Creating Layered Surfaces to Visualize with AFNI + SUMA, with applications to laminar fMRI

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Introduction:

The field of depth-dependent ("laminar") fMRI strives to investigate the in vivo input and output circuitry of the human brain. It has grown out of improvements in all facets of MRI, from hardware and data acquisition to analysis and visualization methods. Much work in this domain has thus far focused on unimodal cortex with known underlying circuitry, but gradually the scope is widening to association cortices subserving higher cognitive processes[1]. A critical piece of such advancements will be to have flexibility to explore and visualize neuroanatomy and function which is less understood at the meso-scale. Here we introduce two new tools, *SurfLayers* and *quickspecSL*, which extend existing AFNI[2] and SUMA[3] functionality, as well as new SUMA clipping plane functionality, all of which allow for unique, fine-grained exploration and visualization of activation within layers of the cortical ribbon.

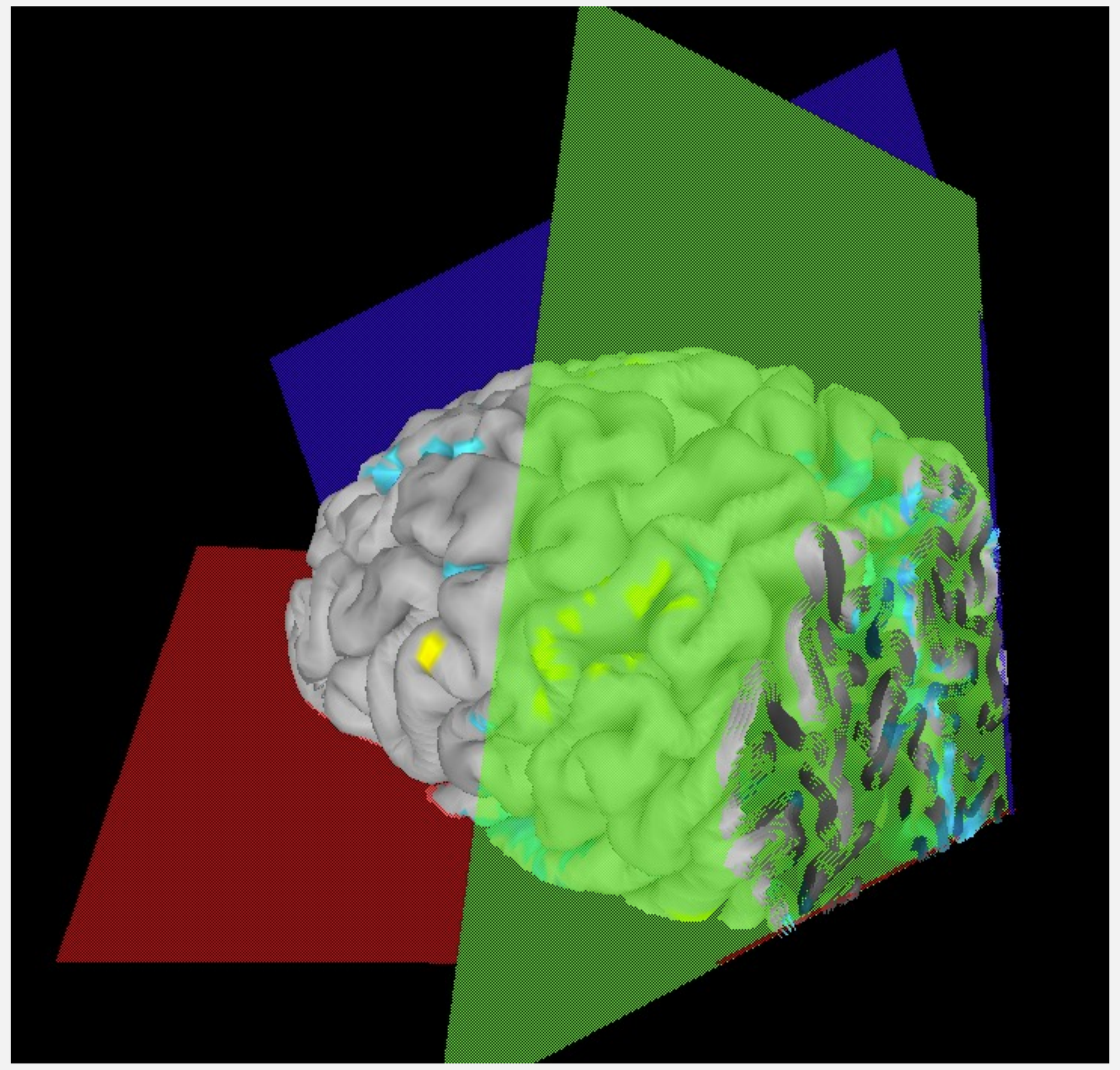

Figure 1. Three of 6 possible semi-transparent clipping planes are visible through the 3T whole-brain bootcamp dataset. The planes are tilted and rotated, and 2 intermediate surfaces created by SurfLayers are shown in 'onestate' between the white matter and pial surfaces. In SUMA, keystrokes allow for easy rotation, tilting, translation and the turning on and off of all or individual clipping planes.

Methods: Three single-subject datasets are used for demonstration. The first is from AFNI bootcamp data of an audiovisual task at 3T[4]. The second is a 7 Tesla dataset of left hand, index-to-thumb finger tapping. The third is a 7T dataset of passively viewing a retinotopic meridian mapping stimulus (contrast: vertical – horizontal wedges). The latter two tasks were presented with PsychoPy[5] and these data were collected with a Siemens 7T MAGNETOM scanner with a 32ch Nova head coil. These datasets were also collected using a zoomed, accelerated 3D GRASE functional sequence with reduced PSF blurring at 0.8mm isotropic with TR = 3 seconds[6]. A 0.7mm isotropic MP2RAGE structural scan[7] was also collected and presurfer[8] was used for skull-stripping followed by FreeSurfer[9] 7.1.1 surface reconstruction and finally *@SUMA_Make_Spec_FS*. All GLM analyses used an *afni_proc.py* pipeline, for which the 7T scripts were tailored for very small FOV epi-anatomy co-registration. No smoothing was applied. Temporal autocorrelation-corrected activation T-statistics were also spatially cluster-corrected[10].

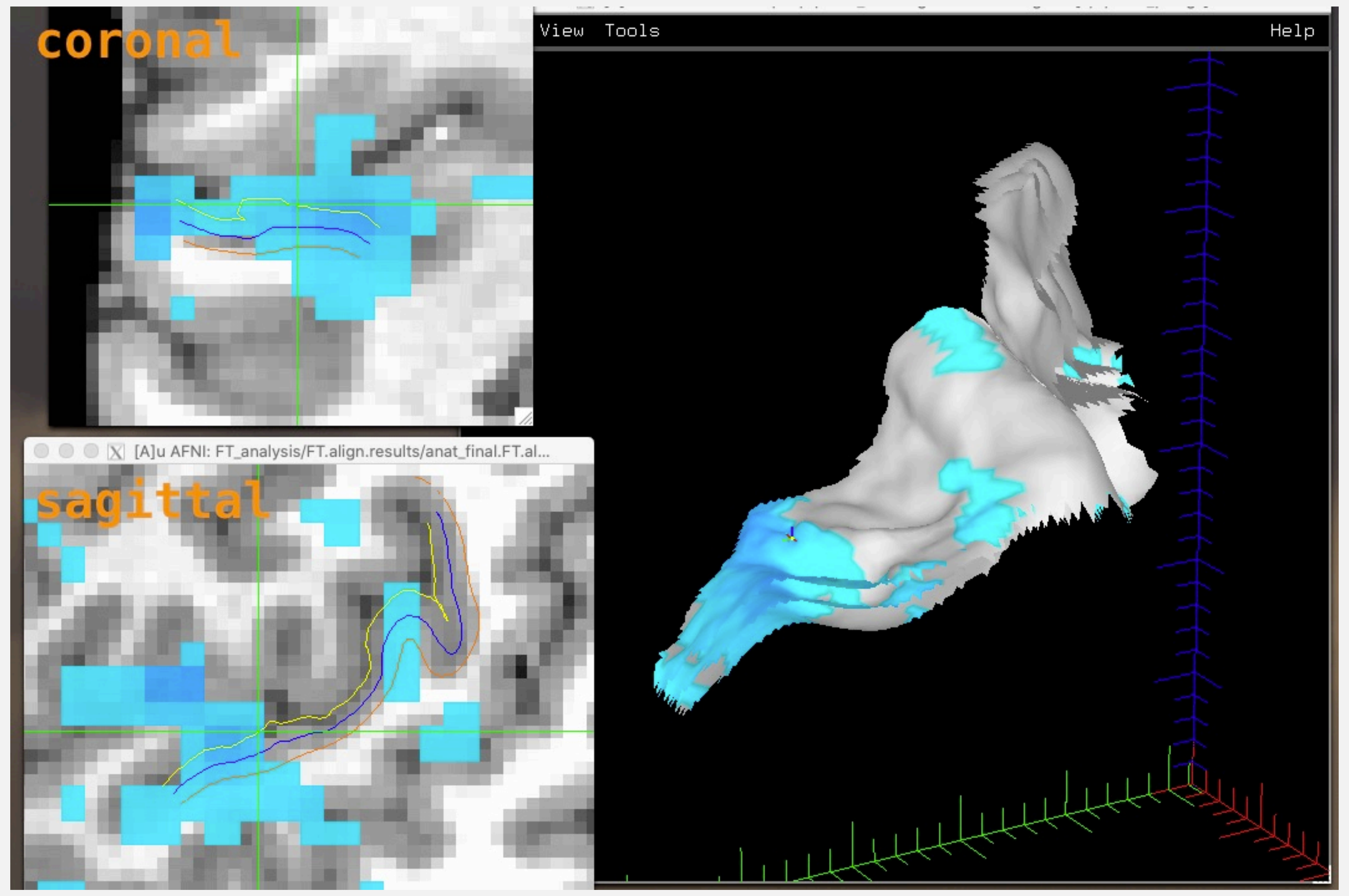

Figure 2. Surface patch of primary auditory cortex derived from an atlas. AFNI and SUMA are "talking" to each other, and the GLM contrast is visual – auditory. Three patch surfaces are present, but the most superior is hidden in SUMA, allowing the user to click into the middle of the layered surface patches. This in turn moves the crosshairs (red) in the AFNI GUI to the corresponding location in voxel space.

Results: *SurfLayers* generates any number of intermediate surfaces between two existing 'bookend' surfaces, usually, but not necessarily, white matter and pial. It works on either whole hemispheres or patches thereof (figures 1 and 2). Optionally, *quickspecSL* can create specification (.spec) files from these surfaces, enabling single- or two-hemisphere visualizations along with the ability to 'hop through' each surface. *quickspecSL* can also create .spec files that link inflated surfaces with their local domain parent surfaces, retaining anatomical veracity in volumetric space (figure 3). The functional statistics can be mapped to these surfaces with *3dVol2Surf* on the command line or interactively with the AFNI GUI and its *Vol2surf* plugin. At the same time, the SUMA interface "talks" with the volumetric interface of AFNI via TCP/IP. By default, a given voxel value is displayed on a surface at the intersection of that voxel and that surface.

The SUMA GUI has also been modified to show these layers better. **Clipping planes** allow for ready interaction by sliding, tilting and translating up to 6 simultaneous planes through displayed surfaces or patches (figures 1 and 4). Planes are quickly set to move between a range of gross to very fine increments.

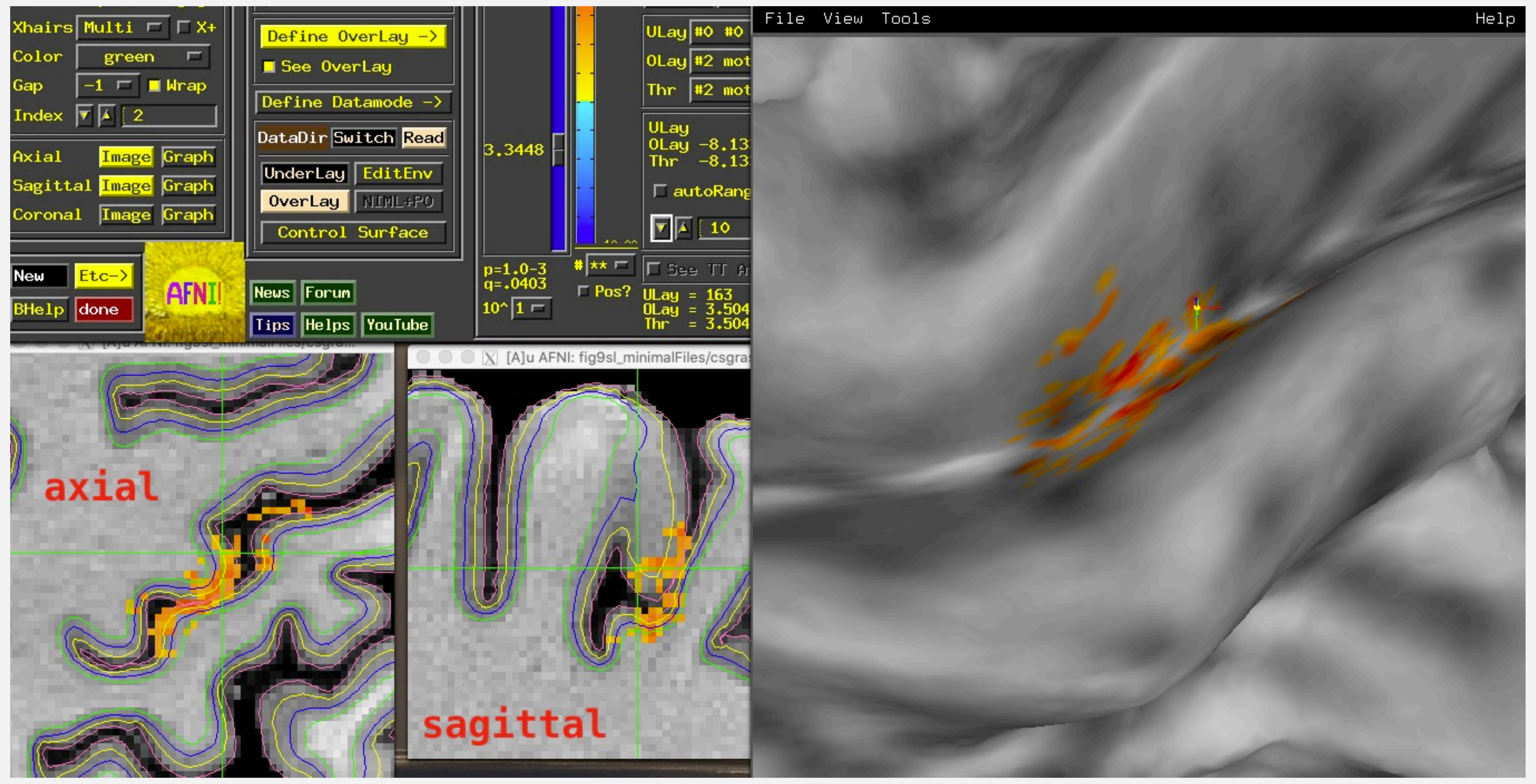

Figure 3. Finger tapping dataset at 7T, with zoomed-in surface (right) showing a large amount of cortical inflation by *SurfSmooth* for easier inter-sulcal viewing. The correspondence between inflated and anatomically-correct surfaces (only the latter displays at left) was specified with quickspecSL. With this way of viewing surfaces, one surface at a time is shown and simple keystrokes 'hop through' one surface to another through the depth of the cortex.

Conclusions:

We have created new extensions to AFNI+SUMA enabling fast creation of intermediate cortical surfaces for laminar fMRI/MRI data exploration, visualization and potential preprocessing steps (e.g., surface smoothing at different depths). Intermediate surfaces from *SurfLayers* integrate into the AFNI+SUMA ecosystem with *quickspecSL* for interactive assessments. Alternatively, clipping planes in SUMA also allow for fast and direct observations of laminar profiles throughout the cortex.

Such utilities complement other popular and powerful voxel-level, volumetric approaches to laminar fMRI analysis and visualization[11]. *SurfLayers* processes both native and standardized surfaces in GIFTI format. Future directions will incorporate equi-volume cortical divisions[12], allow for interpolation of non-FreeSurfer surfaces with nodal correspondence, and allow for the saving and driving of clipping plane specifications.

These new additions to AFNI and SUMA are now freely available with a current AFNI install or update. **See also accompanying poster video for real-time demonstrations** of all figures shown here. The 'driver' scripts that automatically set up AFNI and SUMA for these figures are also available by running **@Install_SURFLAYER_DEMO1**. Feedback and suggestions are welcome.

Example commands:

```
SurfLayers –surf_A lh.smoothwm.gii –surf_B lh.pial.gii –n_intermed_surfs 2 –outdir directoryName
quickspecSL –surf_A lh.smoothwm.gii –surf_B lh.pial.gii –surf_intermed_pref isurf
```

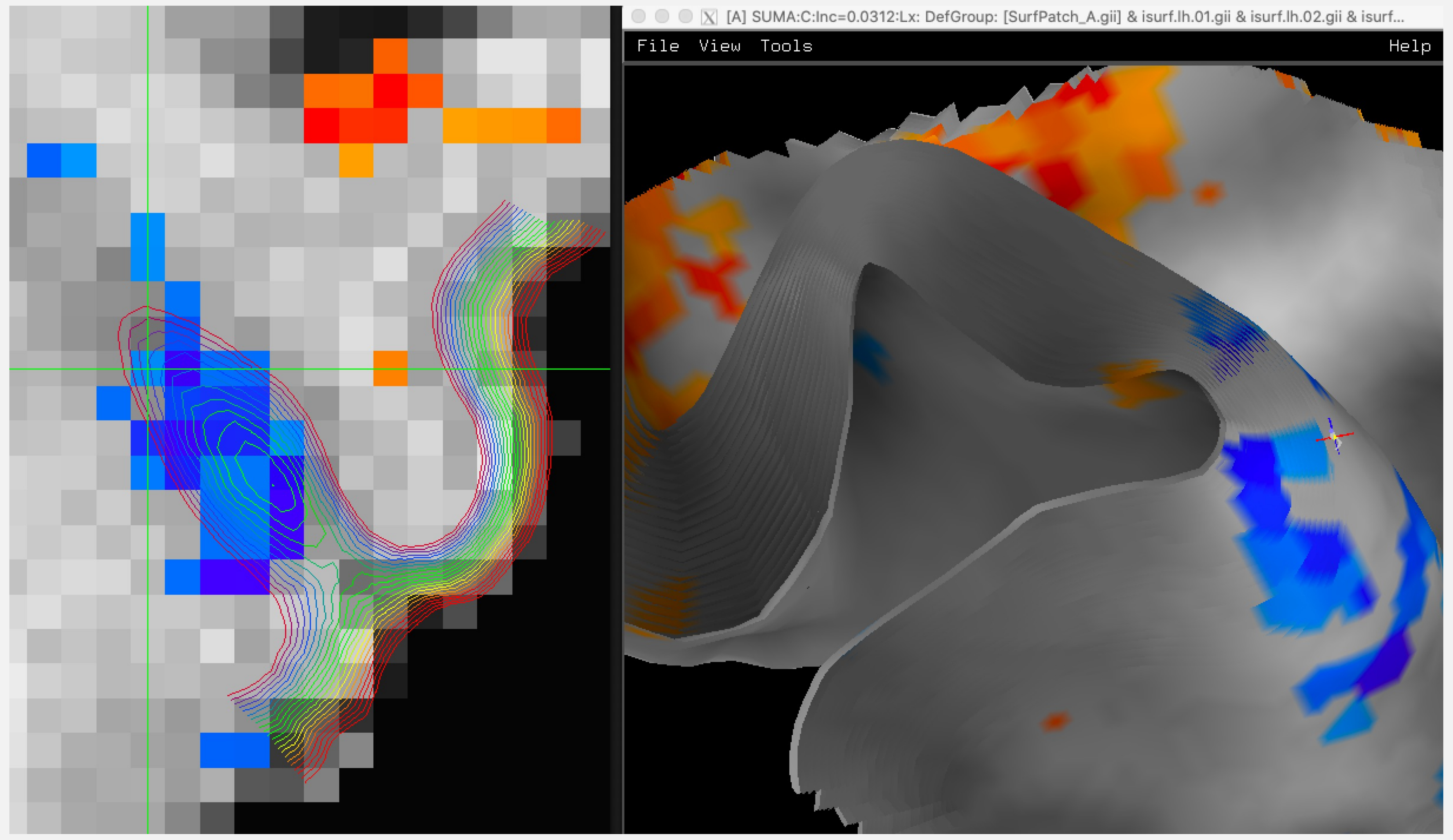

Figure 4. Retinotopic dataset at 7T showing many surface patches of the calcarine sulcus. The initial patch was manually drawn on an inflated surface based on the retinotopic pattern, and then projected to boundary surfaces with *SurfPatch*. *SurfLayers* was then run to create 20 intermediate layers. Here, a clipping plane is active but not visible, obliquely clipping through V1. With such a dense number of surfaces shown with 'onestate', the cubic nature of the 0.8mm isotropic voxels is more clearly visible, allowing one to essentially see true voxel dimensions within the upsampled surface domain.

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