

# Differences in endocranial shape between Homo and Pongids assessed through non-rigid deformation analysis of high-resolution CT images

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ORSA

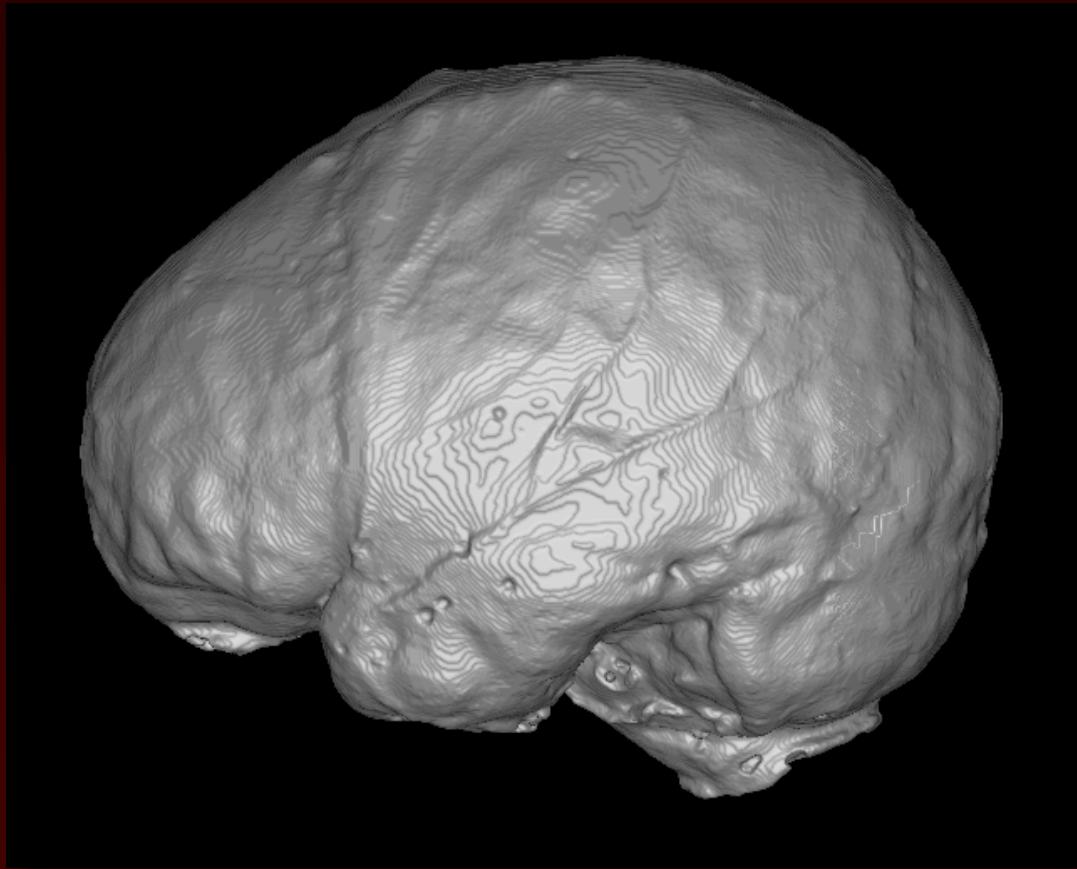


# What we'd *like* to study about fossils:



<http://muskingum.edu/~neuro/neurpage/brains.htm>

# What we are *able* to study about fossils:

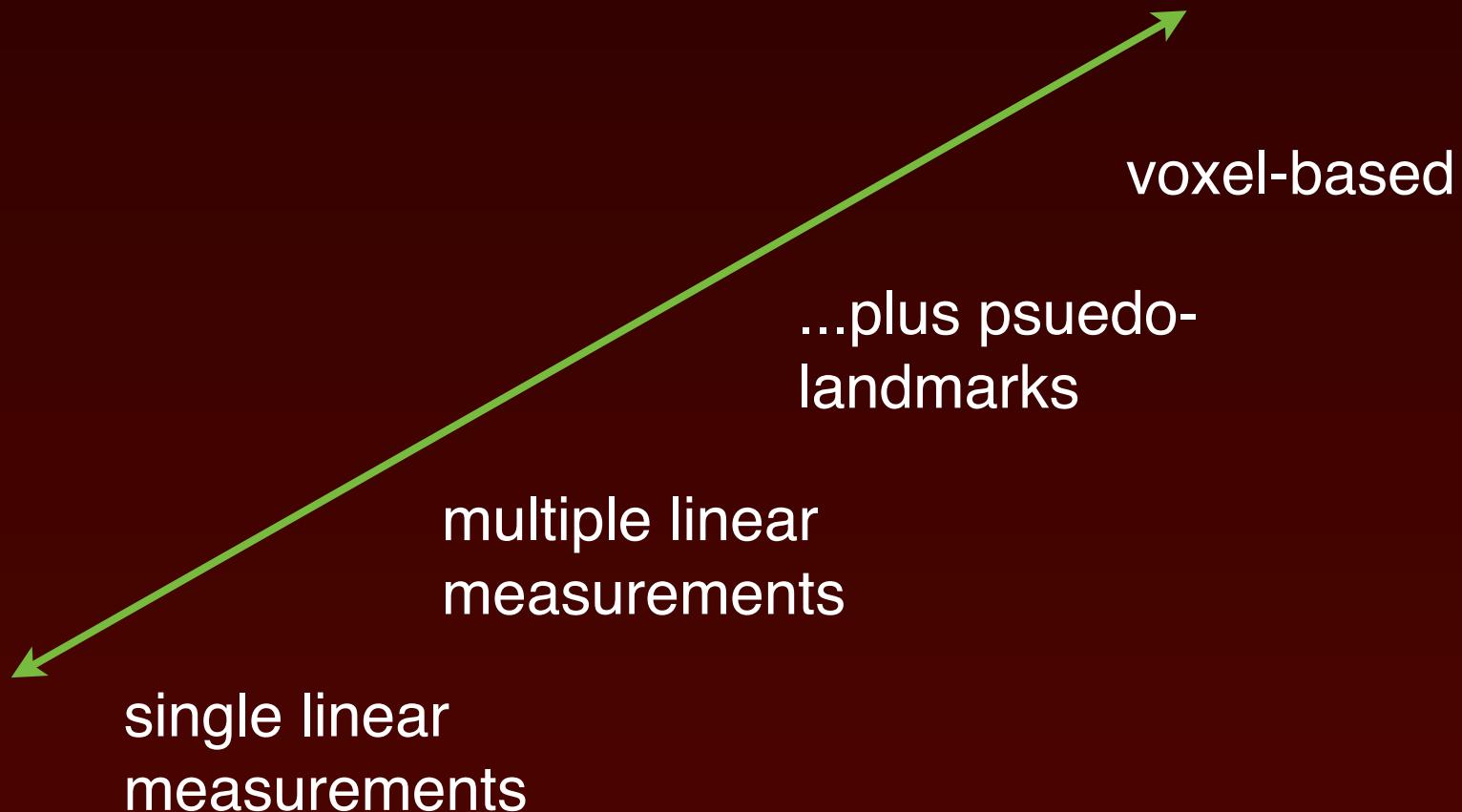


- only fossil evidence of brain evolution
- very complicated morphological shape

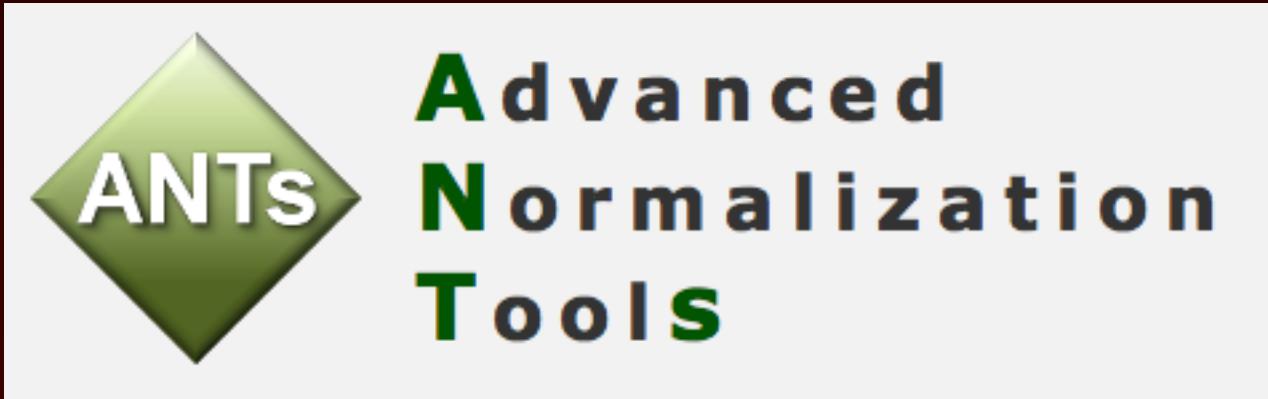
# Goal of the present study:

- Describe differences between endocranial shape of *Homo sapiens* vs. *Pongids*
- Replicate the study by MacLeod, Falk, Mohlberg, and Zilles (2003, “Patterns of surface shape in great ape endocasts”) using alternative methods and different sample
- Demonstrate non-rigid deformation techniques that can be applied to this question
- Illustrate the usefulness of freeware software tools available for these analyses

# Continuum of types of comparisons



# Software tools used for this study:



<http://www.picsl.upenn.edu/ANTS/>

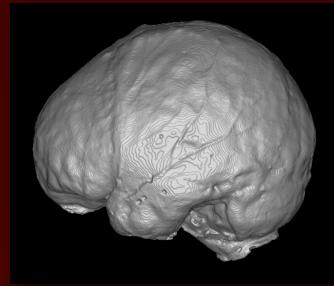
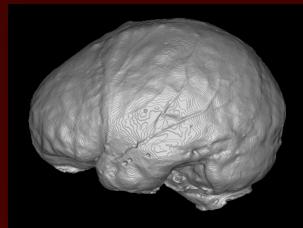
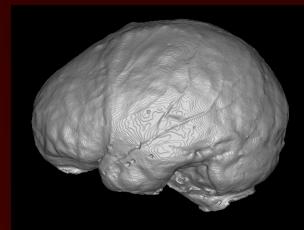
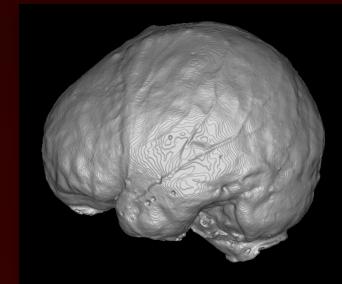
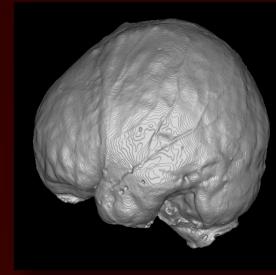
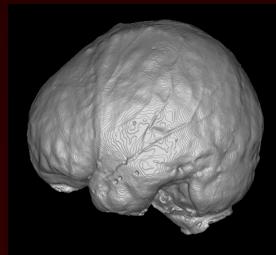
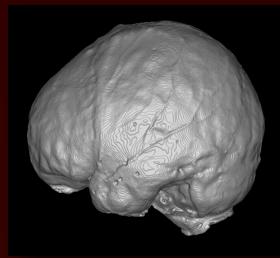
Many powerful, flexible tools for image analysis

Freeware

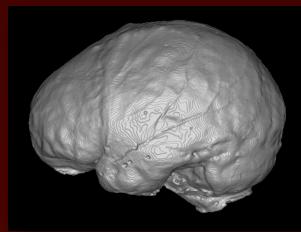
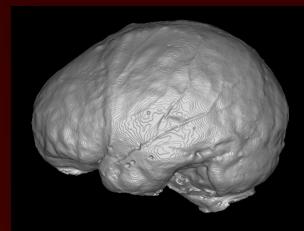
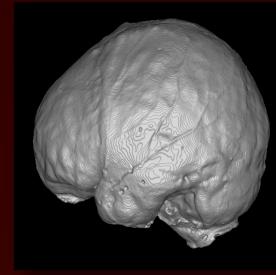
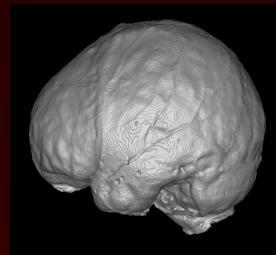
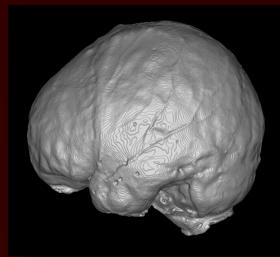
Binaries and source code available

Can be compiled on Windows, Linux, Mac OS X

# Step 1: align images in 3D space (rigid rotation)

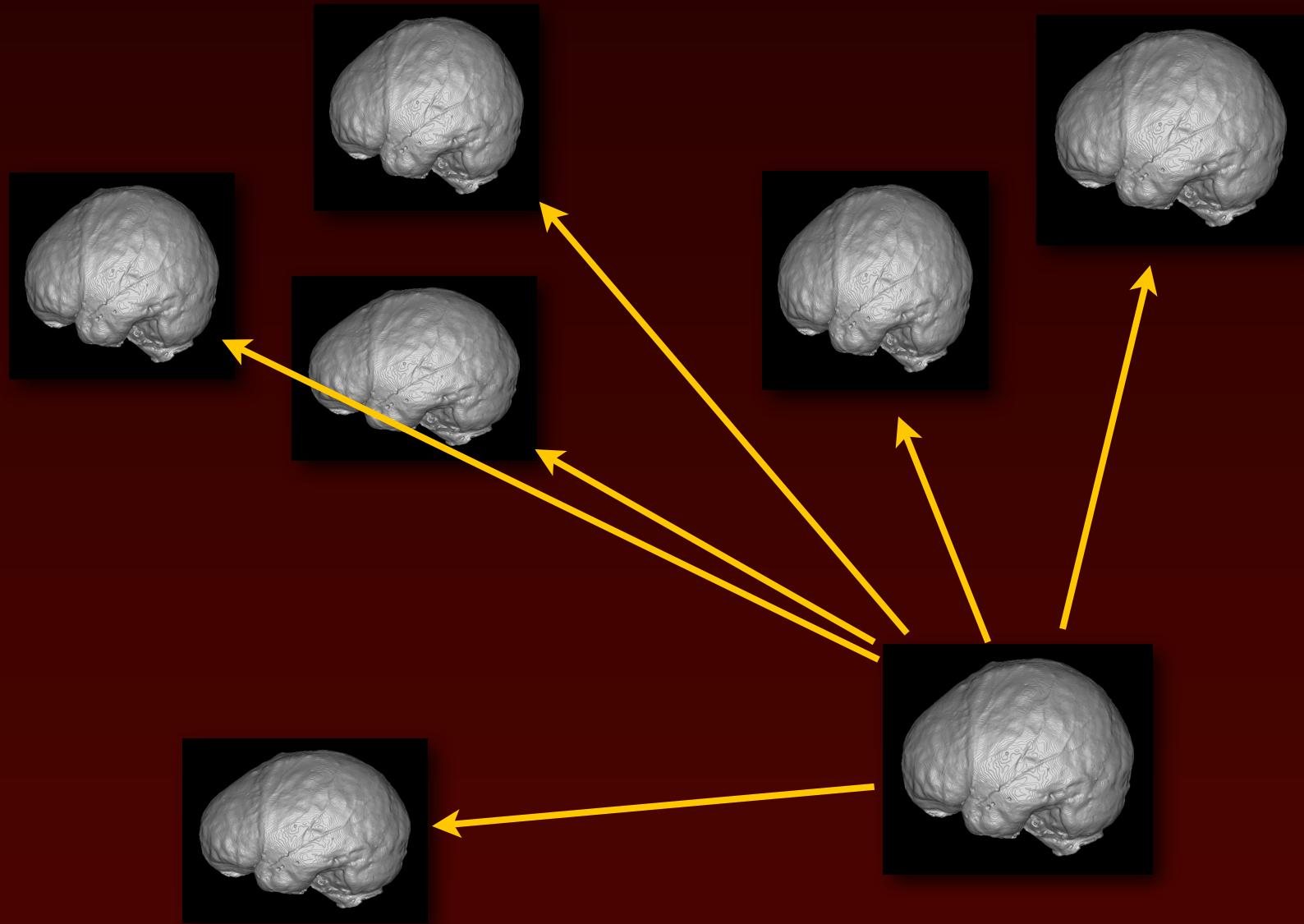


## Step 2: create a starting template (e.g., choose one at random)



initial template

## Step 3: morph template into each individual



Each arrow represents a separate 3D mapping

# What exactly are the mappings?

Volumes representing vectors in 3D space indicating the directions and distances that voxels in the target (template) image are mapped to voxels in the subject image

i.e.:

X-vector file

Y-vector file

Z-vector file

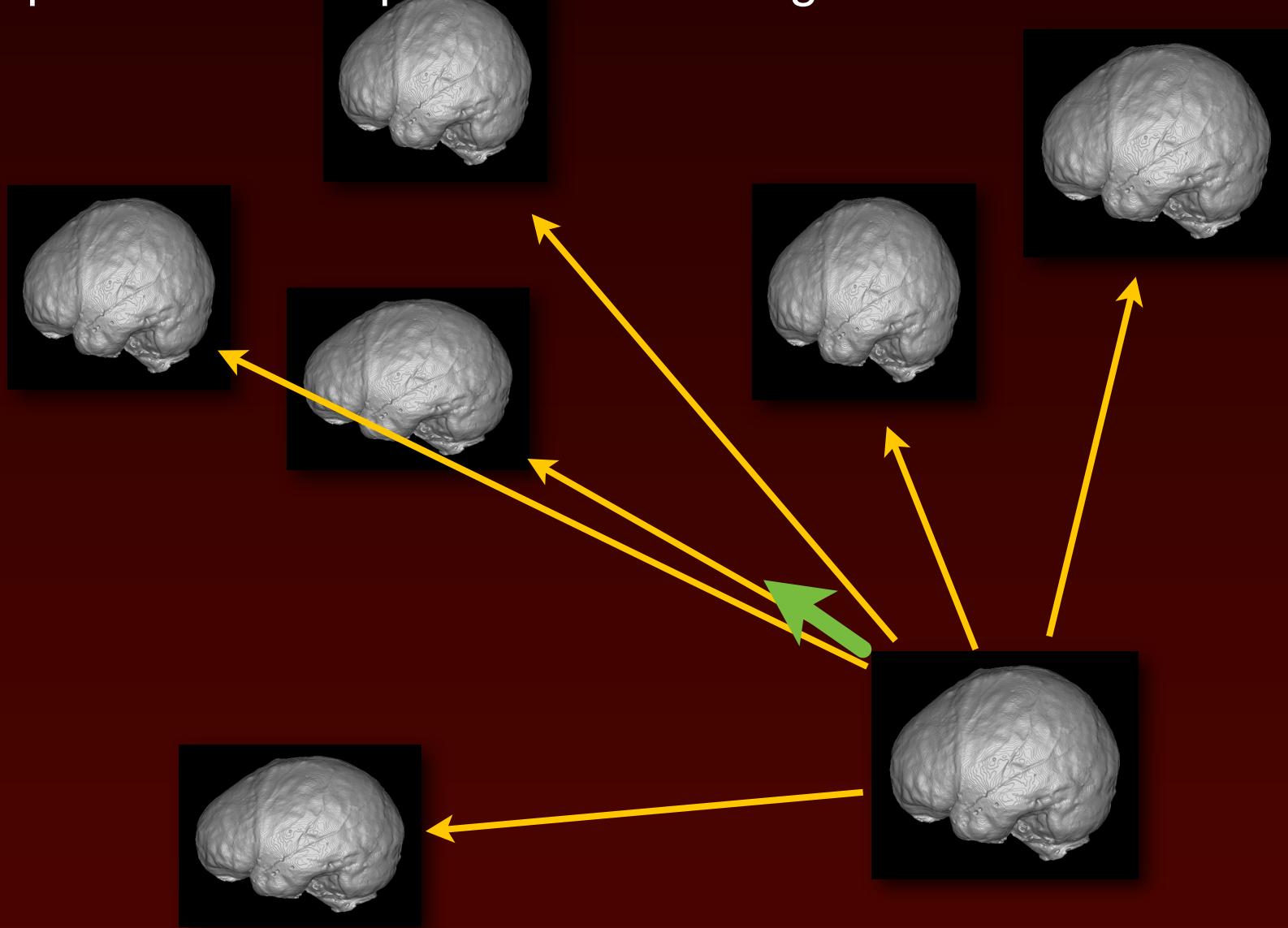
## Step 4: average the distortion maps

Averaging the X-vector files gives the average distance the template is in the X dimension from the individuals in the population.

Averaging the Y-vector files gives the average distance the template is in the Y dimension from the individuals in the population.

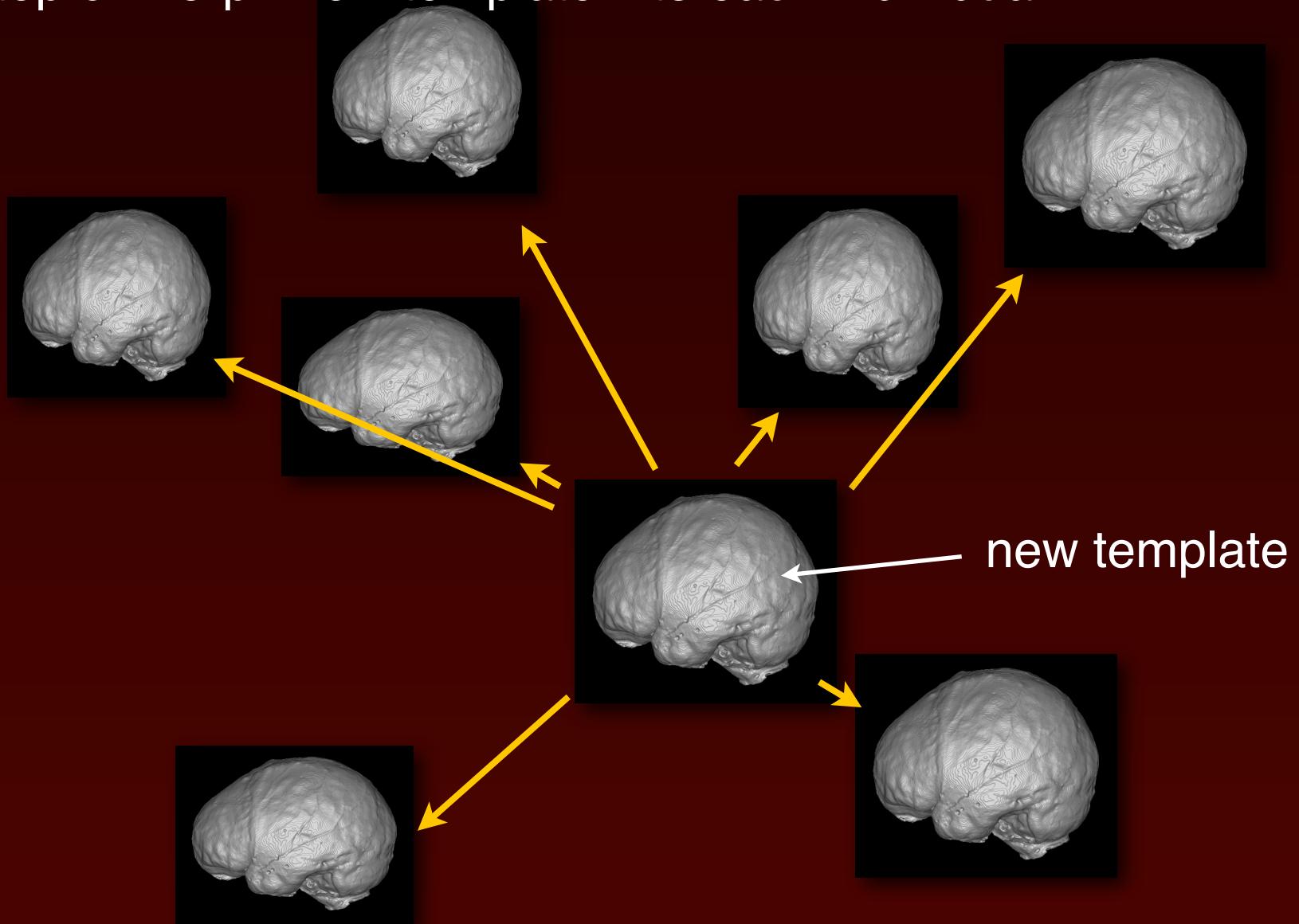
Averaging the Z-vector files gives the average distance the template is in the Z dimension from the individuals in the population.

## Step 5: 'move' template in the 'average' direction



Average mapping (green arrow) points towards average shape

## Step 6: morph new template into each individual



Repeat this process until the template doesn't change in subsequent iterations

This effectively moves the template into the average shape space of the population

# Present study sample

CT scans of latex/plaster endocasts from Ralph Holloway's collection:

18 *Homo sapiens*

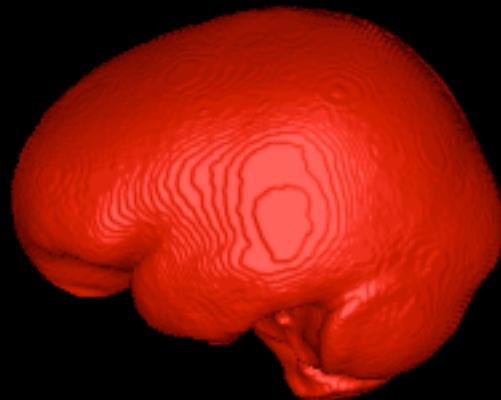
33 *Pan troglodytes*

33 *Pan paniscus*

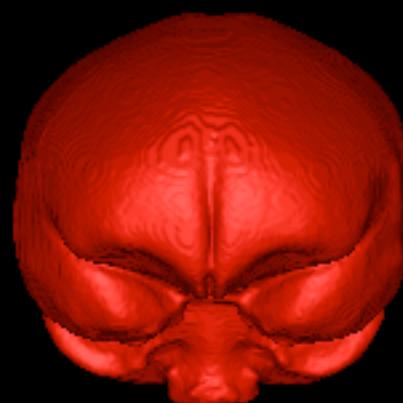
38 *Gorilla gorilla*

# Average *Homo sapiens* endocranial shape

left lateral



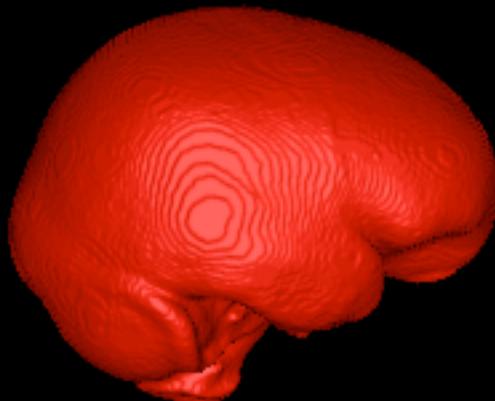
anterior



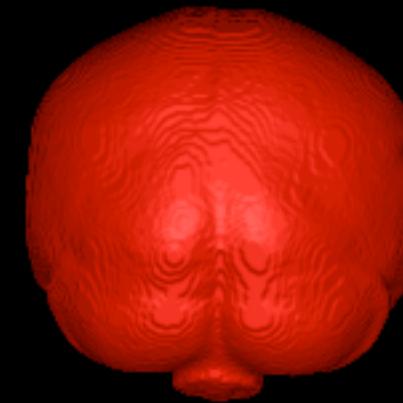
superior



right lateral



posterior

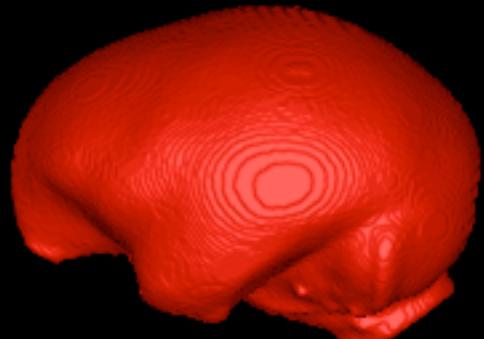


inferior

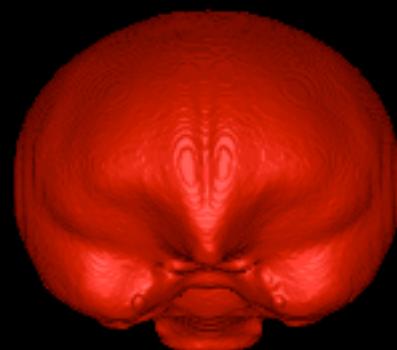


# Average *Pan troglodytes* endocranial shape

left lateral



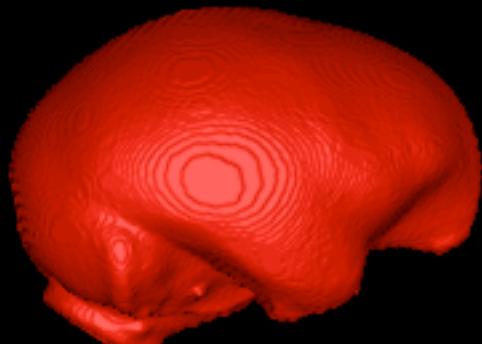
anterior



superior



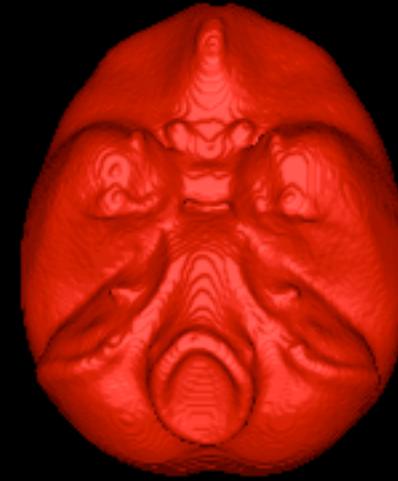
right lateral



posterior

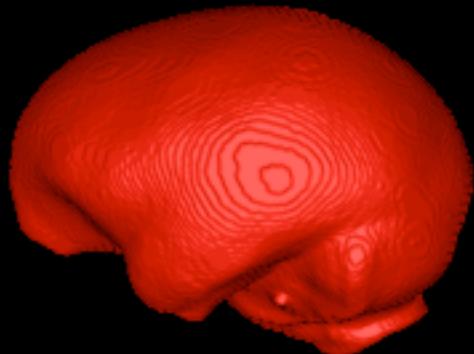


inferior



# Average *Pan paniscus* endocranial shape

left lateral



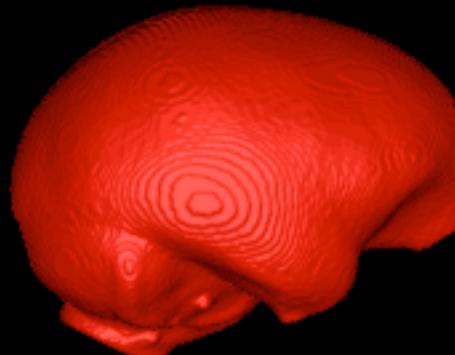
anterior



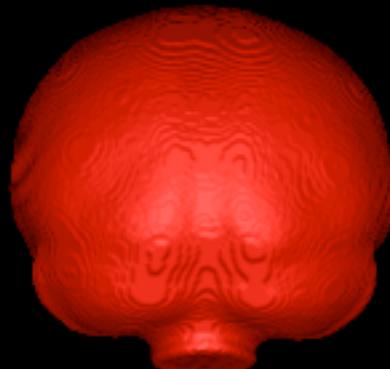
superior



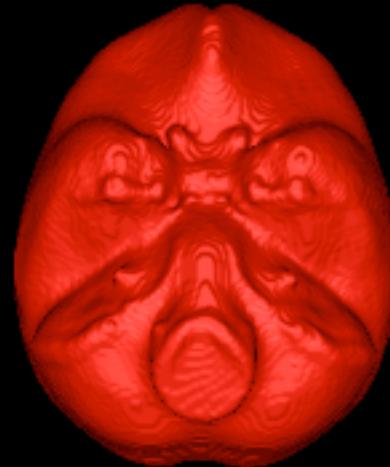
right lateral



posterior

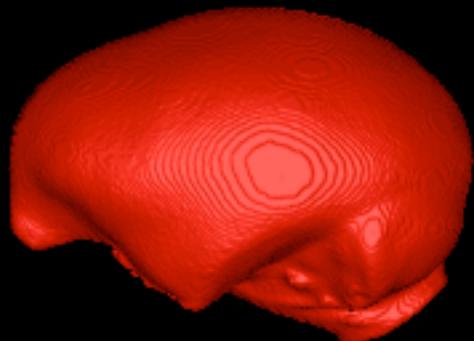


inferior

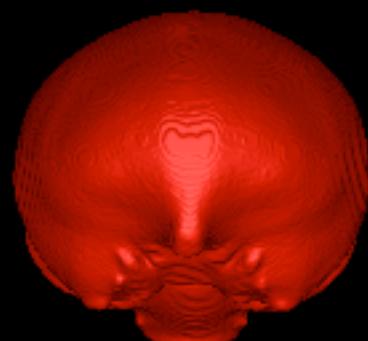


# Average *Gorilla gorilla* endocranial shape

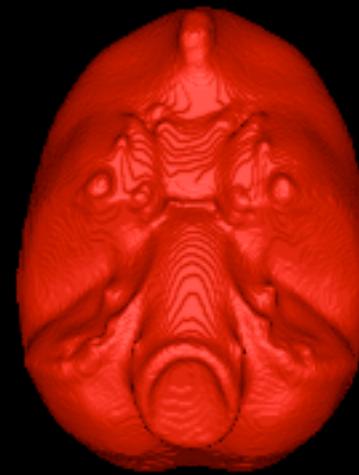
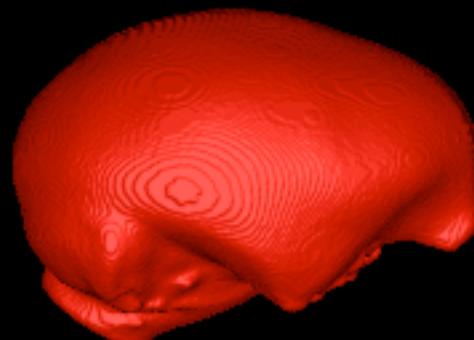
left lateral



anterior



superior



right lateral

posterior

inferior

## Note:

The template is itself an actual image, which can therefore be (virtually) measured and compared (using freeware software tools) to real specimens (e.g., fossils)

The file itself can be easily transferred to other researchers

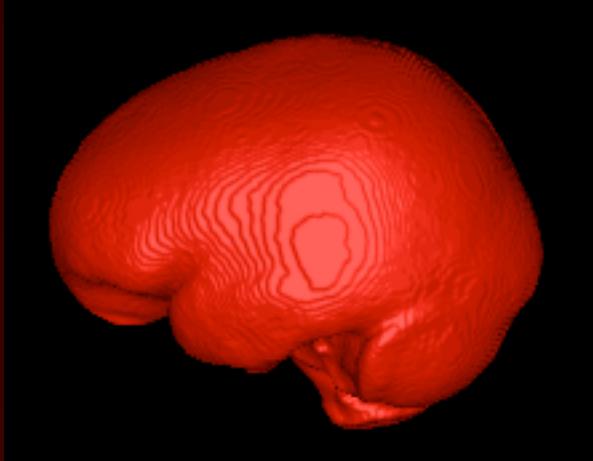
## Additional possible analyses:

Degree of localized scaling can be calculated for each voxel of a given distortion map for an individual. These values are mathematically known as Jacobians.

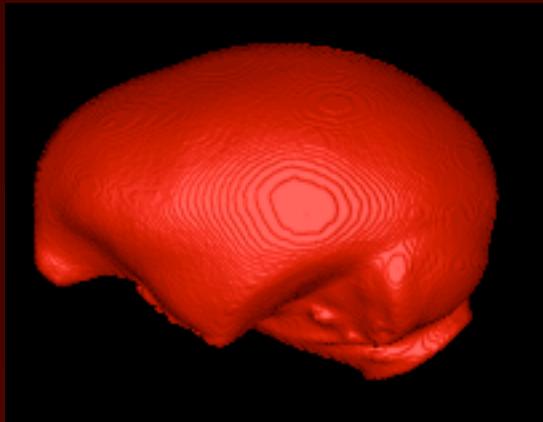
A Jacobian map thus represents a detailed mathematical description of how an individual is different from the average shape for that species

These can be color coded in various ways to highlight differences between an individual and the average

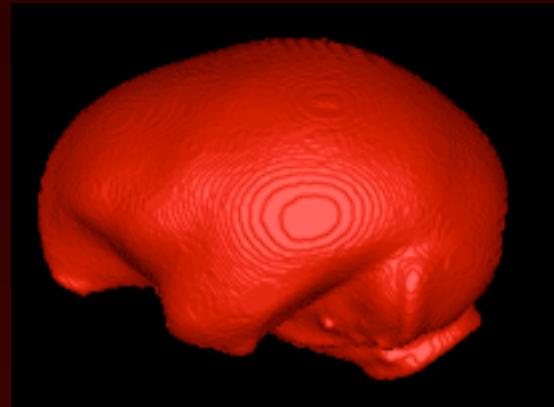
# Morphing *Pongids* into *Homo sapiens*



*Homo sapiens*



*Gorilla gorilla*



*Pan troglodytes*



*Pan paniscus*

## Volumes:

*Homo sapiens*: 1310 ml

*Pan troglodytes*: 387 ml

*Pan paniscus*: 331 ml

*Gorilla gorilla*: 507 ml

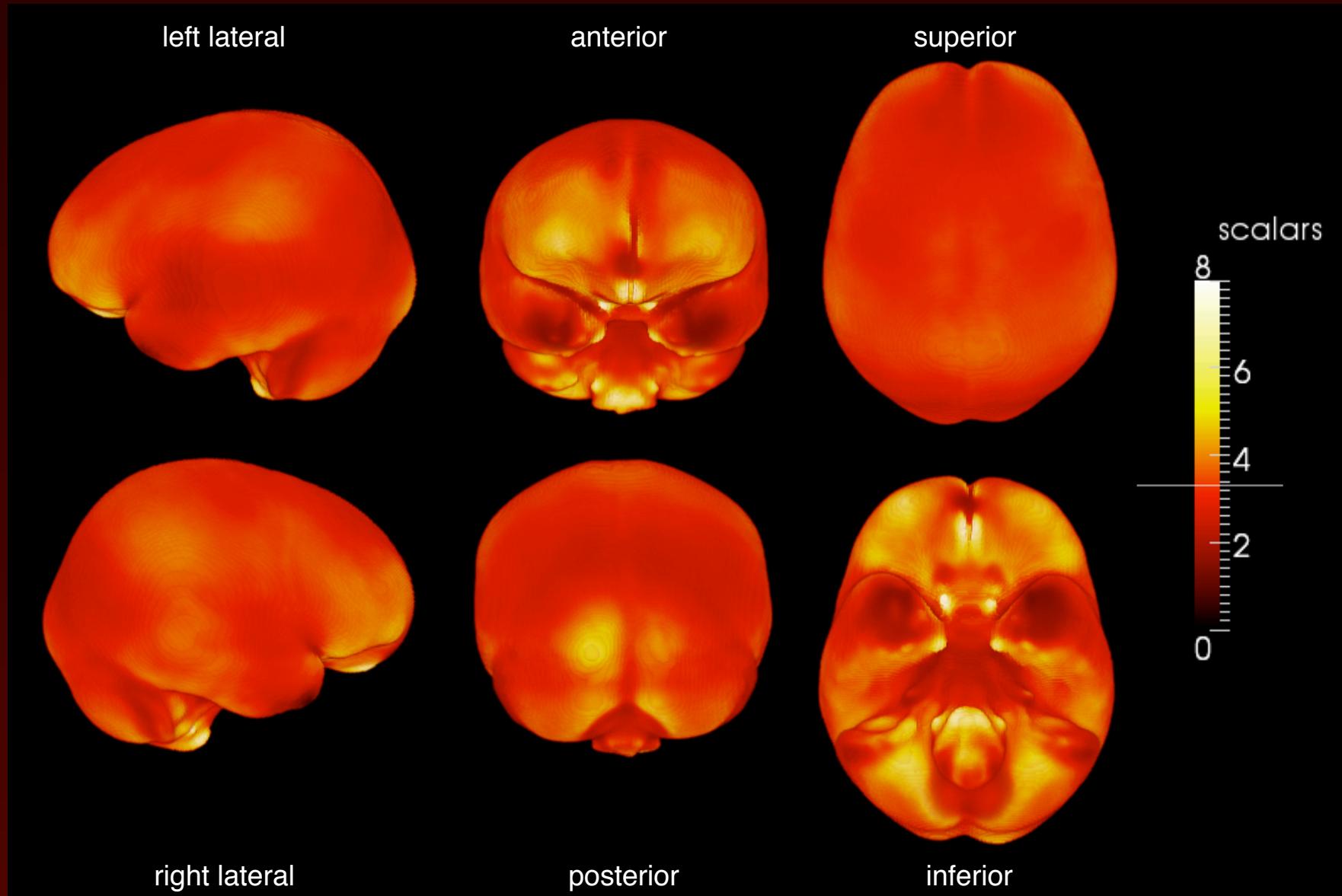
## Ratios:

Homo/Pan troglodytes: 3.4x

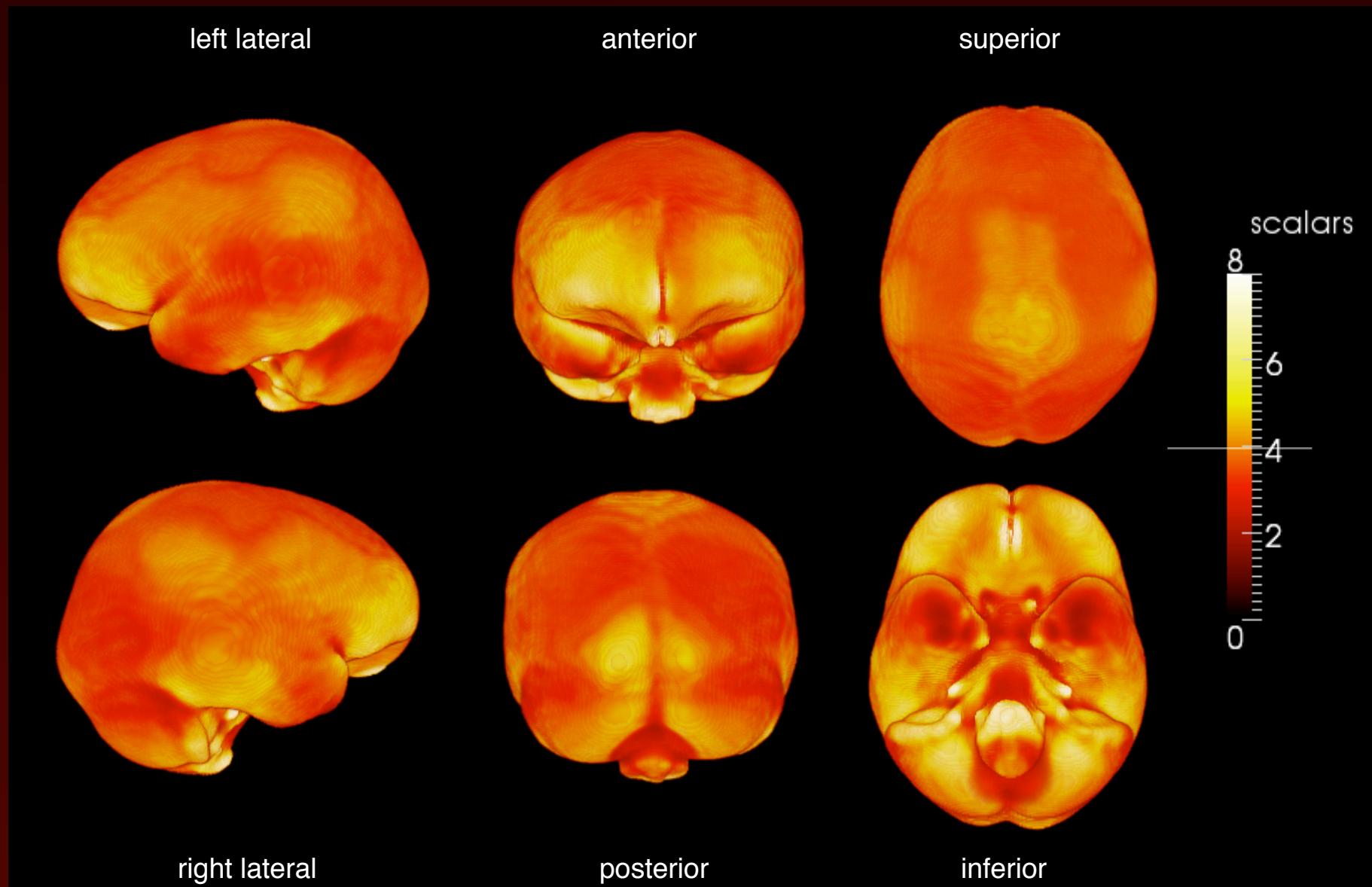
Homo/Pan paniscus: 4.0x

Homo/Gorilla gorilla: 2.6x

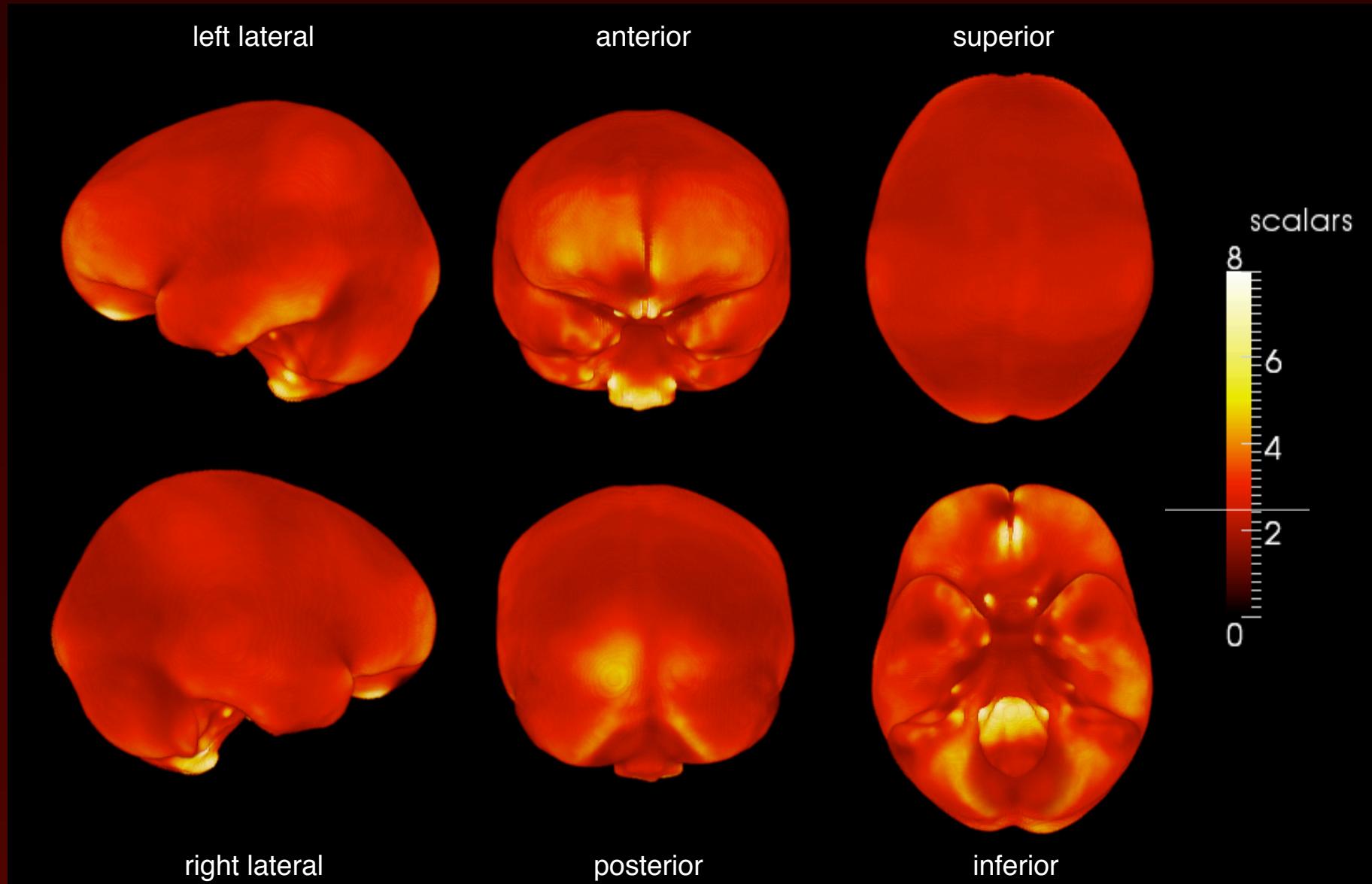
*Pan troglodytes* morphed into *Homo sapiens*  
(foramen magnum not constrained)



*Pan paniscus* morphed into *Homo sapiens*  
(foramen magnum not constrained)



*Gorilla gorilla* morphed into *Homo sapiens*  
(foramen magnum not constrained)



# Conclusions:

- Areas differentially enlarged in humans relative to pongids:
  - Prefrontal (particularly orbital)
  - Inferior cerebellar
  - Occipital poles (particularly left)
  - Inferior and lateral temporal

# Summary of some gross anatomical change in the brain in *Homo*:

Larger overall size

Significantly larger prefrontal (particularly orbital prefrontal)

Larger temporal lobe

Larger parietal lobe (probably)

## Future directions...

Describe evolutionary changes in endocranial shape with these methods

# Acknowledgements:

- Felicia Jefferson and staff at the Hospital of the University of Pennsylvania CT facility
- Samantha Cox and Jen Rosado at Penn for help scanning the specimens
- Robert Mahaney for help preprocessing the scans for analysis
- Open Research Scan Archive ([http://plum.museum.upenn.edu/~orsa/ORSA/Welcome.html](http://plum.museum.upenn.edu/~orsa/ORSA>Welcome.html))



Problem: foramen magnum isn't matched correctly

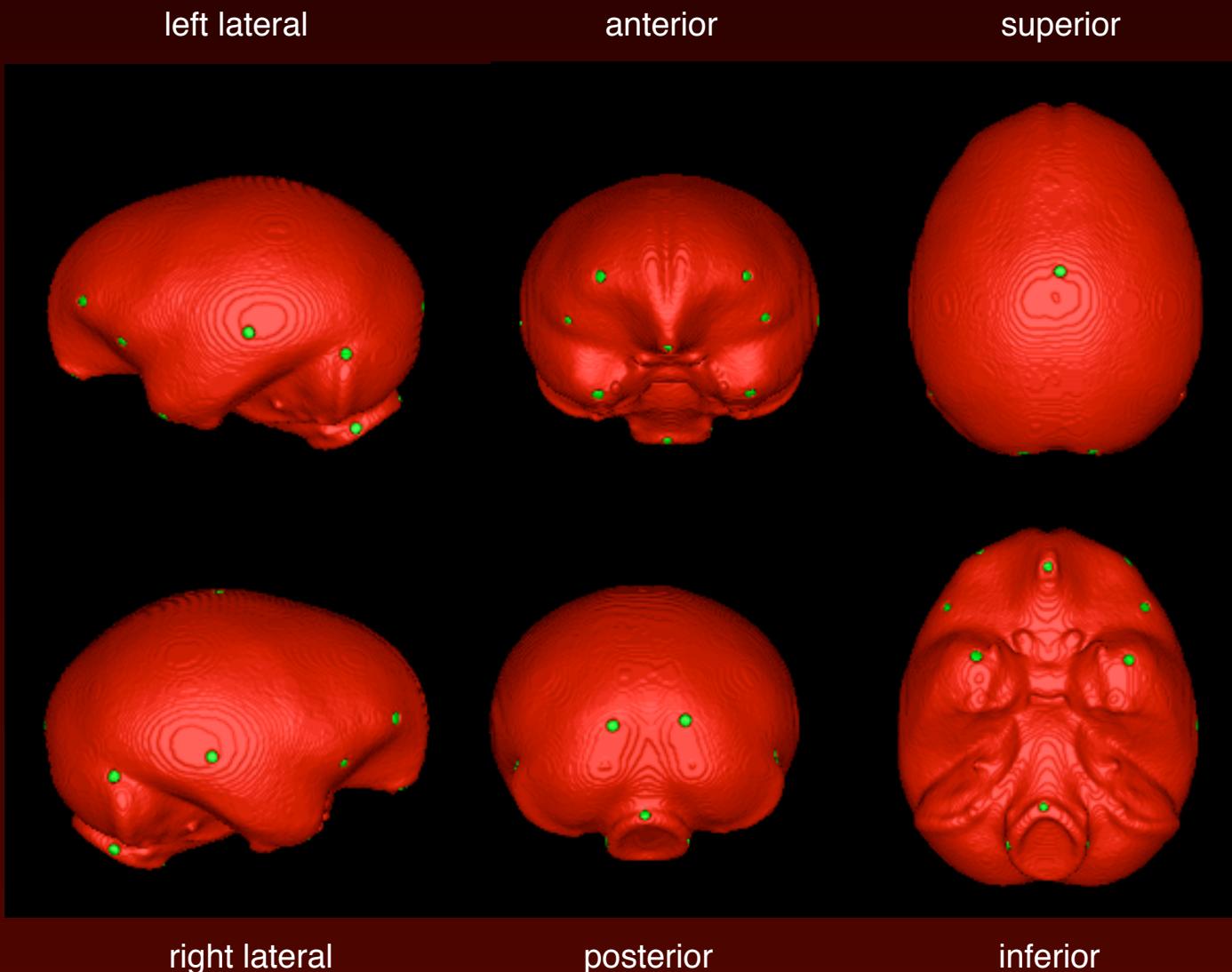
*Homo  
sapiens*

*Pongo* morphed  
partway to *Homo*

*Pongo*  
*pygmaeus*



# comparison mapping locations on *Pan troglodytes*



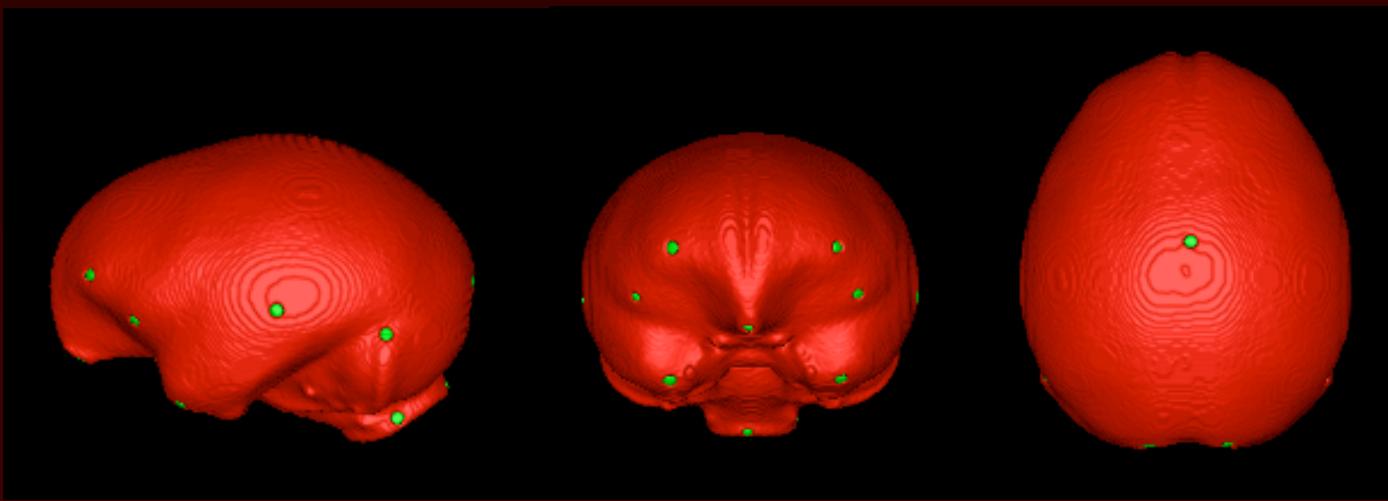
# comparison mapping

locations  
chosen on  
*Pan troglodytes*

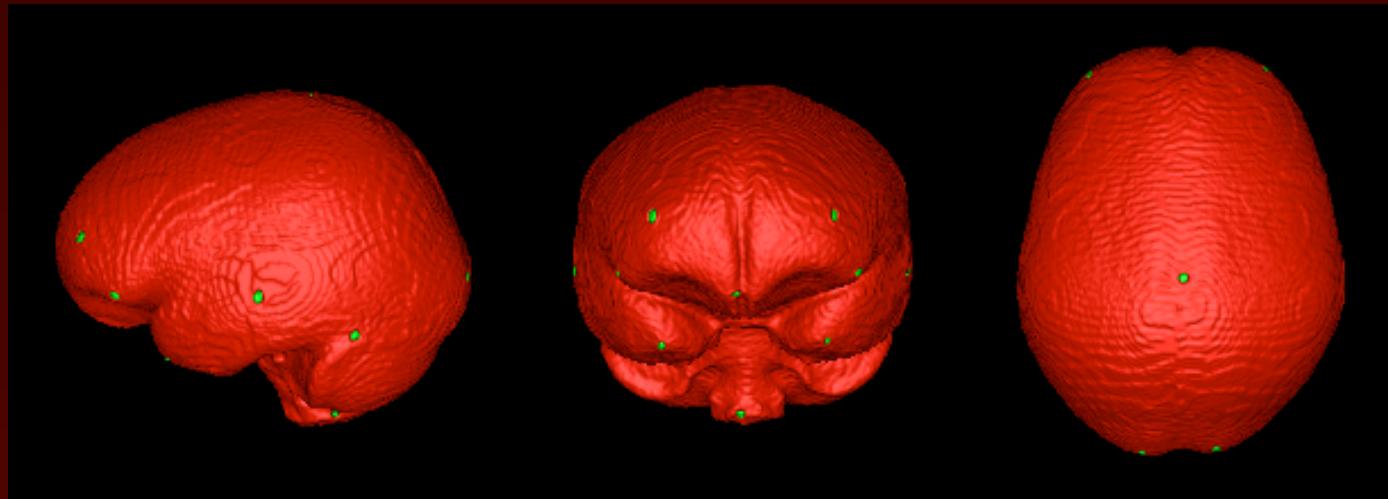
left lateral

anterior

superior



locations warped  
to *Homo sapiens*  
space



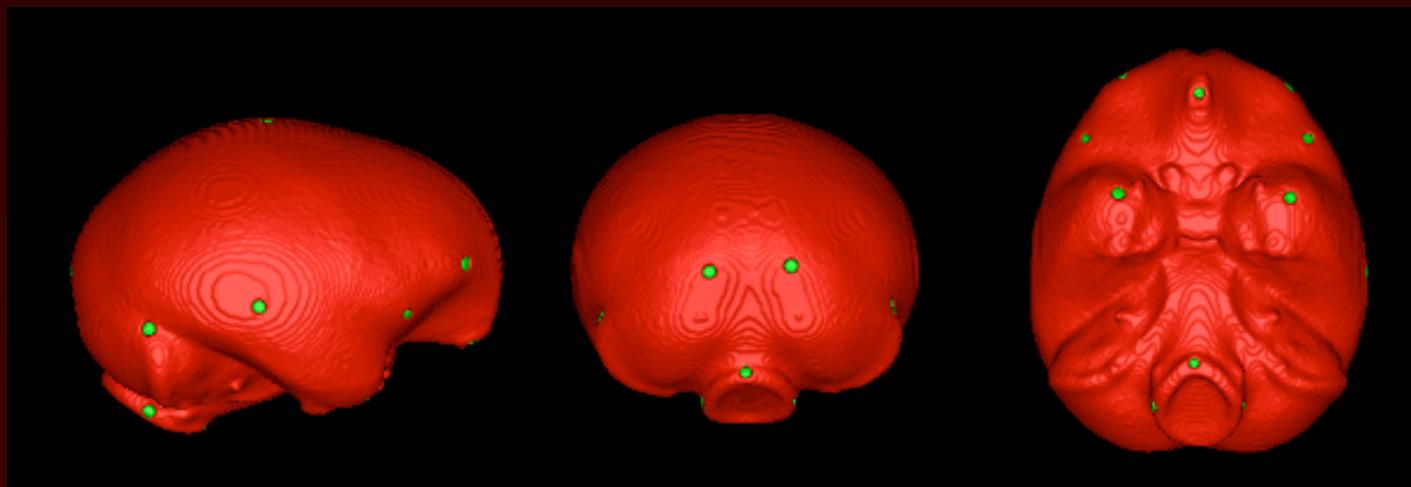
# comparison mapping

locations  
chosen on  
*Pan troglodytes*

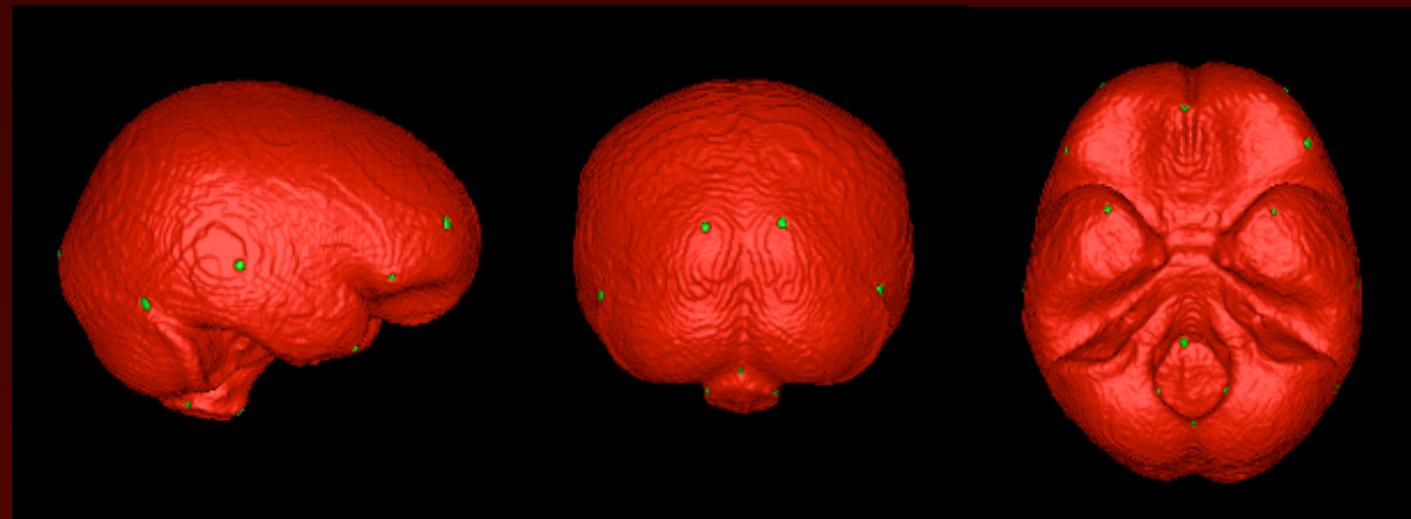
right lateral

posterior

inferior



locations warped  
to *Homo sapiens*  
space

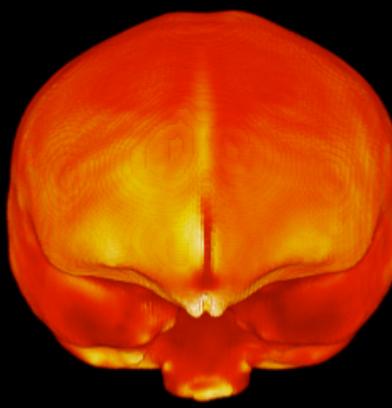


*Pan troglodytes* morphed into *Homo sapiens*  
(foramen magnum constrained)

left lateral



anterior



superior



scalars

8

6

4

2

0



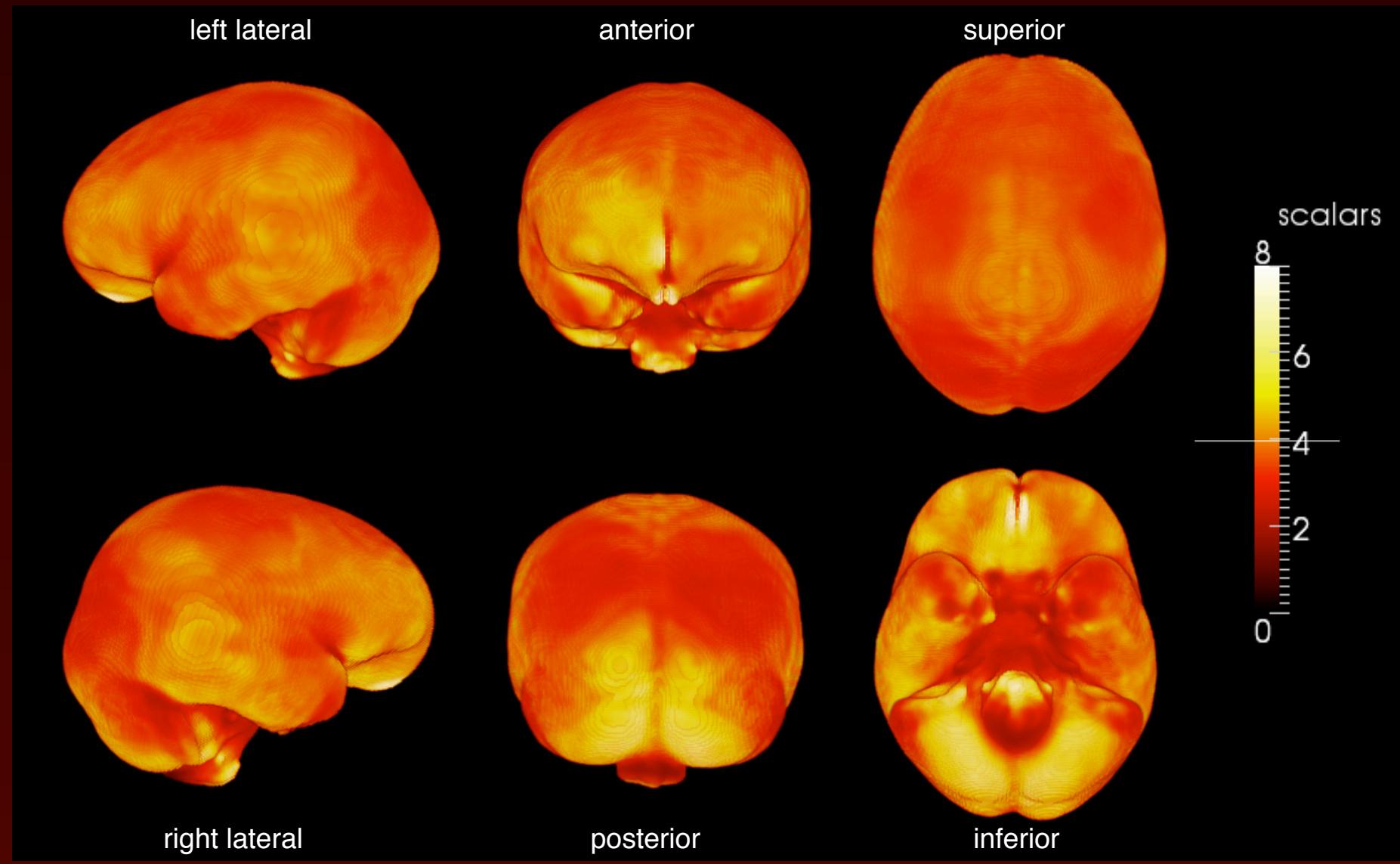
right lateral

posterior

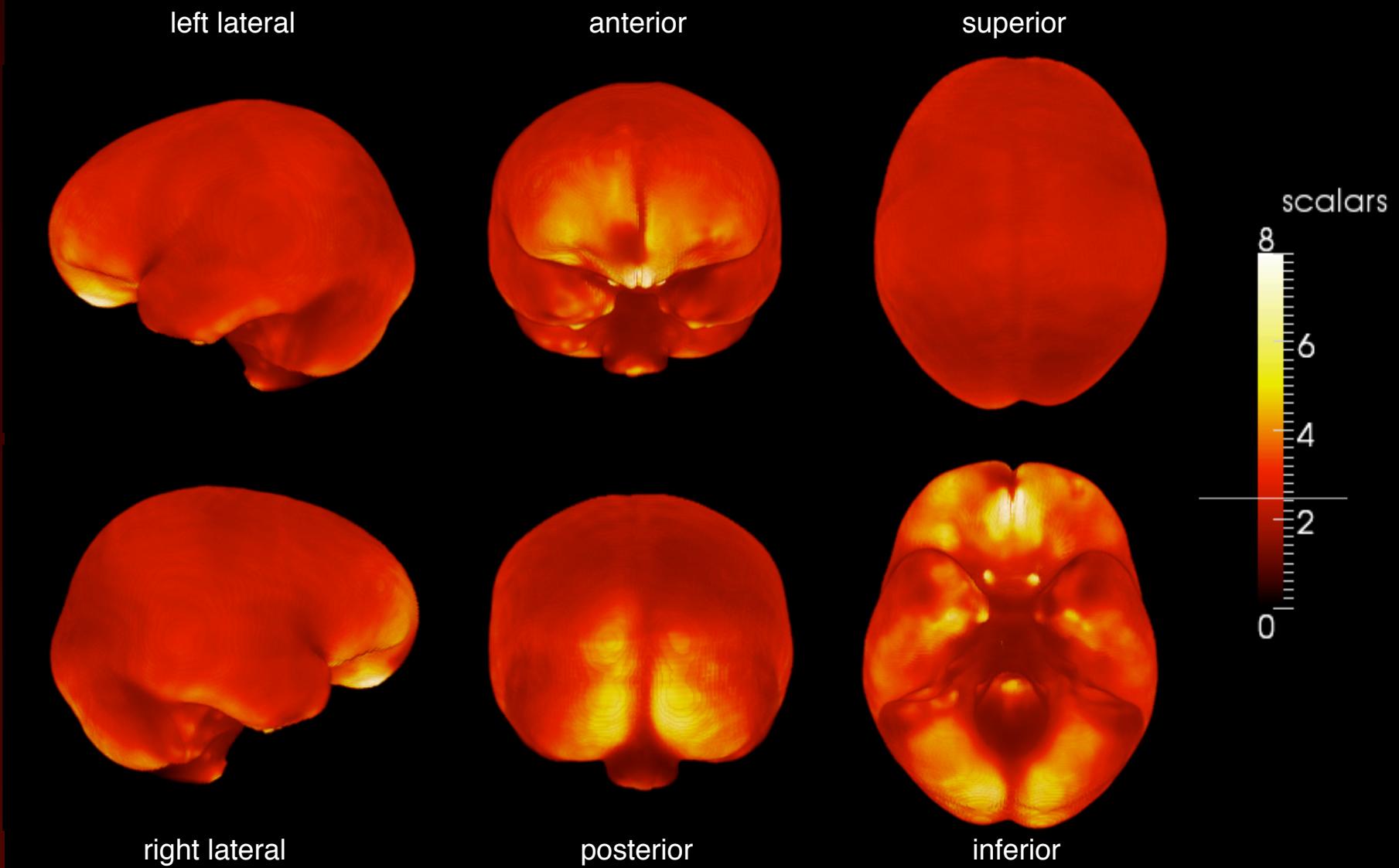
inferior



*Pan paniscus* morphed into *Homo sapiens*  
(foramen magnum constrained)



# *Gorilla gorilla* morphed into *Homo sapiens* (foramen magnum constrained)

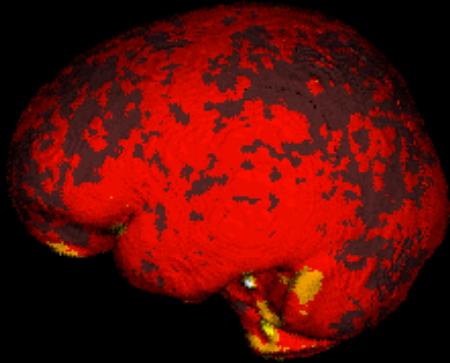


# Additional benefits

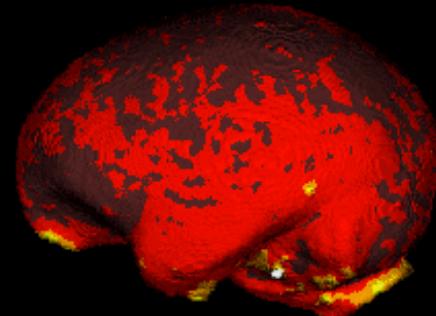
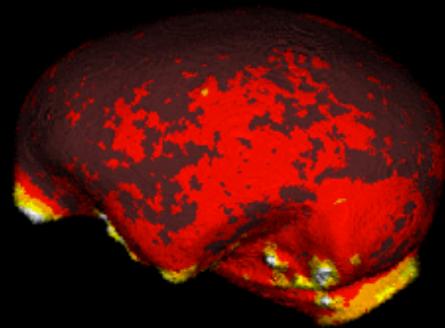
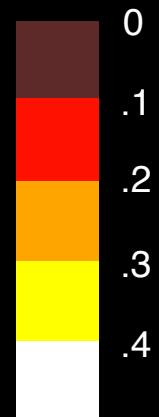
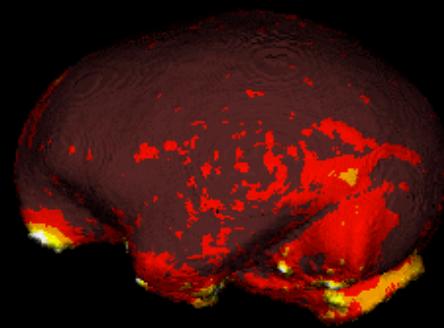
Degree of variation in Jacobians (i.e., scaling factors) can easily be calculated, thereby highlighting the locations where the shape is most variable across individuals in a population

# Standard deviations of log Jacobians

*Homo sapiens*



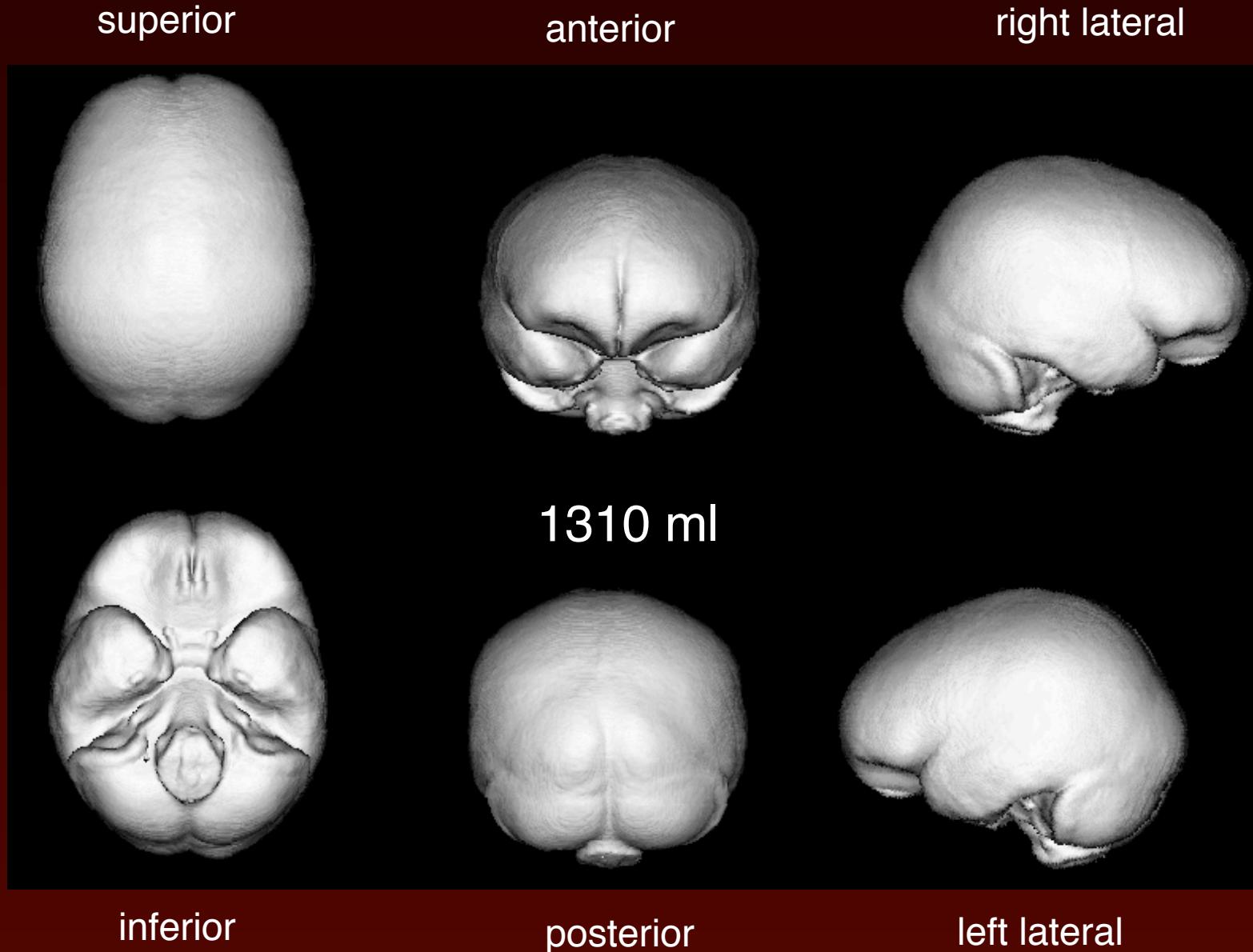
*Pan troglodytes*



*Gorilla gorilla*

*Pan paniscus*

# Average *Homo sapiens* endocranial shape



# Average *Pan troglodytes* endocranial shape

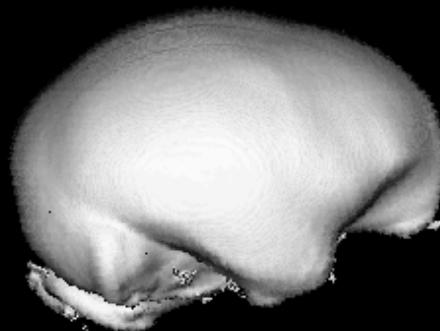
superior



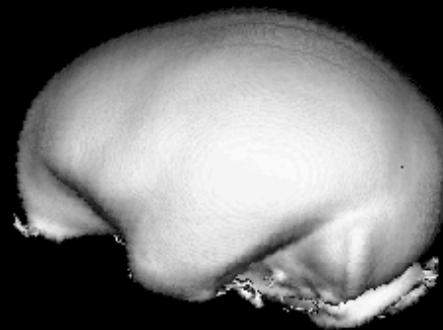
anterior



right lateral



387 ml



inferior

posterior

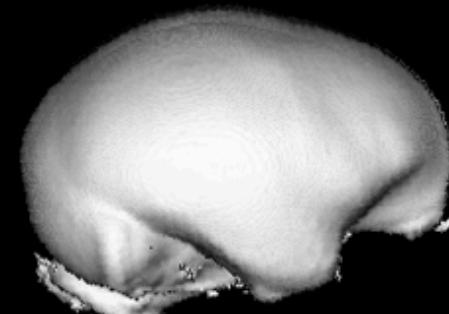
left lateral

# Average *Pan paniscus* endocranial shape

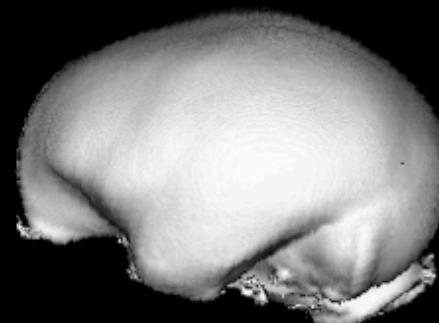
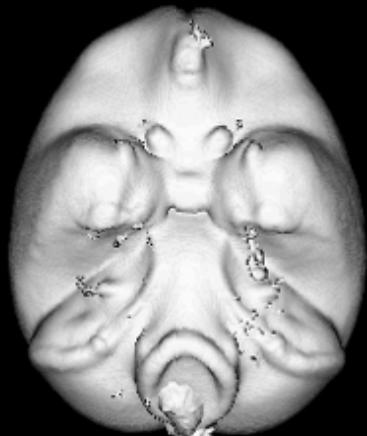
superior

anterior

right lateral



331 ml



inferior

posterior

left lateral

# Average *Gorilla gorilla* endocranial shape

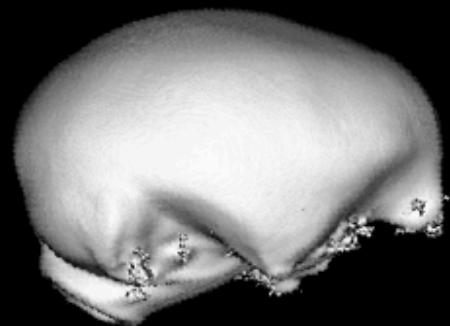
superior



anterior



right lateral



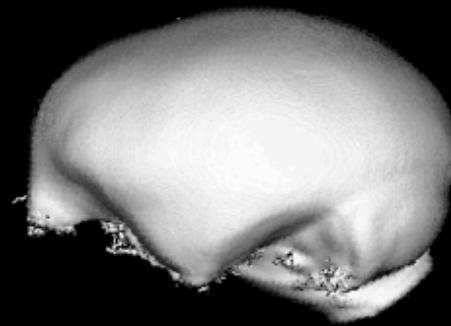
507 ml



inferior

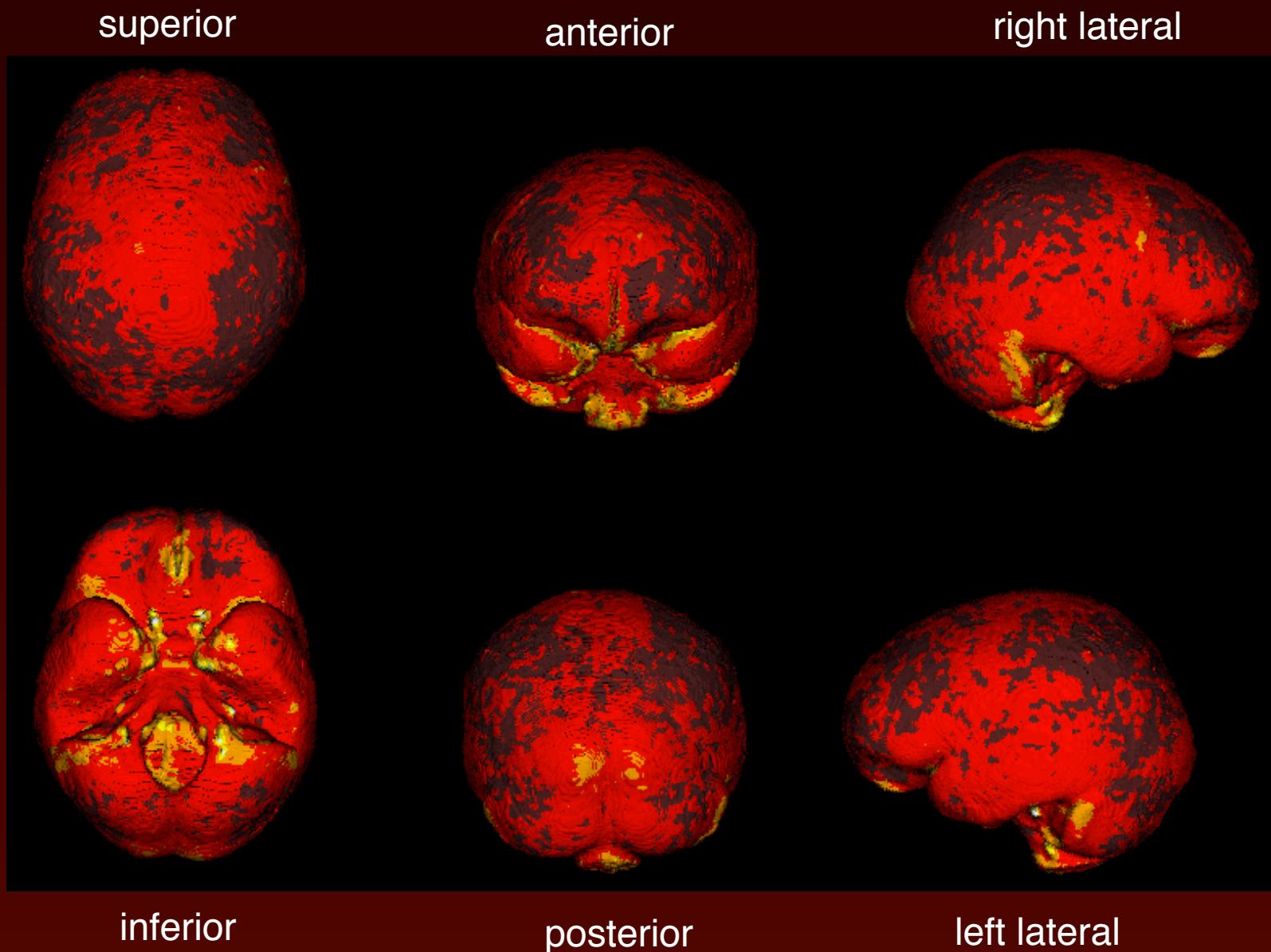


posterior

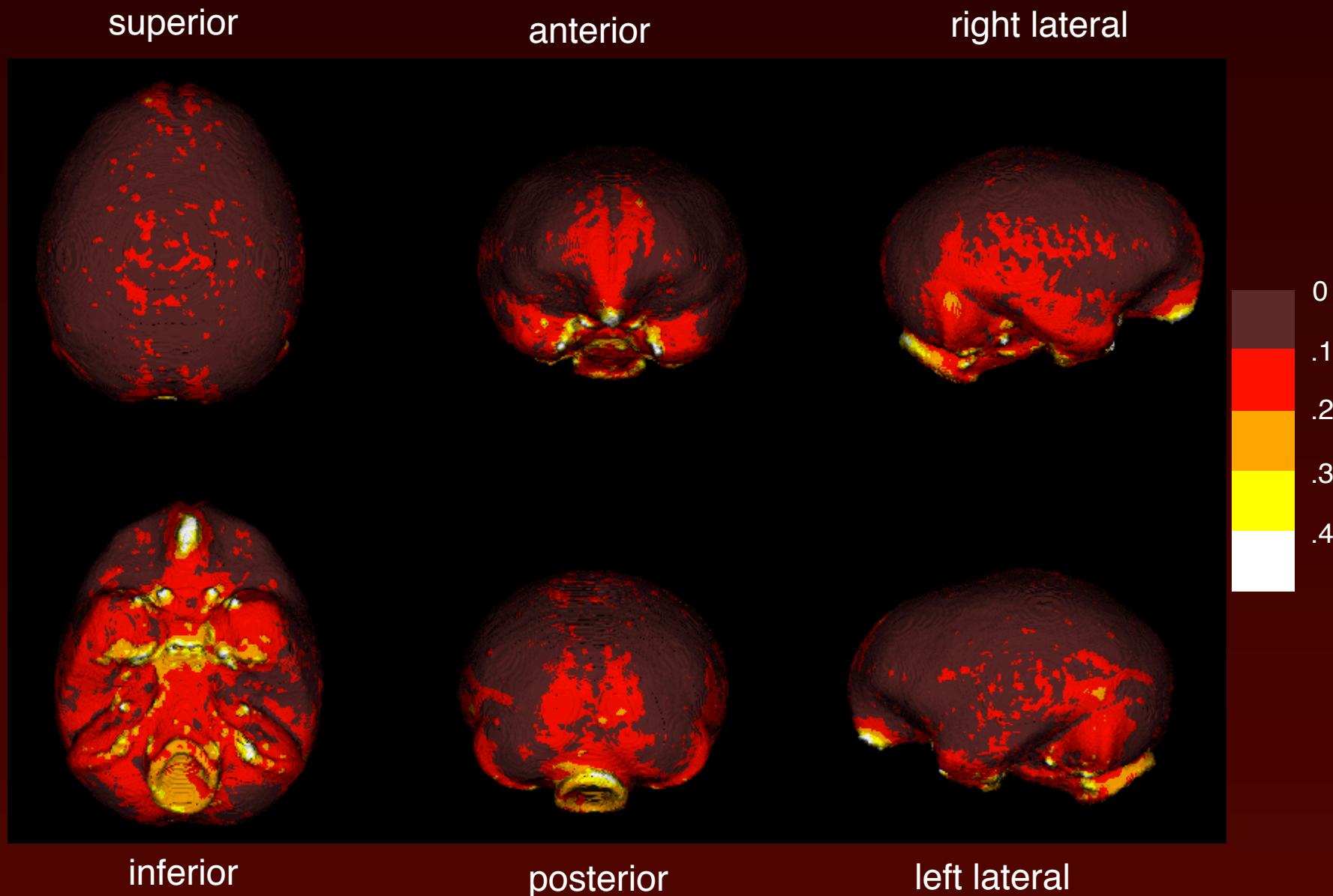


left lateral

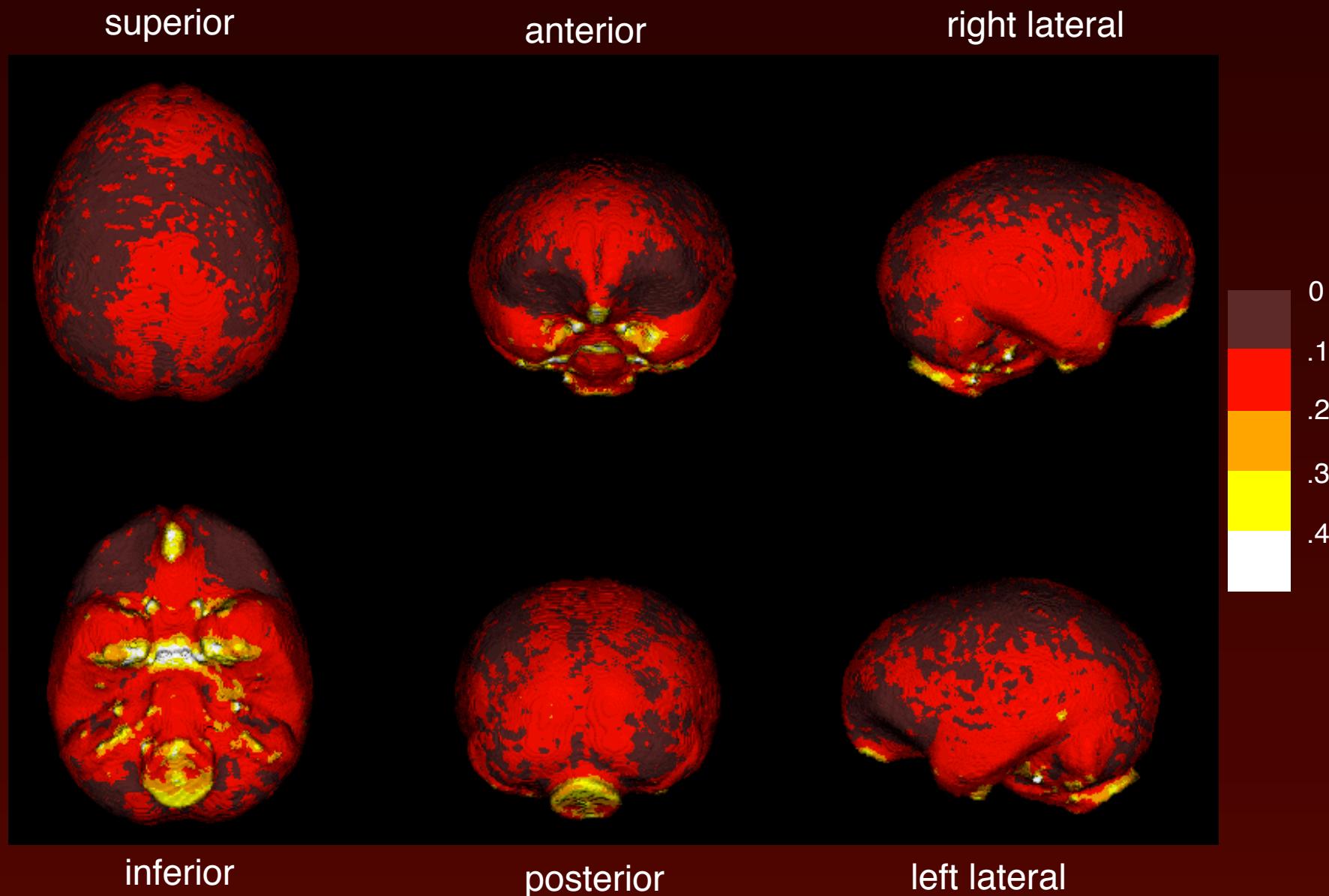
# Standard deviations of log Jacobians for *Homo sapiens*



# Standard deviations of log Jacobians for *Pan troglodytes*



# Standard deviations of log Jacobians for *Pan paniscus*



# Standard deviations of log Jacobians for *Gorilla gorilla*

