Through Thick and Thin:
Measuring Thickness in MRI with AFNI

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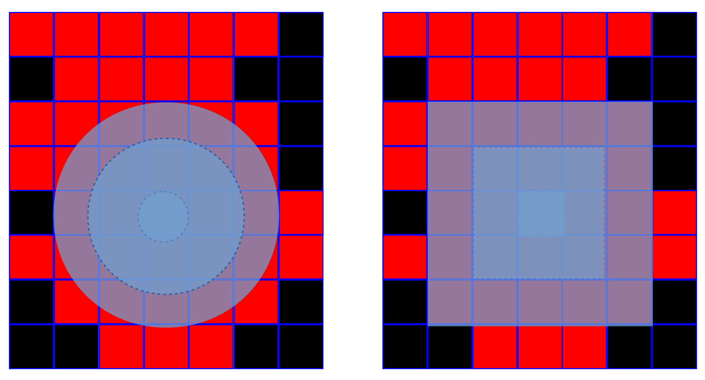
Thickness, especially cortical thickness, is a widely used metric in MRI, yet there is little in a gold standard to establish its veracity. Common methods (e.g. FreeSurfer) rely on complex procedures that generate surfaces and then compute thickness as a distance between nodes. Others rely on diffeomorphic mappings of nonlinear transformations (e.g. ANTs). Here, we present a suite of three novel, very fast volumetric thickness measurement tools. These are all based on simple image processing methods, implemented as scripts in the AFNI software package. The first two methods require only a mask of the object. The third takes two more masks for the "inside" and "outside" of the target. All these methods produce both measures of depth and overall thickness in the volume. These versatile tools can be applied to ROIs like anatomical regions or lesions or to cortical segmentation.

THE NEW METHODS

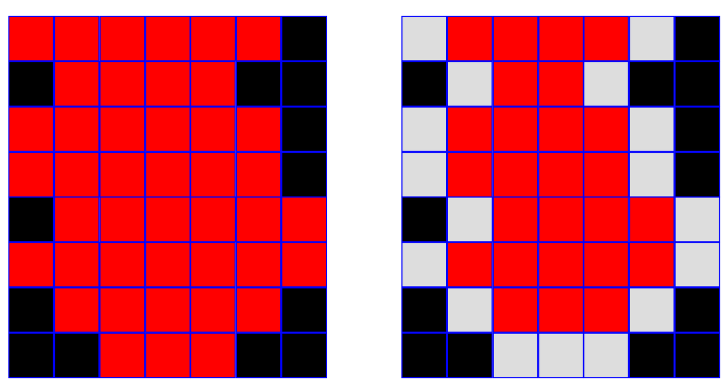
BALL & BOX



Balls   Boxes

This method defines depth as the size of the largest sphere or cube that will fit around a voxel, while staying entirely within the mask. Using cubes extends depth measures into corners more readily. An additional dataset is produced by mapping spheres of the depth of each voxel from smallest to largest, each at least partially encompassing its predecessor. The thickness is then defined volumetrically as the largest depth sphere, often from a neighboring voxel, that contains each given voxel.

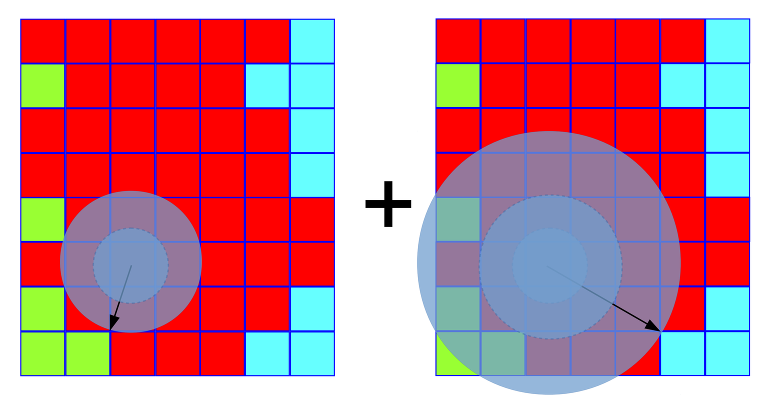
EROSION



Erosion - level 1   Erosion - level n

This method finds thickness by the proxy of levels of an iterative simple morphological erosion, the process of removing voxels that are at the edge of the mask. With each iteration, more voxels are eroded from the mask until none remain. Like the first method, this method also produces a depth measure that can be converted to thickness either volumetrically or to a surface.

IN-OUT

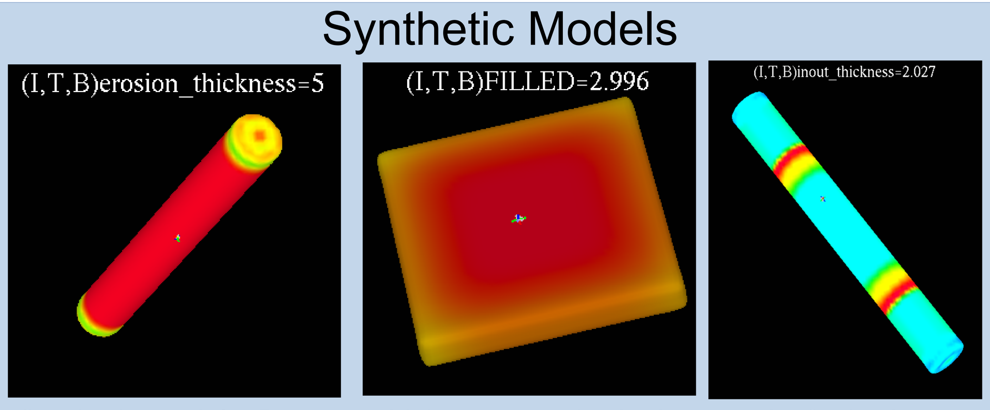


Distance to Inside   Distance to Outside

Mask   Inside   Outside

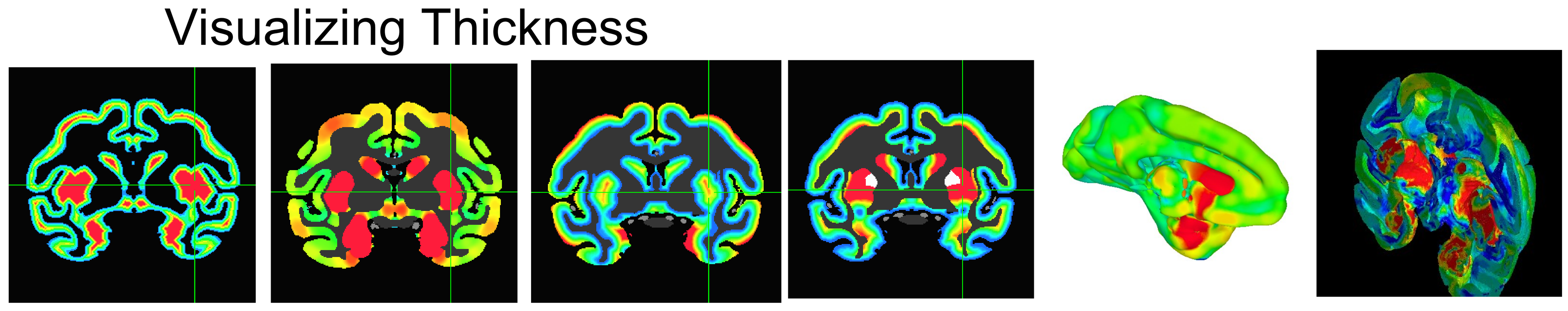
Like the ball and box method, this method also grows spheres in local neighborhoods around each voxel but instead looks for the minimum sphere that reaches the inside mask and another size sphere to reach the outside mask. The radii of these two spheres represent distances to the inside and outside masks. The thickness is defined as simply the sum of these two distances.

Synthetic Models

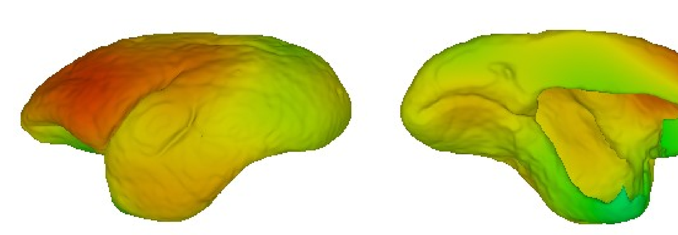


Synthetic models. Because thickness standards do not exist for brains, each method was validated with models of simple shapes of predetermined sizes on voxel grids of 0.5mm³. For the first two methods, simple cylinders and rectangular blocks were generated at 1mm increments over a range of 2-8mm. For the In-Out methods, these models were extended with interior and exterior concentric volumes, and the target volume to be an annular cylinder or hollow box.

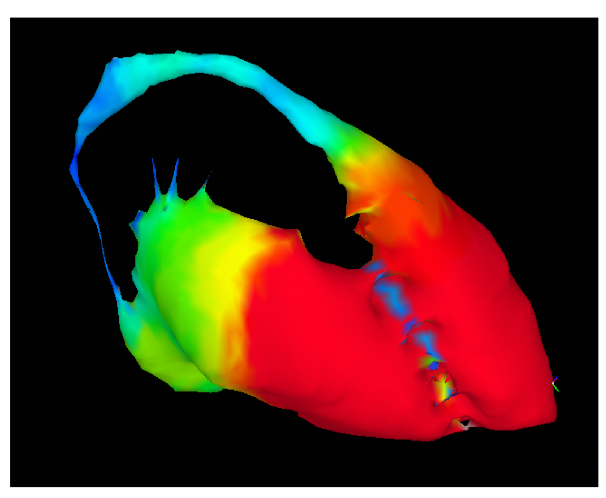
Visualizing Thickness



Depth   Thickness - Volume   Distance to inside   Distance to outside   Thickness projected to surface   Thickness on surface cutaway view

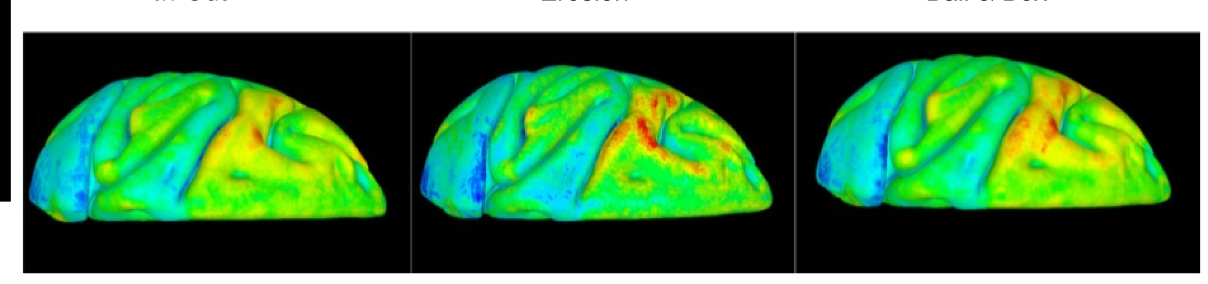


NIH Marmoset Template Cortical Thickness



D99 Macaque Atlas Striatum Thickness

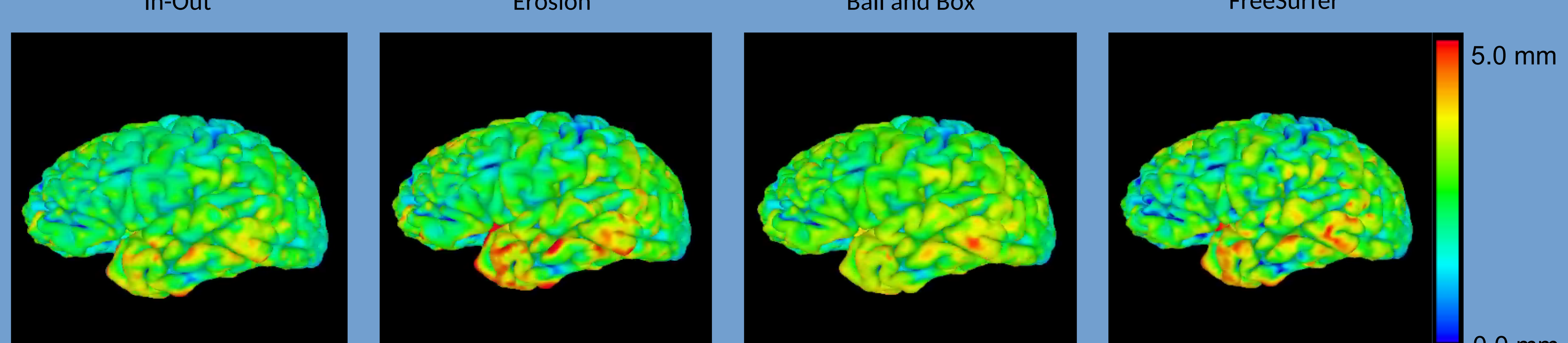
In-Out   Erosion   Ball & Box

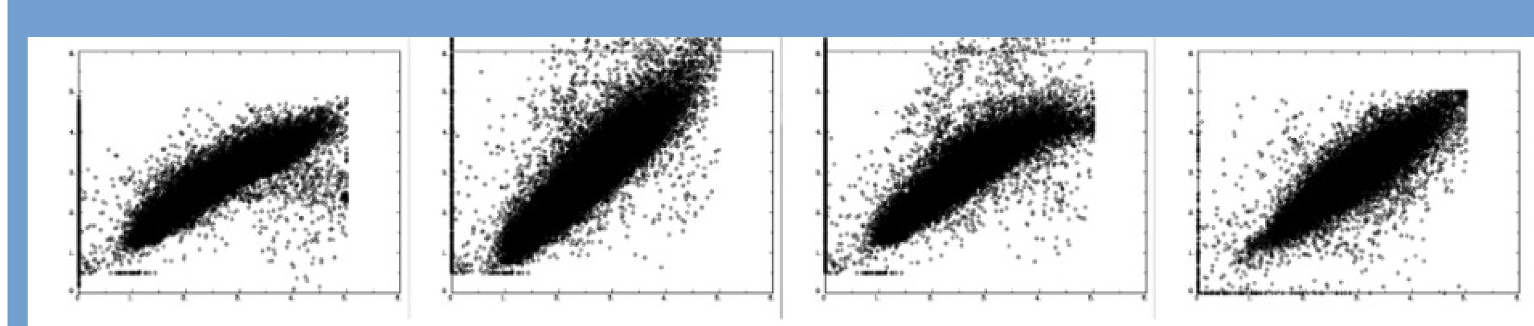


NMT Macaque Template thickness measurements with three methods

Comparison with FreeSurfer - multi-session data

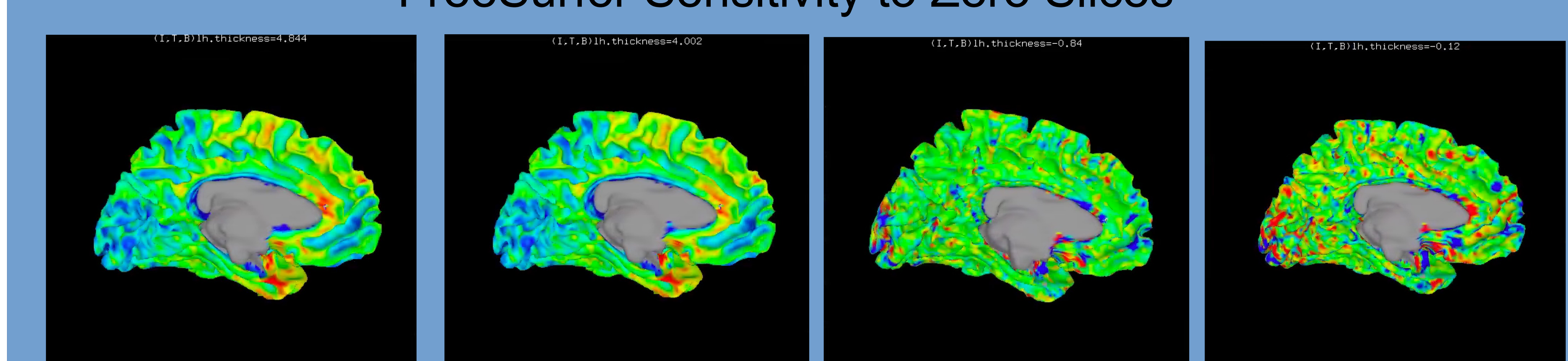
In-Out   Erosion   Ball and Box   FreeSurfer





thickness maps from the morning/evening scans were highly comparable and correlated to those produced by FreeSurfer (r=0.69,0.72,0.79 across subjects for Ballbox,Erosion,In-Out,respectively, and inter-session FreeSurfer gave a correlation of 0.85).

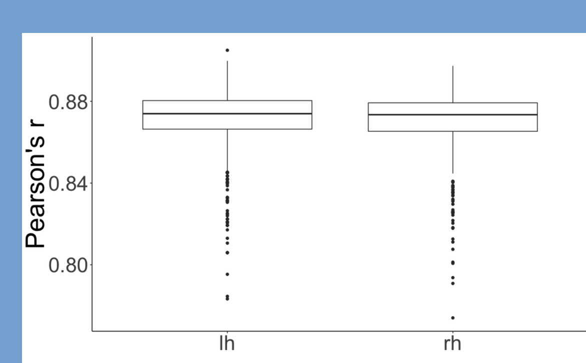
FreeSurfer Sensitivity to Zero Slices

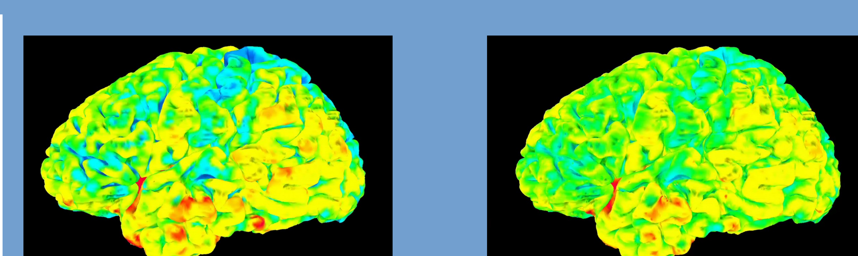


even number of slices   even number of slices + 2 zeropadded slices   difference between even, even+2   difference between even, odd (original MNI152 1mm)

N27 standard mesh 60 white matter surfaces colored with FreeSurfer thickness computations
Adding empty slices containing only zeros gives different results in FreeSurfer. Difference results scaled by +/- 0.5mm from blue to red. Results vary most dramatically with odd number of slices vs even number, but both have surprising differences.

ABIDE I FreeSurfer Thickness Comparison 1035 Subjects - ASD and Control





AFNI   FreeSurfer

ABIDE database analysis - With Ball & Box method, very high correlation over all vertices per subject with FreeSurfer thickness measurement. Example subject shown.

THICKNESS SUITE IN AFNI

@measure_bb_thick
@measure_erosion_thick
@measure_in2out

@thickness_master

@surf_to_vol_spackle

SurfMeasures

CONCLUSIONS:

Thickness has several meanings, and all methods provide different interpretations. It can mean distance from in to out, the size of ball that can fit inside the object, deformation distance, shortest distance between sheets,.... Each software provides a metric based on its own algorithm. Among these new methods, each treats protuberances differently- ball and box show what size ball/box fits there; erosion shows how far from a nearby edge; and in-out shows distance from inside to outside, similarly to the surface-based measures. Here we provide a set of simple programs and metrics that can be used on a variety of objects including brain cortex, but also with any other mask, such as lesions and regions. The methods are applicable to animal studies too with the advantage of simplicity, speed - directly relatable to the data and verifiable with synthetic models.

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