112 W-PM

MetroTrac: A Metropolis Algorithm for Probabilistic Tractography

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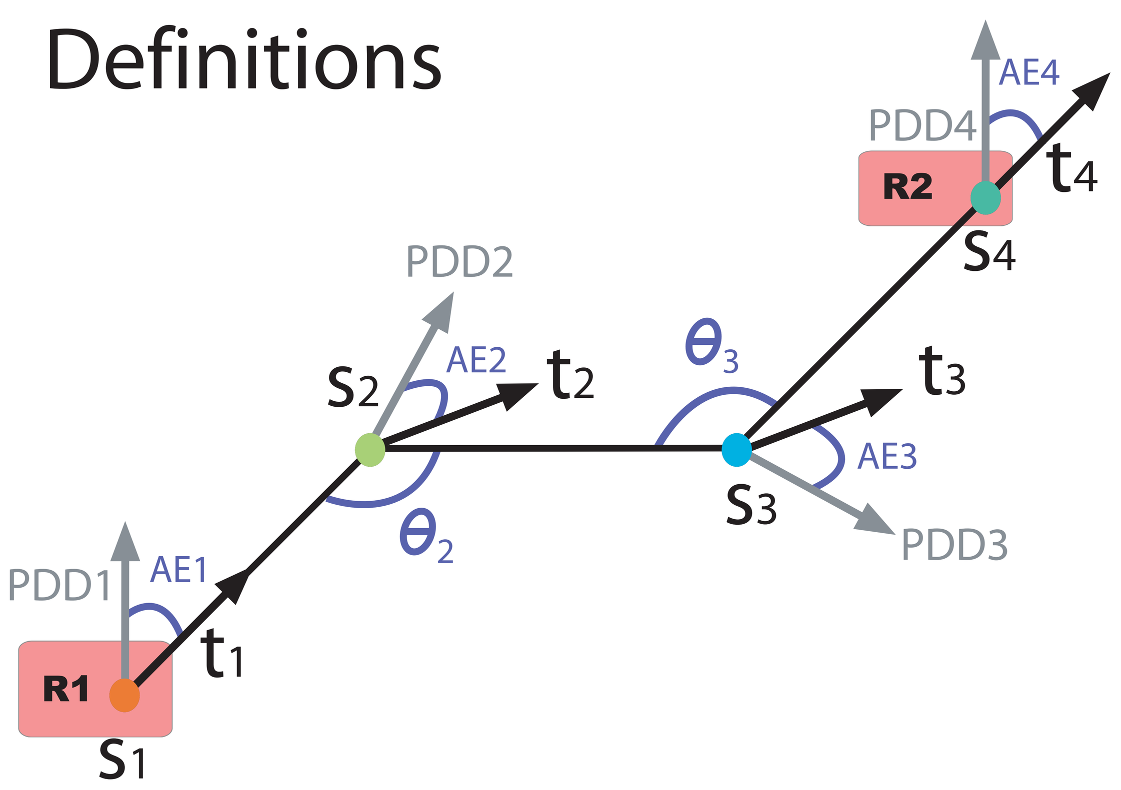
Introduction

Deterministic tractography algorithms, e.g. STT [1], produce reliable estimates of large fiber tracts but do not account for the uncertainty inherent in DW data. Here we present a Bayesian probabilistic tractography framework [2] that incorporates (a) a local diffusion likelihood model [3] and (b) a fundamental fiber regularization parameter found in many deterministic algorithms.

We introduce a Metropolis algorithm (MetroTrac) that correctly samples from this distribution. MetroTrac is efficient at sampling pathways that connect specific regions, even when these regions are separated by major crossing pathways.

Definitions



$S(R1,R2)$: Set of all paths that connect $R1$ and $R2$

$s=\{s_1,s_2,s_3,\ldots,s_n\}\in S(R1,R2)$: Pathway

t_i : Tangent at node s_i

$D=\{D_1,D_2,D_3,\ldots,D_n\}$: DTI data along s

PDD_i : Principal Direction of Diffusion for D_i

FA_i : Fractional Anisotropy for D_i

$$AE_i=\cos^{-1}\left(t_i^T PDD\right)$$

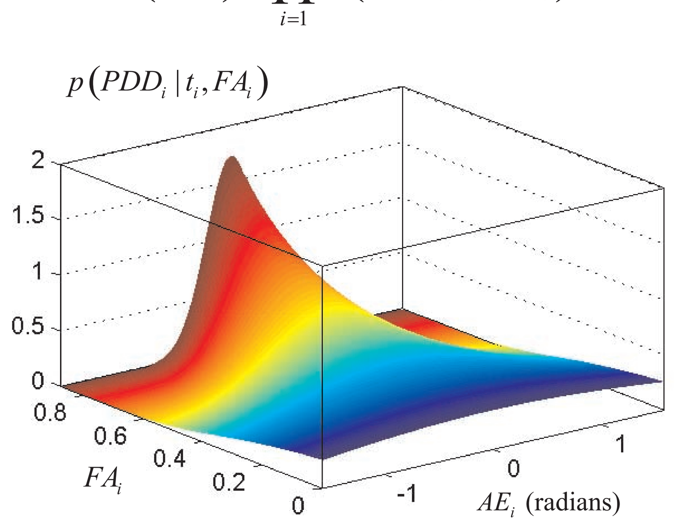
$$\theta_i=\cos^{-1}\left(\left(\frac{s_i-s_{i-1}}{\|s_i-s_{i-1}\|}\right)^T\frac{s_{i+1}-s_i}{\|s_{i+1}-s_i\|}\right)$$

Bayesian Pathway Scoring

Target Posterior: $p(s\mid D)\propto p(D\mid s)\,p(s)$

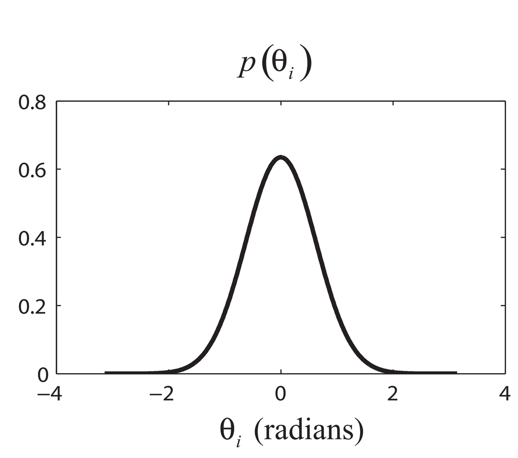
Likelihood (Parker et al. [3]):

$$p(D\mid s)=\prod_{i=1}^{n}p(PDD_i\mid t_i,FA_i)$$



Prior (*smoothness*):

$$p(s)=\prod_{i=2}^{n-1}p(\theta_i)$$



Methods

We tested the algorithm in 4 subjects by probing for suspected callosal pathways terminating in human MT+, a visual region on the lateral surface of the occipital lobe.

* Left MT+ was localized in each subject using fMRI (moving pattern vs. fixation).

* DTIQuery [6] used for tractography visualization.

* DTI details (Dougherty et al. [4,5]): 48-54 axial 2mm slices were collected on a 1.5T scanner for b=0 and b=800 using a diffusion-weighted, single-shot spin-echo EPI sequence [TE = 63ms; TR = 6s; bandwidth=110 kHz; partial k-space acquisition; 8-14 repeats; 12 directions (6 non-colinear); voxel size=2x2x2mm].

MetroTrac Principles

Pathway scores obey properties of independence (from data not along path) and symmetry (along path):

Independence

$p(s\mid D,D^c)=p(s\mid D)$,

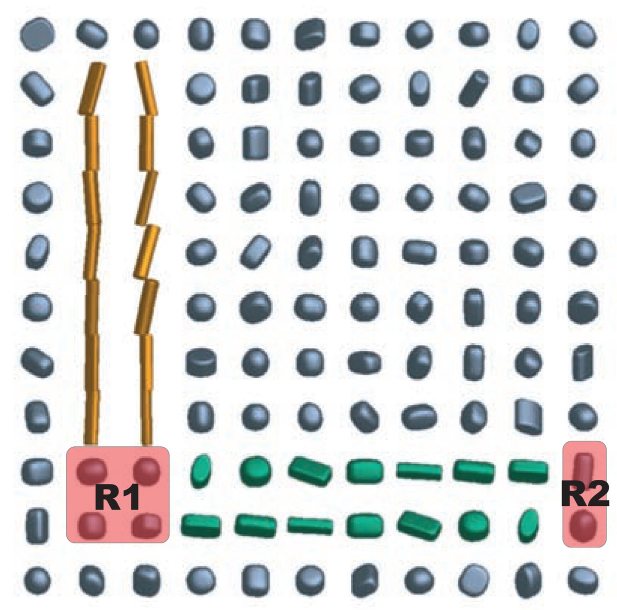
where D^c is DTI data not along path s.

Symmetry

$s=\{s_1,s_2,s_3,\ldots,s_n\}$

$s'=\{s_n,s_{n-1},s_{n-2},\ldots,s_1\}$

$p(s\mid D)=p(s'\mid D)$



MetroTrac Algorithm

* It is impossible to score all possible white matter tracts.

* MetroTrac uses the Metropolis algorithm [7] to discover tracts with the highest scores.

*Asymptotically, the algorithm is guaranteed to sample paths with a frequency proportional to their score.

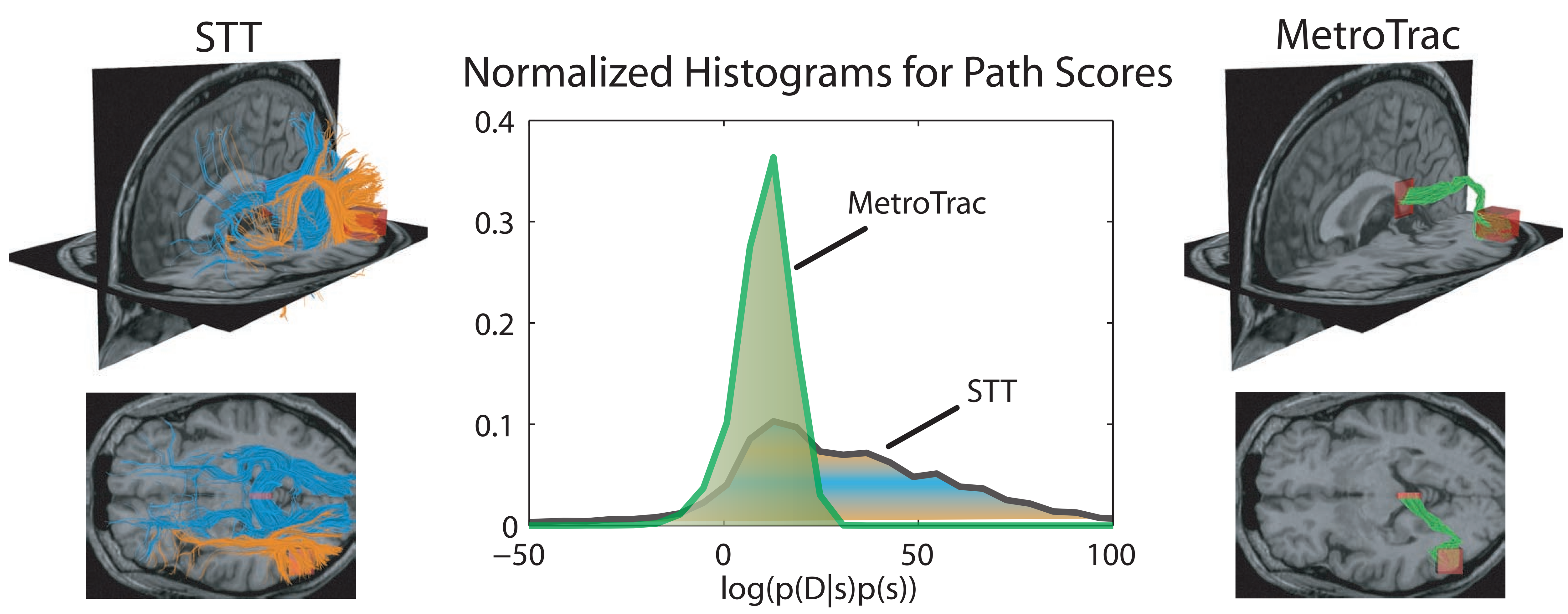
* The convergence rate depends on how well the software designer chooses path mutations.

MetroTrac Detects Pathways Invisible to STT

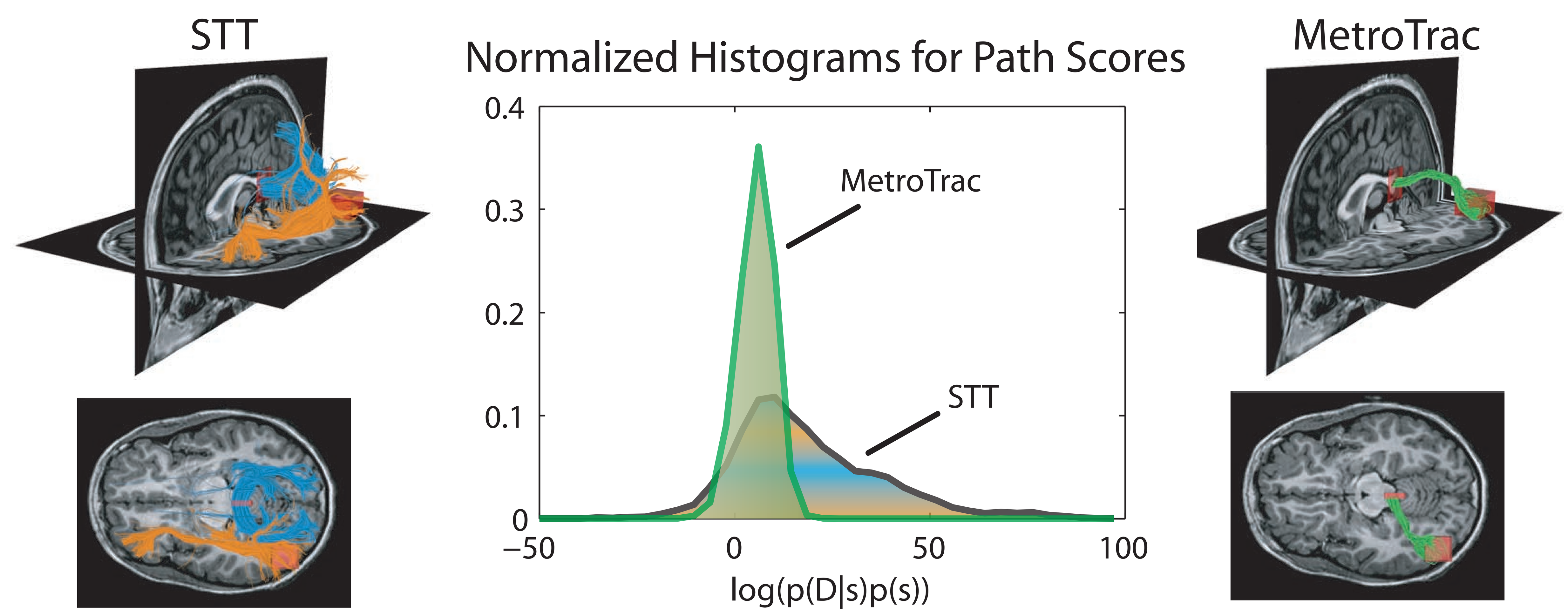
STT tracts were seeded with uniform spacing (1mm) in the entire left hemisphere, with blue tracts intersecting the splenium and orange tracts intersecting a region containing left MT+.

Unlike STT, **MetroTrac** sampled pathways that connected a region around the splenium and a region containing left MT+.

Example Case 1 of 4 (34y male)



Example Case 2 of 4 (11y male)



Conclusions

* MetroTrac implements a novel pathway scoring procedure that adheres to the principles of symmetry and independence.

* MetroTrac efficiently samples pathways using a Metropolis algorithm to ensure, asymptotically, that path frequency is proportional to score.

* MetroTrac reveals pathways that are missed by STT.

* These revealed pathways have scores that are well within the range of the pathways that are found by STT.

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