A Surface-based Coordinate System for a Canonical Cortex

M.I. Sereno[1], A.M. Dale[2], A. Liu[2], and R.B.H. Tootell[2]

[1]University of California, San Diego, CA and [2]MGH NMR Center, Charlestown, MA

Introduction

The cerebral cortex makes up the largest part of the human brain. It has the topology of a folded, 2-D sheet. Nevertheless, most approaches to analyzing and displaying human brain imaging data have relied upon a 3-D coordinate system (1). There are a number of advantages to analyzing imaging data in a cortical-surface-based coordinate system.

Automatic Reconstruction of the Cortical Surface

To apply surface-based techniques routinely, the cortical surface reconstruction process must be automated. Several years ago, a method was devised for recovering the complete cortical surface of each hemisphere from high resolution MRI images in the context of improved solutions to the inverse problem for EEG and MEG (2). Since then, these programs have been improved and extended to incorporate functional MRI imaging data (3) (see also http://cogsci.ucsd.edu/~sereno).

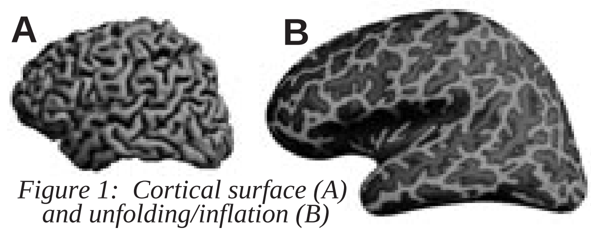

Figure 1: Cortical surface (A) and unfolding/inflation (B)

Making a Canonical Cortical Surface

To make it possible to average data in a surface-based format, it is necessary to construct a "canonical" cortical surface. This can be done by averaging 2-D surfaces rather than 3-D volumes (4). The brains are first individually unfolded ("inflated") to remove minor and major sulci (see Figure 1). This reconstruction and unfolding process has now been applied to a large number of hemispheres (see Figure 2 for a sample of 18 brains from our data base). The brains can then be morphed into each other, a pair at a time, using a "shrink-wrapping" algorithm similar to that used for initial surface refinement. A single, unfolded, curvature-marked (sulcus/gyrus) brain surface can be obtained with a binary tree, and then completely flattened (or conversely, re-folded). Each point of this surface accesses a unique surface point on each of the hemispheres in the database and, hence, any of their associated functional data.

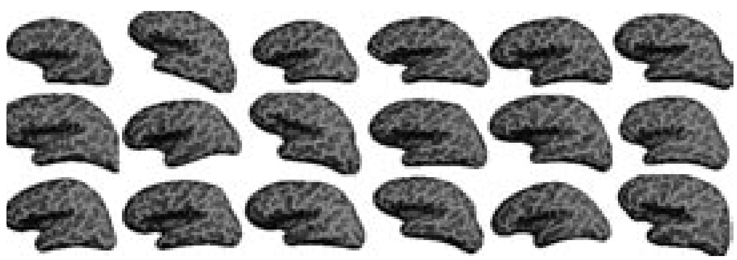

Figure 2: 18 unfolded left hemispheres

Cortical Surface Coordinate System

To refer sensibly to locations on the unfolded cortex, we have established a 2-D coordinate system on the 2-D surface. An obvious choice for spheroidal objects is latitude and longitude (two angles measured from the center of the spheroid). These coordinates can be applied after inflating the average cortical surface into an exact ellipsoid (see Figure 3 for a single-brain example). This parameterization of the unfolded cortex has the attractive property that nearby points will refer to nearby points on the cortical map—which is not generally true of a 3-D coordinate system.

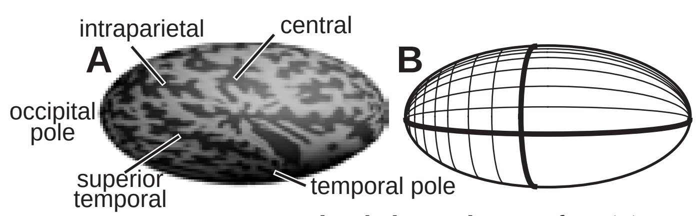

Figure 3: Canonical right hemisphere surface (A) (one brain only) and coordinate system (B)

Links with 3-D coordinate systems

It is straightforward to establish links with existing 3-D coordinate systems such as the Talairach space. Many other studies will continue to use them, and there is a rich database of mapping data already specified in 3-D coordinate systems that could usefully be translated into, and compared with, data in the newer 2-D system.

References

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4. Miller, M.I., G.E. Christensen, Y. Amit, and U. Grenander. Proc. Nat. Acad. Sci. 1993, 90:11944-11948.