

FIBER-TRACKING ON HARDI DATA USING ROBUST ODF FIELDS

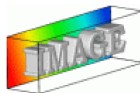
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GREYC IMAGE (CNRS UMR 6072)

September 18, 2007



CENTRE NATIONAL
DE LA RECHERCHE
SCIENTIFIQUE



1 INTRODUCTION & STATE OF THE ART

- Presentation of diffusion MRI
- State of the art

2 OUR CONTRIBUTION

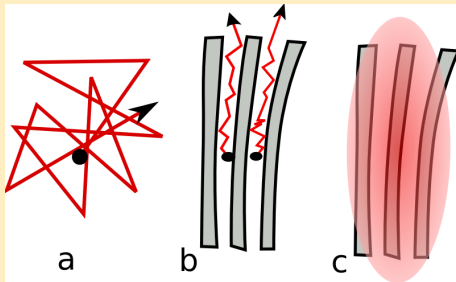
- Variational framework for the estimation of ODF
- Robust estimation

3 RESULTS

- Validation on synthetical data
- Results on human brain data

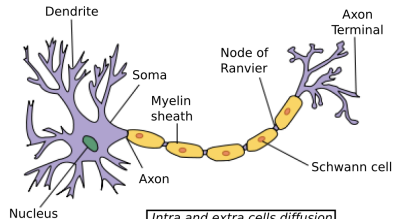
DIFFUSION MRI: HOW ?

BROWNIAN MOTION



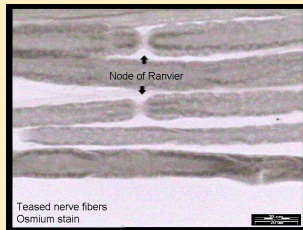
- a: Brownian motion of water molecule
b: Internal structures constraints
c: Signal = local macroscopic diffusion
[LeBihan86]

NERVE FIBERS



Intra and extra cells diffusion

[LeBihan95, Beaulieu98, Biton06]



<http://www.technion.ac.il/>

DIFFUSION MRI: IN PRACTICE

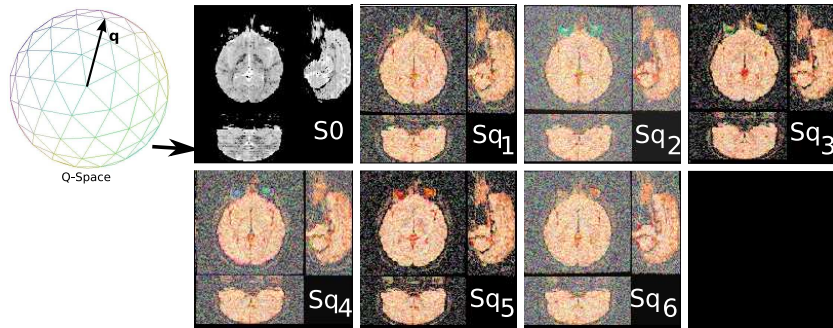
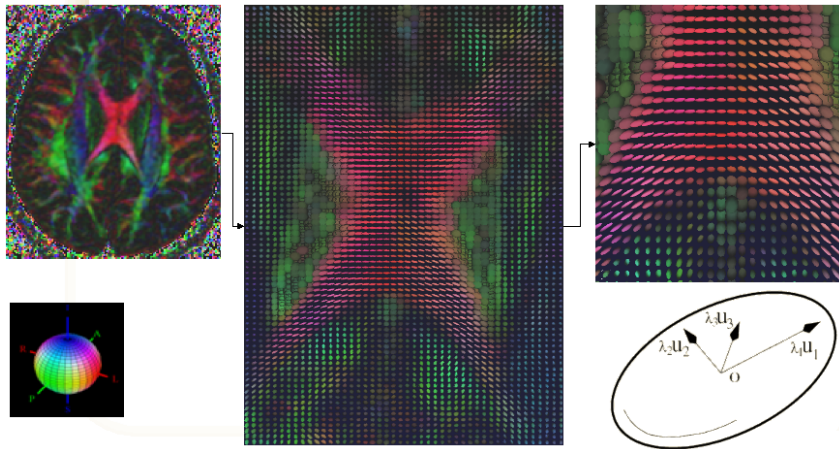


FIGURE: Acquisition in $\mathbf{q}$ -space on a sphere of radius $\|\mathbf{q}\|$: a baseline image S_0 and several other gradients images $S(\mathbf{q})$.

Estimate the ADC: $D(\mathbf{q}) = -\frac{1}{b} \ln \left(\frac{S(\mathbf{q})}{S_0} \right)$ [Stejskal-Tanner65]

3D Representation of the Gaussian diffusion model (DTI) [Basser94]

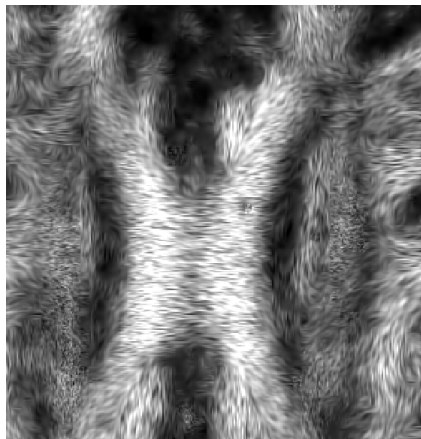
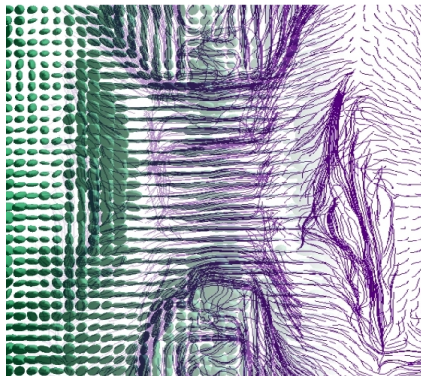
DTI: EXAMPLE



[Basser97, Poupon00, Wedeen01, Westin02, etc.]

DTI on corpus callosum, diffusion represented by a volume of ellipsoids.

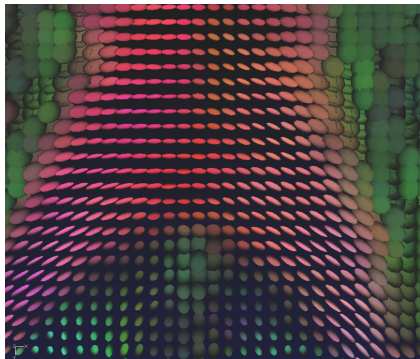
DIFFUSION MRI: FIBER-TRACKING



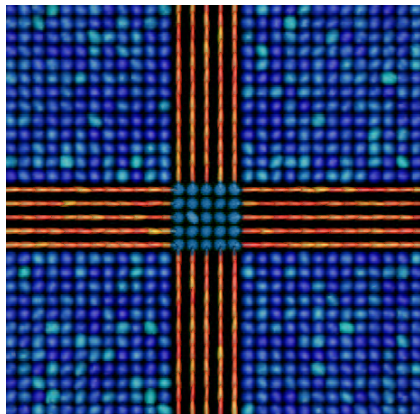
[Basser98, Contouro99, Mori99, Coulon01, Vemuri01, Hagmann03, Ramirez03, Tschumperlé03, Lenglet04, etc.]

Fiber-tracking across human tissues (brain white matter) is done by following the principal eigen vector of tensors.

DTI: 2ND-ORDER MODEL LIMITS

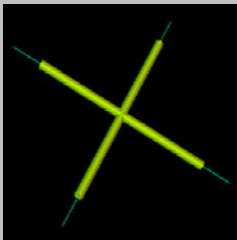


DTI are correct when dealing with single direction of fibers

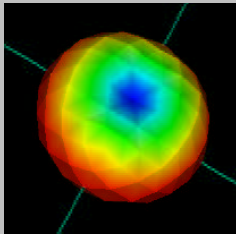


Problem when having crossing fibers: Gaussian function can't catch multiple maxima

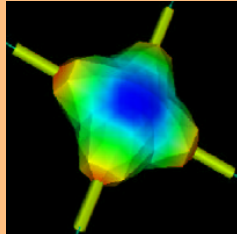
DTI VERSUS HIGHER ORDER MODELS



Fibers
Raw data



DTI
2nd-order tensor
[Basser94]



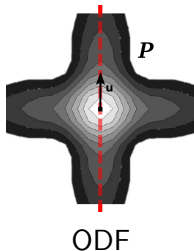
higher orders
approaches

Numerous approaches exist: GDTI [Liu03], PASMRI [Jansons03], HODT / DOT [Özarslan03,06], Spherical Deconvolution [Tournier04], ODF [Tuch04], etc.

ORIENTATION DENSITY FUNCTION (ODF)

The ODF Ψ at direction $\mathbf{u}$ is defined as the radial projection of the diffusion PDF

$$\begin{aligned}\Psi(\mathbf{u}) &= \int_0^\infty P(\alpha\mathbf{u})d\alpha \\ &= \int P(r, \theta, z)\delta(\theta, z)rdrd\theta dz\end{aligned}\tag{1}$$

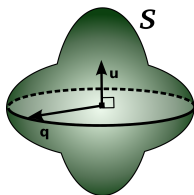


Problem: How to get the PDF ?

FUNK-RADON TRANSFORM (FRT)

The FRT (2) is a smoothed version of the true ODF (1) [Tuch04]

$$\mathcal{G}_{q'}(\mathbf{u}) = 2\pi q' \int P(r, \theta, z) J_0(2\pi q' r) r dr d\theta dz \quad (2)$$



FRT

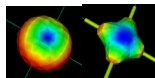
Besides, the ODF can be directly expressed from diffusion signal in spherical harmonics by a Least Square minimization [Descoteaux06]

$$ODF \approx \mathcal{G}_{q'} = \tilde{P}\tilde{B}\mathbf{C} = \sum_j 2\pi P_{l_j}(0) c_j Y_j \quad (3)$$

LEAST SQUARE ODF ESTIMATION

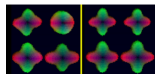
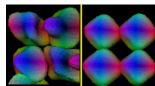
Least Square ODF estimation :

- Enables resolution of any specific local structure (crossing fibers)
- Model-free method: no assumption on macroscopic diffusion
- Light matrix computations



But...

- Least Square method not adapted to Rice noise model [Sijbers98]
- No guaranty on spatial coherence of the ODF field



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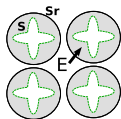
OUR CONTRIBUTION

$$\min_{\mathbf{C} \in \Omega_C} \left\{ E(\mathbf{C}) = \int_{\mathbf{p} \in \Omega_S} [\sum_k^{n_s} \psi(\mathbf{S}_{r_k})] + \alpha \varphi(\|\nabla \mathbf{C}_{(\mathbf{p})}\|) d\mathbf{p} \right\}, \quad (4)$$

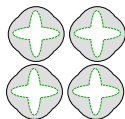
$$\text{with } \mathbf{S}_{r_{(\mathbf{p})}} = \tilde{B} \tilde{P}^{-1} \mathbf{C}_{(\mathbf{p})}$$

The best fitting coefficients are computed with a gradient descent coming from the Euler-Lagrange derivation of the energy E . This leads to a set of *multi-valued* partial derivate equation.

$$\begin{cases} \mathbf{C}_{t=0} = \mathbf{U}_0 \\ \frac{\partial \mathbf{C}_j}{\partial t} = P_j^{-1} \sum_k^{n_s} \tilde{B}_{k,j} \psi'(\mathbf{S}_{r_k}) + \alpha \operatorname{div}(\varphi(\|\nabla \mathbf{C}\|)) \end{cases} \quad (5)$$



iteration 0



iteration 1



...



iteration n

ADVANTAGES: REGULARITY

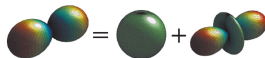
- Ensure a global regularity of the ODF field: $\varphi(\|\nabla \mathbf{C}_{(p)}\|)$

Spherical harmonics coefficients characterize anisotropy [Frank02]



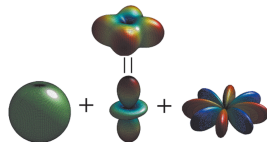
$$l = 0$$

Isotropic diffusion



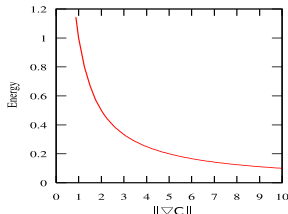
$$l = 2$$

Single fibers
orientation



$$l = 4$$

Several fibers
orientation



Example of possible
regularization function φ

ADVANTAGES: ADAPTIVE TO NOISE DISTRIBUTION

- ψ -likelihood function adapted to MRI noise law:

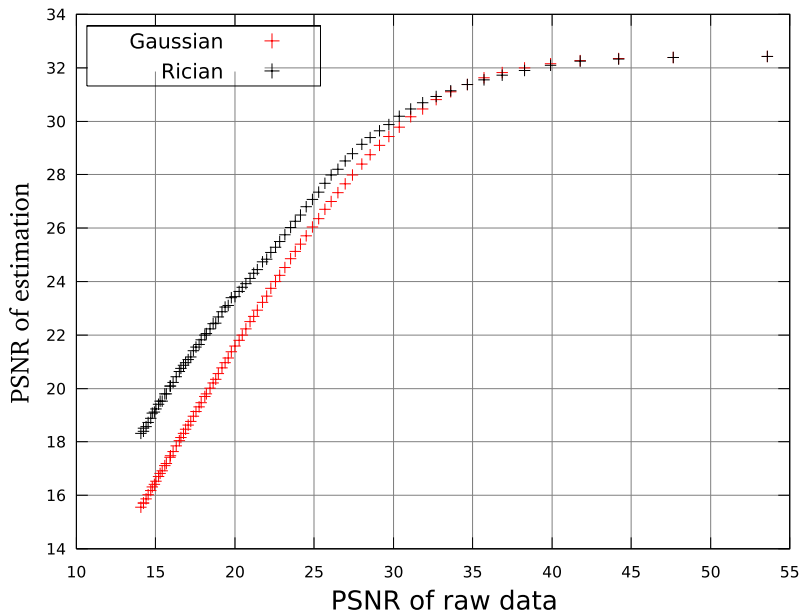
The best ψ function is the one specific to MR scanners, ie. Rice distribution
We seek $\mathbf{S}_r$ which maximizes a posteriori (MAP) the log-posterior probability

$$\log p(\mathbf{S}_r|\mathbf{S}) = \log p(\mathbf{S}|\mathbf{S}_r) + \log p(\mathbf{S}_r) - \log p(\mathbf{S}) \quad (6)$$

Consequently the pointwise likelihood is

$$\psi(\mathbf{S}_r) = \log p(\mathbf{S}|\mathbf{S}_r, \sigma) = \log \frac{\mathbf{S}}{\sigma^2} - \frac{(\mathbf{S}^2 + \mathbf{S}_r^2)}{2\sigma^2} + \log l_0 \left(\frac{\mathbf{S} \cdot \mathbf{S}_r}{\sigma^2} \right) \quad (7)$$

SIMULATION: INFLUENCE OF RICE MODEL



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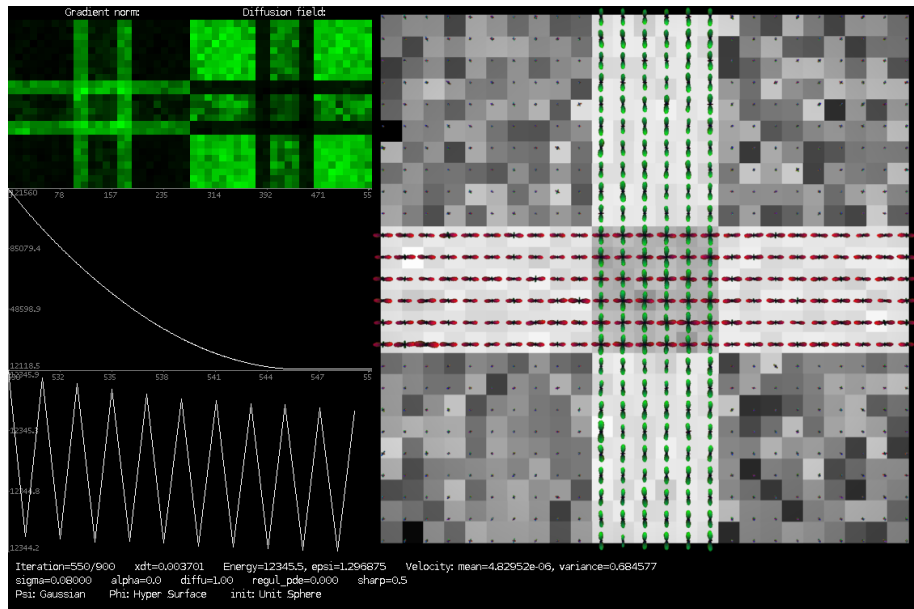
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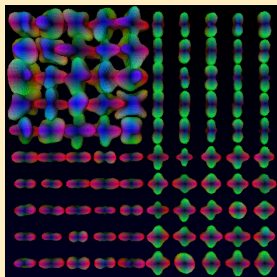
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SIMULATION: ENERGY MINIMIZATION

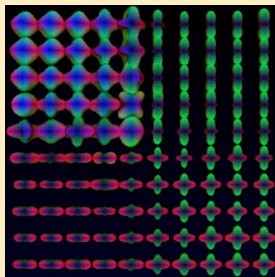


SIMULATION: REGULARIZATION

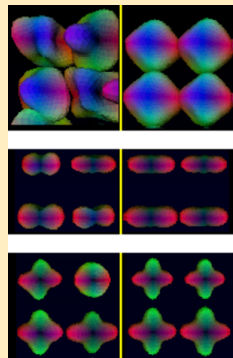
WITHOUT



WITH



ZOOM

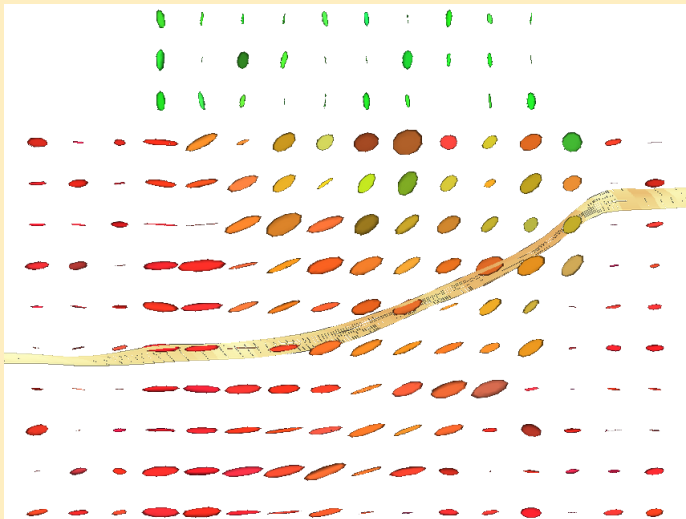
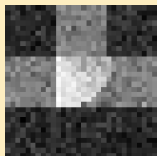


GFA



DTI

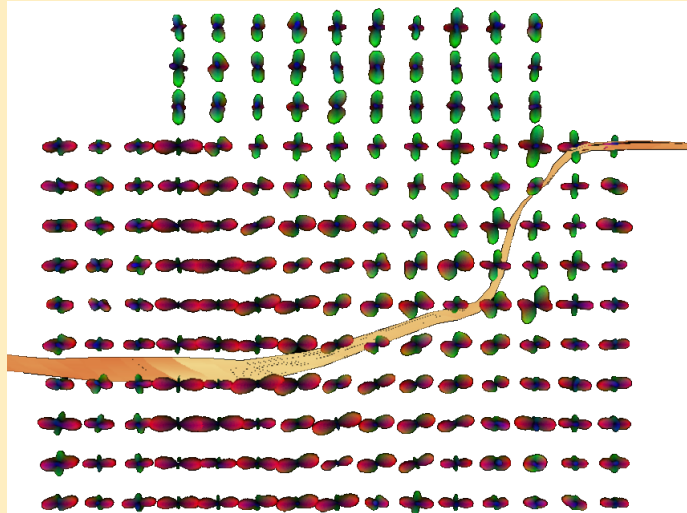
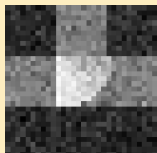
GFA



CONSEQUENCES ON FIBER-TRACKING

LS

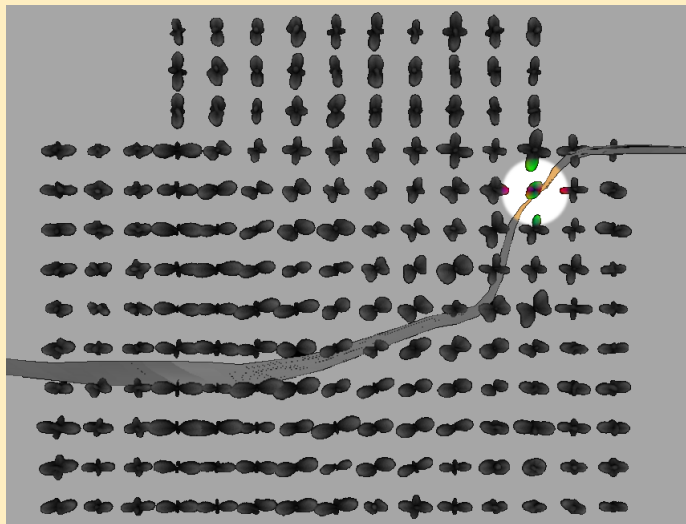
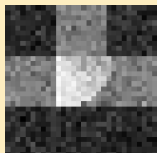
GFA



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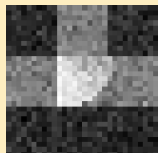
LS

GFA

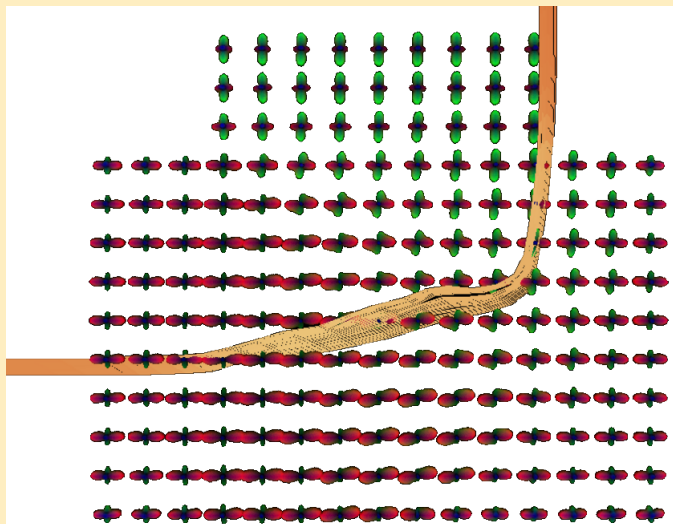


CONSEQUENCES ON FIBER-TRACKING

GFA

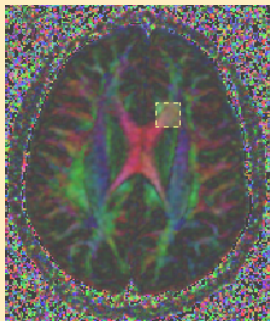


PDE



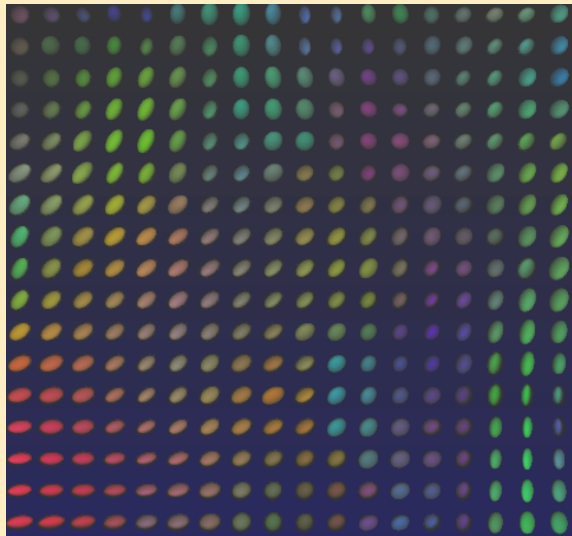
RESULTS ON HUMAN BRAIN HARDI DATA

GFA



(GREYC IMAGE)

DTI FIELD



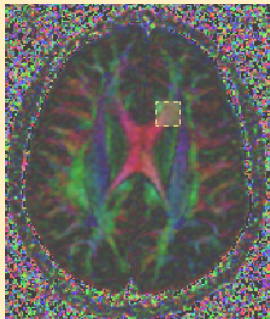
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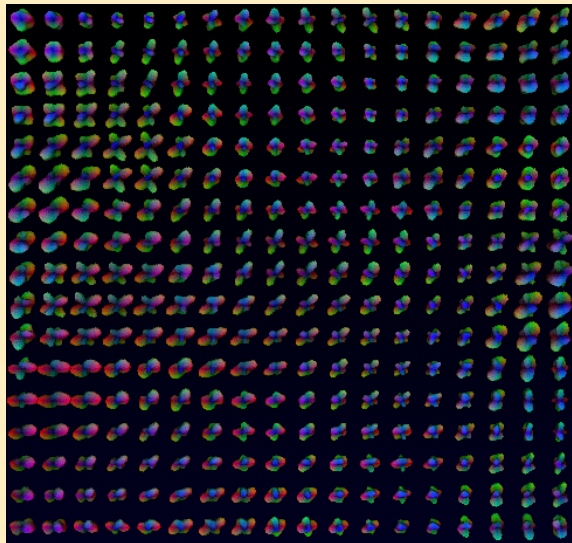
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GFA



(GREYC IMAGE)

ODF FIELD



DIFFUSION MRI

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- Framework to estimate ODF
- Respect of regularity and robustness to noise constraints
- More details on the technical report *A Variational Framework for the Robust Estimation of ODFs From High Angular Resolution Diffusion Images* on <http://www.greyc.ensicaen.fr/~assem1al>

Thanks to CHU of Caen and GIN Cyceron for their data and their fruitful discussions