Automatic Extraction of 3D cortical profiles as the basis for anatomically-based cortical parcellation

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Introduction:

We present a framework for the creation of three-dimensional cortical profiles based on cortical surface reconstruction.

At present the creation and use of such profiles to extract laminar fingerprints of cortical regions is limited to two dimensions and requires labour-intensive manual interaction [1]. To obtain profiles corresponding to local neural organization, some researchers have advocated Laplace equation methods [2]. The present approach derives cortical profiles more directly, handling the third dimension in a natural way. Using the input of high-resolution structural MRI scans, automated computational stages are pipe-lined to achieve high accuracy in minimal computational time.

Material & Methods:

T1-weighted images were acquired using a standard MP-RAGE sequence (TI = 650 ms; TR = 1300 ms; TR,A = 10 ms; TE = 3.93 ms; alpha = 10°, 1.0mm isotropic resolution), and a Siemens TIM-Trio 3T scanner (Erlangen, Germany). Non-uniformity correction, denoising and registration into the MNI space were performed, prior to a probabilistic tissue classification into three tissue classes [3]. This segmentation was then used to construct probabilistic edge maps, representing the borders between gray matter and white matter, and GM/CSF. A topology-constrained level set method was used to represent implicitly an evolving surface, and the level set was initialized with spherical topology close to the target boundary [4,5,6]. The gradient vector flow field of the edge maps was used to control and improve the convergence behavior [7,8]. The inner and outer cortical surfaces were detected separately for each hemisphere and surface. We used a narrow band implementation [9] and multi-threading to reduce computation time. Periodic re-initialization based on tri-cubic interpolation [10,11] was implemented to improve stability and accuracy. The polygonal representations were extracted using a topology-preserving Marching Cubes algorithm [12]. The cross-cortical profiles were then calculated starting from each vertex of the GM/WM boundary mesh and integrating through the final level set function using a 4th order Runge-Kutta method [13] , until the GM/CSF boundary mesh was reached.

Results:

The extraction of polygonal representations of the cortical surfaces produces consistent results in a few hours for each entire hemisphere (Figure 1). The cortical profile lines are generally curved, and are always perpendicular to the iso-surfaces represented by the level sets. The number of profiles, and thus the density of coverage, can easily be increased by further subdivision of the mesh (Figure 2).

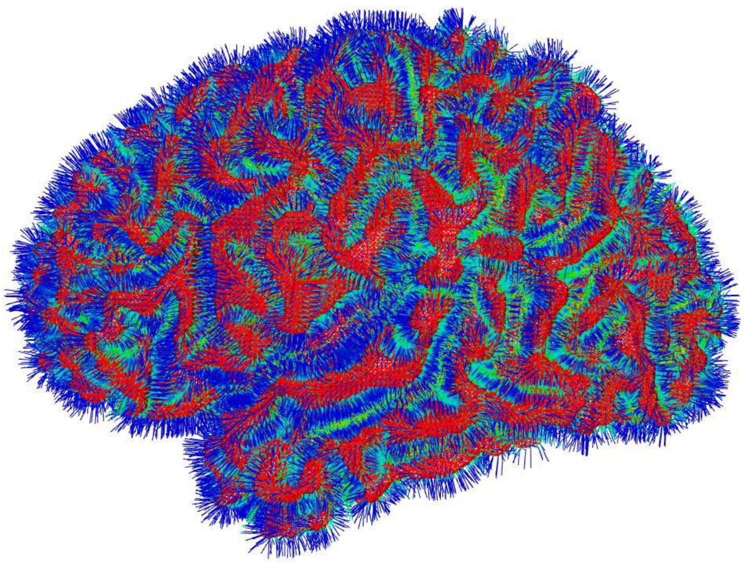

Figure 1: GM/WM boundary mesh with cortical profiles

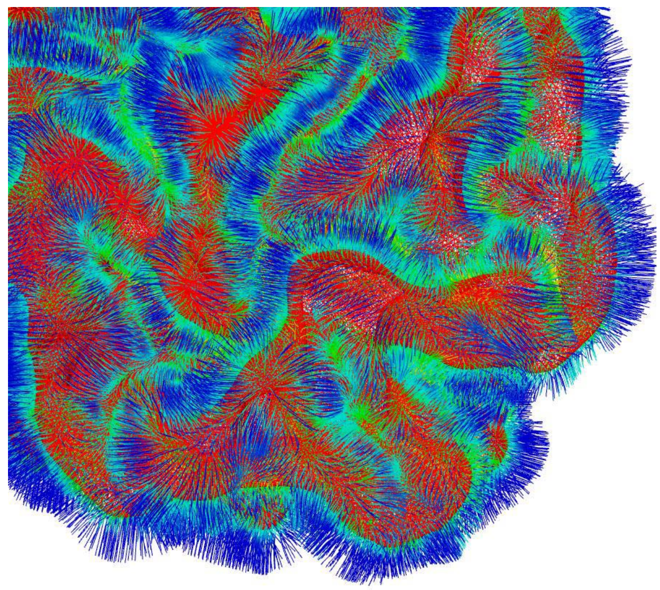

Figure 2: zoomed view, with a higher density of profiles

Discussion:

A surface representation of the cortex can be efficiently calculated using a level set methodology. The level set function thus derived allows the enrichment of this representation with the creation of realistic cortical profiles. The success of this approach suggests that the additional calculation of a Laplace field may be unnecessary. The curve of the profiles mimics the columnar organisation of the cortex, and is therefore a more natural representation than simple straight lines. These profiles are optimally suited for anatomically-based cortical parcellation.

References:

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