Diffusion-weighted MRI

Acquisition, Analysis and Applications

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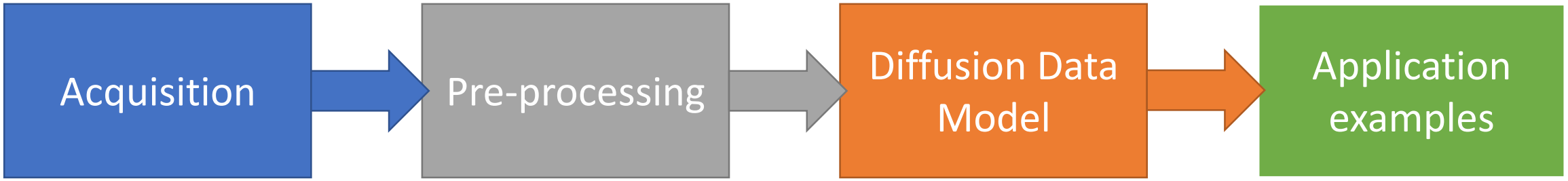
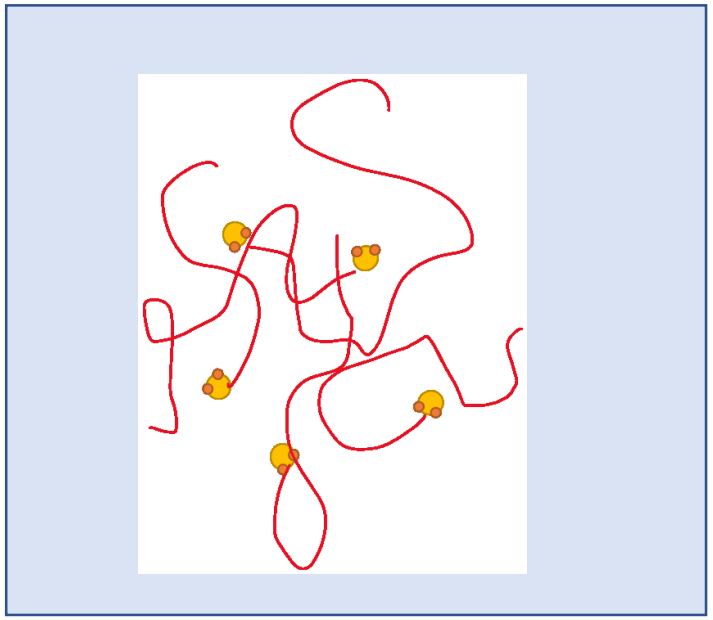
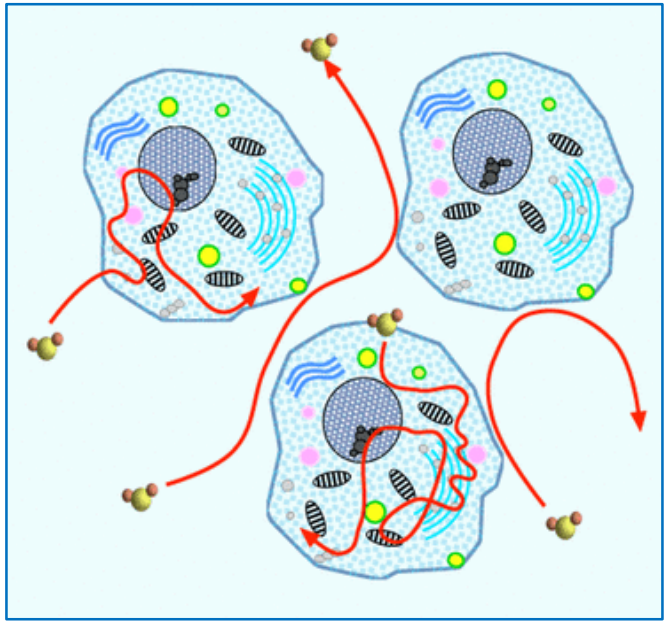


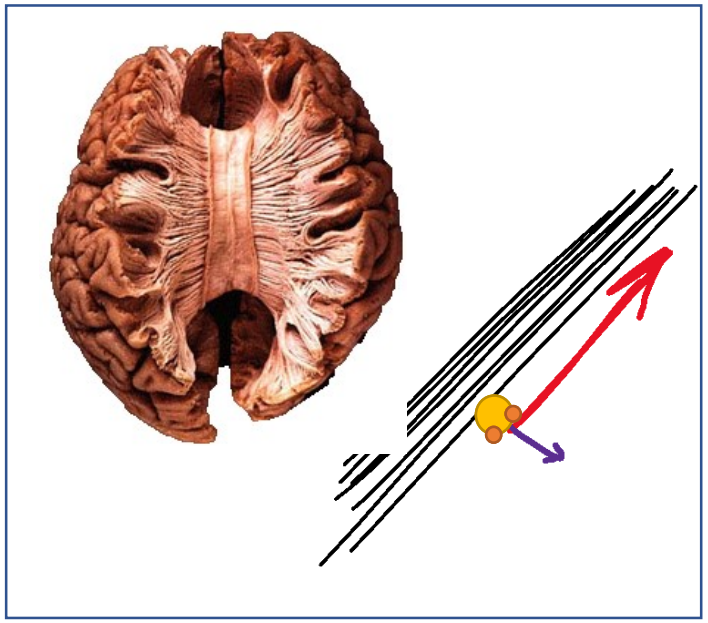
Why diffusion?



Water = free, unhindered diffusion

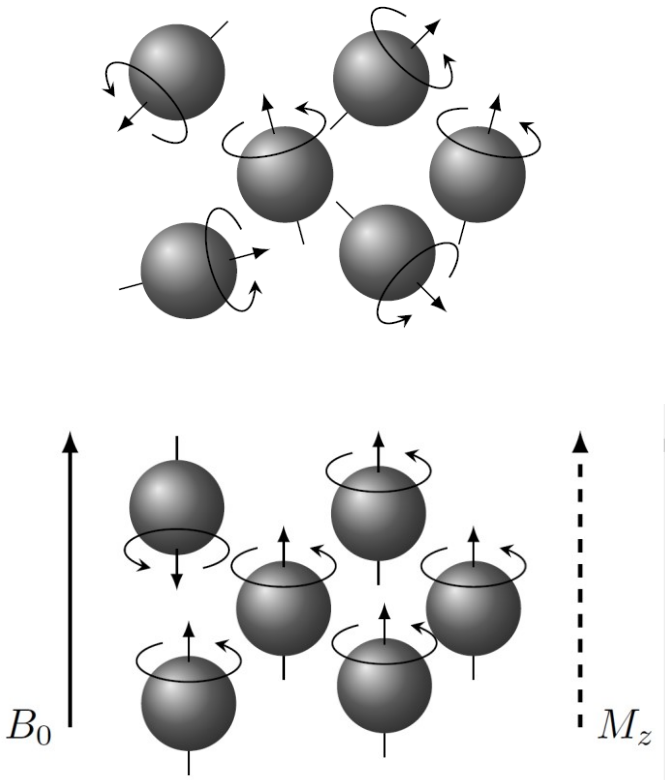


Diffusion in tissue => hindered by cell membranes etc.

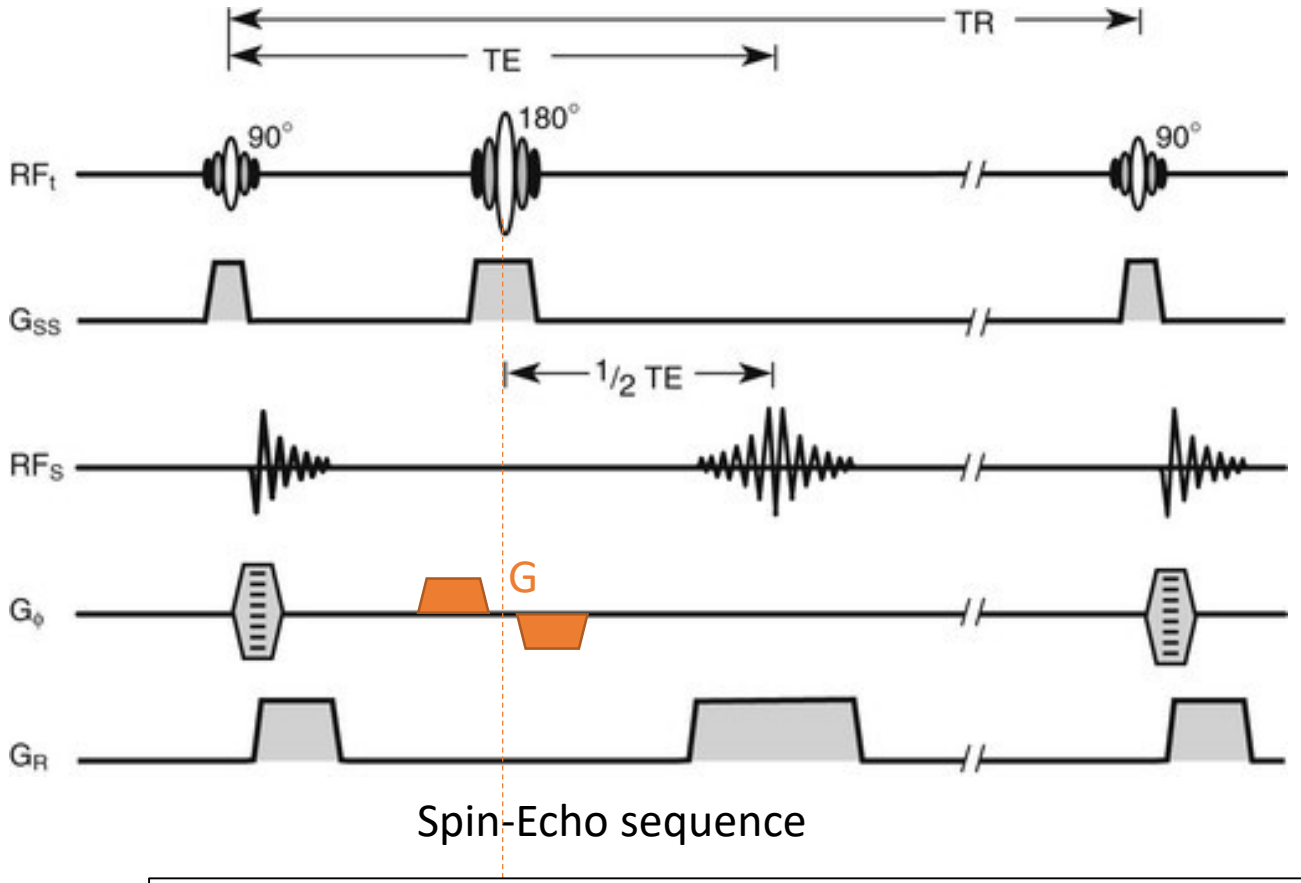


White matter tracts, highly organized tissue
=> Directional diffusion hindrance

Acquisition



Protons in B_0 field



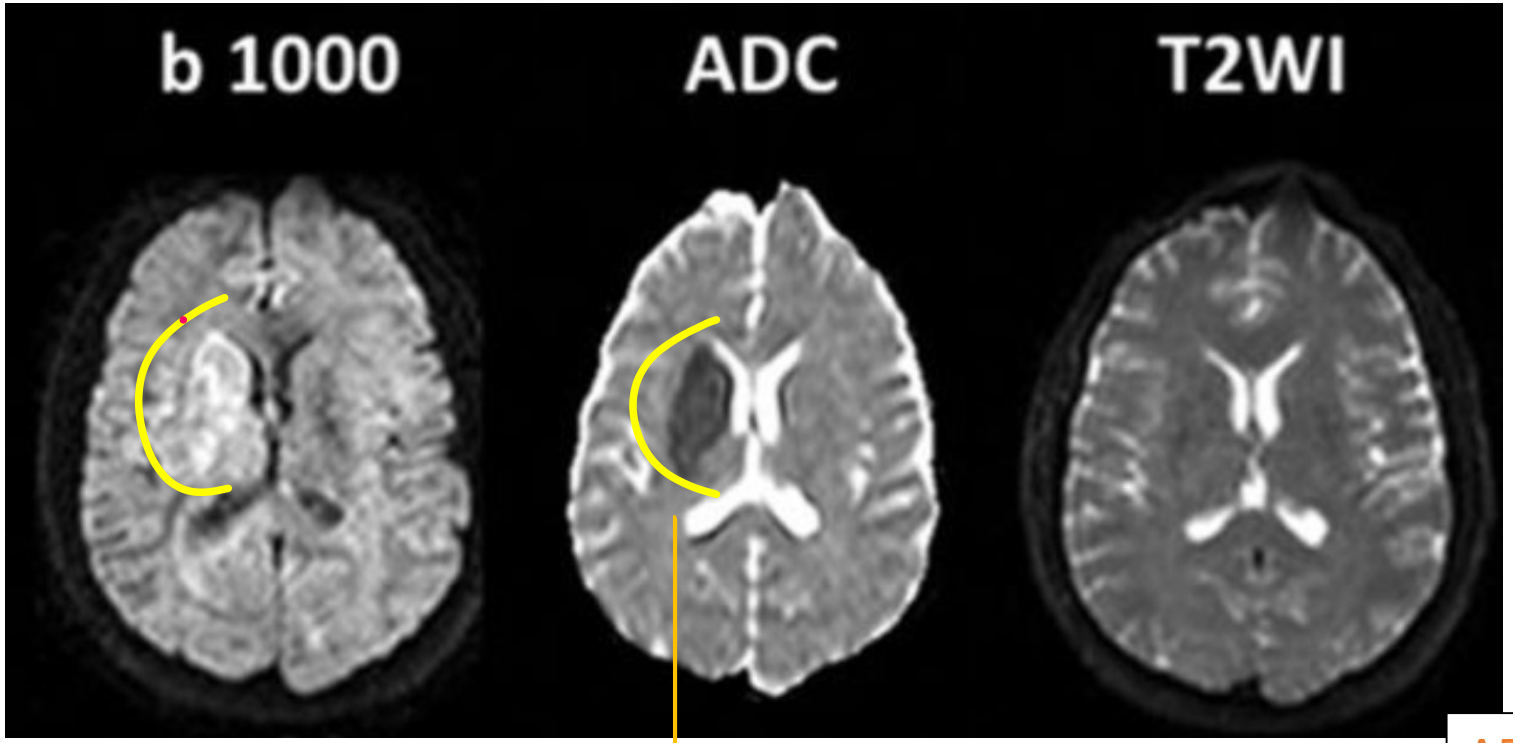
Spin-Echo sequence

We use additional phase gradients to encode diffusion – molecules subject to diffusion are brought *out of phase* and we measure less signal after rephasing

Simple model: Apparent Diffusion Coefficient (ADC)

$$\frac{S_{b>0}}{S_{b=0}} = e^{-b \cdot ADC}$$

We approximate the signal loss as an exponential decay steared by the gradient strength (*b value)* and the omnidirectional diffusivity (the ADC)

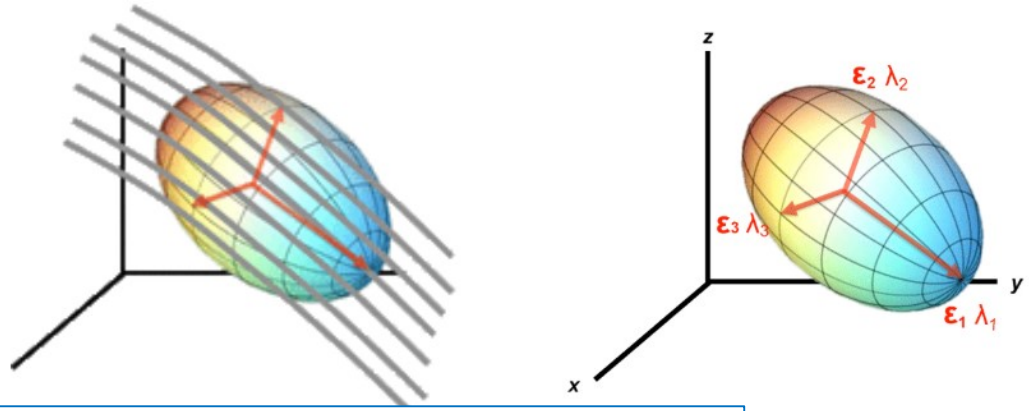


$S_{b=1000}$

$S_{b=0}$

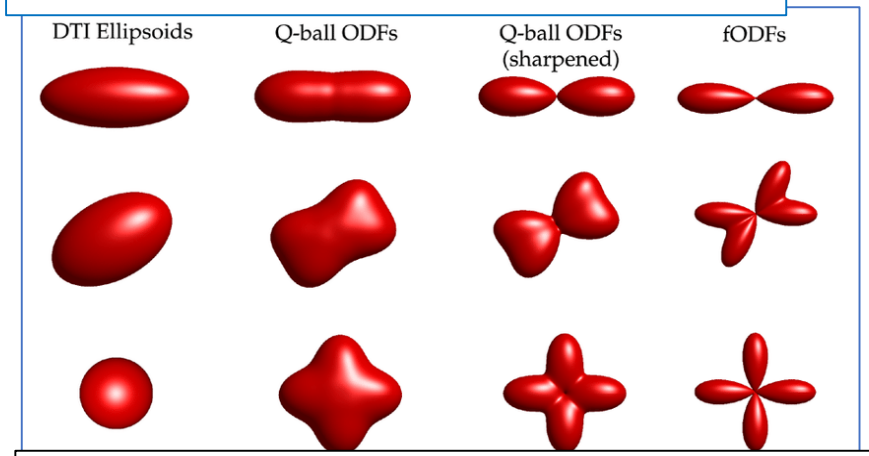
ADC can reveal areas of restricted diffusivity as a result of stroke

Directional model: Diffusion Tensor Imaging

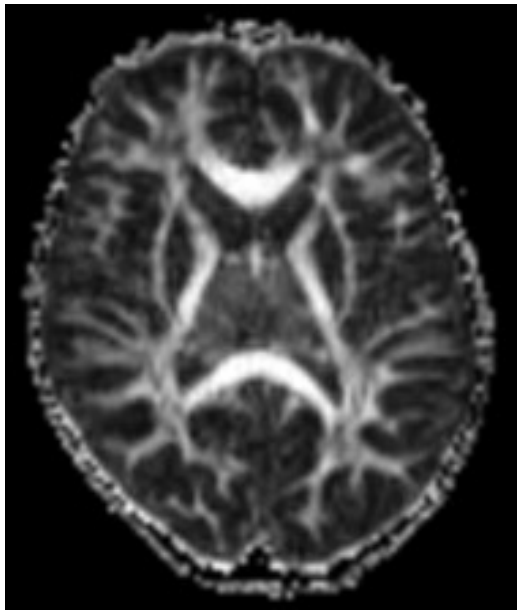


$$\mathcal{D} = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix}$$

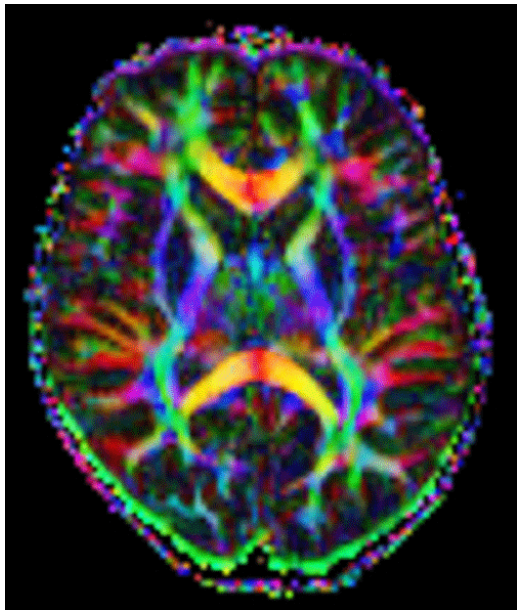
Higher-order models



DTI fails to model fiber crossings – we need higher order models (and pay for them with more acquisitions)



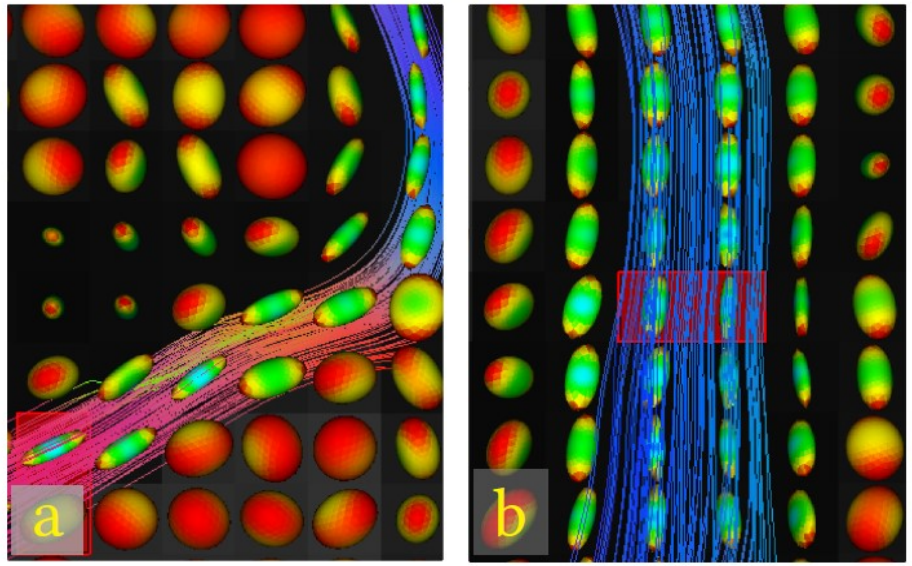
FA map



Principal direction

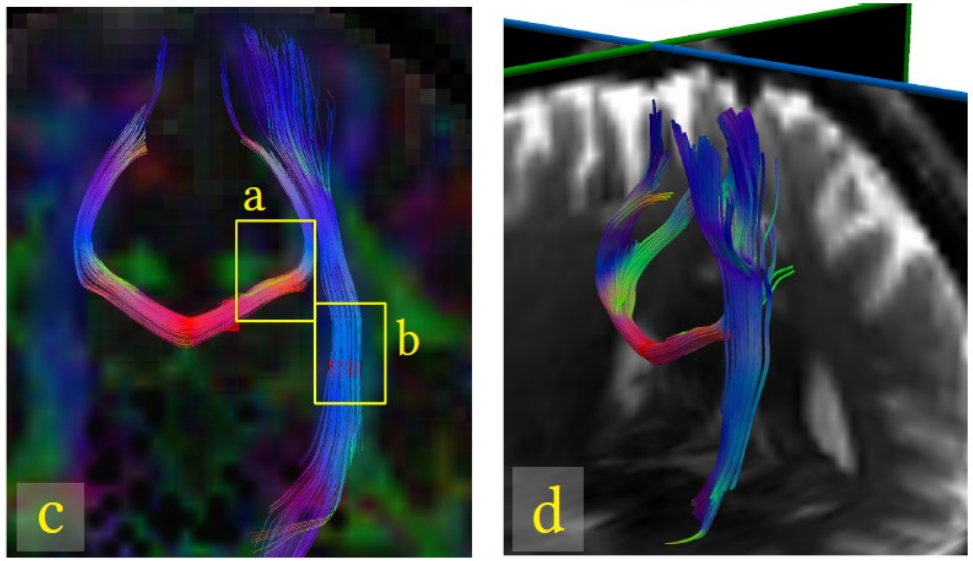
Fiber Tractography

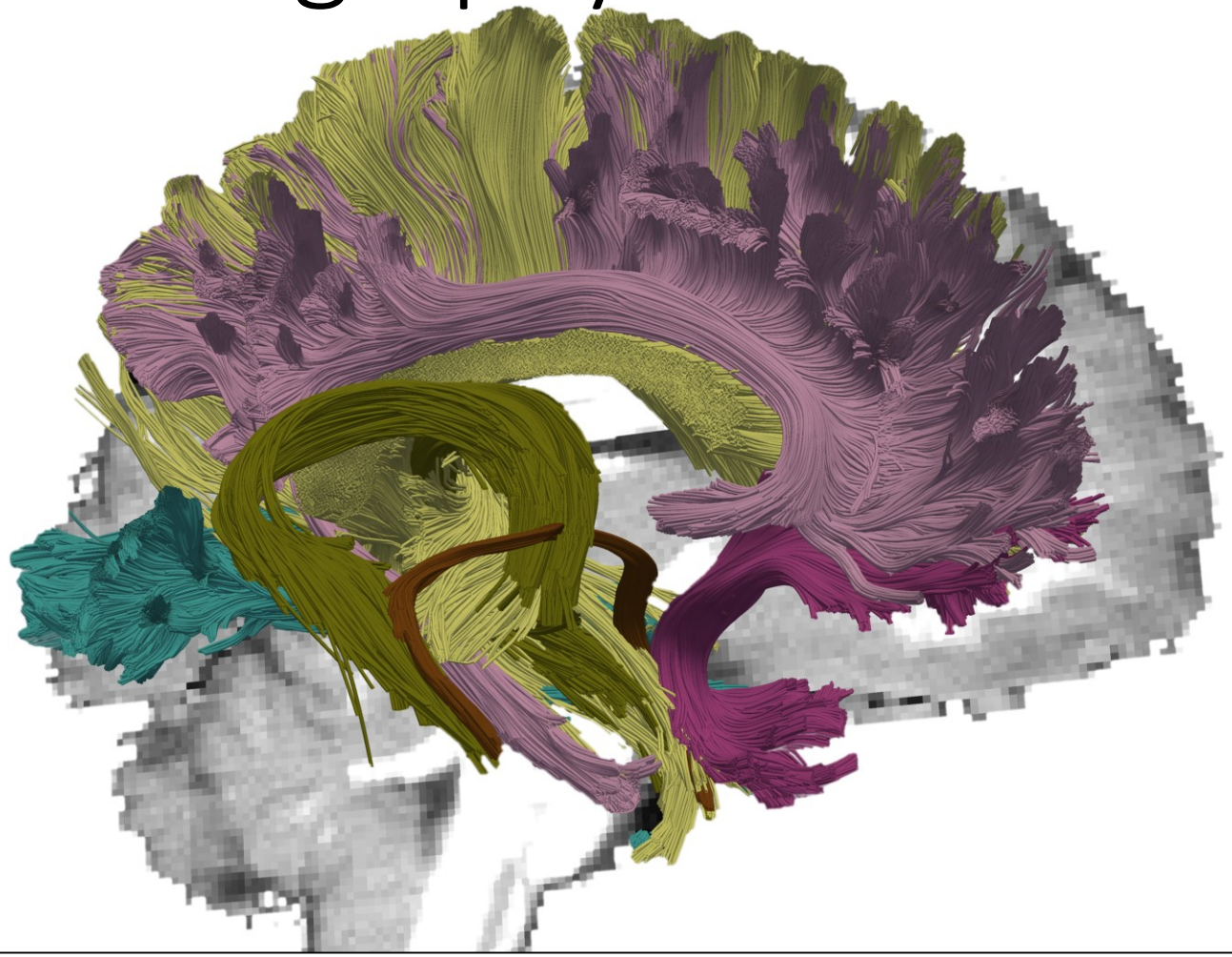
Streamline Tracking



2D View

3D View





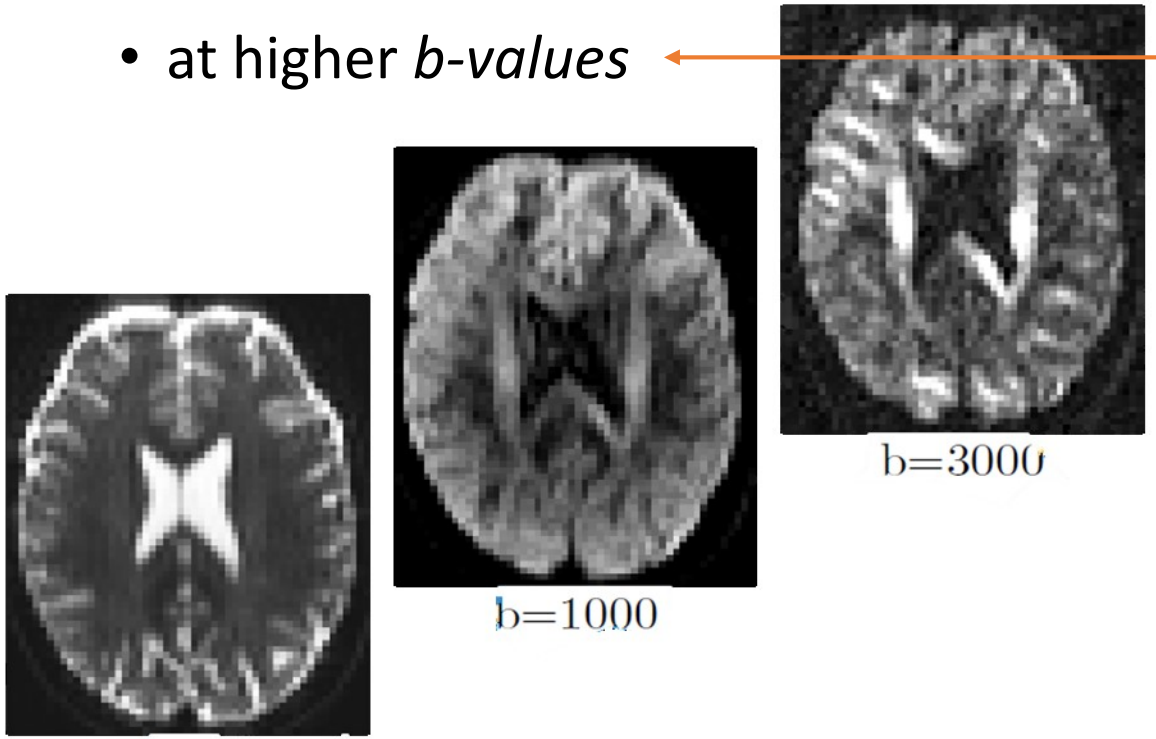
The directional models allows for estimating the paths of white matter tracts and evaluate f.i. how different regions of the brain are interconnected.

Motion and artifacts

- We want precise tractography, thus need higher order models
- They require
  - more gradient images (3D-volumes)
  - at higher *b-values*

eddy-currents, gross motion

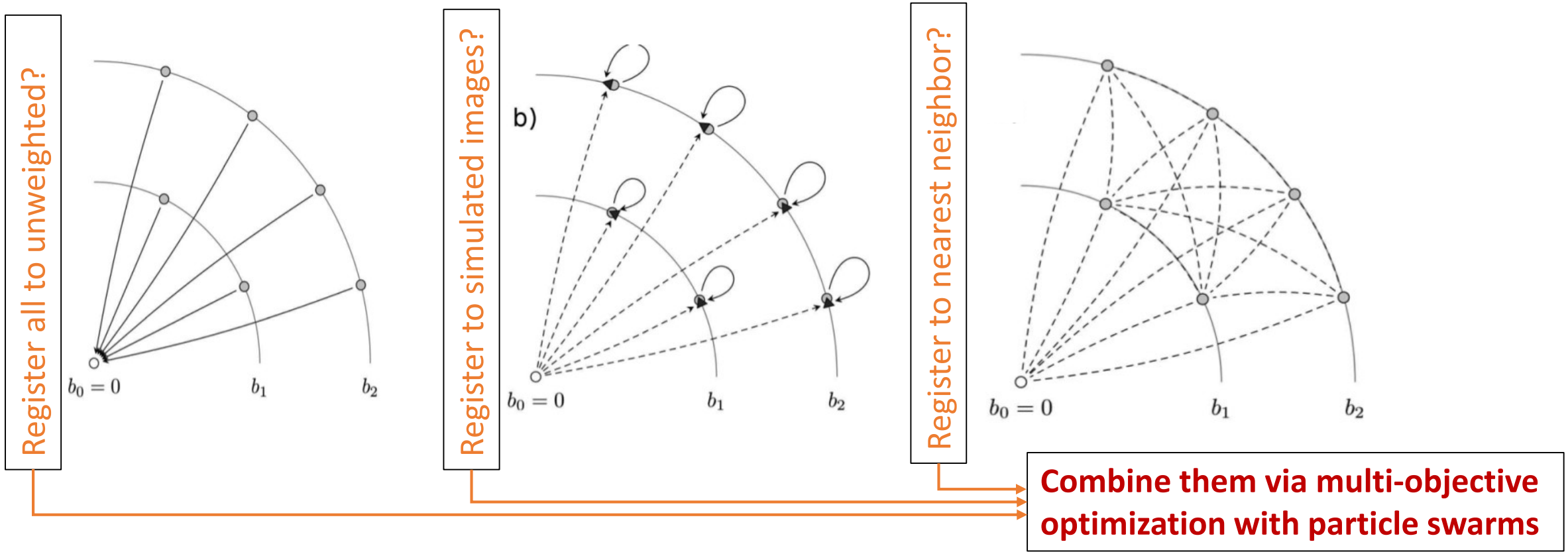
eddy-currents, higher b = lower SNR



Examples of images at different *b* values

Robust artifact and motion correction

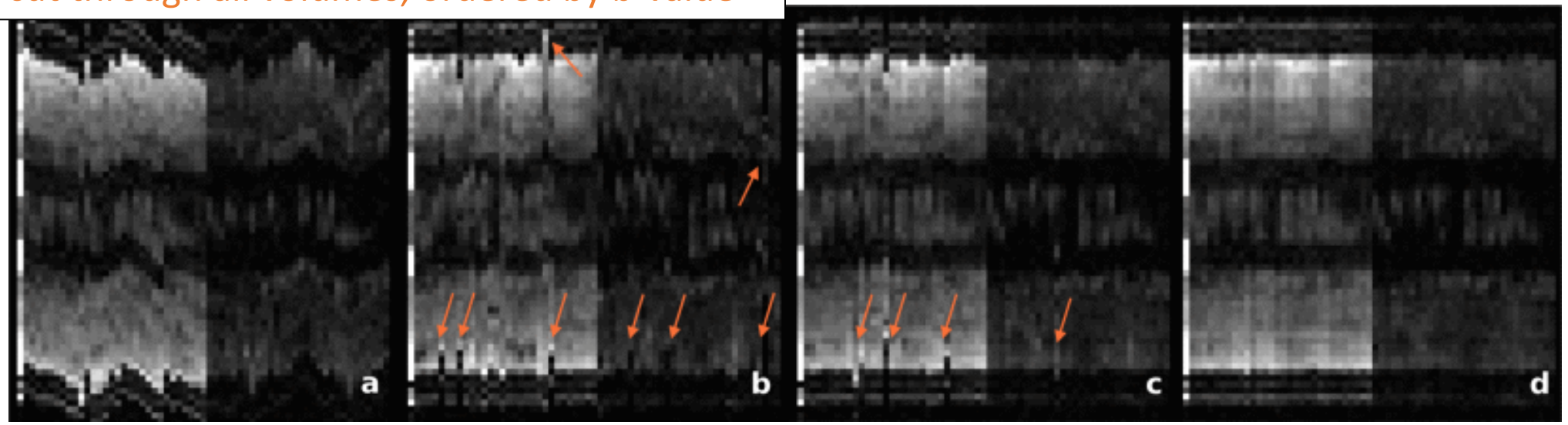
- Best method – prospective correction with motion tracking
- When not available → **How to make a robust retrospective correction?**



Hering, J., Wolf, I., & Maier-Hein, K. H. (2016). Multi-Objective Memetic Search for Robust Motion and Distortion Correction in Diffusion MRI. *IEEE transactions on medical imaging*, *35*(10), 2280-2291

Effects of robust motion correction

A cut through all volumes, ordered by b-value



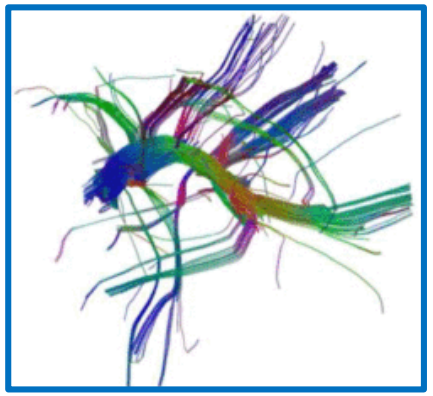
Visualization via tractography

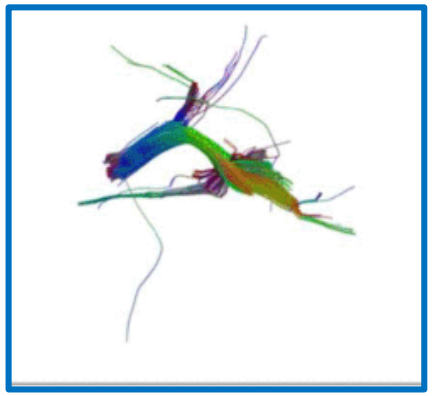
Objective 1

Objective 2

Proposed MO

Ground-truth

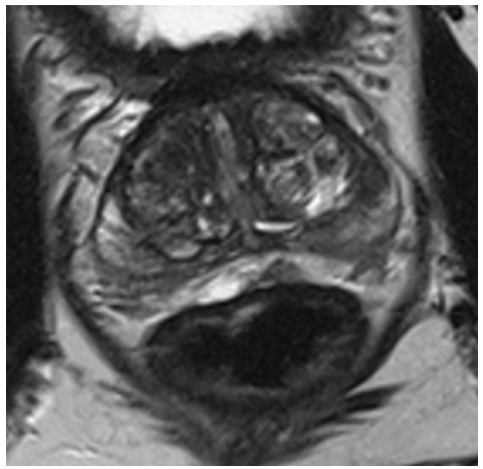


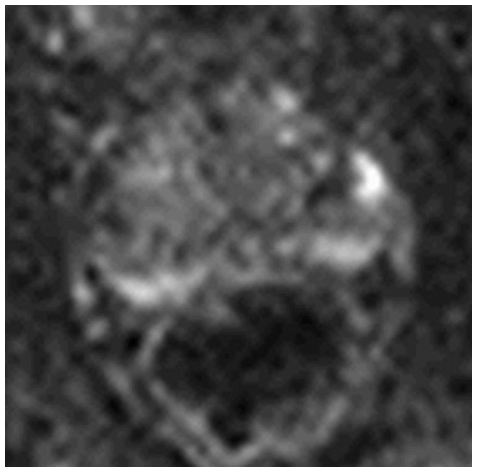


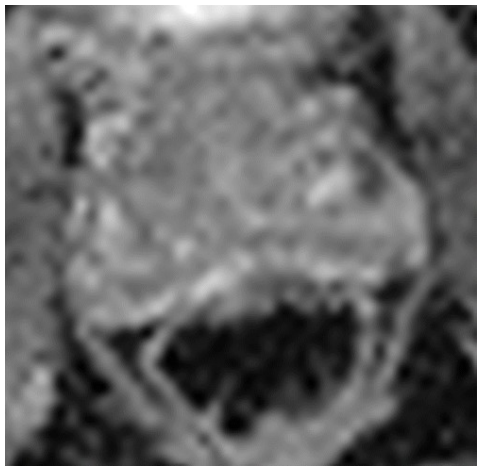
Recent applications

DWI meets AI

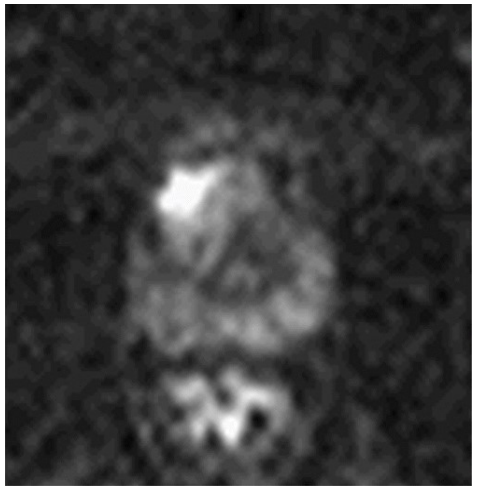
Applications : AI for prostate

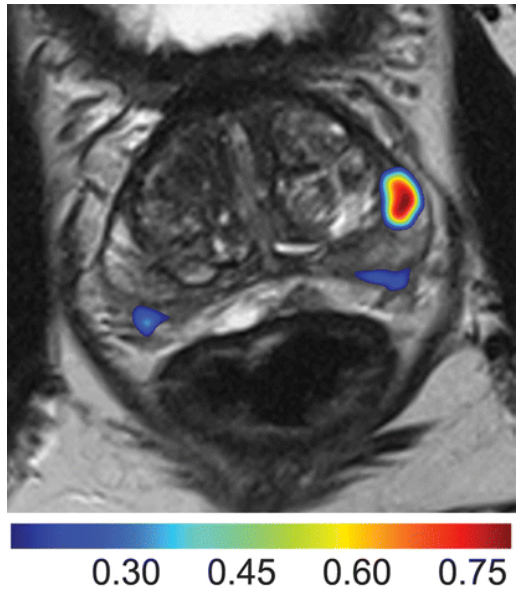


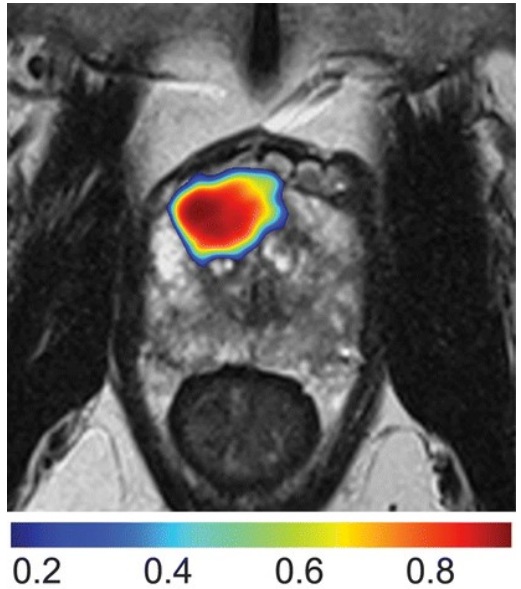




T2W DWI b=1500 s/mm^2 ADC



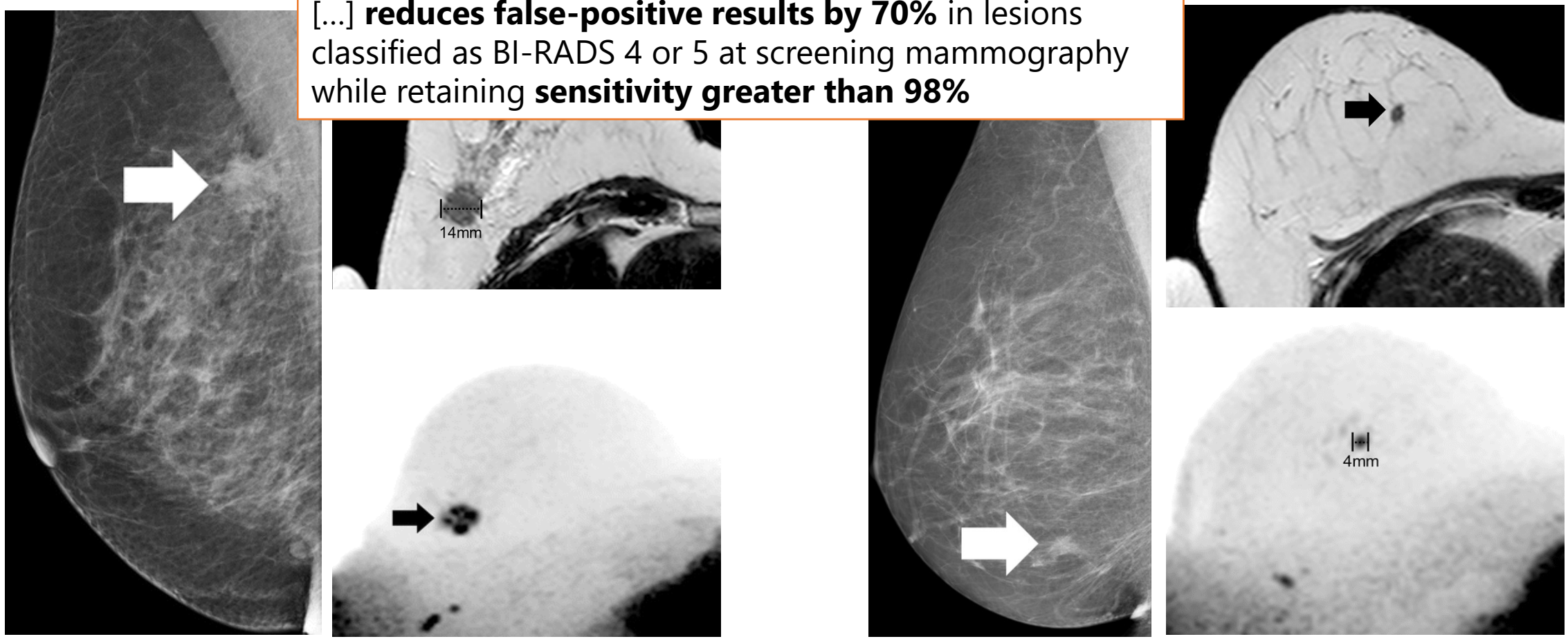




Schelb, Patrick, et al. "Classification of Cancer at Prostate MRI: Deep Learning versus Clinical PI-RADS Assessment." *Radiology* (2019): 190938.

Applications : Mamma-screening

[…] **reduces false-positive results by 70%** in lesions classified as BI-RADS 4 or 5 at screening mammography while retaining **sensitivity greater than 98%**

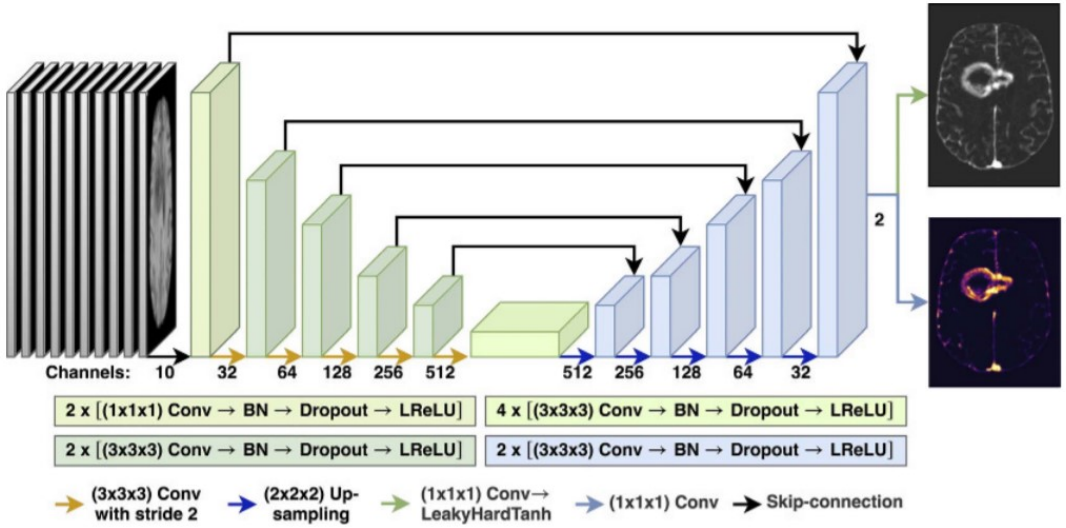


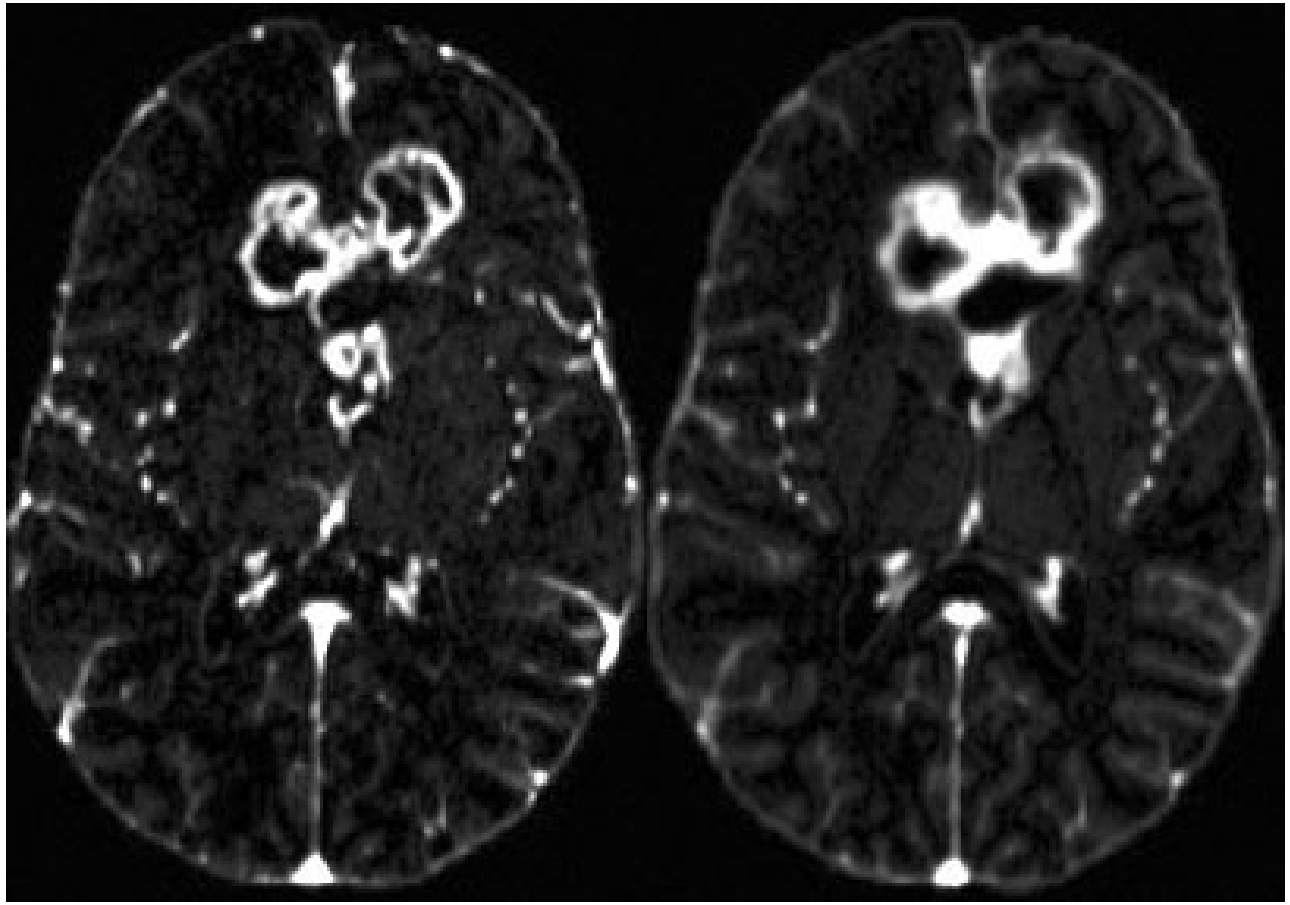
Bickelhaupt, Sebastian, et al. "Fast and noninvasive characterization of suspicious lesions detected at breast cancer X-ray screening: capability of diffusion-weighted MR imaging with MIPs." *Radiology* 278.3 (2015): 689-697

Applications : AI for virtual contrast

Input data: native T1w, T2w, FLAIR, DWI (b=0, b=1200 mm^2/s), SWI.

Contrast data: ce-T1w, intravenous (Gd-DOTA, Dotarem)

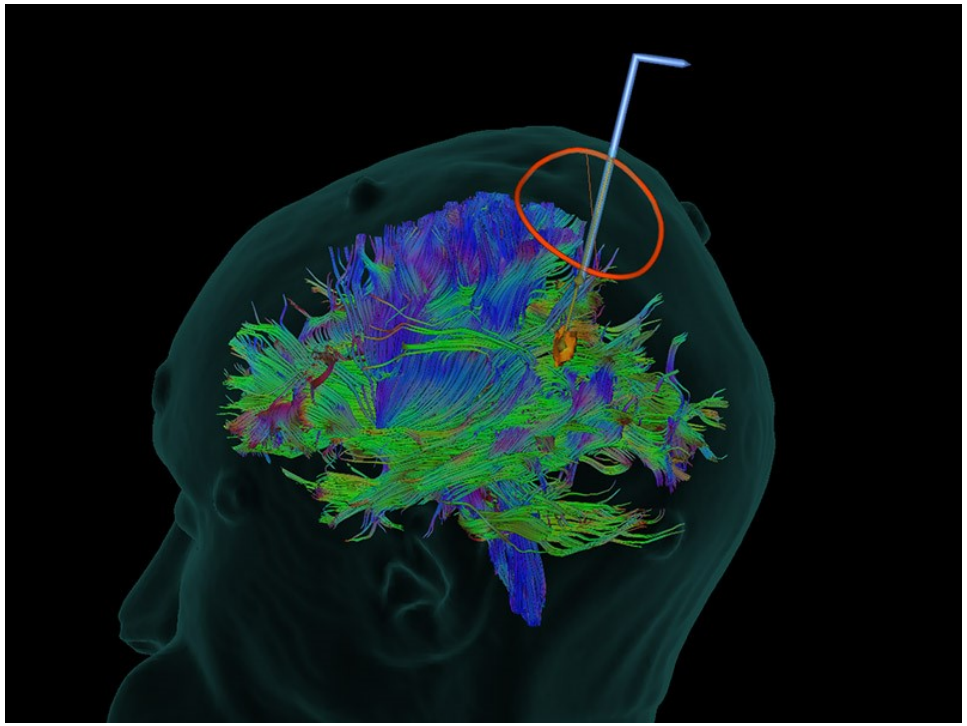


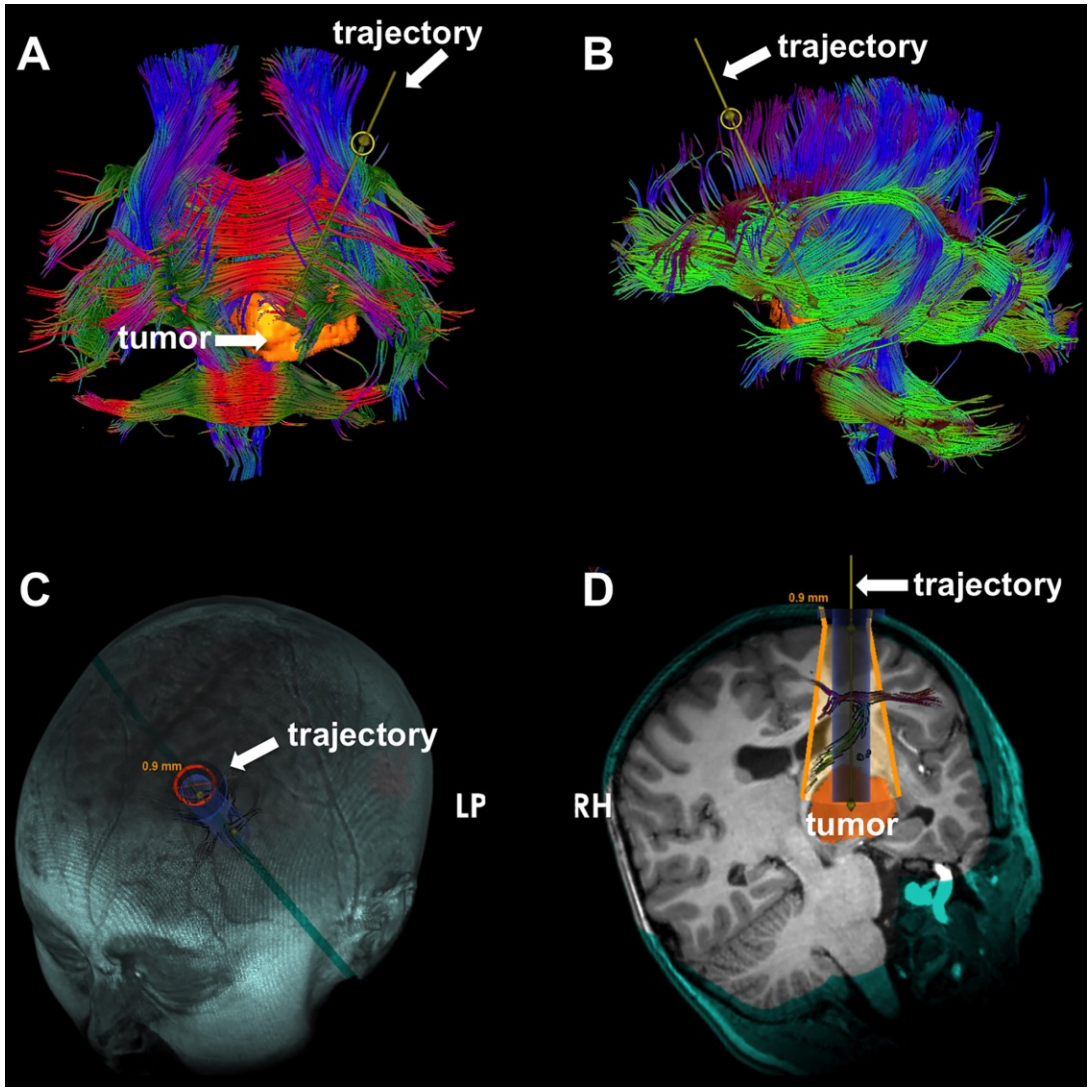


Kleesiek, Jens et al. (2019). Can Virtual Contrast Enhancement in Brain MRI Replace Gadolinium?: A Feasibility Study. *Investigative Radiology*. 54. 1. 10.1097/RLI.0000000000000583.

Applications : Tracking for navigation

Planning and intra-operative navigation in neurosurgery



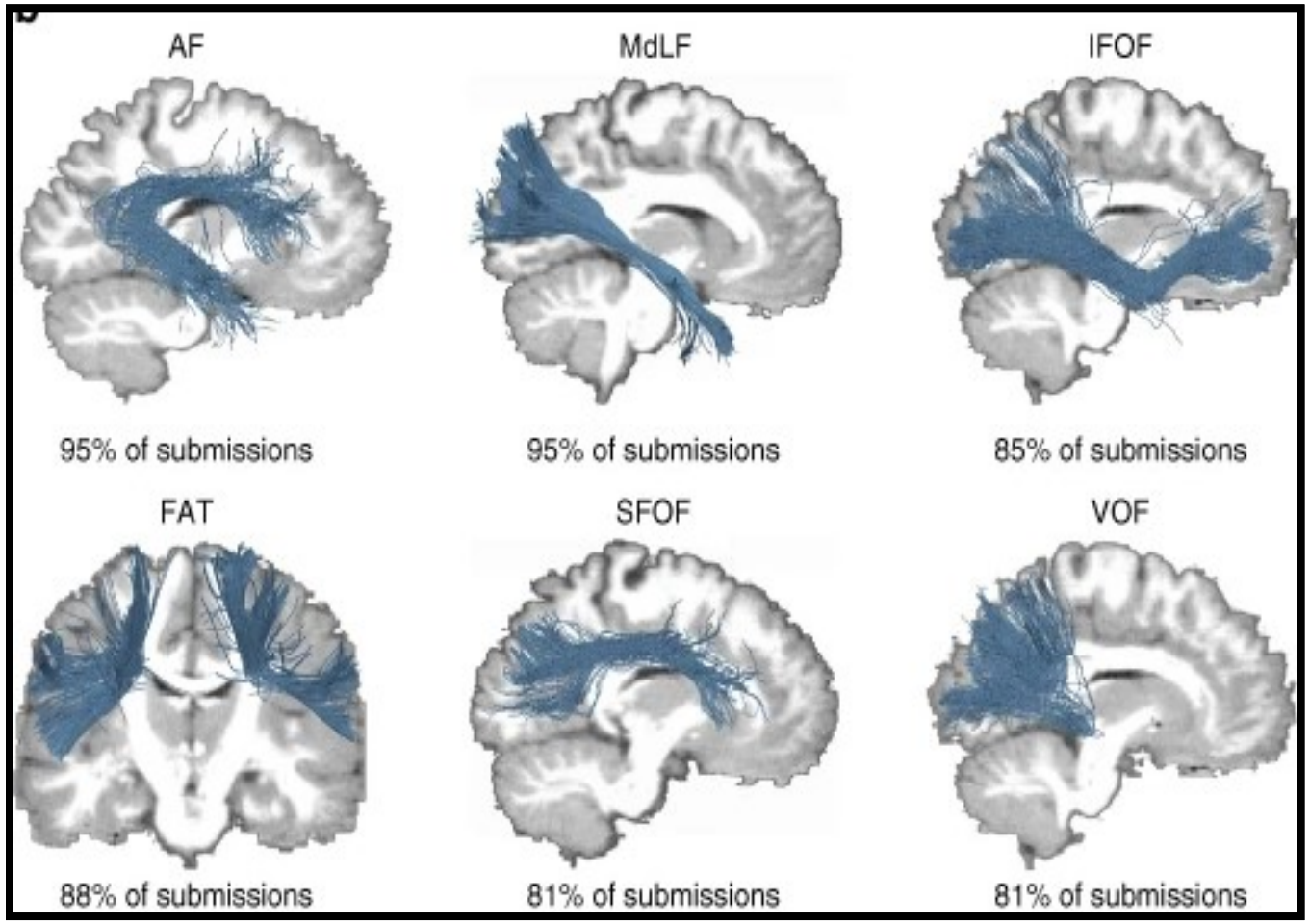


synaptive medical BrightMatter™ Guide

Research : Can we fully trust tractography?

[…] most state-of-the-art algorithms produce tractograms containing **90% of the ground truth bundles**

However, they may contain **more invalid than valid bundles**, and half of these invalid bundles occur systematically […]



Maier-Hein, K.H., Neher, P.F., Houde, J. *et al.* The challenge of mapping the human connectome based on diffusion tractography. *Nature Communications* **8,** 1349 (2017) doi:10.1038/s41467-017-01285-x

Discussion

Thank your for your attention!

For discussion:

- DWI has nice applications, can improve diagnosis, but can we afford it?

- The economic pressure on radiology is immense, maybe we should start researching how to achieve the same as presented, but with less data, other modalities?