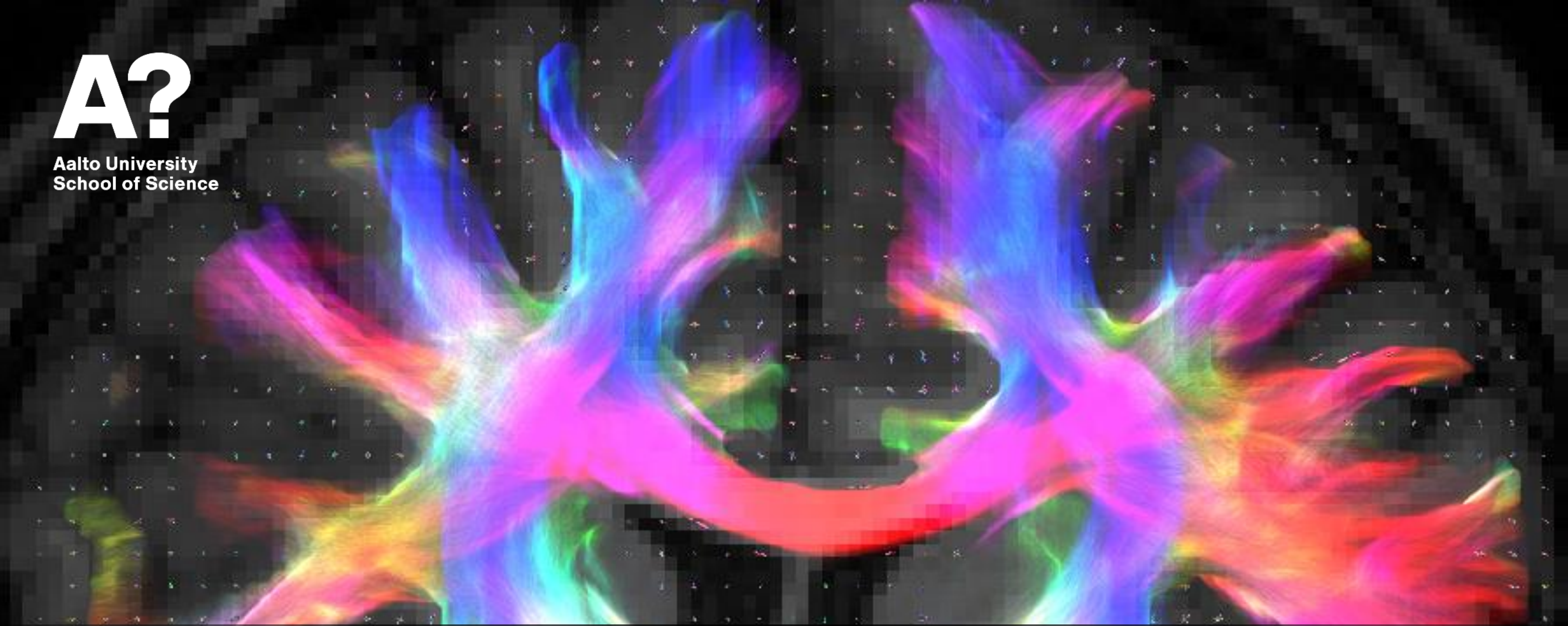
Aalto University
School of Science



Session 3:

Diffusion tensor imaging (DTI)

NBE-E453001 - Special Course in Human Neuroscience V D:

Imaging Brain Microstructure and Connectivity with Diffusion MRI

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Session 3 outline

Basics and challenges of DTI

Group discussion in Flinga

Quiz (10 min)

Break (5 min)

Practical demonstration of preprocessing

Discussion and feedback

Assignments before session 4

Intended learning outcomes

By completing the course, the student can

- **understand diffusion MRI acquisition and analysis methods**
- describe applications of these methods
- **explain the principles of investigating brain microstructure and structural brain connectivity with diffusion MRI**
- **recognize issues in applying these methods in research and clinic**
- apply diffusion MRI methods to investigate brain microstructure and structural brain connectivity (e.g., analyze a dataset or design a project)

Course outline

Session 1: Physics of diffusion MRI acquisition and artefacts (24.4.)

Self-study (pre-assignment) and lectures, quiz

Homework: Learning log and essay + self-study (material given at the end of the session)

Session 2: Data preprocessing (29.4.)

Self-study, lecture, practical demonstrations, group discussion, individual reflection, quiz

Homework: Learning log + self-study

Start of the project work

Course outline

Session 3: Diffusion tensor imaging (14.5.)
Self-study, lecture, practical demonstrations, group discussion, individual reflection, quiz

Homework: Learning log (DL 18.5.) self-study, return first draft of project work report (DL 20.5.)

Session 4: Constrained spherical deconvolution and tractography (21.5.)

Self-study, lecture, practical demonstrations, group discussion, individual reflection, quiz

Homework: Learning log (DL 25.5.). self-study, give peer feedback on the project work report (DL 29.5.)

Course outline

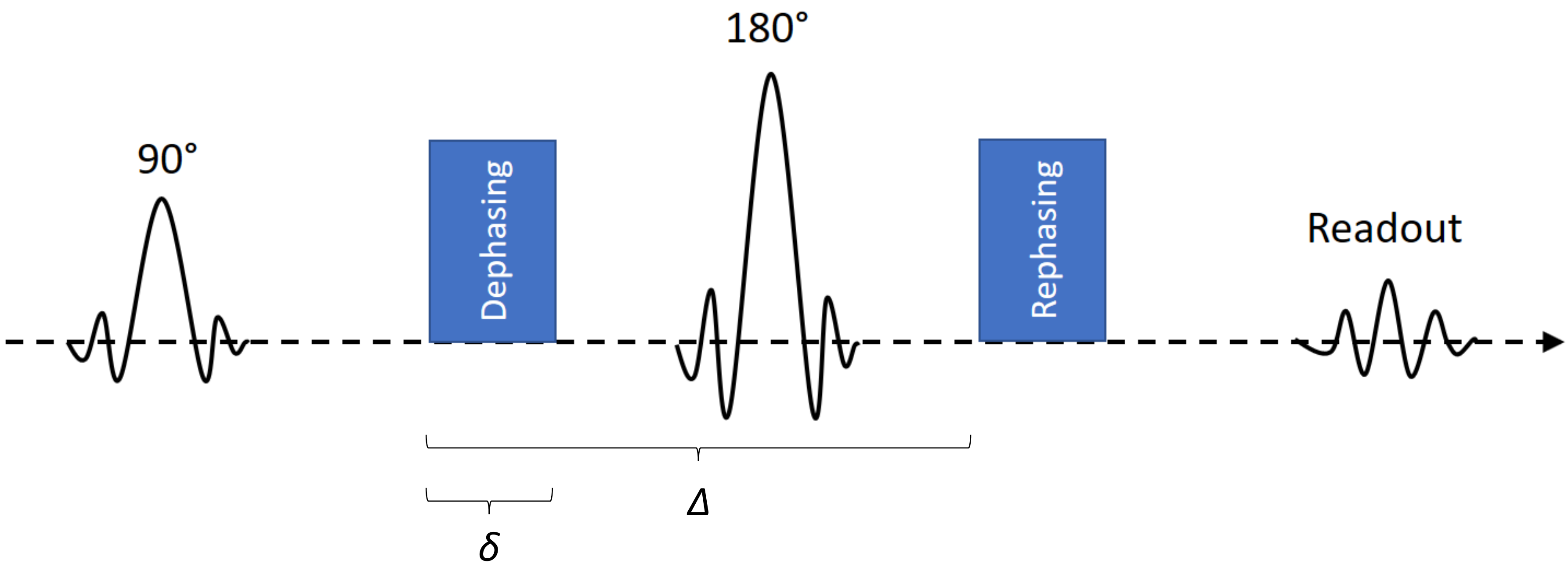
Session 5: Connectivity networks and microstructural analyses (30.5.)

Self-study, lecture, practical demonstrations, group discussion, individual reflection, quiz

Homework: Learning log + self-study, return project work report (5.6.)

Session 6: Summary of the course, presentations of project works (6.6.)
Seminar presentations, lecture, group discussion, feedback, individual reflection

Measuring diffusion with pulsed-gradient spin echo



Diffusion coefficient

- Along the orientation of the diffusion gradient:

$$\frac{S(b)}{S(0)} = e^{-bD}$$

S: *DW signal*
S_0: *non-DW signal*
D: *diffusion coefficient*
b: *diffusion-weighting (b-value)*

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

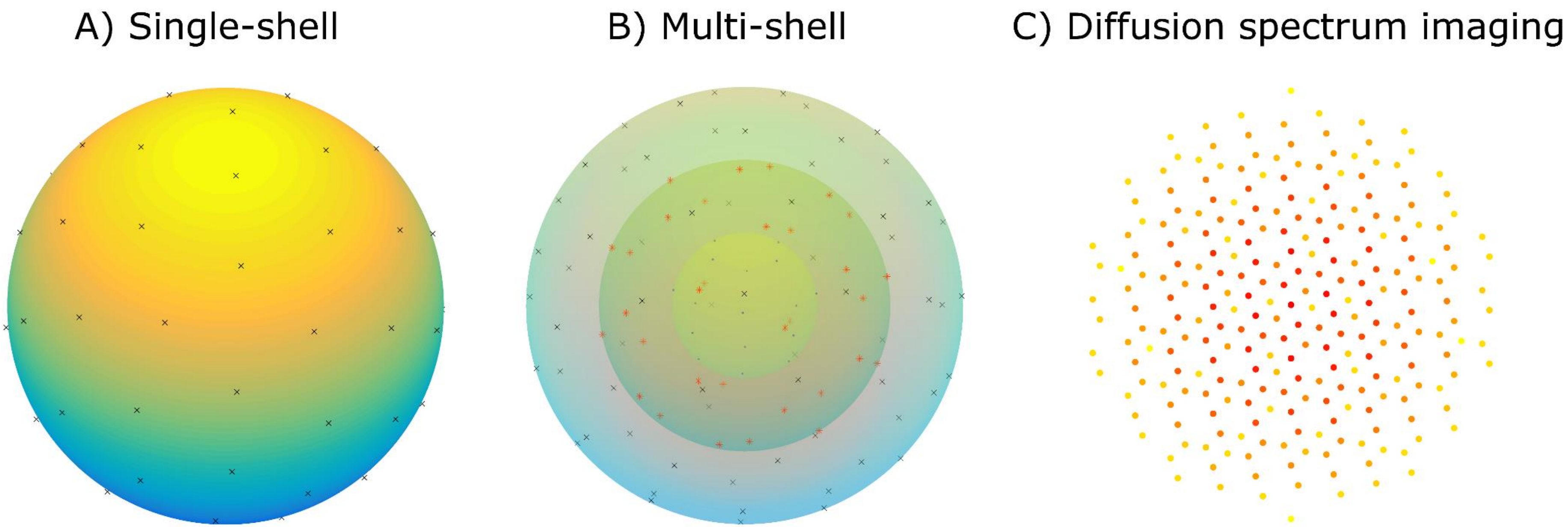
γ: *the gyromagnetic ratio*
δ: *the duration of the gradients*
Δ: *the time between the gradients*
G: *the magnitude of the gradients*

Note: assumes Gaussianity, which is generally not the case

Stejskal & Tanner, 1965

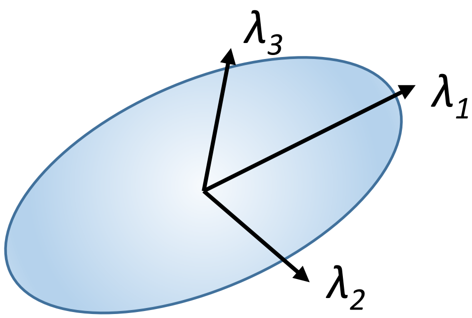
Timo Roine, timo.roine@aalto.fi

Diffusion-weighted q-space schemes



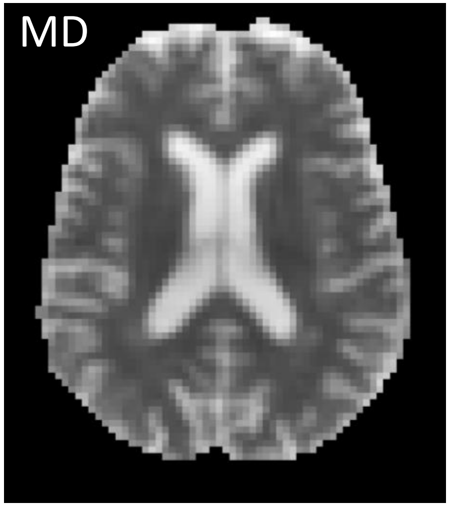
Diffusion tensor imaging (DTI)

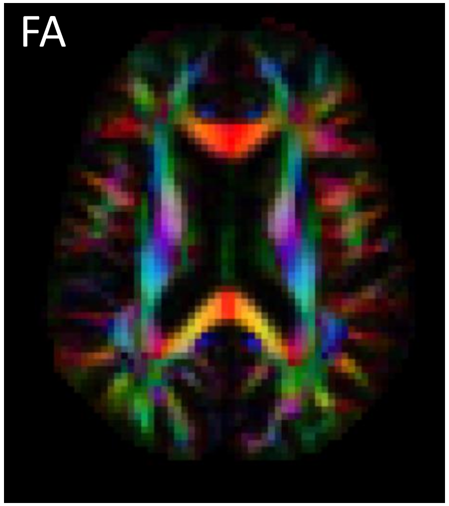
- The diffusion tensor $\mathbf{D} = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{xy} & D_{yy} & D_{yz} \\ D_{xz} & D_{yz} & D_{zz} \end{bmatrix}$



- Six independent elements → minimum six DW images needed

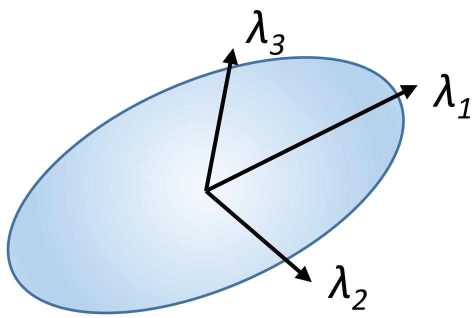
- Mean diffusivity (MD)
- Fractional anisotropy (FA)
- axial/radial diffusivities
- planarity/sphericity



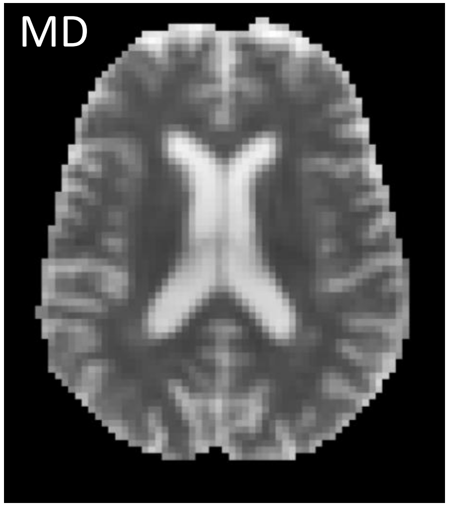


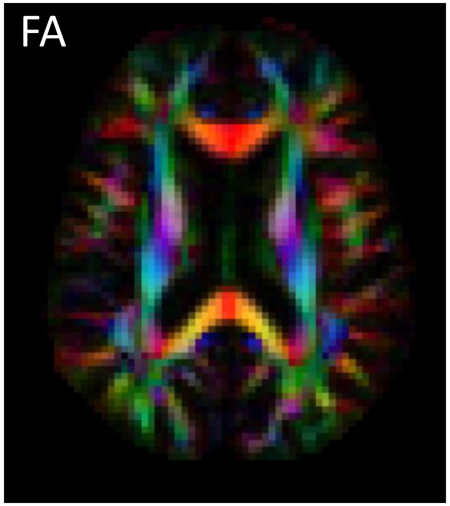
Basser et al. 1994

Diffusion tensor imaging (DTI)



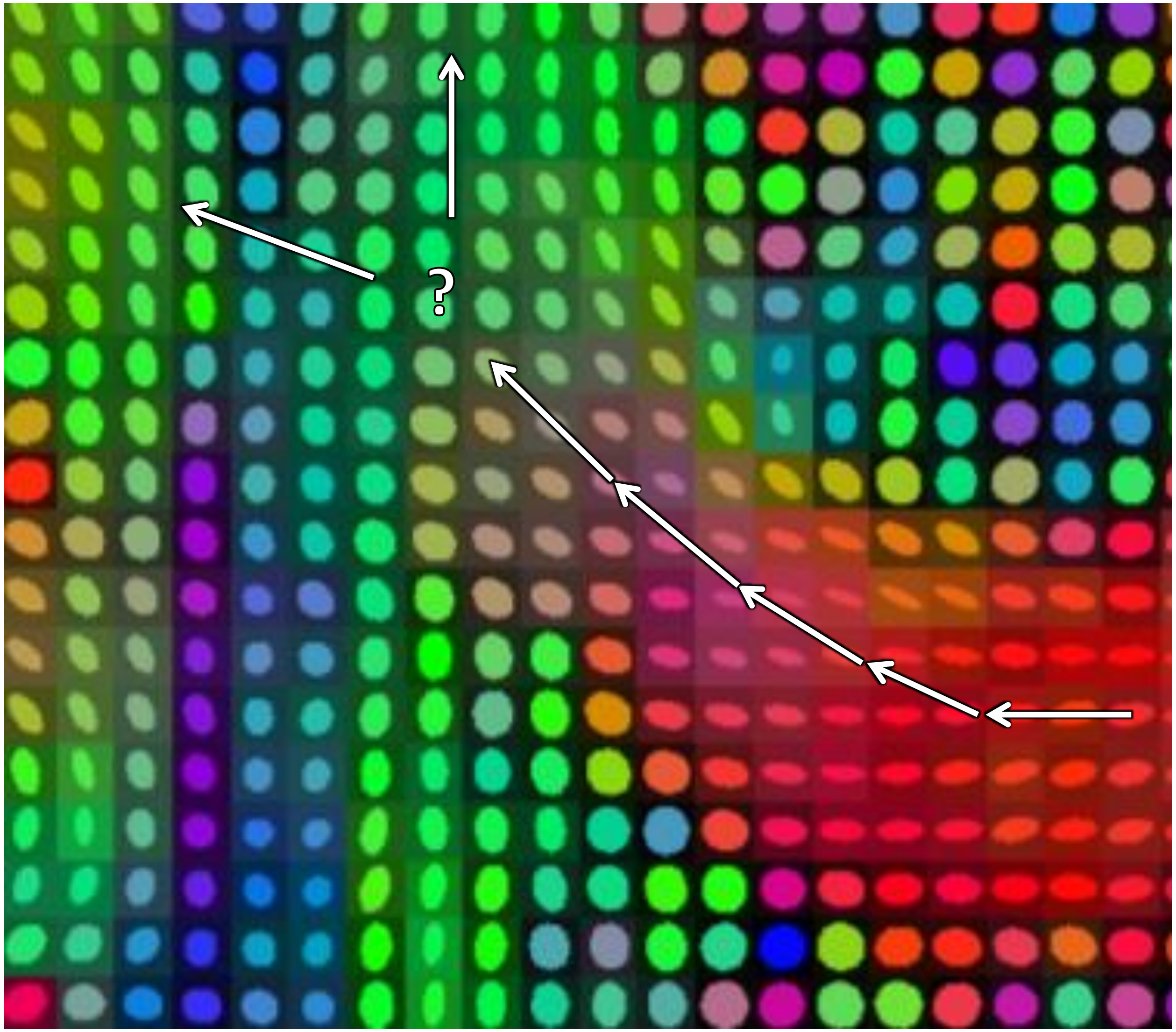
- MD = $\frac{\lambda_1+\lambda_2+\lambda_3}{3}$
- FA = $\sqrt{\frac{1}{2}}\frac{\sqrt{(\lambda_1-\lambda_2)^2+(\lambda_2-\lambda_3)^2+(\lambda_3-\lambda_1)^2}}{\sqrt{{\lambda_1}^2+{\lambda_2}^2+{\lambda_3}^2}}$





Basser et al. 1994

Main shortcoming of DTI: no fiber crossings



Prevalence of crossing fibers

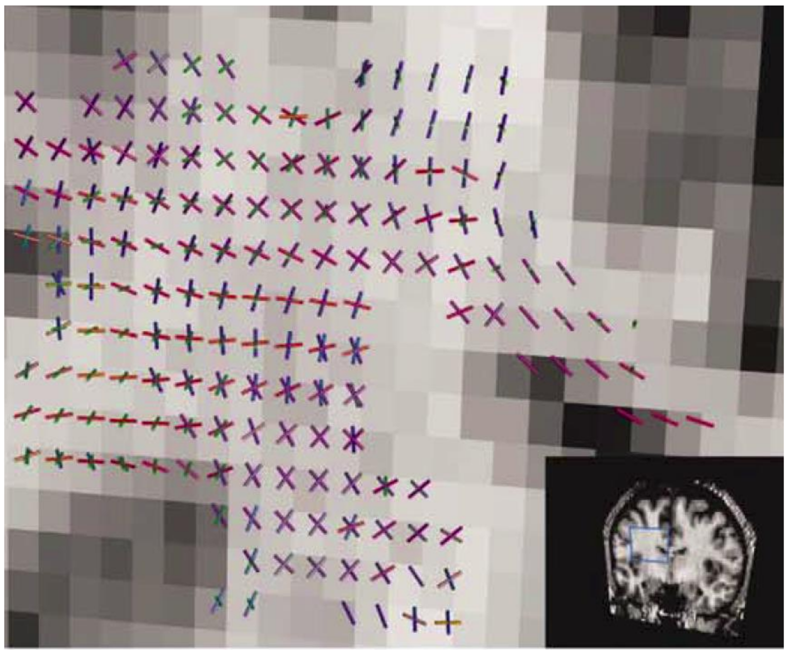


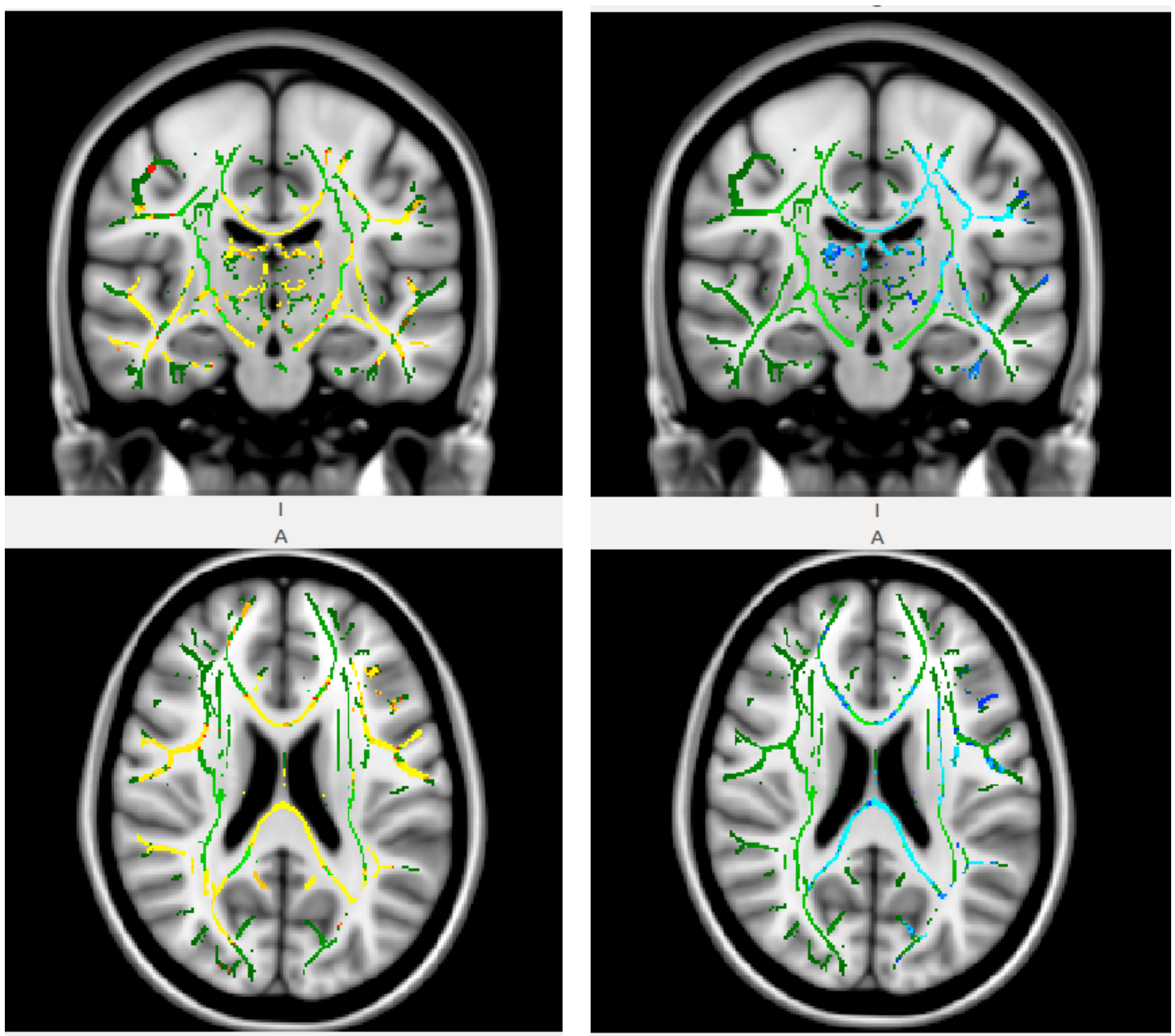
TABLE I. Percentages of single and multifiber voxels throughout the WM for CSD and bedpostx and for different subjects

No. of orientations		1	2	≥3	≥2
CSD	Subject 1	9.5%	47.1%	43.3%	**90.5%**
	Subject 2	8.4%	45.0%	46.6%	**91.6%**
bedpostx	Subject 1	36.1%	62.9%	0.9%	**64.0%**
	Subject 2	37.5%	61.9%	0.4%	**62.3%**
Behrens et al. [2007]		∼ 67.7%	∼ 33.3%	0%	∼ **33%**

For reference, we also included the estimates previously reported in Behrens et al. [2007].

Jeurissen et al. 2013

Tract-based spatial statistics



Roine U et al. 2019 ISMRM
Roine U et al. manuscript

Tensor fitting, microstructural metrics, and DTI-tractography

Useful commands

- dwi2tensor dwi_preprocessed.mif dt.mif
- tensor2metric dt.mif –vector ev.mif –fa fa.mif –adc adc.mif
- tckgen dwi_preprocessed.mif –algorithm Tensor_det –seed_image brainmask.mif (or a ROI drawn in mrview)