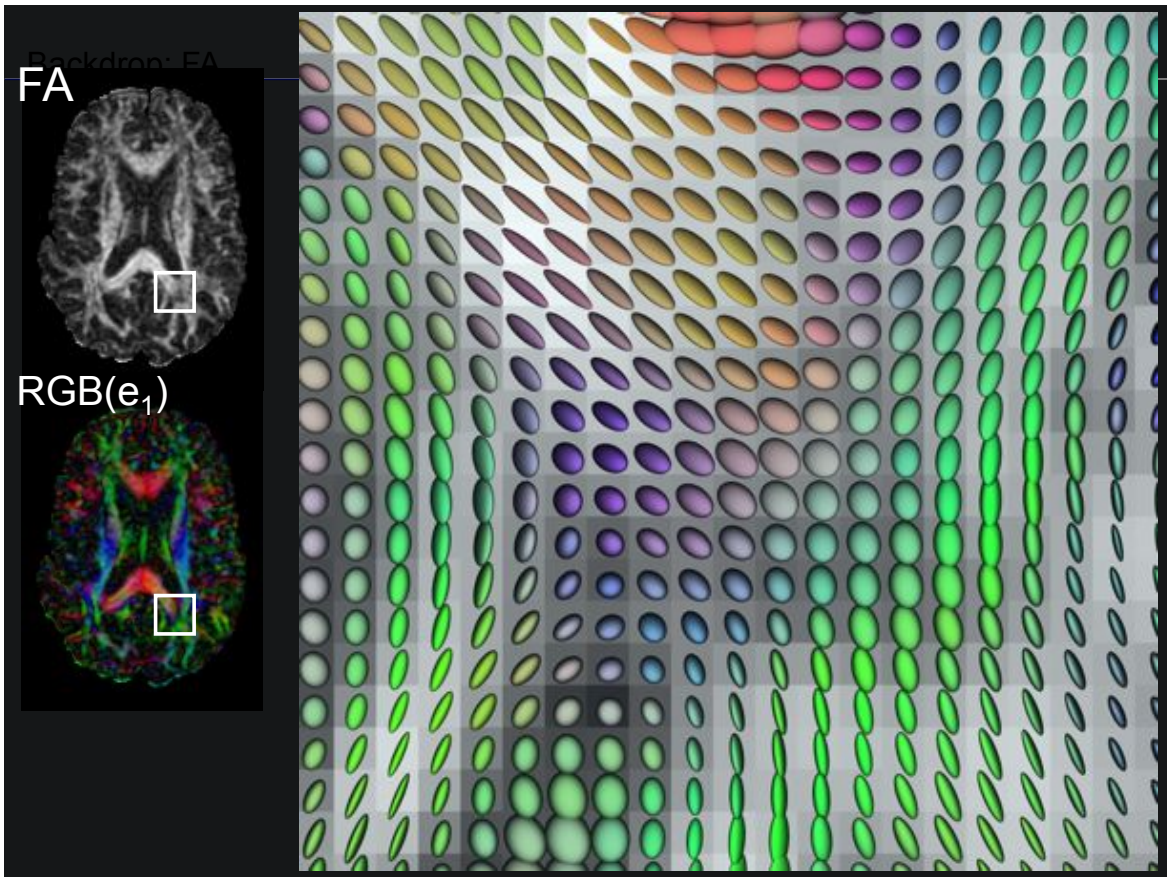
D





Derived scalars:
Bulk mean diffusivity
Fractional Anisotropy FA


FA
RGB(e_1)


FA
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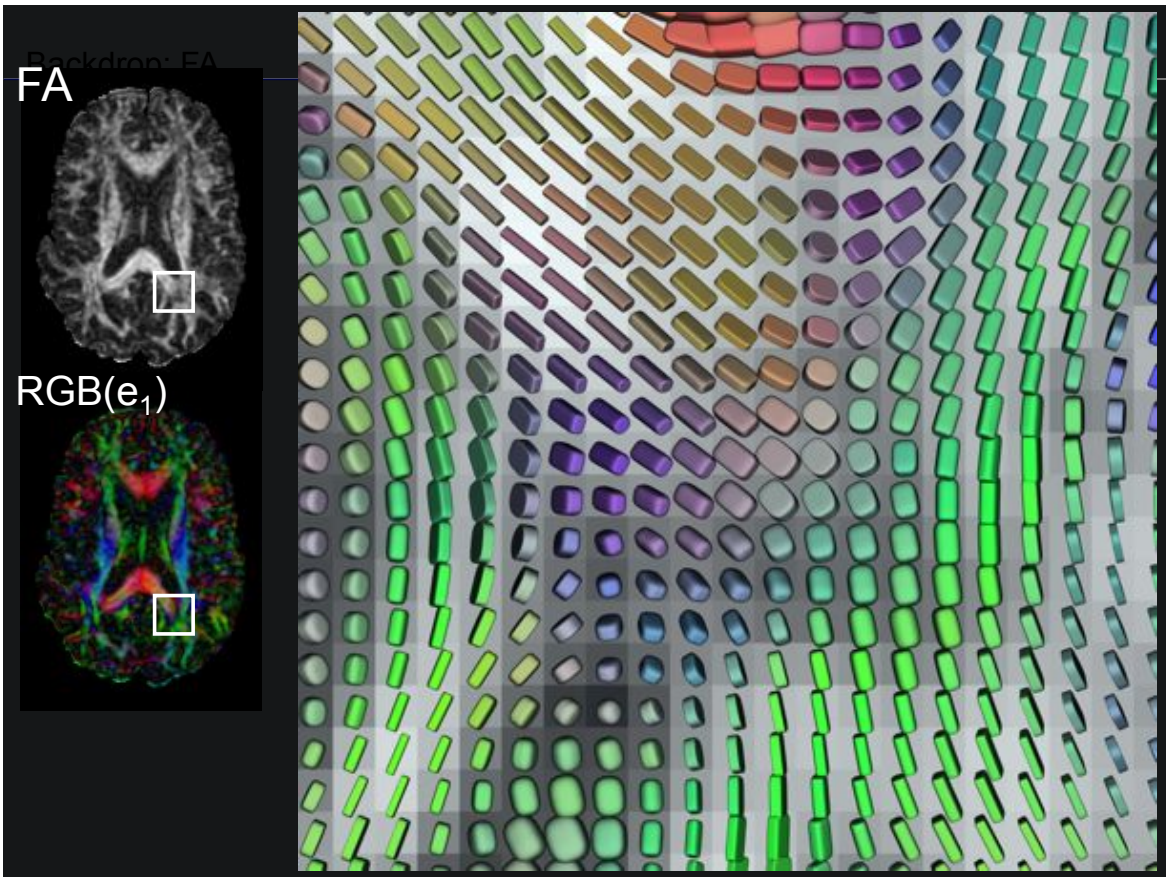


Tractography

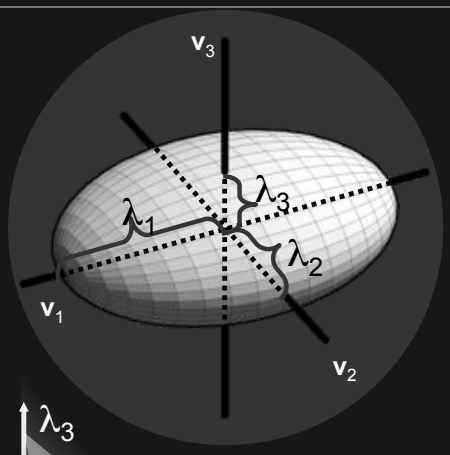
- Path integral of principal eigenvector
- Various parameter settings…

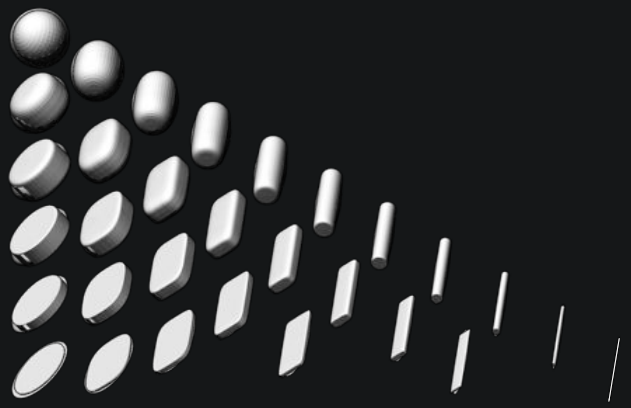
(demo)

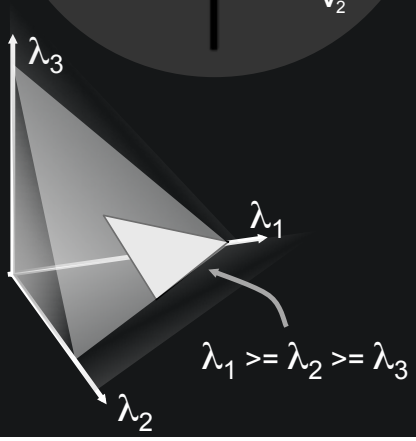
Tensor Shape = model parameters

$$\mathbf{D} = \mathbf{R}\Lambda\mathbf{R}^{-1}$$

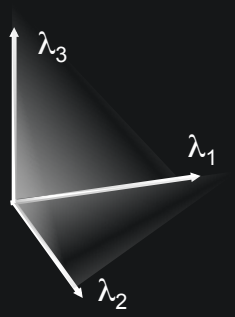
$$= \begin{bmatrix} | & | & | \\ \mathbf{v}_1 & \mathbf{v}_2 & \mathbf{v}_3 \\ | & | & | \end{bmatrix} \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix} \begin{bmatrix} \mathbf{v}_1 \\ \mathbf{v}_2 \\ \mathbf{v}_3 \end{bmatrix}$$







Tensor shape parameterizations

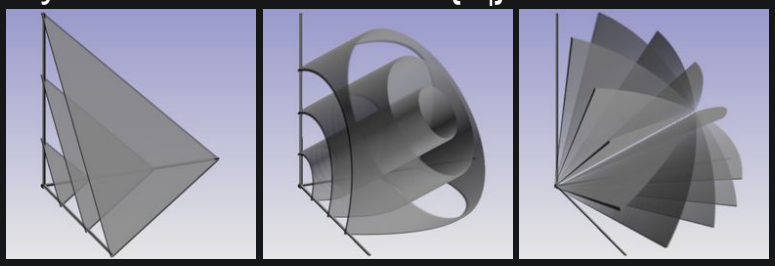


tr(**D**) = Dxx+Dyy+Dzz
|**D**| = sqrt(tr(**D**^{T}**D**))

E = deviatoric(**D**)
= **D** - trace(**D**)***I**/3

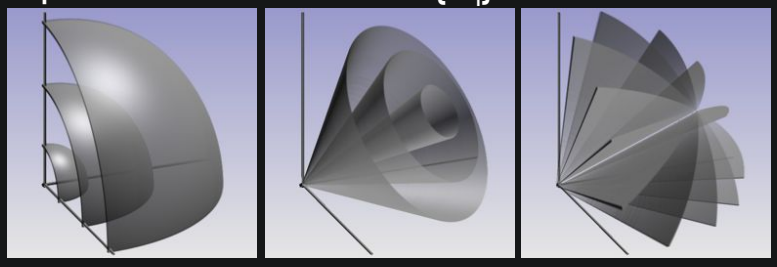
Mode = det(**E**/|**E**|)
(Criscione 2000)

Cylindrical Coordinates: {K_i}



K_1 = tr(**D**) K_2 = |**E**| K_2 = mode

Spherical Coordinates: {R_i}



R_1 = |**D**| R_2 = FA R_3 = mode

Clinical DTI Applications: Model Parameters

- Changes in FA due to pathology
  - Really the mainstay of DTI applications
- Change in FA/trace relationship
  - E.g. Tumor Infiltration Index (Lu et al. ‘04)
- Less so: Connectivity around tumors
- Point: model parameters are reliably measured, biologically meaningful, clinically significant
- High-level point: don’t lose track of why we do imaging and medical image analysis

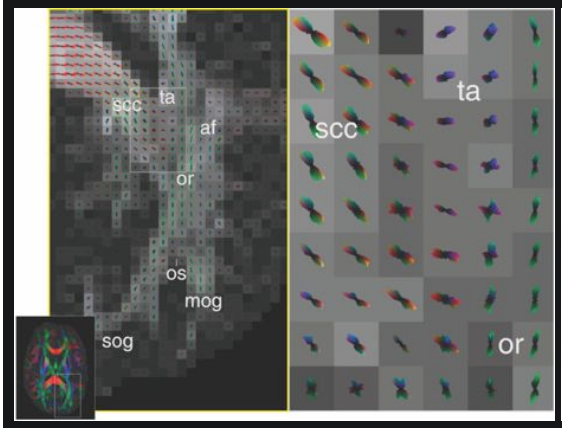
Beyond the Single Tensor Model

- Two (or more) Tensors

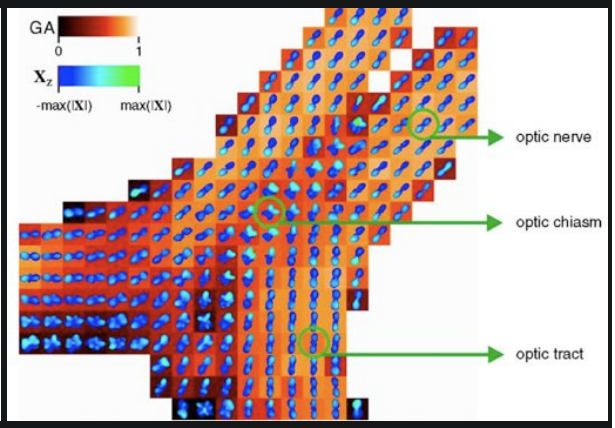
$$A_i = A_0(\alpha e^{-b\mathbf{g}_i^T\mathbf{D}_1\mathbf{g}_i} + (1-\alpha)e^{-b\mathbf{g}_i^T\mathbf{D}_2\mathbf{g}_i})$$

- No model: Spherical harmonics
- Diffusion Orientation, Funk-Radon Transforms
  - ADC peaks != fiber directions
  - Fiber crossing resolution
- Tension with clinical applications

Associated visualizations



Tuch ‘04



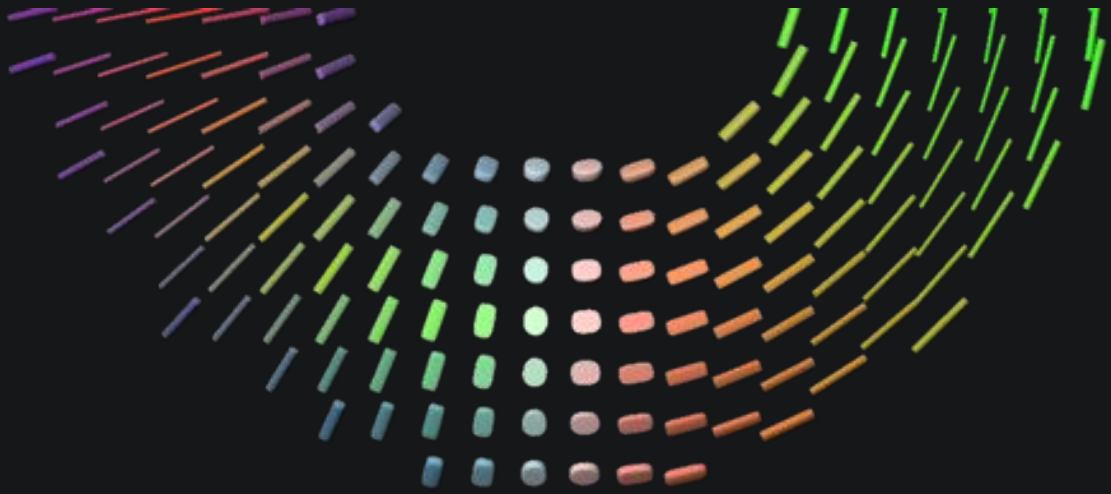
Ozarslan ‘06

Visualization as a data & model inspection

- Visualize **underlying** DWI data
  - How noisy is it?
  - Does data support complex analysis?
- Inspect relationship of DWI to single tensor model
  - Systematic errors highlight fiber crossings
- General ideas:
  - Use intuition of old (single tensor model) as **guide**
  - Use visualization to **illuminate** the path forward
  - Experience lends **perspective** to canned routines

Synthetic Data

- (again) using intuition about old as guide to new…



Synthetic Data

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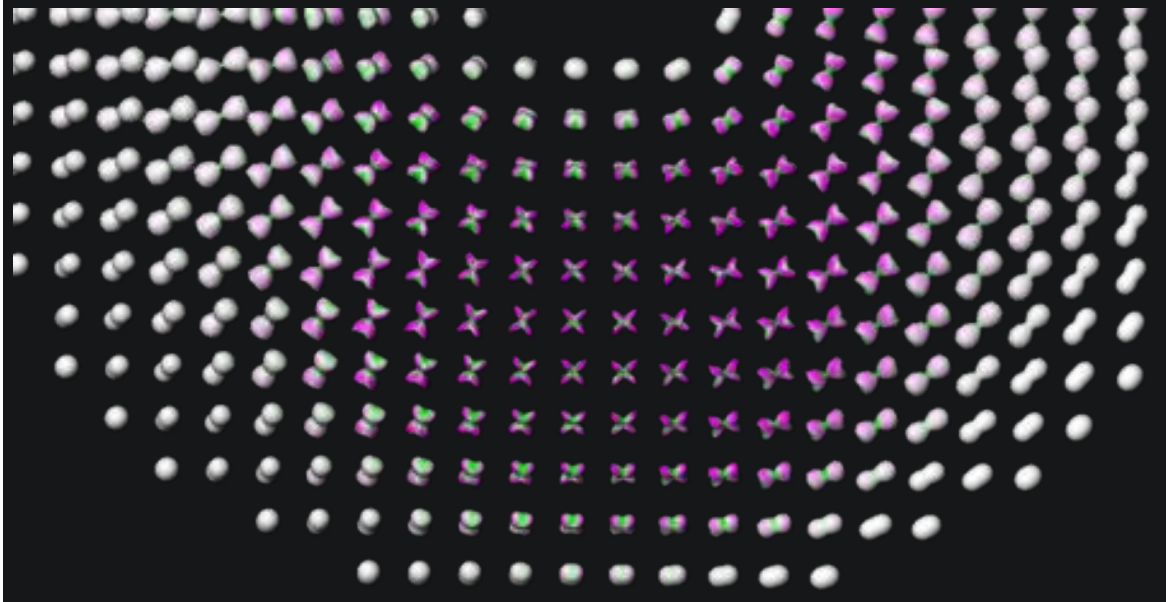
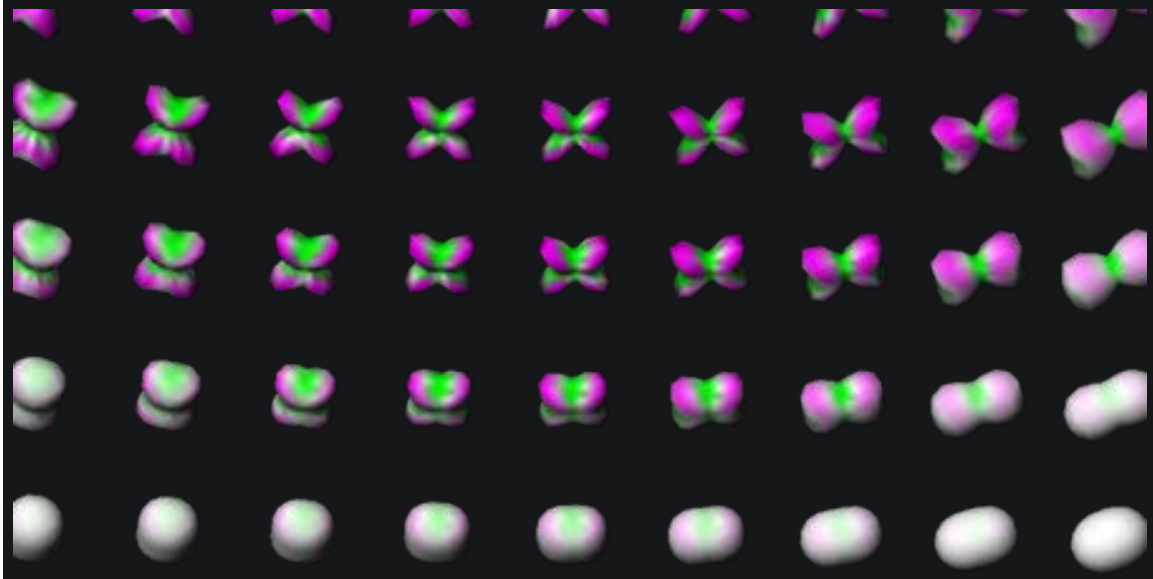


ADC profile colored by single-tensor error

Synthetic Data

- (again) using intuition about old as guide to new…



ADC profile colored by single-tensor error

- How does it look in real data?

(demo)

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thank you