A Segmented Numerically Robust 3D Atlas of a Mouse Brain
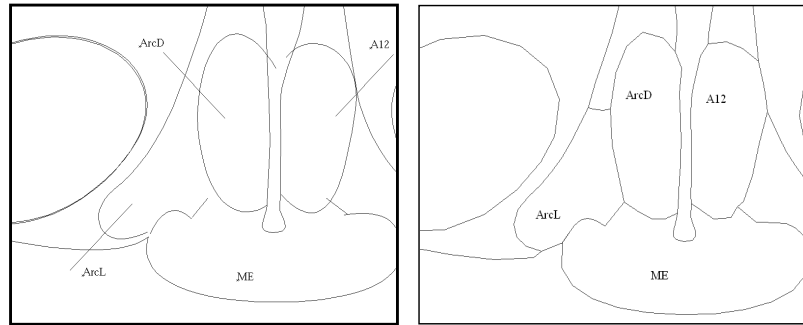
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Introduction: Atlases are the primary source of information for studying the brain. They can be prepared in computer graphics packages such as Adobe® Illustrator© providing drawings of multiple slices though a brain. However the drawings are not numerically robust, making them unusable for numerical computation or solid model reconstruction. These anomalies can be classified as: multiple definitions of ROI boundaries, non-intersecting or over-extended spline segments, overlapping regions, extra markers or labels remotely placed in the drawings and extra boundary lines within the same functional or physical area, Fig. 1a. We have developed routines and algorithms that automatically address these types of flaws and generate a unique database which contains closed loops of lines defining each physical or functional region, Fig. 1b. Dataset for each slice can then be combined and triangulated with a multiple material marching cube routine to reconstruct volumetric surfaces with all boundary interfaces preserved.[1]

Routines: Each slice of an atlas is input through an ASCII file in DXF format. For each slice, the information of splines (curves defining boundaries), labels and their location are extracted. Splines are then approximated by finite number of line segments to reduce the size and complexity of the data while maintaining precise shape of the original ones. Each line is considered an element which contains two nodes, their coordinates, and connectivity information. All elements in the current slice are examined for intersections with other elements. In case of an intersection, the routine decides to either trim the element or split it into two new ones by introducing a new node. Subsequently, seed points resident in the dataset are used to classify regions into closed loops using a counterclockwise path. After this step, each element is assigned two material codes identifying two regions it separates, thus all members of each loop have one material code in common which is that of the enclosed tissue or neurological area of the brain. Each element or line segment can belong to two loops. Elements with just a single material code assigned are regions of overlap which get zippered. Remaining lines with no material codes are either the frame box of the original atlas map or extraneous markers and are deleted.
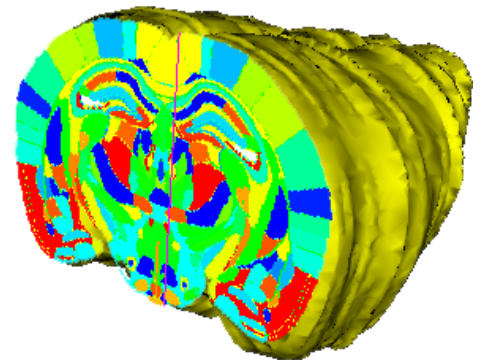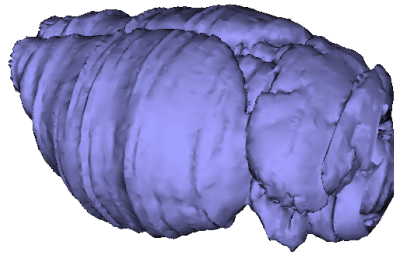
Segmented 3D atlas: The database of segmented images is passed through a multiple material marching cube algorithm to generate 3D surface models. The marching cube algorithm is a robust, innovative method based on an enhanced version of marching cubes algorithm which generates boundary surfaces of between different materials with just one sweep of the database.[1] This algorithm guarantees integrity and continuity of the surface mesh preserving all interior boundaries. To reduce the size of the 3D model, adjustment algorithms, such as decimation and smoothing, are applied.

Results: A fully segmented surface which depicts the outer surface of a C57BL/J6 mouse is shown in figure 2a. It was formulated from 100 slices of the Paxinos, et.al. mouse atlas.[2] Figure 2b shows a cut-away of the volumetric numerical atlas revealing the internal material delineations. Each material is a complete, non-overlapping volume surface whose surfaces are composed of triangular facets. This 3D model can be rotated and scaled to register MR image datasets, after which every pixel in the MR dataset is classified with fully segmented tissue region of the brain atlas.

References: [1] Wu, Z. and J.M. Sullivan, Jr., "Multiple material marching cubes algorithm", IJNME, V58, pg 189-207, (2003). [2] Paxinos, G. and Franklin, K, (2001), "The Mouse Brain in Stereotaxic Coordinates", 2nd Ed, Academic Press.