Automated extraction of nested sulcal features from human brain MRI data

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Goal

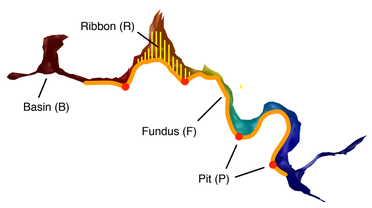
Features in human brain MR images can be used to co-register, compare, or anatomically localize or compartmentalize data in the images. In the present study, we automatically extract nested features from sulcal folds of the brain and compare these nested features with individual features extracted by other software algorithms. By nesting features of one type within features of another type, we can represent collections of features as a graph for later application of graph analysis methods in the Mindboggle software (www.mindboggle.info).

Feature extraction

We extracted features from 12 manually labeled MRI volumes and their FreeSurfer-generated (white or pial) surfaces using four software packages:

		Mindboggle	BrainVisa	Kiho Im	Gang Li
Basin	a fold	watershed segmentation of the brain's surface by curvature		lm2010	
Ribbon	medial surface within a fold	[under development]	Mangin1995		
Fundus	bottom curve of a fold	curve connecting pits	Cointepas2001		Li2010
Pit	depression in a fold	points deepest in a basin: "basin" or maximal curvature: "non-basin"		lm2010	

Mindboggle treats the above features as a nested set: *pits* are points that lie within *fundus* curves, and each fundus curve is the bottom edge of a *ribbon*, and a ribbon is the medial surface within a basin. Mindboggle uses the fundus curve to tie these features together, by connecting pits and anchoring ribbons to the basin surface. The fundus curves connect not only pits but other high curvature points via a minimum spanning tree algorithm. We are currently developing a ribbon extractor that grows a medial surface from a fundus curve within a basin, where the basin is generated by a watershed segmentation algorithm.



Feature comparison tests

Test 1: *Is a given type of feature consistent across subjects?*
Measure Hausdorff distance between fundus curves in co-registered subjects.

Test 2: *Are features consistent with label boundaries?*
Measure Hausdorff distance between fundus curves and manual label borders.

Test 3: *How much does a given type of feature improve registration accuracy?*
Measure overlap between manual target labels and fundus-registered manual source labels.

Test 4: *How close are different algorithms' pits to different algorithms' fundi?*
Measure minimum distance from pits to fundi across algorithms.

Results

We report fundus results, since pits results are biased in favor of the number of pits generated, basins are defined differently and are computed on different surfaces, and ribbons are currently generated only by BrainVisa. The results are very similar across the fundus extraction algorithms according to Test 1 and 2 mean (and SD) distances (mm), and preliminary Test 3 overlaps (not shown):

	Mindboggle	BrainVisa	Gang Li
Test 1:	2.45 (1.64)	2.16 (1.57)	2.47 (1.66)
Test 2:	4.34 (3.65)	4.48 (3.28)	3.47 (2.37)

For Test 4, as expected, the distance between Mindboggle fundi and Mindboggle pits (both basin pits used to generate fundi and non-basin pits) is less than the distance between any other combination of fundi/pits (note: Mindboggle uses a different (pial) surface than the other algorithms):

		Pits	
		Mindboggle: basin / non-basin	Kiho Im
Fundi	Mindboggle	0.19 / **0.51**	2.64
	BrainVisa	3.13 / 2.35	3.21
	Gang Li	4.08 / 2.78	1.48

Conclusion

Our nested features are comparable to individual features extracted by different software packages as measured by their consistency across subjects, consistency with label boundaries, and registration results.

References

Cointepas, Y., Benali, H., Garnero, L., Mangin, J.-F., and Poline, J.-B. (2001), 'BrainVISA: Software platform for visualization and analysis of multi-modality brain data', 7th Annual Meeting for the Organization of Human Brain Mapping, NeuroImage, vol. 13, no. 6, S98.

Mangin, J.-F., Frouin, V., Bloch, I., Régis, J., López-Krahe, J. (1995), "From 3D Magnetic Resonance Images to structural representations of the cortex topography using topology preserving deformations', Journal of Mathematical Imaging and Vision, vol. 5, no. 4, pp. 297-318.

Im, K., Jo, H.J., Mangin, J.-F., Evans, A.C., Kim, S.I., and Lee, J.-M. (2010), 'Spatial distribution of deep sulcal landmarks and hemispherical asymmetry on the cortical surface', Cerebral cortex, vol. 20, no. 3, pp. 602–611.

Li, G., Guo, L., Nie, J., and Liu, T. (2010), 'An automated pipeline for cortical sulcal fundi extraction', Medical Image Analysis, vol. 14, no. 3, pp. 343–359.

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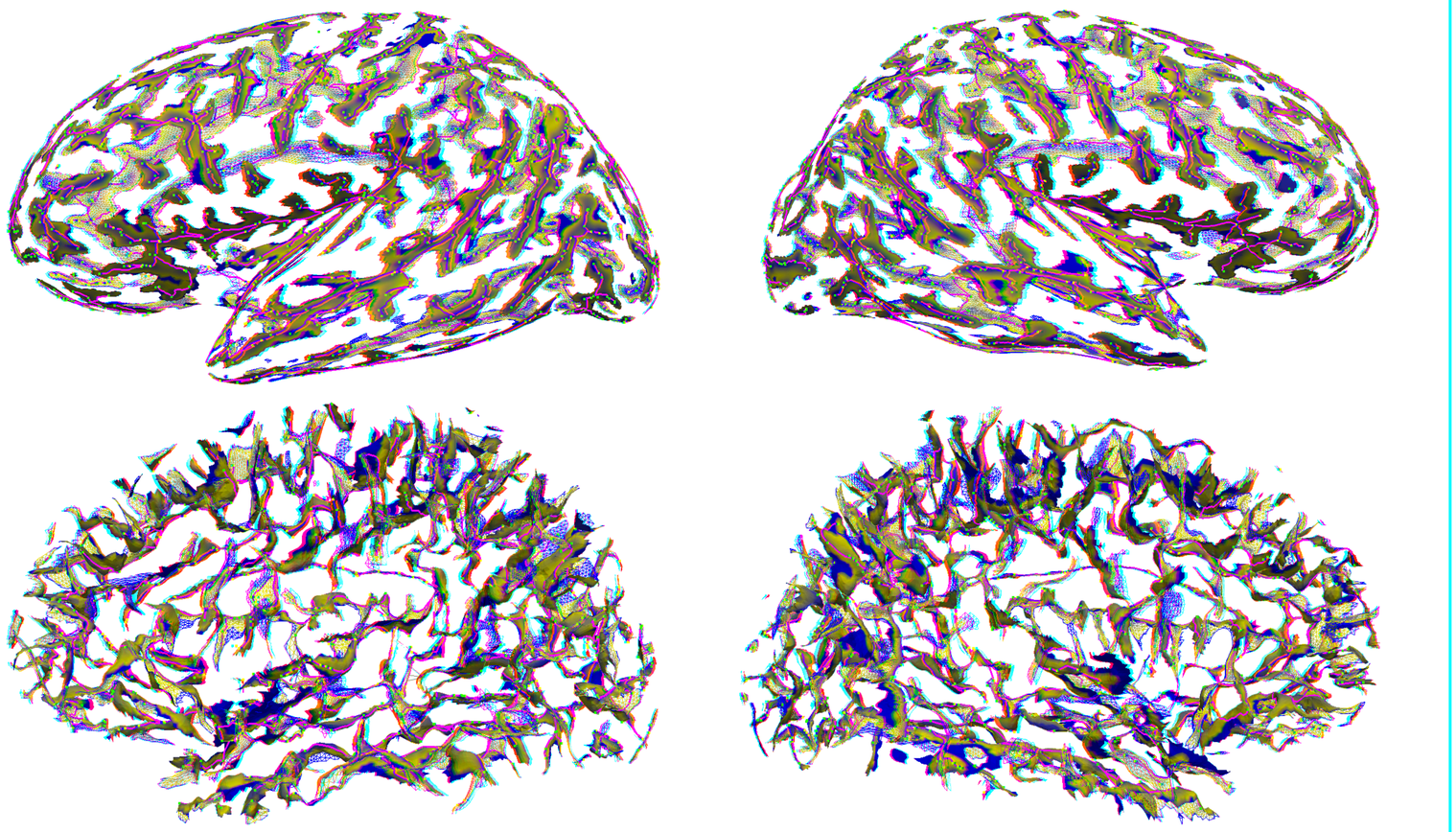

Figure 1. Anaglyphic 3-D representation of nested features on the inflated surface (top) and in the original brain volume (bottom) generated by Mindboggle. The figures represent sulcus basins, fundus curves, and pits. Basins were extracted from the pial surface and curvature values are color-coded (yellow to blue).

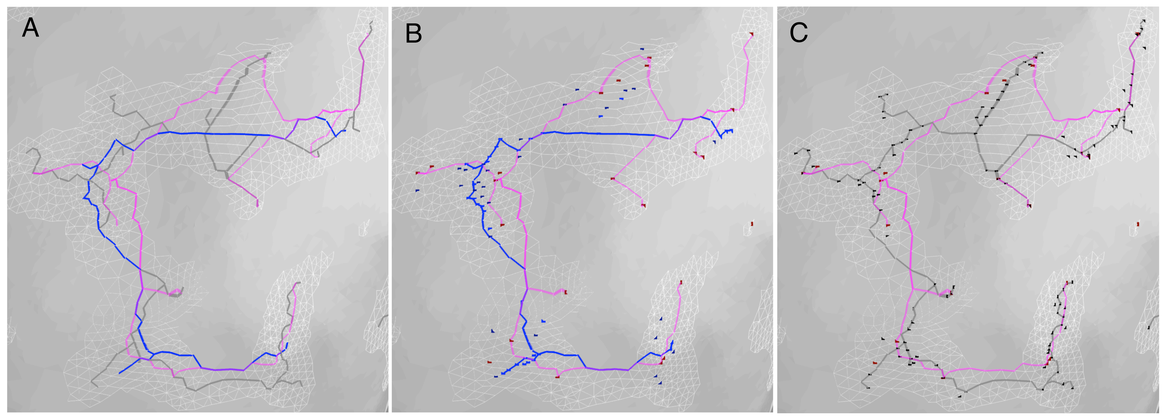

Figure 2. Mindboggle fundus curve construction

A. Three types of fundi generated by Mindboggle:
Vertex-connected fundi (blue)
Skeleton-connected fundi (gray)
Pit-connected fundi (magenta), the default.
All are connected using a minimum spanning path tree algorithm.

B. Vertex-connected fundi (blue) have candidate and strict vertices following Gang Li's neighborhood derivative tests. Pit-connected fundi (magenta) connect pits.

C. Skeleton-connected and pit-connected fundi: Skeleton-connected fundi (gray) are formed by thinning a Hamiltonian distance transform.

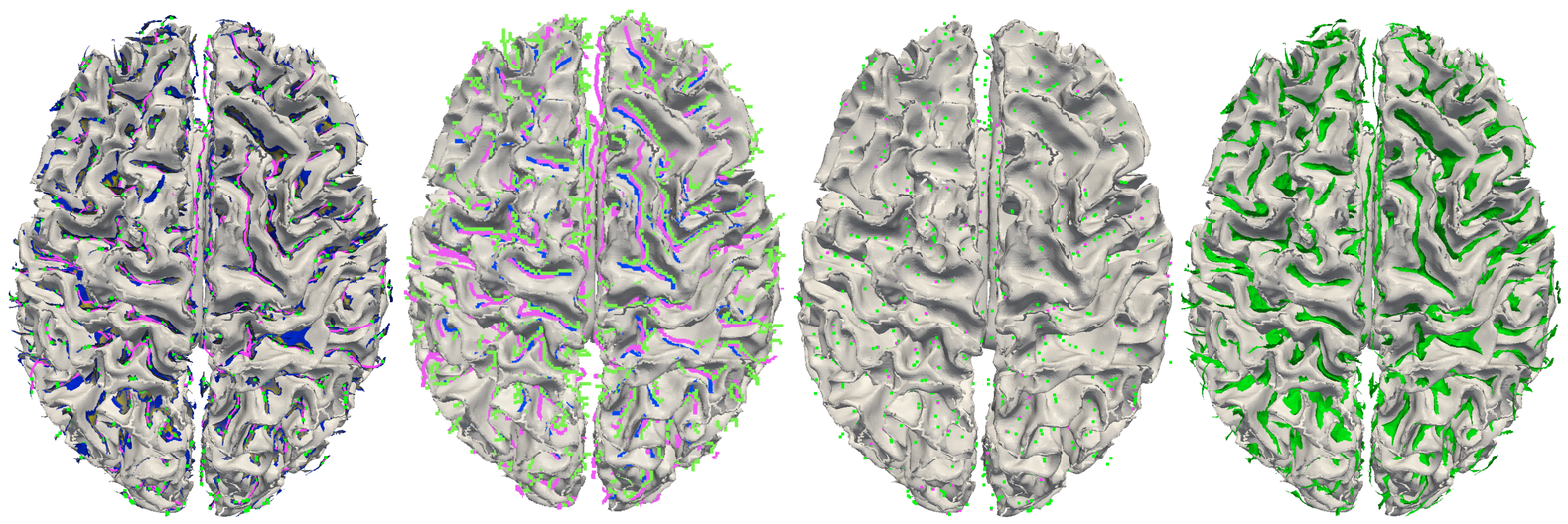

Figure 3. Comparison of features across algorithms

Mindboggle features, top view of brain:
basins (yellow-blue), fundi (magenta), pits (green)

Mindboggle fundi (magenta)
Gang Li's fundi (blue)
BrainVisa fundi (green)

Mindboggle basin pits (green)
and non-basin pits (magenta).
(Kiho Im's pits are not shown.)

Mindboggle basins (green)
Kiho Im's basins (gray)