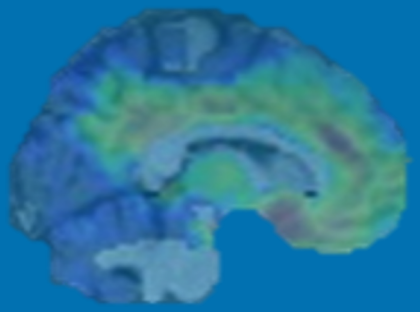
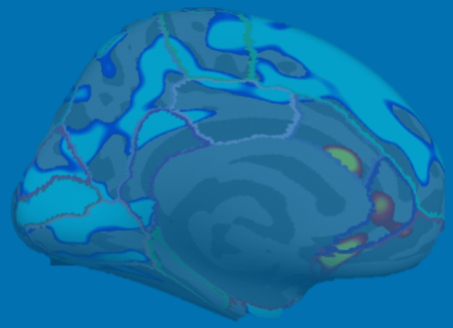


CIBM
Center for Biomedical Imaging



INTRODUCTION BRAIN MORPHOMETRY

Meritxell Bach Cuadra[1,2]

[1]*CIBM Center for Biomedical Imaging*

[2]*Radiology Department, Lausanne University Hospital and University of Lausanne*

Invited lecture, CIBM translational MR neuroimaging & spectroscopy (PHYS-760), May 2nd 2023, EPFL

UNIL | Université de Lausanne

mial Medical Image Analysis Laboratory

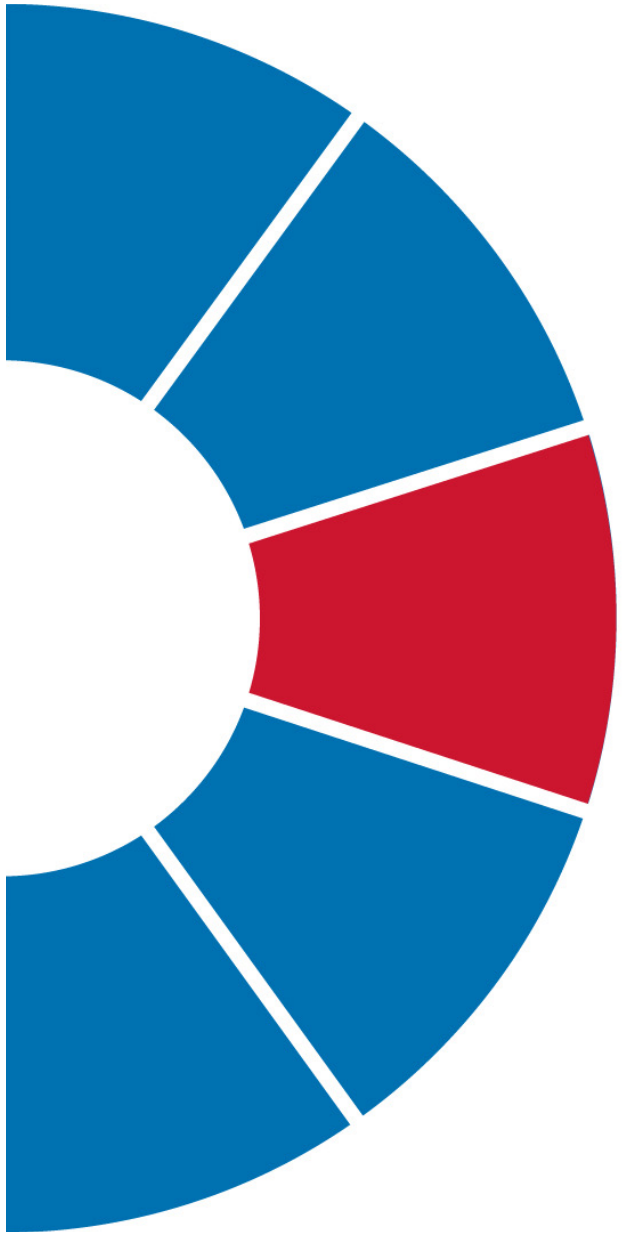
CHUV

OBJECTIVES

- Overview of morphometry methods for study of in-vivo brain MRI.
- Understand the basics of voxel-wise morphometry:
  - Pre-processing steps
- Be aware of surface-based morphometry:
  - and enumerate advantages and disadvantages in comparison with VBM

OUTLINE

- Definition
- Voxel-based morphometry
  - Pre-processing
- Surface-based morphometry
- Advantages and disadvantages



DEFINITION AND METHODS

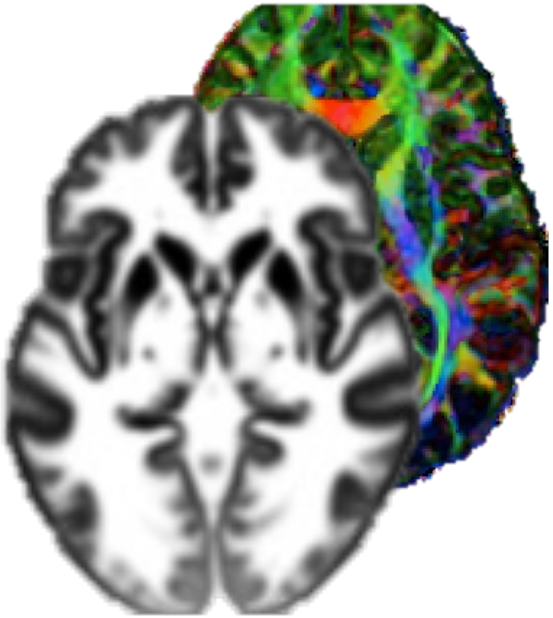
DEFINITION - IN COMPUTER VISION

Brain morphometry* measurement of brain structures and changes thereof during development, aging, learning, disease and evolution....

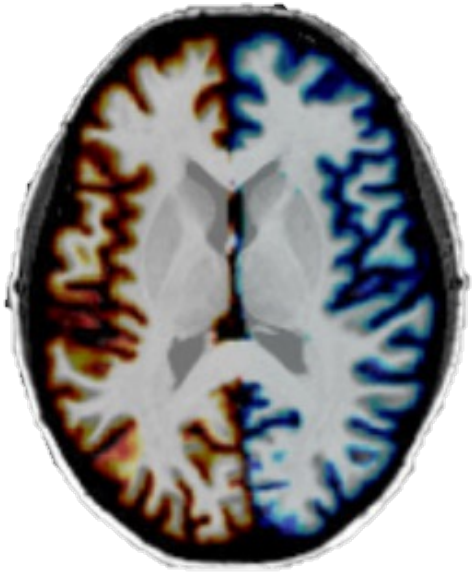
*Wikipedia

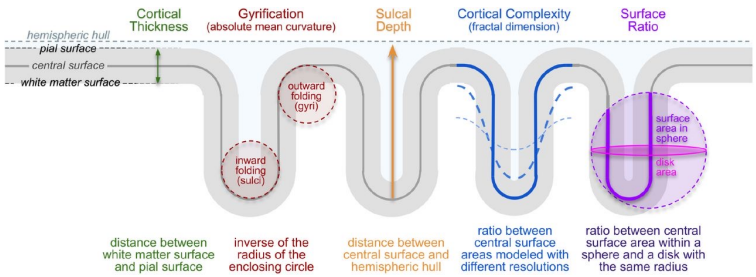
METHODS

Voxel-based

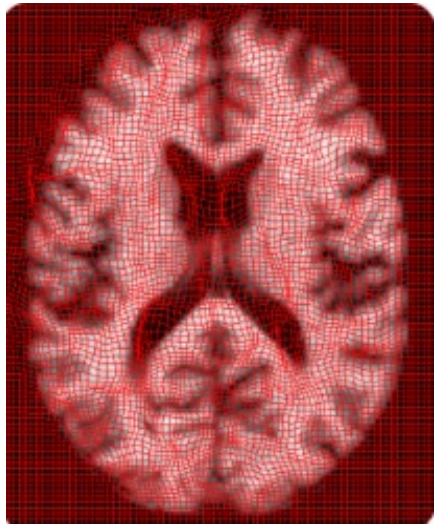


Surface-based



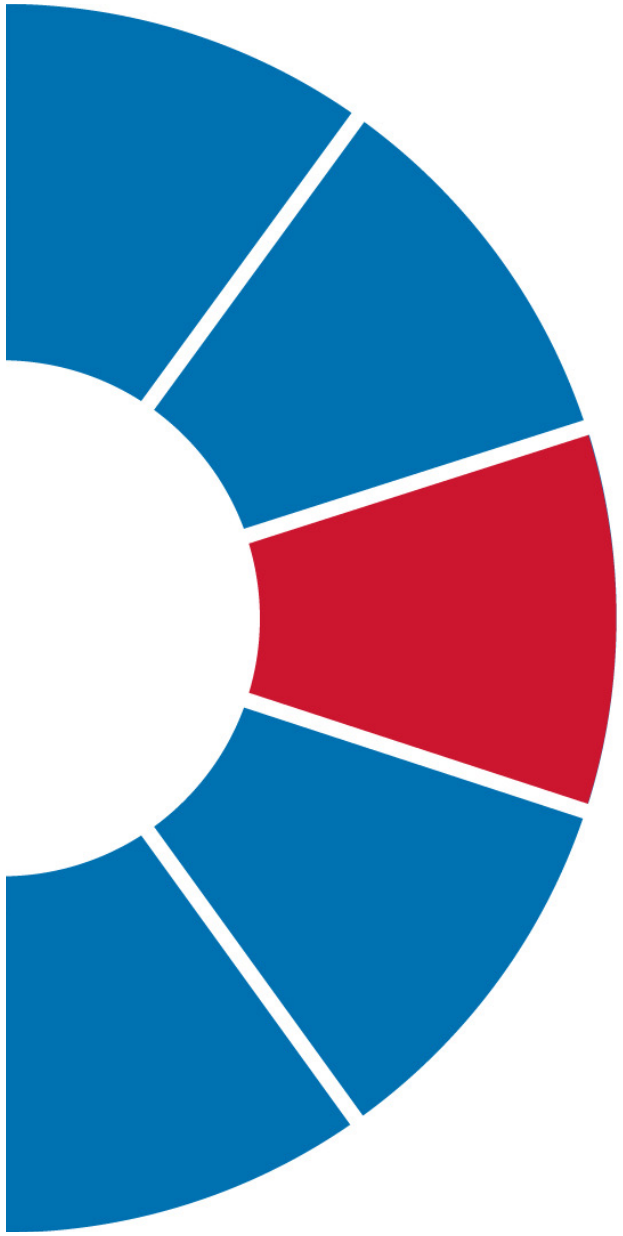


Deformation-based



$$J = \begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \cdots & \frac{\partial f_1}{\partial x_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial f_m}{\partial x_1} & \cdots & \frac{\partial f_m}{\partial x_n} \end{bmatrix}$$

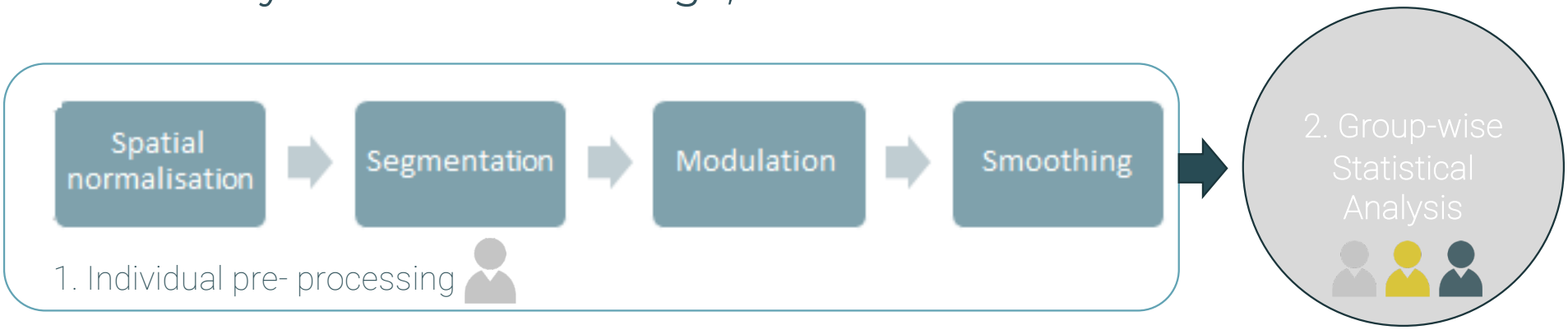
Figures adapted from CAT website



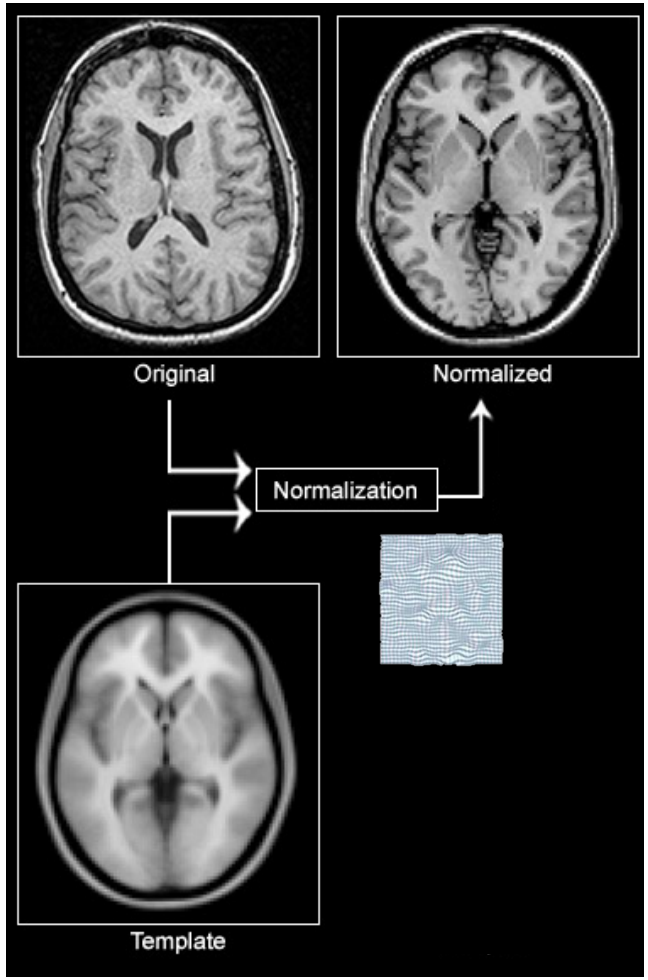
VOXEL-BASED MORPHOMETRY

VBM

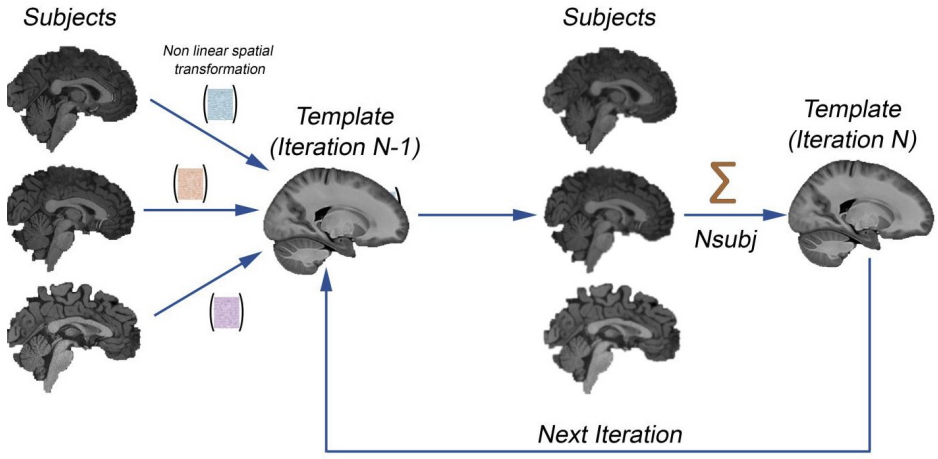
- Tissue maps : regional differences in volume
- Whole brain: no a priori on where these differences occur
- Produce a map of statistically significant differences among populations of subjects
  - compare a patient group with a control group
  - identify correlations with age, test-score etc.



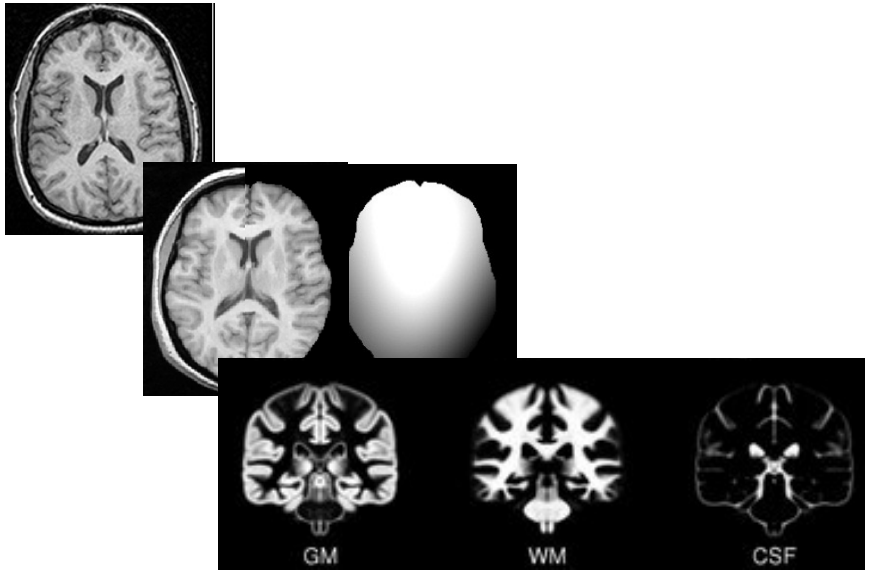
SPATIAL NORMALIZATION

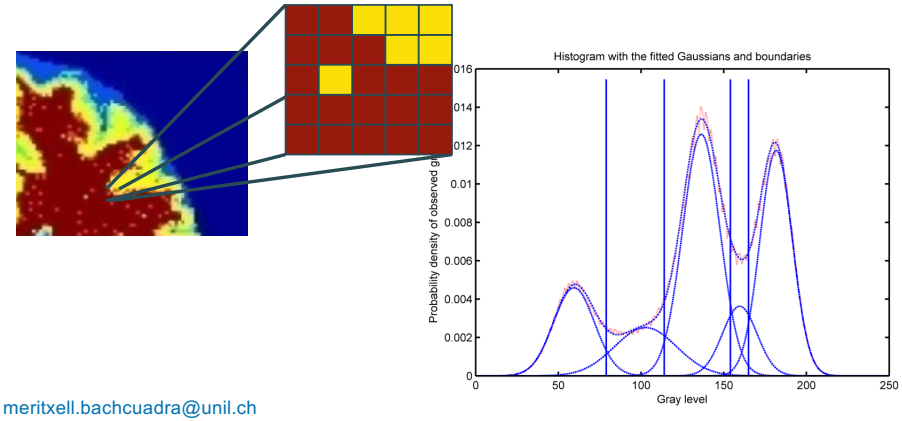


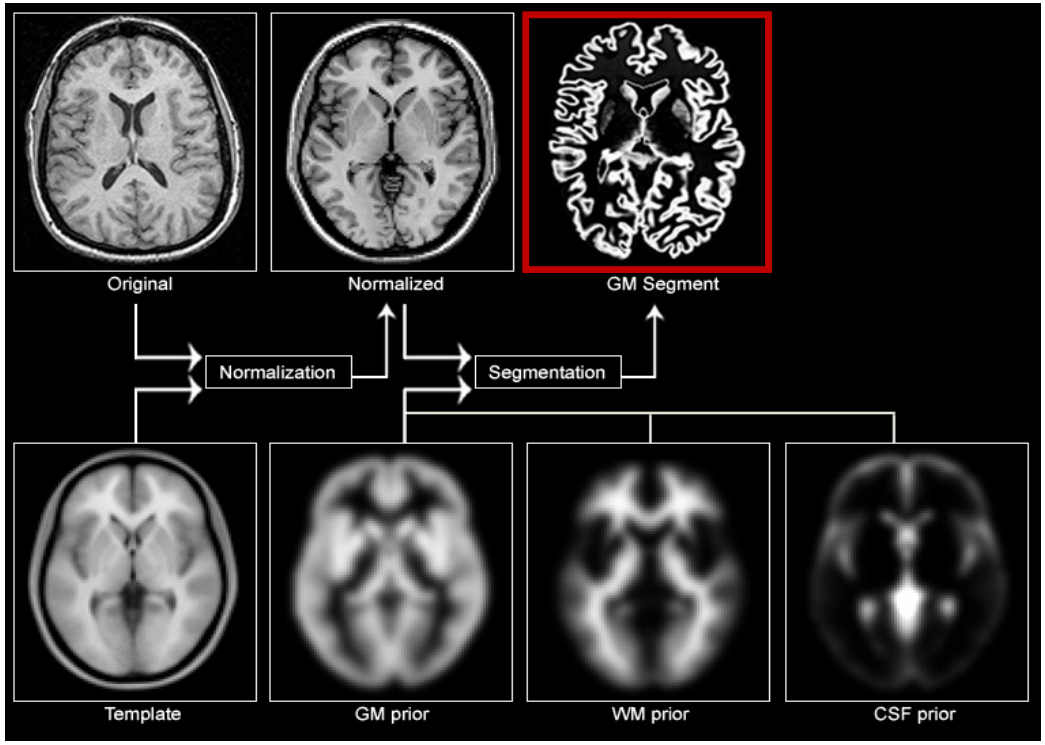
- Transforming all the subject's imaging to the same reference space
- Corrects for global brain shape differences
- Choice of the template: MNI or own template (Avants et al 2010)



SEGMENTATION

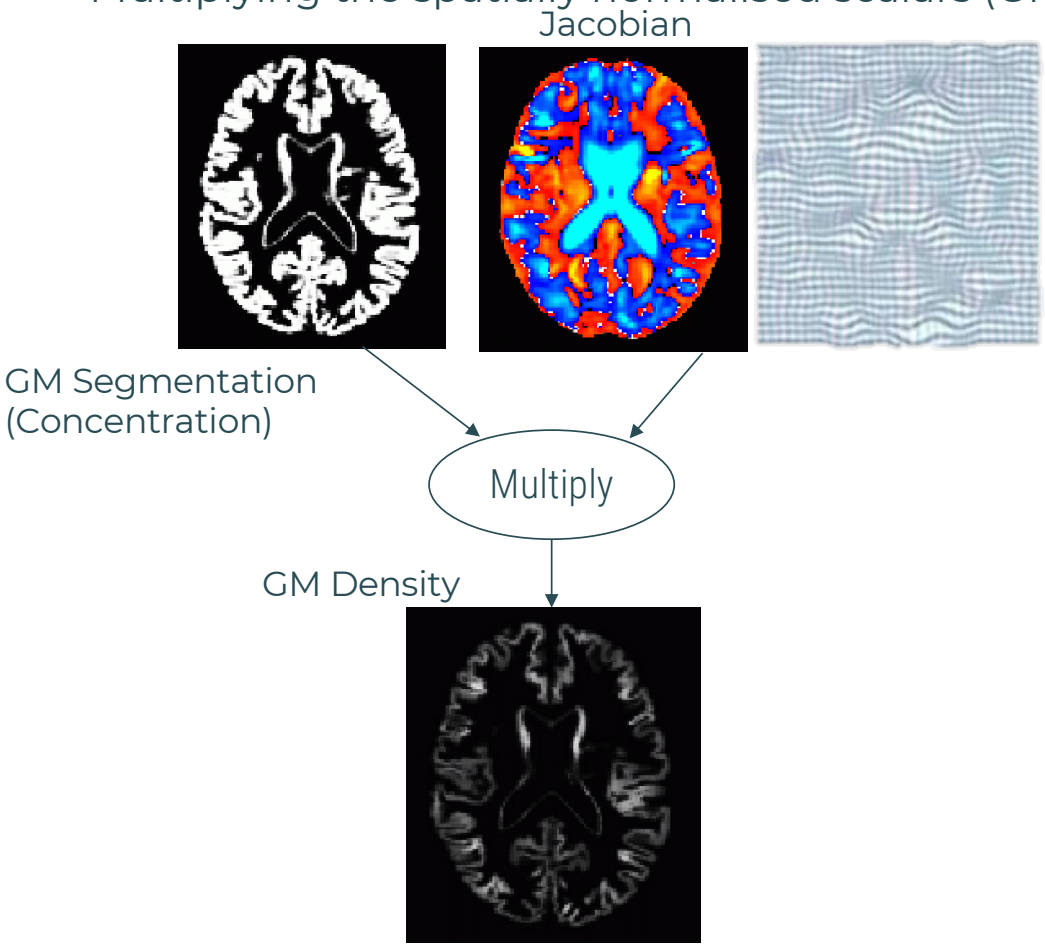


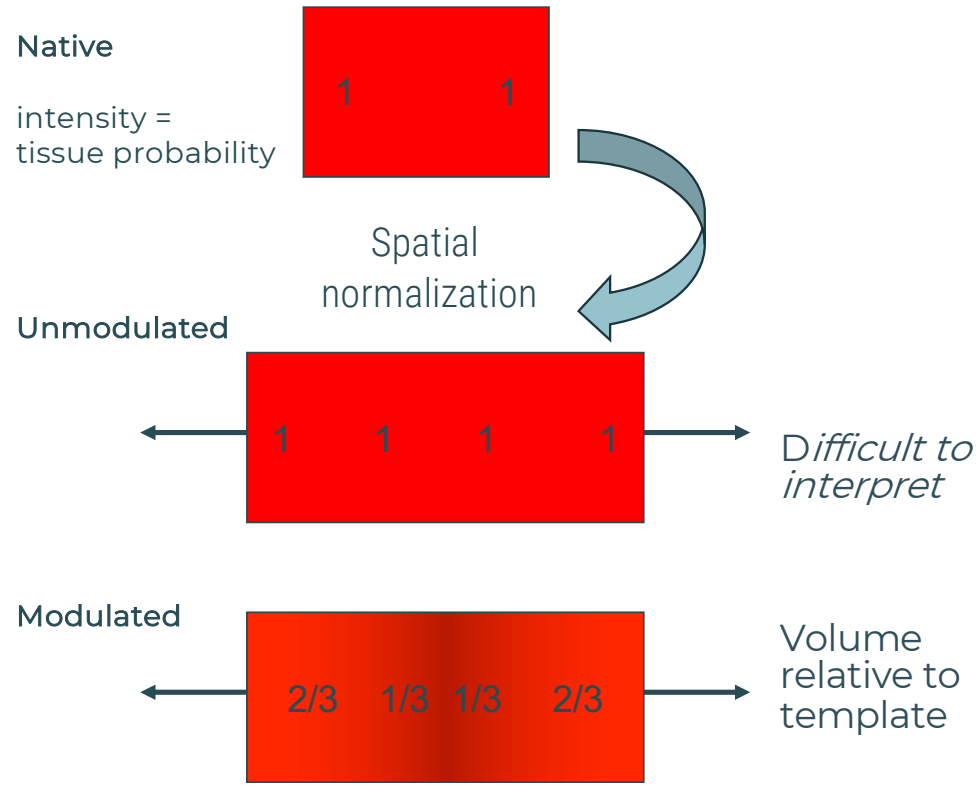




MODULATION

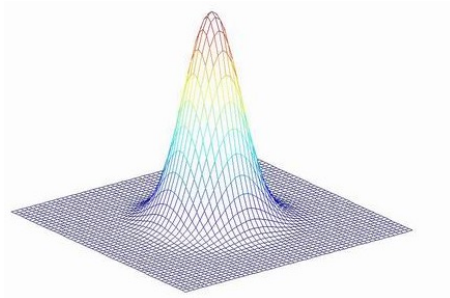
Multiplying the spatially normalised scalars (GM, WM, etc) by Jacobian determinant

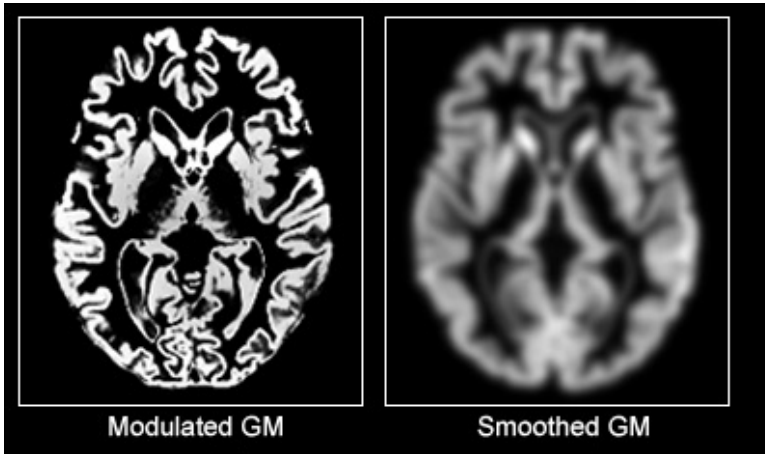




SMOOTHING

- Analysis sensitive to effects that match shape and size of the kernel
- The data will be more Gaussian and closer to a continuous random field for larger kernels
- Smoothing compensate for registration errors
- Results will be rough and noise-like if too little smoothing is used
- Usually recommend >= 6mm but < 12mm

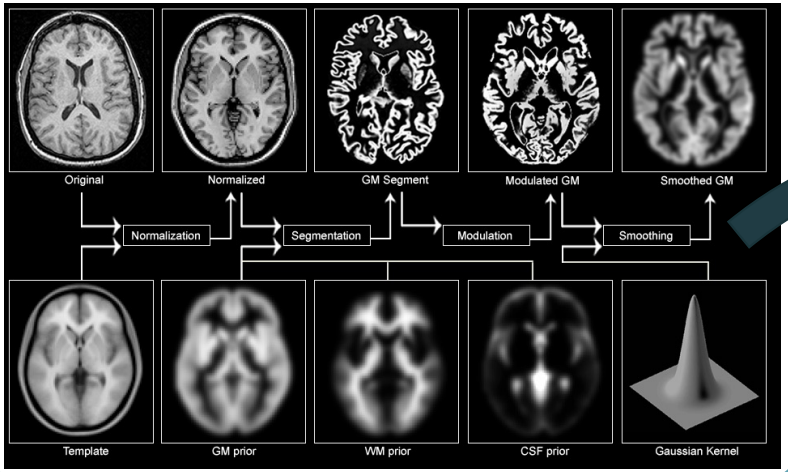




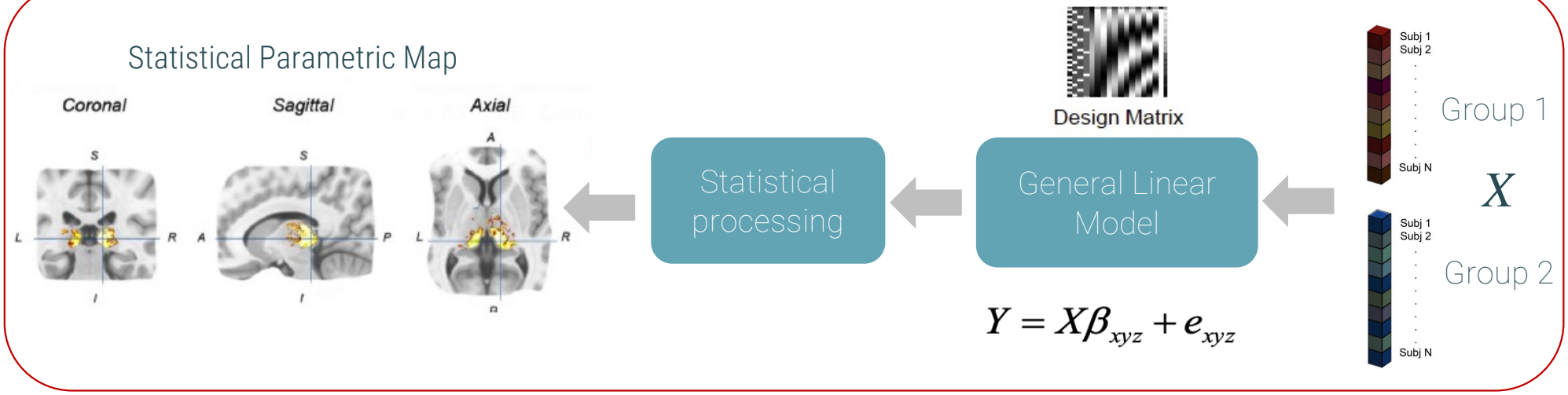
VBM

Whole pipeline

1. Pre-processing



2. Group-wise processing



VBM: SUMMARY

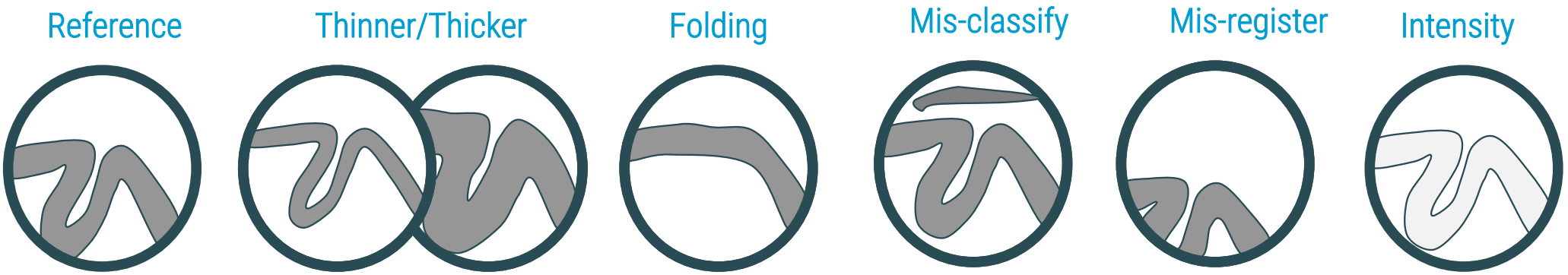
Advantages

- Unbiased way to localize differences
- Whole brain analysis, no knowledge on where differences are is required
- Can be adapted to be sensitive to both small and large differences
- Automated analysis: low user interaction

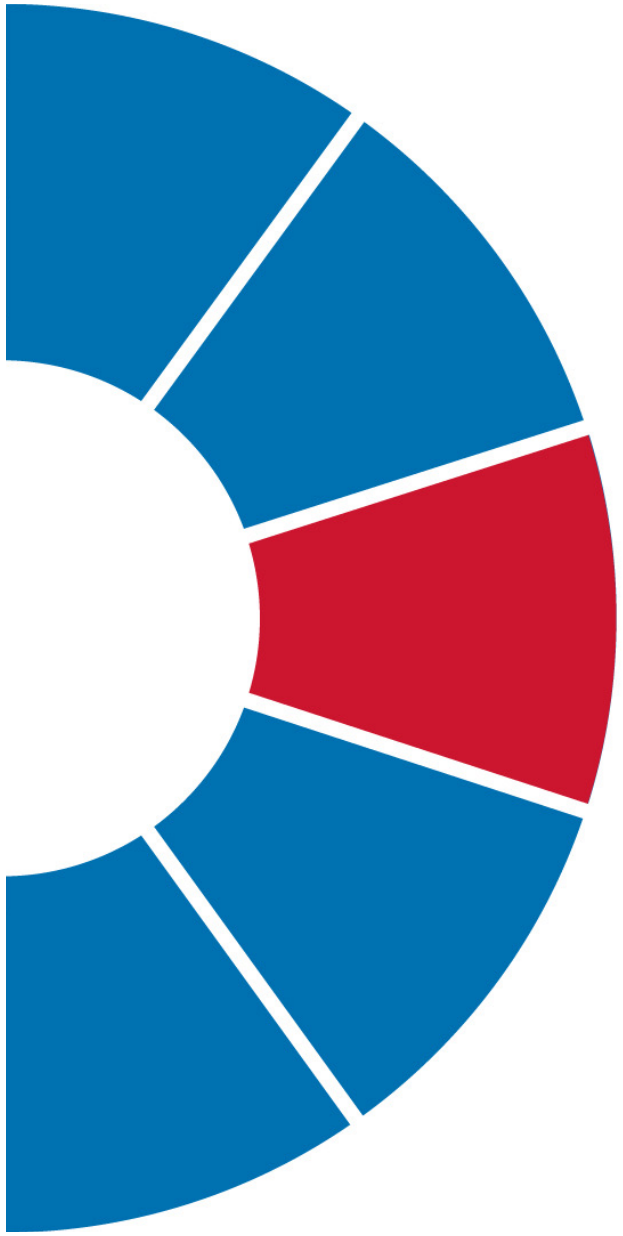
Disadvantages

- Sensitive to:
  - Quality of image (noise and artefacts)
  - Registration errors
  - Segmentation errors
  - Priors might not be appropriate !!!
  - No model of pathology (stroke, tumor, etc)

INTERPRETATION OF FINDINGS

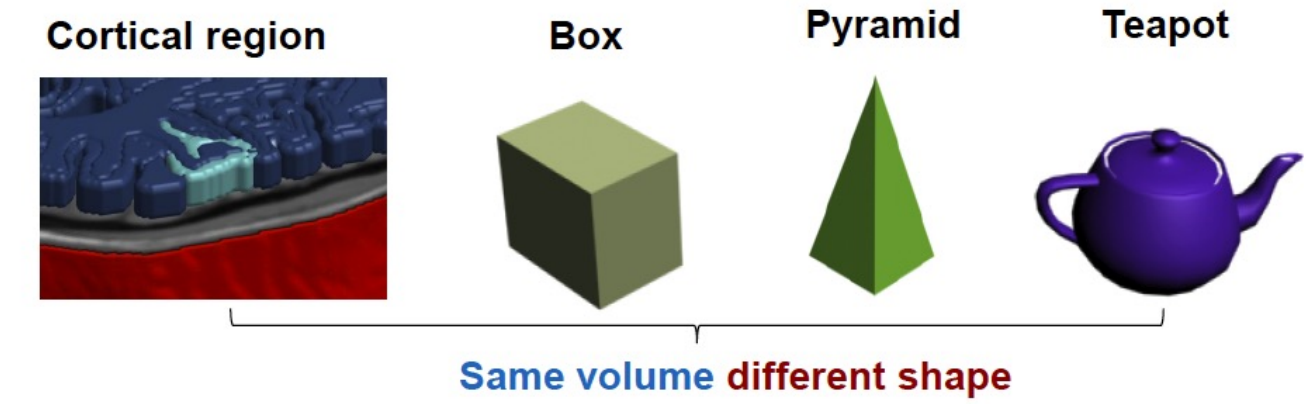


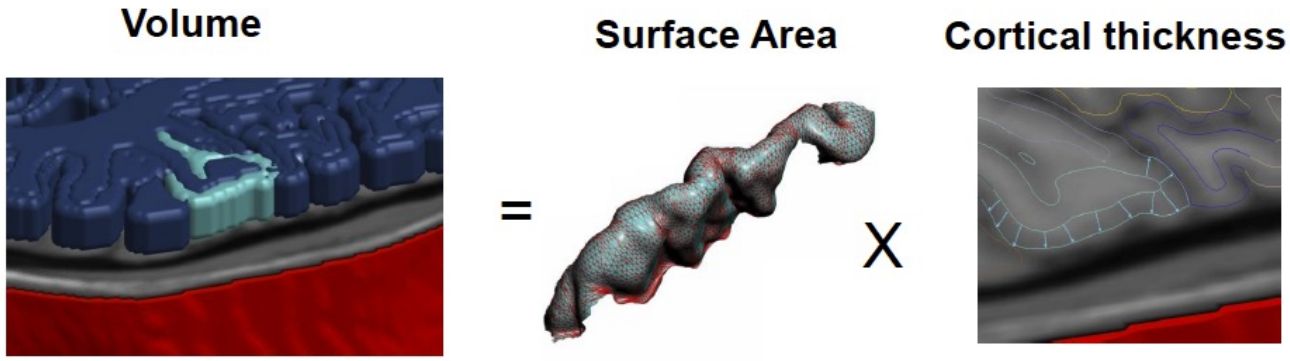
- Statistical Parametric Mapping of regional segmented tissue **density** or **volume**
  - The exact interpretation of density or volume is complicated: not interpretable as neuronal packing or other cytoarchitectonic tissue properties
  - Hypothesis: changes in these microscopic properties may lead to macro-or mesoscopic VBM-detectable differences



SURFACE-BASED MORPHOMETRY

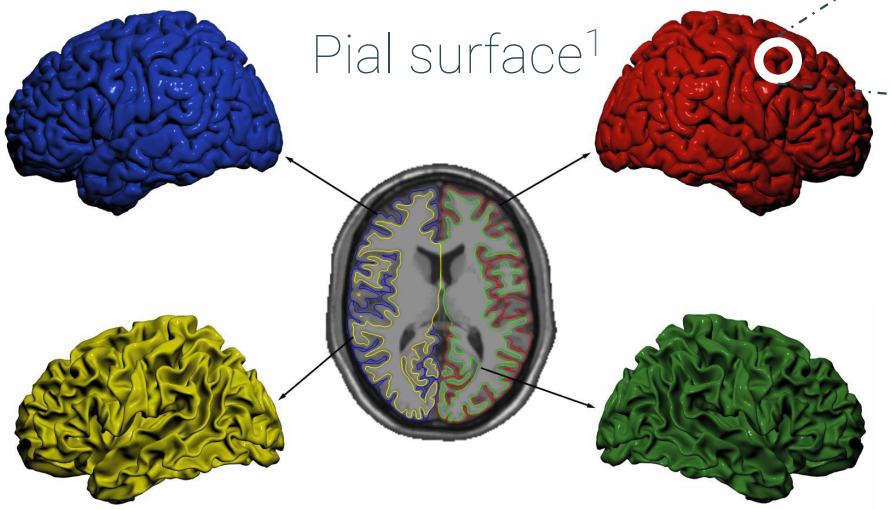
VOLUME VS SURFACE





Courtesy of Dr Y. Alemán-Gómez

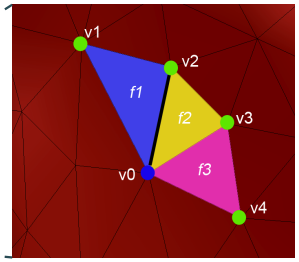
SURFACE-BASED EXTRACTION



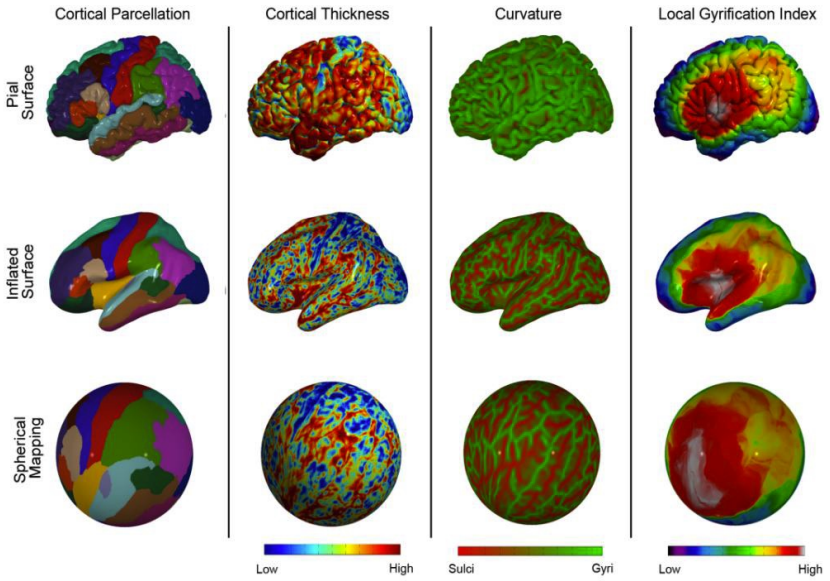
Pial surface[1]

Inner surface[1]

Mesh, vertices

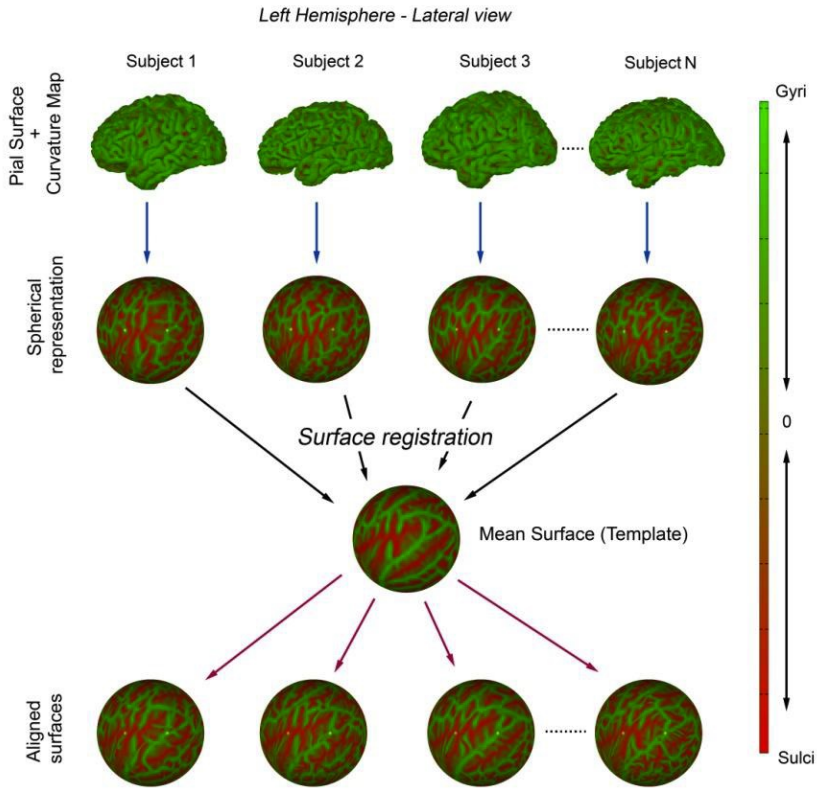


Vertex-wise metrics[2,3,4]

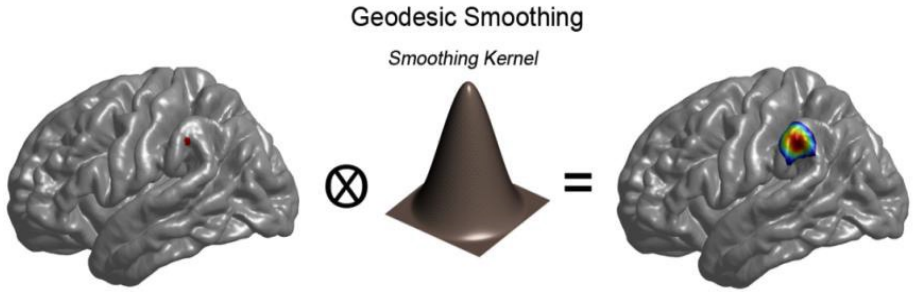


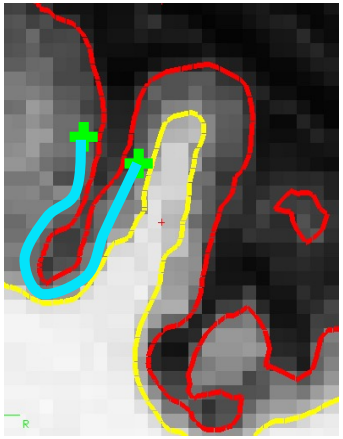
[1] Davatzikoset al. 1996. IEEE Transactions on Medical Imaging, [2]Fischl et al. 2000. PNAS, 3 IEEE Trans. Med. Imag. Dale et al. 1999. Neuroimage, 4 Schaer et al. 2008.

SURFACE REGISTRATION & SMOOTHING



Fischl, et al, 1998, NI.





- 5 mm apart in 3D
- 25 mm apart on surface!

SBM: SUMMARY

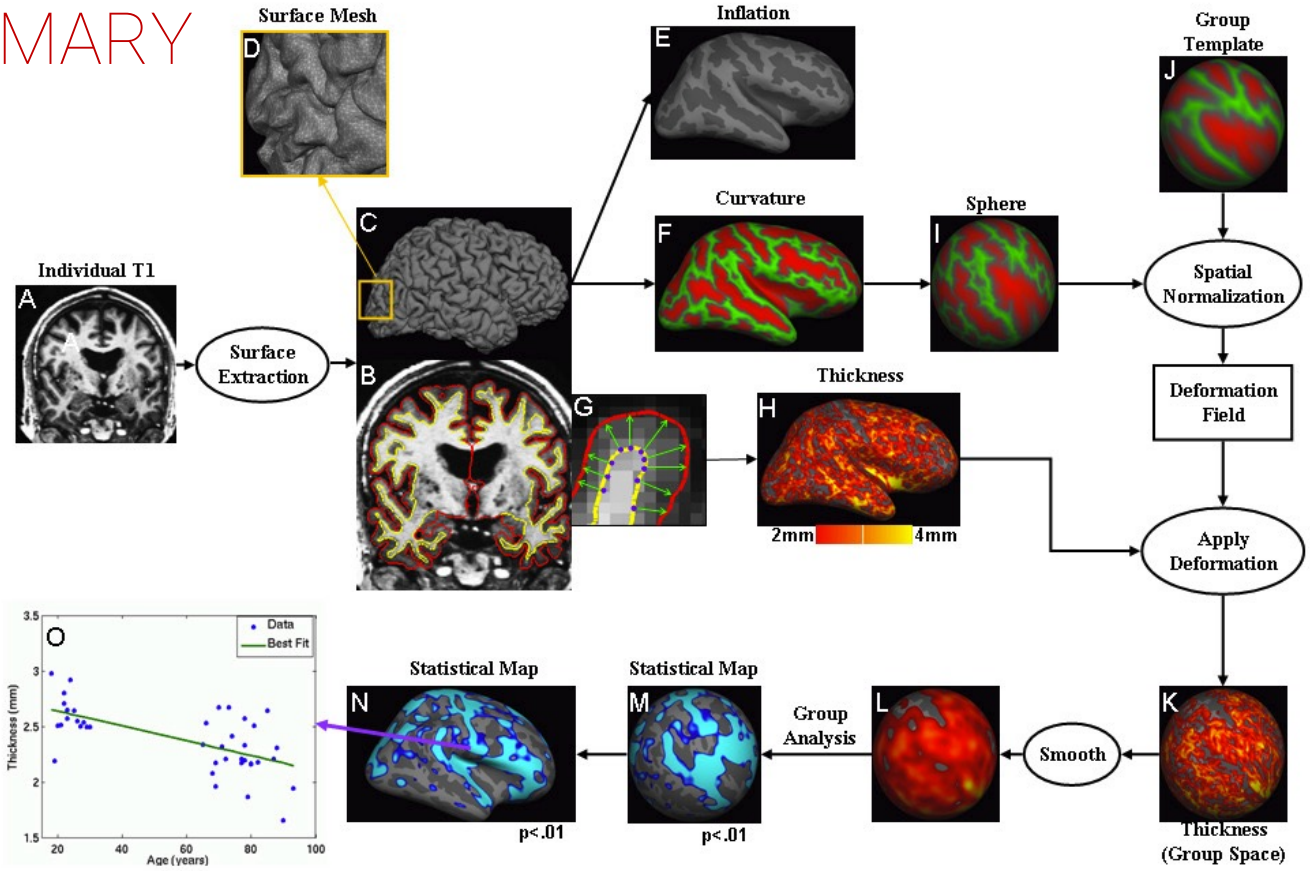
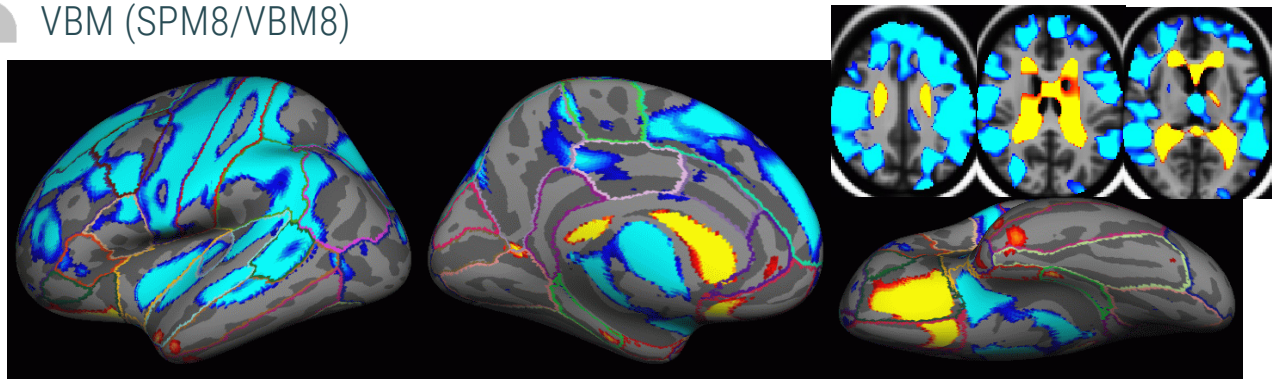
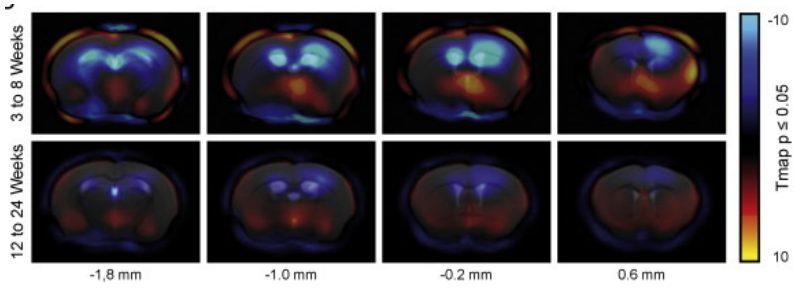


Figure from Greve et al Martinos, MGH

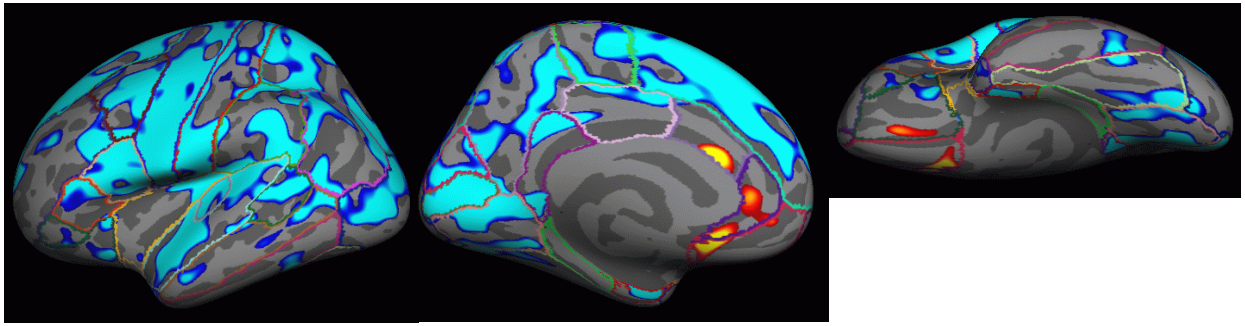
VBM VS SBM: AGE RELATED CHANGES

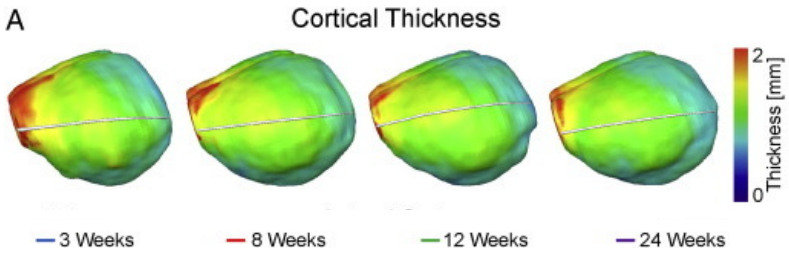
VBM (SPM8/VBM8)





Thickness (FreeSurfer 5.0)

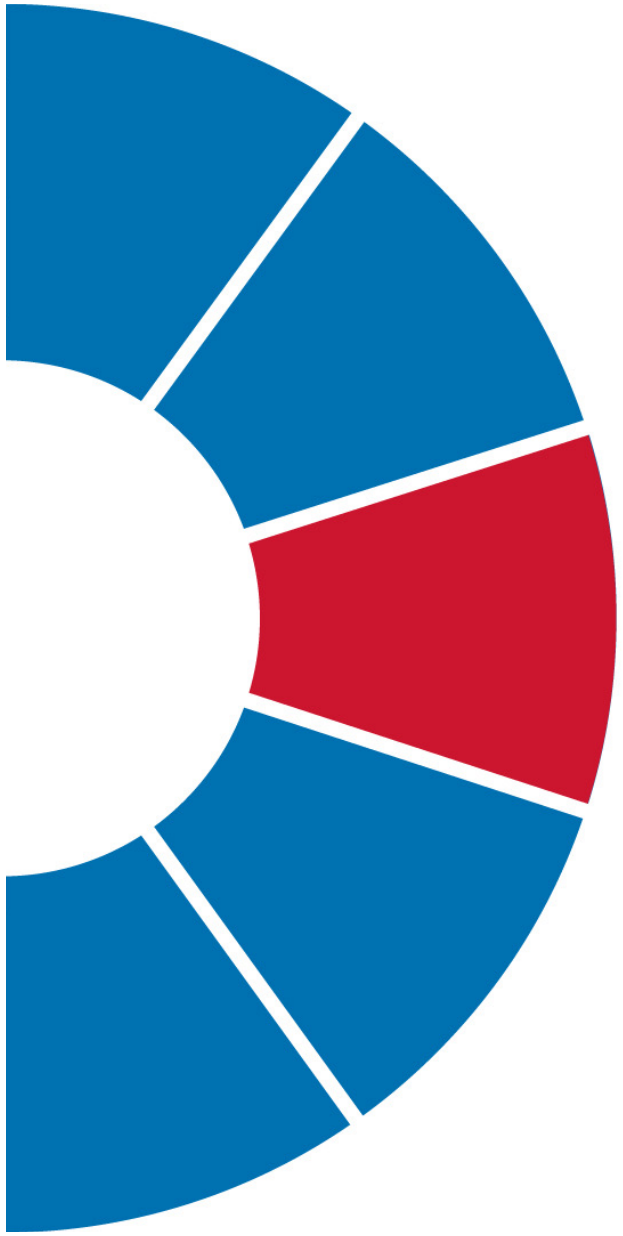




p<.01

Slide adapted from Martinos MGH course on VBM

Hammelrath et al, Neuroimage, 2016.



CONCLUSIONS

COMPARISON[1]

VBM

- Volume = Jacobian X Segmentation
- Strengths
  - GM, WM, CSF, cortical and subcortical
  - Easy to use
- Weaknesses
  - Sensitive to registration and segmentation errors
  - Segmentation is atlas-dependent

SBM

- Thickness, gyration, etc
- Strengths
  - Surface-based Normalization
  - Surface-based Smoothing
  - Surface extraction atlas-independent
- Weaknesses
  - No subcortical, White Matter, or CSF
  - More complicated to analyze

[1]Goto et al MR in Med Sciences 2022

TAKE HOME MESSAGES

Longitudinal changes

- Early development
- Aging
- Disease progression

Diagnosis / Phenotyping

- Cross-sectional group studies
- Single-subject VBM

Tools (VBM, SBM)

- SPM12
- FSL
- ANTS
- Freesurfer
- CAT
- CIVET
- SIENA

Goto et al, MR Med Sciences 2022, Zhou et al Nature Comm. Biology 2022, Antonopoulos ARXIV, 2023

FURTHER INFO

- References & materials
  - Thanks to Y. Aleman Gomez
  - Support slides from Martinos MGH
  - Ashburner & Friston. VBM – the Methods. Neuroimage. 2000
  - Good et al. Neuroimage. 2004
  - http://www.fil.ion.ucl.ac.uk/spm/
  - http://en.wikibooks.org/wiki/SPM
  - http://www.mrc-cbu.cam.ac.uk/Imaging/Common/spm.shtml
  - http://en.wikibooks.org/wiki/SPM-VBM

THANK YOU FOR YOUR ATTENTION

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