Reducing errors in Laplacian thickness using global surface topology

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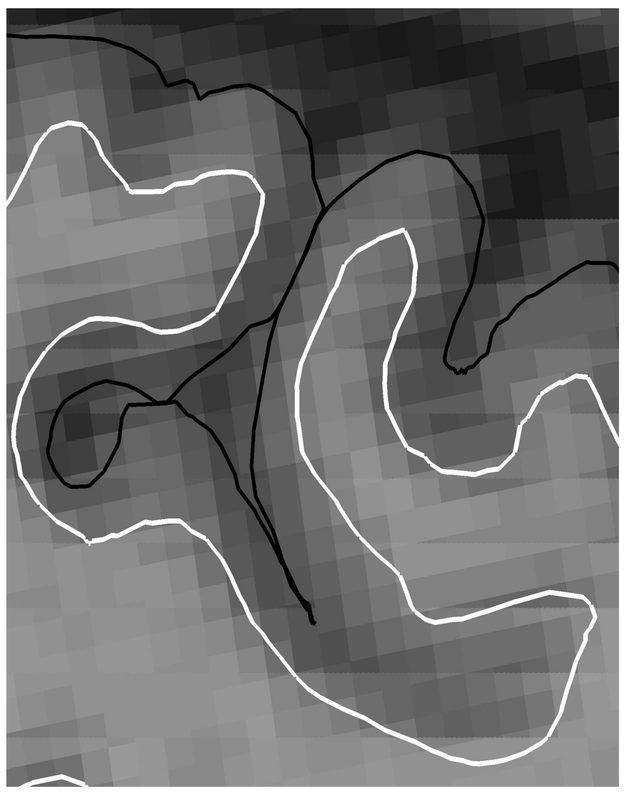
Introduction

Cortical thickness has been frequently defined as the arc-length of the streamline of the harmonic function between the pial and gray/white surfaces with constant, distinct boundary conditions [3,5]. The harmonic PDE is typically solved on a Cartesian grid using CSF and white matter voxels as boundaries. This can introduce artifacts when surface features are at a smaller scale than the grid spacing used for solving the PDE. In one manifestation of this, Cartesian grid based methods may incorrectly treat neighboring gyri (Figure 1) as being connected. Because the gyri have no white matter or CSF between them, the boundary between them is lost.



1. Brain MRI with gray matter surfaces

While previous work attempts to mitigate this [3], it does so at the expense of thickness accuracy: by altering the voxels considered gray matter to separate gyri, the thickness of each gyrus is a half-voxel length shorter.

References

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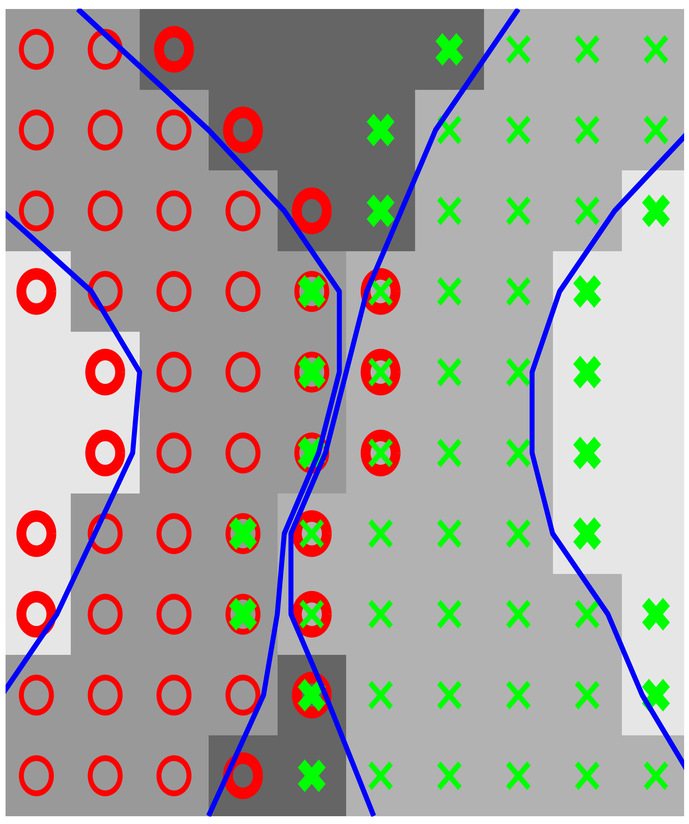
Method

We introduce an alternative domain to solve the harmonic PDE as bounded by the pial and gray/white surfaces where spatial topology is induced not only by Cartesian grid connectivity but also the membership to specific gyrii. In this new "surface topology", two voxels are defined to be adjacent if they are spatially 6-connected, and the segment between the voxel centers does not intersect a surface. Boundary conditions are defined on nodes at the far end of every surface intersected segment. Note that this definition allows for multiple nodes with the proximity in spatial position, but with different connectivity.



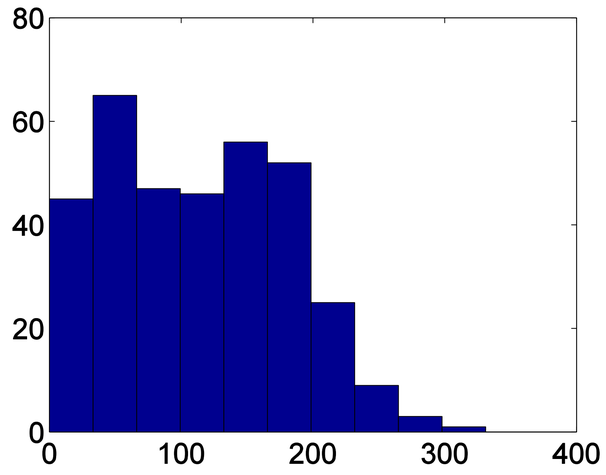
2. Surface Topology: Noughts and Crosses: different connected regions. Bolded shapes: boundary of matching

Experiments

340 brains from the OASIS database [4] were processed using FreeSurfer [1,2] to extract gray matter surfaces. Gray matter voxels were defined as those whose centers lay between the surfaces. Discretization errors were defined as clusters of 8 or more adjacent voxel pairs separated by a surface (considered non-adjacent by surface topology, but adjacent by the Cartesian grid topology). Thickness was calculated using Laplacian streamlines with (Figure 5) and without surface topology.

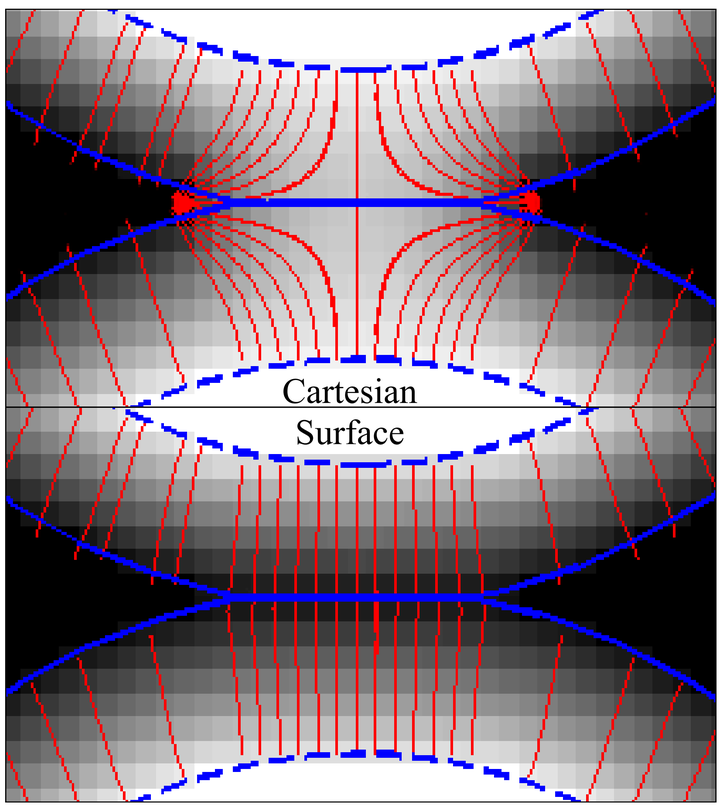
Results

Discretization errors were found to be present in every brain, with a mean 116 occurrences per brain (Figure 2).

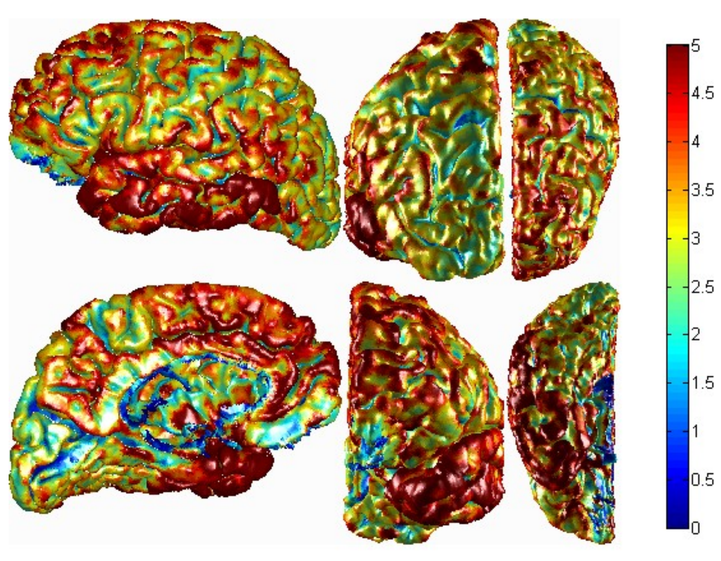


3. Histogram of discretization errors per brain

Our method was shown to decrease thickness measurements in regions near discretization errors (mean .40mm), while yielding unchanged thickness measurements distant from these errors(mean .06mm). This effect can be seen on synthetic 2D data in Figure 4.



4. Laplacian Streamlines using Cartesian and Surface Topologies



5. Laplacian Thickness using Surface Topology calculated on a brain from the OASIS Database