Mindboggle: Automated human brain MRI feature extraction, labeling, morphometry, and online visualization

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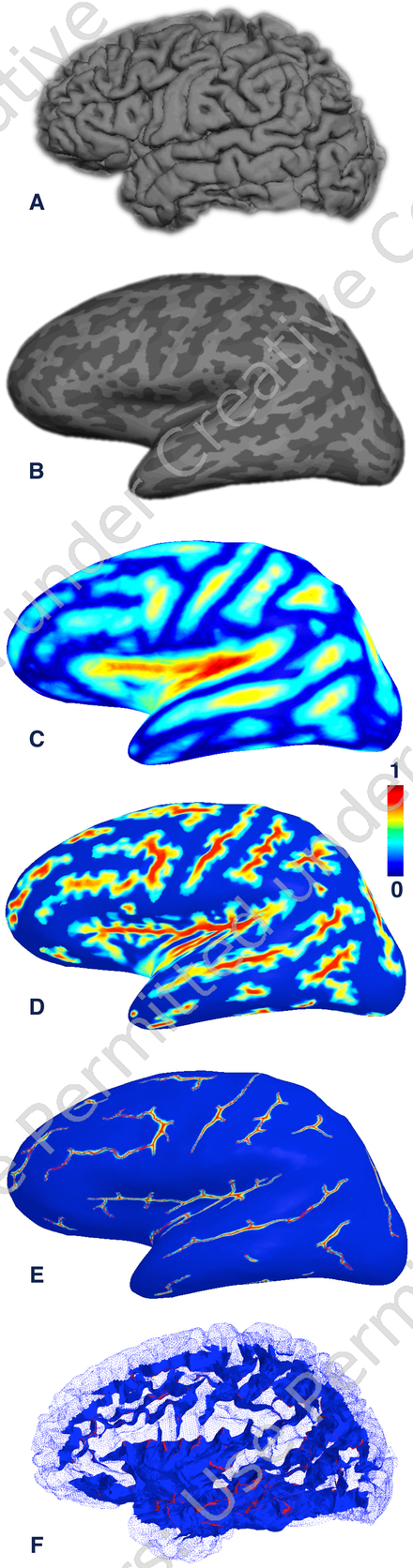


Mindboggle

Mindboggle (mindboggle.info) is a new neuroinformatics platform that currently automates the extraction, labeling, and morphometry of cortical features derived from human brain MR imaging data. It will soon be released as open source Python (and Python-wrapped C++) software built within nipype's flexible and modular software pipeline framework (nipy.org/nipype).

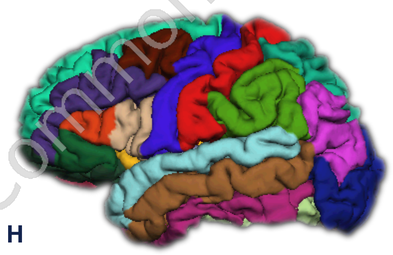
Feature extraction

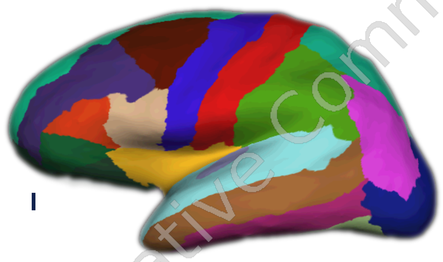
Mindboggle extracts features related to sulcus folds for potential use in biomarker-based diagnosis and prediction of treatment response. Here we focus on one feature, the fundus (curve along the bottom of a fold). To extract fundi, Mindboggle assigns a likelihood value to each point based on its depth and local surface curvature, and employs a hidden Markov measure field model formulated to encourage elongated, connected structures that reach the full length of folds. To identify these fundi, we break them up using labels we have assigned to vertices on the cortical surface mesh.

Left figures:
(**A**) cortical surface of the left hemisphere, (**B**) inflated cortex to expose the deeper recesses of the folded surface, (**C**) travel depth values, (**D**) fundus likelihood values, and (**E-G**) fundus curves on the bottoms of the sulcus folds.

Labeling

Mindboggle initializes labels on the cortical surface by using surface-based registration to an atlas (**H-I**). We use FreeSurfer (surfer.nmr.mgh.harvard.edu) and one of three different atlases: FreeSurfer's standard atlas, a similar atlas trained on our Mindboggle-101 dataset of 101 manually labeled human cortices (paper under review), and a multi-atlas approach using multiple individual atlases from the same dataset.

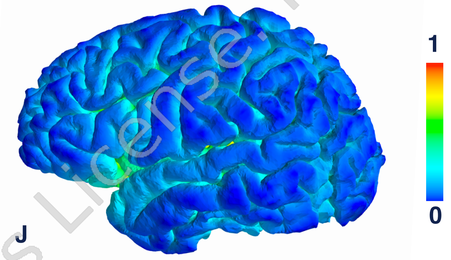


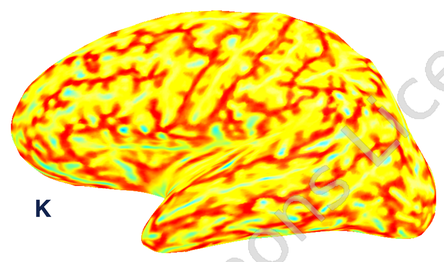


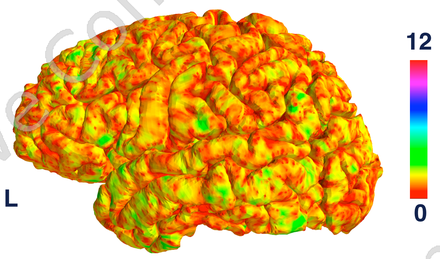
The fundi provide a much more consistent means of defining some label boundaries than a human would be capable of, and we are currently developing methods to use fundi to enforce a closer correspondence between label boundaries and fundi.

Morphometry

Mindboggle computes several shape measures for features and labeled regions, and we are adding more. For example, each vertex of the cortical surface mesh is assigned a new and accurate measure of depth called "travel depth" (**J**, by J.G.), curvature (average (**K**), Gaussian, and principal directions), as well as surface area (**L**) for normalizing shape measures computed over aggregates of vertices.







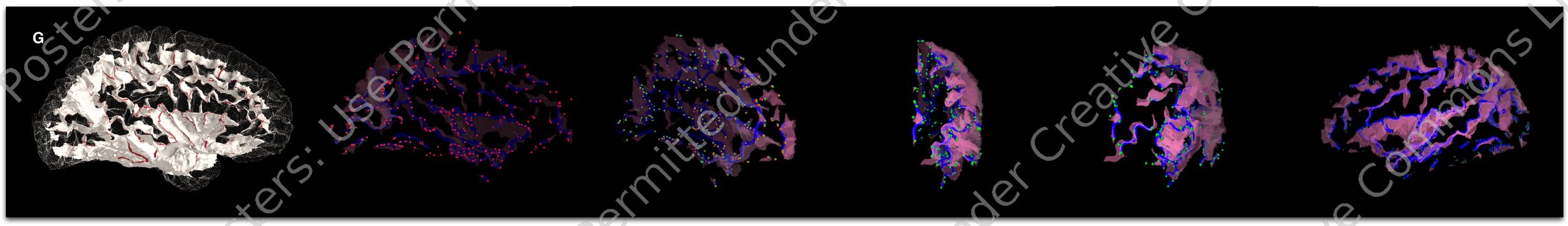
Online visualization

Morphometric analysis of a multitude of features can generate a lot of data, which presents a challenge for visualization and comparison across brains.

XTK (www.goxtk.com) is the premier WebGL library geared towards 3D medical imaging data. We demonstrate a web interface to Mindboggle data with interactive visualizations of brain features using XTK. The data consist of surface mesh patches and curves in visualization toolkit format (vtk.org).

In the future, they will be read from the Mindboggle database as JSON-encapsulated XTK objects. These objects are "WebGL-ready," meaning that they can be immediately visualized without further processing or file parsing.

Bottom figures:
The sulcus folds, fundus curves, and points of geometric interest (**G**) may be interactively viewed online (mindboggle.info).



Acknowledgments

Offline images were created using Mayavi (code.enthought.com/projects/mayavi/) and online images with XTK. This work was funded by the NIMH R01 grant MH084029 ("Mindboggling shape analysis and identification").