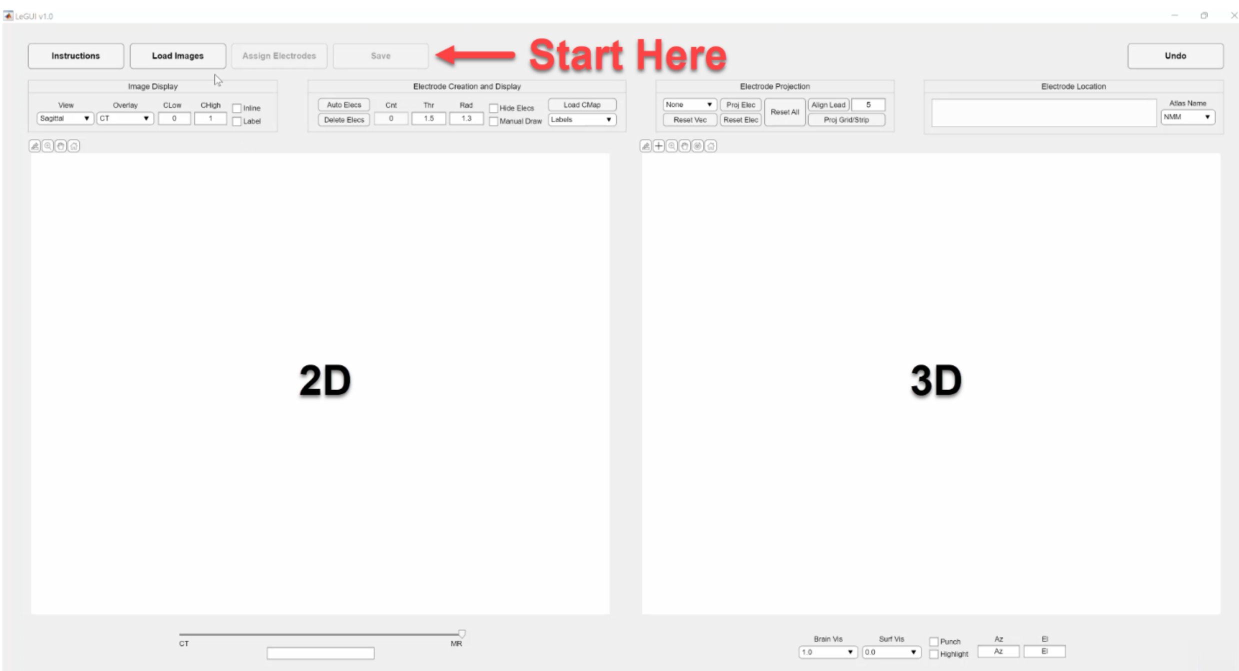
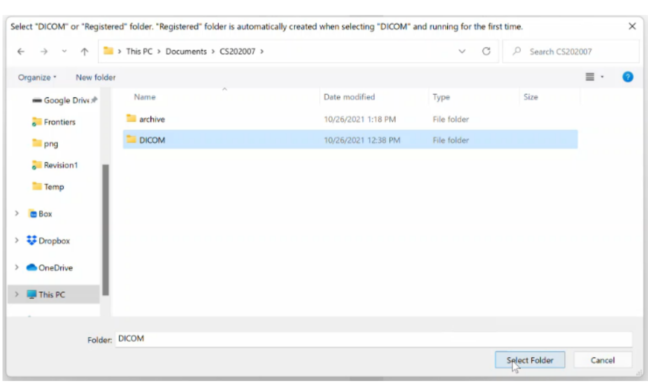
OVERVIEW

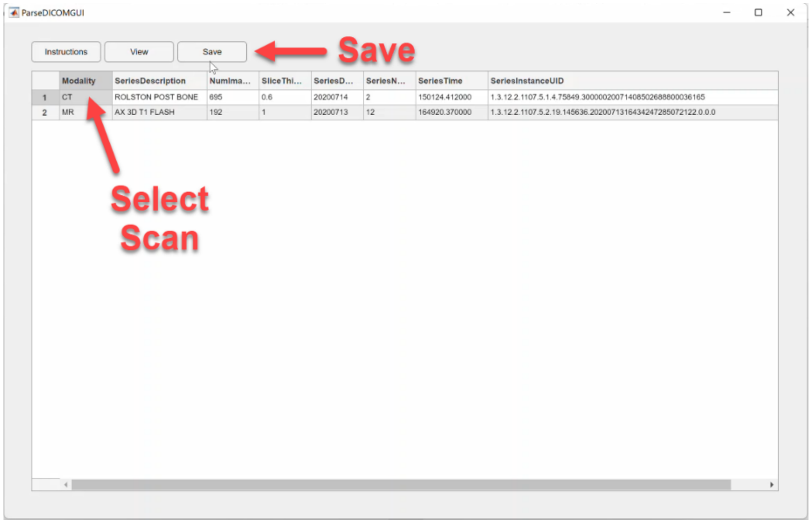
LeGUI consists of a main window with a row of buttons near the top for displaying instructions (“Instructions”), initiating the image processing steps (“Load Images”), assigning labels to electrodes (“Assign Electrodes”), and saving electrode data to a .mat file (“Save”). Below this row of buttons is a row of controls for changing the content in the 2D display (“Image Display”), starting the automatic electrode detection algorithm and adjusting electrode parameters (“Electrode Creation and Display”), projecting ECoG electrodes to the brain surface or adjusting the intercontact spacing of SEEG electrodes (“Electrode Projection”), and viewing the anatomical location of the selected electrode (“Electrode Location”). Below the controls is a window on the left for displaying the 2D slices of the MR and CT images with a slider to adjust the transparency of the selected overlay image. On the right is a window for displaying the 3D surface of the brain along with the 3D locations of the detected electrodes. Controls below the 3D display can be used to adjust the transparency of the brain surface to help visualize the electrodes.



LOADING AND PROCESSING IMAGES

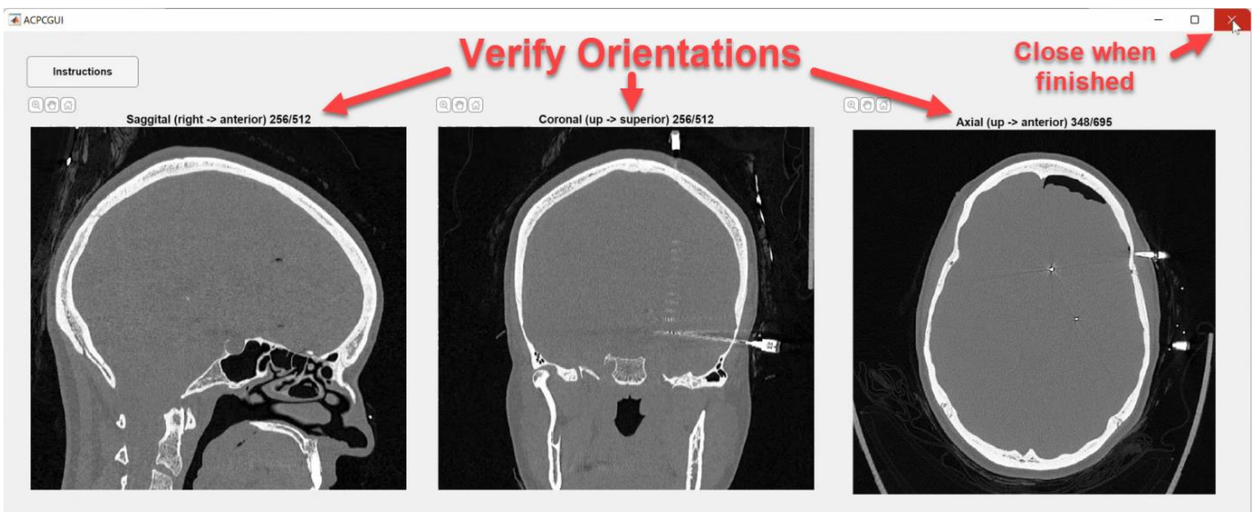


Start by clicking the “Load Images” button. A window will appear asking for the location of the CT and MR DICOM files. Select the folder containing these files and a window will appear indicating the status of the loading process. When finished, a table will appear named “ParseDICOMGUI” with a list of the available CT and MR scans.

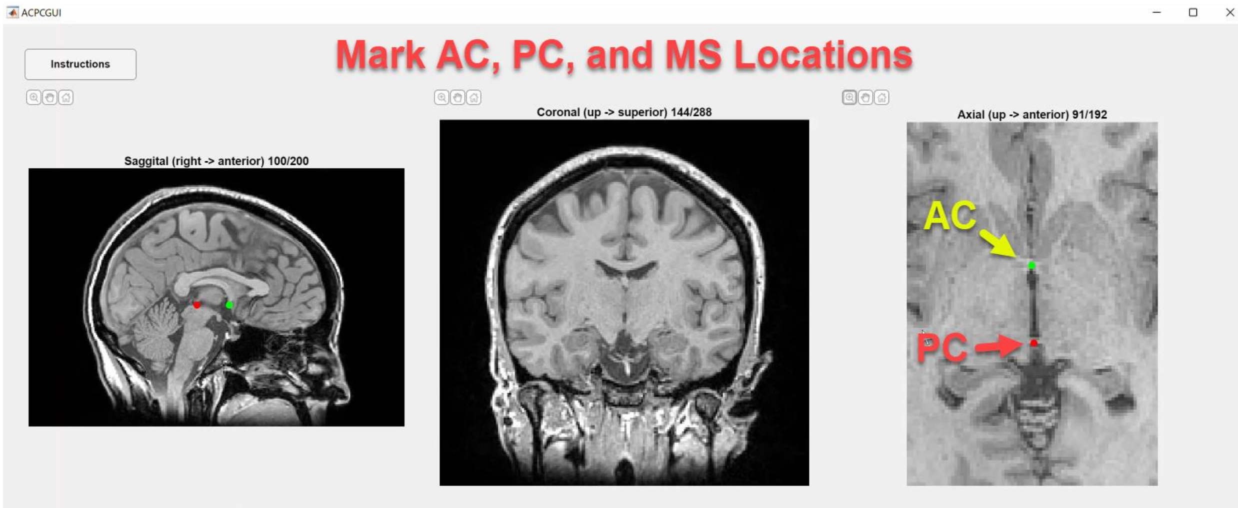


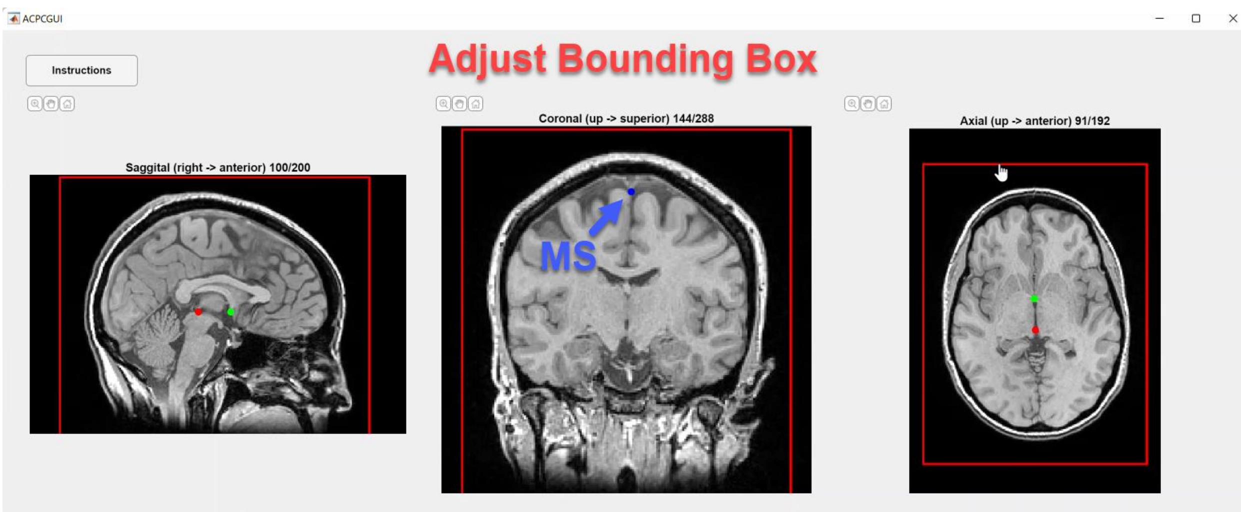
Select the desired CT scan and click "Save" (you can also "View" the scan before saving). A window will appear named "ACPCGUI" with a 2D display of the scan in sagittal, coronal, and axial views. Use the mouse wheel or left/right arrows to scroll through the images of the active display. Each image also has a toolbar for activating the zoom and pan modes for the image.

Verify that the orientations match the titles above each plot and then <u>close the window</u> to finish the saving process. If the titles don't match, press ctrl+left/right arrows to cycle through the list of orientations until a match is found.

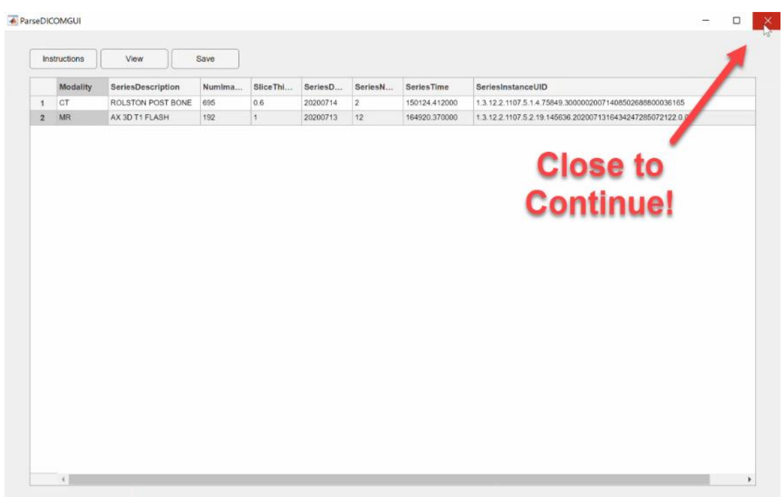


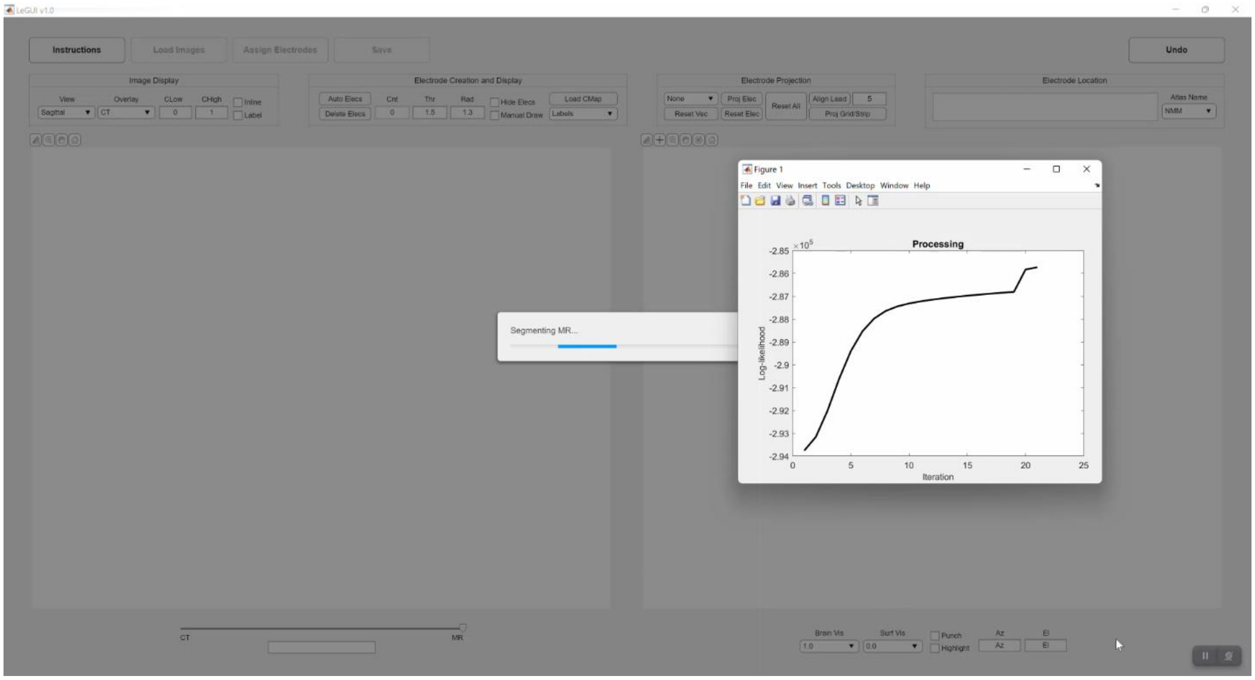
Next, select the desired MR scan from the table and click "Save". The ACPCGUI window will appear again with sagittal, coronal, and axial views of the MR images. For the MR, it is recommended that the anterior commissure (AC), posterior commissure (PC), and superior mid-sagittal (MS) points are marked so the scan can be rotated into ACPC space. These points can be placed with a right click over the respective regions in the image. Placing the AC and PC points is typically done using the axial image. Placing the MS point is typically done using the coronal image. The MS point should be placed between the AC and PC points in the anterior-posterior direction. Zoom into the image to help with the placement. If a mistake is made, the "delete" key can be used to delete all points and start over. The AC, PC, and MS points must be marked in sequence and will be labeled with green, red, and blue dots in the image for visual confirmation. Once all three points are placed, a cropping box will appear. Drag the edges of the box to enclose the entire brain and leave a margin of black space at the edges. This feature is used to crop out excess black space, which improves the resulting visualizations in LeGUI. When finished, close the ACPCGUI window to continue.

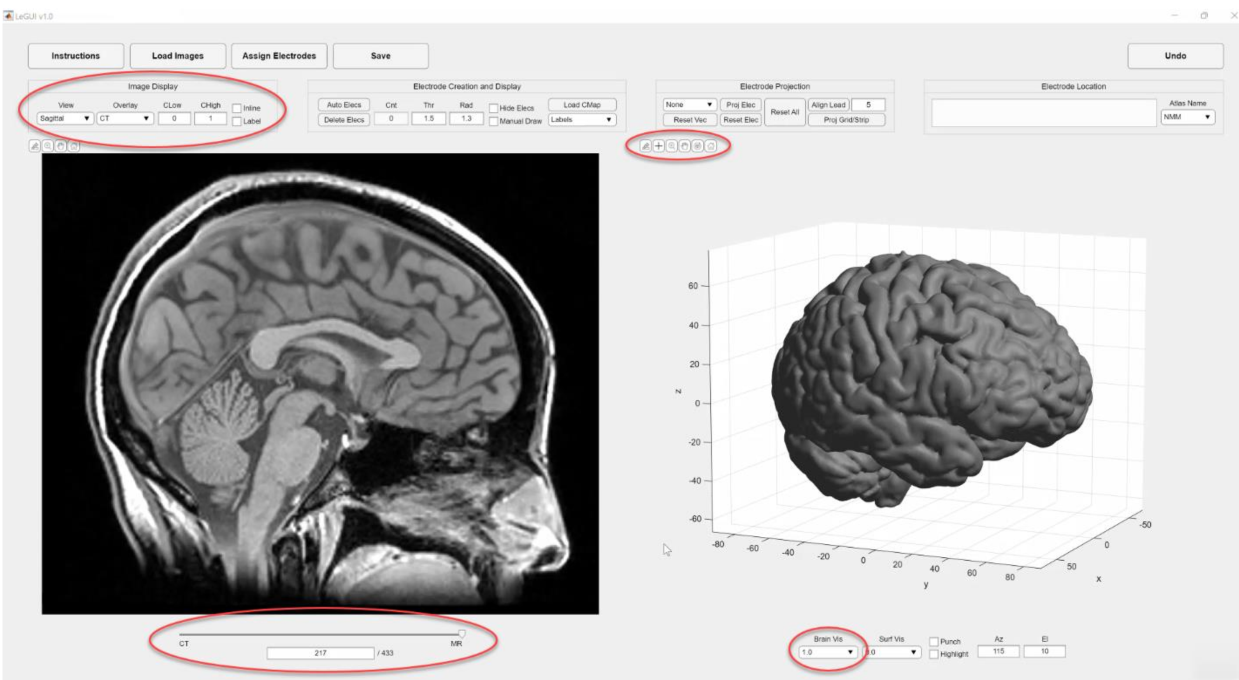




After both and MR and CT scans are saved, close the "ParseDICOMGUI" window to start the image processing steps. These steps include coregistration of the CT to the MR, segmentation of the MR, and normalization of the MR to MNI space. The process will take ~30 min to complete and progress will be displayed in the main LeGUI window.



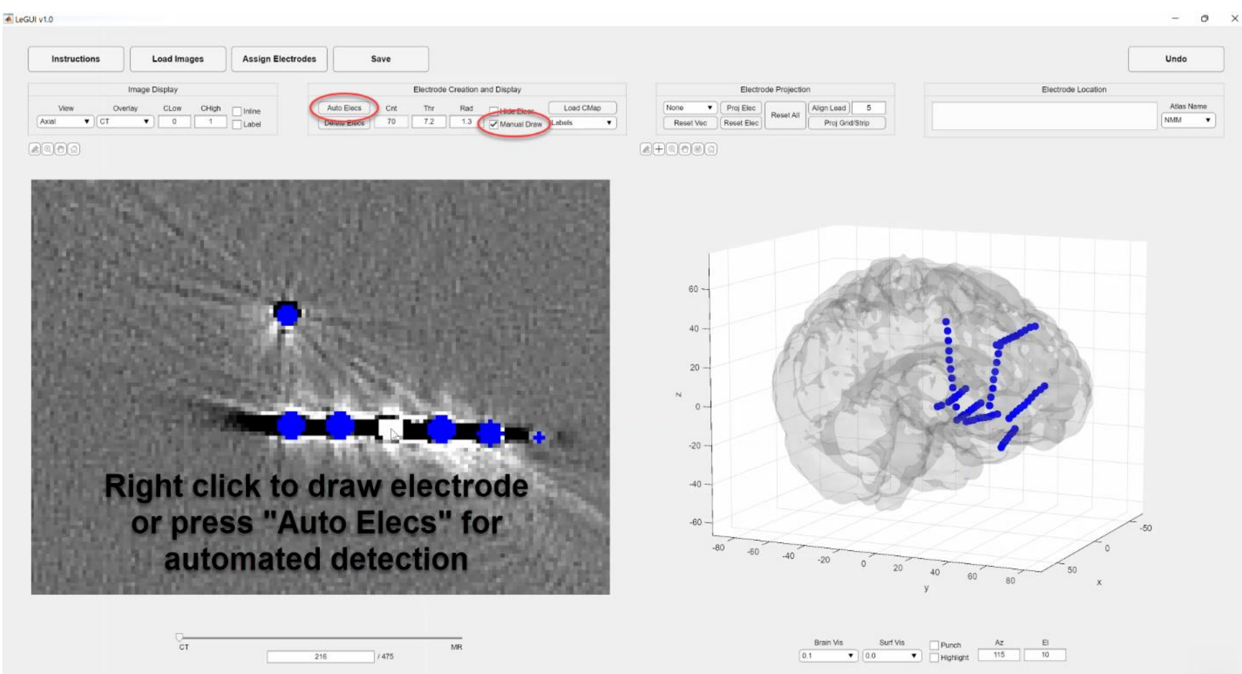




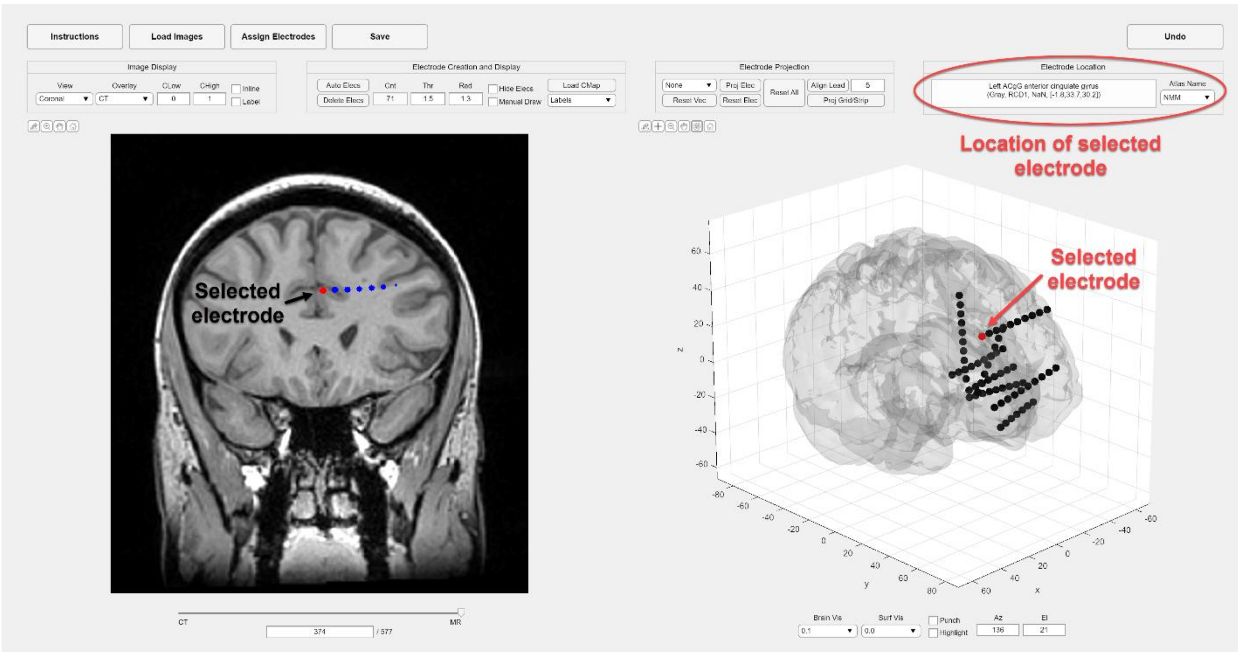
When the processing is finished, the 2D and 3D displays in LeGUI will populate with the MR images and brain surface, respectively. At this point, the controls above the 2D display can be used to change the parameters of the image. The orientation can be changed from a sagittal to coronal or axial view. The overlay can be changed from CT to Gray, White, or Atlas. To view the selected overlay, adjust the slider at the bottom of the image. Dynamically changing the transparency of the overlay is a good way to check that the CT to MR coregistration step was successful. The brightness and contrast can be adjusted by changing values in the “CLow” and “CHigh” edit boxes. For the 3D display, the brain surface can be rotated by selecting the “rotate” toolbar button and performing a left mouse drag across the display. Transparency of the brain surface can be changed using the “Brain Vis” dropdown menu.

ELECTRODE LOCALIZATION

Electrode artifact in the CT can be visualized by selecting “CT” as the overlay and moving the slider bar at the bottom of the 2D image all the way to the left. Electrodes can be created with a right click over the artifact in the CT. When an electrode is created, the centroid of the CT artifact is computed, and a blue dot is drawn in the 2D image at the centroid location. This centroid-snapping feature allows for rapid electrode creation. However, sometimes an electrode will snap to the incorrect location in the image. If this happens, “manual” mode can be activated by selecting the “Manual” check box in the “Electrode Creation and Display” control box. Once selected, the centroid-snapping feature will be disabled, and electrodes will be drawn at the tip of the mouse cursor. Use the toolbar “zoom” and “pan” buttons to better visualize electrode artifact in the CT and assist the manual drawing of electrodes. Alternatively, all electrodes in the CT image can be automatically detected by pressing the “Auto Elec” button in the “Electrode Creation and Display” control box. The detection algorithm has been tuned to work well for both surface ECoG and depth SEEG electrode types. However, the algorithm occasionally will fail to detect an electrode or will create a false positive electrode at a location in the image with other radio-opaque objects such as wires in a ECoG grid or strip. If detection errors occur, electrodes can be manually created with a right-click of the mouse or deleted by selecting the electrode with a left-click and pressing the “delete” key. Electrodes that are drawn in the 2D display also appear in the 3D display to provide a more intuitive representation of the electrode space.

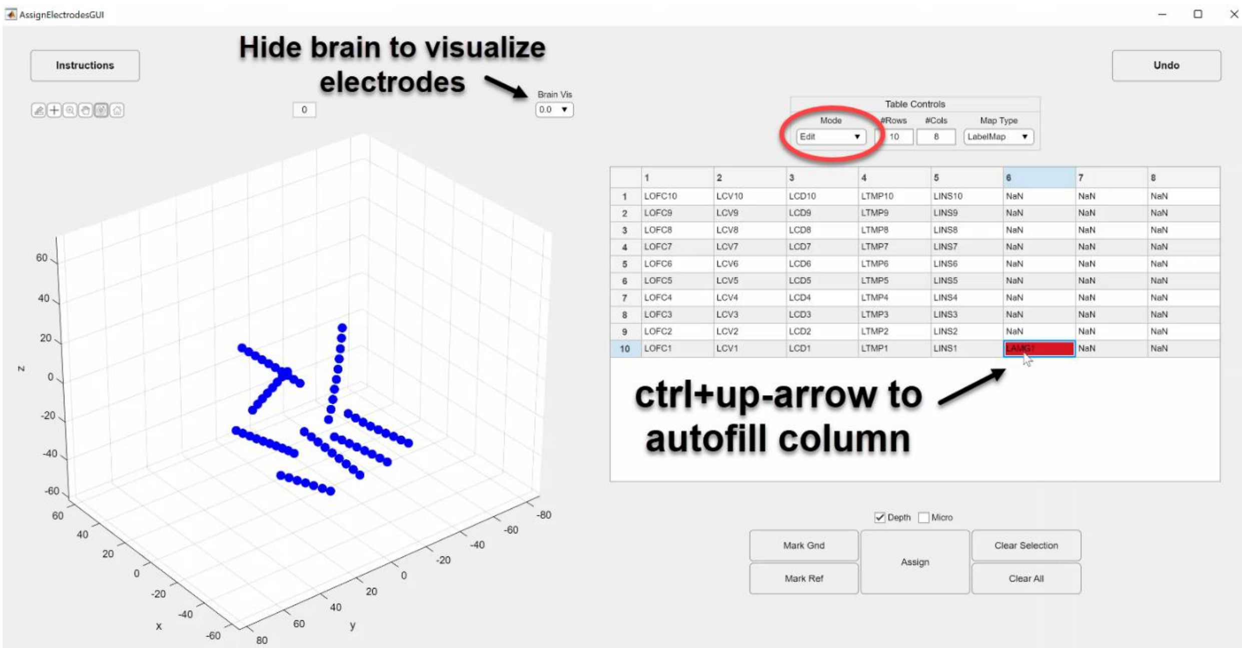


Electrodes can be selected with a left click of the mouse in either the 2D or 3D displays. Selected electrodes are colored red. Multiple electrodes can be selected at once by holding the “shift” key during selection. Electrodes that are selected in either the 2D or 3D display will automatically update to reflect the selection in the other display. The location of a selected electrode is displayed in the upper right "Electrode Location" panel. Anatomical location from the specified atlas ("Atlas Name" dropdown) is displayed first followed (in parentheses) by the gray/white classification, user-assigned label, channel number, and x/y/z coordinates in patient space (this will be ACPC space with mid-commissural point as zero if specified earlier).

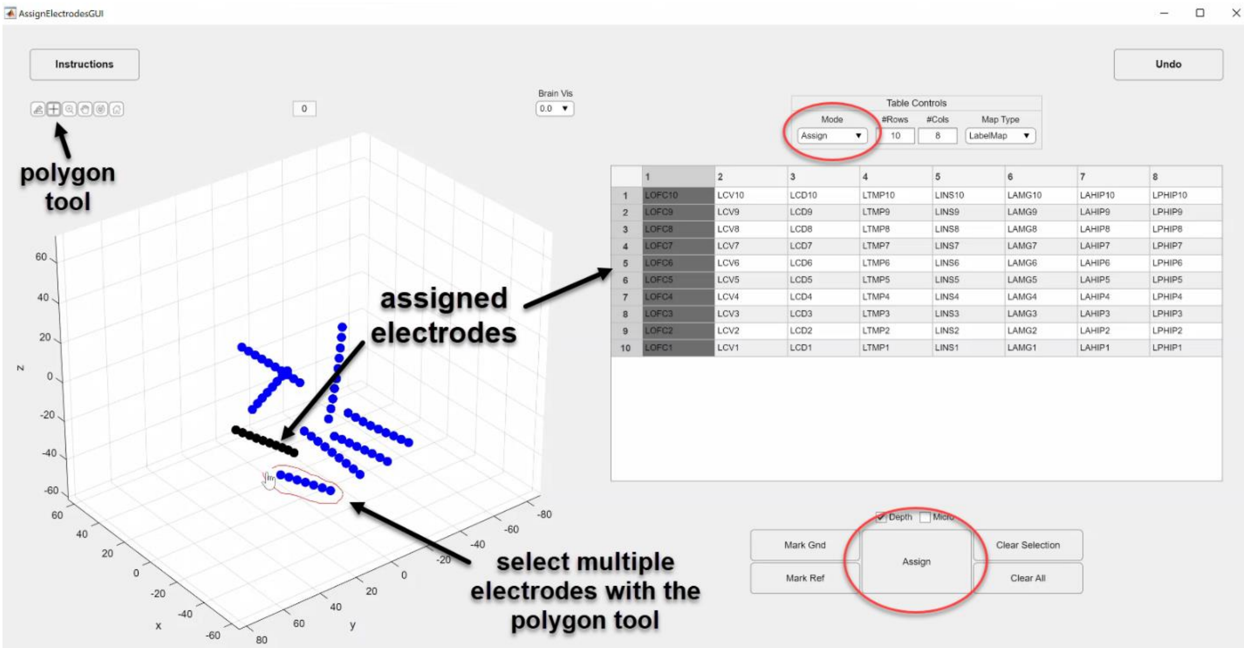


ELECTRODE ASSIGNMENT

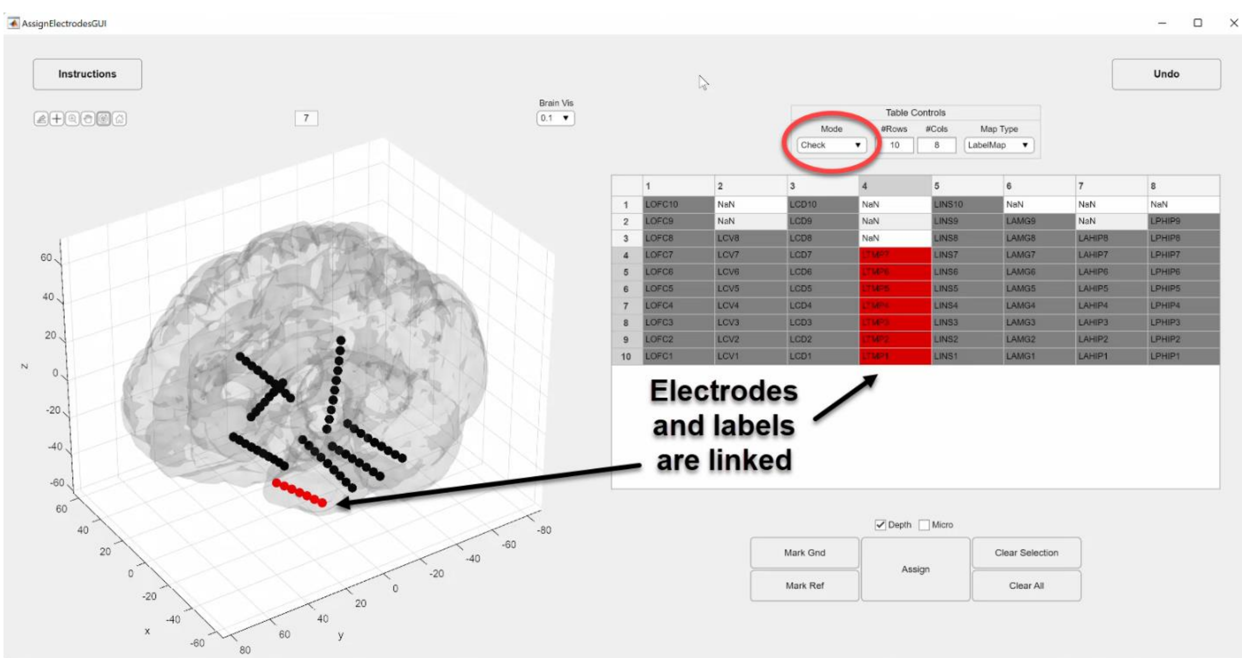
Electrodes can be assigned labels and channel numbers using the "AssignElectrodesGUI". Start by pressing the "Assign Electrodes" button. A window will appear that shows the 3D brain and electrodes on the left and an empty table on the right. Hide the brain so the electrodes are visible and count the number of SEEG leads and the max number of contacts on a lead. These will become the number of columns and rows in the table, respectively. Next, make sure the "Mode" is set to "Edit" and enter the desired number of rows and columns in the table. The table will expand to the specified dimensions and the cells in the table will be filled with NaNs. Labels can now be added to the table that represent the contacts on each lead. Change the "MapType" to "LabelMap" and start adding labels to the cells in the table. Labels are typically defined by the location of the lead followed by a number that represents the contact location on a lead. For example, for a lead that is targeted to the left amygdala, the label for the first (deepest) contact would be LAMG1. Subsequent contacts on that lead from deep to shallow would have the labels LAMG2, LAMG3, …, LAMG10. The "AssignElectrodesGUI" has an autofill feature to speed up labeling. Start by placing LAMG1 on the bottom row of the appropriate column in the table and press ctrl+up-arrow while the LAMG1 cell is selected. The remaining cells in that column will be automatically filled with the LAMG label followed by increasing contact numbers. Likewise, ctrl+down/left/right-arrows will fill with increasing numbers in the direction of the arrow. To fill with decreasing numbers, ctrl+shift+up/down/left/right-arrows can be used. If there are leads in both the left and right hemispheres, a column of NaNs can be used to separate the two sides. Also, if leads have different numbers of contacts, NaNs must be used to fill the gaps. Gaps can be filled later after assignments have been made using the color-coded "assigned" electrodes as a guide. A similar labeling procedure can be used for ECoG grids and strips. Grids can be placed into the table as a block of rows and columns that equal the total number of contacts, and strips can be placed as a single column like SEEG leads. It is recommended that the table layout approximate the 3D layout of electrodes in the brain. For example, SEEG leads would be placed in the table with the most anterior lead as the left-most column and the most posterior lead as the final right-most column with the deepest contacts as the bottom row.



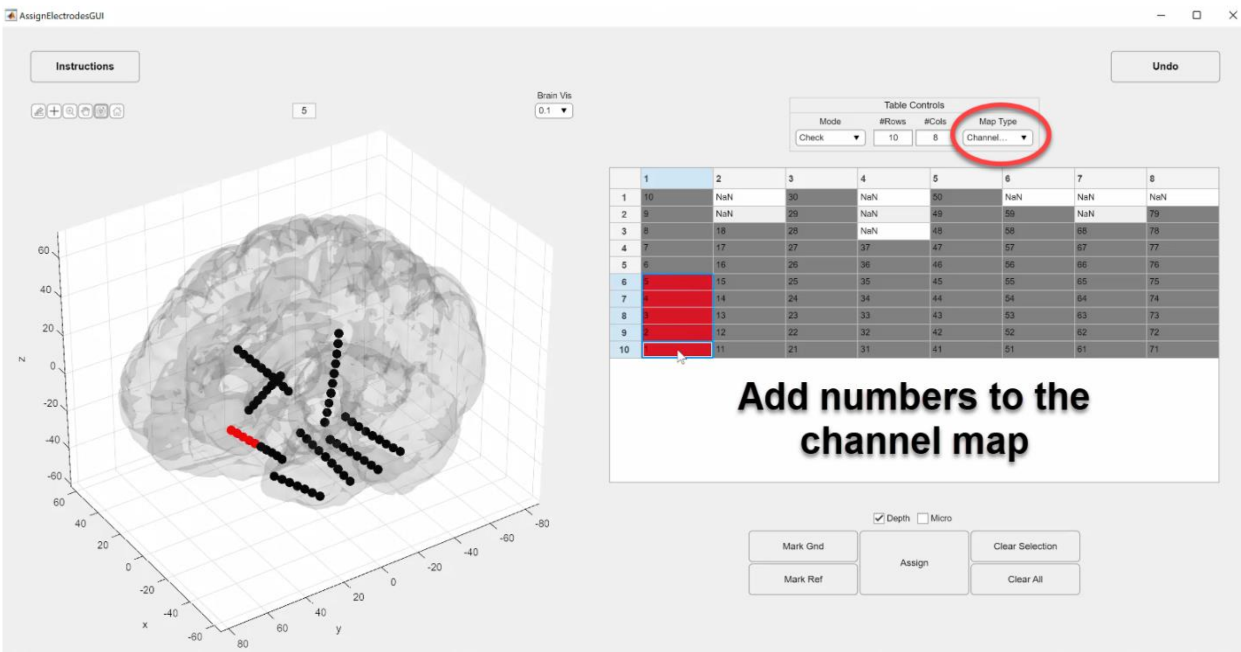
Once labels have been added to the table, electrodes can be assigned to each of the labels. To make an assignment, change the "Mode" to "Assign", select an electrode in the 3D plot, select the corresponding cell in the table, and then click the "Assign" button. If assignment was successful, both the electrode and cell will change color. Electrodes that are assigned as depth electrodes ("Depth" checkbox) will be colored black. If "Depth" is unchecked (i.e. surface or ECoG), the electrode color is green. If "Micro" is checked, the color is purple. Continue this assignment procedure until all electrodes in the 3D plot are assigned. Alternatively, a slightly faster way to make assignments is to select multiple electrodes in the 3D plot using the polygon tool (or shift+left-click), selecting the corresponding cells in the table (shift+left-click), and pressing the "Assign" button. An algorithm will try to match shallow to deep electrodes in the 3D plot with top to bottom cells from the selected column in the table. This multiple electrode assignment method only works if the table layout adheres to the SEEG column-based labeling described earlier. This assignment method could also be applied to ECoG grids and strips by selecting columns of electrodes in a grid or strip and then selecting the corresponding column of cells in the table.



After all assignments have been made, they should be checked (verified) for correctness. Change the “Mode” to “Check” and select a cell in the table. If the assignment is correct, the appropriate electrode in the 3D display will be highlighted red. The up/down/left/right arrows can be used to move through the cells in the table while visually checking that the appropriate electrodes are highlighted in the 3D display. If there are mistakes, the “Clear Selection” button can be pressed to remove the assignment. The “Clear All” button can be pressed to remove all assignments and start over. After assignments have been checked, “Mode” should be changed back to “Edit” and any unassigned cells in the table should be changed to NaN.



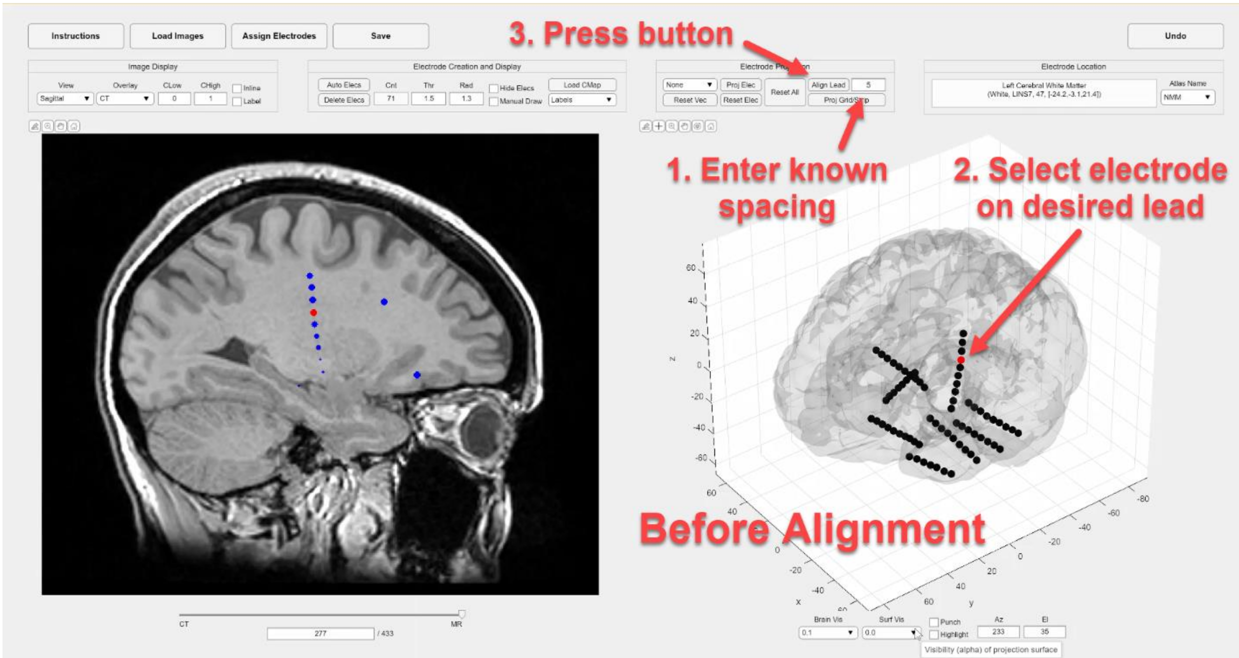
At this point, channel numbers can be added that correspond with the recorded data channels from the data acquisition system. This is an optional step. However, if channels are not specified, the resulting “ChannelMap.mat” file that is saved by LeGUI will be empty. Channel numbers are determined by the specific recording system used and how that system is connected to the actual electrodes. To assign channel numbers, change the “Mode” to “Edit” and the “Map Type” to “ChannelMap1”. The table with the previously defined labels will switch to all NaNs indicating that “ChannelMap1” is now being displayed instead of “LabelMap”. Numbers should be added to the table that map data channels to the corresponding (previously assigned) electrodes. Like the label assignment described earlier, the autofill feature can be used to fill columns or rows with increasing or decreasing values. Only numbers can be added to the table when “ChannelMap1” is active.

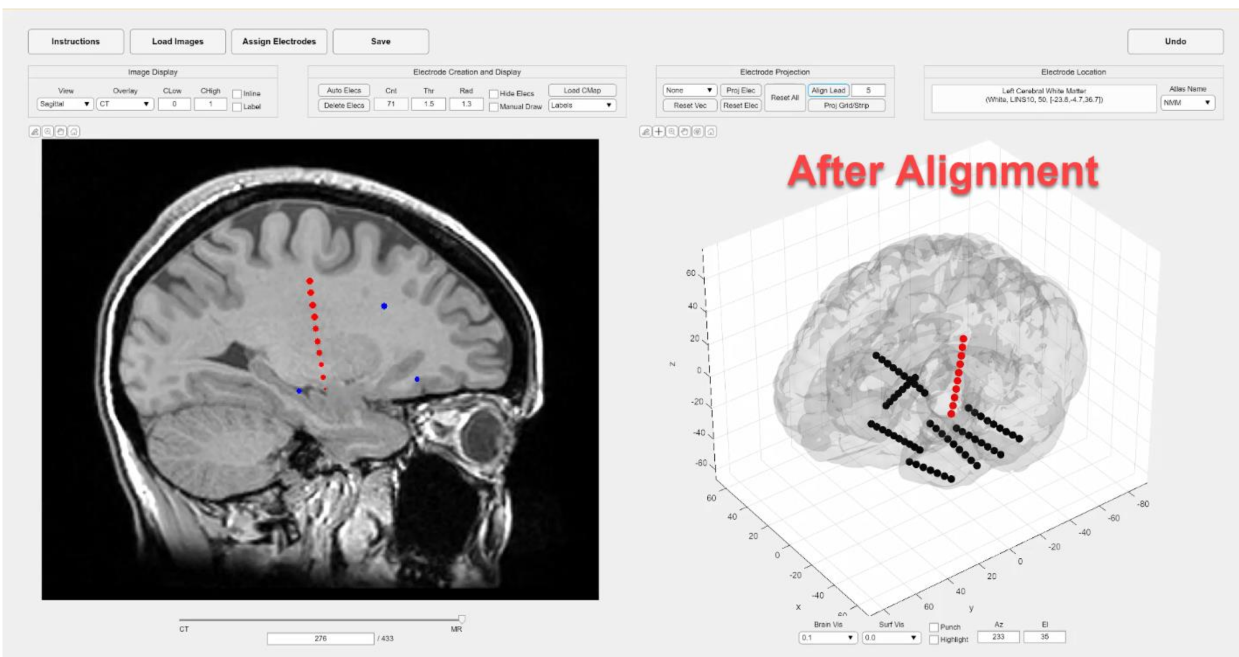


After all label and channel assignments have been made, verify that NaNs are added to all unassigned cells in the table, and <u>close the “AssignElectrodesGUI” window</u>. Data will be transferred back to the main LeGUI window, and the 3D electrodes will be color-coded base on the assignments to indicate a successful transfer. The remaining LeGUI features including electrode alignment (SEEG), electrode projection (ECoG), and inline projection will now be active and ready to use.

ALIGNMENT AND PROJECTION

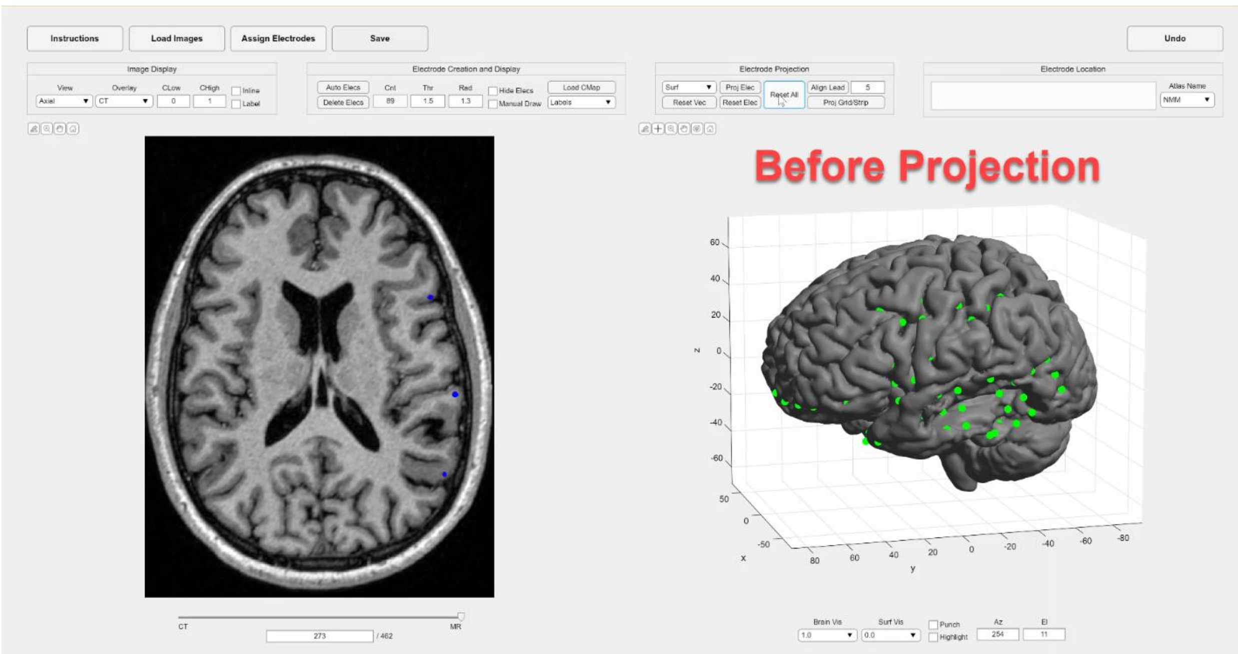
The electrode contact locations may have some jitter following localization because of inaccurate centroids due to a low-quality CT. This jitter can be corrected using the “Align Lead” function in LeGUI. The intercontact spacing for SEEG leads can be adjusted to exactly match the known spacing by selecting a contact on the desired lead and pressing the “Align Lead” button. Make sure to enter the known spacing in millimeters in the edit box next to the button before aligning. This function only works after electrodes have been assigned labels using the “AssignElectrodesGUI”.

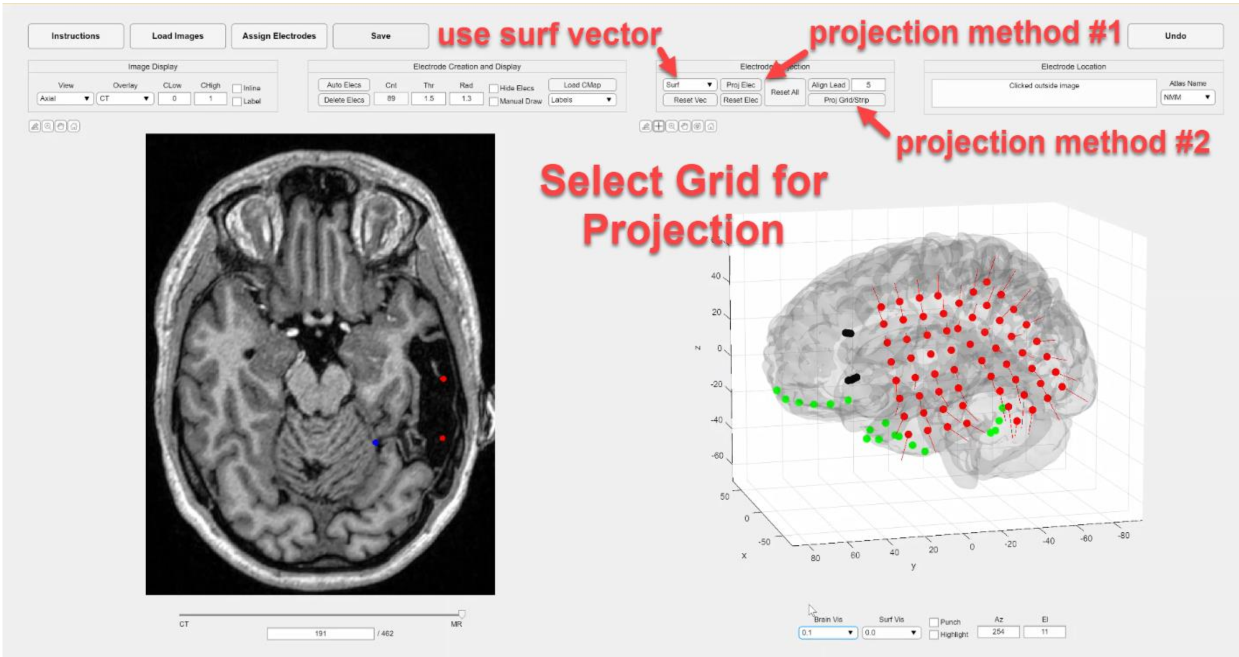


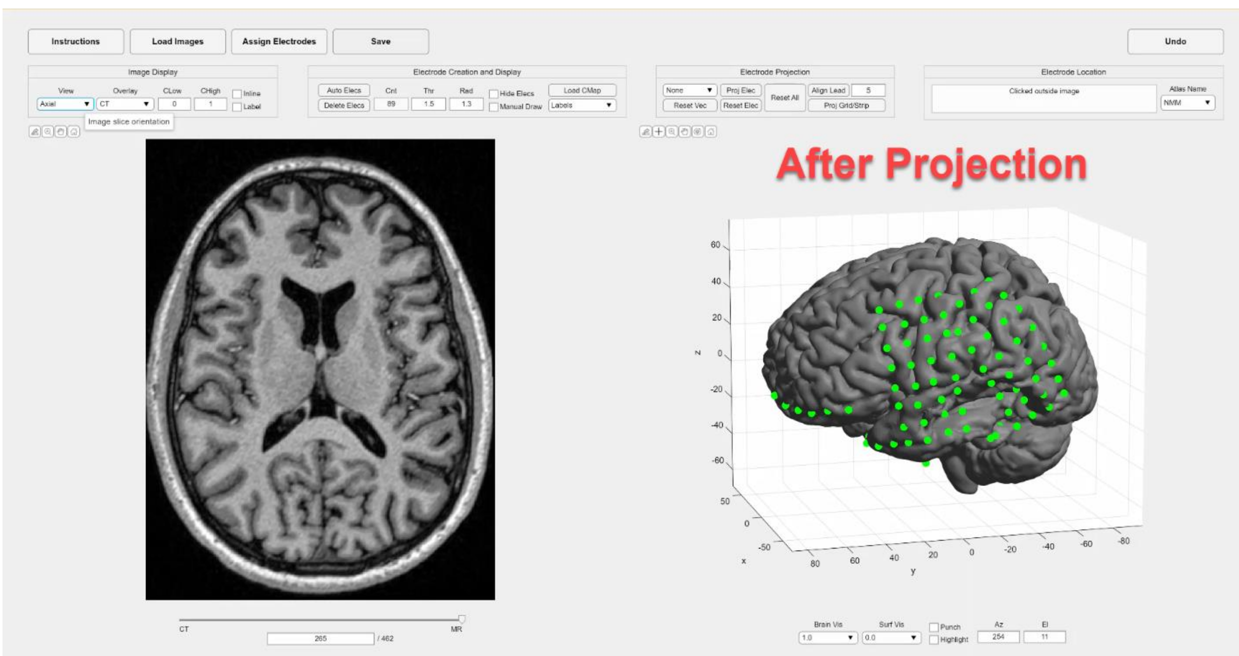


For ECoG grids and strips, electrodes may need to be projected to the brain surface to account for brain shift from surgery. LeGUI uses two methods to project electrodes. The first method uses the normal vector to a patch of smoothed brain surface closest to the electrode as the projection vector. The second method uses the normal vector calculated from the nearest neighbor electrodes as the projection vector (Hermes, 2010). These two methods can be accessed using the “Electrode Projection” control panel in LeGUI. To perform a projection using the first method, select the projection vector type “Surf” from the dropdown menu in the “Electrode Projection” panel, select one or more electrodes to be projected in the 3D display, and press the “Proj Elec” button to project to the surface. Electrodes can also be nudged along the projection vector in small increments by pressing the up and down arrow keys.

Electrodes can be projected using two other vector types “View” and “Center” from the dropdown. “View” projection vectors extend from the center of a selected electrode out in a direction perpendicular to the view angle of the 3D display. This type of projection can be used to move an electrode in various non-standard directions by simply changing the view angle using the “rotation” tool. The “Reset Vec” button can be used to reset the projection vector to the current view if the view angle is changed. “Center” projection vectors extend from the center of the brain (mid-commissural point if ACPC alignment was performed) out through the selected electrode. The second projection method can be performed by selecting all of the electrodes in an ECoG grid or strip and pressing the “Proj Grid/Strip” button. Only one grid or strip can be selected at a time. If the projection fails, electrodes can be reset to their original locations by pressing the “Reset Elec” or “Reset All” buttons. Electrodes must be assigned labels before performing these projections.







SAVING

LeGUI saves the processed images, surfaces, electrode locations, and assignments to a folder called "Registered" that is in the same directory as the "DICOM" folder. The image data is saved automatically during the initial processing steps. The electrode data is saved by pressing the "Save" button in the main LeGUI window. If the user forgets to save, a warning message will be displayed when closing LeGUI allowing the user to save at that time. A list of the saved files with descriptions are in the "ReadMe.txt" file that is also saved to the "Registered" folder. File descriptions are provided below.

Description of files (and contents) generated by LeGUI:

ChannelMap.mat (These variables should be used for analysis since they are mapped to recorded data channels)

- LabelMap: Cell of labels specifying electrode location and contact number (i.e. ROFC1 for right orbital frontal cortex contact 1) in 2D layout to approximate actual electrode layout
- ChannelMap1: Matrix of recorded channel numbers in 2D layout to approximate actual electrode layout
- ChannelMap2: If data was recorded using two systems this can be used for mapping 2nd system (if different)
- DepthElec: List of channel numbers from either ChannelMap1 or 2 that represent depth electrodes
- MicroElec: List of channel numbers from either ChannelMap1 or 2 that represent micro electrodes
- GndElec: List of channel numbers from either ChannelMap1 or 2 that represent ground electrodes
- RefElec: List of channel numbers from either ChannelMap1 or 2 that represent reference electrodes
- AtlasNames: Cell of atlas names that correspond to the columns of ElecAtlasProj and ElecAtlasProbProj
- ElecAtlasProj: Cell of atlas labels where rows represent recorded channel and columns represent a specific atlas
- ElecAtlasProbProj: Cell of atlas label probabilities taken from a 1cm search radius where rows represent recorded channel and columns represent results for a specific atlas
- ElecTypeProj: Cell of gray/white/unknown labels where rows represent recorded channel
- ElecCOMIdxProj: Matrix of voxel indices (row/col/page) that represent the centroids of each electrode where rows represent recorded channel
- ElecFullIdxProj: Cell of voxel indices that represent the volume of each electrode sphere where rows represent recorded channel
- ElecXYZProj: Matrix of electrode locations (x/y/z) in patient world space (units mm) where rows represent recorded channel
- ElecXYZMNIProj: Matrix of electrode locations in standard MNI space (units mm) where rows represent recorded channel

Electrodes.mat (These variables are used by the LeGUI and are organized by draw-order of electrodes)

- ElecMapRaw: Cell where rows represent electrode draw-order and columns represent values from LabelMap, ChannelMap1, and ChannelMap2
- DepthElecRaw: List of depth electrodes numbered by corresponding row in ElecMapRaw
- MicroElecRaw: List of micro electrodes numbered by corresponding row in ElecMapRaw
- GndElecRaw: List of ground electrodes numbered by corresponding row in ElecMapRaw
- RefElecRaw: List of reference electrodes numbered by corresponding row in ElecMapRaw

- AtlasNames: Cell of atlas names that correspond to the columns of ElecAtlasRaw and ElecAtlasProjRaw
- ElecAtlasRaw: Cell of atlas labels where rows represent electrode draw-order and columns represent a specific atlas
- ElecAtlasProjRaw: Projected version of ElecAtlasRaw
- ElecAtlasProbProjRaw: Cell of atlas label probabilities taken from a 1cm search radius where rows represent electrode draw-order and columns represent results for a specific atlas
- ElecTypeRaw: Cell of gray/white/unknown labels where rows represent electrode draw-order
- ElecTypeProjRaw: Projected version of ElecTypeRaw
- ElecCOMIdxRaw: Matrix of voxel indices (row/col/page) that represent the centroid of each electrode where rows represent electrode draw-order
- ElecCOMIdxProjRaw: Projected version of ElecCOMIdxRaw
- ElecFullIdxRaw: Cell of voxel indices that represent the volume of each electrode sphere where rows represent electrode draw-order
- ElecFullIdxProjRaw: Projected version of ElecFullIdxRaw
- ElecXYZRaw: Matrix of electrode locations (x/y/z) in patient world space (units mm) where rows represent electrode draw-order
- ElecXYZProjRaw: Projected version of ElecXYZRaw
- ElecXYZMNIRaw: Matrix of electrode locations in standard MNI space (units mm) where rows represent electrode draw-order
- ElecXYZMNIProjRaw: Projected version of ElecXYZMNIRaw

Surfaces.mat

- BrainSurfRaw: Faces/vertices for brain surface
- ProjSurfRaw: Faces/vertices for a highly smoothed brain surface that is used to define vectors and project electrodes

ACPCmm.mat: Matrix where rows represent x/y/z coordinates of AC, PC, and superior mid-saggital points in patient world space

MR_coreg.mat: Coregistration results of CT to MR image generated by SPM12
MR_seg8.mat: Segmentation results of MR generated by SPM12

CT.nii: CT image coregistered and resliced to match MR.nii
MR.nii: MR image aligned to mid-commissural ACPC coordinate system (if performed)
MRWhite.nii: White matter segmentation results from SPM12
MRGray.nii: Gray matter segmentation results from SPM12
MRCSF.nii: CSF segmentation results from SPM12
MRBone.nii: Skull segmentation results from SPM12
MRSkin.nii: Skin segmentation results from SPM12

iy_MR.nii: Inverse deformation matrices from patient to MNI space
y_MR.nii: Deformation matrices from MNI to patient space

lw*.nii: All files with prefix "lw" are atlases deformed to patient space for viewing in LeGUI and for analysis (labels are preserved).

RELOADING DATASETS

Datasets that have been processed with LeGUI will have a corresponding “Registered” folder. To load a previously processed dataset, open LeGUI, press the “Load Images” button, and select the “Registered” folder. LeGUI will load and populate the main window with the MR and CT images, brain surface, and 2D and 3D electrodes that were detected previously. At this point, changes can be made to the electrodes and corresponding assignments and resaved, which will overwrite the “ChannelMap.mat” and “Electrodes.mat” files in the “Registered” folder.

LOADING NIFTI FILES

If DICOM files are not available for the MR and CT, nifti files can be loaded instead. Place the nifti files in an empty folder named “Registered” and name the files MR.nii and CT.nii. Open LeGUI, press the “Load Images” button, and select the “Registered” folder. LeGUI will now process the images using the same steps described above.

CUSTOM ATLASES

The Neuromorphometrics (NMM) and SPM Anatomy Toolbox atlases are bundled with LeGUI and can be selected using the “Atlas Name” dropdown menu in the “Electrode Location” control panel. These atlases can be found in the “nmm” and “atlases” subfolders within the main “LeGUI” folder of the downloaded source code. If the executables are downloaded, an “atlases” folder comes bundled with the download and must remain in the same root directory as the executable file. To load custom atlases, place the nifti file for an MNI-registered atlas in the “atlases” folder along with a text file that contains the labels. The MNI-registered atlas and the text file must have the same name. Choose a short, but descriptive name since it will automatically appear in the “Atlas Name” dropdown when a dataset is loaded in LeGUI. The text file must follow a tab-delimited format with the index number for each label as the first column and the label name as the second column. An example of this format can be found by opening the “Anat.txt” file in the “atlases” folder that comes bundled with LeGUI.

ADVANCED SETTINGS

An advanced settings menu is available at the top left corner of LeGUI, which allows the user to change default parameters for coregistration, segmentation, electrode detection, gray/white classification, and anatomical (atlas) labeling. The coregistration and segmentation values must be changed prior to running “Load Images” for the first time. The gray/white and atlas values must be changed prior to pressing the “Save” button. Detailed descriptions of each parameter are provided as a tooltip when the menu is open in LeGUI.