

Introduction to statistical shape analysis II: Semi- landmarks and beyond

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8/19/20



How many landmarks are enough to characterize shape and size variation?

- Criteria for landmarks to be homologous and reproducible results in very sparse data from images
- For many data sets, this may not be sufficient to capture shape changes, especially along curves or smooth surfaces
- Point-landmark too stringent for effective biometrics in many 3D applications

Watanabe, Akinobu. "How many landmarks are enough to characterize shape and size variation?." PloS one 13.6 (2018): e0198341.



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Image data provides rich phenotype descriptions – how can this be leveraged?

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Landmark types

- Type I: Points with homology provided by a biologically location on the form
- Type II: Points with homology determined by geometric criteria
- Type III: Points with a location dependent on other landmark points



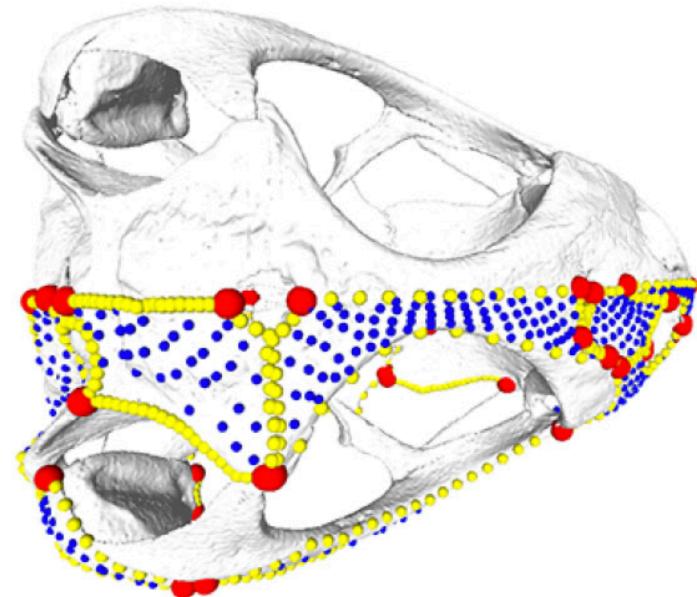
Landmark types

- Type I: Points with homology provided by a biologically location on the form
- Type II: Points with homology determined by geometric criteria
- Type III: Points with a location dependent on other landmark points
- **Pseudolandmarks: Points placed automatically without reference to anatomical landmarks.**



3D semi-landmark placement

- Generally placed on a template
- Equally spaced points are placed along curves
- Surface patches are evenly sampled
- Landmarks can be used to anchor patches or curves



Bardua, C., Felice, R. N., Watanabe, A., Fabre, A. C., & Goswami, A. (2019). A practical guide to sliding and surface semilandmarks in morphometric analyses. *Integrative Organismal Biology*, 1(1), obz016.

What is wrong with equidistant samples?

Produce spacing as a by-product of the analysis since the analysis is ignorant of the actual spacing.



Figure 3. (a) Form with one true landmark in the lower left corner and 31 other points equally spaced along the outline. (b) Bent form with one true landmark (1) and 31 other points in equal spacing. (c) The position of the points now optimizes bending energy.

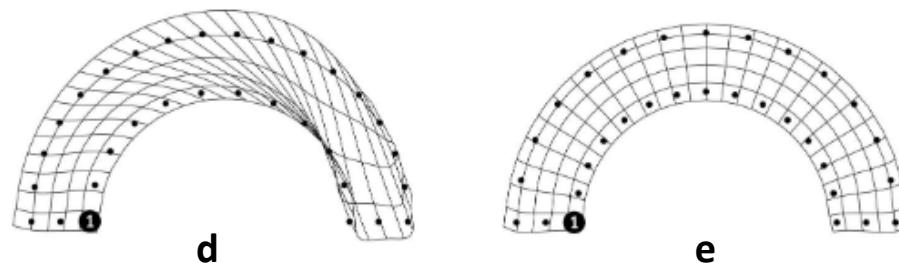


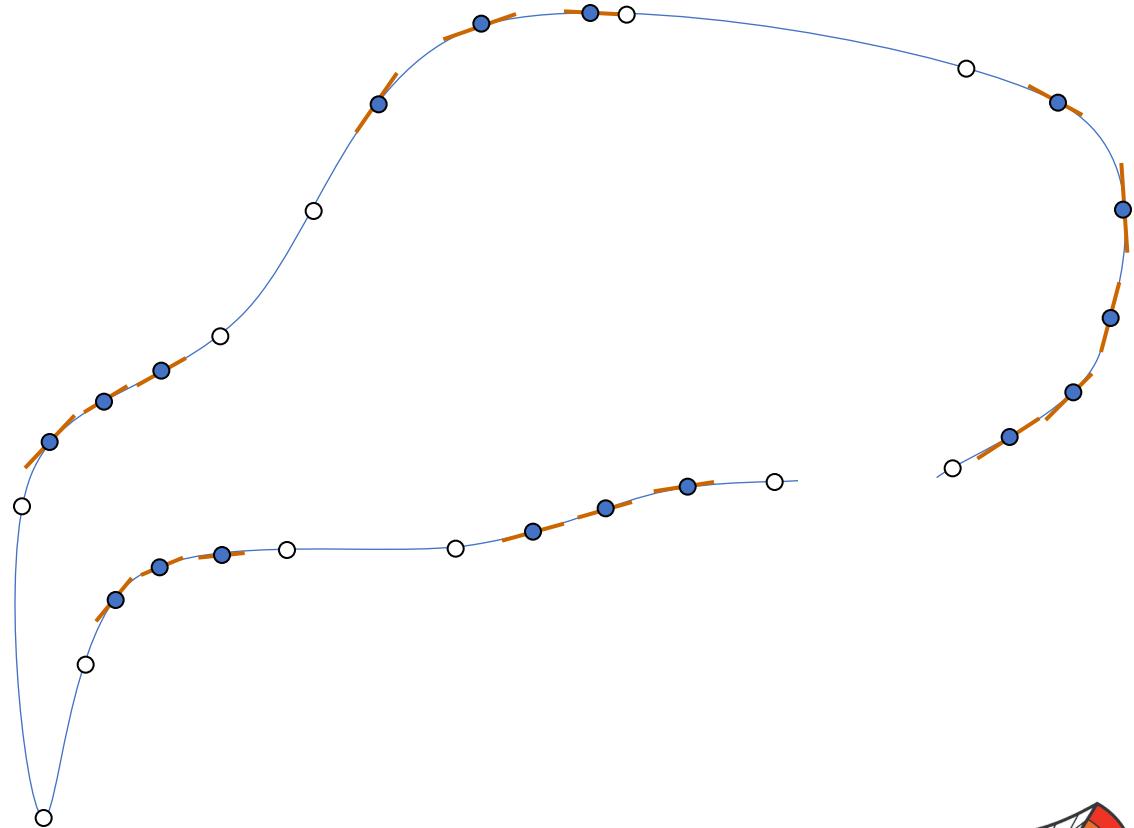
Figure 4. Splines corresponding to Figure 3. (a) Deformation grid from the form in Figures 3a and 3b. (b) Deformation grid from the form in Figures 3a and 3c.

Gunz, Philipp, Philipp Mitteroecker, and Fred L. Bookstein. "Semilandmarks in three dimensions." *Modern morphometrics in physical anthropology*. Springer, Boston, MA, 2005.
73-98.



Sliding semi-landmark method

- 1) Slide semi-landmark points along the surface until they satisfy matching criteria with a single reference specimen
- 2) Calculate Procrustes average shape
- 3) Slide semi-landmark points along the surface until they satisfy matching criteria with the Procrustes average
- 4) Repeat steps 3 and 4 until convergence



Bookstein, Fred L. "Landmark methods for forms without landmarks: morphometrics of group differences in outline shape." *Medical image analysis* 1.3 (1997): 225-243.

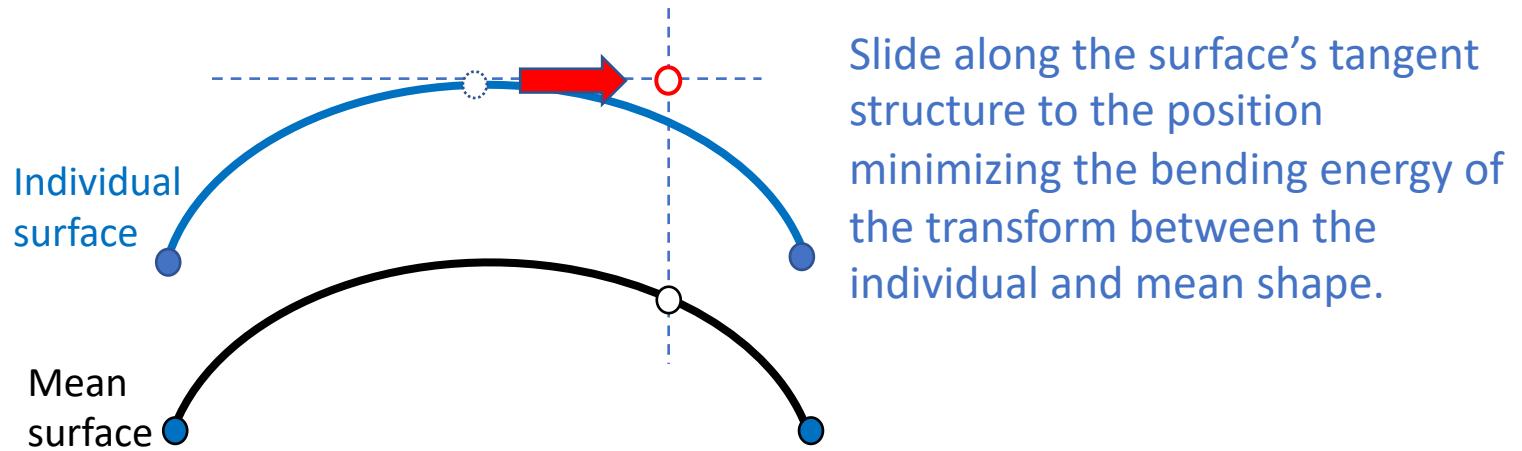


Determining position of sliding semi-landmarks

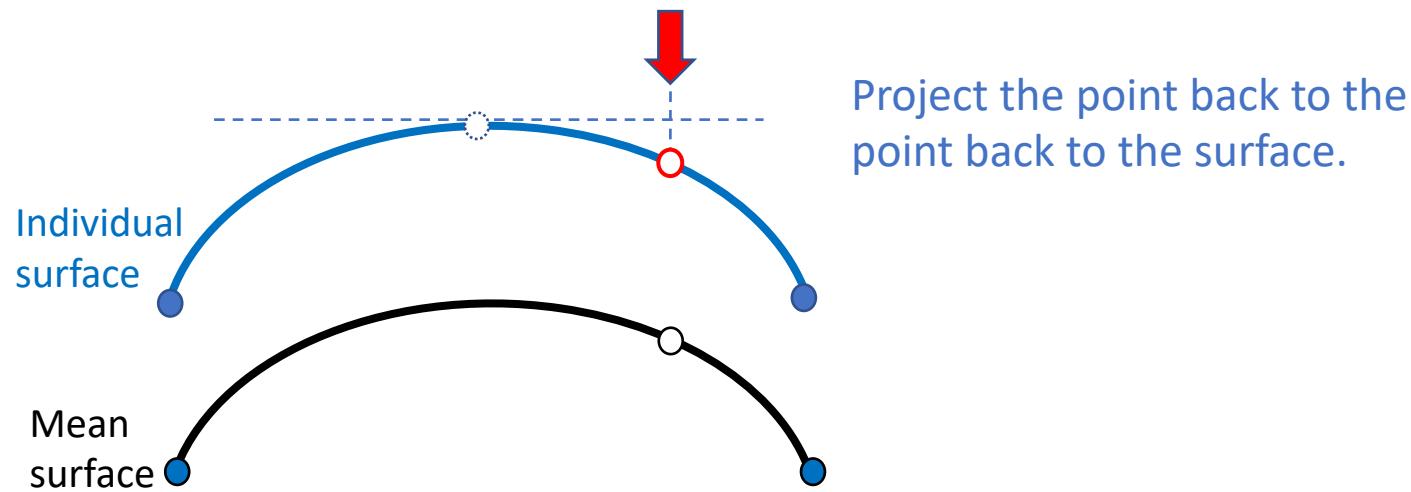
- 1) Minimum bending energy criterion:** select semi-landmark positions that result in the smoothest possible transformation to the mean shape
- 2) Procrustes distance criterion:** estimate the tangent to the mean surface for each semi-landmark point and remove the component of the difference between the mean and each specimen that lies along this tangent.



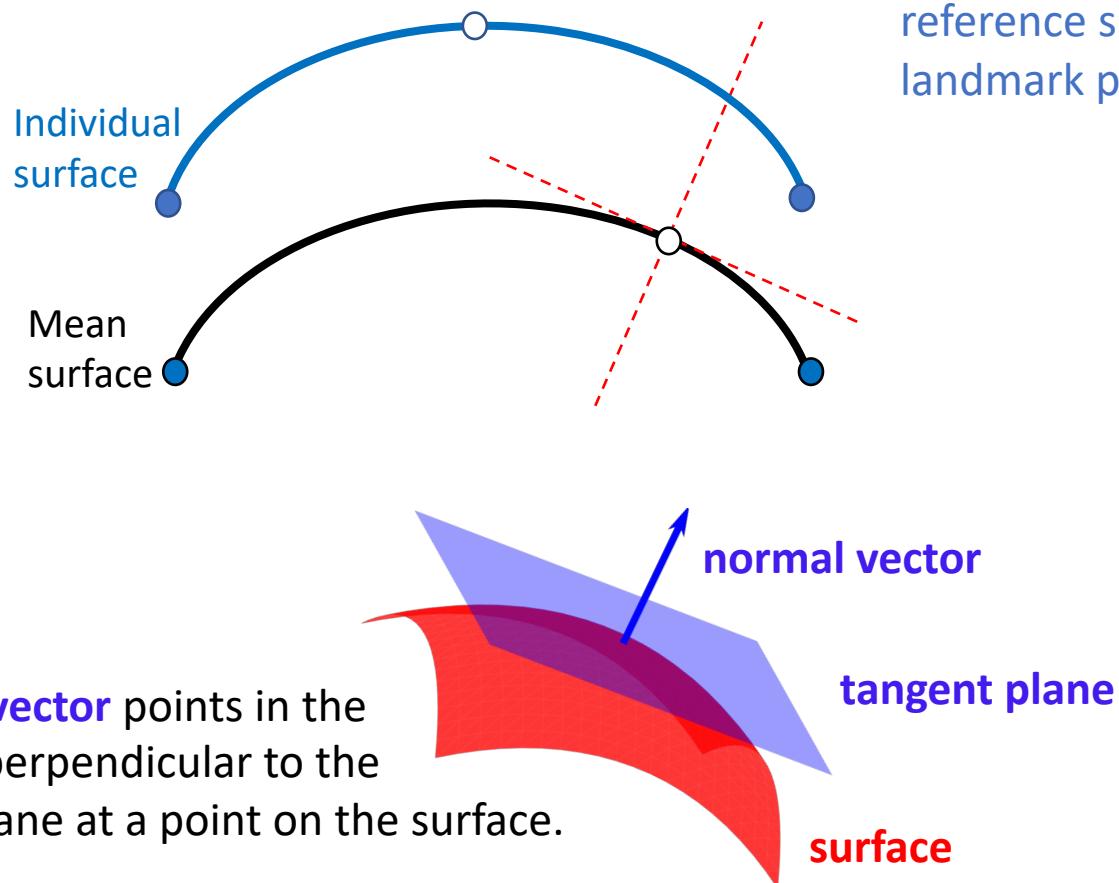
Minimum bending energy criteria



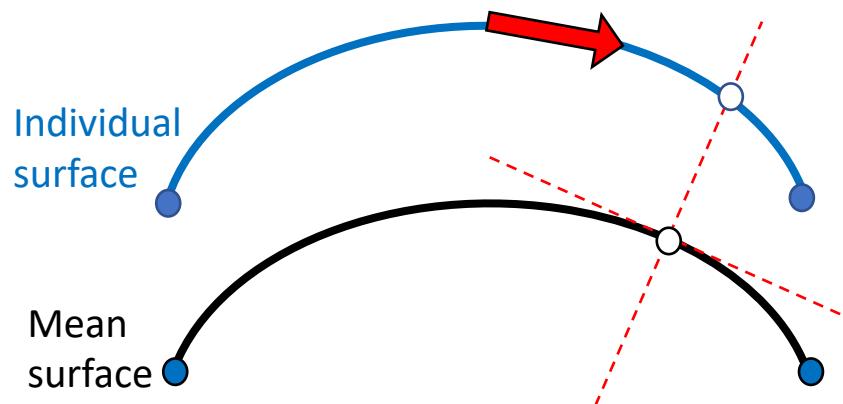
Minimum bending energy criteria



Procrustes distance criteria

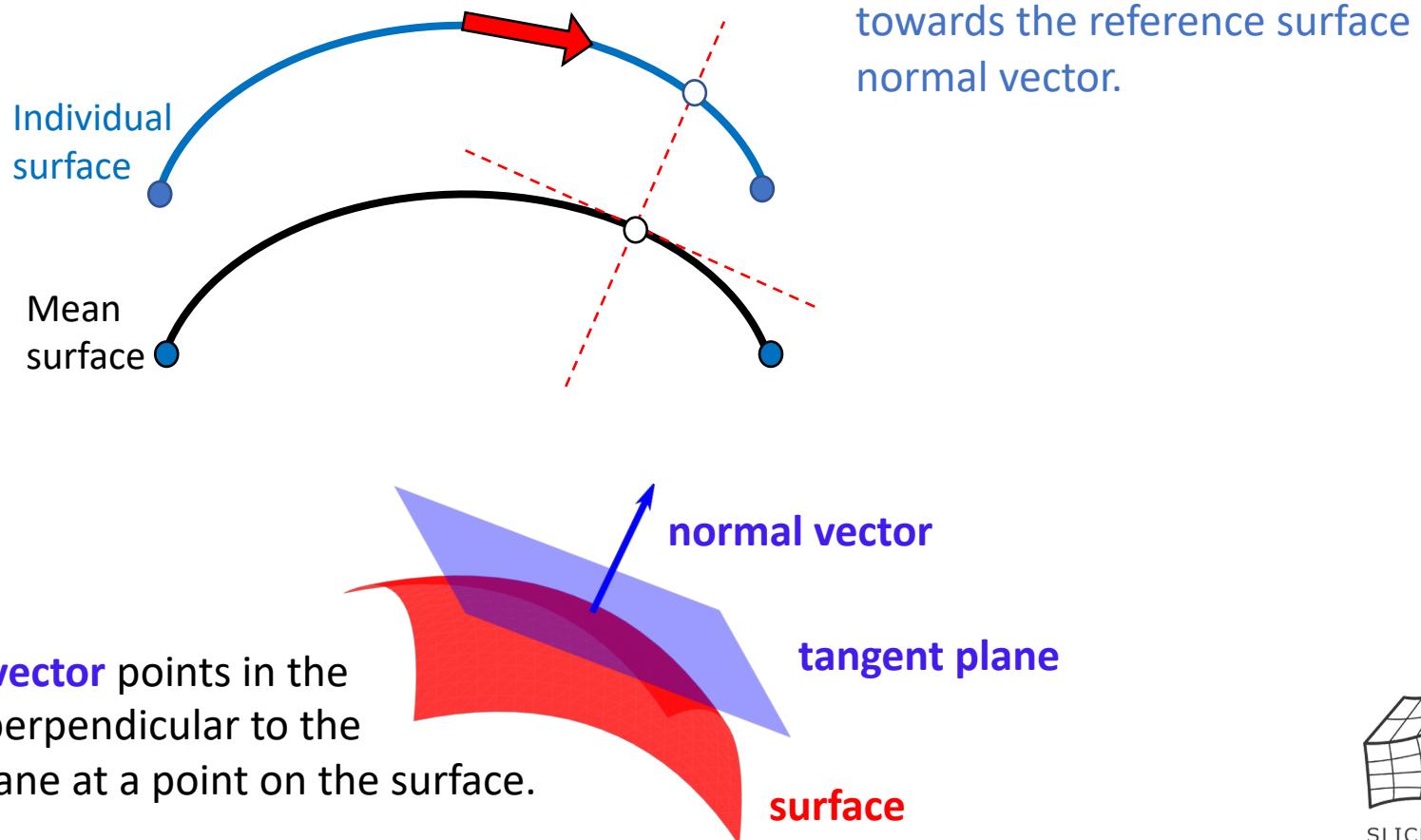


Procrustes distance criteria

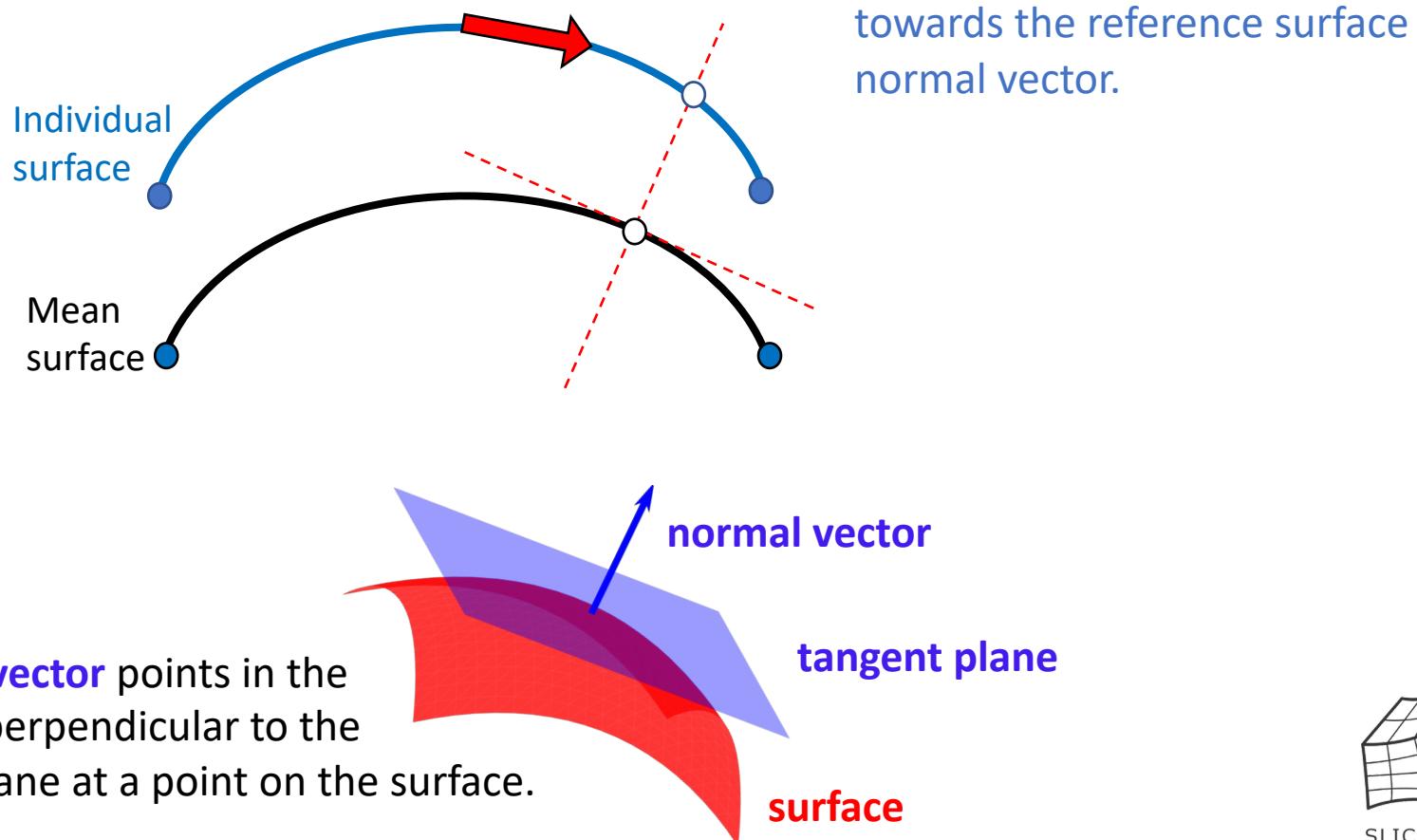


Slide the semi-landmark
towards the reference surface
normal vector.

Procrustes distance criteria



Procrustes distance criteria



Minimum bending energy or Procrustes distance?

- Use different background assumptions
- The difference between the criteria can alter the results when morphological variation in the sample is low
- More noticeable with smaller numbers of semi-landmarks

Perez, S. Ivan, Valeria Bernal, and Paula N. Gonzalez. "Differences between sliding semi-landmark methods in geometric morphometrics, with an application to human craniofacial and dental variation." *Journal of anatomy* 208.6 (2006): 769-784.



Limitations of semi-landmarks

- Limited homology
- The method of handling semi-landmarks can influence the results
- The number of semi-landmarks may also influence the results
- Sliding semi-landmark positions are dependent on the dataset. Not possible to compare new shapes without recalculating

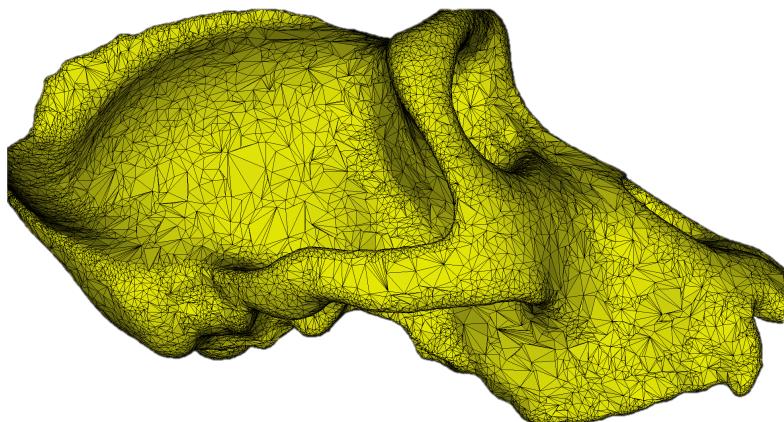


Working with semi-landmarks in 3D

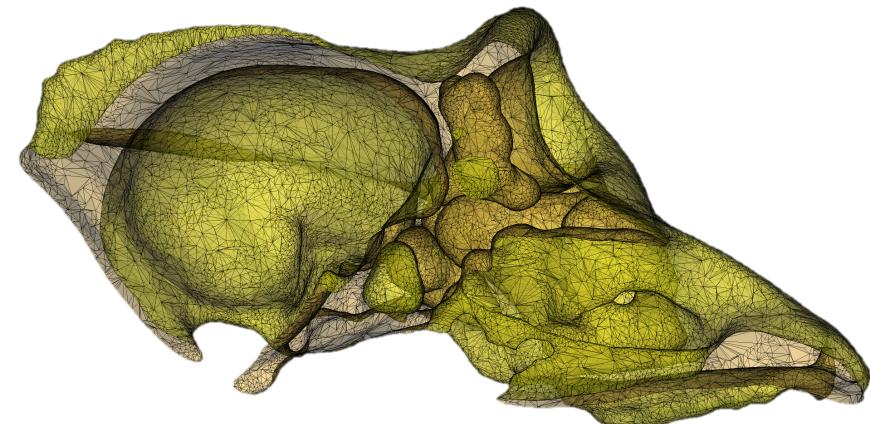


Initial semi-landmark placement

- Generating equally spaced samples on a surface can be surprisingly complex
- SlicerMorph provides flexible tools for generating semi-landmarks and pseudo-landmarks for different data types



Exterior of mesh



Complex internal structures



SLICERMORPH

Semi-landmarking: Curves

3DSlicer

DATA DCM SAVE Modules: **Markups**

Help & Acknowledgement

Create:

Node	Description
MarkupsCurve	

Display

Control Points

Resample

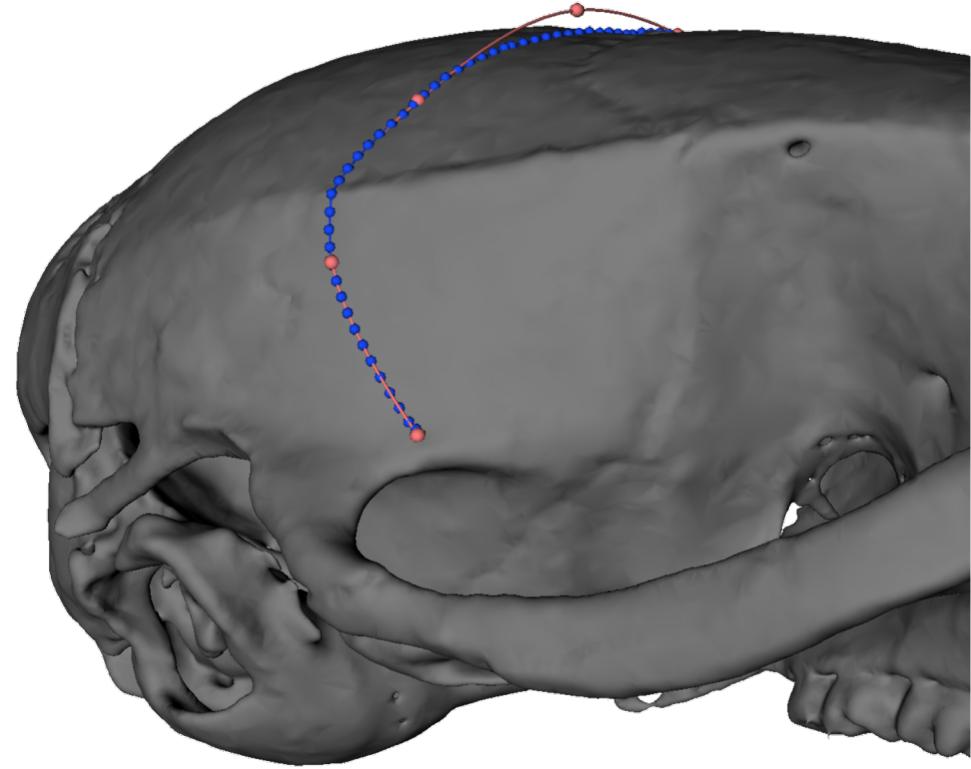
Output node: (Overwrite current node)

Number of resampled points: 50

Constrain points to surface: mask

Advanced

Resample curve



Patch-based placement of semi-landmarks

3DSlicer

DATA DCM SAVE Modules: SemiLandmark

Help & Acknowledgement

Reload & Test

Reload Reload and Test Edit Restart Slicer

Parameters

Model: gor_skull

Landmark set: Gorilla_template_LM1

Semi-landmark grid points: 1 0 0

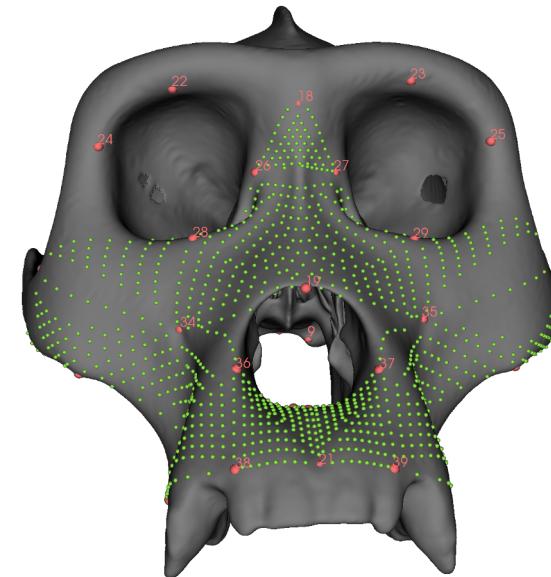
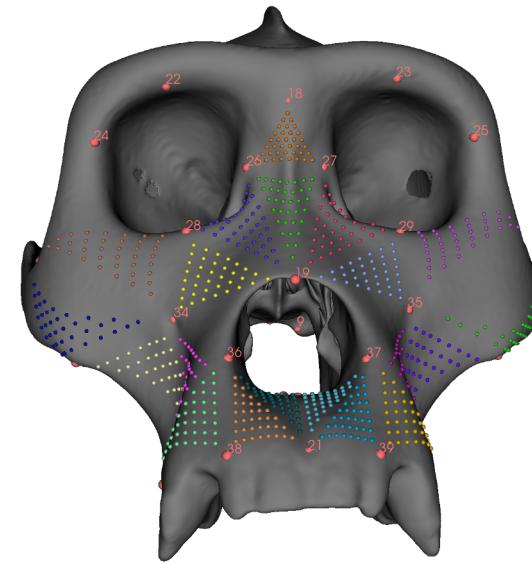
Select number of rows/columns in resampled grid: 10

Enable Screenshots

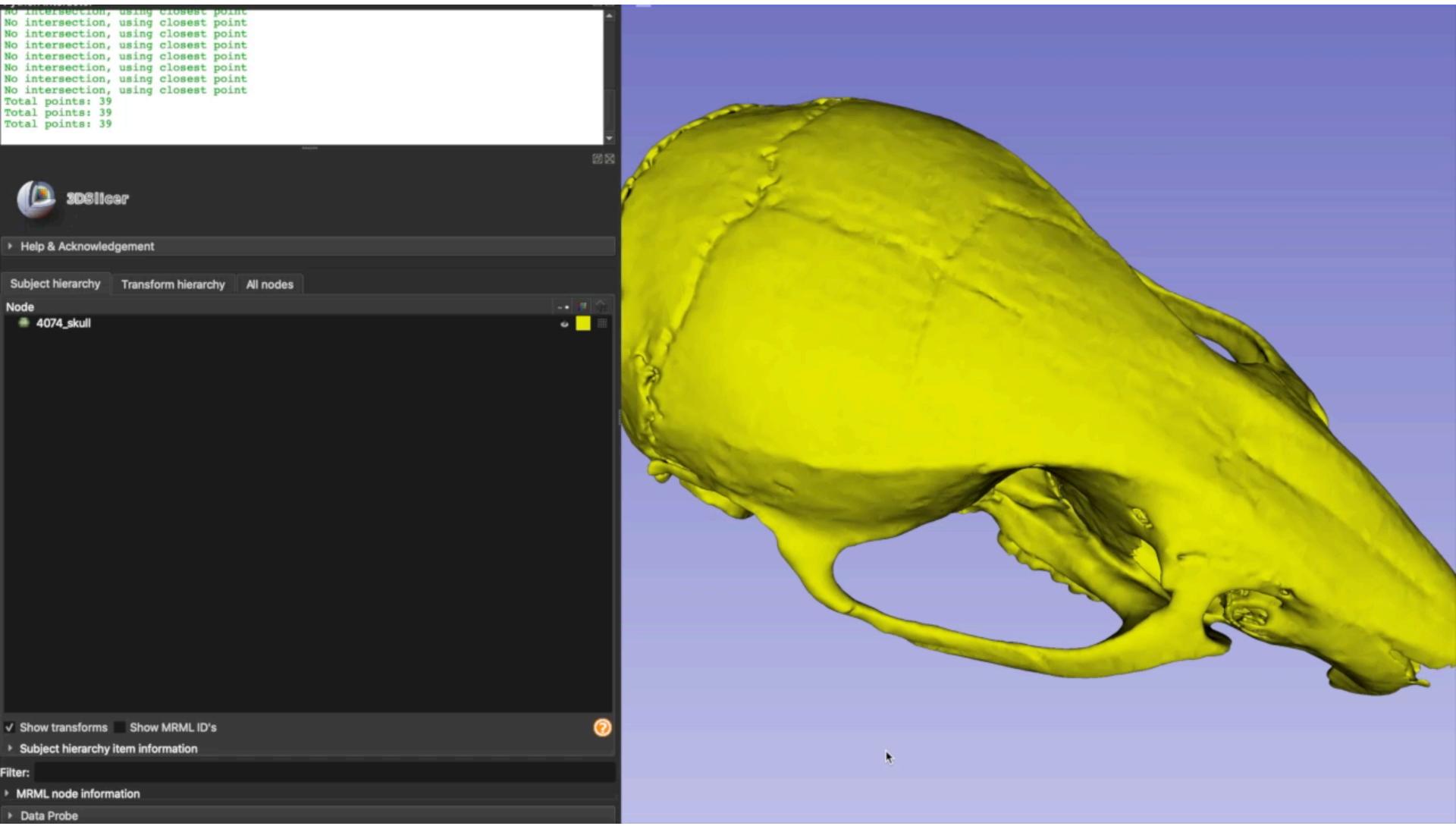
Apply

Node	IDs
semiLM_28_19_34	vtkMRMLMarkupsFiducialNode44
semiLM_28_19_26	vtkMRMLMarkupsFiducialNode47
semiLM_27_19_26	vtkMRMLMarkupsFiducialNode48
semiLM_27_19_29	vtkMRMLMarkupsFiducialNode49
semiLM_35_19_29	vtkMRMLMarkupsFiducialNode50
semiLM_35_29_31	vtkMRMLMarkupsFiducialNode52
semiLM_35_33_31	vtkMRMLMarkupsFiducialNode53
semiLM_35_33_41	vtkMRMLMarkupsFiducialNode54
semiLM_35_37_41	vtkMRMLMarkupsFiducialNode55
semiLM_30_37_41	vtkMRMLMarkupsFiducialNode56

Merge highlighted nodes



Semi-landmark tools in SlicerMorph



Spherical sampling

3DSlicer

Modules: SphericalSampling

Help & Acknowledgement

Reload & Test

Reload Reload and Test Edit Restart Slicer

Input Parameters

Base mesh: full_zf_atlas_model

Spacing tolerance: 3.00

Template Geometry

Original Geometry Ellipse Sphere

Template scale factor: 106.00

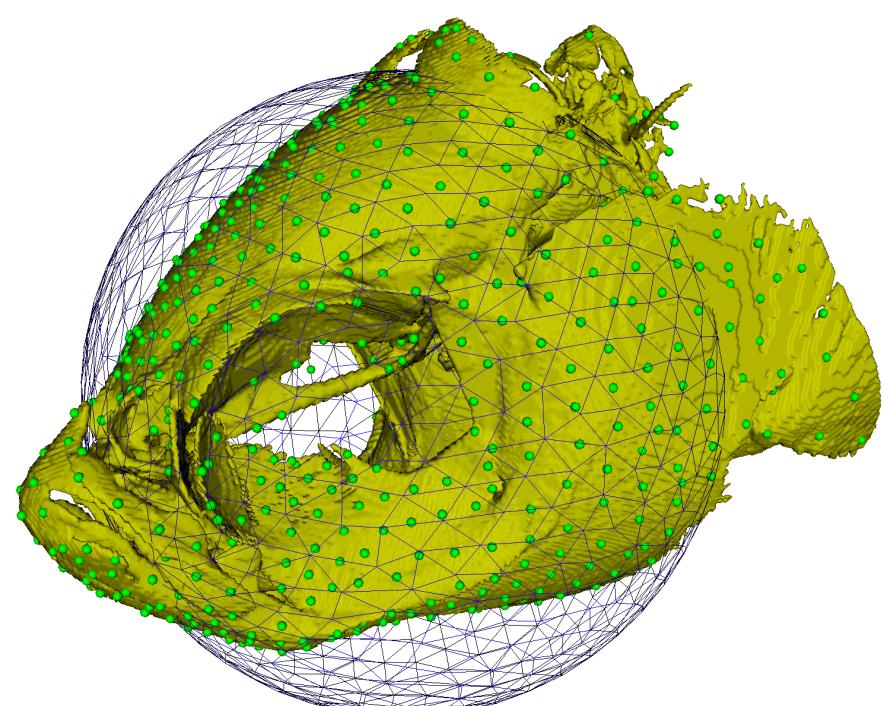
Maximum projection factor: 200.00

Run Sampling

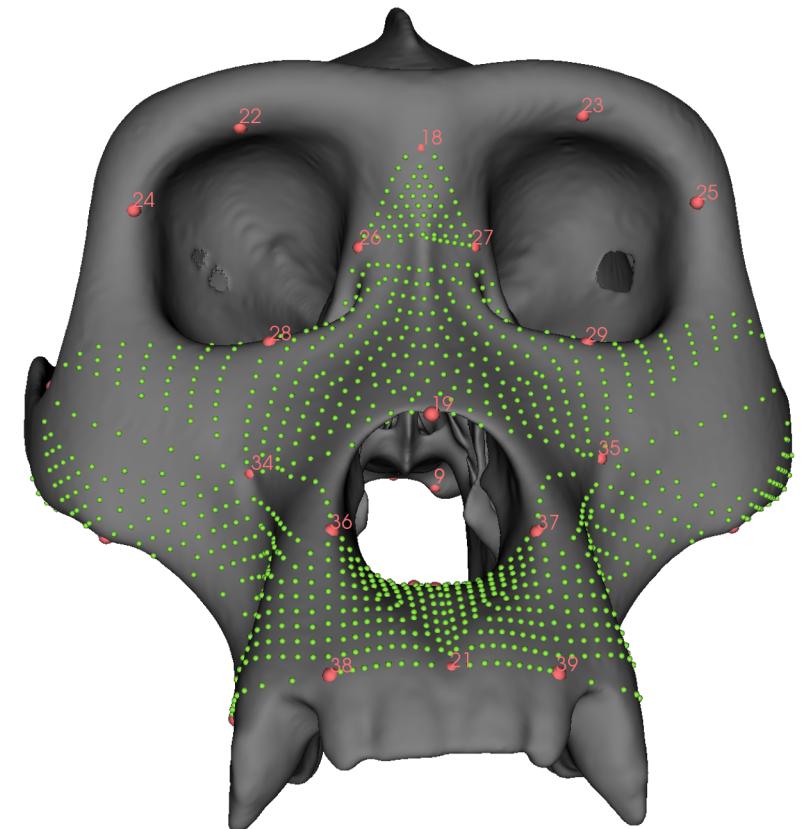
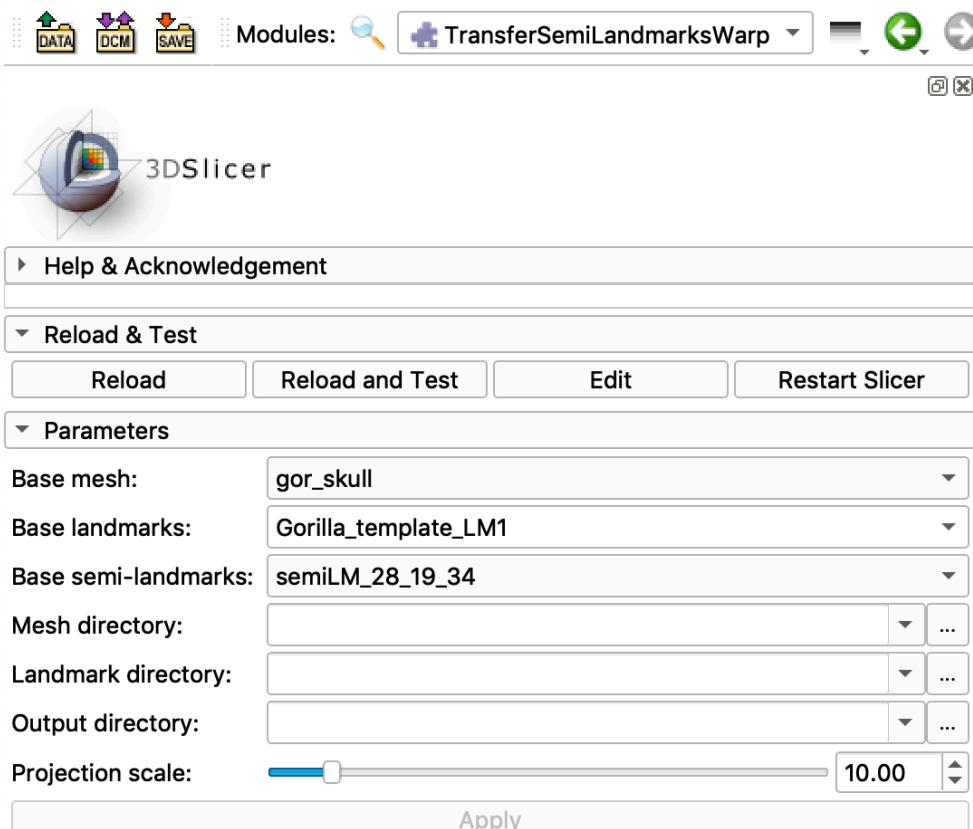
Get subsample number

The subsampled template has a total of 1133 points.
The subsampled template has a total of 934 points.
After filtering there are 781 semi-landmark points.
The subsampled template has a total of 889 points.
After filtering there are 780 semi-landmark points.
The subsampled template has a total of 889 points.
The subsampled template has a total of 934 points.
The subsampled template has a total of 934 points.

Generate template
Project points to surface
Enforce spatial sampling rate



Transferring Semi-landmarks-TPS



Transferring Landmarks - ALPACA

3DSlicer

Modules: DATA DCM SAVE ALPACA

Help & Acknowledgement

Reload & Test

Reload Reload and Test Restart Slicer

Edit Edit UI

Single Alignment Batch processing

Align and subsample a source and target mesh

Source mesh: e/Dropbox/SlicerWorkspace/notebooks/in/A_J_.ply

Source landmarks: /Dropbox/SlicerWorkspace/notebooks/in/A_J_.fcsv

Target mesh: ox/SlicerWorkspace/notebooks/in/B6CBAF1.J_.ply

Select subsampling voxel size: 0.70

Advanced parameter settings

Run subsampling

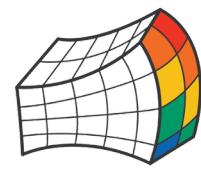
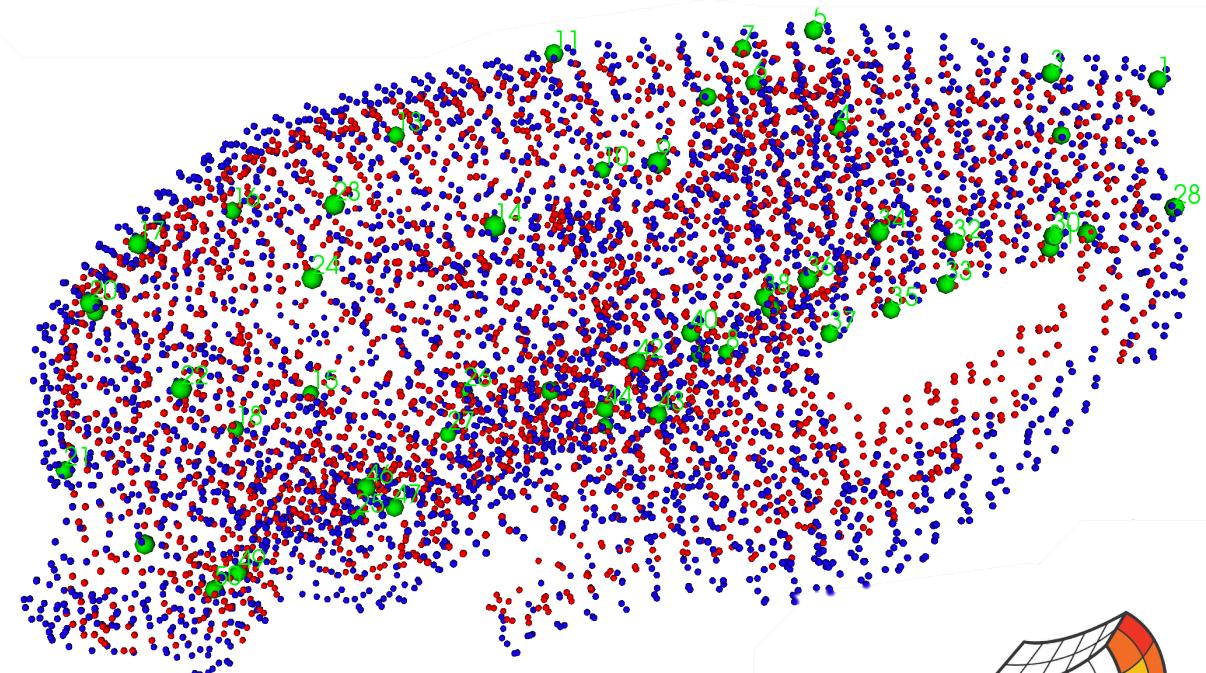
Your subsampled source pointcloud has a total of 2806 points.
Your subsampled target pointcloud has a total of 3209 points.

Run rigid alignment

Display rigidly aligned meshes

Run CPD non-rigid registration

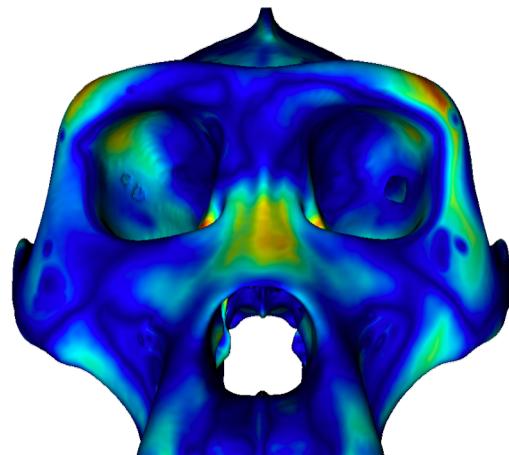
Show registered source model



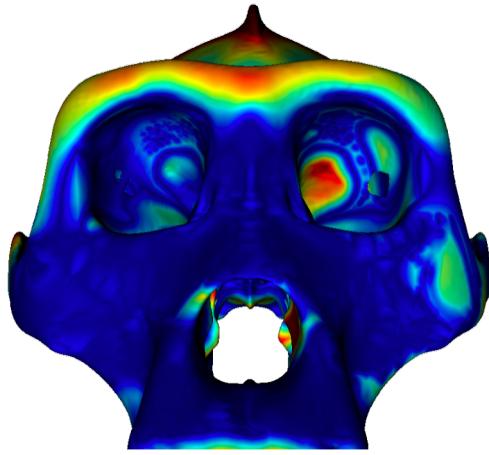
SLICERMORPH

Comparing Semi-landmark methods

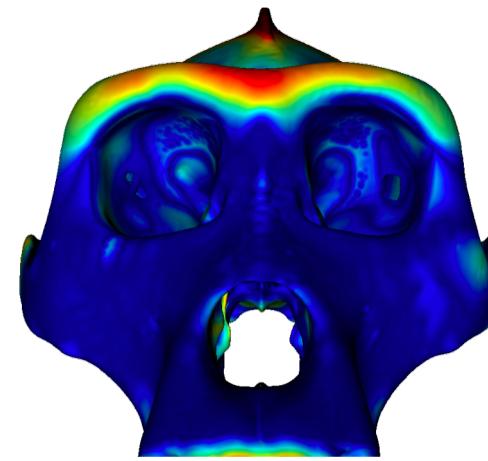
Species	N	Manual landmarks (mm)	Individually placed patch semi-landmarks (mm)	TPS-placed patch semi-landmarks (mm)	Spherical surface sampling (mm)
Gorilla	22	1.267 (SD=0.177)	1.177 (SD=0.162)	1.076 (SD=0.521)	1.124 (SD=0.120)



Manual landmarks only



Individually placed patch semi-landmarks

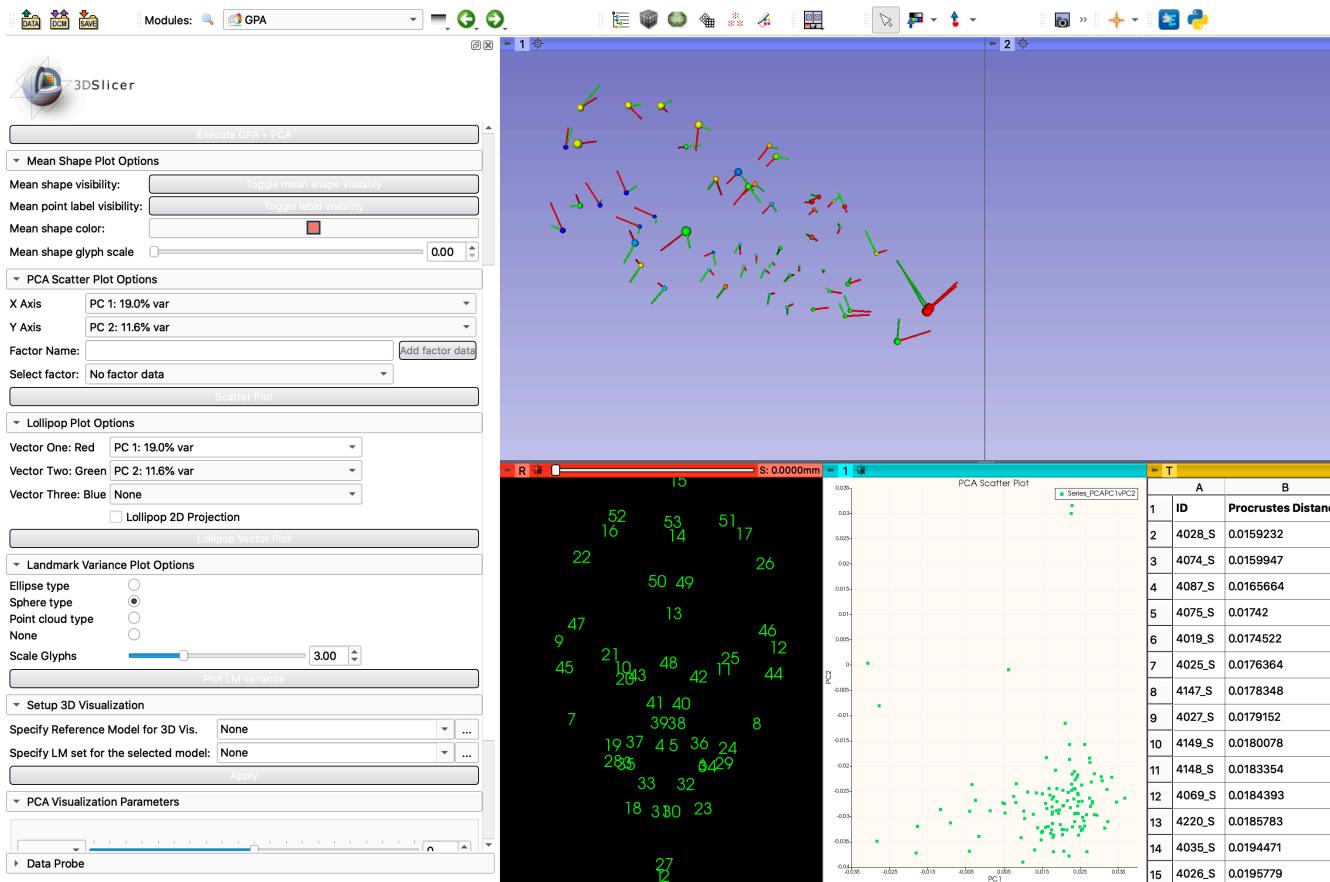


TPS-placed patch semi-landmarks



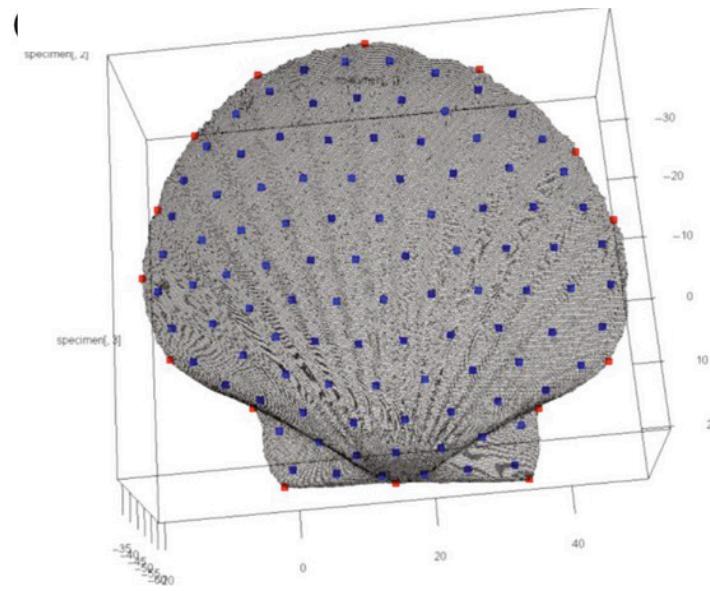
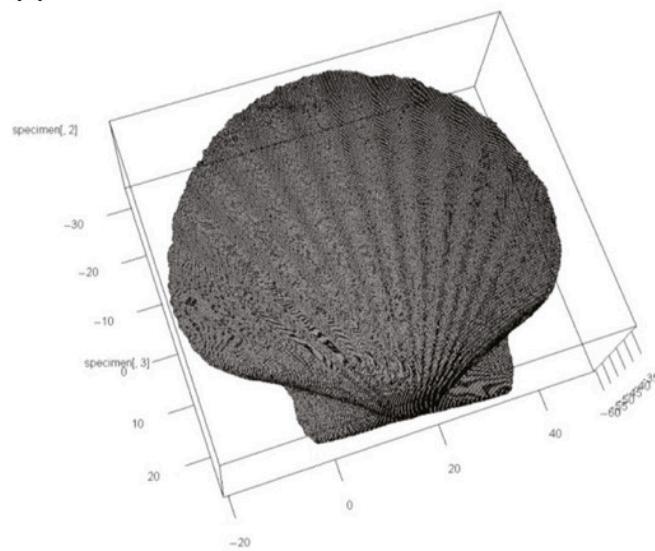
Semi-landmark analysis in SlicerMorph: GPA

The SlicerMorph GPA module supports standard GPA/PCA analysis and visualization



Semi-landmark analysis in R: Morpho and Geomorph

R Toolboxes [Morpho](#) and [Geomorph](#) for morphometric analysis provide support for transferring, sliding, and analyzing semi-landmarks

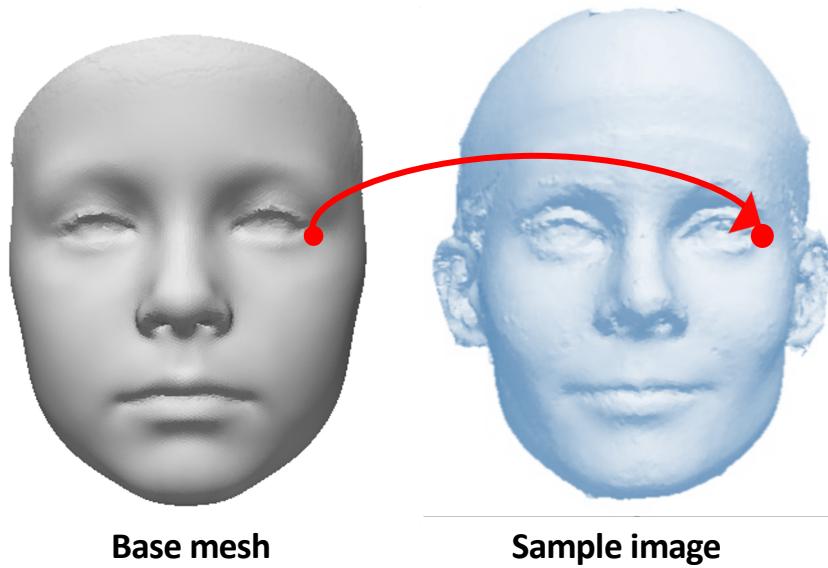


Beyond Semi-Landmarks



Deformation-based morphology (DBM)

- Calculate or select a base mesh
- Establish point correspondences between the base mesh and all meshes in data set
- Vertices of the base mesh define a new set of dense surface landmarks



Hutton, T. J., Buxton, B. F., Hammond, P. (2001). "Dense surface point distribution models of the human face," in Proceedings IEEE Workshop on Mathematical Methods in Biomedical Image Analysis (MMBIA 2001) (Kauai, HI).

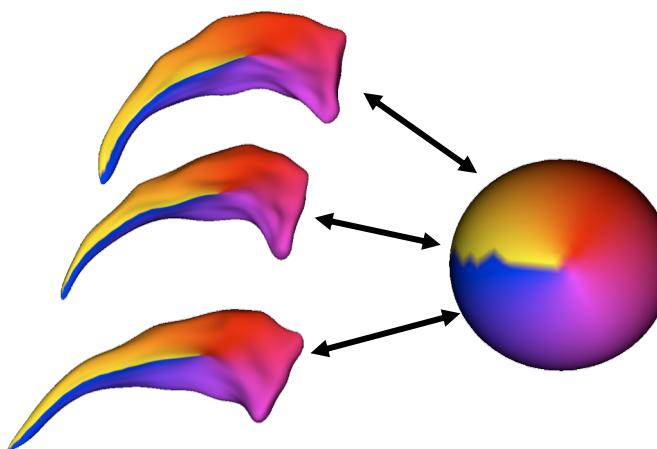
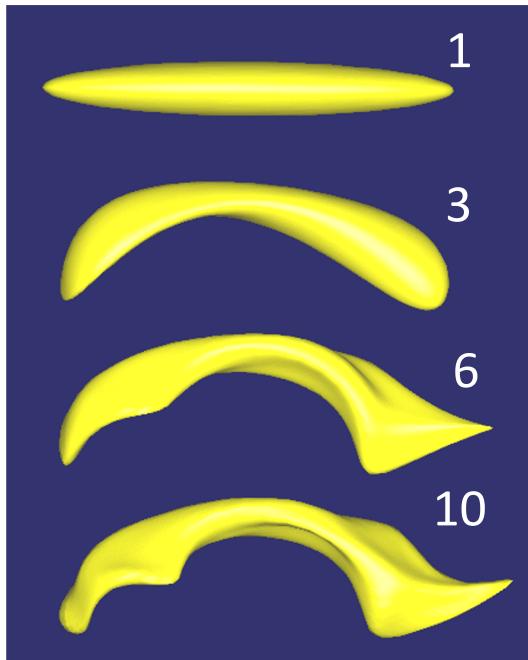


Limitations of DBM

- No guarantee of homology
- Results need to be interpreted with respect to initial alignment
- High dimensional data output
- Computationally intensive
- Quality of the mapping of the point correspondences between the base mesh and individuals should be assessed



Spherical harmonic representation and point distributed models (SPHARM-PDM)



SPHARM
description is
computed from
the mesh and its
spherical
parameterization

Styner, Lieberman, Pantazis, Gerig: Boundary and Medial Shape Analysis of the Hippocampus in Schizophrenia, Medical Image Analysis, 2004, pp 197-203

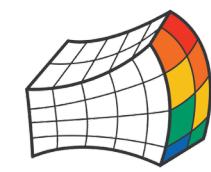
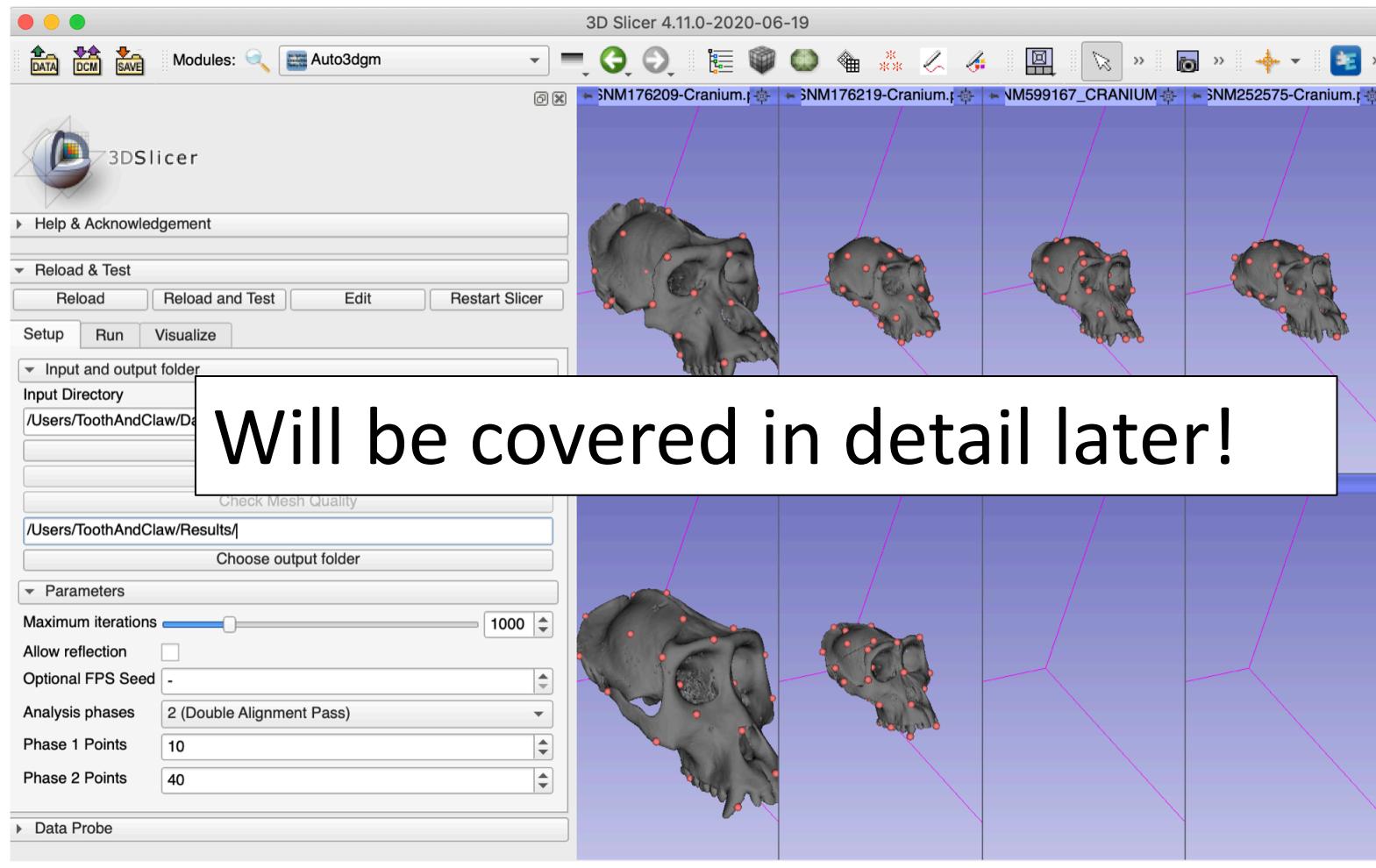


Limitations of SPHARM methods

- Requirement for spherical topology of meshes
- Challenging for complicated or noisy data sets
- Developed for high N of shapes with similar morphology – should perform a quality assessment to check for correspondence issues



Auto3DGM



SLICERMORPH

Questions?



Resources

Gunz, Philipp, Philipp Mitteroecker, and Fred L. Bookstein. "Semilandmarks in three dimensions." *Modern morphometrics in physical anthropology*. Springer, Boston, MA, 2005. 73-98.

Watanabe, Akinobu. "How many landmarks are enough to characterize shape and size variation?." *PloS one* 13.6 (2018): e0198341.

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Perez, S. Ivan, Valeria Bernal, and Paula N. Gonzalez. "Differences between sliding semi-landmark methods in geometric morphometrics, with an application to human craniofacial and dental variation." *Journal of anatomy* 208.6 (2006): 769-784.

Bookstein, Fred L., and William DK Green. "A feature space for edgels in images with landmarks." *Journal of Mathematical imaging and vision* 3.3 (1993): 231-261.

Cutting, Court, et al. "A three-dimensional smooth surface analysis of untreated Crouzon's syndrome in the adult." *The Journal of craniofacial surgery* 6.6 (1995): 444-453.

Andresen, Per Rønsholt, and Mads Nielsen. "Non-rigid registration by geometry-constrained diffusion." *Medical Image Analysis* 5.2 (2001): 81-88.

Ekrami, Omid, et al. "Measuring asymmetry from high-density 3D surface scans: An application to human faces." *PloS one* 13.12 (2018): e0207895.

Darvann, Tron A., et al. "Automated quantification and analysis of facial asymmetry in children with arthritis in the temporomandibular joint." *2011 IEEE International Symposium on Biomedical Imaging: From Nano to Macro*. IEEE, 2011.

Styner, Lieberman, Pantazis, Gerig: Boundary and Medial Shape Analysis of the Hippocampus in Schizophrenia, *Medical Image Analysis*, 2004, pp 197-203

