Reconstructing Topologically Correct Cerebral Surfaces - A Method Based on Simple Points

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INTRODUCTION

The cerebral cortex is topologically equivalent to a sphere when connected through the brain stem. The unidealities in the MR imaging process cause, however, small defects in the cerebral surface segmented from a 3-D MR image using an intensity-based method. We present here a voxel-based method to correct the topology of a segmented tissue map based on a concept from computational topology called a simple point. The algorithm is simple to implement and extremely fast. It affects only a minimal set of voxels keeping the fine details of the cortex intact. The reconstructed surface can be used for surface-based analyses of the cerebral morphology.

IMAGE ACQUISITION AND PREPROCESSING

We have acquired 10 T1-weighted MP-RAGE images with a voxel-size of 1 cubic-mm (TR/TE=9.7/4.0, FOV=256 mm) using Siemens Magnetom Sonata scanner. The images are anisotropically filtered and fed into a tissue classification algorithm that also corrects for the MR intensity inhomogeneity artifact [1]. The algorithm uses Bayesian EM approach which interleaves between the tissue classification and the inhomogeneity correction. The left and right hemispheres are further separated in the tissue maps by applying gross anatomical region masks from expert segmentations using a deformable registration algorithm. Isolated islands of brain tissue as well as air cavities inside the brain are removed as a preprocessing step using a connected component algorithm.

THE METHOD

For ensuring a unique one-to-one mapping of the cerebral surface onto a sphere, a topology correction algorithm is required (Figure 1). The cerebral surface reconstructed directly from a tissue map contains defects, handles and holes. A hole and a handle are converse concepts. E.g. the hole of a torus can be removed either by filling the hole, or cutting the torus, i.e. breaking a handle, from one point. There is no unique way of deciding how to optimally correct a defect. A decision criterion could be, e.g., how big a change an operation, a hole closing or a handle breaking, causes to the surface.

We aim at reconstructing the inner surface of the cerebral cortex between gray and white matter. We rely on the ideas presented by Aktouf et al. [2], and we augment them in a fashion similar to [3] to find an optimal set of holes closing and handles breaking steps. The basic idea of the algorithm can be understood with an analogy to the work of a sculptor (Figure 2). As the sculptor begins with a hexagonal block of sculpting material, the algorithm begins with a hexagonal volume of object voxels surrounding the target object. The algorithm carves voxels from the volume as the sculptor carves his statue. The algorithm has knowledge of the target object, so it carves only background voxels. Also, a voxel can be removed only if it is topologically simple, i.e. it does not alter the topology of the object. Eventually there are left only object voxels and voxels whose removal would alter the topology of the object. Because we began with a hexagon that is homeomorphic to a sphere, the end result is a topologically spherical object. It has its original features and detail, and a few additional voxels that are needed to fill the holes.

The simple point rule given in [4] can be precalculated for each of the possible configurations of the 26-connected neighborhood of a voxel and stored into a lookup table for fast access during the processing. A Euclidean distance map orders the carving process, in order to form a so called centered topological hull of the object [2]. The distances are put into a fast-access priority queue. The basic algorithm works in linear time.

We work both inside out (handles breaking) and outside in (holes closing) to find all the handles and holes in the image (or internal and external topological hulls). To compute an optimal set of corrections we assume that all the handles that affect a hole are connected to it, and visa versa. We form a number of connection trees (a forest) with the holes and handles as edges. In each tree we find the set of corrections (either hole closings or handle breakings) that causes the least changes into the original tissue map, by calculating the volume of the change. Since the tree formation exploits a linear time connected component algorithm, and we combine two linear time topological hull algorithms, the proposed method works in linear time.

The surface is eventually reconstructed using the marching cubes algorithm. We need to take into account the connectivity of the object and the background assumed in the simplification algorithm. The same connectivity rules are exploited to compute the case table for the marching cubes reconstruction (see [5]). Here, it was assumed that the brain was a 6-connected object, and the background 26-connected.

RESULTS

All computations were performed using a PC with Pentium M 730 Processor and 512 Mb of memory. The algorithm takes in average 15.1 (standard deviation 0.8) seconds to run, the number of changes was 73.5 (9.4) with 209.9 (19.9) voxels changed, and the single maximal correction was 30.3 (19.9) voxels.

CONCLUSIONS

We presented a 3-D algorithm for reconstructing topologically correct cerebral surfaces exploiting a concept from digital topology called a simple point. The results show that the method is extremely fast, and it affects only a minimal set of voxels (compared to order of 100000 voxel in a single hemisphere). The algorithm also very straightforward to implement, making it appealing for more general use in surface-based analyses of the cerebral morphology.

REFERENCES

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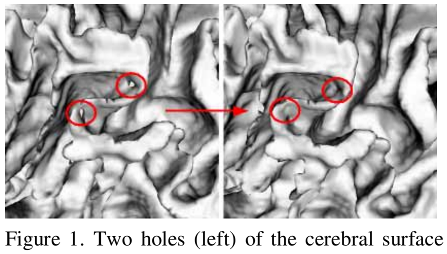

Figure 1. Two holes (left) of the cerebral surface filled (right). The defects could be conversely corrected by cutting the handles.

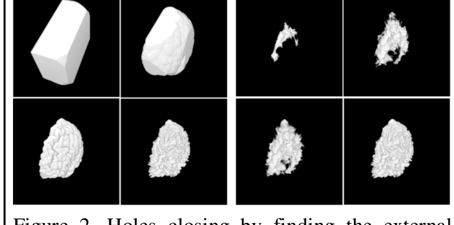

Figure 2. Holes closing by finding the external topological hull (left) and handles breaking by finding the internal topological hull (right).