Efficient Estimation of Propagator Anisotropy and Non-Gaussianity with MiSFIT

Guillem París, Santiago Aja-Fernández, Antonio Tristán-Vega
Image Processing Laboratory – University of Valladolid
Universidad de Valladolid

Thesis goal: Design advanced dMRI techniques and measures for realistic clinical environments

EAP – *"A formalism that provides a powerful framework to describe and predict the diffusion behaviour in complex materials." D.S. Tuch, 2002*

- Captures both the radial and angular information of the diffusion signal, unlike ODF
- Accurate computation of **descriptors** and **scalar maps**
- Related to the diffusion signal: $P(\boldsymbol{p}) = \mathcal{F}_{3D}[E](\boldsymbol{p})$
- Several reconstructing methods: MAPL & MiSFIT

MAPL

Laplacian-Regularized MAP-MRI [3]

- Current standard in research
- Based on representation of q-space MR signal onto Hermite functions, which have shown to rapidly converge in both real and Fourier spaces.
- Time-consuming: 20 hours or more, when positivity constraint is applied.

MiSFIT

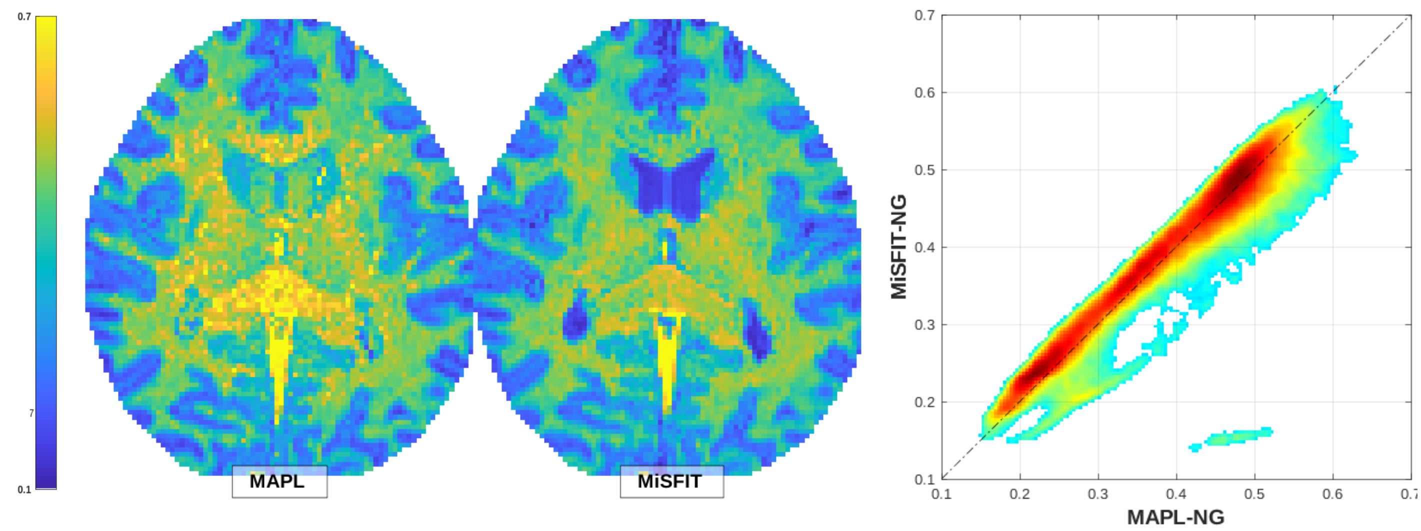
Micro-Structure Adaptive Convolution Kernels and dual Fourier Integral Transforms [1]

$$_{c}E(\boldsymbol{q}) = (1-f)e^{-b(q)D_{iso}} + f \iint_{S} \Phi(\mathbf{v}) e^{-b(q)\left[(\boldsymbol{u}^T\mathbf{v})^2(\lambda_{\parallel}-\lambda_{\perp})+\lambda_{\perp}\right]} d\mathbf{v}$$

- Semi-parametric approach:
  - Radial information reduced to, at most, 3 parameters to estimate $f, \lambda_{\parallel}, \lambda_{\perp}$
  - Angular information: fully non-parametric
- **Time needed: 2 minutes!**
- For this method, we developed two measures as defined in MAP-MRI [2]: PA and NG

NG — Non-Gaussianity

…or how much the EAP diverges from a Gaussian behaviour



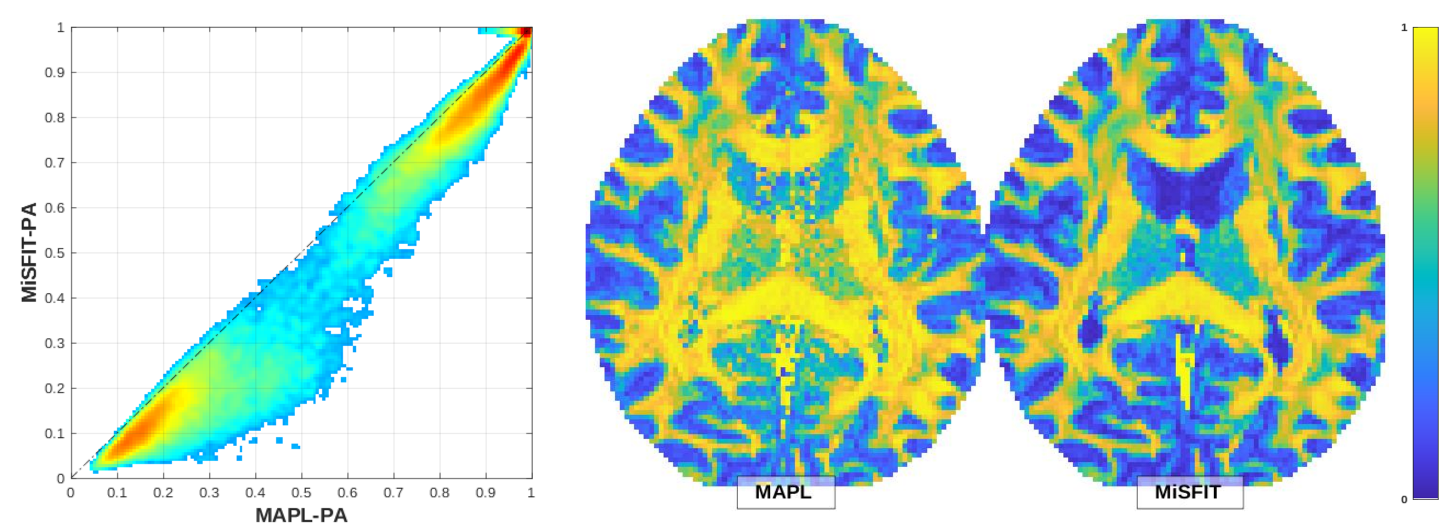
Defined by:

$$NG = \sin\theta_{E,E_G} = \sqrt{1 - \left(\frac{\langle E(q), E_G(q)\rangle}{\|E(q)\|\|E_G(q)\|}\right)^2}$$

- Expected to be low in Gaussian-diffusing zones
- Alternative to Kurtosis measure (Jensen et al., 2005), but in this case it takes into account the entire propagator, not only the moments up to order 4.

PA — Propagator Anisotropy

…or how much the EAP diverges from an isotropic behaviour



Defined by:

$$PA = \sigma(\sin\theta_{E,E_I}, \epsilon) = \sqrt{1 - \frac{\|E_I(q)\|^2}{\|E(q)\|^2}}$$

- Expected to be low in isotropic-diffusing zones
- In MAP-MRI: $PA = \sigma(\sin\theta_{E,E_I}, 0.4)$

Results & Conclusions: **PA** and **NG**

Visual results:

- **NG** — MiSFIT presents less noise and a better delineation of areas with known Gaussian diffusion (i.e. CSF).
- **PA** — MiSFIT presents less noise and a better delineation of fiber tracts, known areas for their high anisotropy.
- 2D histograms: Similar and correlated outputs. MiSFIT underestimates compared to MAPL.

Results & Conclusions: **MiSFIT**

Computational efficiency:

- MAPL fits the whole basis
- MiSFIT non-linearly fits 3 parameters and the ODF is computed with linear LS problem

Time required:

- MiSFIT takes 2 minutes to compute all parameters and scalars
- MAPL can take up to 28 hours

Applicability in realistic clinical environments:

- Greater applicability in realistic clinical environments, but tied to multi-shell acquisitions

Next Steps

- **PA/NG** — **Quantitative Analysis** using Ground Truth generated by synthetic signals, as in [1]
- **MiSFIT/MAPL** — **Repeteability Analysis** using the CUBRIC-MICRA dataset, which consists on 30 sessions of 6 healthy subjects

[1] A. Tristán-Vega et al., NeuroImage, 227 (2021), 117616 [2] E. Özarslan et al., NeuroImage, 78 (2013), 16-32 [3] R.H.J. Fick et al., NeuroImage, 134 (2016), 365-385 [4] R.B. Toga et al., NIH Human Connectome Project data base.