Topology Correction for Cortical Surface Models

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The Problem: The human cerebral cortex comprises a thin layer of gray matter at the outer surface of the brain. It is highly folded, but topologically equivalent to a sheet. We would like to enforce this topology in cortical models, without sacrificing model accuracy, i.e. the extent to which a model matches the cortical geometry.

Motivation: Because the cortex is highly convoluted, much of its surface is hidden in deep folds, so the 3D distance between two cortical locations may drastically underestimate their actual separation. Generating a topologically-correct cortical surface model allows for better estimation of geodesic distances, and for analysis that is not appropriately performed in the volumetric embedding space. For instance, surface representations have facilitated inter-subject alignment based on cortical curvature [4], and the topographic mapping of sensory areas [5]. Flattening the surface to expose hidden regions has proved useful for the purpose of visualization, for instance, of functional data superimposed on the cortical surface.

Proper flattening of the cortex requires that the surface model be isomorphic to a sheet. Topological defects (hole and handles) typically arise from segmentation errors and particular non-cortical structures, such as the fornix, lateral ventricle, and basal ganglia. While many small defects can be corrected automatically, certain types of larger defects are currently corrected manually, by trained individuals. [1, 2]

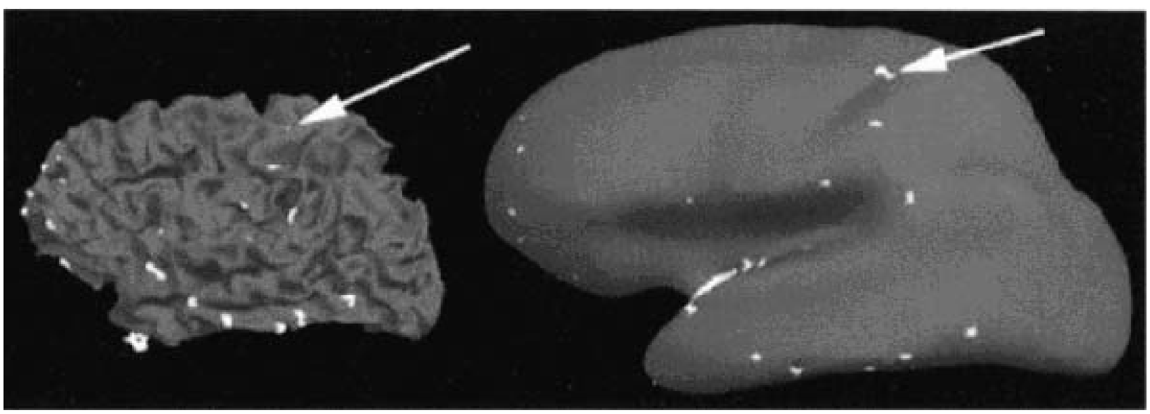

Figure 1: Detected defects painted onto the original folded white/gray-mater interface (left) and an inflated version of the same surface (right). The arrows indicate a defect across the posterior and anterior banks of the central sulcus shown in detail in Figure 2. Reproduced from [2].

Previous Work: Considerable work has been performed to automate almost all steps of the surface-reconstruction process [1, 3, 2]. This research has been encapsulated into a free software package called *FreeSurfer* (http://surfer.nmr.mgh.harva and has been used to reconstruct the cortical surface from hundreds of MRI head images. [2] presents a method by which defects may be detected, and by which most smaller defects in the initial reconstruction may be automatically corrected.

Approach: Using the Freesurfer framework [1, 3, 2], topological defects can be localized in a mesh that represents the white/gray matter boundary. We are using this as the basis for a correction method that might handle a broader class of defects. We are currently investigating a variety of approaches, which include:

- Performing morphological operations on the mesh to identify defects (holes / handles) of varying scale.
- A Bayesian framework to evaluate meshes on the basis of the intensity and covariance structure of the underlying volumetric images, the curvature of the mesh, and other factors.

Impact: Functional brain studies are central to research in neuroscience, and are conducted regularly in the field. Full automation of cortical flattening algorithms would eliminate time-consuming, manual defect correction, and improve the accessibility of these methods. Broader use of flattening methods and standardization of cortical coordinate systems would facilitate the comparison of functional brain studies conducted across the field.

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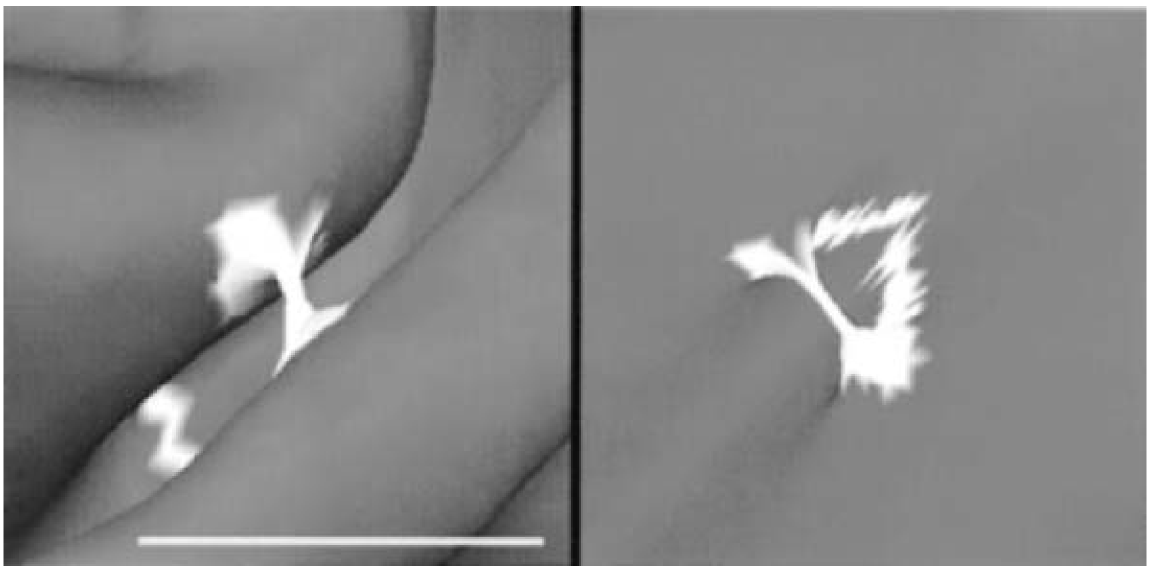

Figure 2: Close-up of defective regions painted white on the corresponding folded (left) and inflated (right) surface indicated by arrows in Figure 1. The white bar at the bottom of the left image is a scale bar indicating 1 cm. Reproduced from [2].

References:

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