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New Validation Technique for Cortical Data Smoothing

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Introduction:

Over the years, various diffusion based cortical surface data smoothing techniques [1,2] have been proposed but without numerical validation. We present a novel validation technique that uses the analytical solution of a diffusion equation as the ground truth. The proposed framework is used in validating and comparing the performance of *heat kernel smoothing* [2] and the *weighted spherical harmonic representation (SPHARM)* [3].

Methods:

Data. Three Tesla T1-weighted MR scans were acquired and went through a sequence of image preprocessing steps [3]. Both outer and inner cortical surfaces are obtained as high-resolution triangle meshes. Cortical thickness is computed at each mesh vertex and projected onto a unit sphere. Since the unit sphere is a closed algebraic surface, the basis functions are given analytically and are used in constructing the ground truth.

Heat kernel smoothing. Heat kernel smoothing solves an isotropic diffusion equation by iteratively performing kernel smoothing n times. The method has been used in various brain imaging applications due to its numerical simplicity. Figure 1 shows heat kernel smoothing of a sulcal pattern with a varying number of iterations.

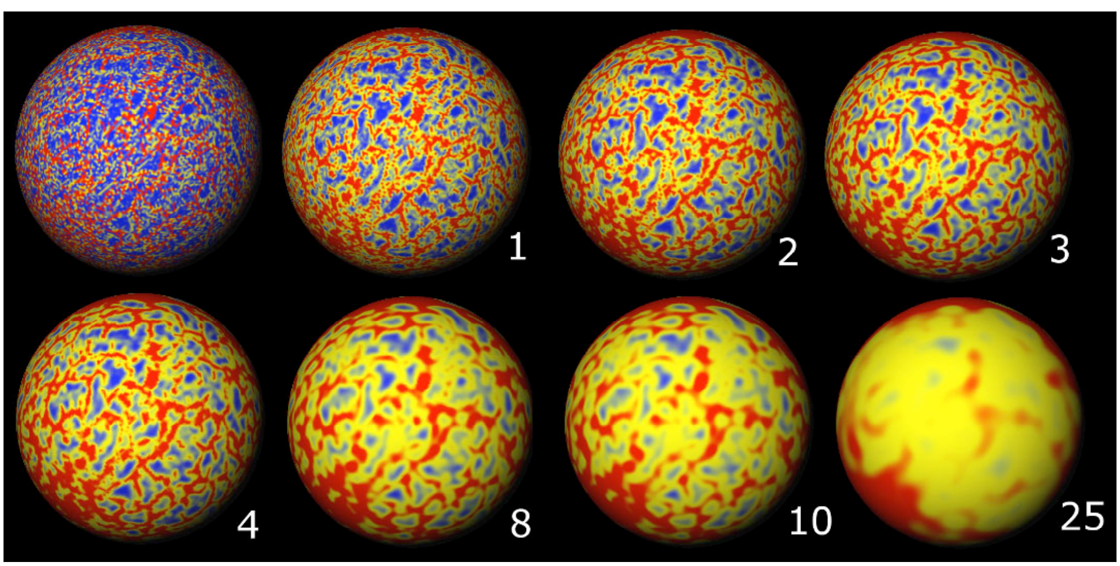

Figure 1.

Weighted-SPHARM. The weighed-SPHARM is a new cortical data smoothing technique formulated within the Hilbert space theory. The smoothing is done by summing up to the k-th degree series expansion of a diffusion equation. Figure 2 shows the smoothing of sulcal pattern with different degrees. The bottom row is the spherical harmonics of degree 5, 30 and 45.

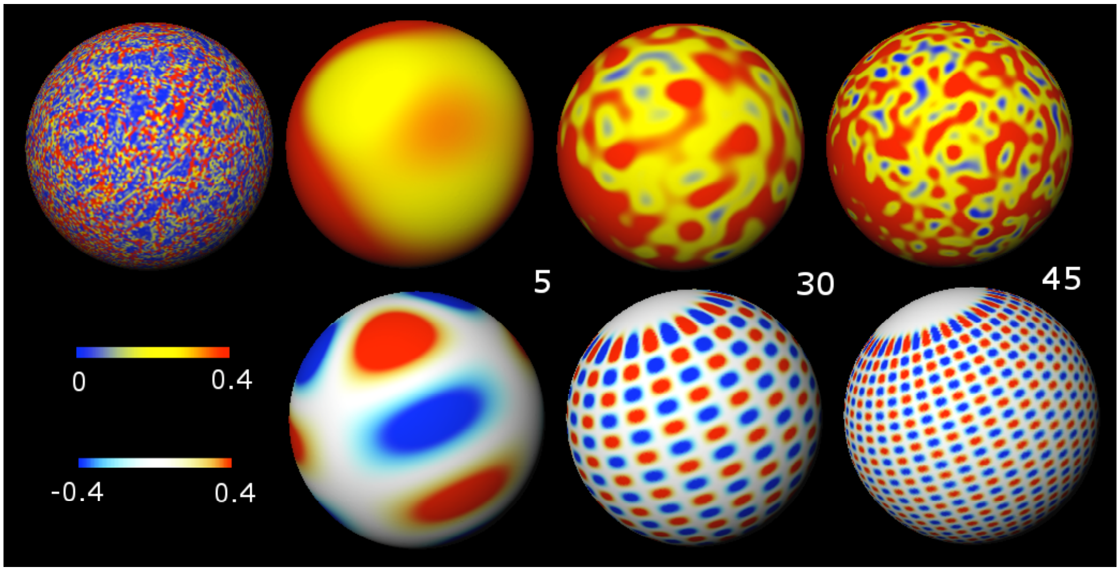

Figure 2.

Validation Framework. Any square integrable functional data such as cortical thickness can be represented as a linear combination of spherical harmonics. We take this representation as the input of both heat kernel smoothing and the weighted-SPHARM. The input signal is referred to as simulated cortical thickness in Figure 3. The unique solution to a diffusion equation with the input as an initial condition is again given as a linear combination of spherical harmonics. This analytical result serves as the ground truth (Figure 3). Then we have compared the output of heat kernel smoothing and the weighed-SPHARM to the ground truth.

Results:

The relative error for the weighted–SPHARM is up to 0.013 at some vertex and the mean relative error over all mesh vertices is 0.0012. We have used σ= 0.001 and the degree k=42. The performance of heat kernel smoothing depends on the number of iterations as shown in the plot of Figure 3. We have used varying number of iterations ($1<n<70$) and the corresponding bandwidth $\sigma=0.001/n$. The minimum relative error is obtained when 21 iterations are used. The relative error is up to 0.055 at some vertex and the mean relative error is 0.0067. The weighted-SPHARM outperforms heat kernel smoothing by the factor of ten. However, heat kernel smoothing provides a sufficiently good approximation.

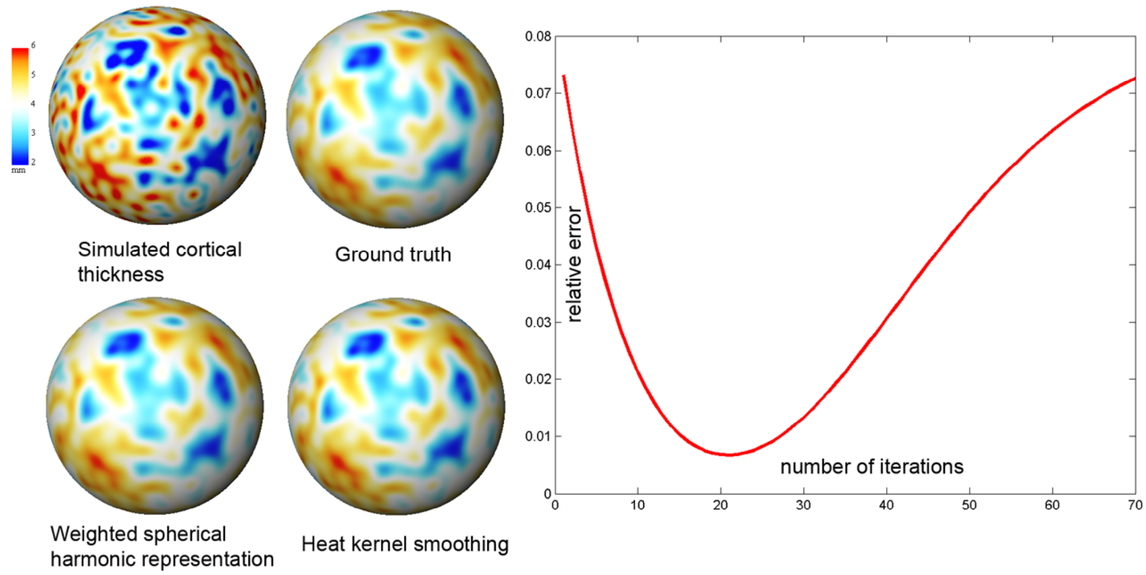

Figure 3.

Conclusions:
We have proposed a framework for validating cortical data smoothing techniques. The MATLAB implementation can be found in
http://www.stat.wisc.edu/~mchung/softwares.html.

References:
[1] Andrade, A. et al., 2001. Human Brain Mapping. 12:79-93.
[2] Chung, M.K. et al., 2005. NeuroImage 25:1256-1265.
[3] Chung, M.K. et al., 2007. IEEE Transactions on Medical Imaging. 26:566-581.