Fast Normalization of Probabilistic Tractography

S. E. Jones[1,2], and K. Sakaie[2]

[1]Neuroradiology, Cleveland Clinic, Cleveland, OH, United States, [2]Cleveland Clinic

BACKGROUND

An emerging need from the growing application of tractography to clinical disease is a robust scalar measure of connectivity between points in the brain. Probabilistic tractography can generate estimates of both connectivity and confidence intervals on connectivity values [Behrens TEJ et al, Nature Neuroscience 6: 750-757 (2003). Parker GJM et al, JMRI 18:242-254 (2003)]. Furthermore, Morris et al [Morris DM et al, Neuroimage 42: 1329-1339 (2008)] have recently demonstrated that systematic bias as a function of tract length can be normalized through use of a so-called null connection map. The null connection map is generated by implementing the tractography algorithm a number of times using isotropic fiber orientation probability distribution functions. Unfortunately, the large computational burden of probabilistic tractography is exacerbated by calculation of the null connection map. We propose a fast method for computation of the null connection map that may enable improved measures of connectivity.

METHODS

The proposed method is based on a partial differential equation field solution of Laplace's equation. The motivation for this approach is the observation that the null connection map should mimic the solution of the diffusion equation with boundaries placed at the edges of the parenchyma. If D represents the track density at any point within the brain's parenchyma, within this computational volume we solve the three-dimensional Laplace's equation $\nabla^2 D = 0$. Dirichlet boundary conditions are used at the brain's periphery, and the solution is forced by a fixed "source" at the seed ROI and/or the target ROI. The solution is computed twice, with and without inclusion of the target ROI. By weighted subtraction of the two solutions, a track density map is computed that solely represents tracks connecting the seed to the target, without tracks leaving the boundary. This field-solution track density map is then compared to the probabilistic tracking map generated by standard stochastic methods. The Laplacian computational method uses a Gauss-Seidel iteration with successive over-relaxation with an SOR of 1.7 (Numerical Recipes, WH Press, et al, Cambridge University Press). The Laplacian algorithm was written using IDL (ITT Visual Information Solutions. Boulder, CO, USA).

RESULTS

The Laplacian algorithm reached 0.01% convergence after 2000 iterations, which requires about 3 minutes of computational time on an Intel TM2 quad core CPU running at 2.4 GHz. The stochastic algorithm required 50 minutes to generate a comparable null connectivity map.

The figure compares the track density maps from the two methods, with color intensity reflecting track density. The axial image is in a plane between the seed and target ROIs. Locations of maximal tracking are coincident, although the magnitudes differ, likely due to subtle differences in parameterization. Notice that fall-off of track density away from the central core is better visualized using the field solution. At these locations, the probabilistic methods may only have one or fewer tracks counted.

CONCLUSION

We introduce a fast method for calculation of null connectivity maps based on a field solution of Laplace's equation. This overcomes the disadvantage of probabilistic tracking regarding the inefficiency for distant seed-target pairs, as such points generally are connected by very few successful tracts. We are currently investigating an extension of this method to generate the connectivity itself, which may offer the advantages of probabilistic tractography with minimal computational cost.

Track density using probabilistic technique

Track density using Laplacian field solution technique