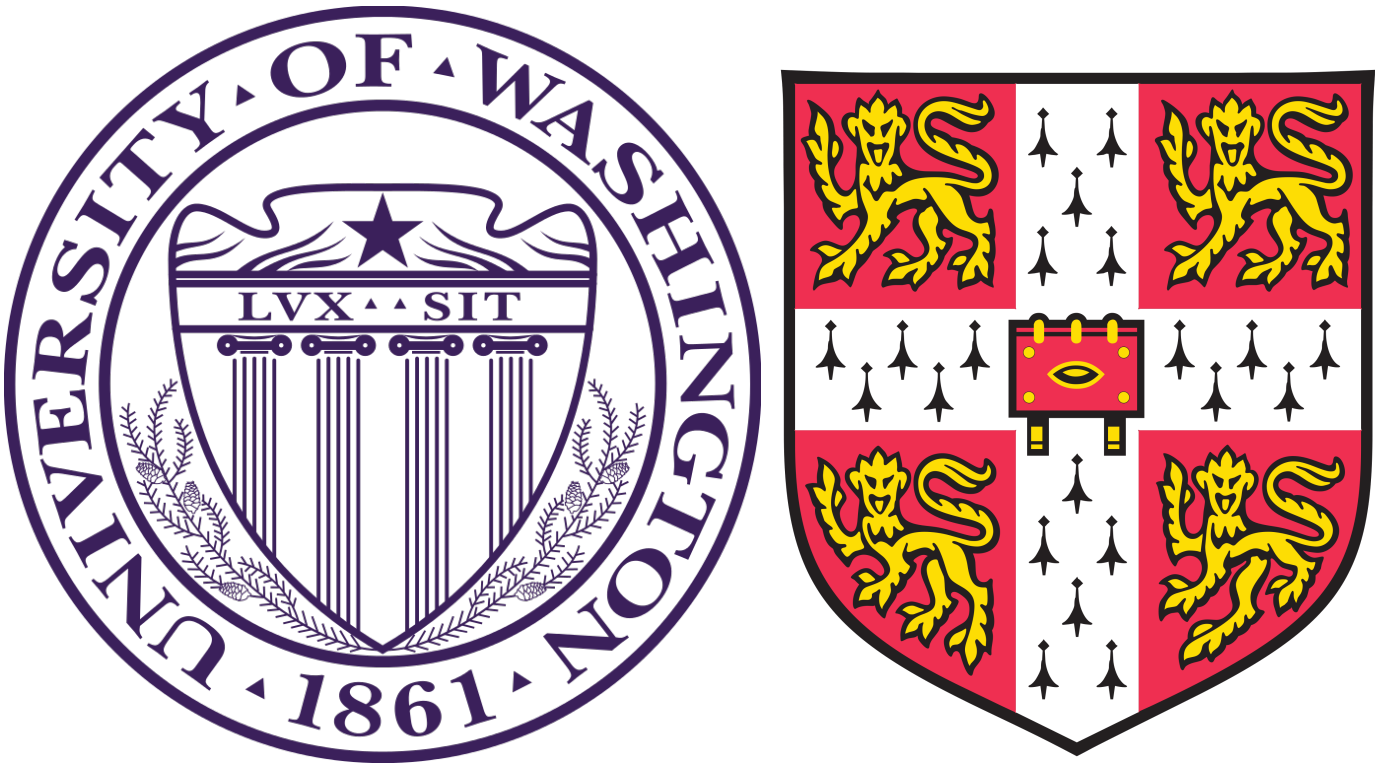


Diffusion Kurtosis Imaging for the Human Connectome Project

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Introduction

The Human Connectome Project

Diffusion MRI (dMRI) measurements provide detailed information about human brain connectivity and microstructure *in vivo*. HCP is measuring high-quality multi-modal MRI data from 1,200 individuals and make these data publicly available [3]. It has already made measurements from approximately 900 subjects available through Amazon’s Simple Storage Service (S3).

What model should we use to explain the data?

Diffusion Tensor Imaging (DTI)

Approximates diffusion in every voxel as a Gaussian distribution [1]:

$$S(\theta, b) = S_0 e^{\theta^T \mathbf{Q} \theta}$$

b is the **b-value**,

S_0 is the signal in the absence of diffusion gradient sensitization ($b = 0$)

\mathbf{Q} is a positive-definite quadratic form:

$$\mathbf{D} = \begin{pmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xz} \\ \sigma_{yx} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{zx} & \sigma_{zy} & \sigma_{zz} \end{pmatrix}$$

DTI: 6 parameters

Diffusion Kurtosis imaging (DKI)

DKI is an extension of DTI that accounts for non-Gaussian behavior in complex tissue, with many barriers to the diffusion process (cell membranes, myelin sheaths, etc.) [2]:

$$S(\theta, b) = S_0 e^{-bD(\theta) + \frac{1}{6}b^2 D(\theta)^2 K(\theta)}$$

$$D(\theta) = \sum_{i=1}^3 \sum_{j=1}^3 \theta_i \theta_j Q_{ij}$$

$$K(\theta) = \frac{MD^2}{D(\theta)^2} \sum_{i=1}^3 \sum_{j=1}^3 \sum_{k=1}^3 \sum_{l=1}^3 \theta_i \theta_j \theta_k \theta_l W_{ijkl}$$

\mathbf{W} is a rank 4 tensor (3-by-3-by-3-by-3 matrix).

DKI: 21 parameters

Diffusion Statistics

- Mean diffusivity (MD) characterizes the mean displacement of water molecules within a voxel.
- Fractional anisotropy (FA) characterizes the variance in diffusivity in different directions.

Variance in these parameters accounts for variance in psychiatric and neurological disorders, normal development and aging, and psychological traits.

Brain measurements that provide a close tie between brain tissue properties and behavior.

K-fold cross-validation

Materials and Methods

The human connectome can be assessed *in vivo* using MRI. Diffusion MRI (dMRI) is used to evaluate the microstructure of white matter, and the local orientation of nerve fibers in each voxel.

Data

Measurements were obtained from the WU-Minn Human Connectome Project consortium (<https://www.humanconnectome.org/>).

Of the 900 subjects that are available for analysis, 788 subjects have full diffusion measurements: 270 diffusion weighted

Measurements were obtained at a $1.25 \times 1.25 \times 1.25 \text{ mm}^3$ resolution.

A T1-weighted measurement was also obtained, and *Freesurfer* was used to segment the image into different tissue types. We focused our analysis only on the parts of the volume that contained the white matter.

Dipy (Diffusion Imaging in Python)

(<http://dipy.org/>)

- Open-source software for the analysis

- Implemented in Python. Performance is enhanced using Cython and OpenMP

- Contains implementations of many dMRI models, including DTI, DKI and others



Apache Spark

(<http://spark.apache.org/>)

- Open-source parallel processing framework that enables users to run large-scale data analytics applications across clustered computers.

- Dataflow-based execution system that provides a functional, collection-oriented API.

- Parallel tasks are described as a directed acyclic graph (DAG) – resilience against transient failures by tracking computational lineage

- Optimizes for data locality when scheduling work.

- Programming interfaces in Scala, Java, and Python.

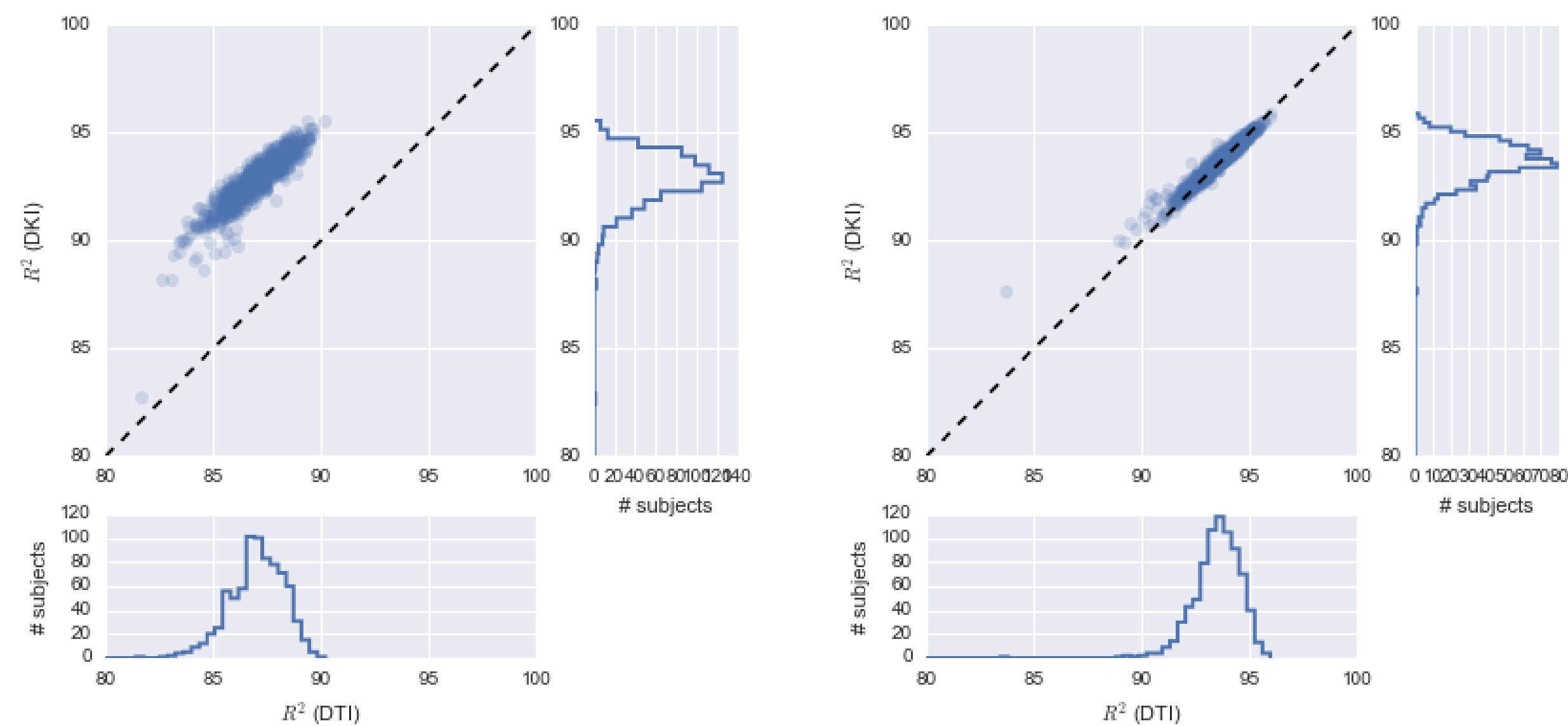


Computational experiments

We used AWS r3.2xlarge instance type, optimized for memory-intensive applications (lower price per GiB of RAM): each instance has 8 vCPU, 61 GiB Memory and 160 GB SSD storage.

Spark: Each compute node ran eight workers; spark default is one worker per CPU, for a total of thirty-two workers. We used.

Results



Conclusions

- DKI more accurately fits the HCP data than DTI
- DKI statistics are more reliable than DTI statistics
- DKI has the additional benefit that it provides additional parameters that lend themselves to a richer biophysical interpretation of the signal.

Future directions

- Foo
- Bar

References

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