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Package dti: A framework for HARDI-Modeling in R

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Introduction

The package **dti** is designed to perform the analysis of diffusion weighted magnetic resonance data. It currently offers estimation of diffusion tensors and tensor characteristics, the analysis of tensor mixtures, O-ball imaging and deterministic streamline fiber tracking. Special emphasis is on adaptive smoothing of DWI data. 2D and 3D visualization is available for DWI data, estimated diffusion tensors, orientation distribution functions and fiber tracking results. The package is available under GPL ≥ 2.0 for the **R** software environment for statistical computing and graphics.

DWI data

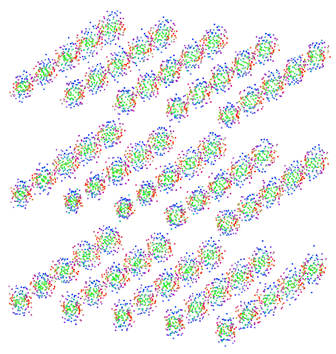


Figure 1: 3D visualization of DWI data

- 56 gradient directions uniformly on the sphere
- $256 \times 256 \times 66$ voxel on a grid
- Easy to obtain subsets by index operations
- Package reads DICOM and NIfTI
- Summaries by `summary()`

```
> library(dti)
> dwiobj <- readDWIdata(gradients, "data", "DICOM")
> show3d(dwiobj[ind1, ind2, ind3], bg="white",
what="data")
```

Tensor Mixture Models

- Describe within-voxel structure
- Gaussian diffusion within voxel compartments
- Model (using prolate tensors):

$$E(\vec{q}) = \sum_{m=1}^{M} w_m \exp(-b\vec{u}^T \mathscr{D}_m \vec{u}), \quad \mathscr{D}_m = (\lambda_1 - \lambda_2) d_m d_m^T + \lambda_2 \mathrm{I}_3 .$$

- Corresponding ODF is a mixture of the ODF's for the compartments

$$\mathrm{ODF}(\vec{u}) = \sum_{m=1}^{M} w_m \frac{1}{4\pi\sqrt{\det \mathscr{D}_m}} \left(\vec{u}^T \mathscr{D}_m^{-1} \vec{u}\right)^{-3/2} .$$

- Mixture coefficients correspond to size of compartments
- Generalizes tensor model
- Characteristics: FA, Effective order, Number of compartments

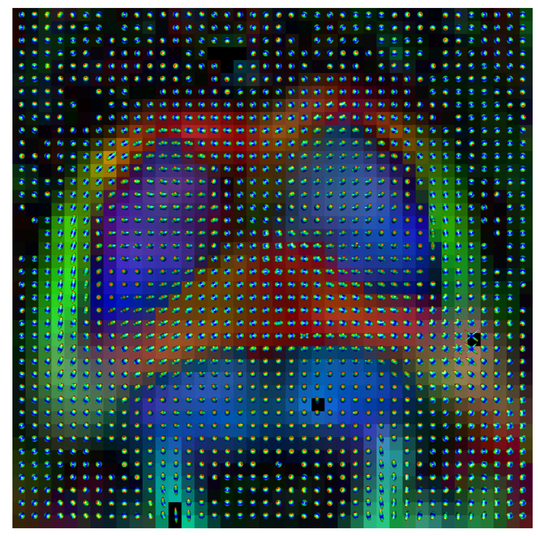


Figure 3: *Estimated ODF from tensor mixture model with color coded FA map in the midbrain. Image created using R-package 'dti'.*

Diffusion Tensor Imaging

- Diffusion propagator fully characterized by a three dimensional tensor $\mathscr{D}$

$$P(\vec{R}, \tau) = P(r\vec{u}, \tau) = \frac{1}{\sqrt{\det \mathscr{D}(4\pi\tau)^3}} \exp\left(-r^2 \frac{\vec{u}^T \mathscr{D}^{-1} \vec{u}}{4\tau}\right) .$$

- Model:

$$E(\vec{q}, \tau) = \int_{R^3} P(\vec{R}, \tau)\, e^{2\pi i \vec{q}\vec{R}} d\vec{R} = e^{-b\vec{q}^T \mathscr{D} \vec{q}}$$

with b-value depending on the effective diffusion time τ.

- Characteristics include fractional anisotropy (FA), anisotropy directions.

```
> dtensobj <- dtiTensor(dwiobj)
> dtindobj <- dtiIndices(dtensobj)
> plot(dtindobj,slice=40)
> show3d(dtensobj[ind1, ind2, ind3], what="ODF")
```

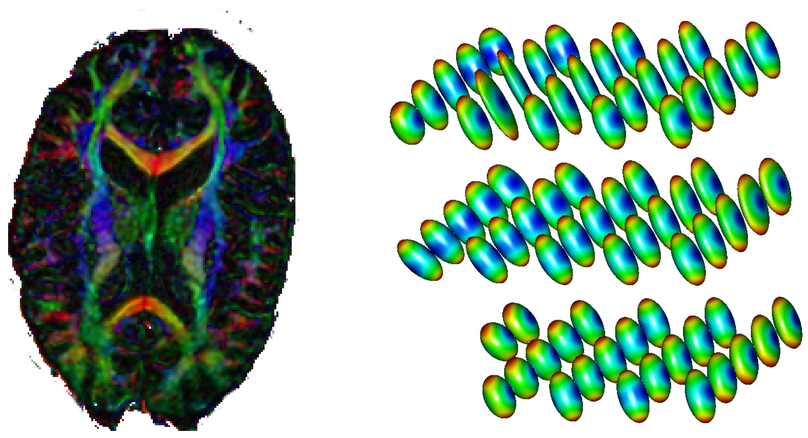
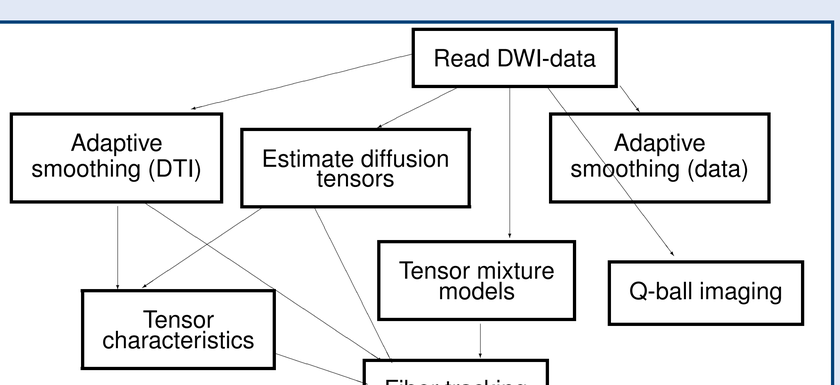


Figure 2: Color coded FA and tensor visualization as ODF




```
> mt3obj <- dwiMixtensor(dwiobj,maxcomp=3)
> mt3obj <- dwiMtImprove(mt3obj,dwiobj)
> mt3obj <- dwiMtCombine(mt3obj,mt2obj)
> show3d(mt3obj[indx, indy, indz]
> tracks <- reduceFibers(tracking(mt3obj))
> show3d(selectFibers(tracks,minlength=100))
```

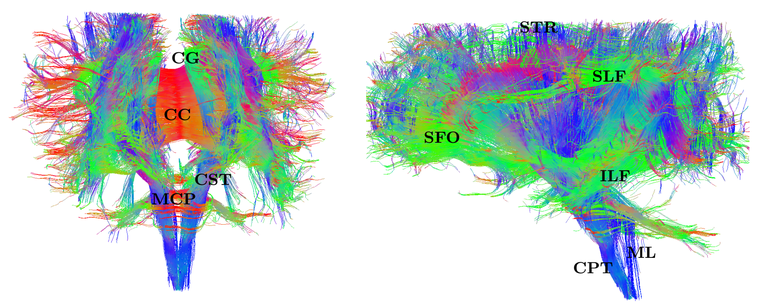


Figure 3: 3D visualization of fiber tracks.

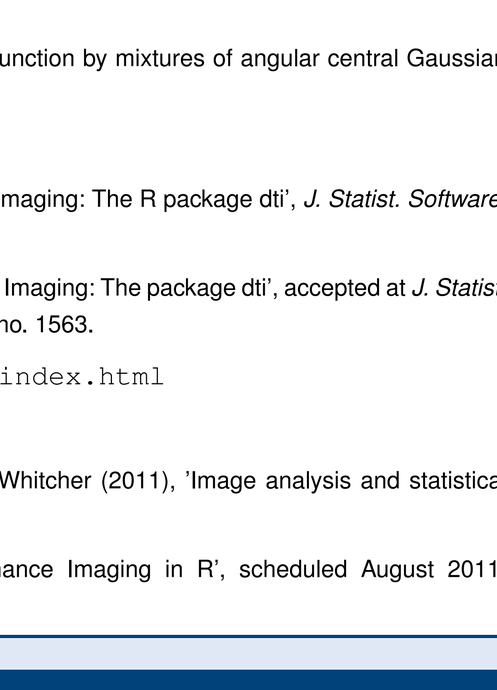


Figure 4: 3D visualization of tensor mixtures for a sub-region.

Further reading

Structural adaptive methods in DW-MRI

- K. Tabelow, J. Polzehl, V. Spokoiny, H.U. Voss (2008), 'Diffusion tensor imaging: Structural adaptive smoothing', *NeuroImage*, vol. 39, pp. 1763–1773. (Structural adaptive smoothing DTI data)
- K. Tabelow, H.U. Voss, J. Polzehl (2010), 'Modeling the orientation distribution function by mixtures of angular central Gaussian distributions', WIAS-Preprint no. 1559. (About tensor mixtures models)

Implementation in **R**: Package **dti**

- J. Polzehl, K. Tabelow (2009), 'Structural adaptive smoothing in diffusion tensor imaging: The R package dti', *J. Statist. Software*, vol. 31, pp. 1–24. (Explaining the usage of the package for DTI)
- J. Polzehl, K. Tabelow (2011), 'Beyond the Gaussian Model in Diffusion-Weighted Imaging: The package dti', accepted at *J. Statist. Software* (Explaining the usage of the package for HARDI) - see WIAS-Preprint no. 1563.
- Download: `http://cran.r-project.org/web/packages/dti/index.html`

Medical imaging in **R**

- K. Tabelow, J.D. Clayden, P. Lafaye DE Micheaux, J. Polzehl, V.J. Schmid, B. Whitcher (2011), 'Image analysis and statistical inference in neuroimaging with R', *NeuroImage*, vol. 55, pp. 1686–1693.
- Upcoming Special issue of *Journal of Statistical Software* 'Magnetic Resonance Imaging in R', scheduled August 2011, `http://www.jstatsoft.org`

Conclusions

The R-package 'dti' is a fully operational framework for the analysis of DWI data and implements the common data analysis for DTI as well as for HARDI measurements.

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