

Structural adaptive smoothing Diffusion Tensor Imaging data: the R-Package *dti*

Diffusion Tensor Imaging (DTI) has become and will certainly continue to be an important tool in medical research and diagnostics. Data obtained with DTI are characterized by a **high noise level**. Thus, estimation of quantities like anisotropy indices or the main diffusion direction may be significantly compromised in clinical or neuroscience applications. Noise reduction is therefore essential. We present a new **structural adaptive smoothing algorithm for diffusion weighted data** its implementation as the **R package *dti***.

Background

The last two decades have seen an impressive advancement in biomedical imaging facilities, driven by new insights into physiological processes but also by parallel developments in image acquisition and processing technologies.



Mathematical competence: structural adaptive methods

- ▷ Aim: Use *local homogeneity assumption* to improve image reconstruction
- ▷ Model: $Y_j \propto P_{\theta}(X_i) \quad \forall j \in U(X_i)$
- ▷ Properties of such algorithms, see [1]:
 - Iterative: determine $U(X_i)$ + estimate $\theta(X_i)$
 - Multiscale: investigate structure at all scales
 - Data independent tuning parameters
 - Propagation within $U(X_i)$
 - Separation of $U(X_i)$ and $U(X_j)$ if Kullback-Leibler distance $\mathcal{K}(\theta(X_i), \theta(X_j))$ is sufficiently large.

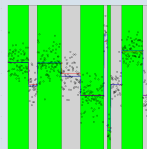


Figure 1: Structural adaptation in 1D

Application: Medical Imaging

- ▷ In vivo examination of the human body by physicians and researchers
- ▷ New challenges for specialized imaging modalities:
 - Significant noise / Weak signals
 - High-dimensional data
 - Modeling the physics
- ▷ New spatiotemporal algorithms demanded instead of visual inspection.
- ▷ For structural adaptive fMRI analysis see **Poster #386 F-PM**

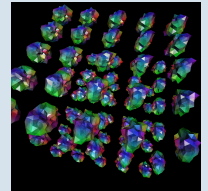


Figure 2: Measured ADC coefficient showing detailed structure and significant noise.

How it works

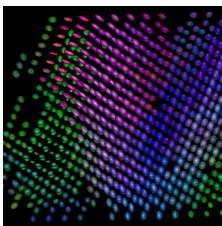


Figure 3a: Estimated tensor ellipsoids in slices 22-24 of the CIBC dataset (from the NIH/NCRR Center for Integrative Biomedical Computing, P41-RR12553).

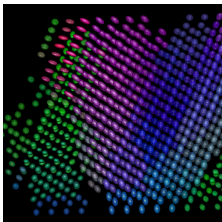


Figure 3b: Structural adaptive smoothing apparently leads to homogenization of regions without blurring the structural borders [2].

Diffusion Tensor Imaging (DTI)

- ▷ Diffusion Weighted Imaging: MR technique to measure water diffusion in the white matter region of the brain
- ▷ Free anisotropic *diffusion tensor model*: $\mathcal{D} = (D_{ij})_{i,j=x,y,z}$ with signal $S_b = \theta_0 \exp(-b^T * \mathcal{D} * b)$ in direction b : DTI.
- ▷ Nonlinear Model

$$S_{b,i} \sim \text{Rice}(\theta_{0,i} \exp(-b^T * \mathcal{D}_i * b), \sigma_{R,i}^2)$$
- ▷ Correct bias by solving fixpoint equation

$$\zeta_{k,i} = I_1(S_{i,k} \zeta_{k,i} / \sigma_{R,i}^2) / I_0(S_{i,k} \zeta_{k,i} / \sigma_{R,i}^2) S_{i,k}$$
- ▷ Parameter estimation:

$$\arg \min_{\theta, \mathcal{D}} \left[\mathbf{R}(\zeta_{\cdot, i}, \theta, \mathcal{D}) = \sum_b \frac{(\zeta_{b,i} - \theta \exp(\mathbf{b}^T \mathcal{D} \mathbf{b}))^2}{\sigma_{b,i}^2} \right]$$

Structural adaptive smoothing of DTI data

- ▷ Structural adaptive smoothing method for DWI data in the context of the diffusion tensor model
- ▷ heterogeneous variances reflect properties of physiological noise
- ▷ Rician variance corresponds to thermal noise
- ▷ Noise reduction while naturally adapt to structures of interest at different scales, see [1].
- ▷ Using *heteroscedastic variances* and *correction for Rician bias* significantly improves the smoothing results, see [2].
- ▷ Structural adaptive smoothing leads to a *homogenization of regions with similar diffusion tensor* ...
- ▷ ... *without oversmoothing the border of such regions* and hence without blurring interesting and important structures!

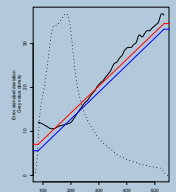


Figure 4: Grey value distribution and error standard deviation as a function of S_0 grey values.

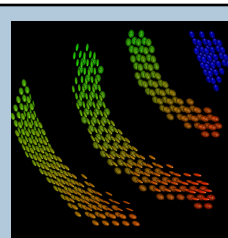


Figure 5a: Artificial example from [2]: True tensor.

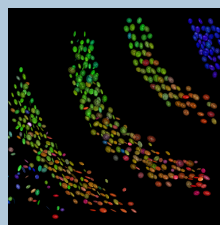


Figure 5b: Voxelwise tensor estimates suffering from added artificial noise.

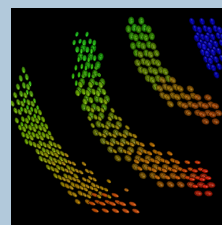


Figure 5c: Smoothed tensor estimates using the p package dti.

Software

Within the project many software packages are developed for evaluation and for usage withing the (Neuro)imaging community.

Download at:
<http://cran.r-project.org>
<http://www.nitrc.org>

The Structural Adaptive Smoothing Software family in R

Most software is provided as packages for the *R Language for Statistical Computing* (<http://cran.r-project.org>), easy to use and integrate.

- ▷ **adimpro** (Image processing tools)
- ▷ **aws** (General structural adaptive smoothing)
- ▷ **fmri** (Structural adaptive analysis), **Poster #386 F-PM**
- ▷ **dti** (Structural adaptive analysis of DWI data)

```
> grad <- read.table("b-directions.txt")
> dwdata <- readDWIdata(grad, "datadir/", "DICOM", 66)
> dtobj <- dti.smooth(dwdata)
> dtind <- dtiIndices(dtobj)
> plot(dtind, slice=30)
```



Package *dti*: Features

- ▷ DWI data import (NIFTI, DICOM).
- ▷ DTI analysis (tensor, FA estimation, ...)
- ▷ Structural adaptive smoothing DWI data in DT context
- ▷ Interface to MedNRIA
- ▷ 2D and 3D visualization
- ▷ Publication-ready images

Package *dti*: Perspectives

- ▷ Fibre tracking
- ▷ Structural adaptive smoothing method for HARDI data.
- ▷ Integration of *adaptive smoothing* and *fiber tracking methods* for HARDI data.

Publications

[1] K. Tabelow, J. Polzehl, V. Spokoiny, and H. U. Voss (2008). Diffusion Tensor Imaging: Structural adaptive smoothing. *NeuroImage*, 39(4):1763–1773.

[2] J. Polzehl and K. Tabelow (2009). Structural adaptive smoothing in diffusion tensor imaging: the R package dti. *J. Statist. Software*, submitted.

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www.matheon.de

www.wias-berlin.de/projects/matheon_a3/

see also **Poster #386 F-PM** (fMRI)

