

Quantifying the variation of sulcal patterns in extant human endocasts: a probabilistic approach

Edwin de Jager¹

Under supervision and with the collaboration of:

Albert van Schoor¹, Amélie Beaudet^{1,2}, Anna Oettlé^{1,3}, Caroline Fonta⁴, Jakobus Hoffman⁵, Laurent Risser⁶, Muriel Mescam⁴

¹ Department of Anatomy, University of Pretoria, South Africa

² School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand, Johannesburg, South Africa

³ Department of Anatomy and Histology, Sefako Makgatho Health Sciences University

⁴ Centre de Recherche Cerveau & Cognition – UMR5549

⁵ South African Nuclear Energy Corporation, Pelindaba, South Africa

⁶ Institute de mathématiques de Toulouse



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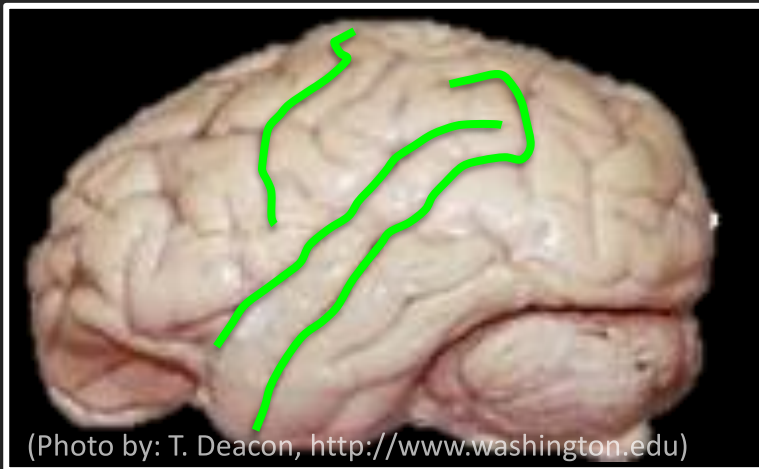
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The Brain

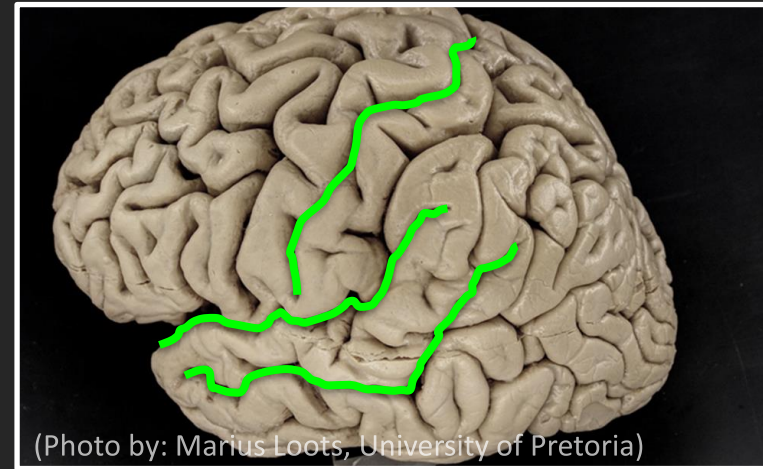
- Great ape species share same basic sulcal pattern
- Differentiable sulcal patterns in great apes and humans:
 - Lateral prefrontal cortex
 - Dorsal lateral occipital cortex

(Connolly, 1950; Falk *et al.*, 2018)



(Photo by: T. Deacon, <http://www.washington.edu>)

Common Chimpanzee



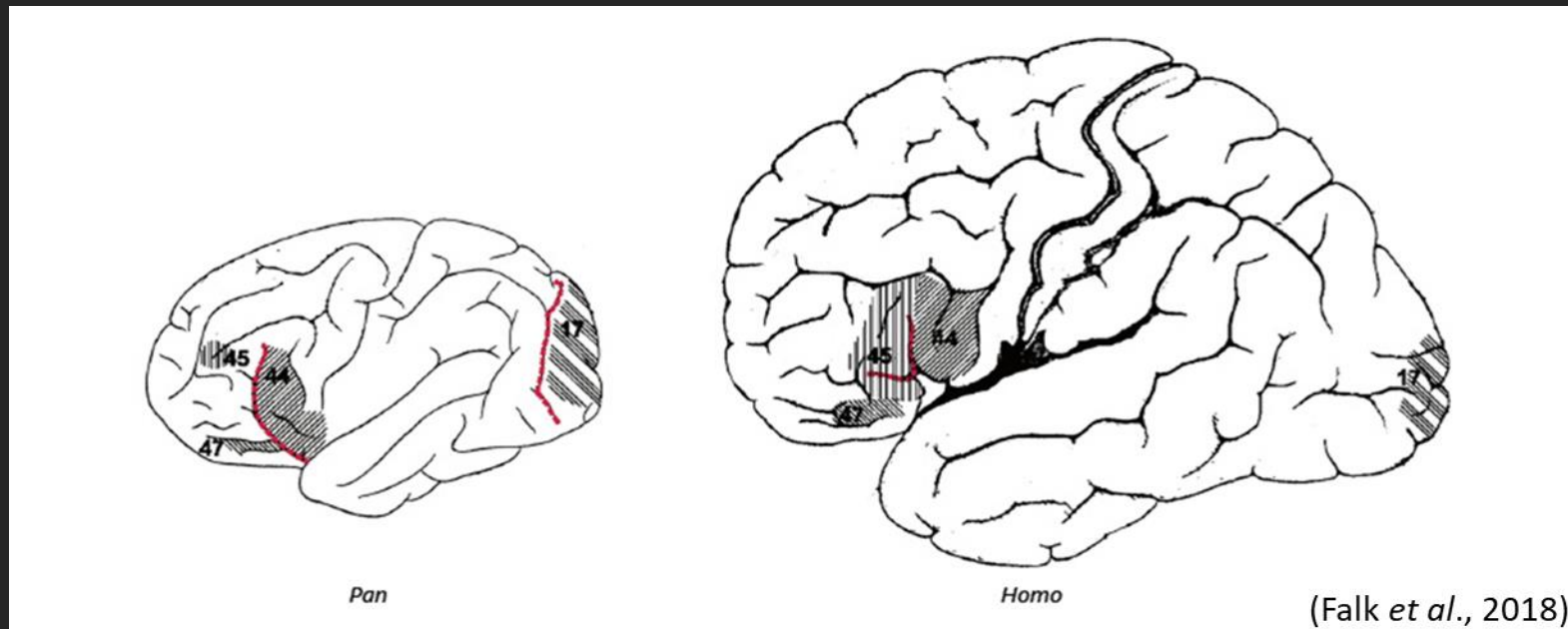
(Photo by: Marius Loots, University of Pretoria)

Human

The Brain

- Great ape species share same basic sulcal pattern
- Differentiable sulcal patterns in great apes and humans:
 - Lateral prefrontal cortex
 - Dorsal lateral occipital cortex

(Connolly, 1950; Falk *et al.*, 2018)

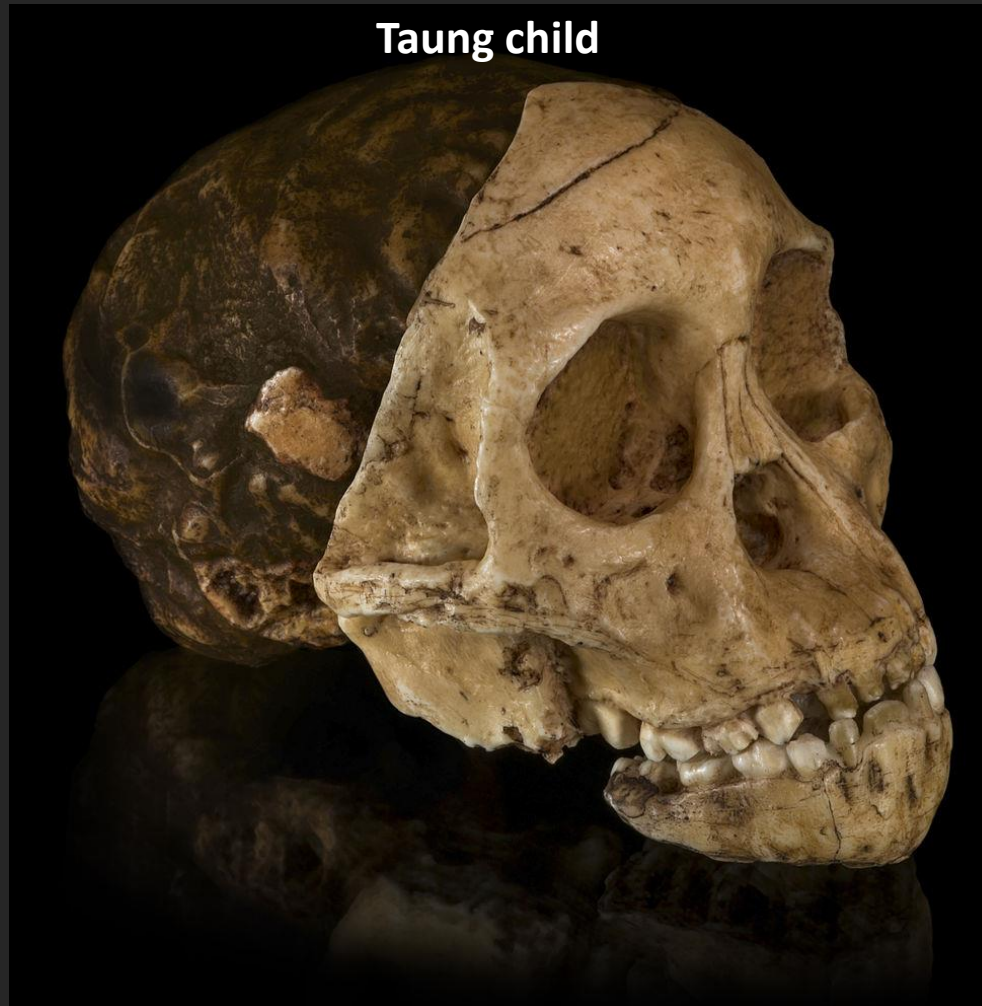




StW 573/"Little foot" (*Australopithecus prometheus*), Sterkfontein caves (South Africa), $\pm 3,67\text{mya}$

Human brain evolution: a long way we've come

- Natural endocasts



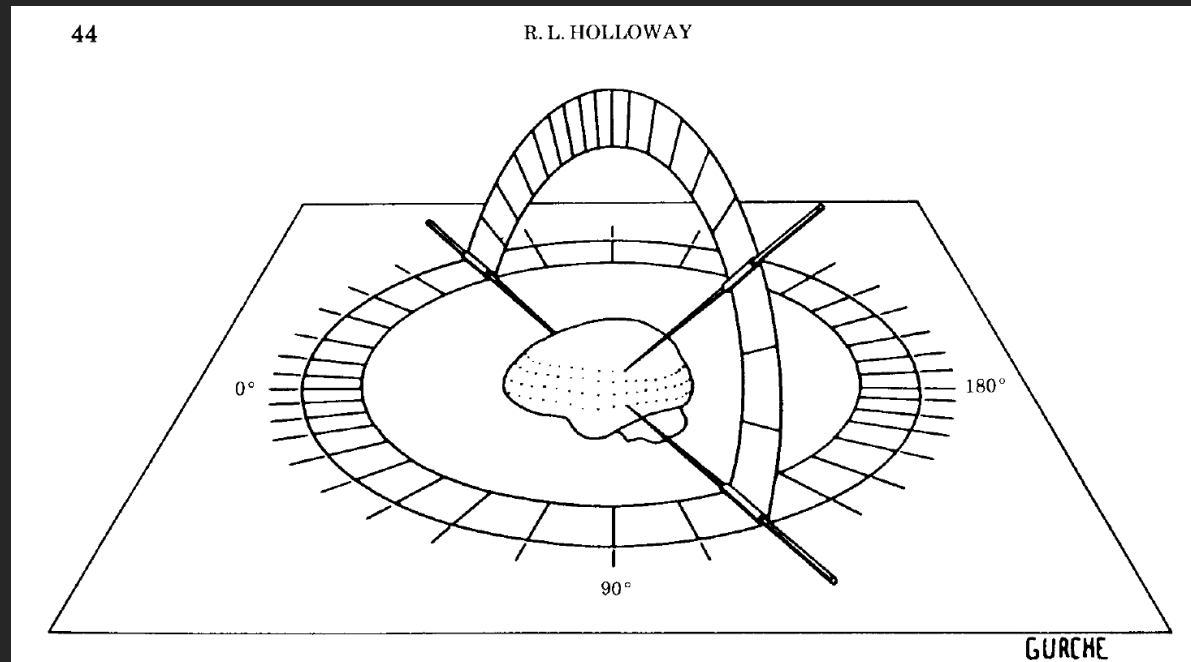
Human brain evolution: a long way we've come

- Synthetic endocasts



Human brain evolution: a long way we've come

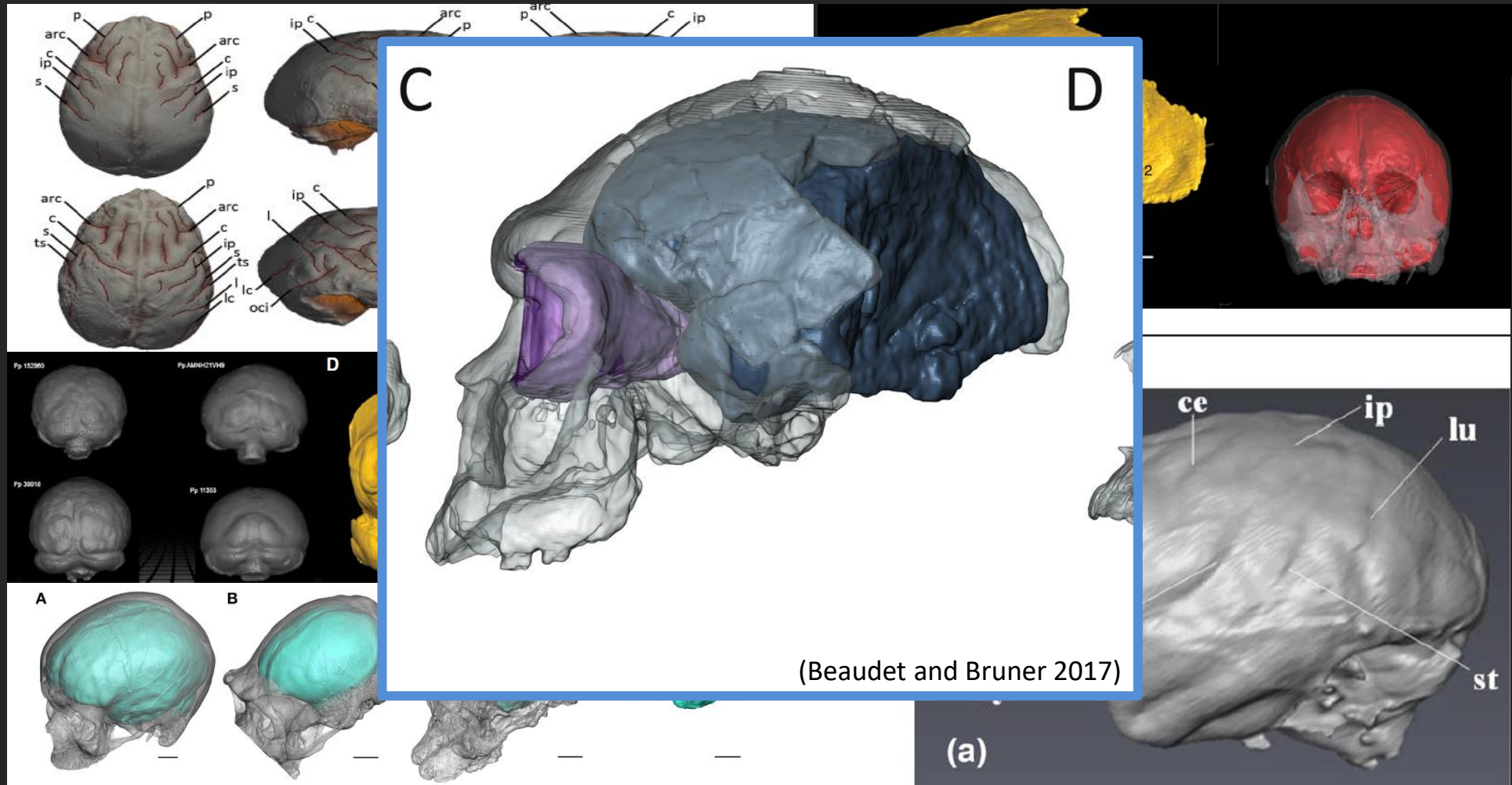
- Visual inspection of endocasts → high intra-observer error
- Notable historical debate: lunate sulcus (Falk, 1980, 2009, 2014; Holloway, 1981; Holloway *et al.*, 2004)



Schematic drawing of stereoplotting apparatus used to locate coordinates of the lunate sulcus on five chimpanzee brain casts – (Holloway, 1981)

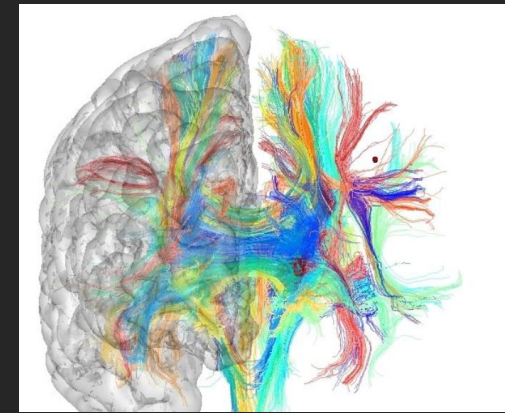
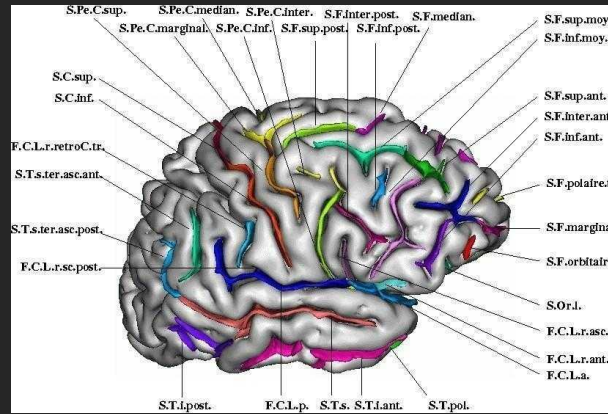
Human brain evolution: a long way we've come

- Modern medical imaging modalities



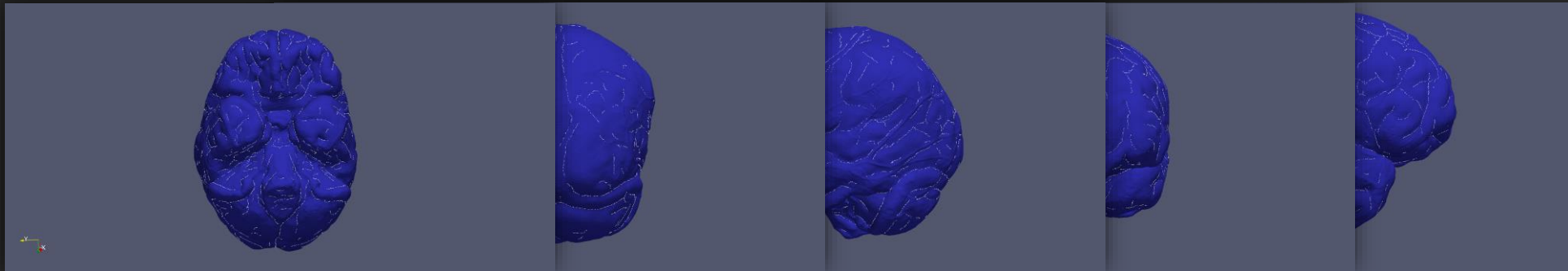
Application of 3D imaging techniques to endocasts

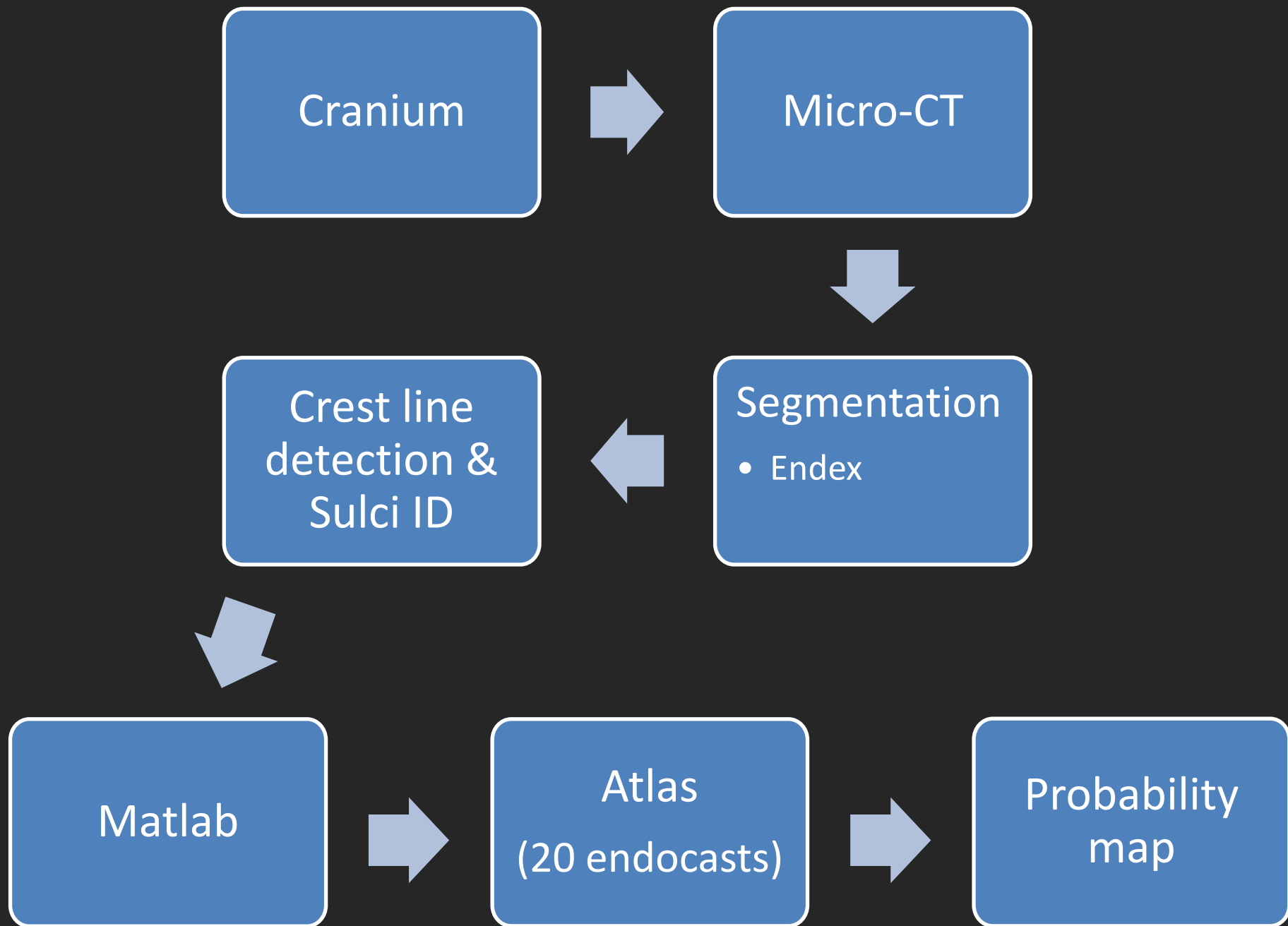
- Immense intervariability in human brains
 - Major challenge during keyhole surgery (Ribas, 2010)
- Population-specific brain atlases (Toga and Thomson, 2001)
 - Density-based approaches
 - Label-based approaches
 - i.e. Statistical/probabilistic anatomy maps (SPAM)
 - Deformation-based approaches



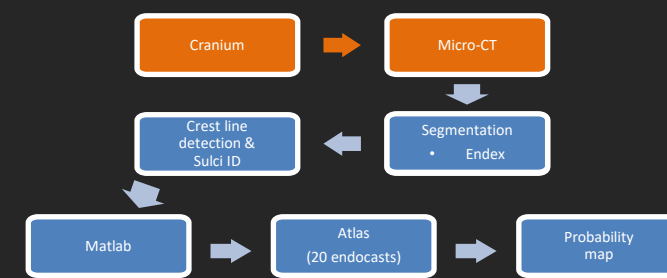
Aim

- Establish an atlas documenting the variation in the extant human endocranial sulcal pattern for use as a comparative platform for studying the fossil record





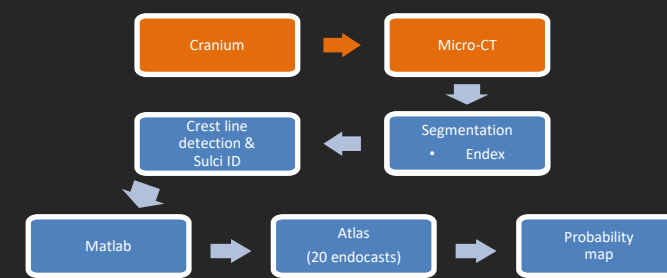
Materials and Methods



- Over 90 extant human dry crania
- Pretoria Bone Collection (University of Pretoria; L'Abbé *et al.*, 2005)
- Nikon XTH 225 ST micro-focus X-ray tomography system
 - MIXRAD facility (South African Nuclear Corporation (Necsa), Pelindaba)
 - Spatial resolution range: 94 to 123 μm



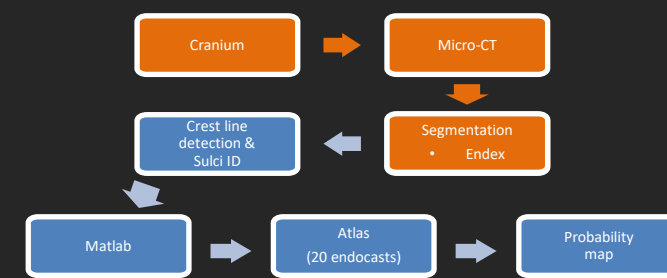
Materials and Methods



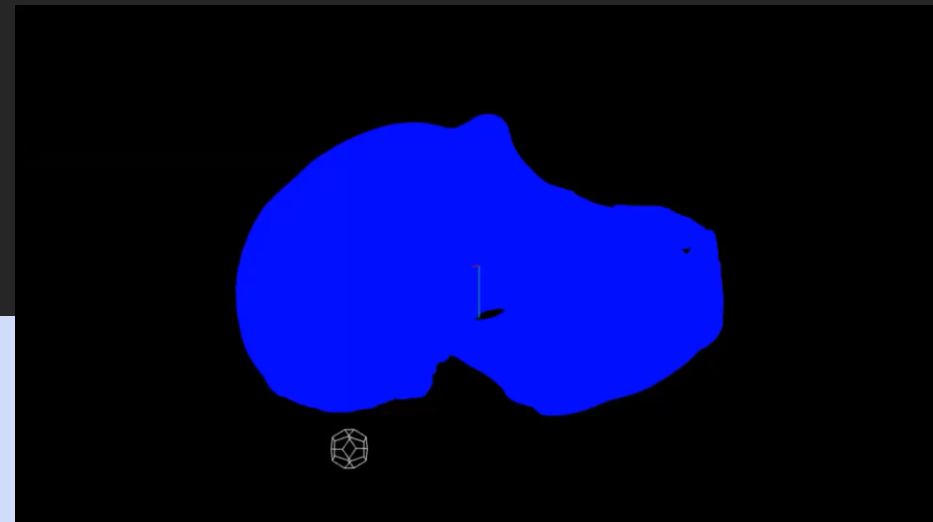
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 - MIXRAD facility (South African Nuclear Corporation (Necsa), Pelindaba)
 - Spatial resolution range: 94 to 123 μm
- High resolution, Non-destructive**



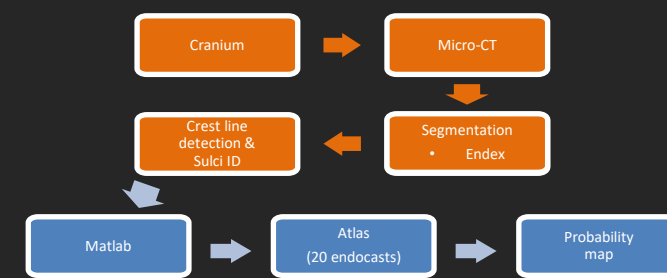
Materials and Methods



- Automatic segmentation
- Endcast Extraction project (ENDEX)
 - 2009 - 2012
 - Gilles Gesquière¹ & Gérard Subsol²
 - ¹ Laboratoire LIRIS – UMR5205
 - ² LIRMM/University Montpellier
 - Open source
 - Subsol *et al.*, 2010



Materials and Methods

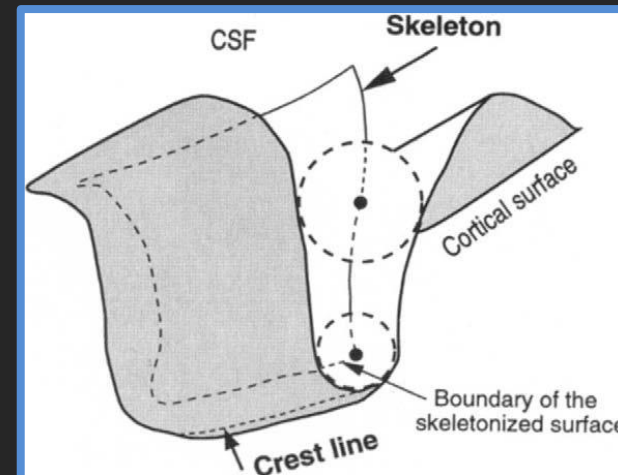
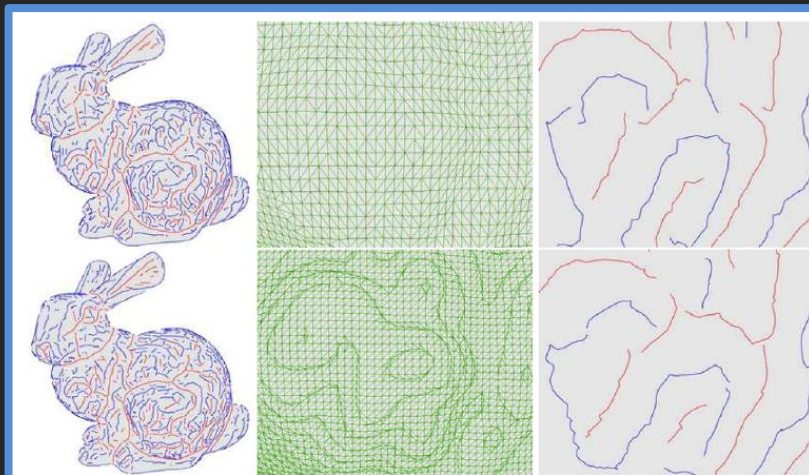


- Rapid, robust detection of crest lines on mesh

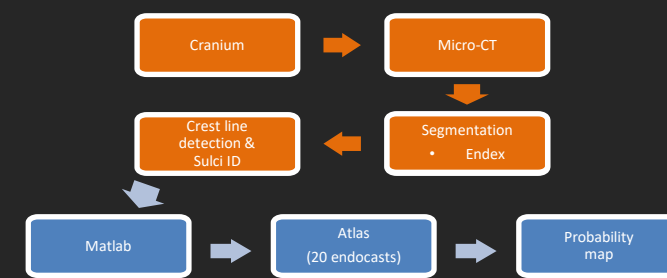
(Subsol, 1995, 1998; Yoshizawa *et al.*, 2008)

- Automatic sulci detection algorithm

- Sulci → variation points on surface of triangulated mesh
- Points detected via geometry-based method
- Crest lines computed on the surface
- Open source:
 - <http://www.riken.jp/briect/Yoshizawa/Research/Crest.html>



Materials and Methods

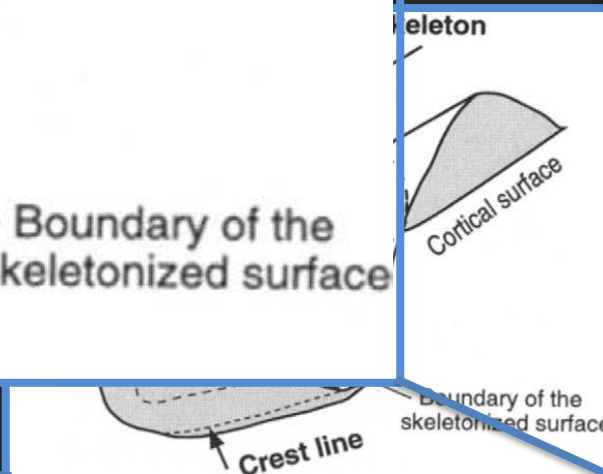
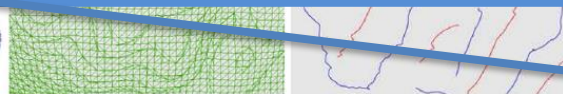
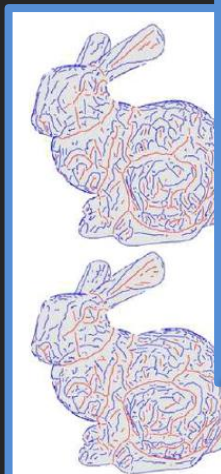
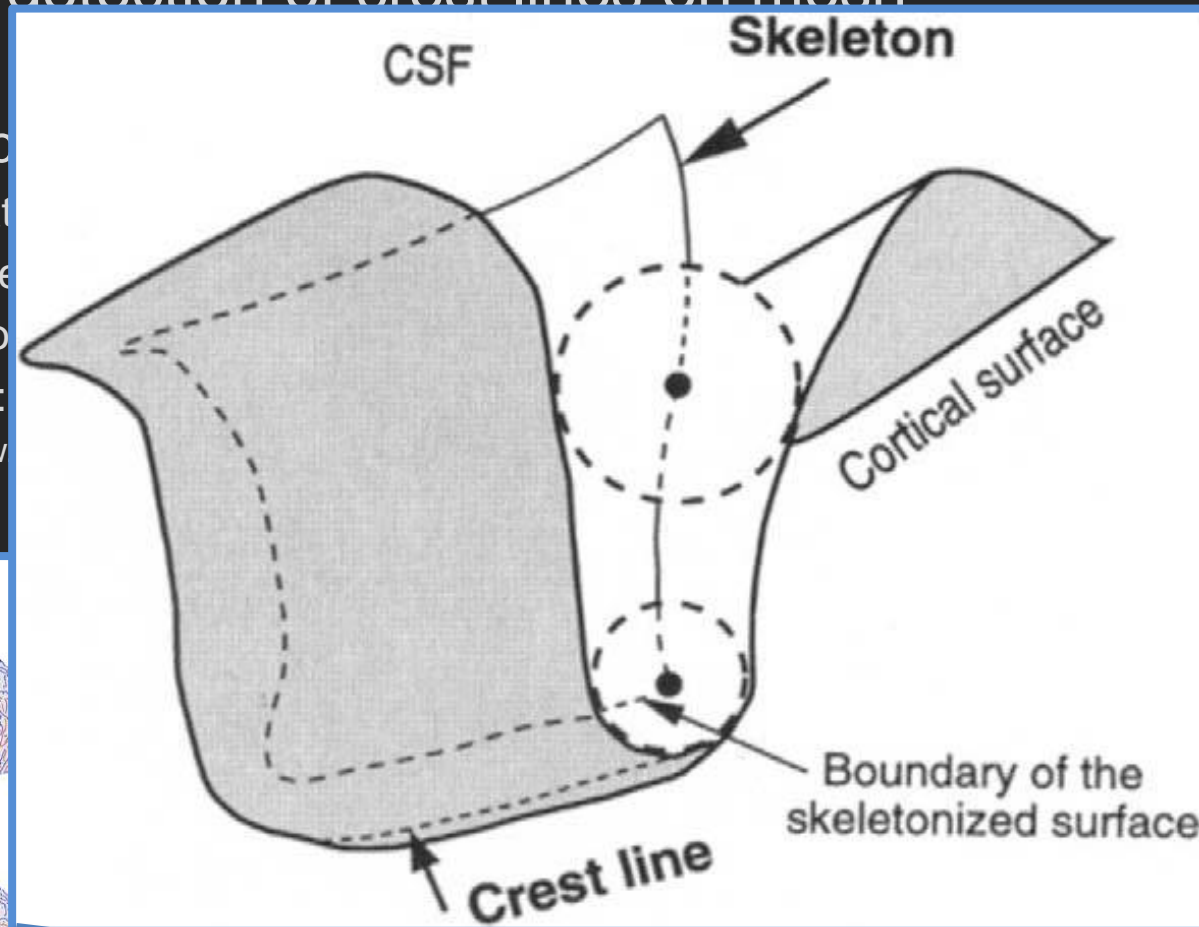


- Rapid, robust detection of crest lines on mesh

(Subsol, 1995, 1998;

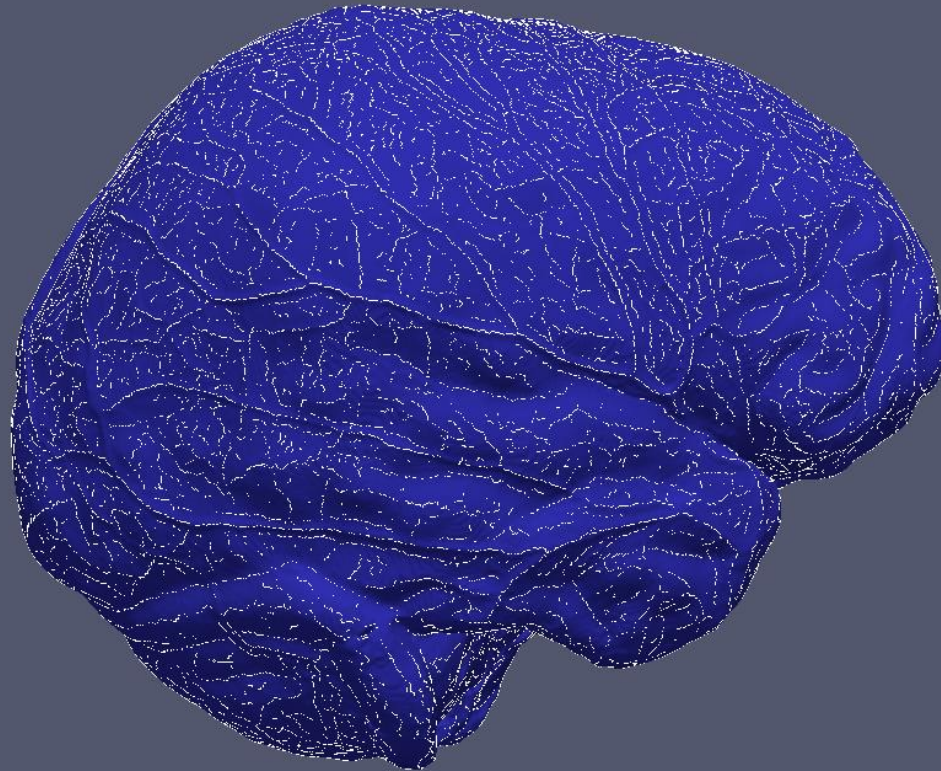
- Automatic sulci

- Sulci → variat
- Points detecte
- Crest lines co
- Open source:
 - <http://www>



Materials and Methods

FULL



 ParaView

 Kitware

 Sandia National Laboratories

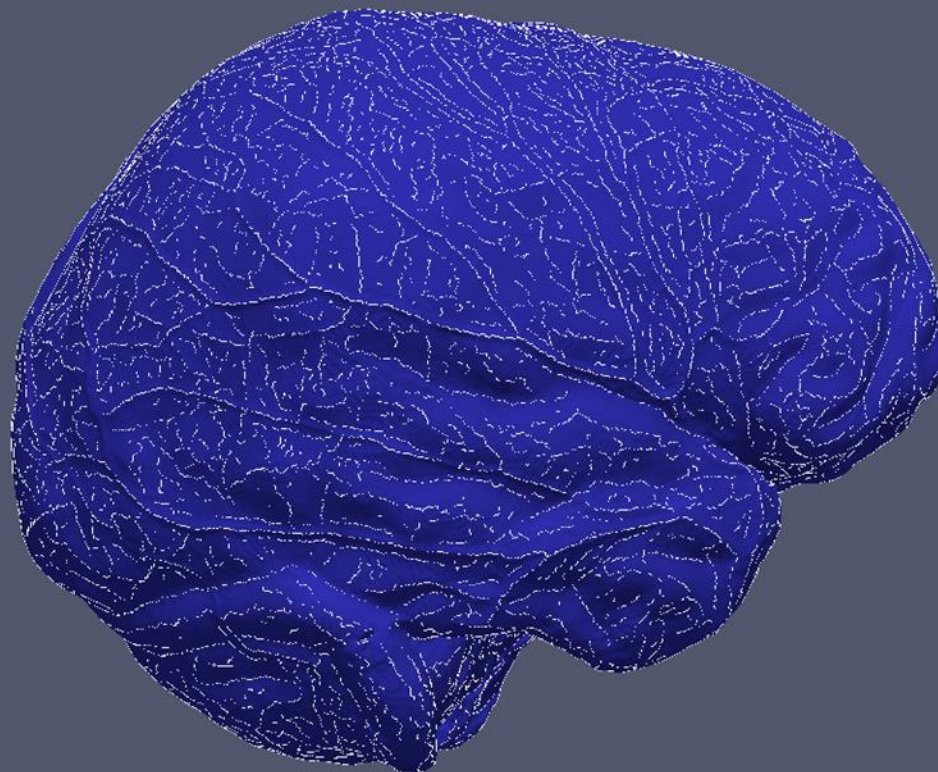
 Los Alamos National Laboratory

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Materials and Methods

X 1



 ParaView

 Kitware

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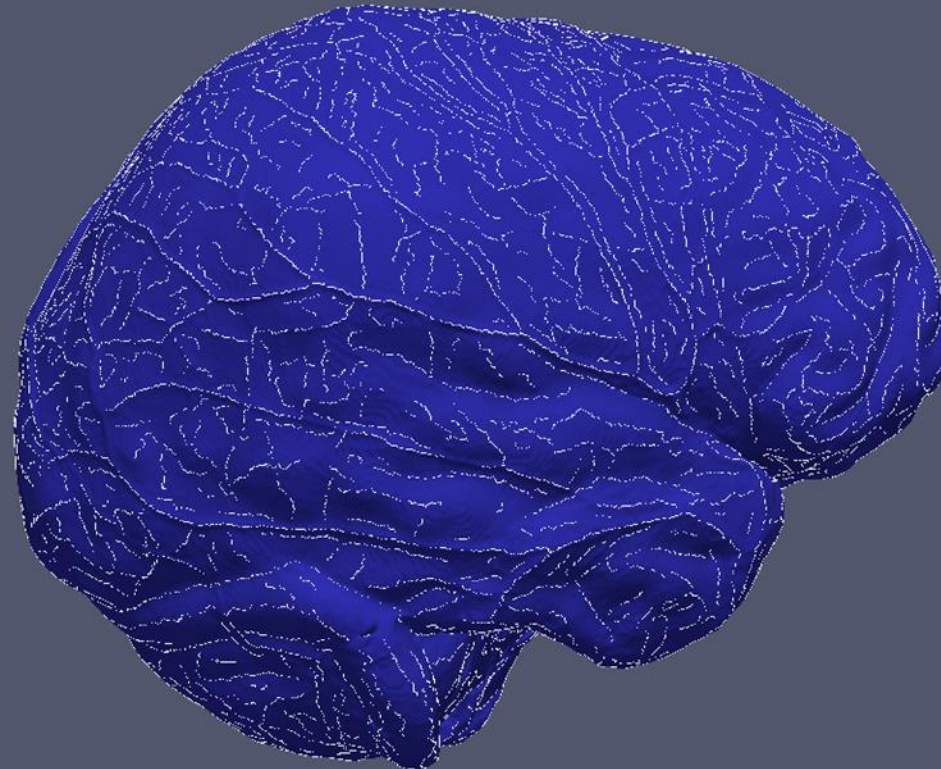
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NATIONAL LABORATORY
EST. 1945

 ASC

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Materials and Methods

X 3



 ParaView

 Kitware

 Sandia
National
Laboratories

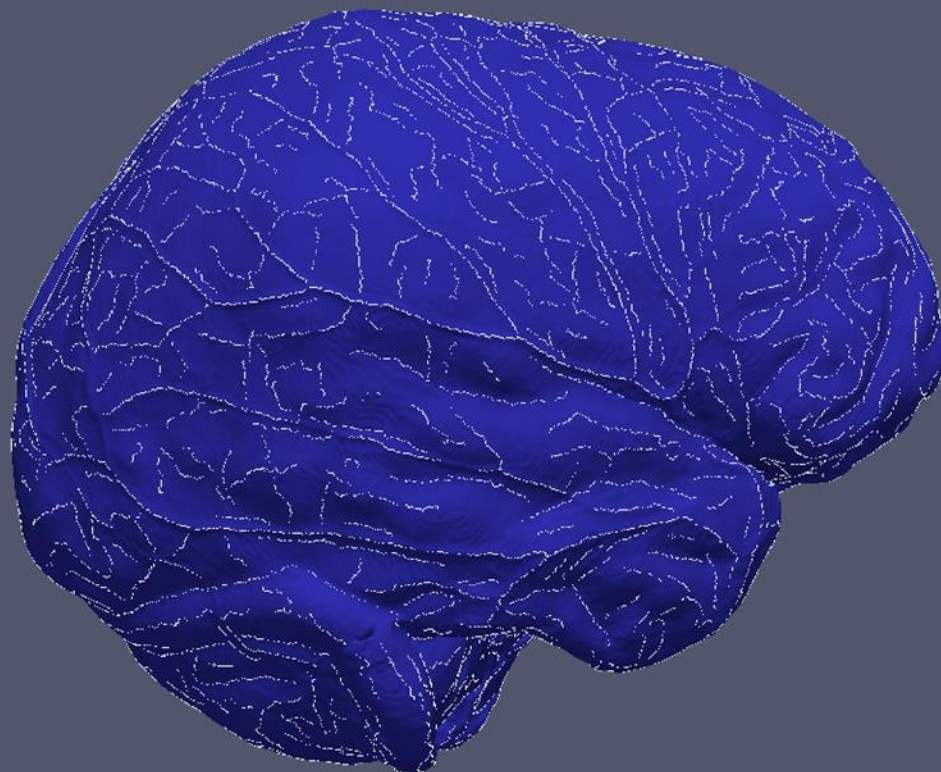
 Los Alamos
NATIONAL LABORATORY
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Materials and Methods

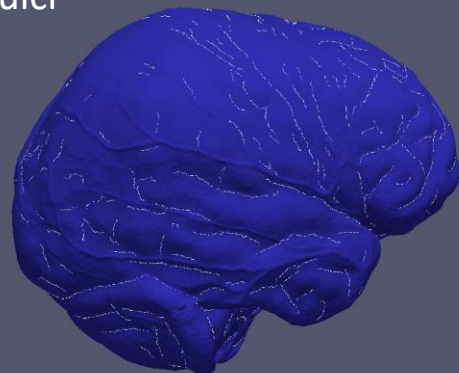
X 5



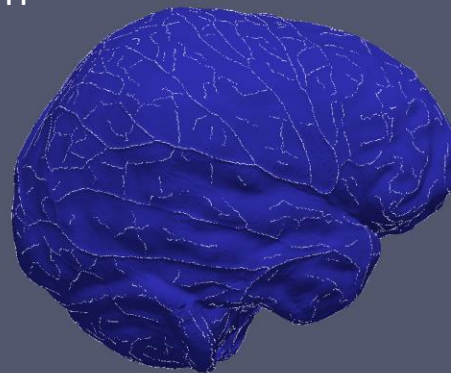
Materials and Methods

X 5

Ravines → Sulci



Ridges → Gyri



 ParaView

 Kitware

 Sandia National Laboratories

 Los Alamos National Laboratory

 ASC

 ARL

Materials and Methods

EXTERNAL MORPHOLOGY OF THE PRIMATE BRAIN

By

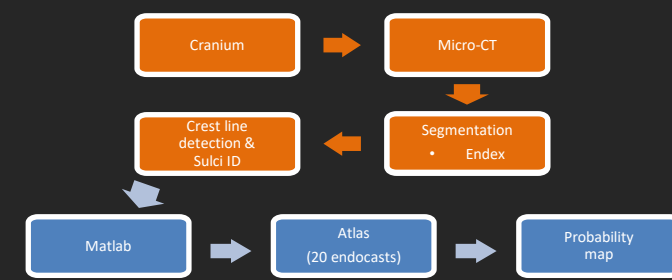
CORNELIUS J. CONNOLLY, PH. D.

*Professor of Physical Anthropology
Catholic University of America
Washington, D. C.*

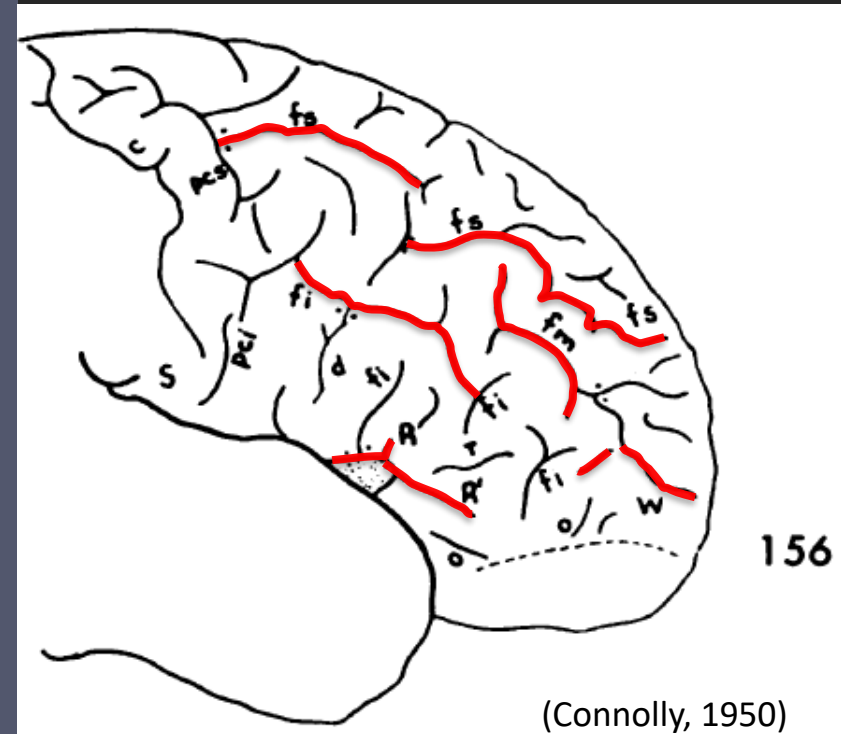
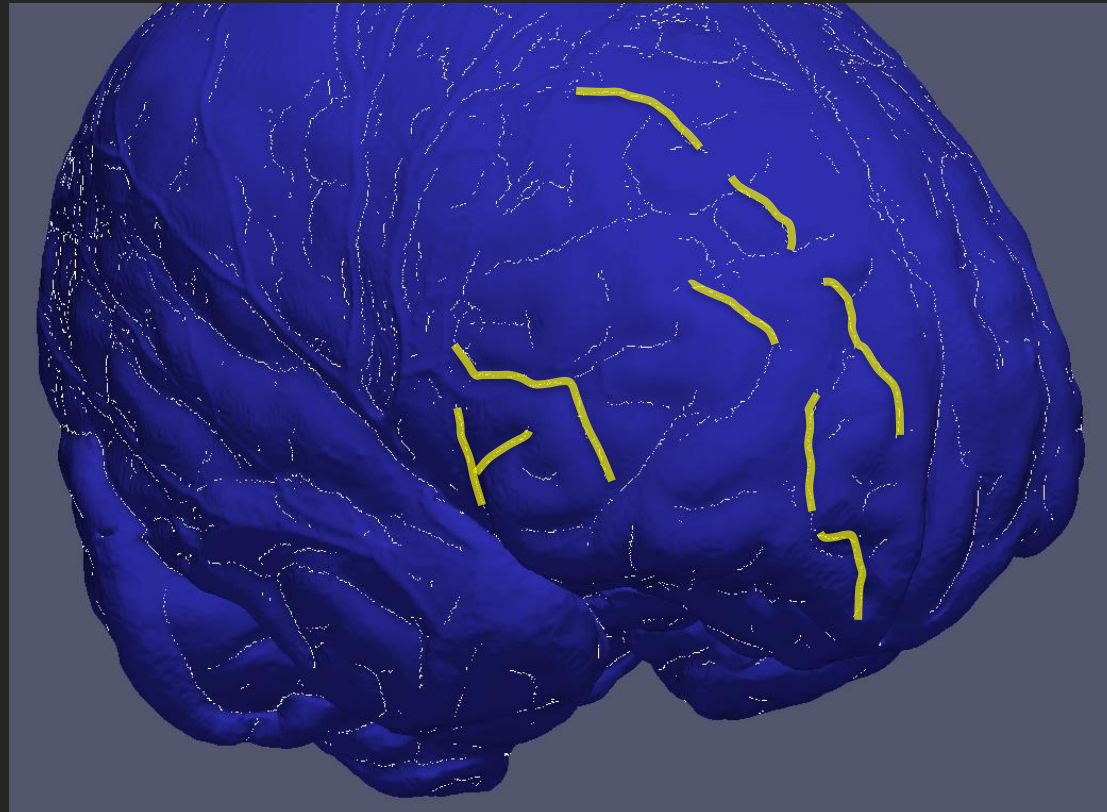
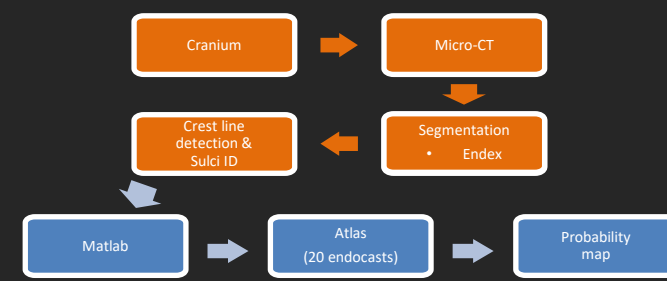
Atlas of the Cerebral Sulci

Michio Ono, Stefan Kubik and Chad D. Abernathey

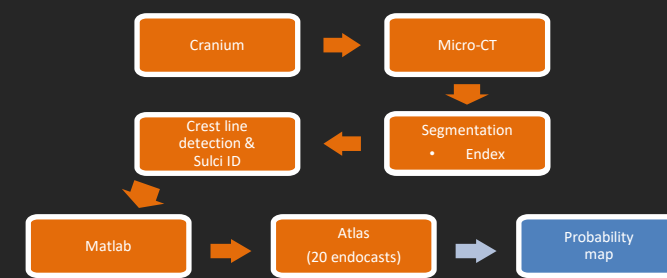
Foreword by M.G. Yaşargil



Materials and Methods



Materials and Methods

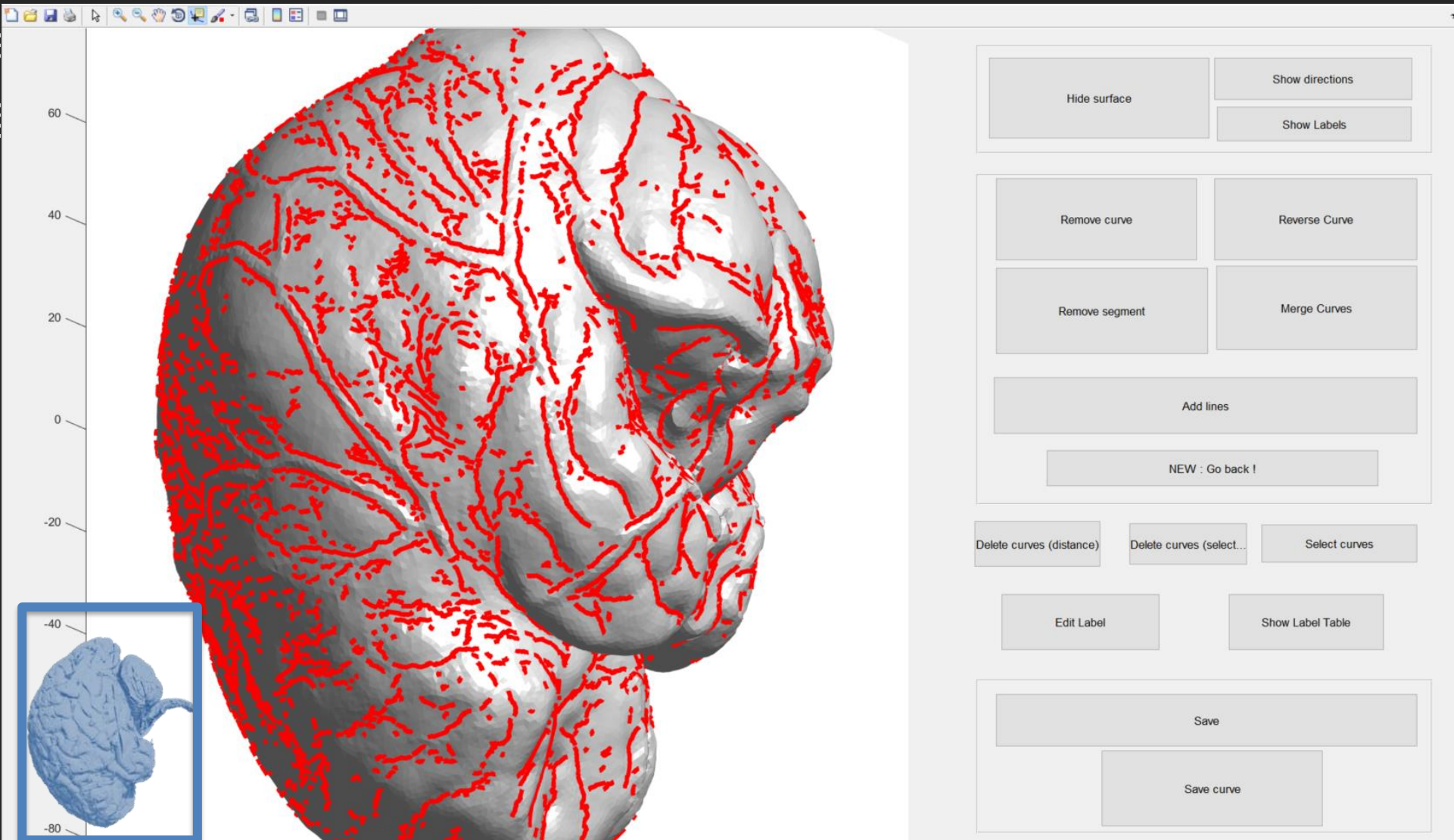


- Matlab R2013a (Mathworks)
- Manual identification & cleaning of unwanted artefacts
 - Refining identification process



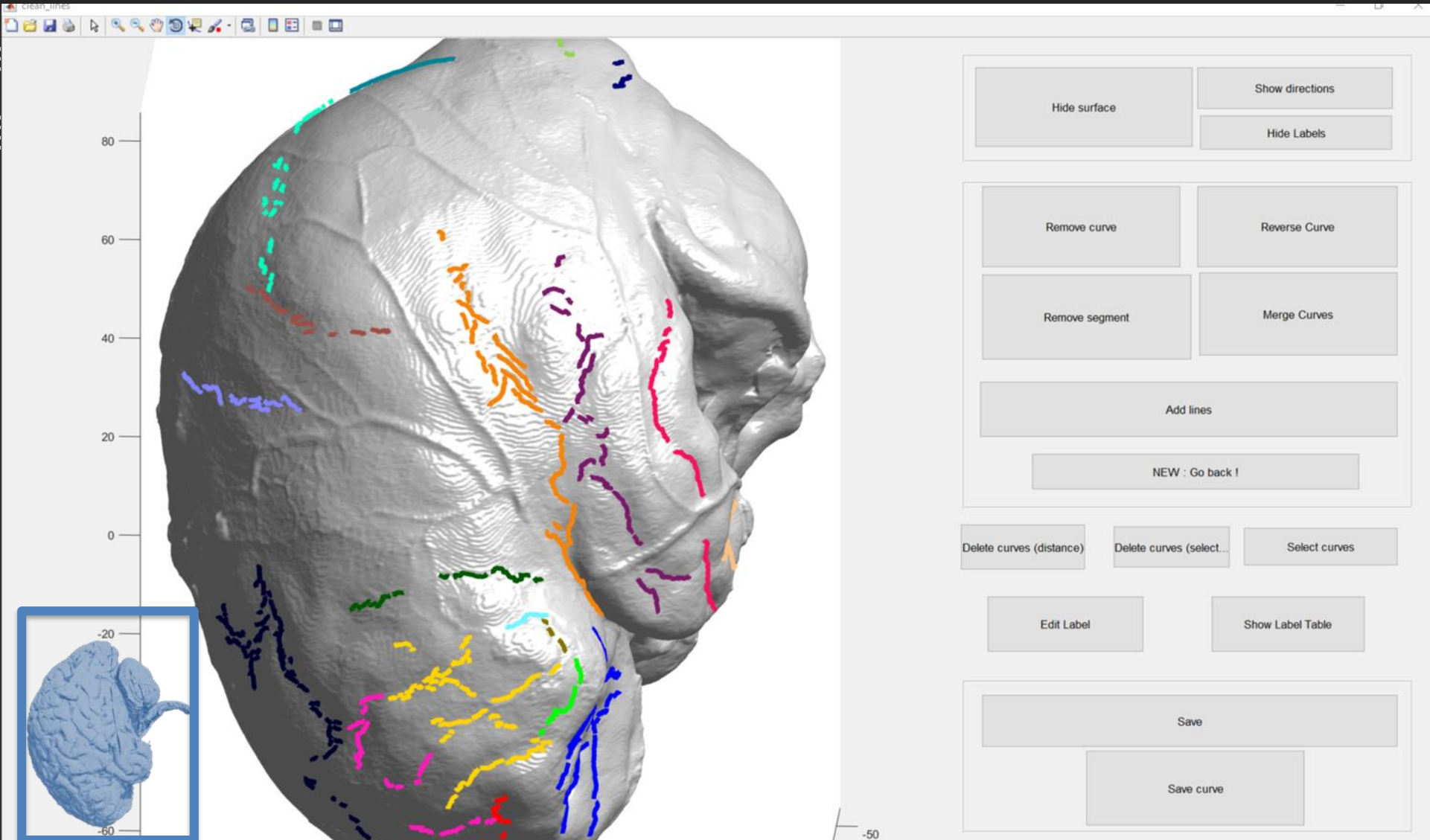
Materials and Methods

- Ma
- Ma



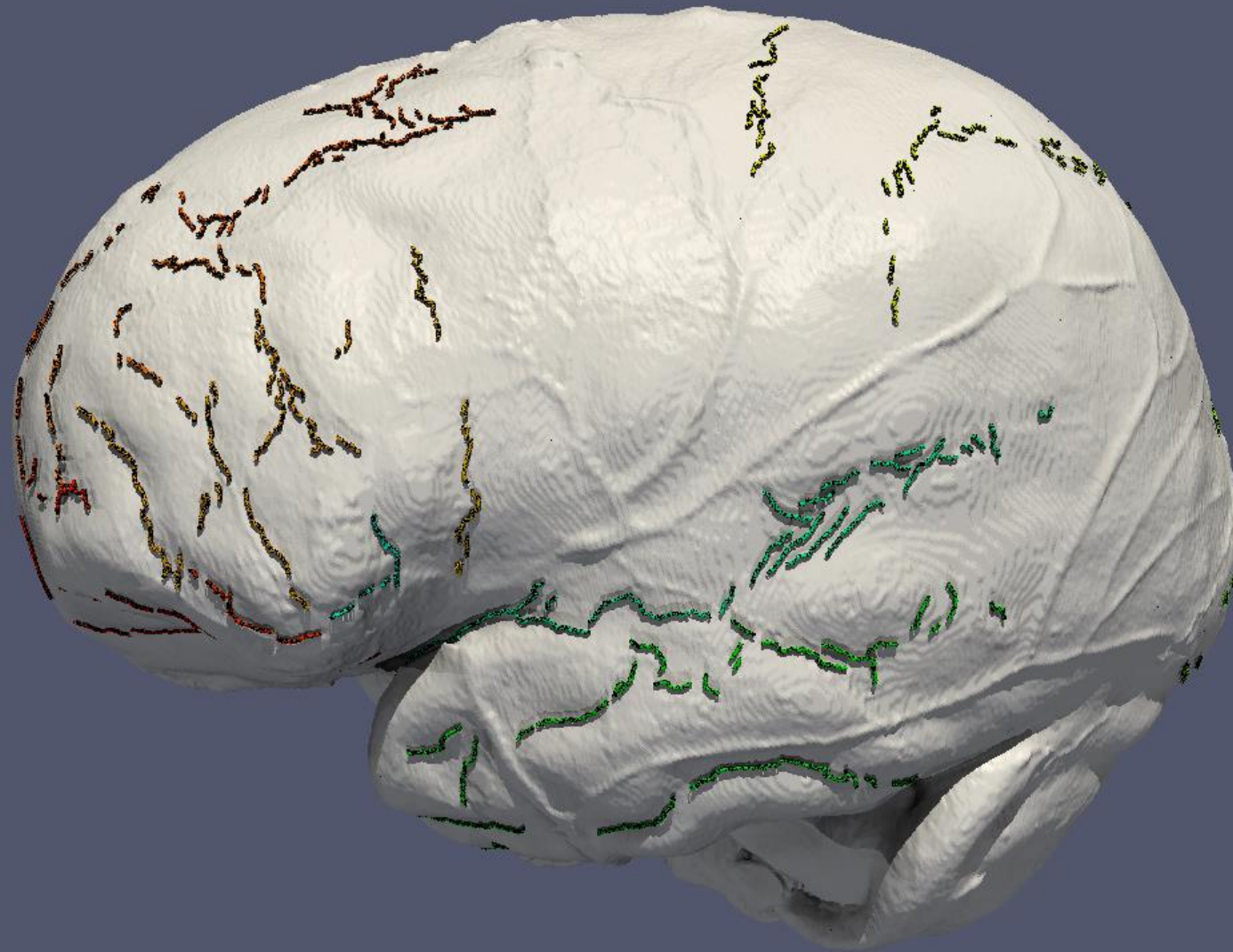
Materials and Methods

- Ma
- Ma



Atlas - Results

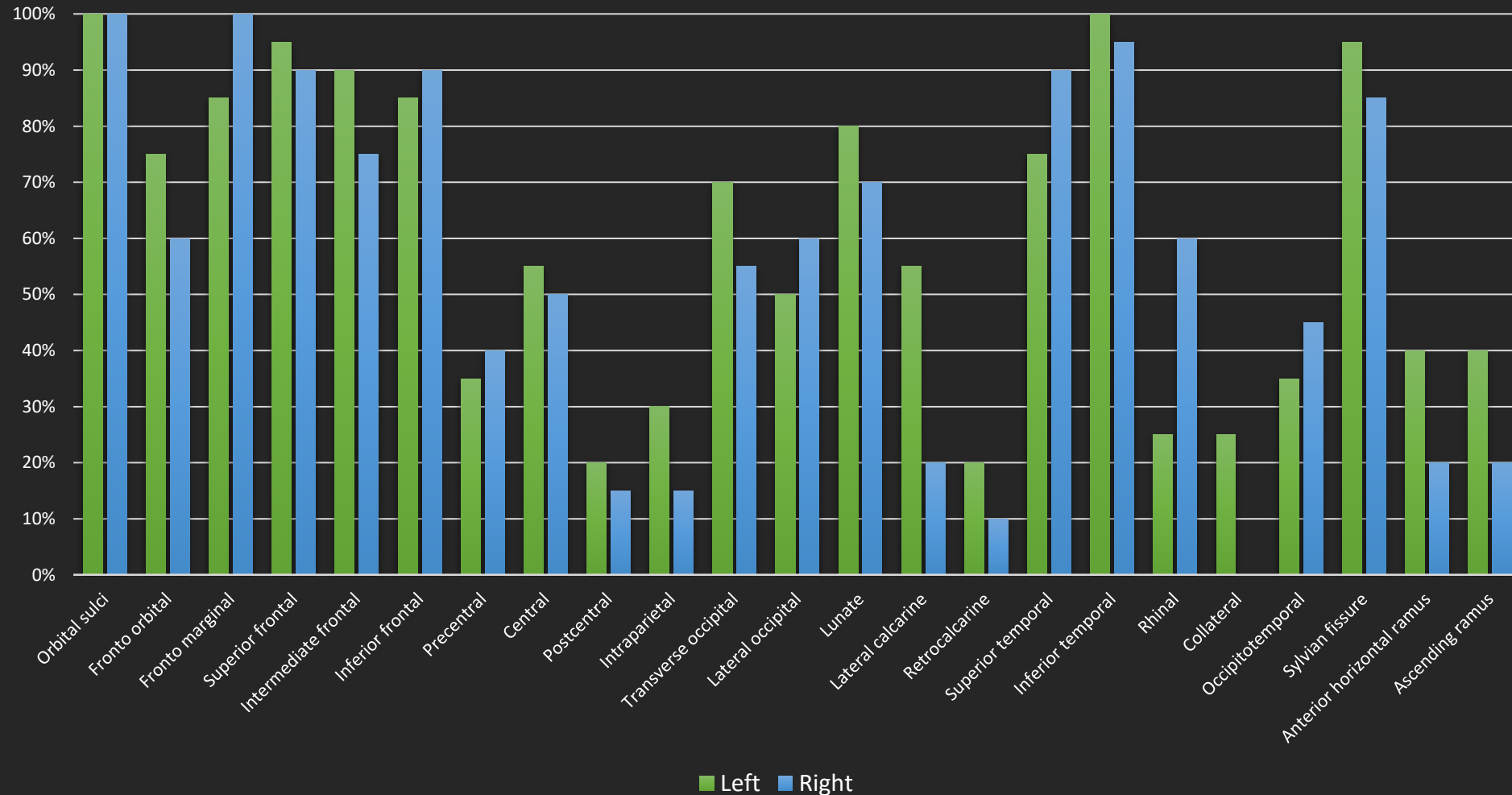
de Jager *et al.*, 2019 Sulcal pattern variability in extant human endocasts (provisionally accepted)



Atlas - Results

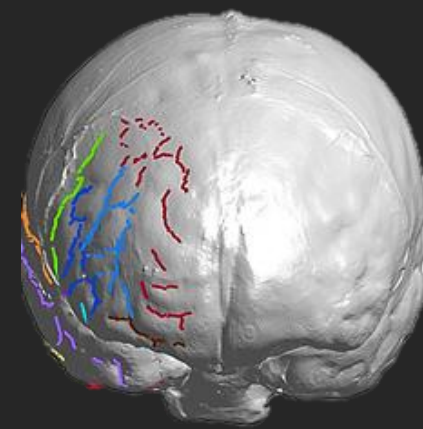
de Jager *et al.*, 2019 (provisionally accepted)

Results (20 endocasts)

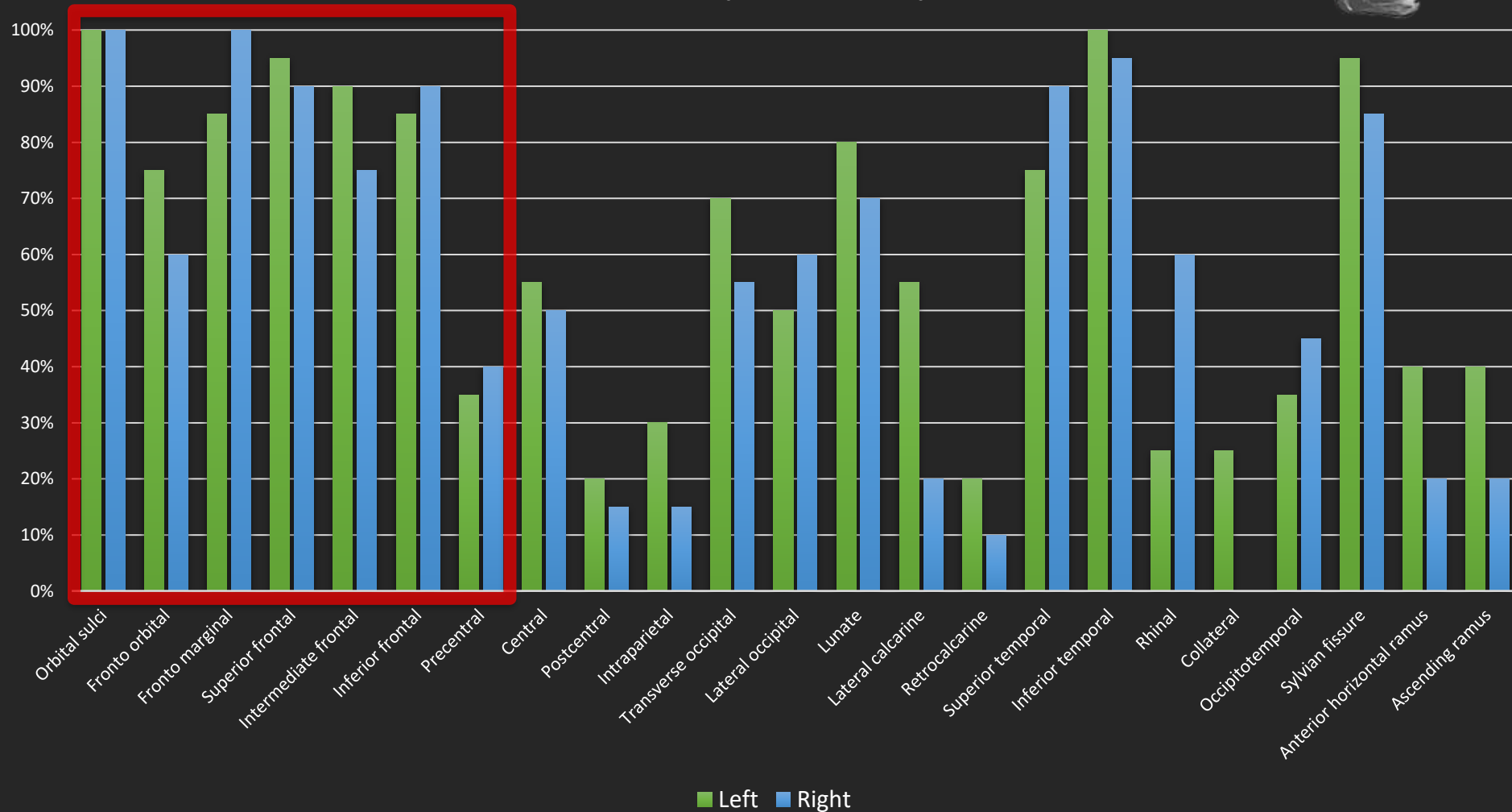


Atlas - Results

de Jager *et al.*, 2019 (provisionally accepted)

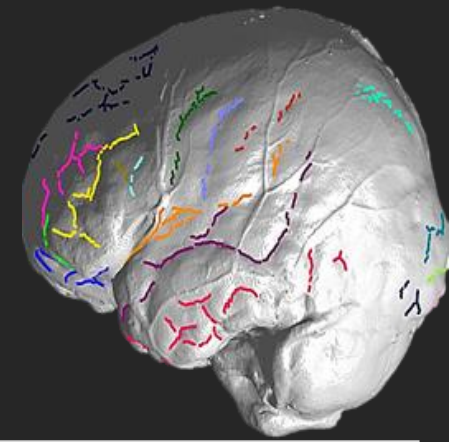


Results (20 endocasts)

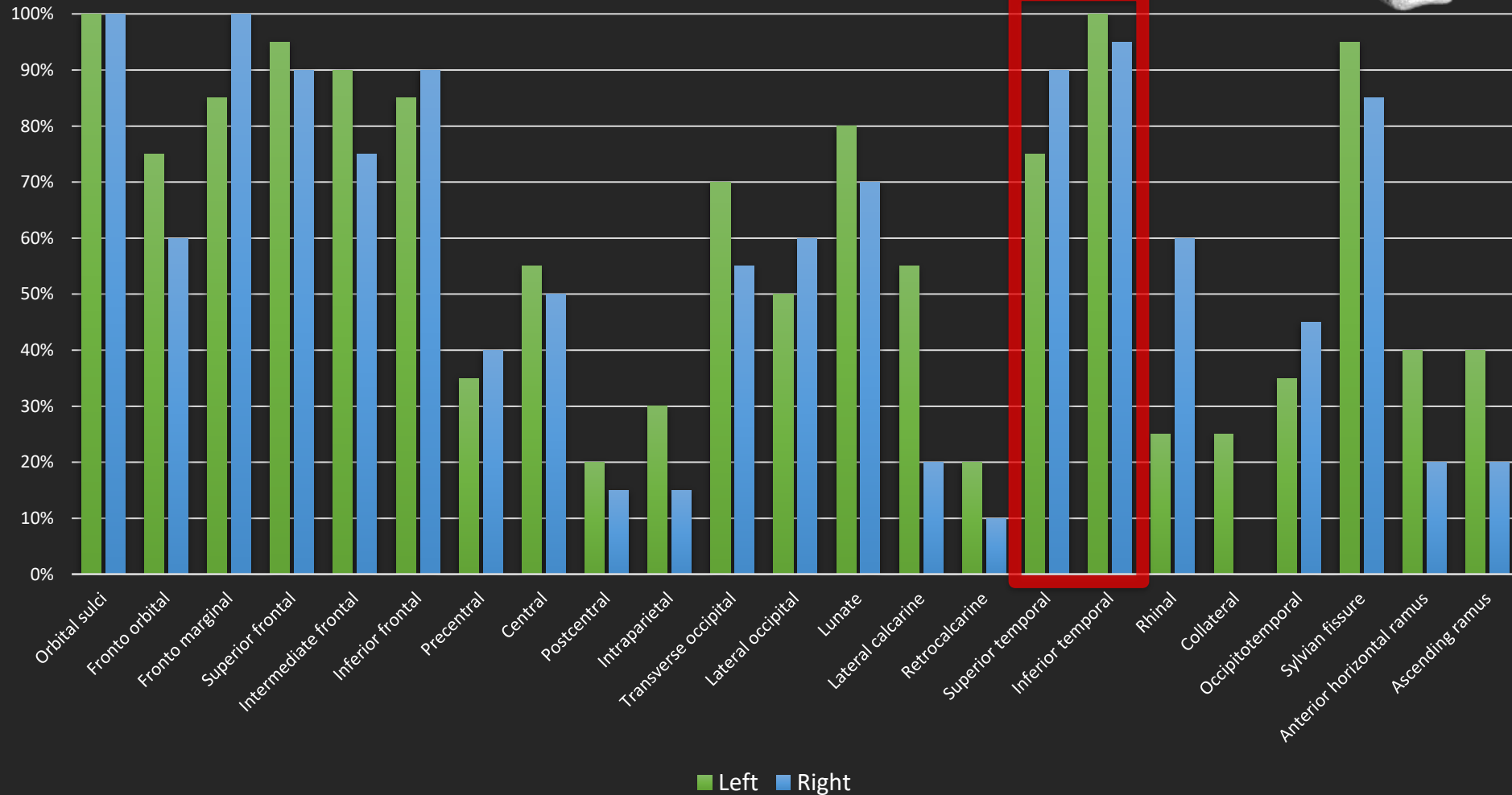


Atlas - Results

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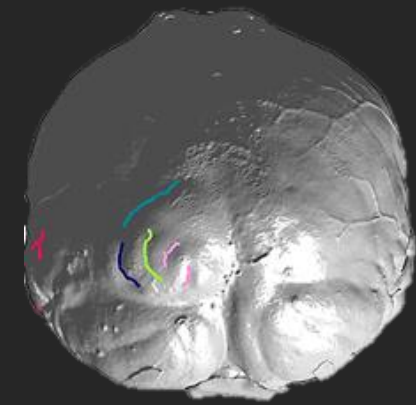


Results (20 endocasts)

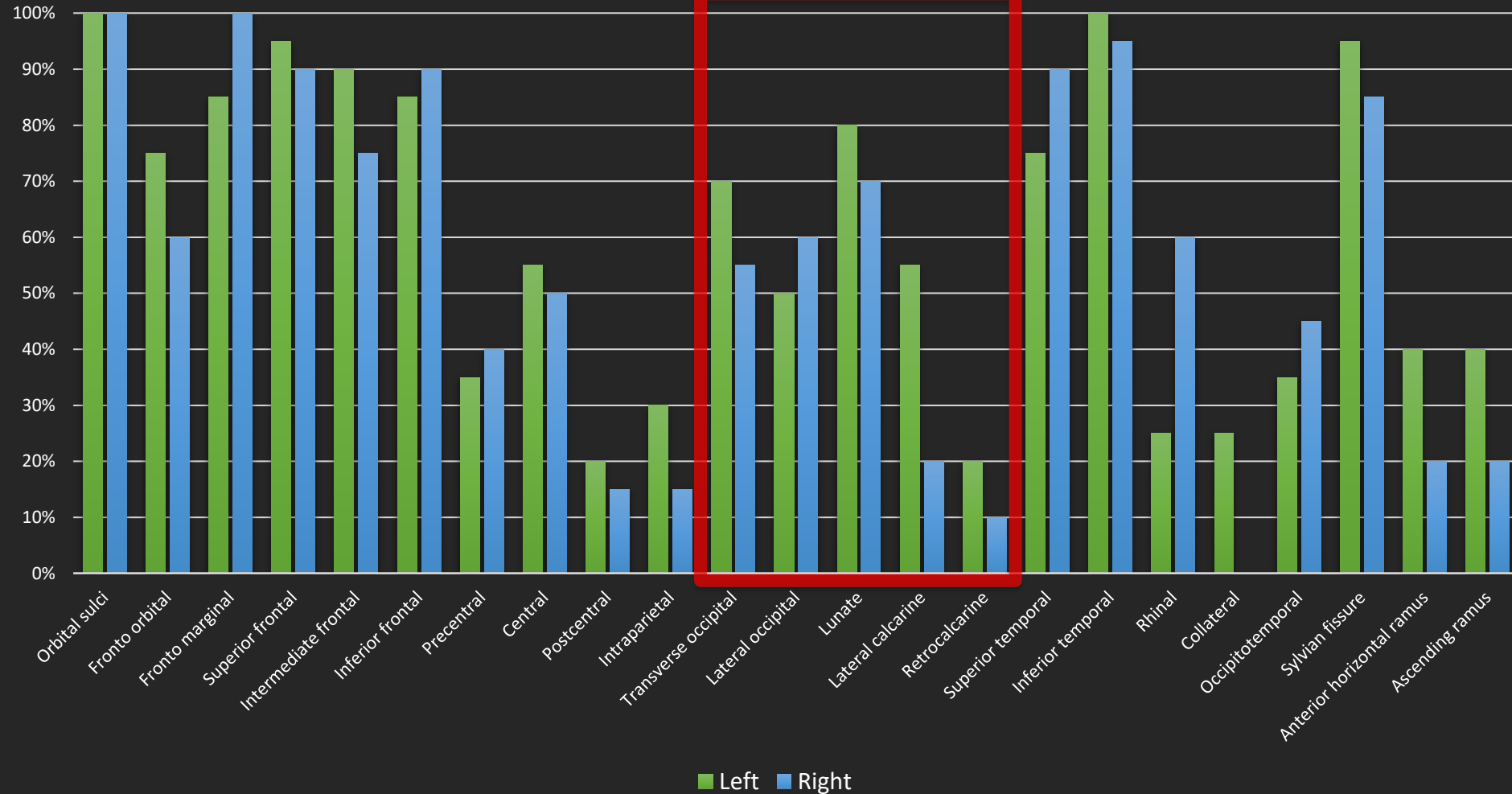


Atlas - Results

de Jager *et al.*, 2019 (provisionally accepted)

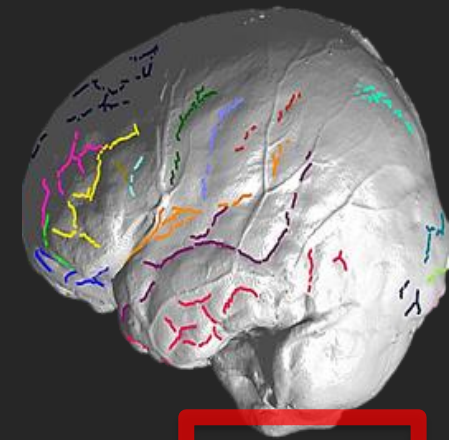


Results (20 endocasts)

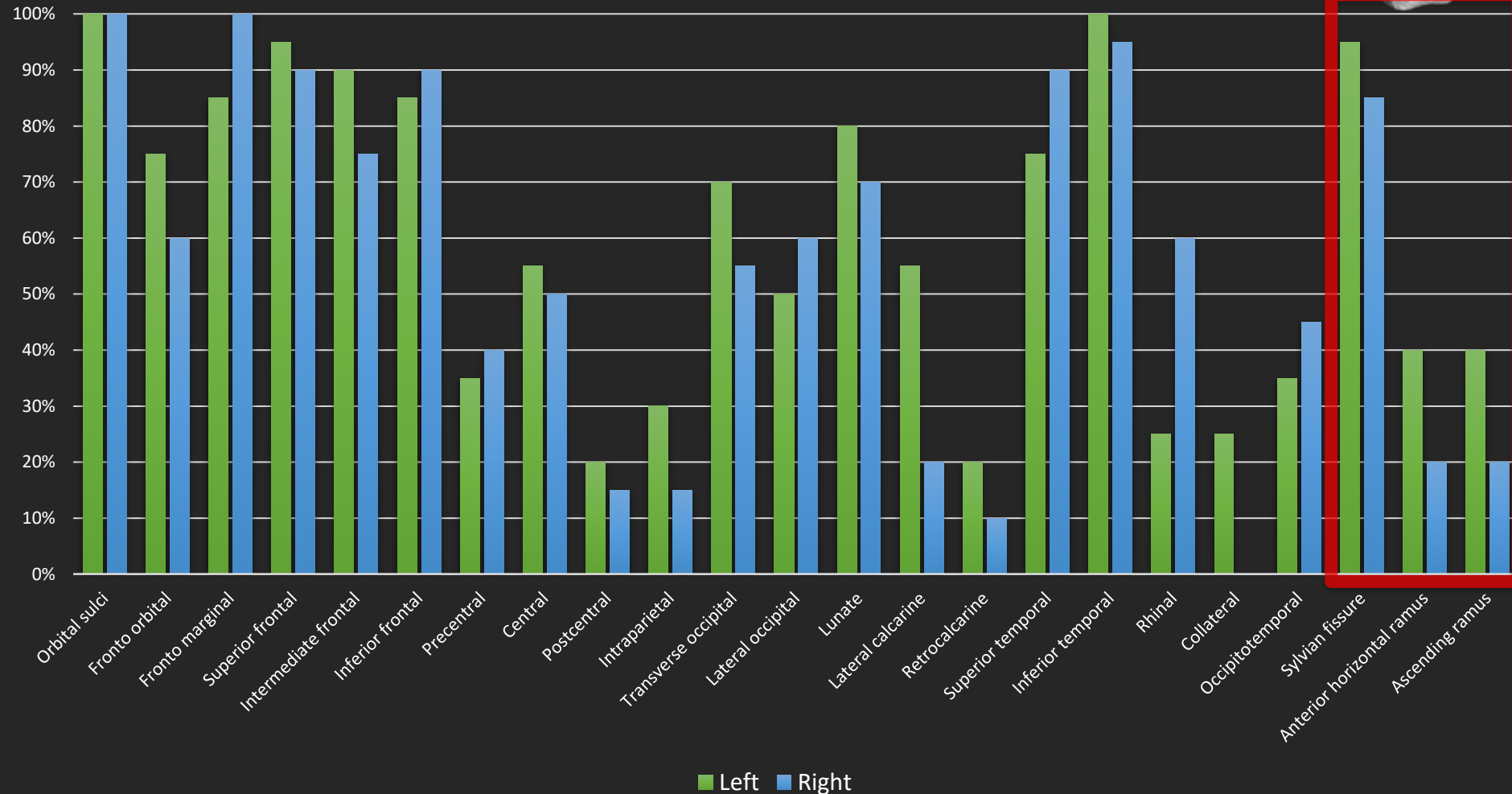


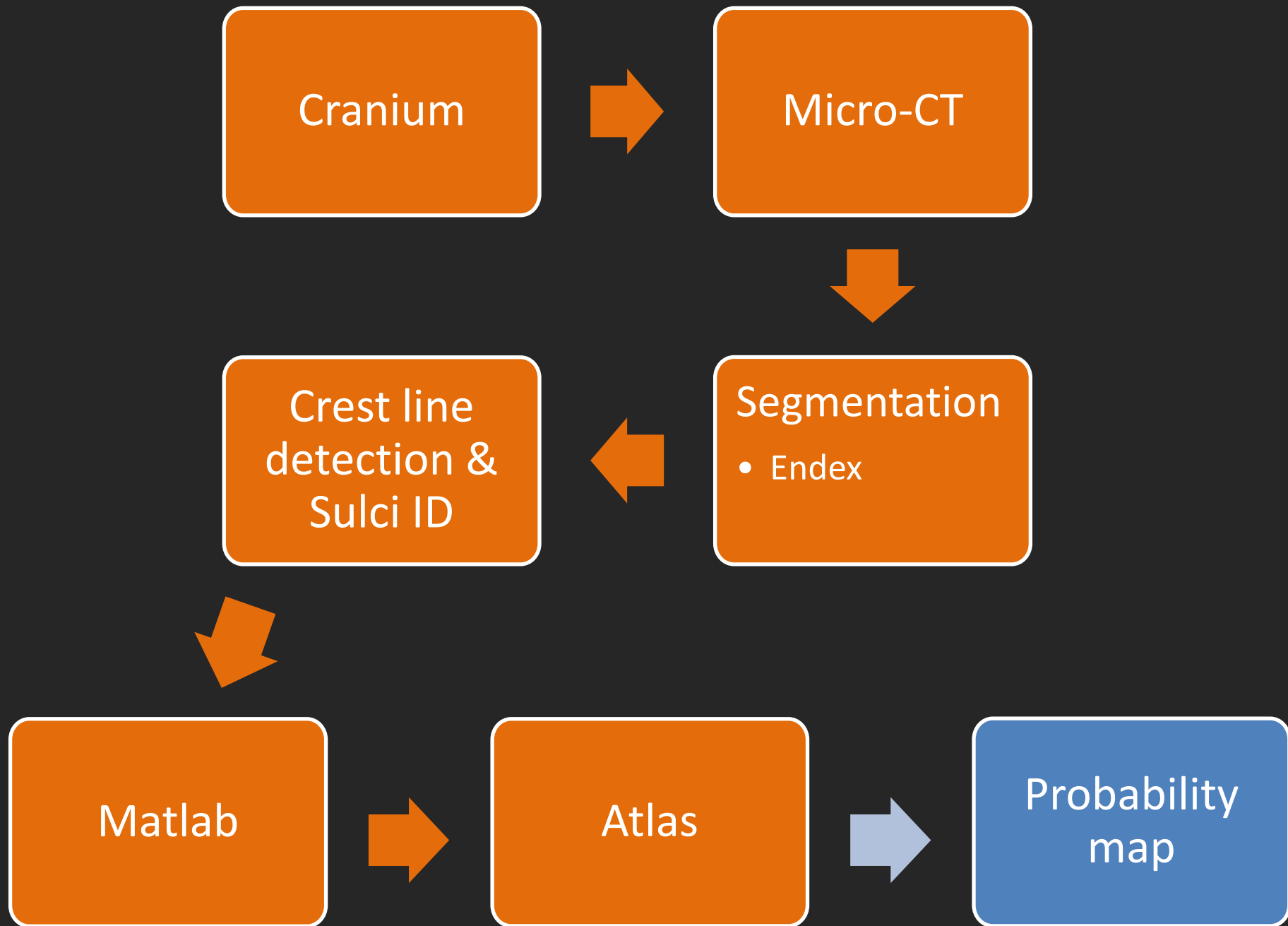
Atlas - Results

de Jager *et al.*, 2019 (provisionally accepted)



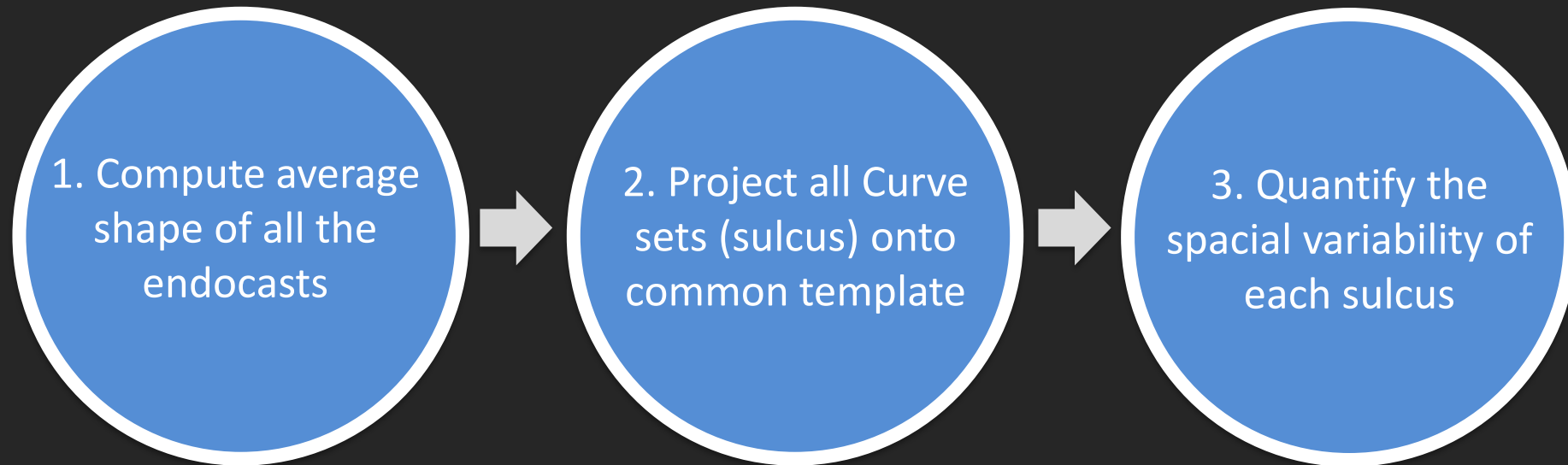
Results (20 endocasts)





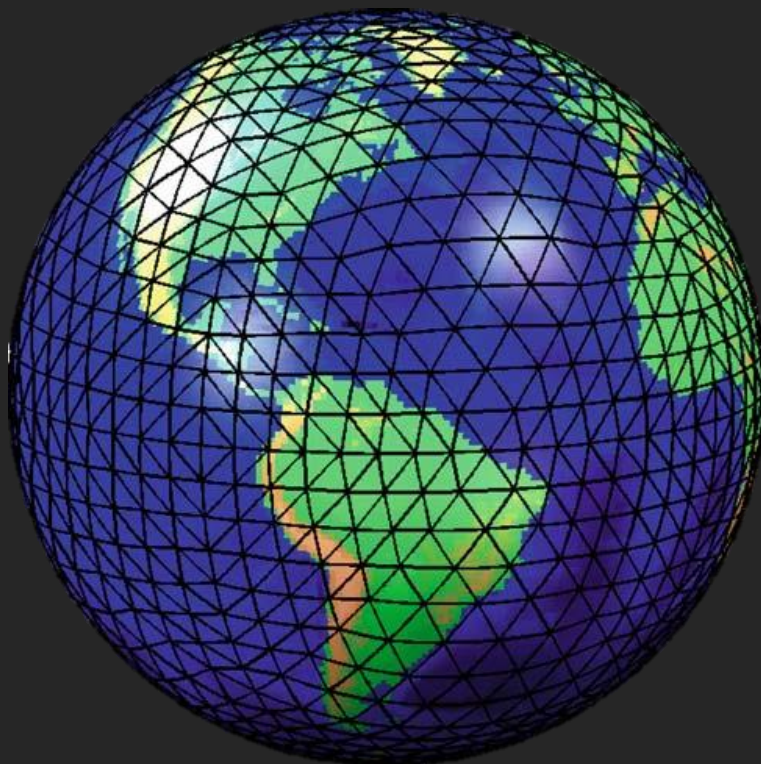
Probability - Method

Secret Formula

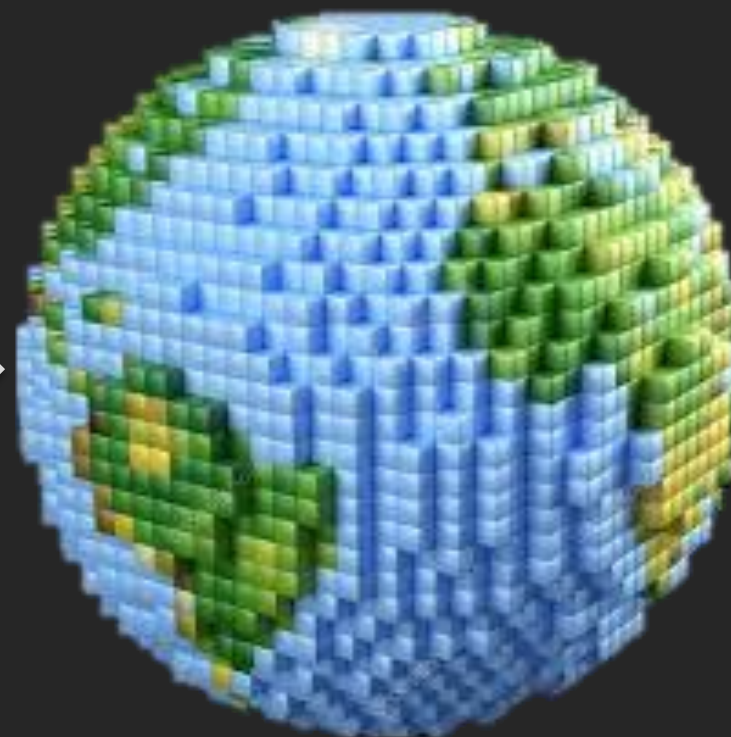


Probability - Method

.vtk mesh



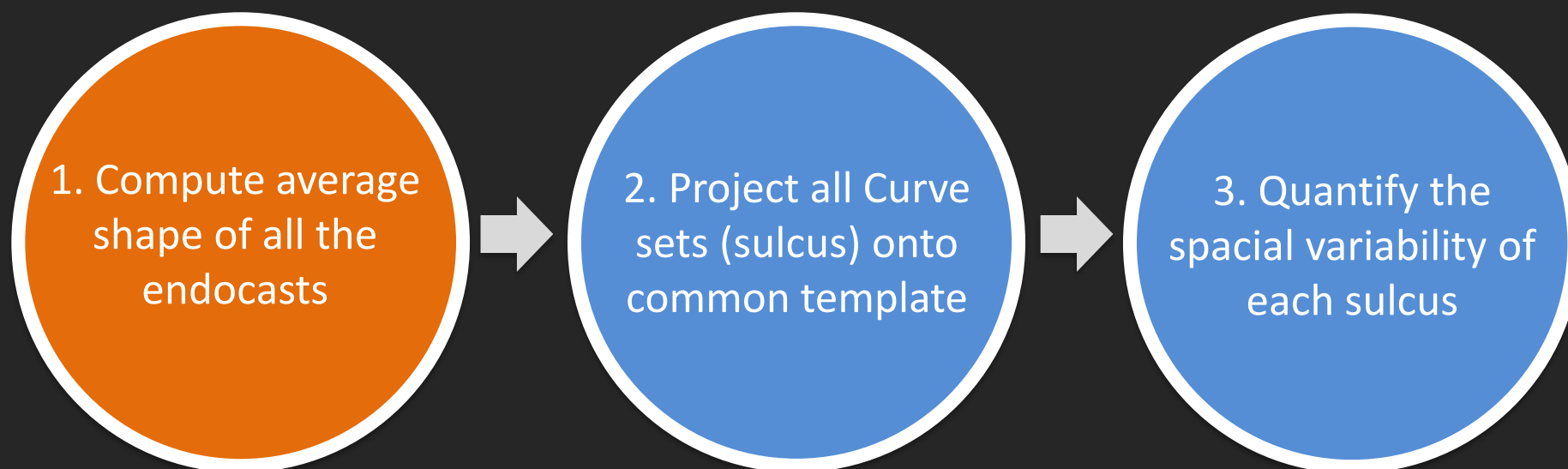
3D vol. image



200x200x200 voxels
(Margin = 10 voxels)

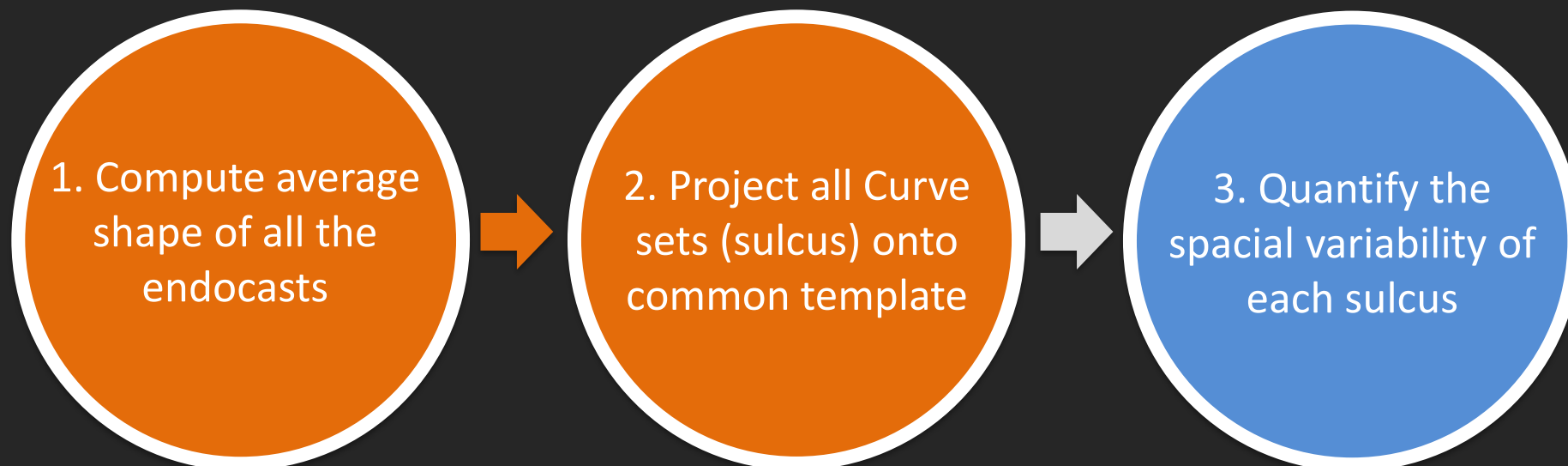
Probability - Method

- Deformed using method of Vialard et al. (2012)
 - Deformation towards Karcher mean of all images of sample (Karcher 1977)



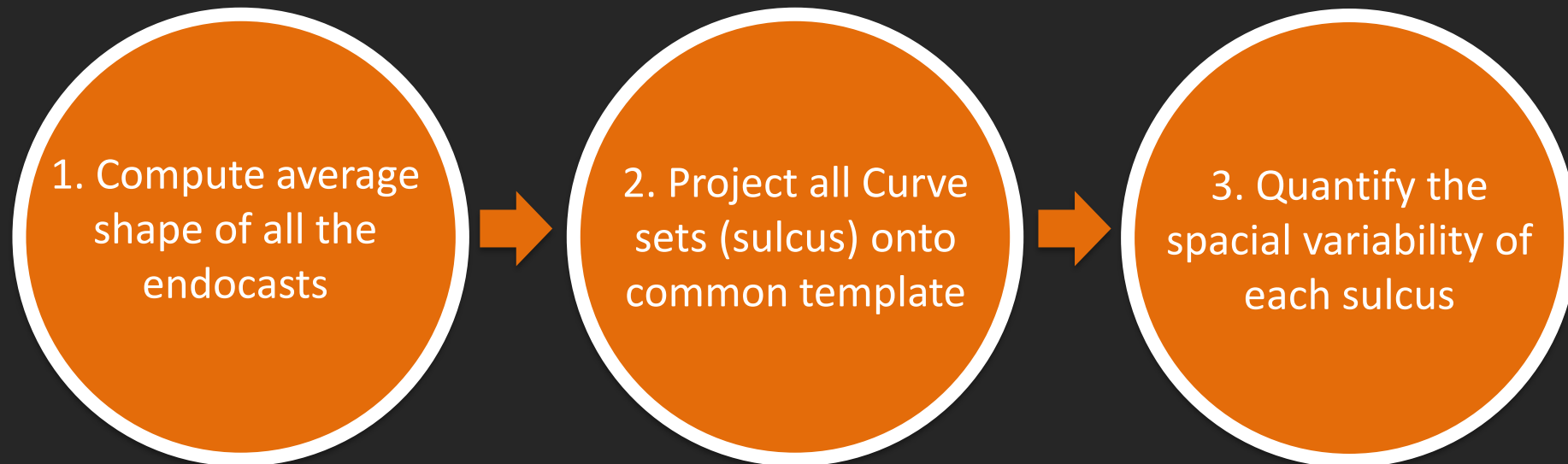
Probability - Method

- Each curve set (sulcus) projected onto the common template
 - Using coordinates
 - Using deformation values from average shape
- Gaussian filter was applied to smooth images
 - Standard deviation = 5 voxels

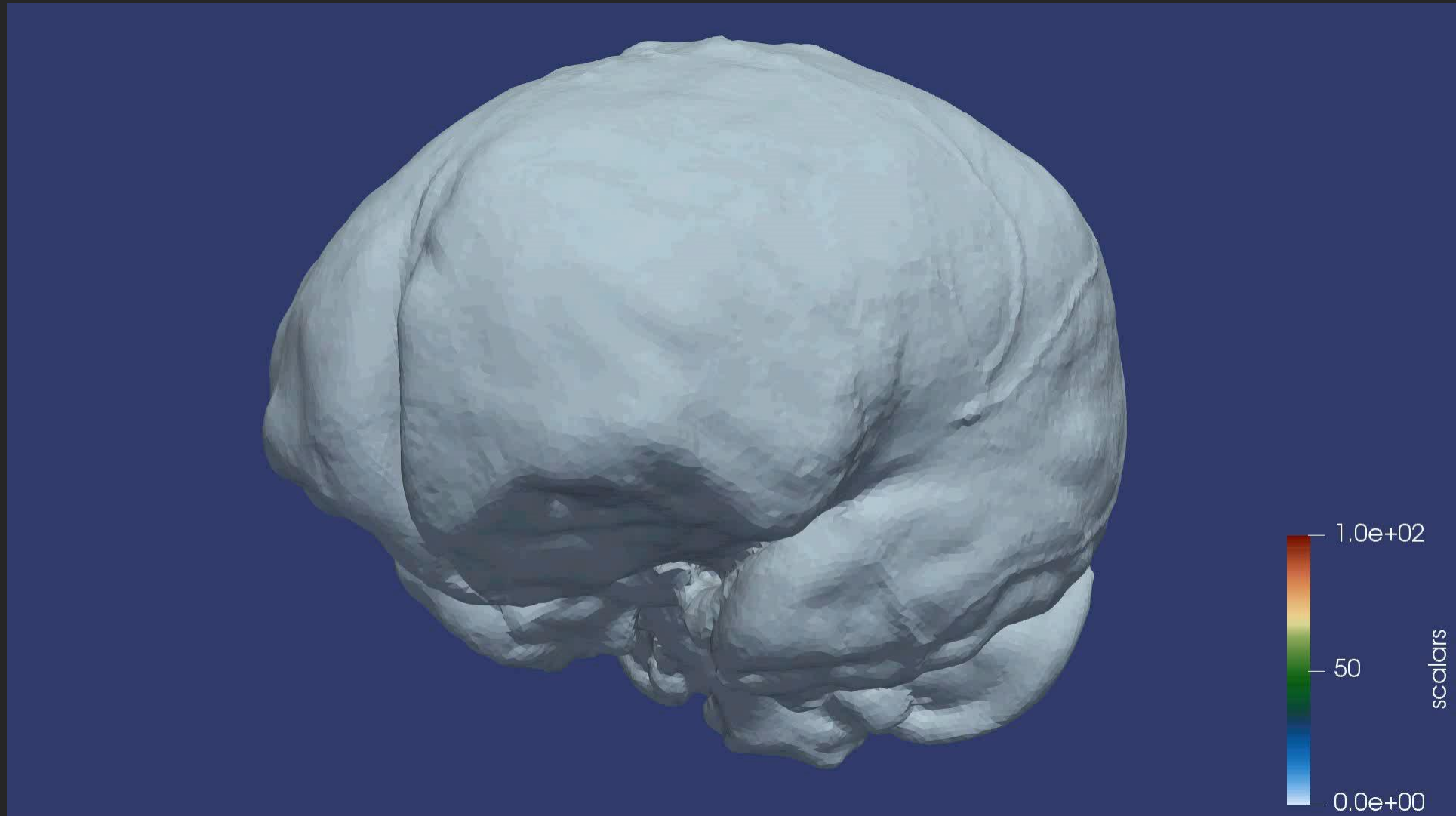


Probability - Method

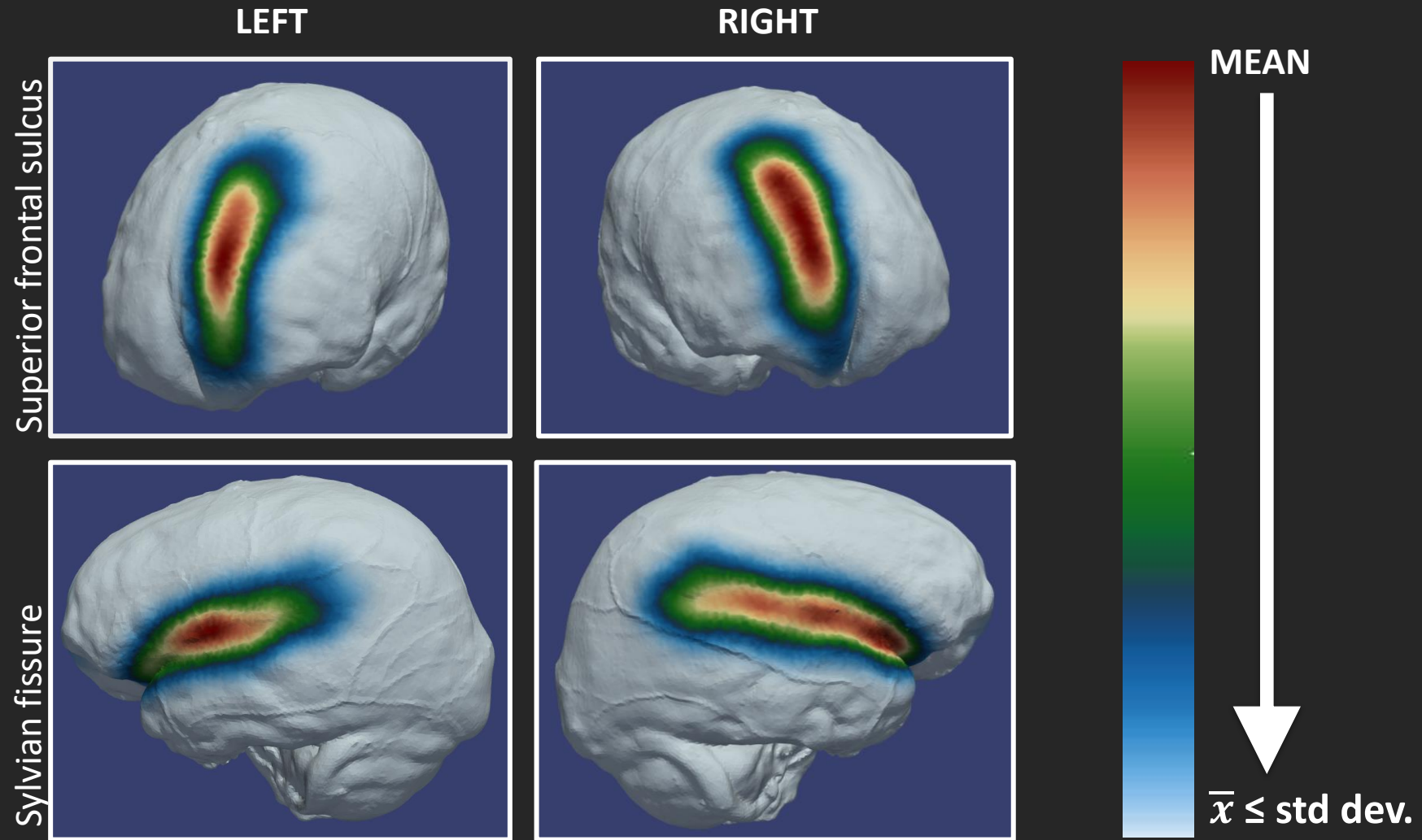
Secret Formula



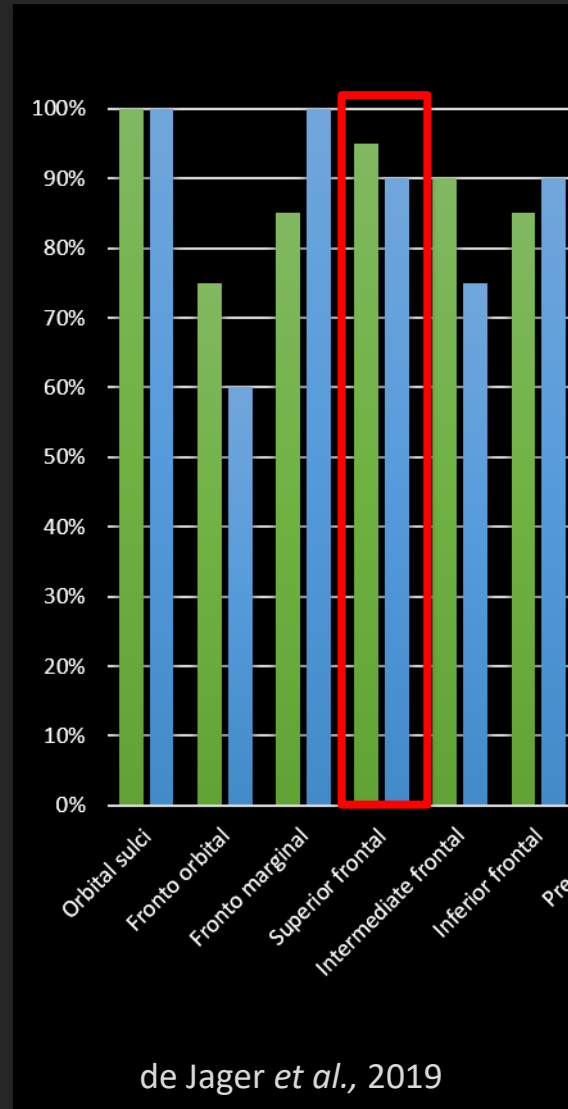
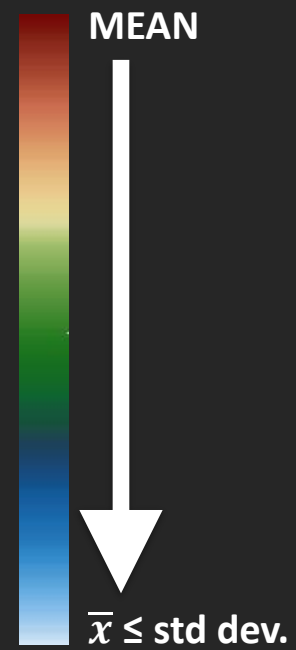
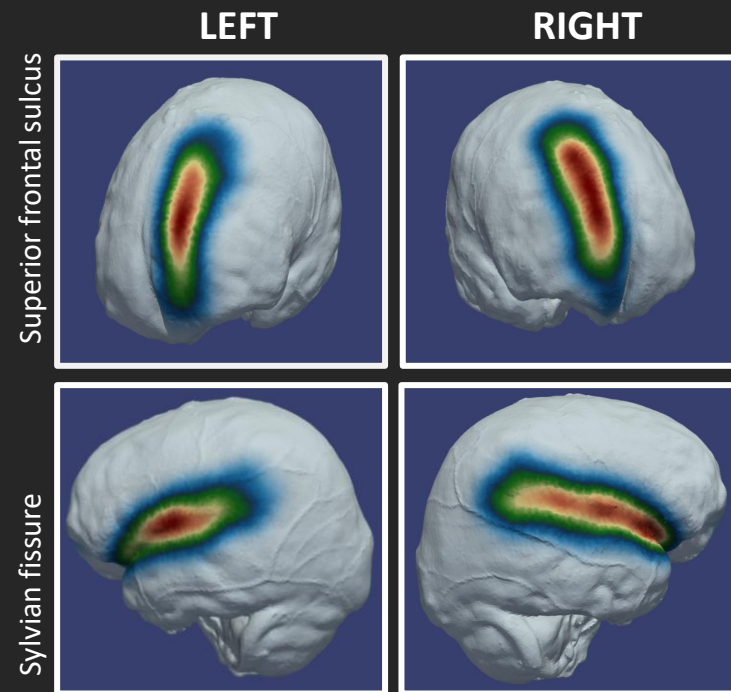
Probability - Results



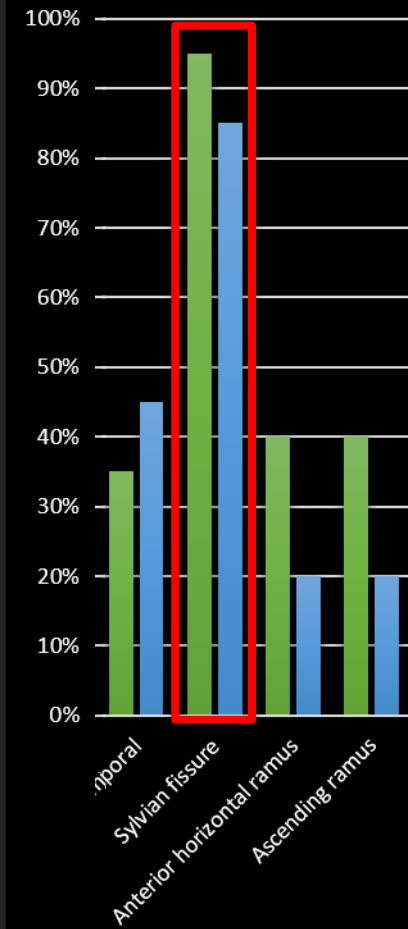
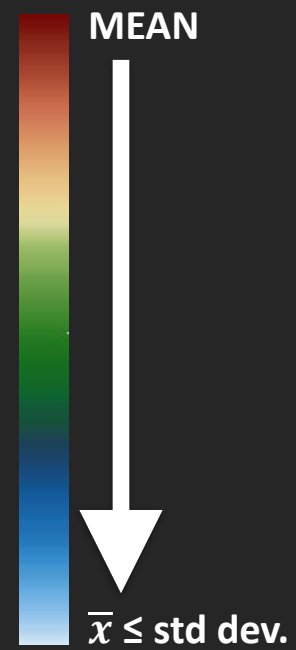
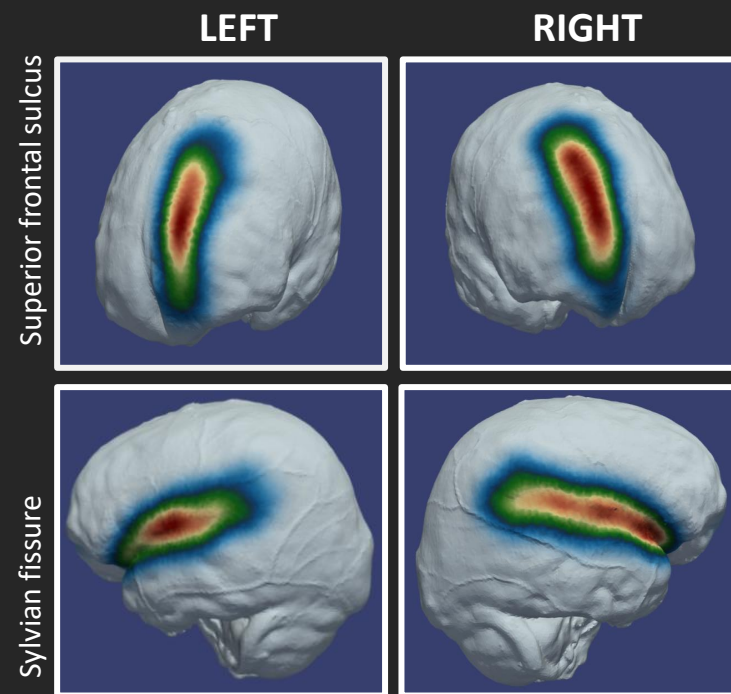
Discussion



Discussion

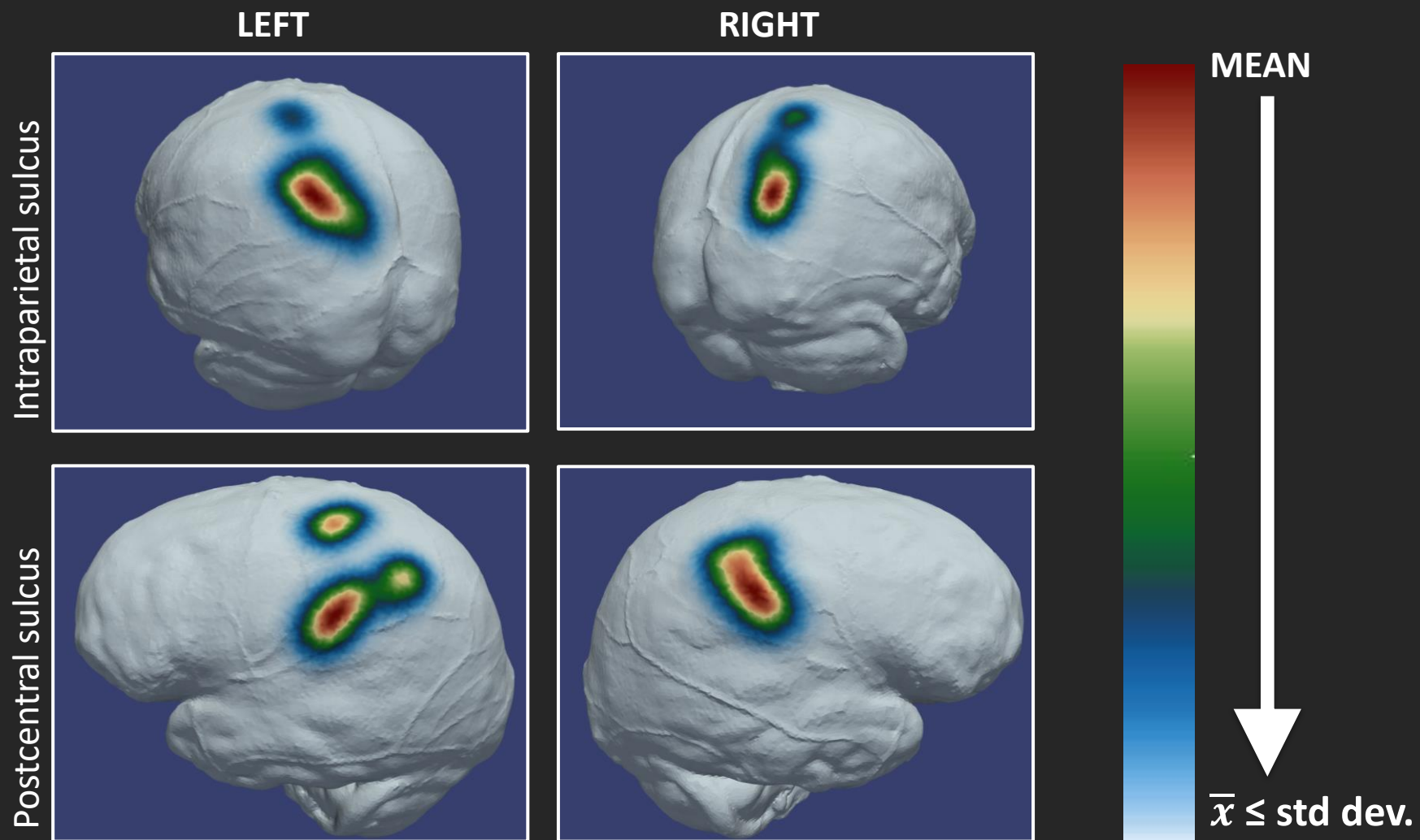


Discussion

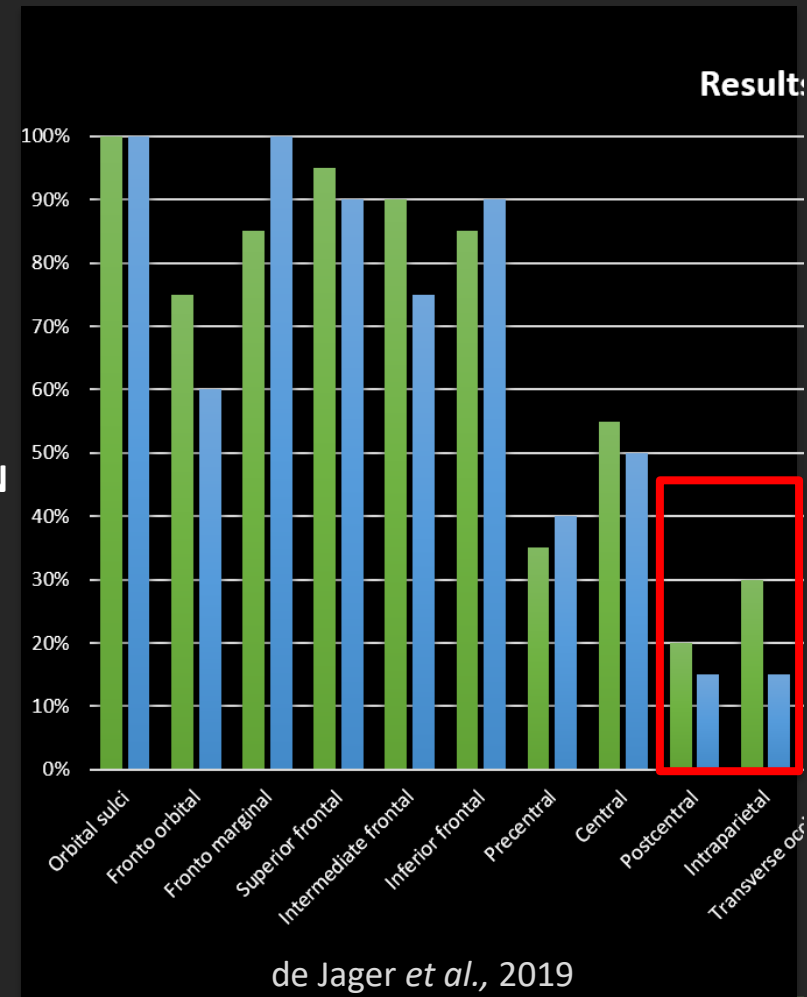
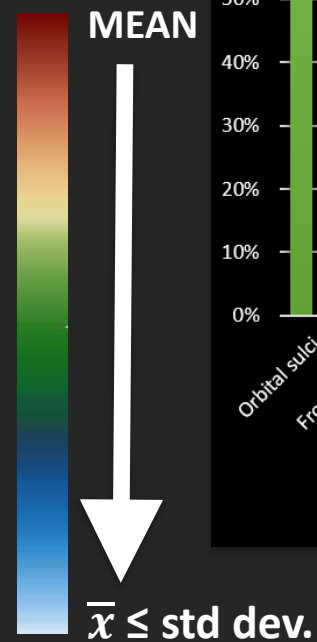
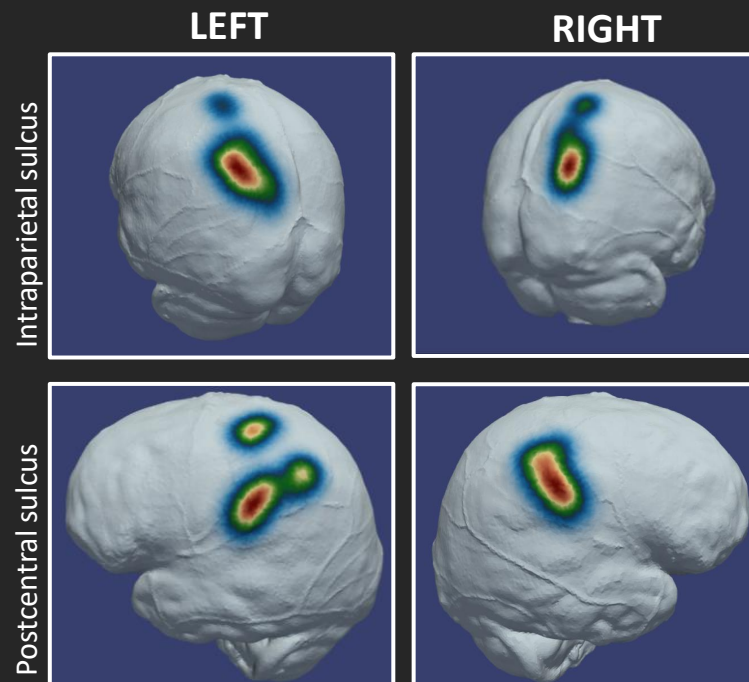


de Jager *et al.*, 2019

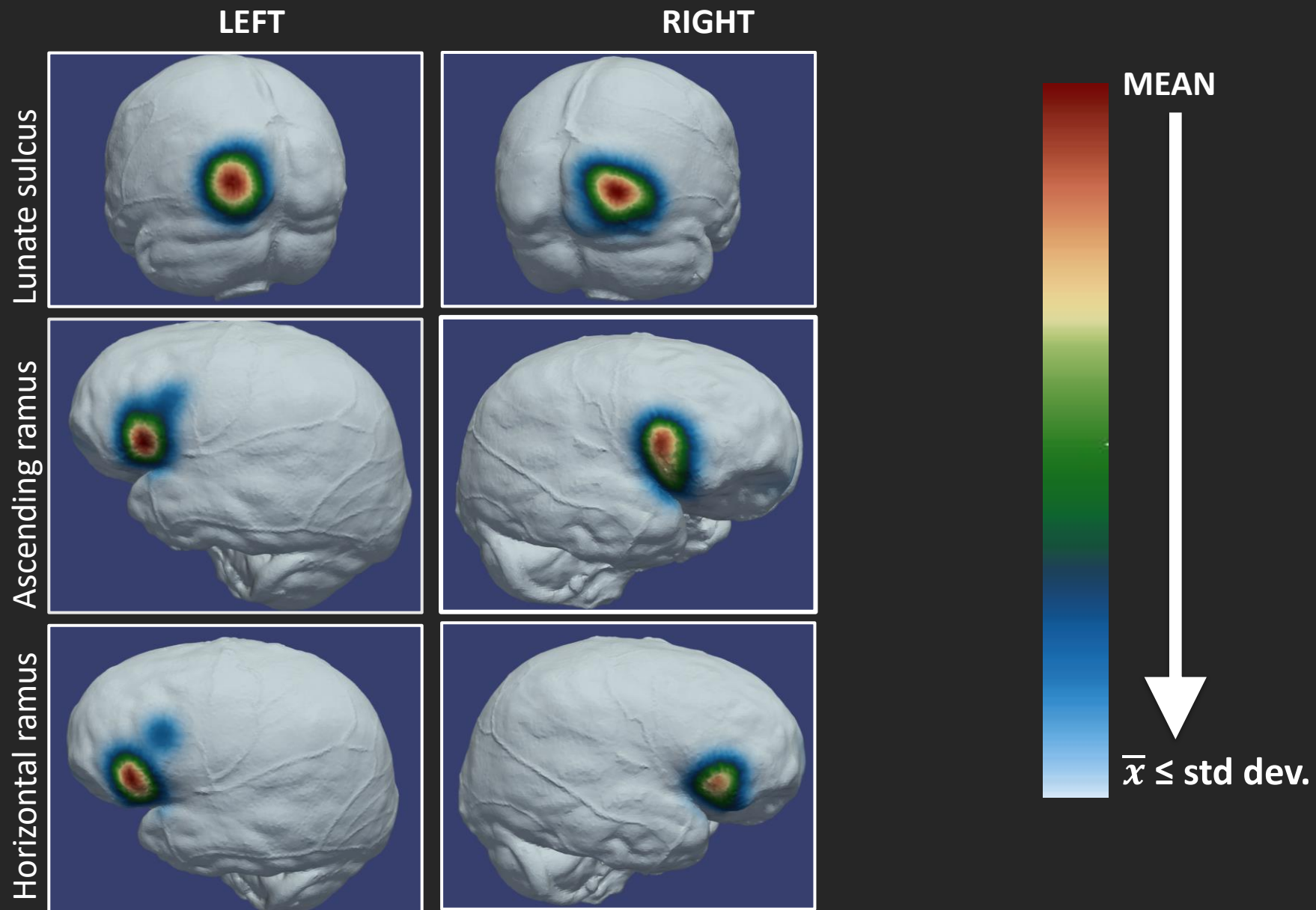
Discussion



Discussion

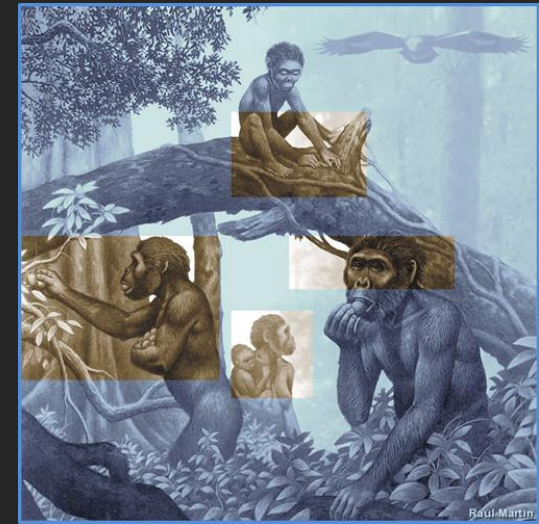


Discussion



Conclusion

- Newly developed imaging techniques
 - Beneficial in documenting the cortical variation in extant human endocasts
 - Used to study “Little Foot” endocast ([Beaudet *et al.*, 2019](#))
 - May contribute towards an automated comparative atlas
 - Study of endocasts in the hominin lineage



Acknowledgments

We thank G. Krüger (Univ. Pretoria) for collection access; F. de Beer and L. Bam (Necsa) for data acquisition; J. Dumoncel (AMIS – UMR5288) for technical support. Supported by the National Research Foundation of South Africa (Grant Number: 112186); we thank the DST-NRF for sponsoring the Micro-XCT facility at Necsa. We are grateful to the Erasmus Mundus program AESOP+. A. Beaudet is funded by the Centre of Excellence in Palaeosciences, the Claude Leon Foundation and the French Institute of South Africa.

Ethical clearance was obtained from the Main Research Ethics committee of the Faculty of Health Science, University of Pretoria August 2017 (No:339/2017).

(References available on request)

