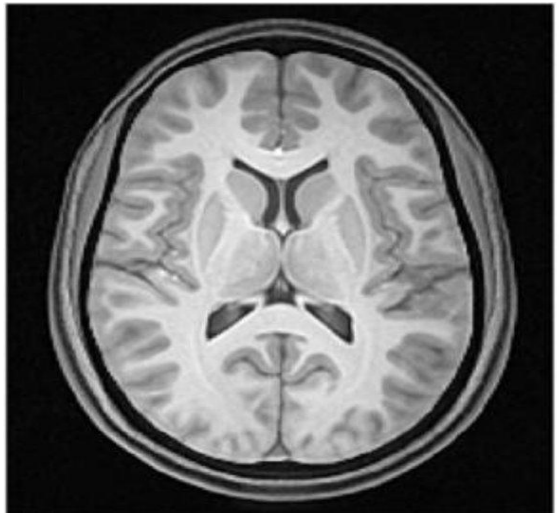
Structural T1w Image Preprocessing & Analysis

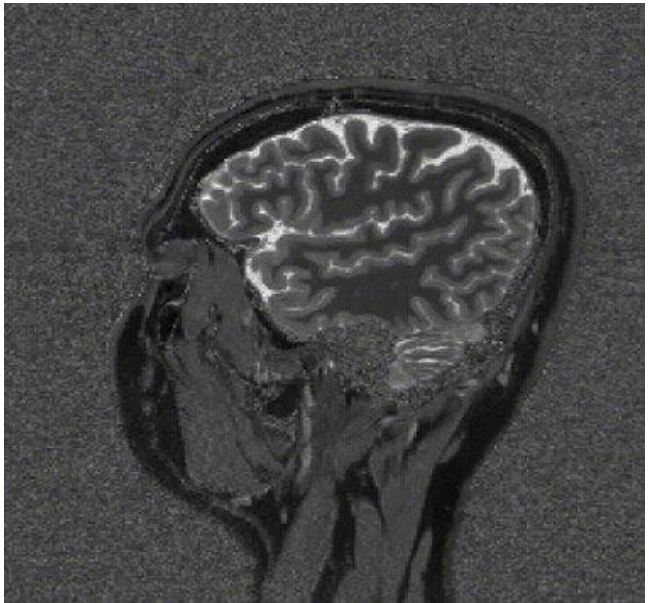
NeuroImaging WorkShop
Session-III
Freesurfer

1. What is T1w Image ?
2. Define GM, WM, cortical thickness.
3. What and why is preprocessing done ?
4. Preprocessing steps and why each is important.
   (Slight idea about SBM vs VBM)

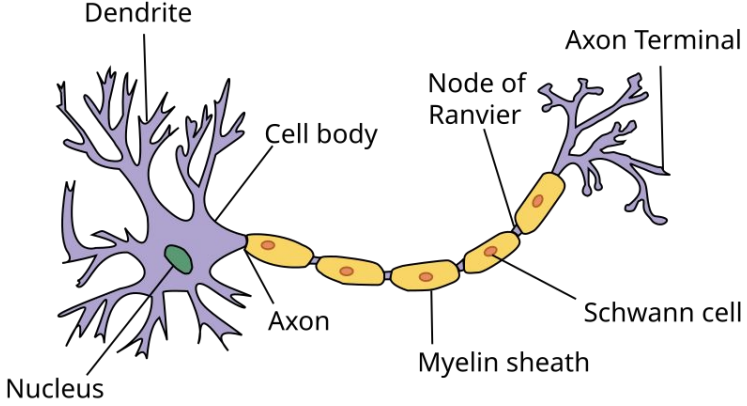
T1w Image

- Fat appears Bright (White in color)
- Fluids appear dark (Grey in color)
- All things that have fluid content are variably dark in T1w Image.





Myelin



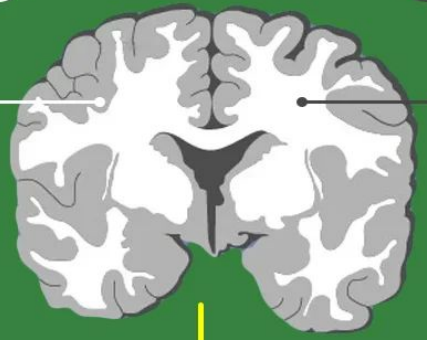
Those axons which have a covering of myelin sheath are known as myelinated axons. These axons protected by myelin sheath are not easily damaged by the external environment and the rate of nerve impulse is also high in comparison to Unmyelinated axons.

Signal damping is high in an individual unmyelinated axons.

In humans, only small diameter axons are unmyelinated. These neurons carry low-priority information, such as smell (olfaction) and temperature sensations.

GRAY MATTER

WHITE MATTER



40%
OF THE BRAIN

60%
OF THE BRAIN

- CONTAINS MOST OF THE BRAINS NEURONAL CELL BODIES
- FULLY DEVELOPS ONCE A PERSON REACHES HIS/HER 20'S
- CONDUCTS, PROCESSES, AND SENDS INFORMATION TO VARIOUS PARTS OF THE BODY.

- MADE UP OF BUNDLES WHICH CONNECT VARIOUSGRAY MATTER AREAS
- DEVELOPS THROUGHOUT THE 20'S AND PEAKS IN MIDDLE AGE
- INTERPRETS SENSORY INFORMATION FROM VARIOUS PARTS OF THE BODY.

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Grey Matter

- Gray matter consists primarily of neuronal cell bodies, or soma. This a spherical structure that houses the neuron’s nucleus. The soma also contains the cell’s cytoplasm, in which other essential organelles, such as mitochondria, can be found.

- The neuronal soma, and the organelles and nucleus within, is the control center of the neuron. Physically, it the point of the neuron from which other connections, such as axons and dendrites, spread. Synaptic input from neighboring neurons can feed onto the soma.

White Matter

- White matter-rich areas of the brain mainly consist of myelinated axons, which are long relays that extend out from the soma.
- These axons are whitish in color due to the relatively high lipid fat content of the myelin protein that sheathes them.
- Axons form connections between brain cells and are usually distributed into bundles, called tracts, in the central nervous system (brain and spinal cord) or nerves (peripheral nervous system).
- Neuron-rich brain regions wouldn’t count for much without the rich veins of axonal connections contained within white matter to join them up.

GM vs WM

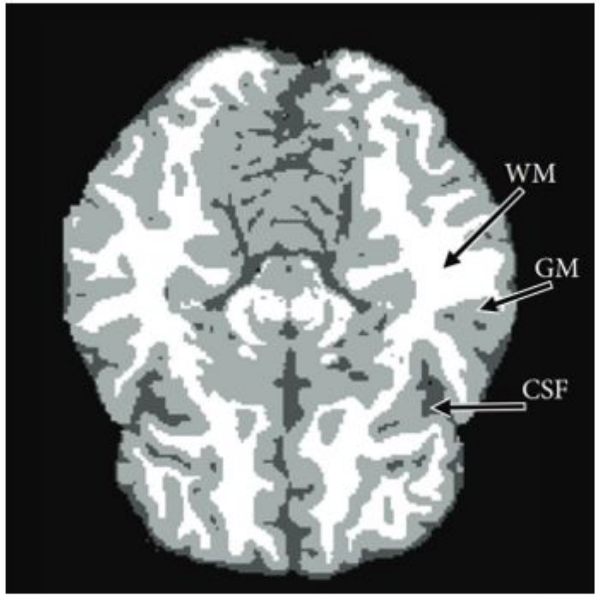
- Grey matter consists of neuronal cell bodies and their dendrites. The dendrites are short protrusions (like little fingers) that communicate with neurons close by.
- In contrast, your white matter consists of the long axons of neurons that transmit impulses to more distant regions of your brain and spinal cord.
- The difference between gray and white matter has to do with the presence or absence of myelin in the nervous tissue. Myelin is a fatty substance which covers the axons of neurons, causing this region of nervous tissue to appear white when dissected and thus leading to the term white matter.

Segmentation into 3 broad classes

Reduction in Grey Matter – Ageing and Neurodegenerative diseases

White Matter hyperintensities – Vascular pathology or lesions

CSF biomarkers – Alzheimer's disease



Cortical Thickness

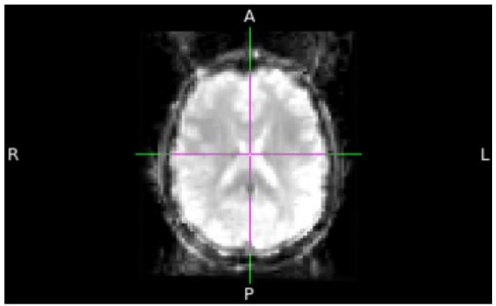
Cortical thickness is the measurement of the width of the gray matter in the human cortex, which is the outer layer of the brain.

Neuroimaging research indicates that human intellectual ability is related to brain structure including the thickness of the cerebral cortex.

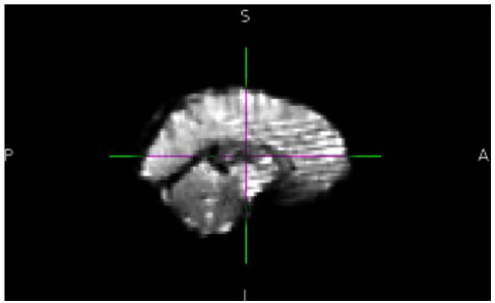
Most studies indicate that general intelligence is positively associated with cortical thickness in areas of association cortex distributed throughout both brain hemispheres.

Importance of Preprocessing

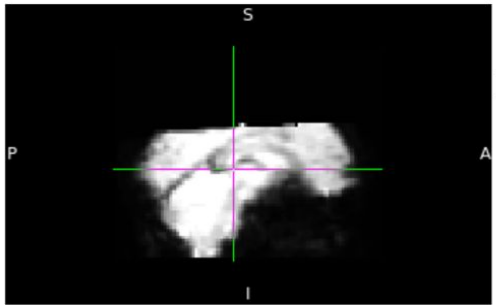
Preprocessing is a crucial step in the analysis of structural T1w images. It involves a series of steps that prepare the raw images for further analysis, ensuring that the results are accurate and reliable.



Ghost like artifact



Scanner related artifact

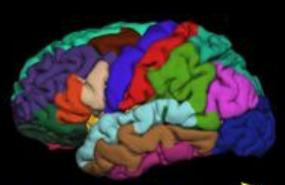


Brain cut like errors

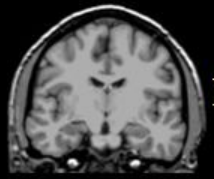
Preprocessing Methods

- SBM (Surface Based Morphometry)
- VBM (Voxel Based Morphometry)
- **VBM** compares differences in gray and white matter volume, density, or concentration **voxel-wise**. VBM uses 3D spatial normalization on a segmented GM image, where **signal intensity represents tissue probability**.
- **SBM** identifies patterns of structural variation using **independent component analysis**. SBM also uses 2D spatial normalization on a 2D cortical sheet that's shown on a **sphere surface**.
- Freesurfer deploys SBM method.

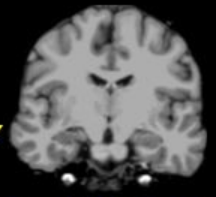
Processing Stream Overview



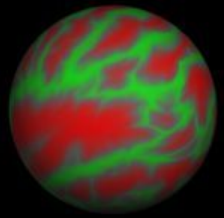
Gyral Labeling



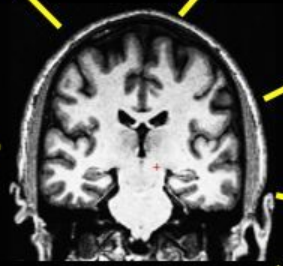
Intensity Normalization



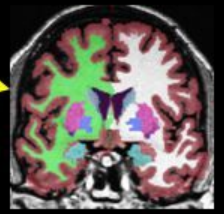
Skull Stripping



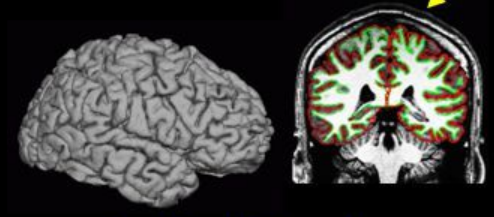
Surface Atlas Registration



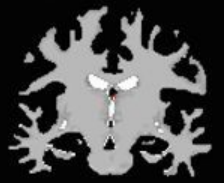
T1 Weighted Input



Volumetric Labeling



Surface Extraction



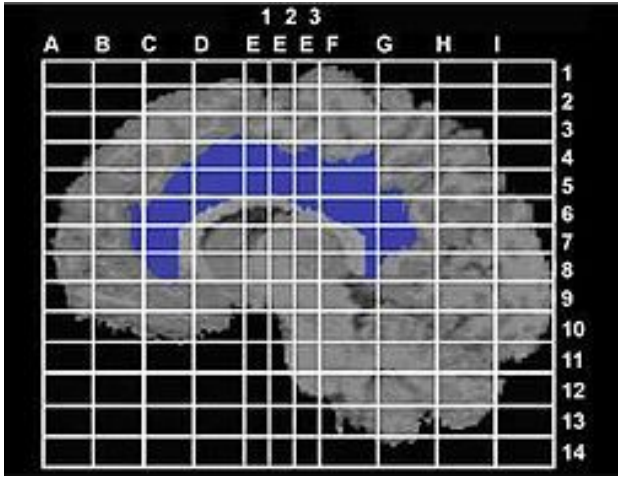
White Matter Segmentation

Motion Correction

Correcting for artifacts: Motion correction algorithms help realign images to compensate for movement during the scanning process, reducing artifacts.

Talairach Transformation

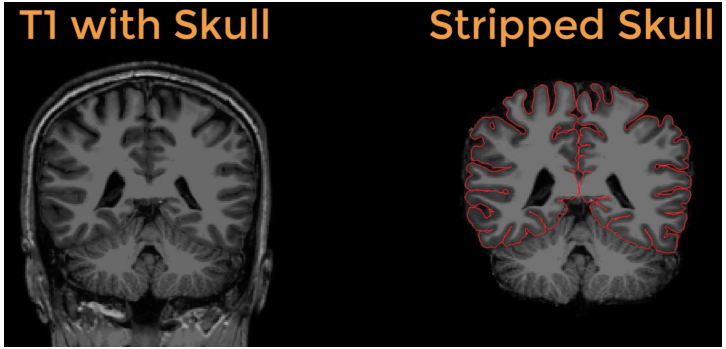
Standardization: Transforming brain images into a standardized coordinate system (Talairach space) allows for comparisons across different brains and studies.
Talairach coordinates, also known as Talairach space, is a 3-dimensional coordinate system (known as an 'atlas') of the human brain, which is used to map the location of brain structures independent from individual differences in the size and overall shape of the brain.



Intensity Normalization

Enhancing comparability: Intensity normalization corrects variations in MRI signal intensity due to scanner differences or patient-specific characteristics, making images more comparable.

Skull Stripping



Focusing on brain structure: Skull stripping removes non-brain tissues from images, allowing analysis to focus on the brain structure.

Segmentation

Identifying brain structures: Segmentation divides the brain into different regions or tissues based on their characteristics, aiding in identifying specific brain structures and analyzing their properties.

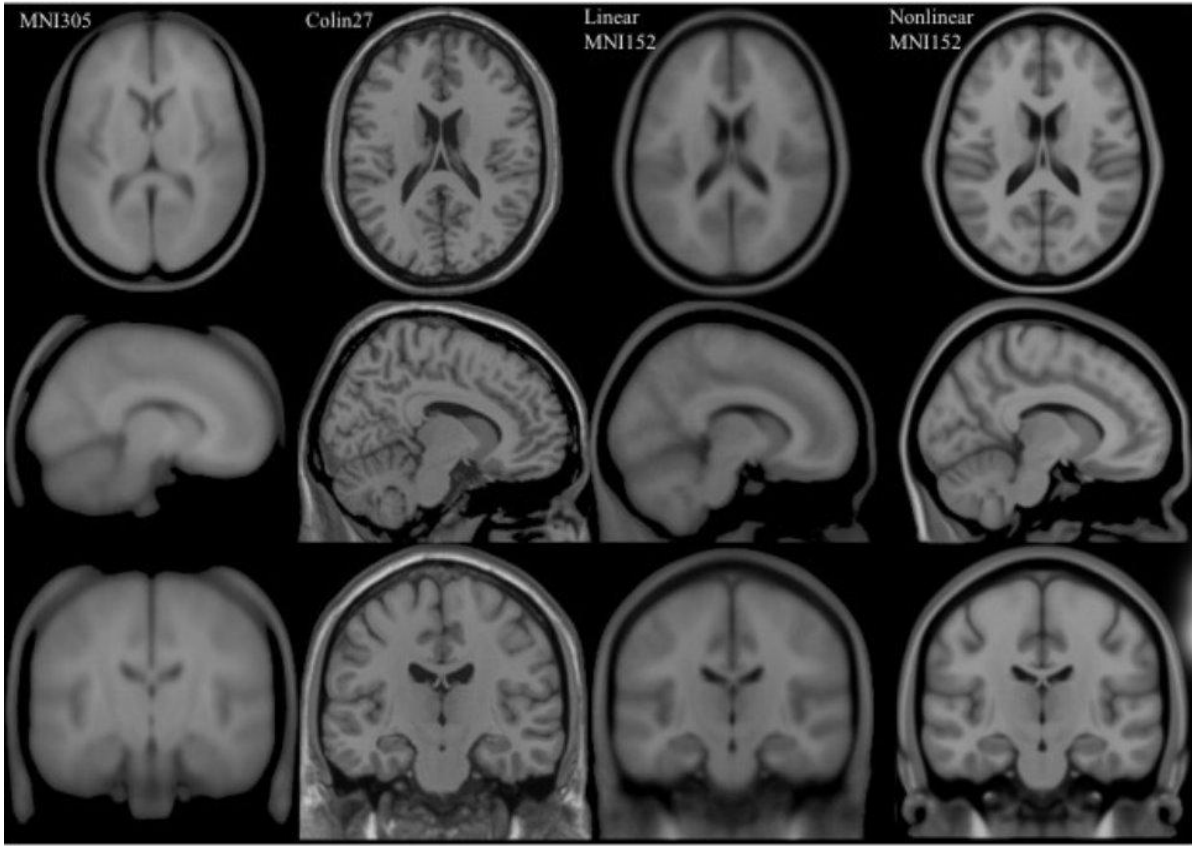
Signal intensity on MRI is used for tissue segmentation. The signal intensity is affected by imaging parameters, such as field strength, TR (repetition time), and TE (echo time).

Normalization and Registration

Normalization warps brain images to a standard template, accounting for anatomical differences between individuals. Registration aligns images from different modalities or time points for direct comparisons.

Spherical Map Registration

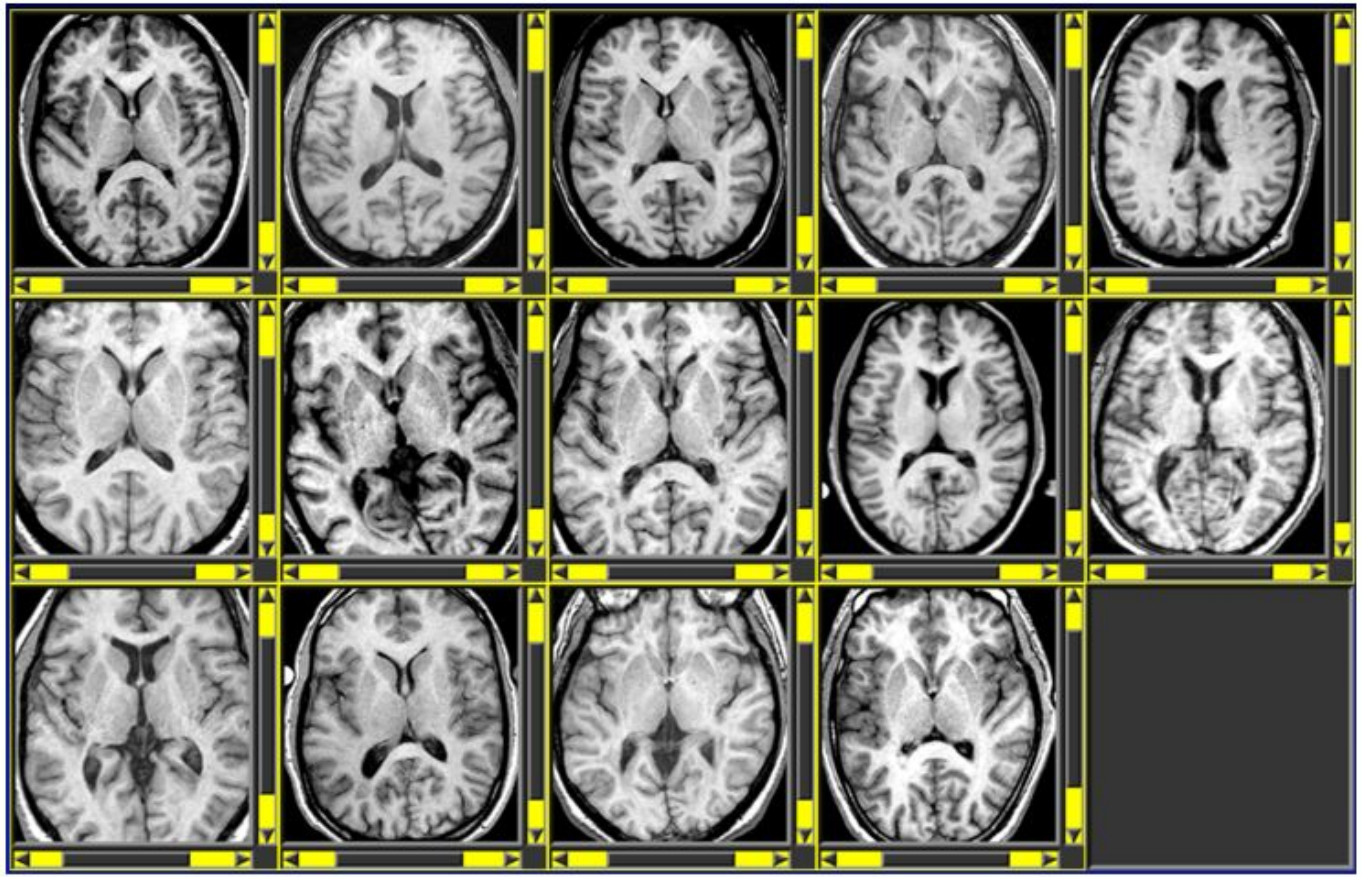
T1w MRI Templates



Transformations

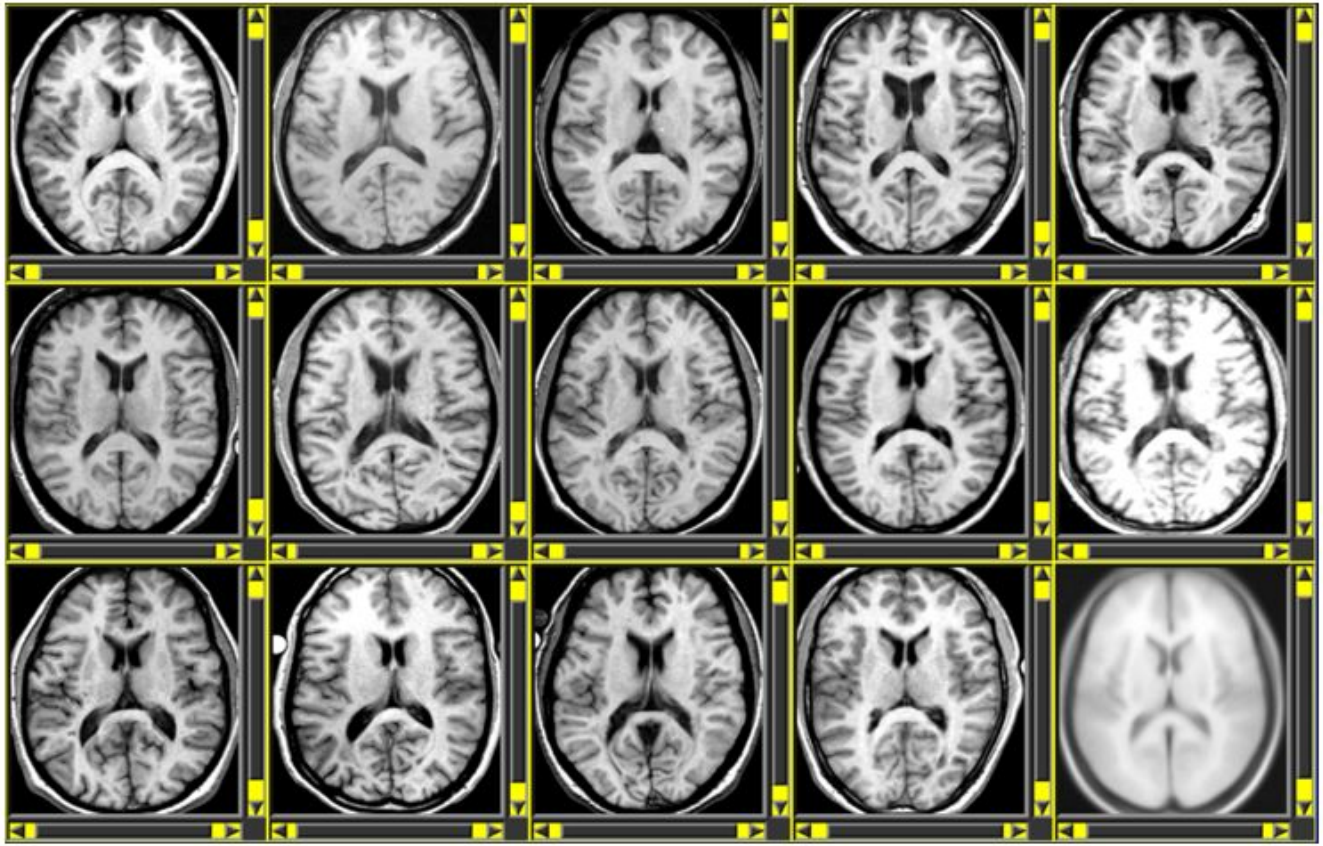
https://andysbrainbook.readthedocs.io/en/latest/_images/04_03_AffineTransformations.gif

Not registered data



Registered data

Reference coordinate spaces and spatial normalization offer a way to map and compare brain anatomy across modalities, individuals, and studies



Cortical Surface Reconstruction

Enabling detailed analysis: Cortical surface reconstruction allows for in-depth analysis of cortical thickness, surface area, and other surface-based measures.

Cortical Parcellation & Hemispheric Separation

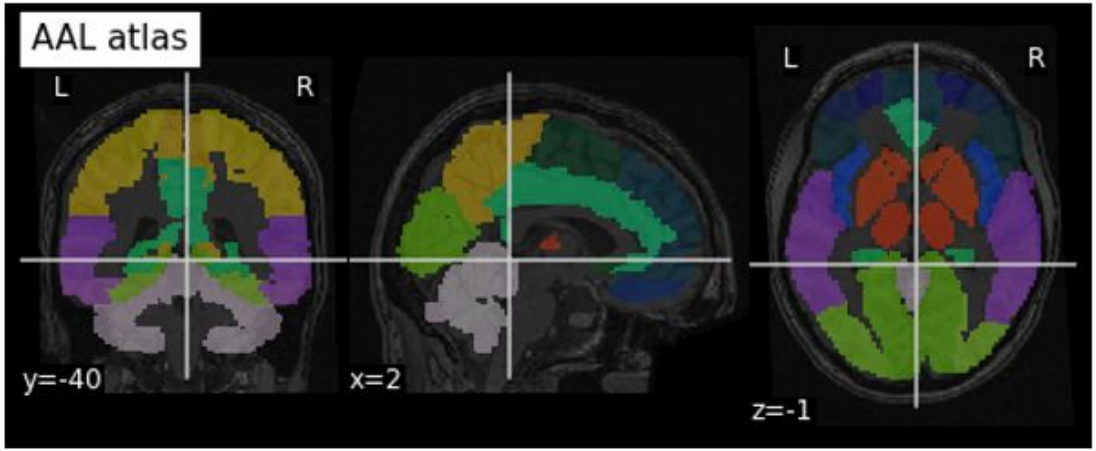
Facilitating further analysis: Cortical parcellation divides the cortex into regions, and hemispheric separation allows for separate analysis of the brain's hemispheres.

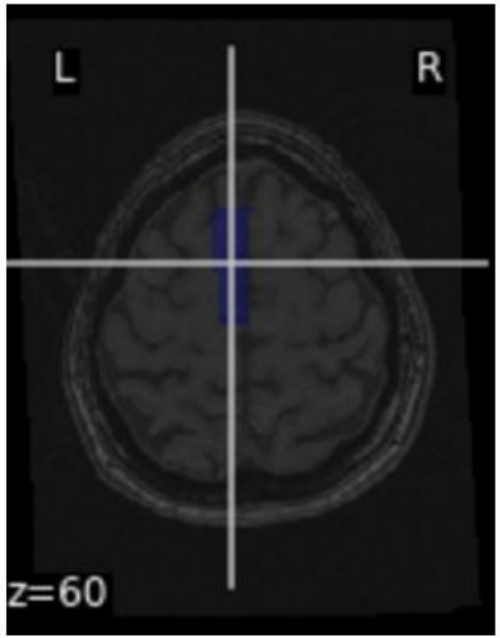
Parcellation Atlases like Desikan Killiany, Destrieux, etc.

They have different No. of brain regions, Brain Networks classes etc.

Further division into sub-components

Segmenting tissue classes into sub-components: atlasing, parcellation

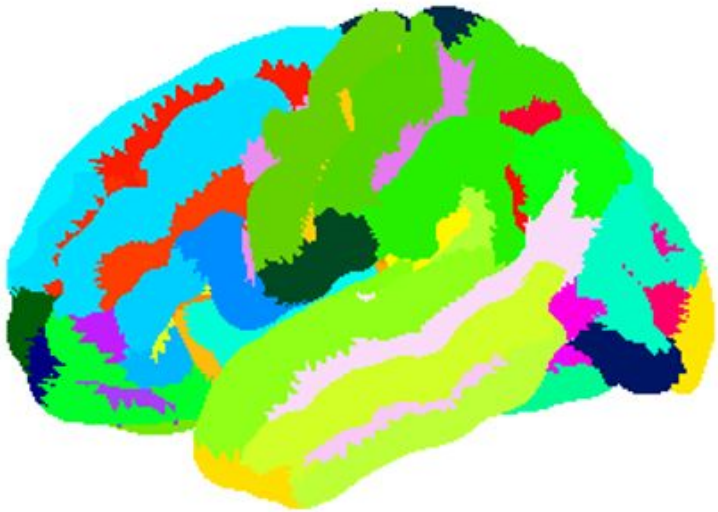




Surface atlases

- The Desikan-Killiany Atlas with 68 ROIs

- The Destrieux Atlas with 148 ROIs.



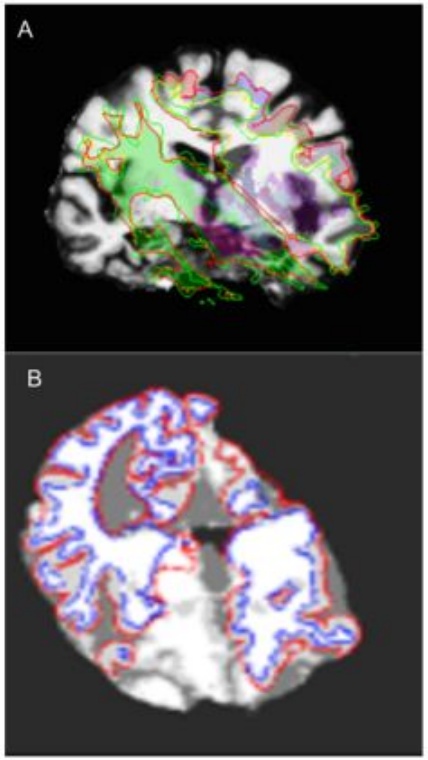
Quality Control and Error Correction

Ensuring data quality: Quality control and error correction involve visual inspection and manual correction of preprocessed images to ensure data accuracy.

Tools are there to visually overlay the segmentation output onto a background image. This visual quality control (QC) process proves particularly useful in smaller studies.

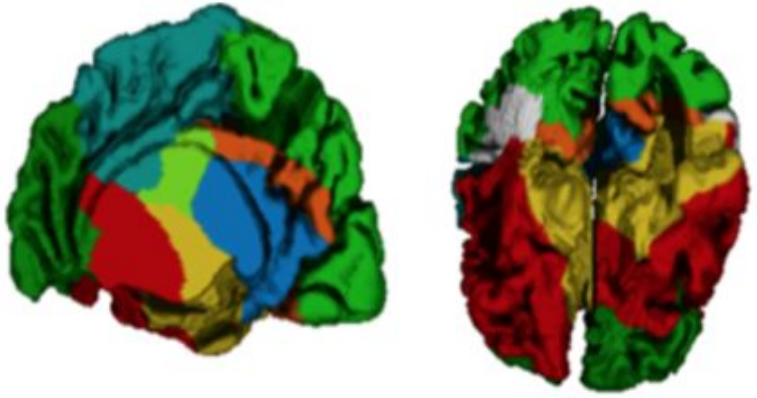
Some automated recommendations from the preprocessing steps can also be indicated based on the amount of transformations an image had to undergo to finally be registered to a standard template.

Why Quality checks?



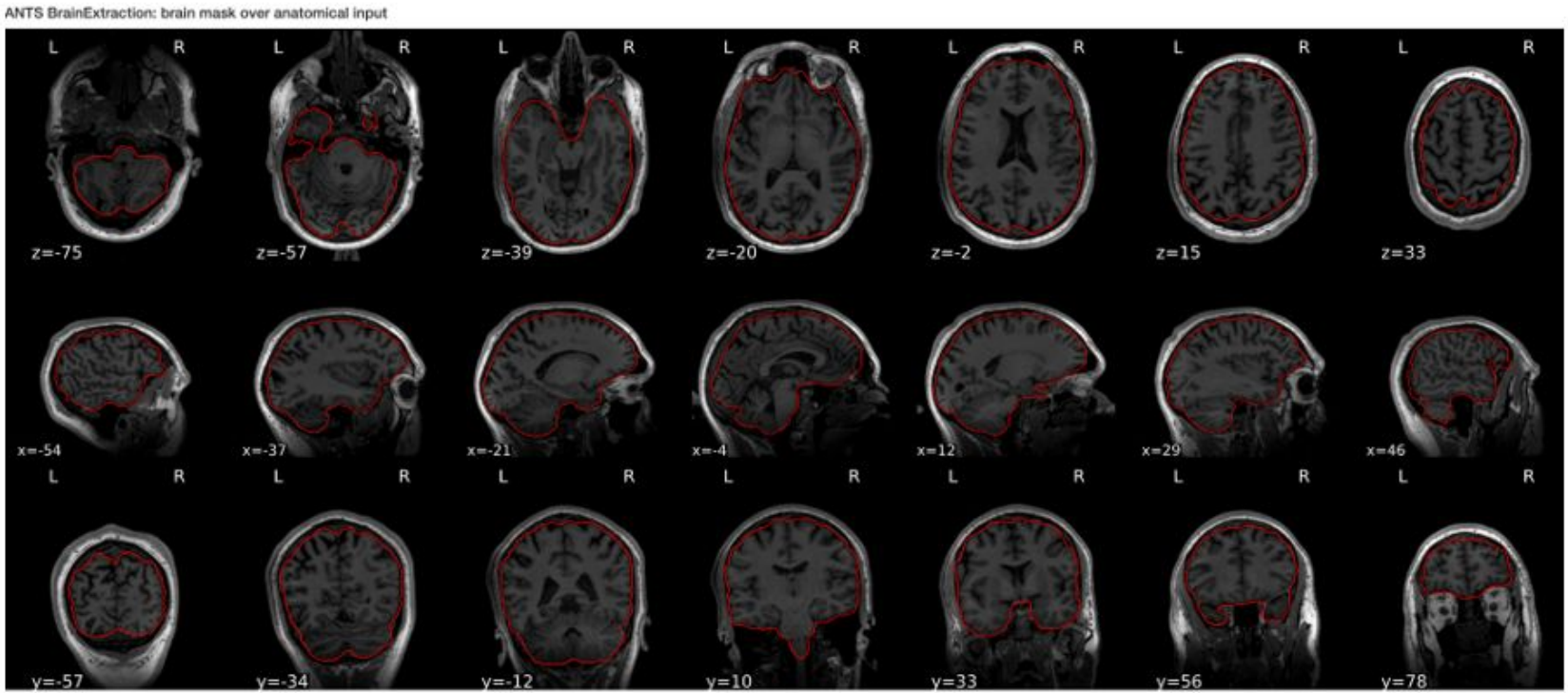
Segmentation Failures: (A) FreeSurfer, (B) CIVET

FreeSurfer Cortical Surface Failure

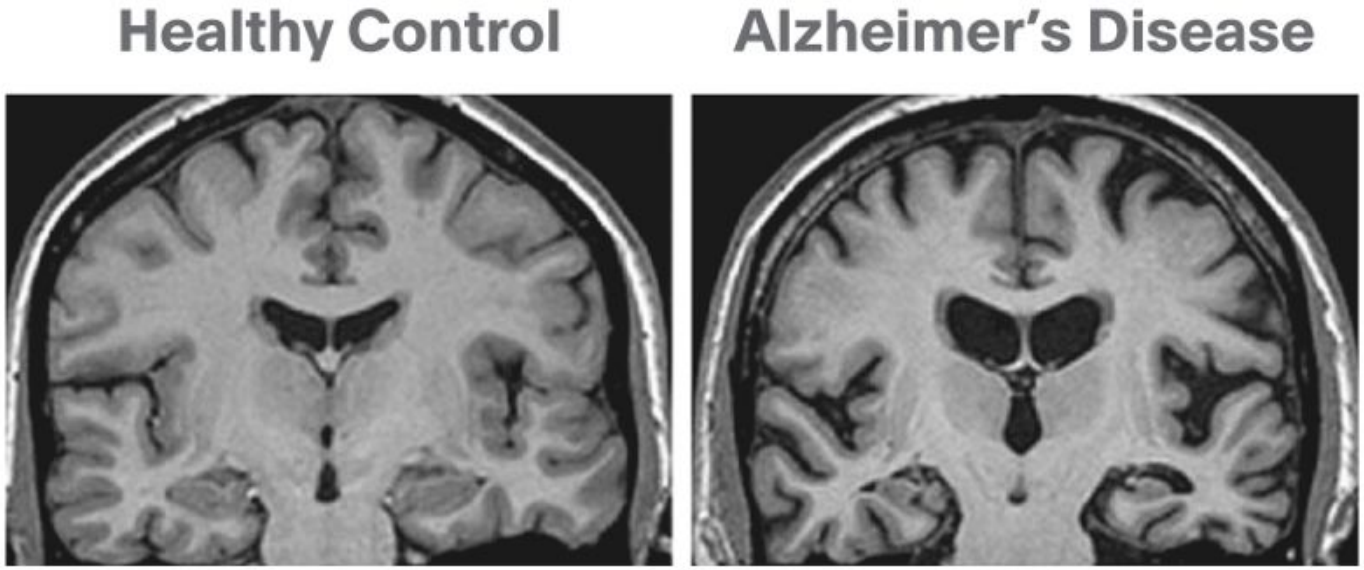


CIVET Cortical Surface Failure

E.g., MRIQC report



T1 image in Healthy vs Alzheimers disease



Statistical Analysis

ANOVA

ANCOVA (Covariates)

QDEC

JASP

Python based statistical Analysis tools

Newer derived parameters like SPC.

Linear or polynomial regression in case of more than 2 time points.

ANOVA vs ANCOVA

Statistical methods used to analyze the differences between the means of multiple groups

ANOVA:

- Purpose: Compares the means of two or more groups to determine if there is a statistically significant difference between them.
- Assumptions:
    - Data is normally distributed within each group.
    - Variances across groups are equal.
    - Observations are independent.
- When to use: ANOVA is appropriate when you have a categorical independent variable (e.g., different treatment groups) and a continuous dependent variable (e.g., test scores).

ANCOVA:

- Purpose: Similar to ANOVA, but also controls for the effects of one or more continuous variables (covariates) that are not of primary interest but may influence the dependent variable.
- Assumptions:
    - Same assumptions as ANOVA.
    - The relationship between the dependent variable and the covariate(s) is linear.
    - The covariate(s) should not be affected by the treatment.
- When to use: ANCOVA is useful when you have covariates that you want to control for in your analysis. For example, if you are comparing the effectiveness of two different teaching methods, you might want to control for the students' prior knowledge.

ADNI Dataset sample study details and Hypothesis Setup

Approx. 50 subjects each of Control Healthy and AD patients.

QDEC

Freesurfer QDEC based visualization of clusters

JASP based analysis