Weierstrass Institute for Applied Analysis and Stochastics

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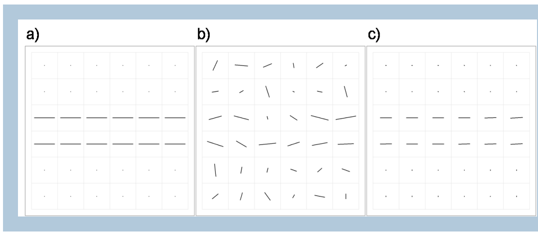
Reducing the number of diffusion gradients by adaptive smoothing

Motivation

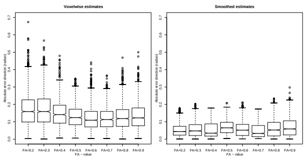


- ▷ Diffusion Tensor $\mathcal{D}$ as lowest order model

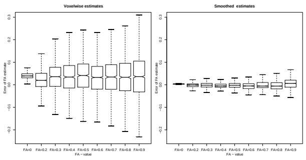
$$S_{\vec{b}} = S_0 \exp(-b\, \vec{g}\, \mathcal{D}\, \vec{g}^T)$$

- ▷ Diffusion Weighted Data suffers from significant noise
- ▷ Noise leads to bias in tensor estimates
- ▷ a) Slice of 3D phantom data. Length of vectors $\propto$ FA, direction of first eigenvector. b) Simulated noisy data. c) Result of structural adaptive reconstruction proposed here.

Structural adaptive smoothing DTI data / Simulation



Absolute error of direction in simulated data.



Error of FA estimates in simulated data.

- ▷ Structural assumption: local constant diffusion tensor
- ▷ Geometric series of bandwidths: $h^{(k)} = h^{(0)} \cdot h^k_{incr}$
- ▷ Idea 1: Use Diffusion tensor to assess spatial information!

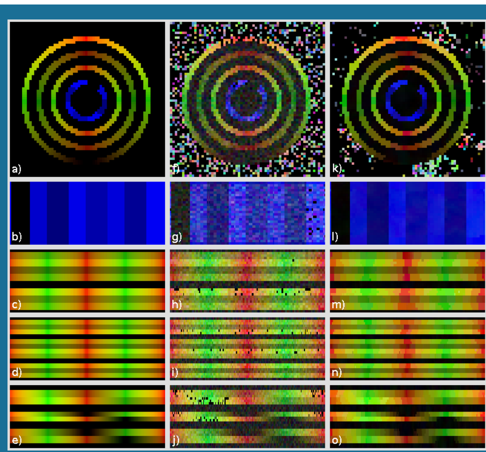
$$\begin{pmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{xy} & D_{yy} & D_{yz} \\ D_{xz} & D_{yz} & D_{zz} \end{pmatrix}$$

$$s^{(k)}_{ij} = \frac{\sum_l w^{(k-1)}_{il}}{\lambda(h^{(k-1)}, g)} \Delta(\hat{\mathcal{D}}^{(k-1)}_i, \hat{\mathcal{D}}^{(k-1)}_j)/(\hat{\sigma}^{(k-1)}_i)^2$$

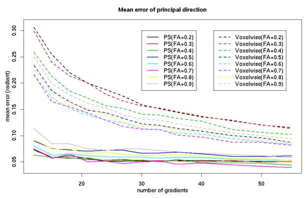
- ▷ Idea 2: Use anisotropy information contained in Diffusion Tensor $\hat{\mathcal{D}}_i$ using an ellipsoidal localization kernel $K_l(., \hat{\mathcal{D}}_i)$
- ▷ Define local weighting schemes

$$w^{(k)}_{ij} = K_l(l^{(k)}_{ij}, \hat{\mathcal{D}}^{(k-1)}_i) K_s(s^{(k)}_{ij})$$

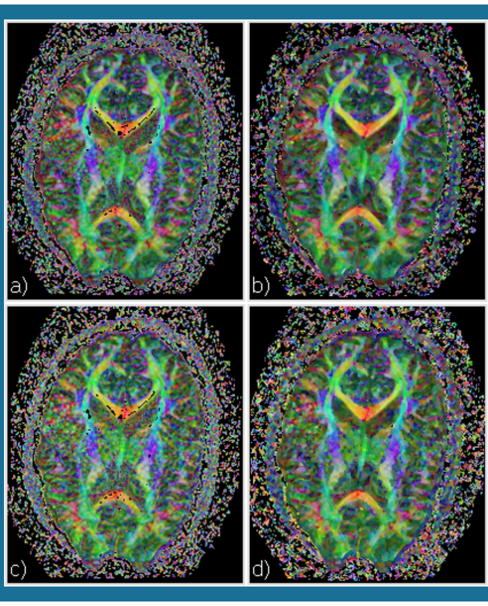
- ▷ Apply weighting schemes to diffusion weighted images S_b, S_0
- ▷ Re-estimate diffusion tensor $\hat{\mathcal{D}}^{(k)}_i$ and it's variance
- ▷ Iterate k



Structural adaptive smoothing DTI data / Number of diffusion gradients



Dependence of the mean error of direction on the number of gradients used for tensor reconstruction.



Upper Figure: Reconstruction of a numerical DTI phantom of $64 \times 64 \times 26$ voxels. The phantom consists of 4 centered cylindrical shells. The inner-most shell contains eight homogeneous segments with a diffusion tensor pointing in z-direction. The second and third shell are characterized by regions with zero z-component in the tensor and constant anisotropy index (FA) within slices. The outermost shell again contains tensors with zero z-component but smoothly varying anisotropy index. Empty space between the cylinder shells and in the center is characterized by an isotropic tensor and a true S_0 value of 2500. Outside the phantom the true S_0 value is set to zero. The S_0-value within the cylindric shells decreses with the FA-value. Noisy S_b and S_0 images are generated using the diffusion tensor model and adding noise with standard deviation 1600 to both the real and imaginary part in k-space.
True phantom (a)-(e), voxelwise estimates (h-j), smoothed result (k-o).

Left Figure: Application of the proposed smoothing algorithm to a brain scan: FA map of an axial slice of the original data using all 55 diffusion weighted images (a). FA map of the smoothed data with the procedure described in the paper (b). FA map of the original data using a reduced set of only 30 diffusion weighted images (c). FA map of the smoothed data with only 30 diffusion weighted images (d). In all images, black regions inside the brain denote areas in which at least one of the eigenvalues was negative.

Software

- R-package (Windows, Unix, ...) see cran.r-project.org

The package 'dti' implements the smoothing procedure described here. Depending on the size of the dataset the smoothing takes from some minutes up to an hour on an appropriate computing environment. Memory optimization is still under development.
The package will be published at CRAN soon.

- Meanwhile ask the authors of this poster.

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Publications

1. K. Tabelow, J. Polzehl, V. Spokoiny, H. U. Voss (2007). Diffusion Tensor Imaging: Structural adaptive smoothing. WIAS-Preprint No. 1232. http://www.wias-berlin.de/publications
2. K. Tabelow, J. Polzehl, H.U. Voss and V. Spokoiny (2006). Analyzing fMRI experiments with structural adaptive smoothing procedures. *NeuroImage* **33** (1), 55 – 62.
3. H.U. Voss, K. Tabelow, J. Polzehl, O. Tchernichovski, K. Maul, D. Salgado-Commissariat, D. Ballon, and S.A. Helekar, Functional MRI of the zebra finch brain during song stimulation suggests a lateralized response topography, *Proceedings of the National Academy of Sciences (PNAS)* (2007), to appear.
4. J. Polzehl, K. Tabelow. fmri: A package for analyzing fmri data, *RNews* (2007), to appear.

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