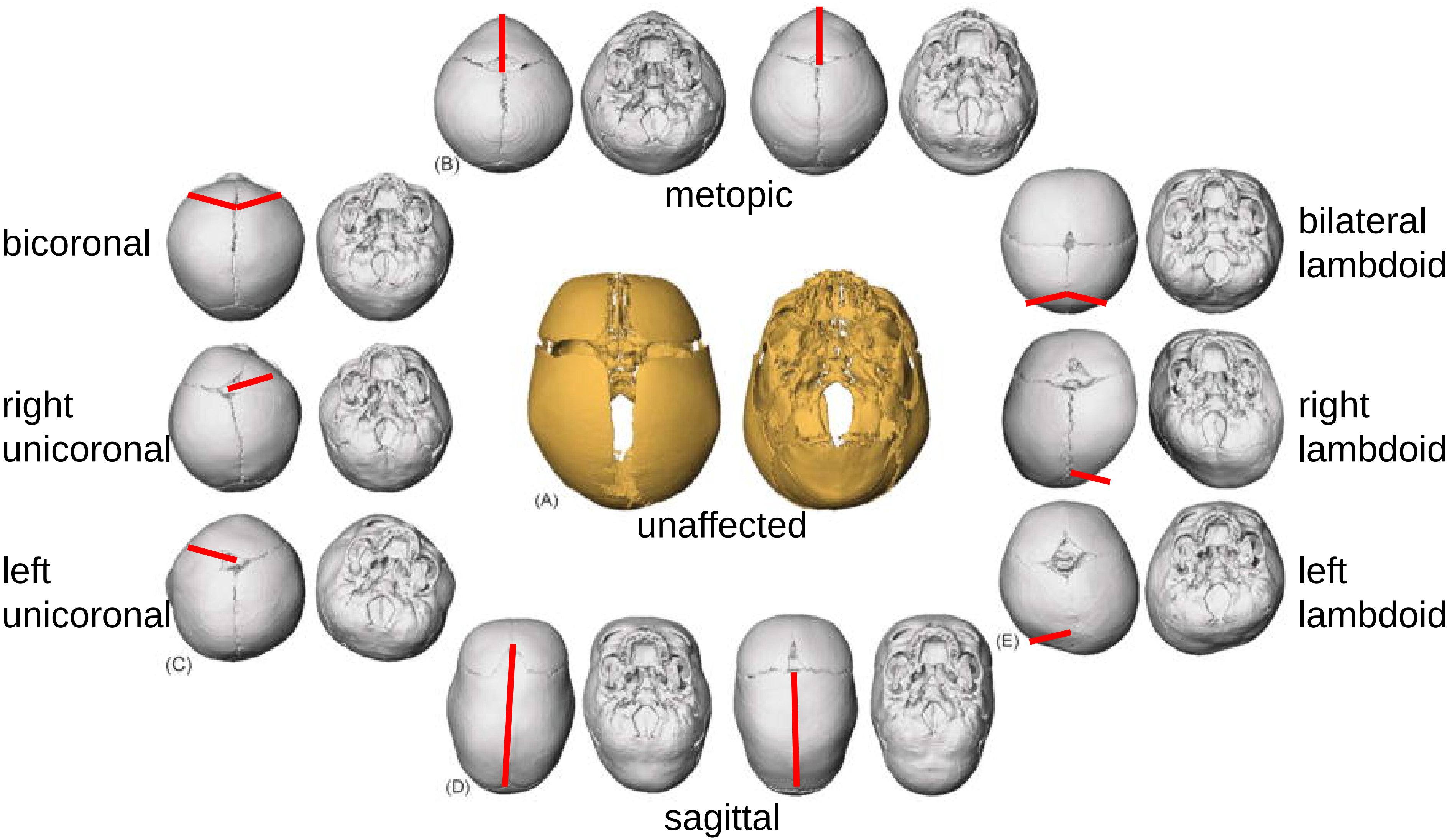
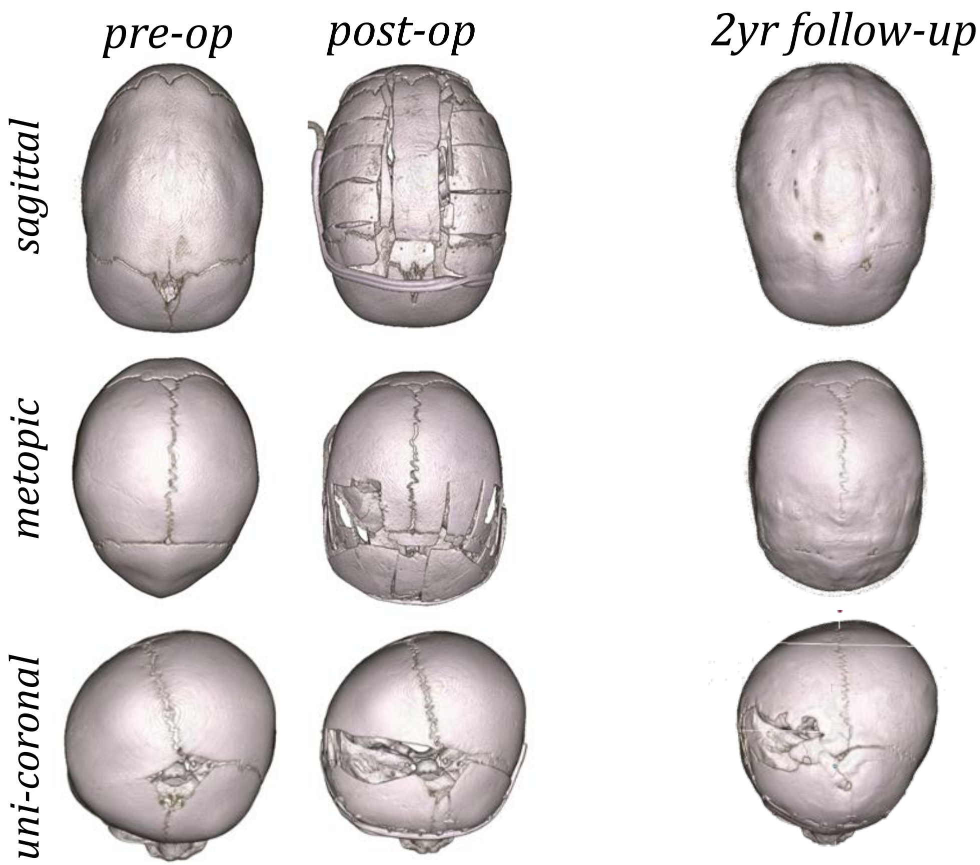
Statistical Shape Analysis of Human Infant Skull

Ezgi Mercan
Murat Maga
Richard Hopper

Skull Shape in Craniosynostosis
A Complex Phenotype



Cranial Reconstruction

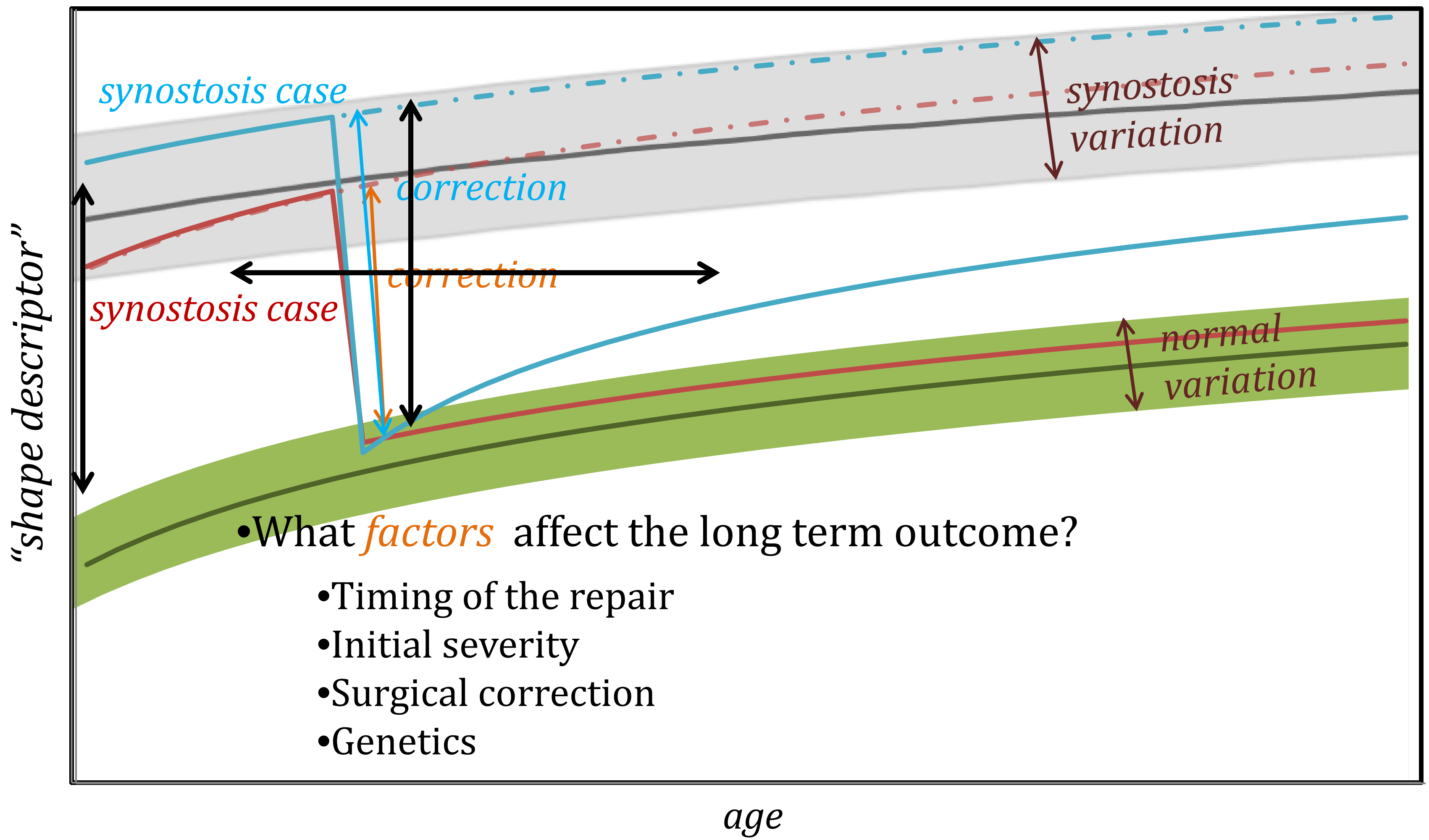


Shape Maintenance

- What *changes* are due to growth ?
- What *factors* affect the long term outcome?
  - Timing of the repair
  - Initial severity
  - Individual characteristics
- How does the skull *grow* in different diagnoses?

Goal: minimal surgical intervention

Hypothetical Growth



- What *factors* affect the long term outcome?
  - Timing of the repair
  - Initial severity
  - Surgical correction
  - Genetics

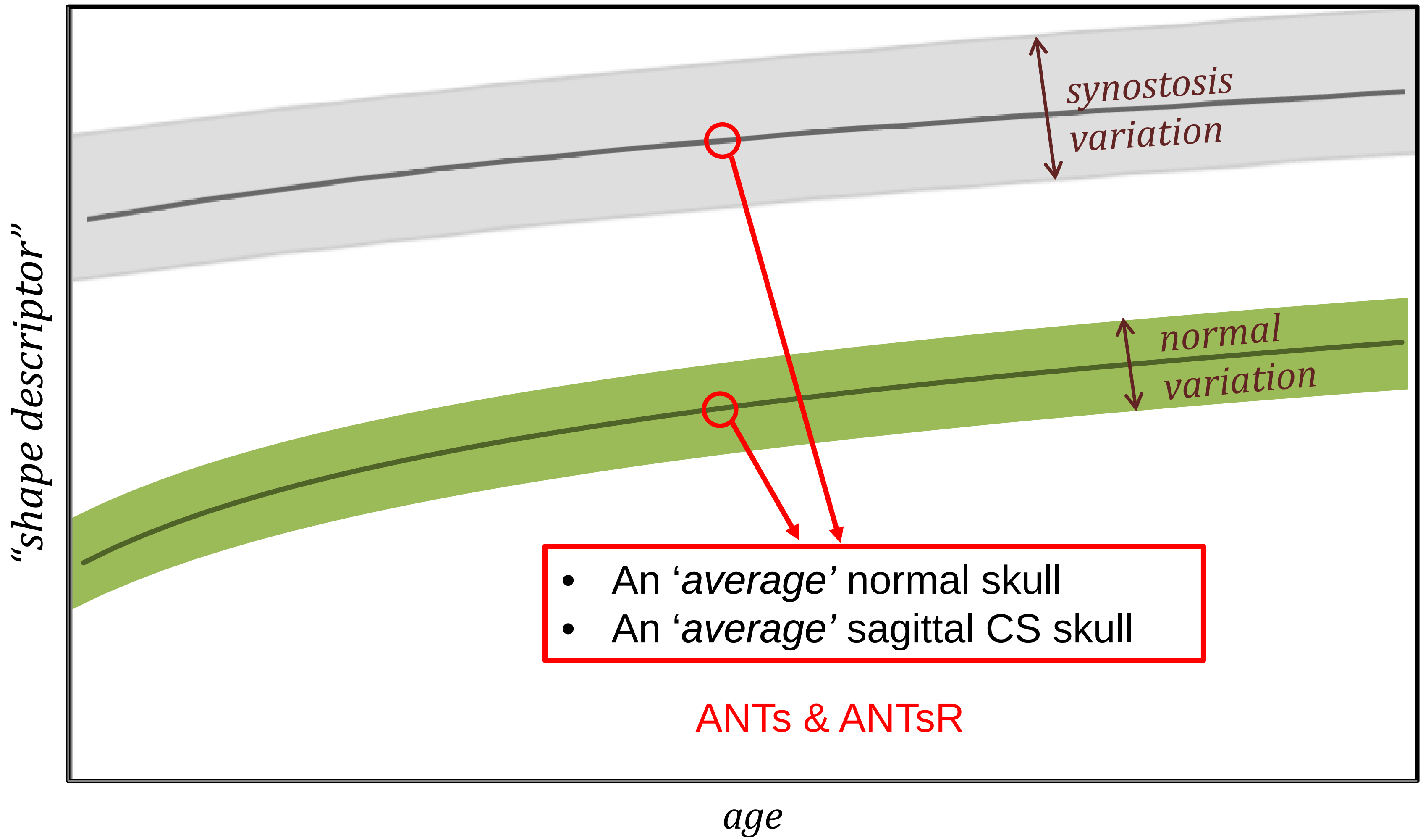
Outline

Template Building

Growth Modeling

Suture Closure Analysis

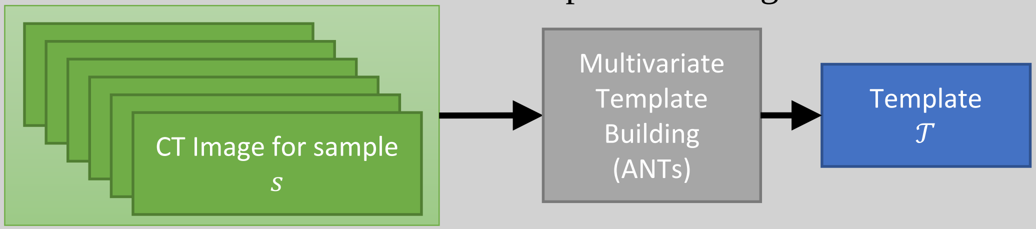
Hypothetical Growth



- Avants BB, Tustison NJ, Song G, Gee JC (2009) ANTS: open-source tools for normalization and neuroanatomy, *TransacMed Imagins Penn Image Comput Sci Lab*.
- Avants BB, Tustison NJ, Song G, Cook PA, Klein A, Gee JC (2011) A reproducible evaluation of ANTs similarity metric performance in brain image registration, *Neuroimage* 54(3), 2033-2044.

Outline

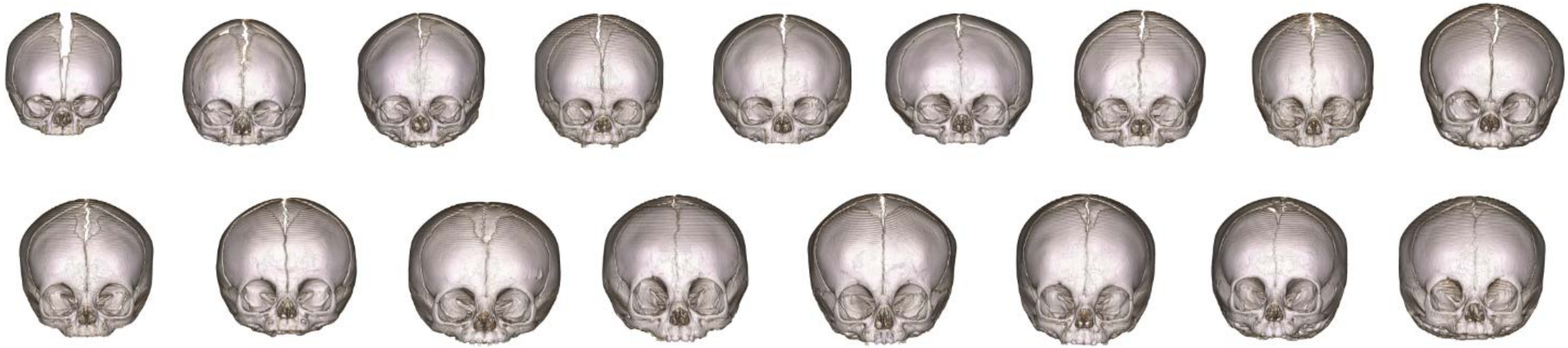
Template Building



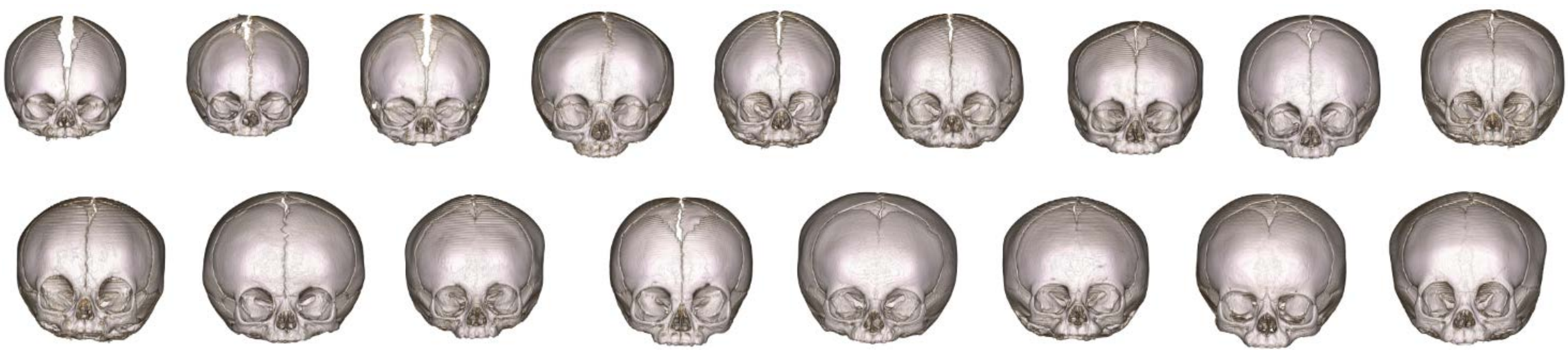
Growth Modeling

Suture Closure Analysis

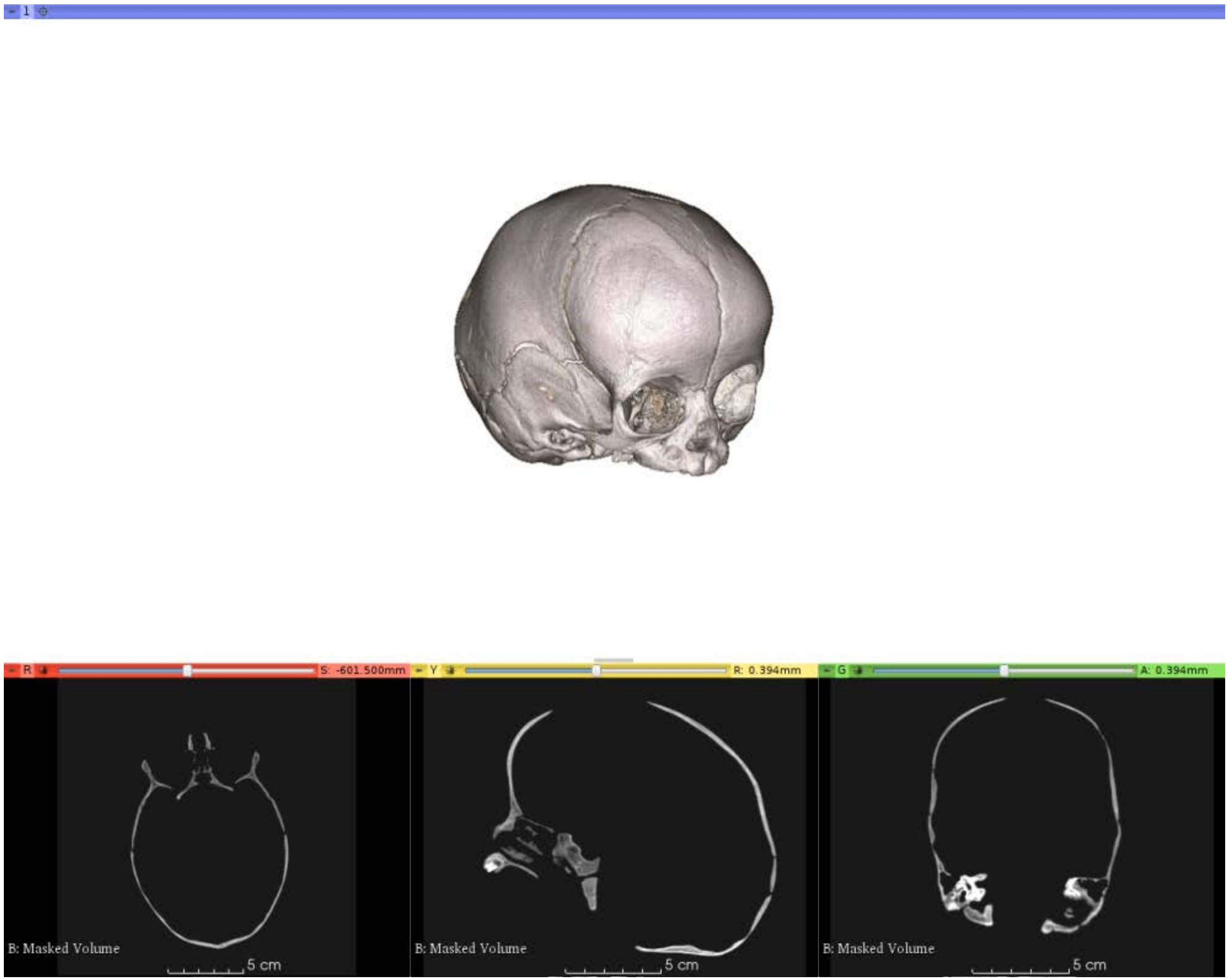
Data



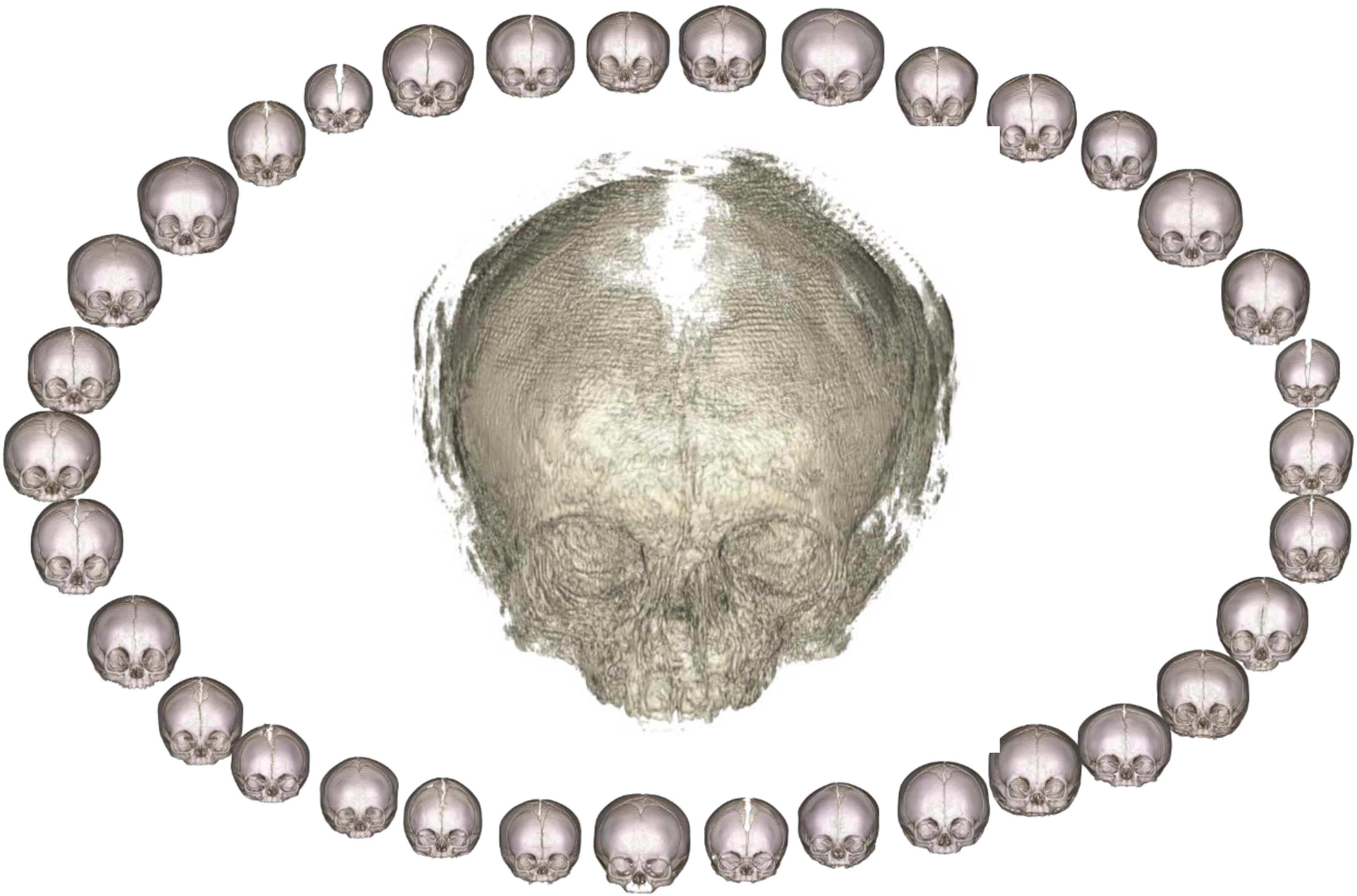
N = 34 normal samples (17 male and 17 female)
N = 81 sagittal CS samples (62 male and 19 female)
0-6 months old



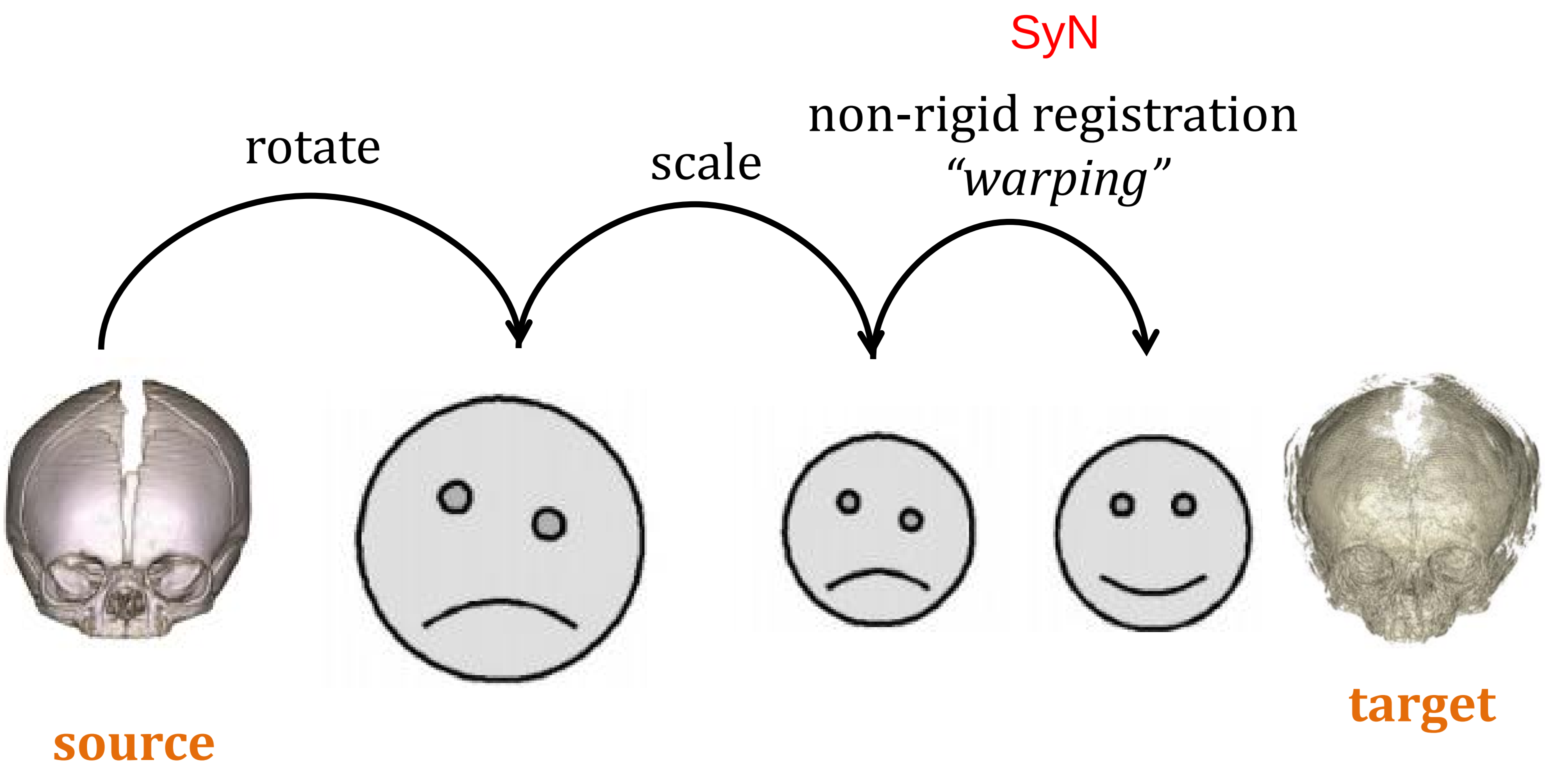
Pre-processing



Average Image



Non-rigid Registration



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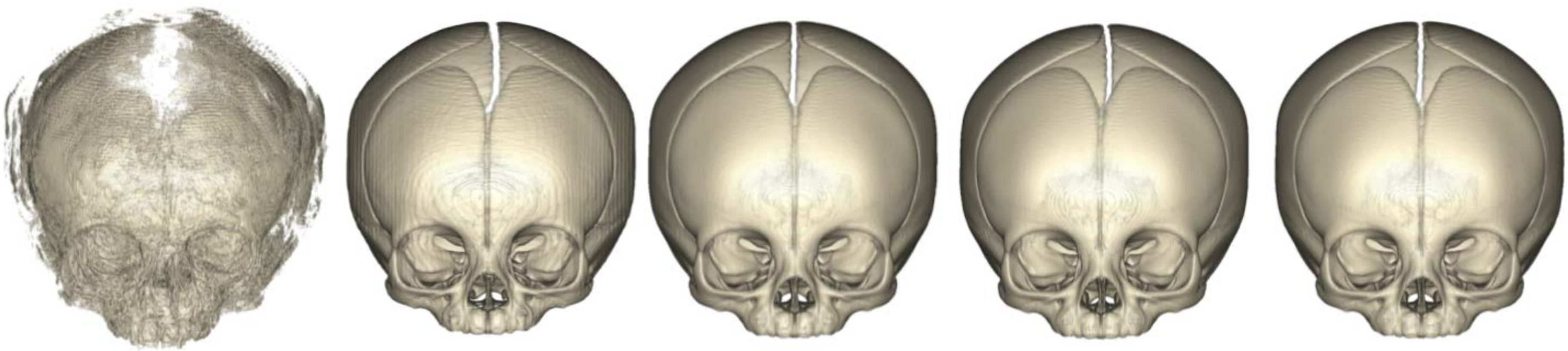
- Avants BB, Tustison NJ, Song G, Cook PA, Klein A, Gee JC (2011) A reproducible evaluation of ANTs similarity metric performance in brain image registration, *Neuroimage* 54(3), 2033-2044.

Template Construction



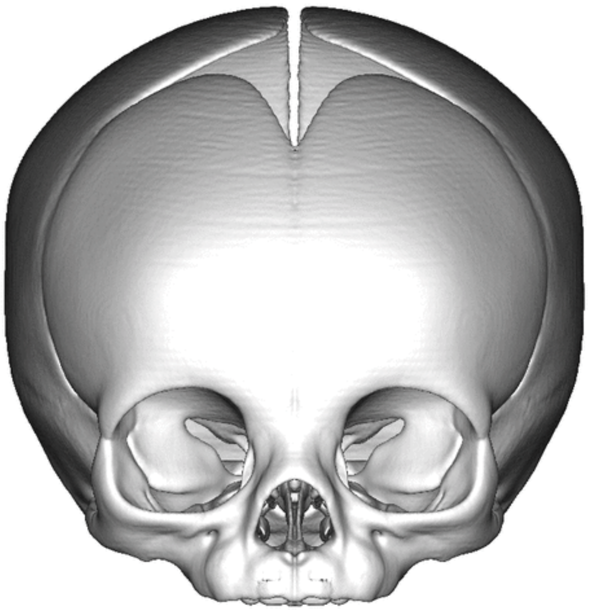
initial template *1st iteration* *2nd iteration* *3rd iteration* *4th iteration*

In each iteration:

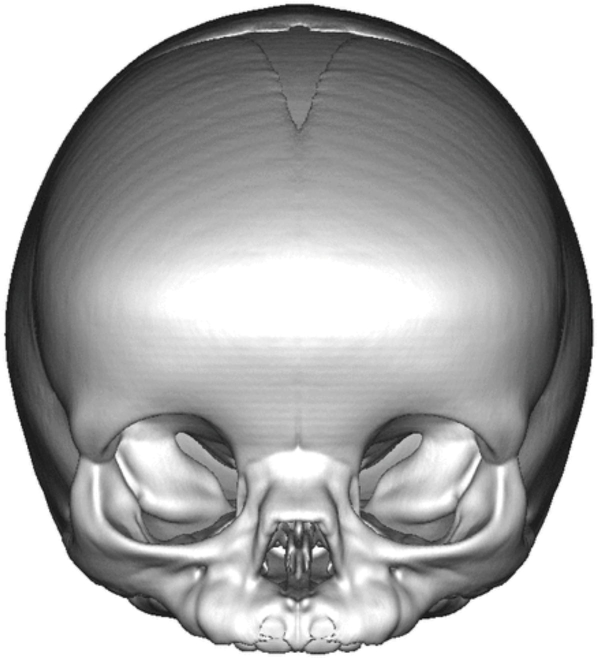
- Warp each sample to the current template
- Average warped images to create a new template
- Repeat until *convergence*

Population Templates

Normal Infant Template



Sagittal CS Template



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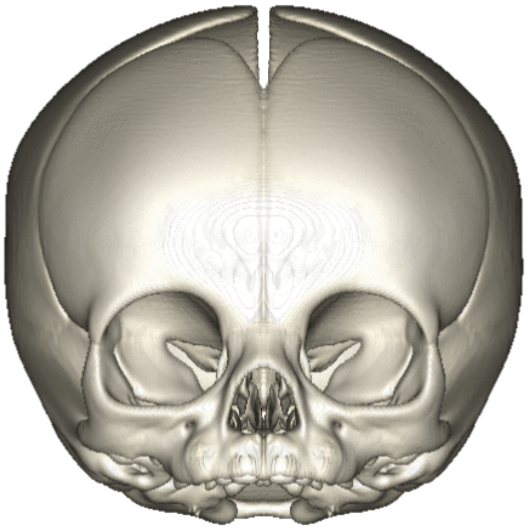
What can a template do?

- Models a population
  - age, sex, ethnicity …
- Generates *references*
- Automates annotation:
  - Landmarking
  - Segmentation



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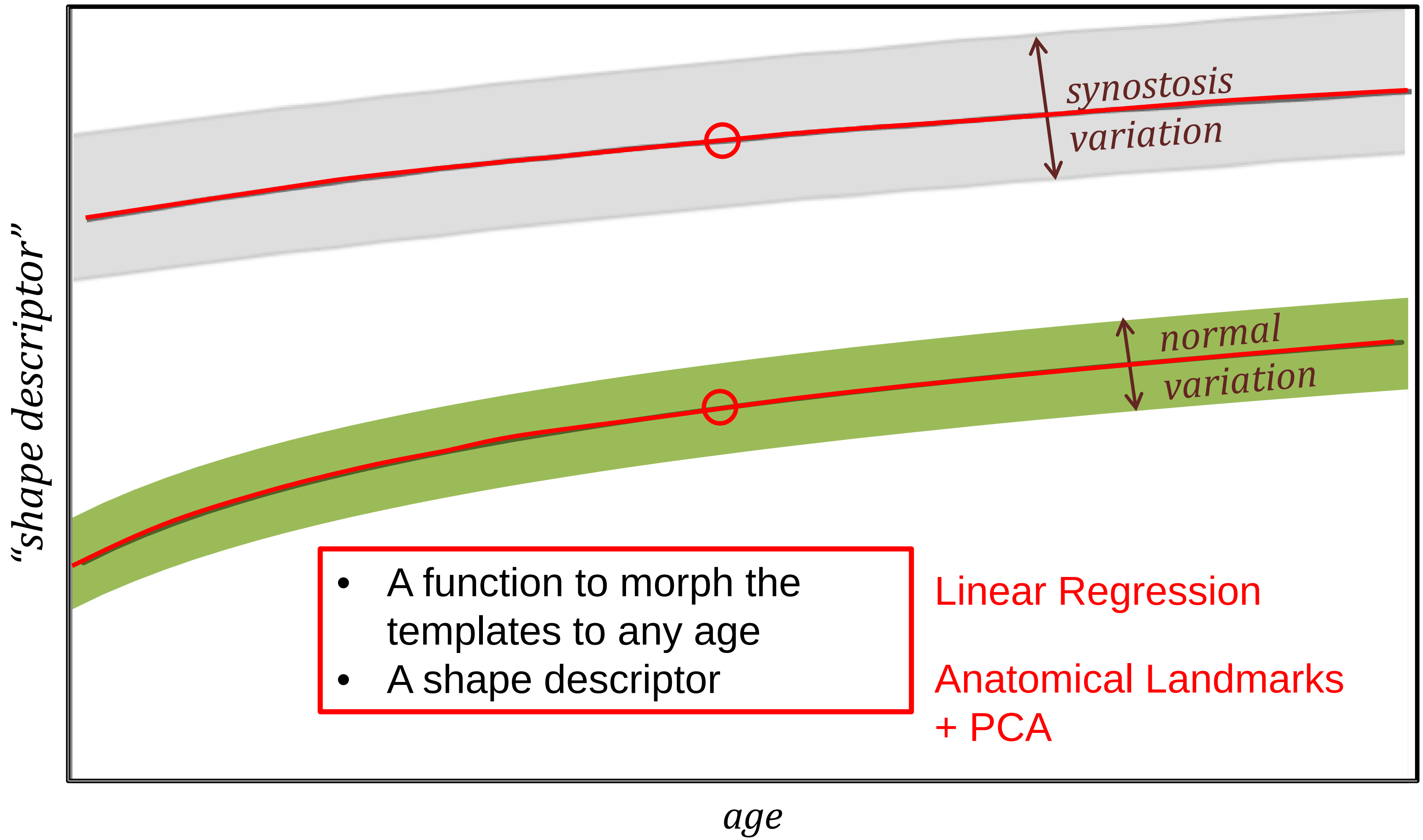
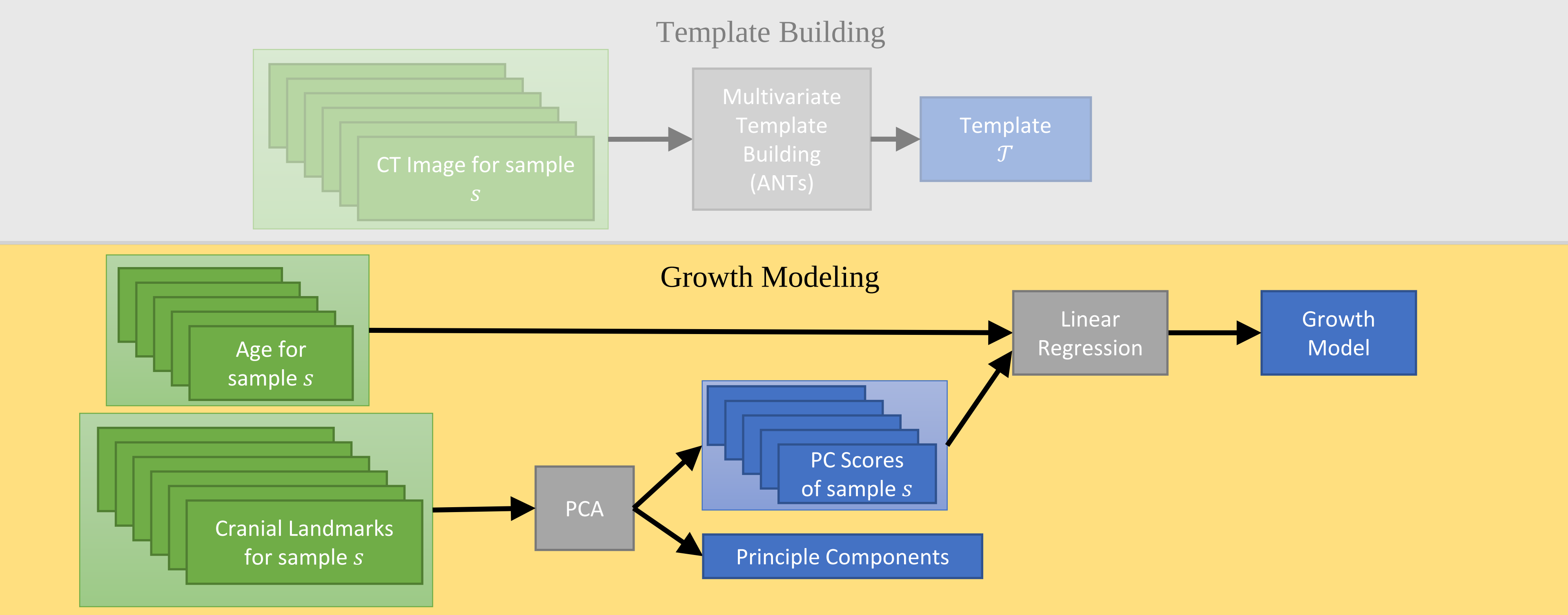
Hypothetical Growth

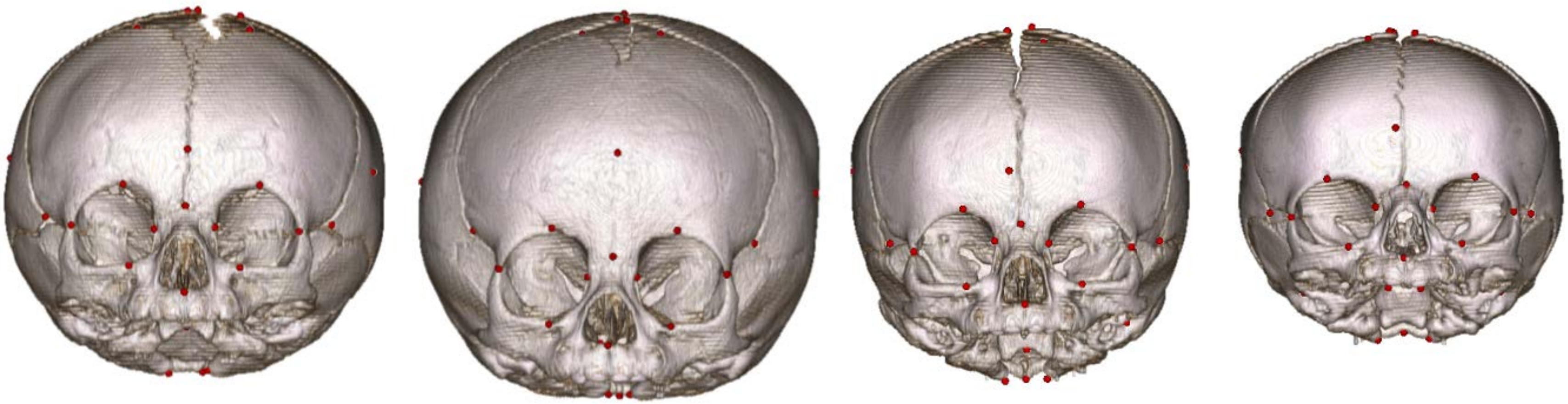


Outline



Suture Closure Analysis

Growth Modeling

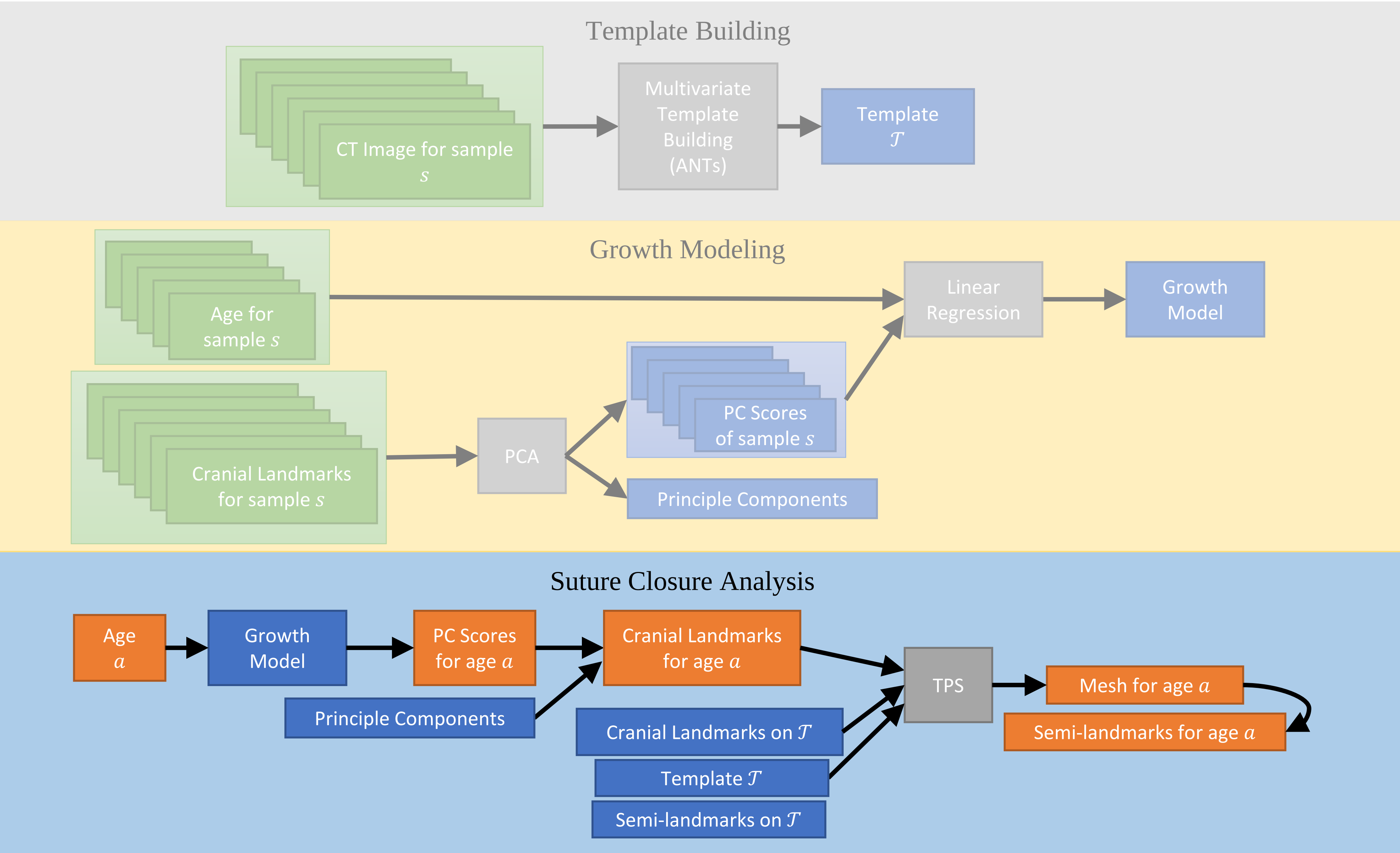


age_1 age_2 age_3 age_4

Thin Plate Splines

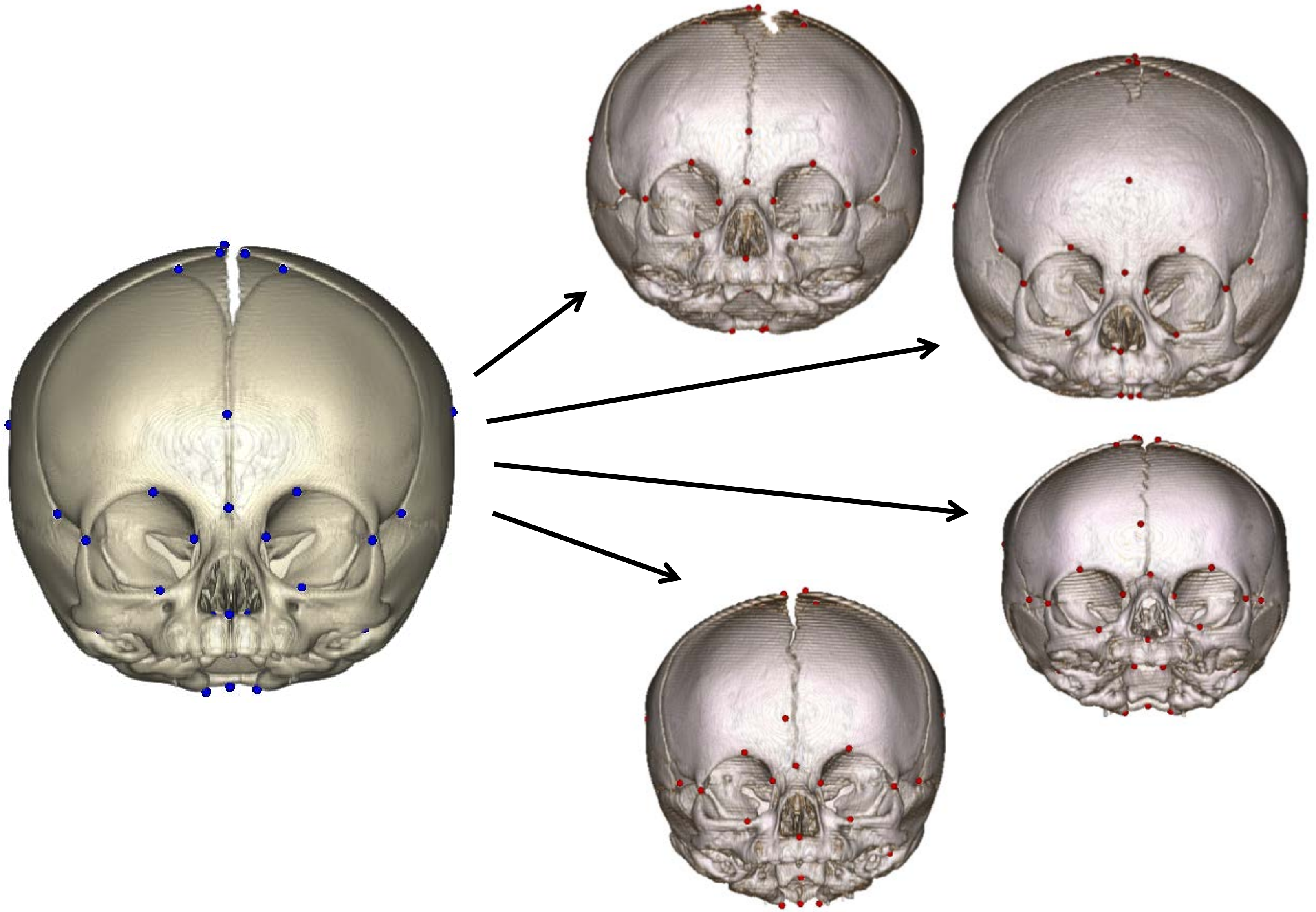
- Bookstein, FL (1989) Principal Warps: Thin-Plate Splines and the Decomposition of Deformations, *IEEE Transactions on Pattern Analysis and Machine Intelligence* 11(6), 567-585.

Outline

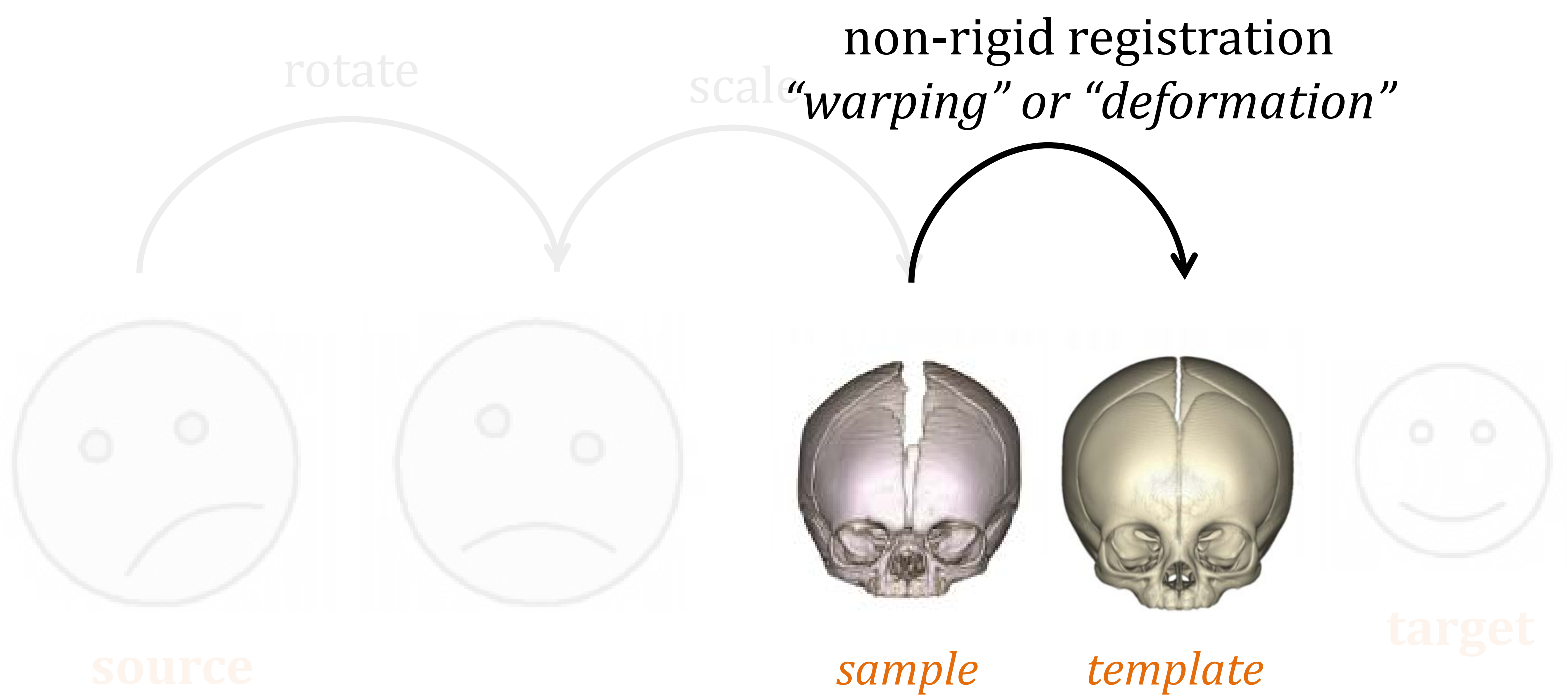


Template Building
CT Image for sample s
Multivariate Template Building (ANTs)
Template $\mathcal{T}$
Growth Modeling
Age for sample s
Linear Regression
Growth Model
PC Scores of sample s
Cranial Landmarks for sample s
PCA
Principle Components
Suture Closure Analysis
Age a
Growth Model
PC Scores for age a
Cranial Landmarks for age a
Principle Components
TPS
Mesh for age a
Semi-landmarks for age a
Cranial Landmarks on $\mathcal{T}$
Template $\mathcal{T}$
Semi-landmarks on $\mathcal{T}$

Automated Landmarking

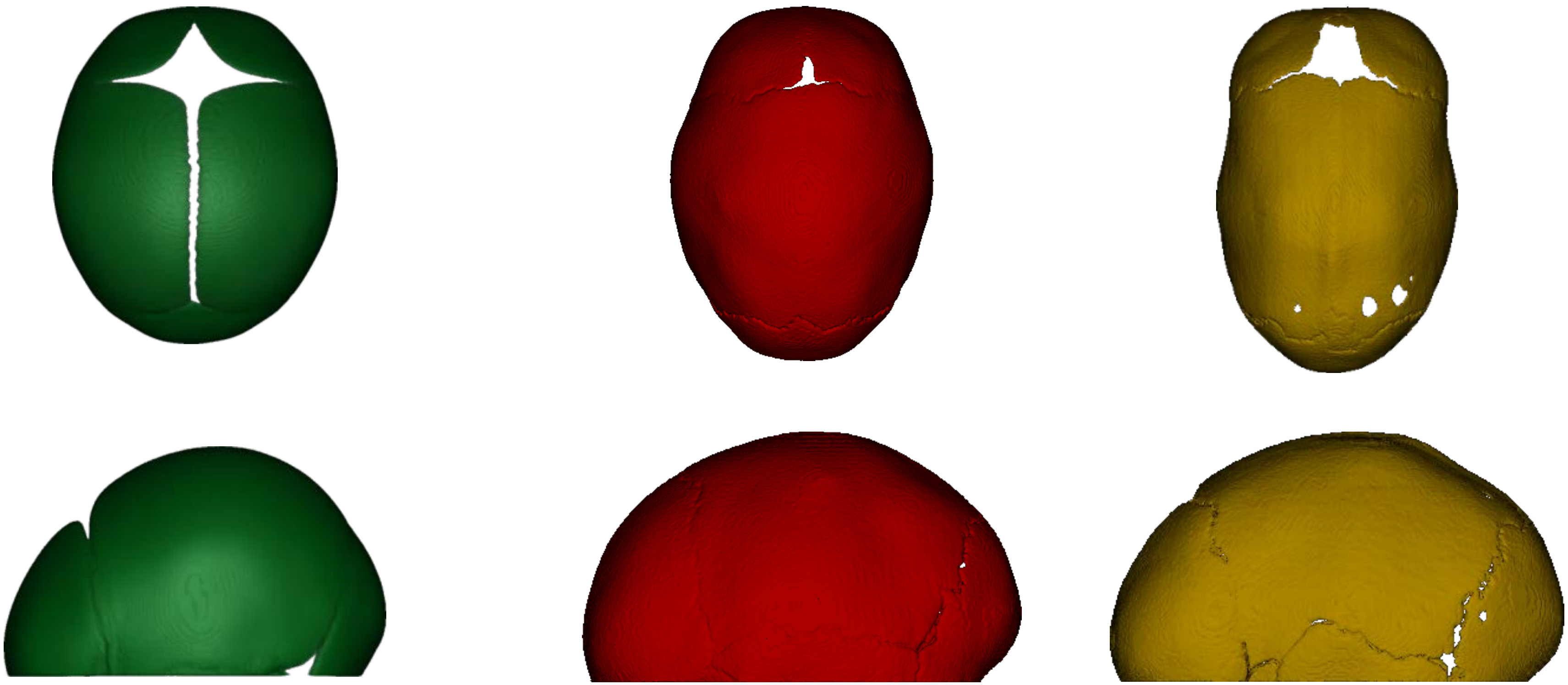


Shape Description



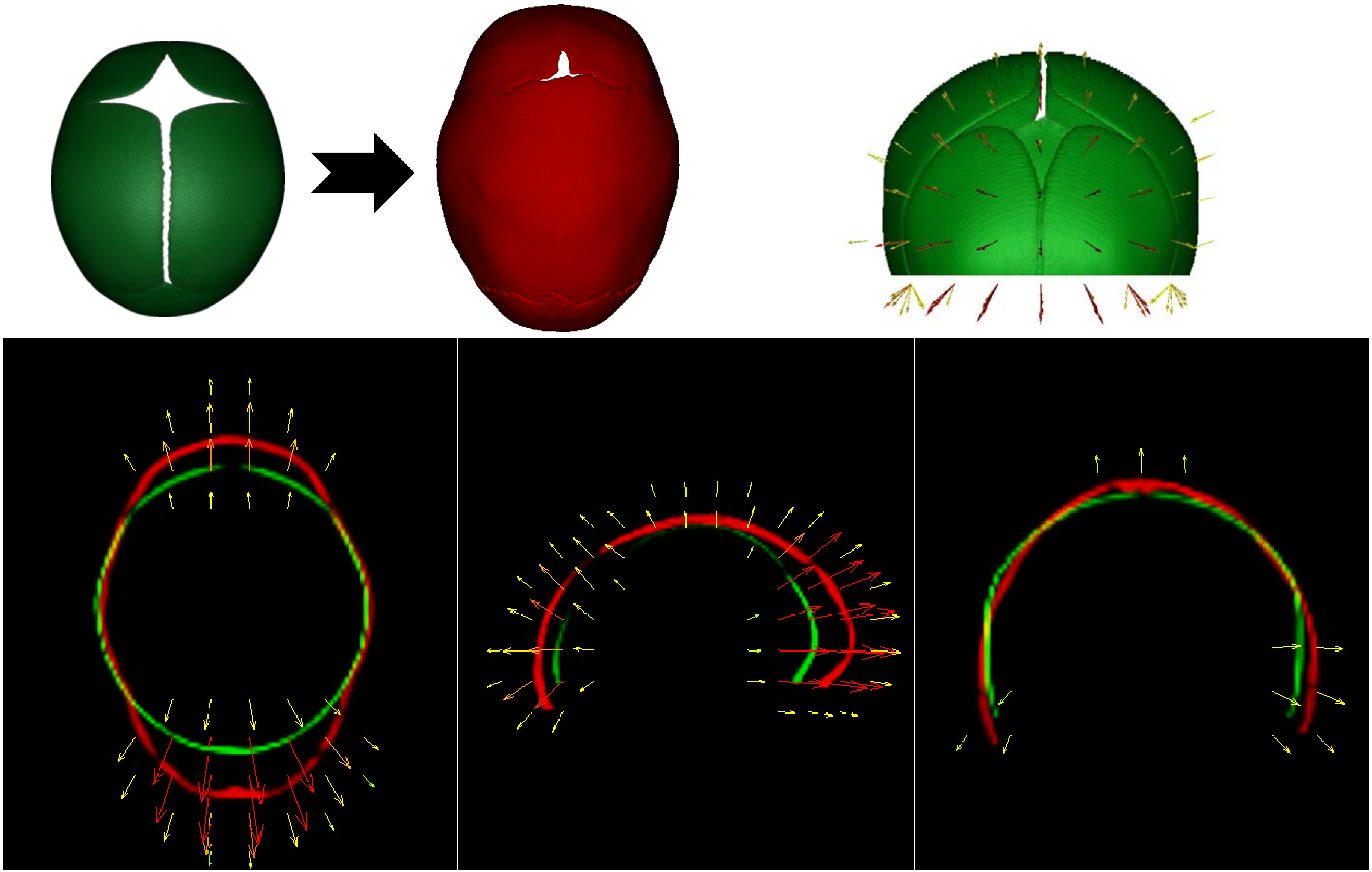
Warp fields, displacement vectors from one sample to the template (or backwards), can be used to describe shape differences.

Shape Description



normal template | sagittal sample1 | sagittal sample2

Shape Description



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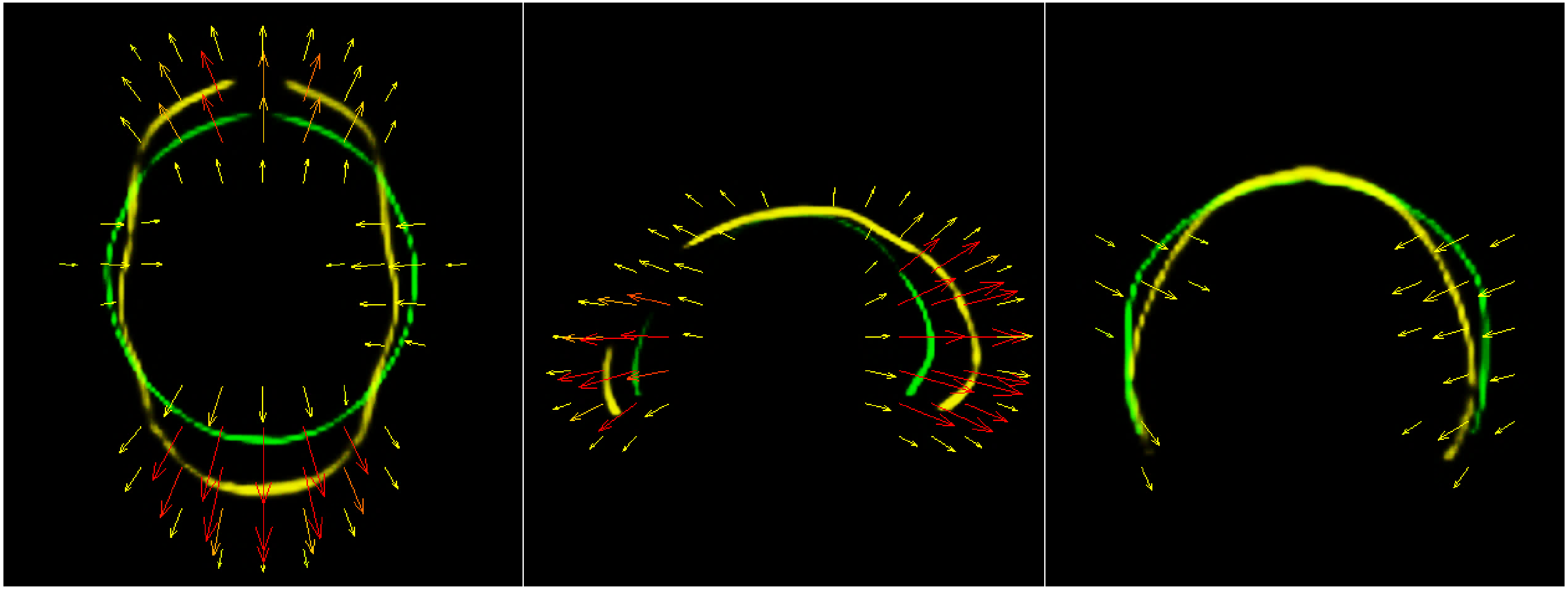
Shape Description



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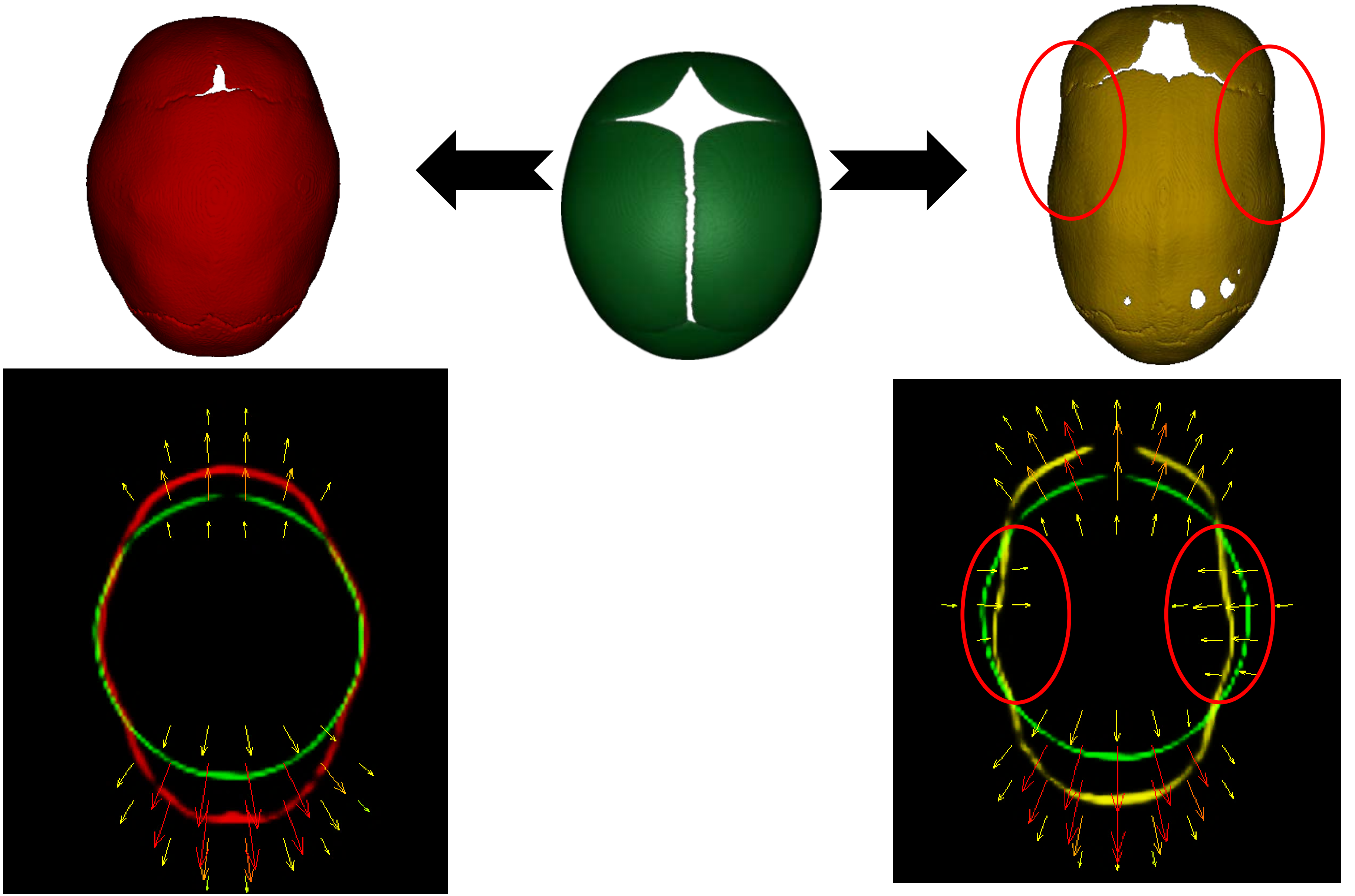
Shape Description



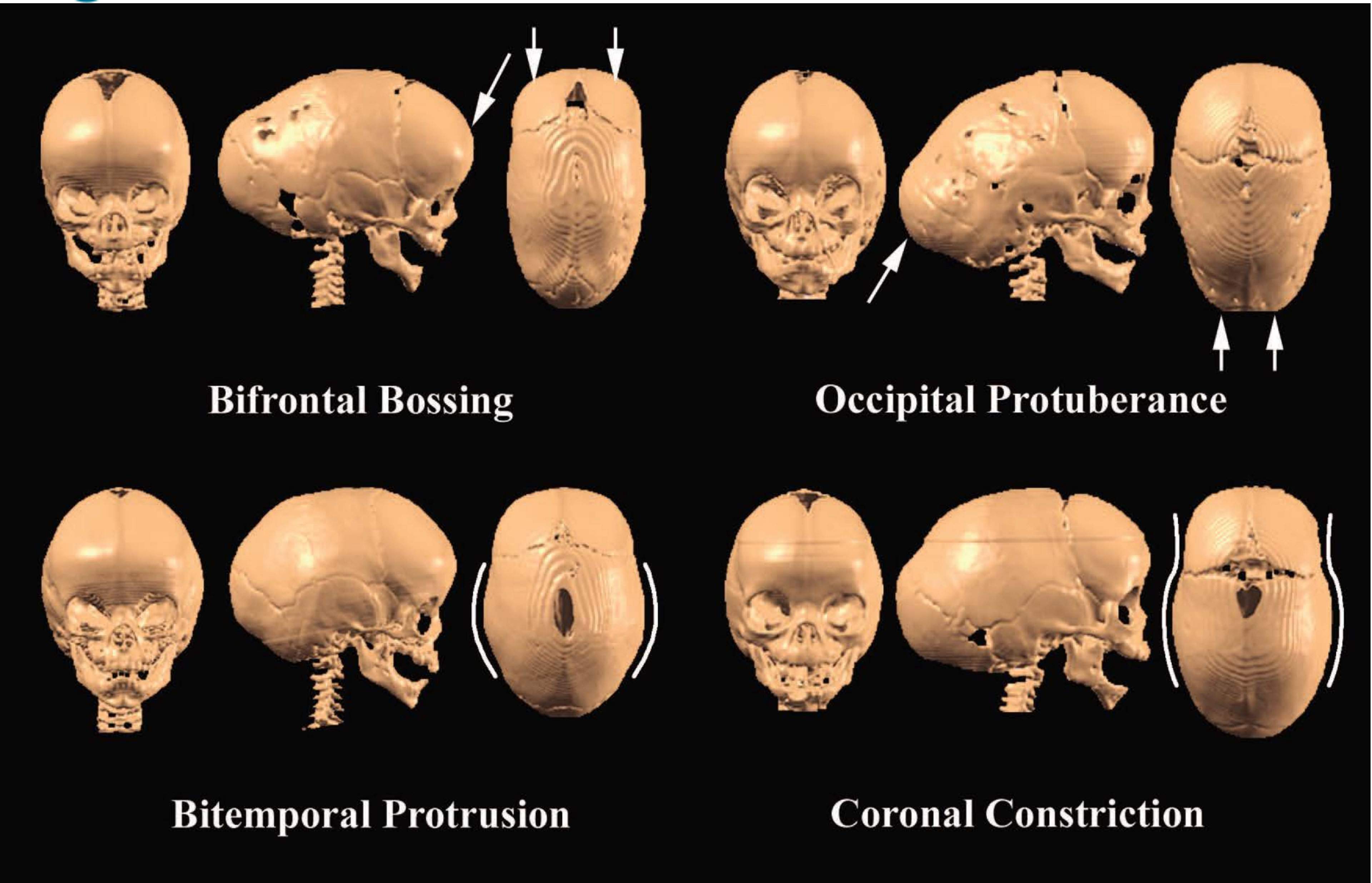
PEDIATRIC/CRANIOFACIAL

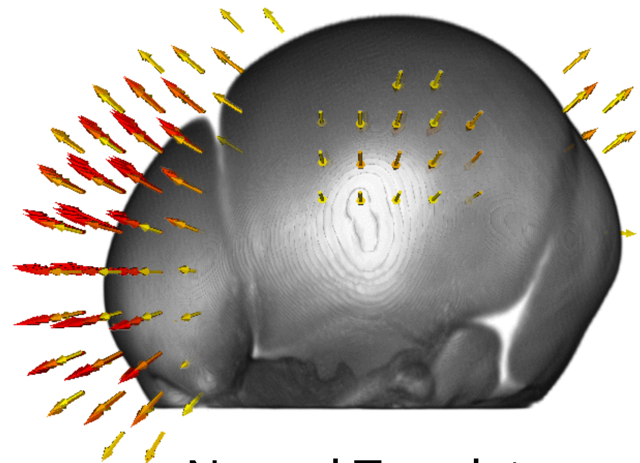
Identifying Reproducible Patterns of Calvarial Dysmorphology in Nonsyndromic Sagittal Craniosynostosis May Affect Operative Intervention and Outcomes Assessment

Rodney E. Schmelzer, M.D.
Chad A. Perlyn, M.D.
Alex A. Kane, M.D.
Thomas K. Pilgram, Ph.D.
Daniel Govier
Jeffrey L. Marsh, M.D.

St. Louis, Mo.

Background: The authors tested the premise that there are four distinctive patterns of calvarial dysmorphology in nonsyndromic sagittal craniosynostosis that can be reproducibly recognized.
Methods: Twenty-nine computed tomographic scan data sets of infants met the following criteria: nonsyndromic sagittal craniosynostosis, age younger than 12 months, and satisfactory computed tomographic data. Osseous reformations were constructed in the anteroposterior, right lateral, and vertex projections for each patient. From these images, four templates—coronal constriction, occipital

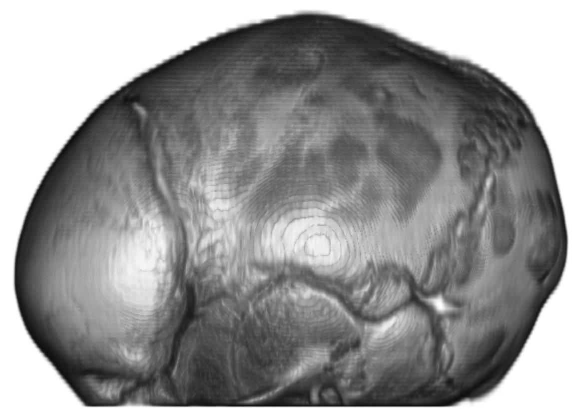

Bifrontal Bossing
Occipital Protuberance
Bitemporal Protrusion
Coronal Constriction



Normal Template

Deformation Field Vectors

1. Principle Component Analysis



Sagittal Sample

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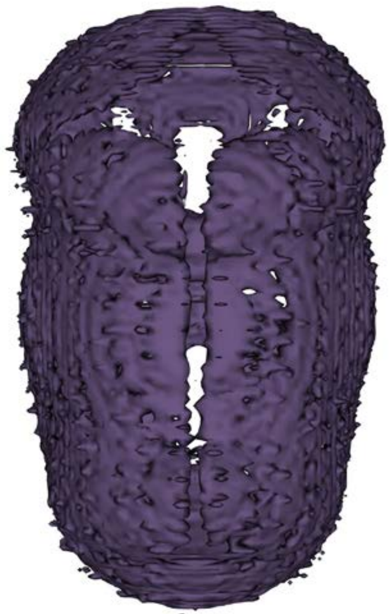
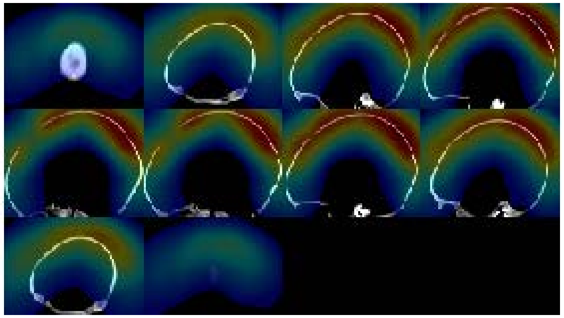
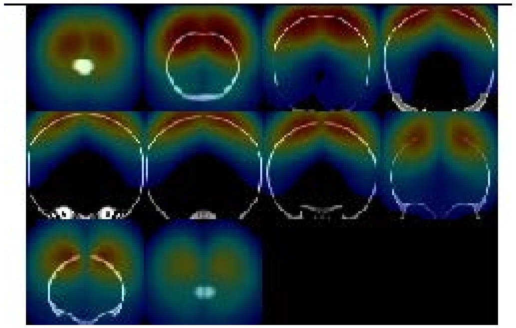
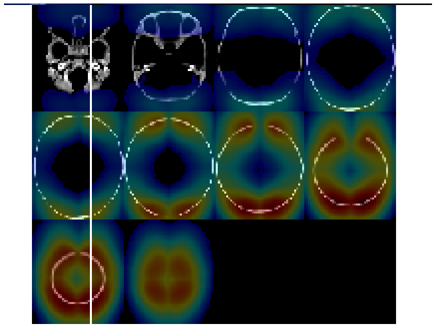
PC1









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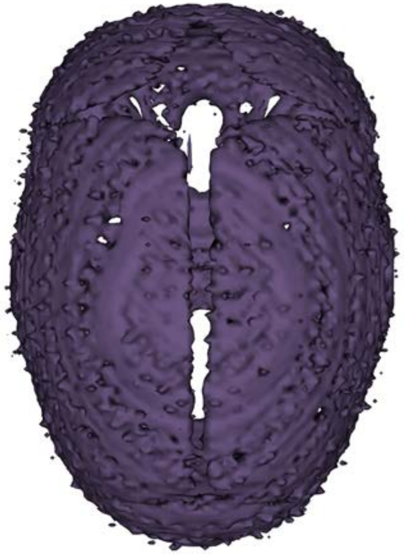
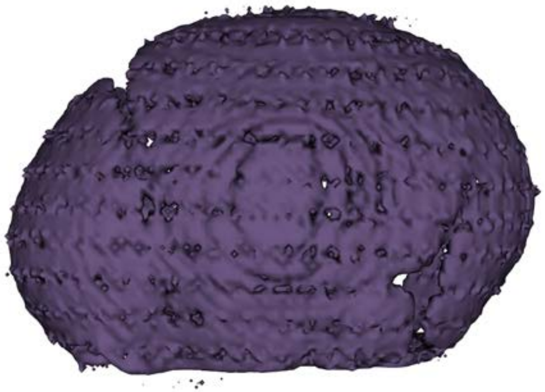
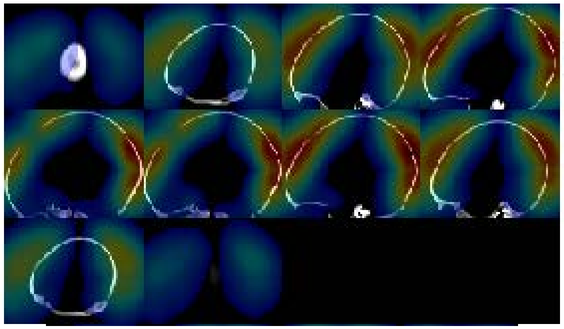
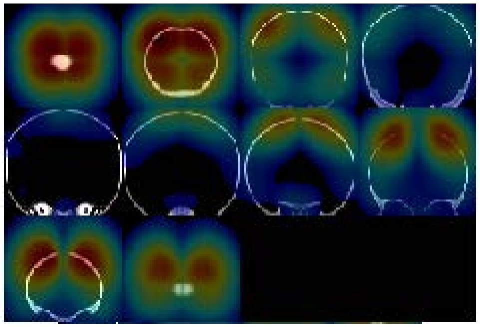
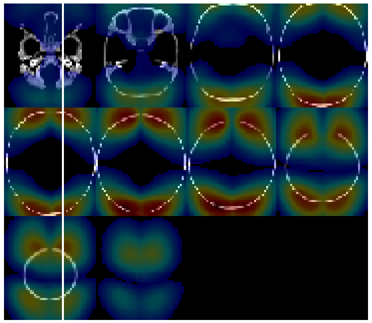
PC2





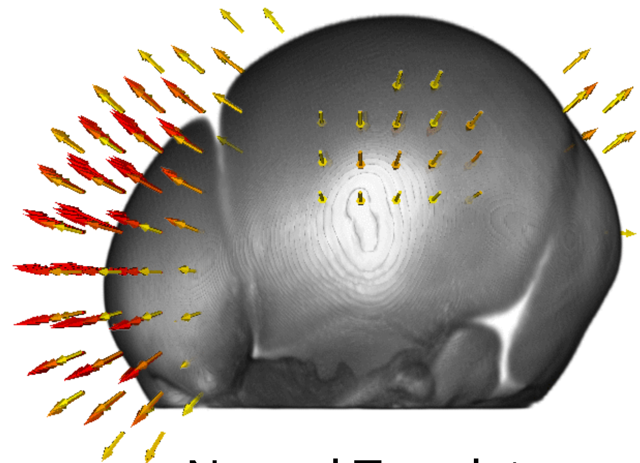




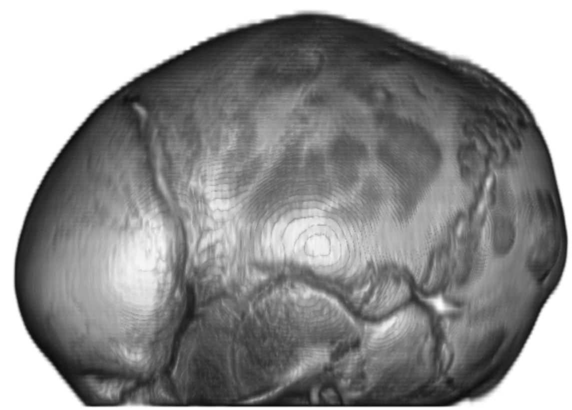


Deformation Field Vectors

1. Principle Component Analysis
2. Angle histograms

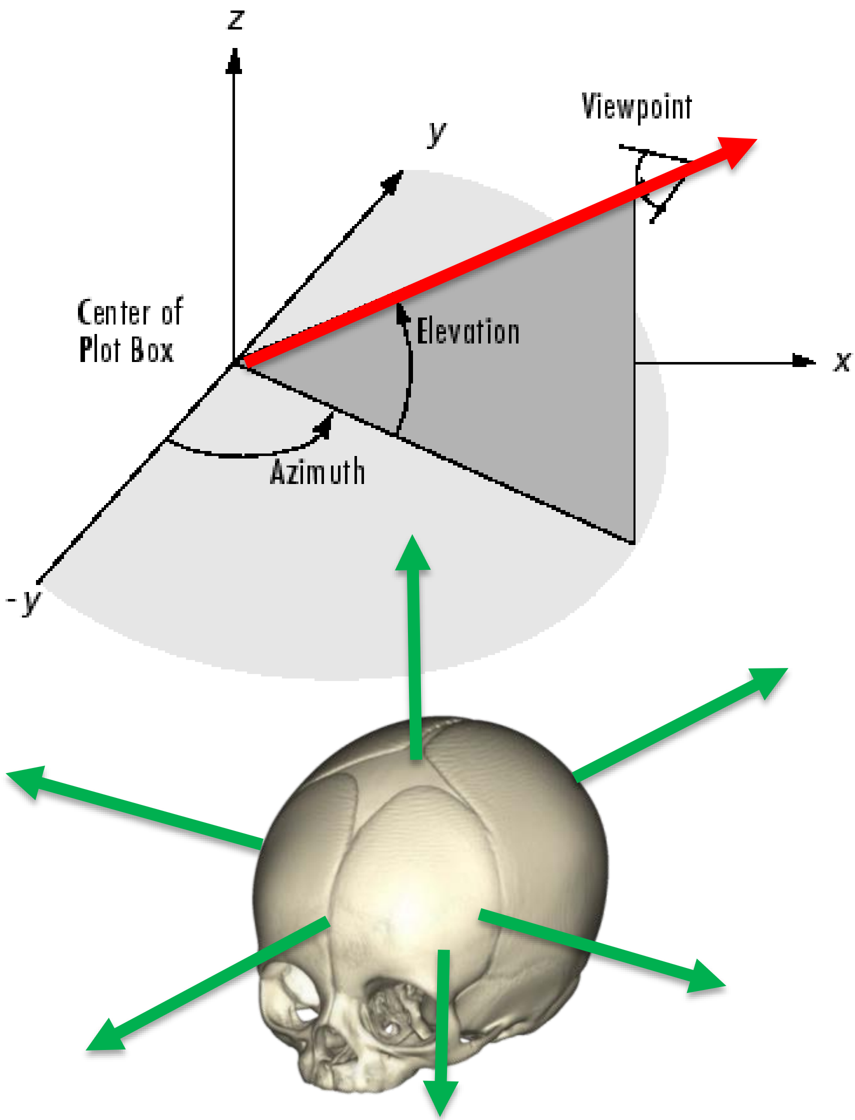


Normal Template

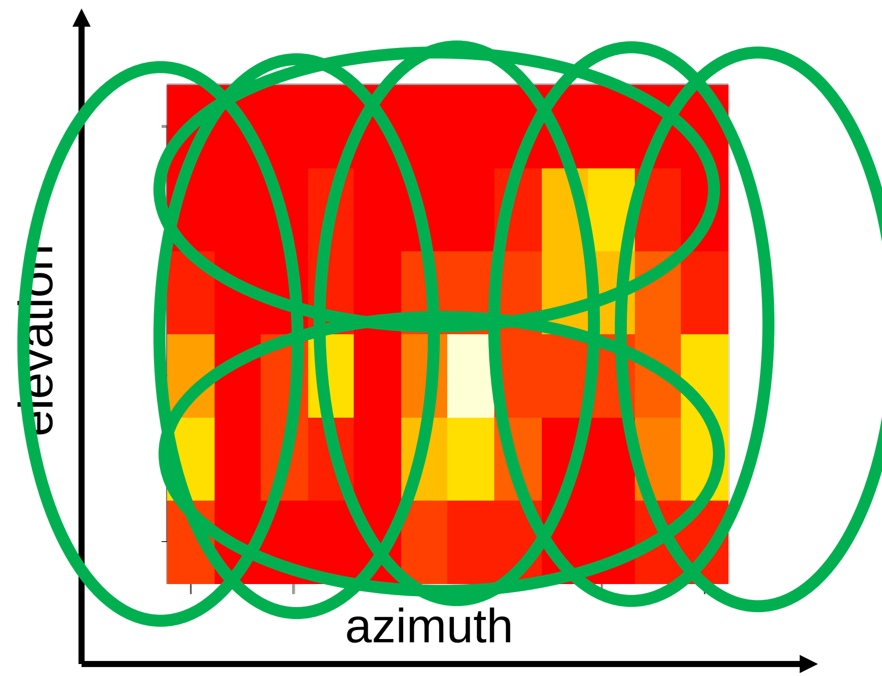


Sagittal Sample

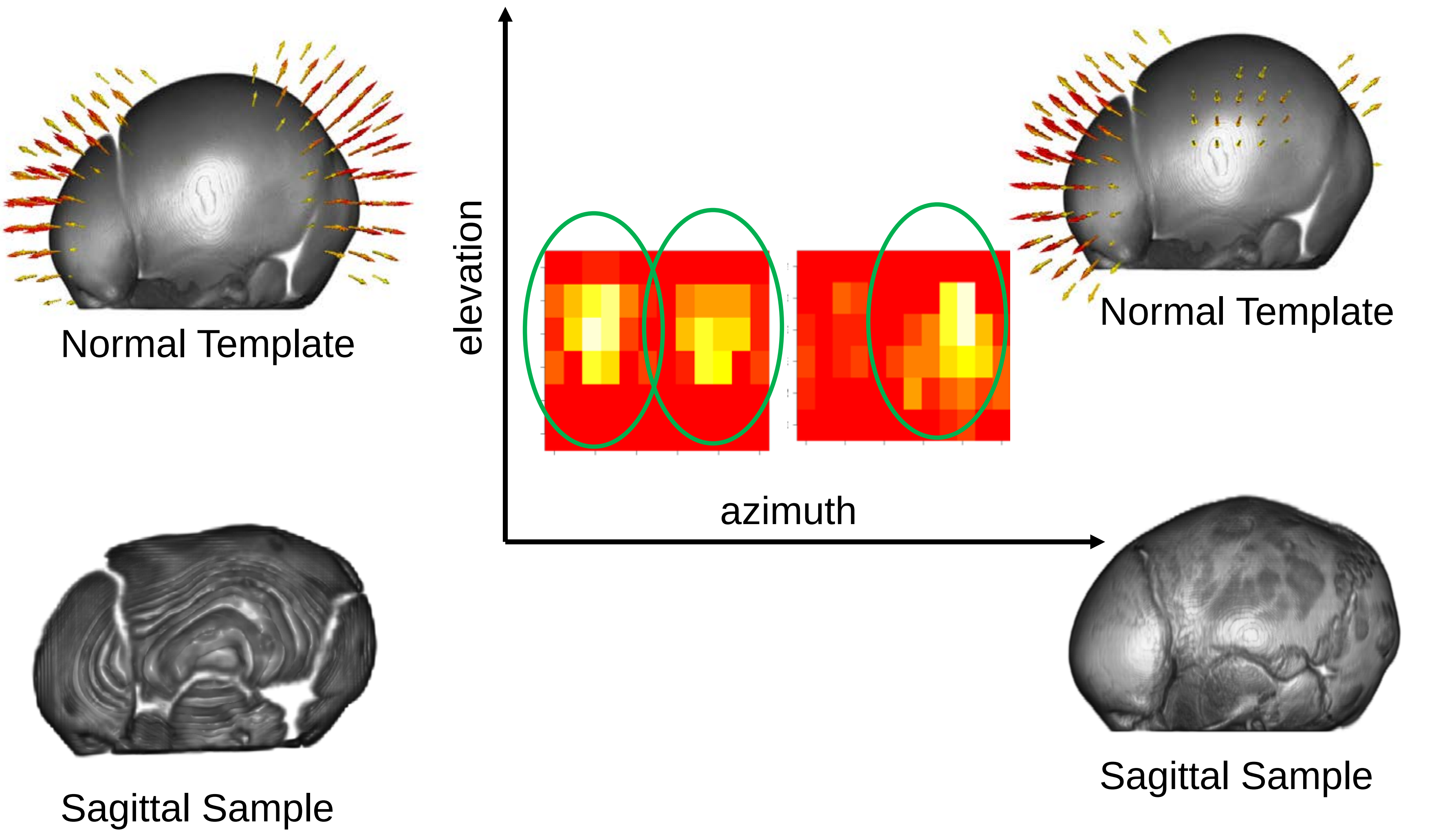
Angle Histograms



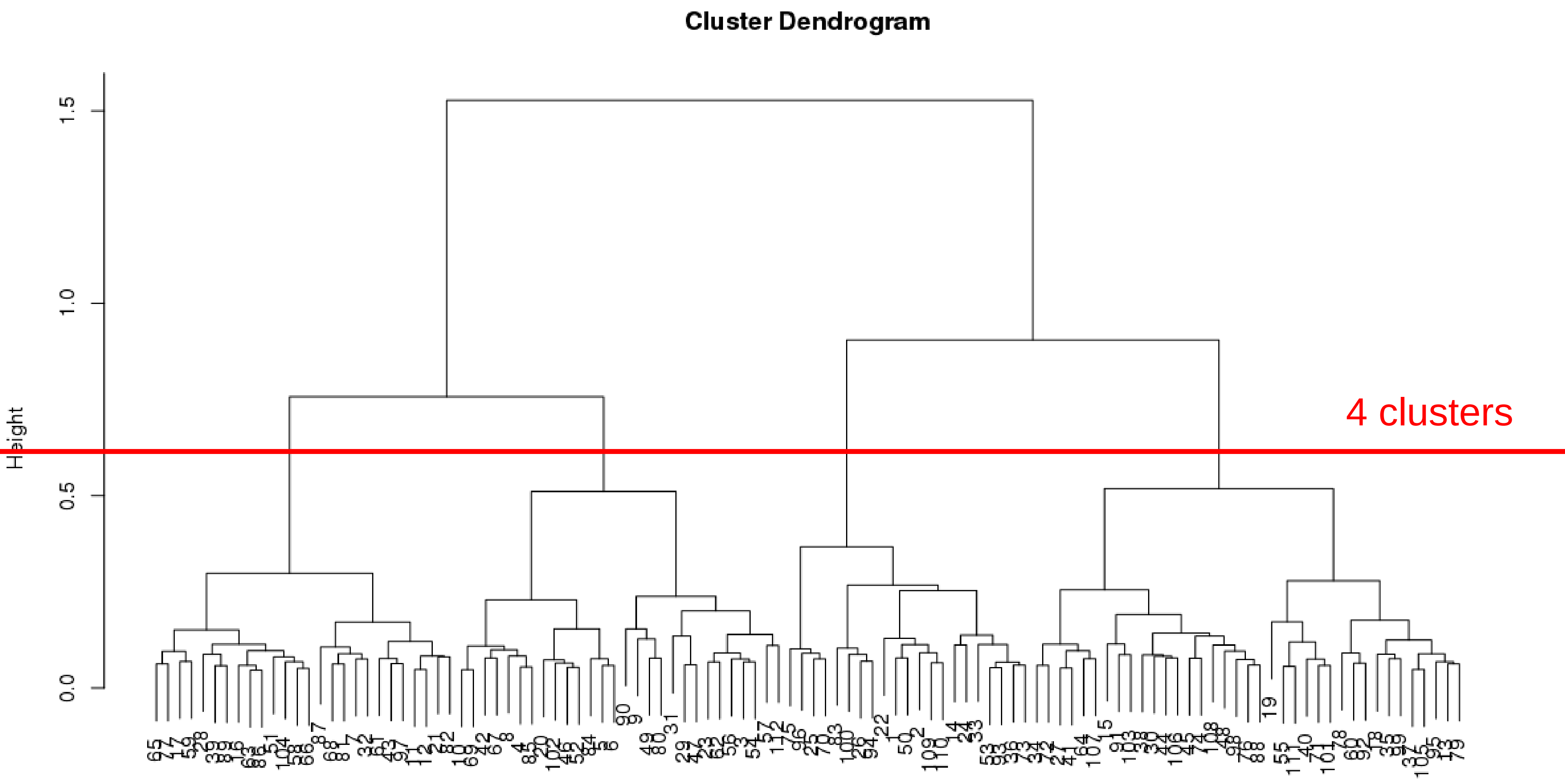
Generate a 2D histogram based on the azimuth and elevation angles of 3D deformation vectors.



Angle Histograms



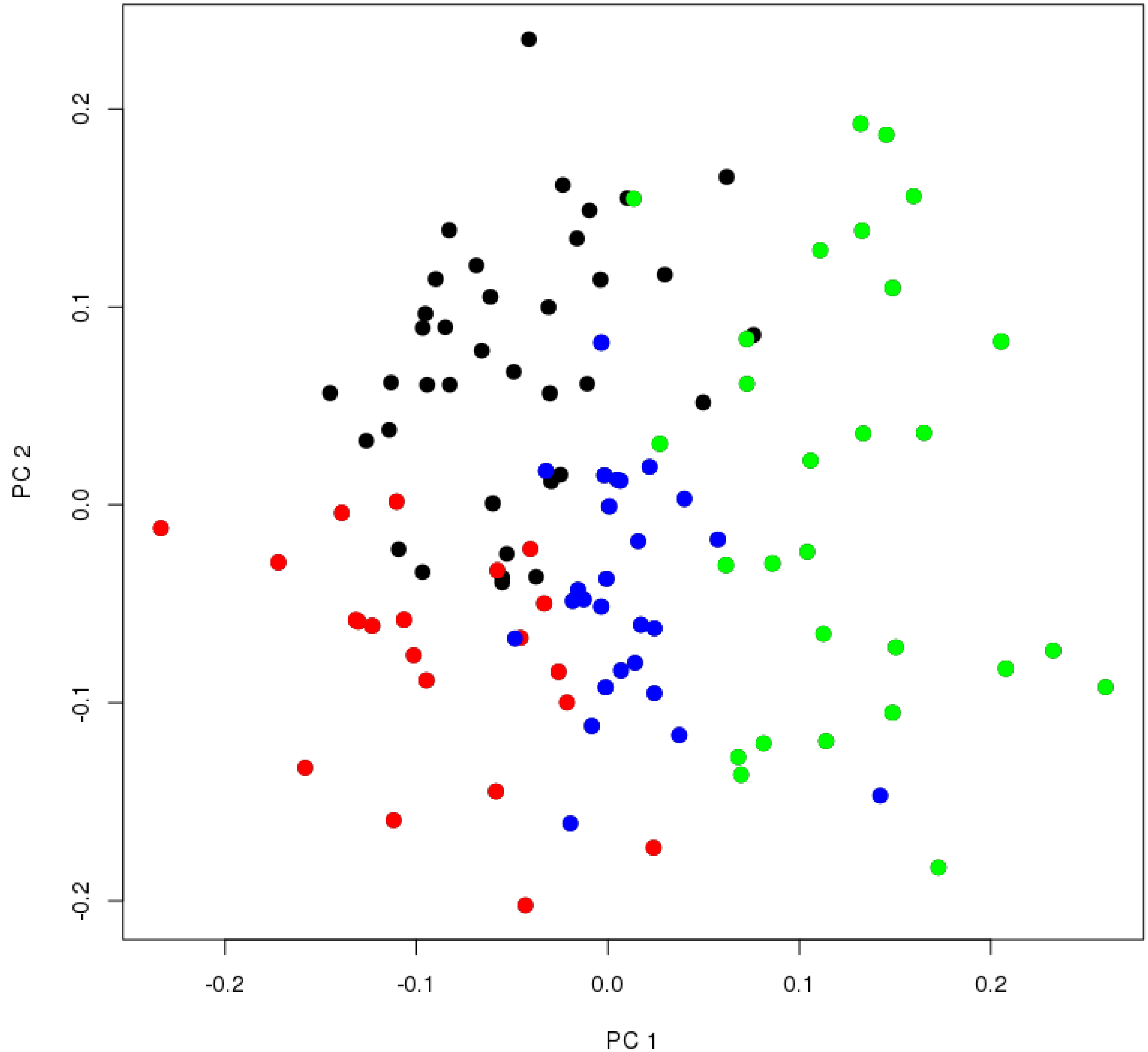
Clustering - Angle Histograms



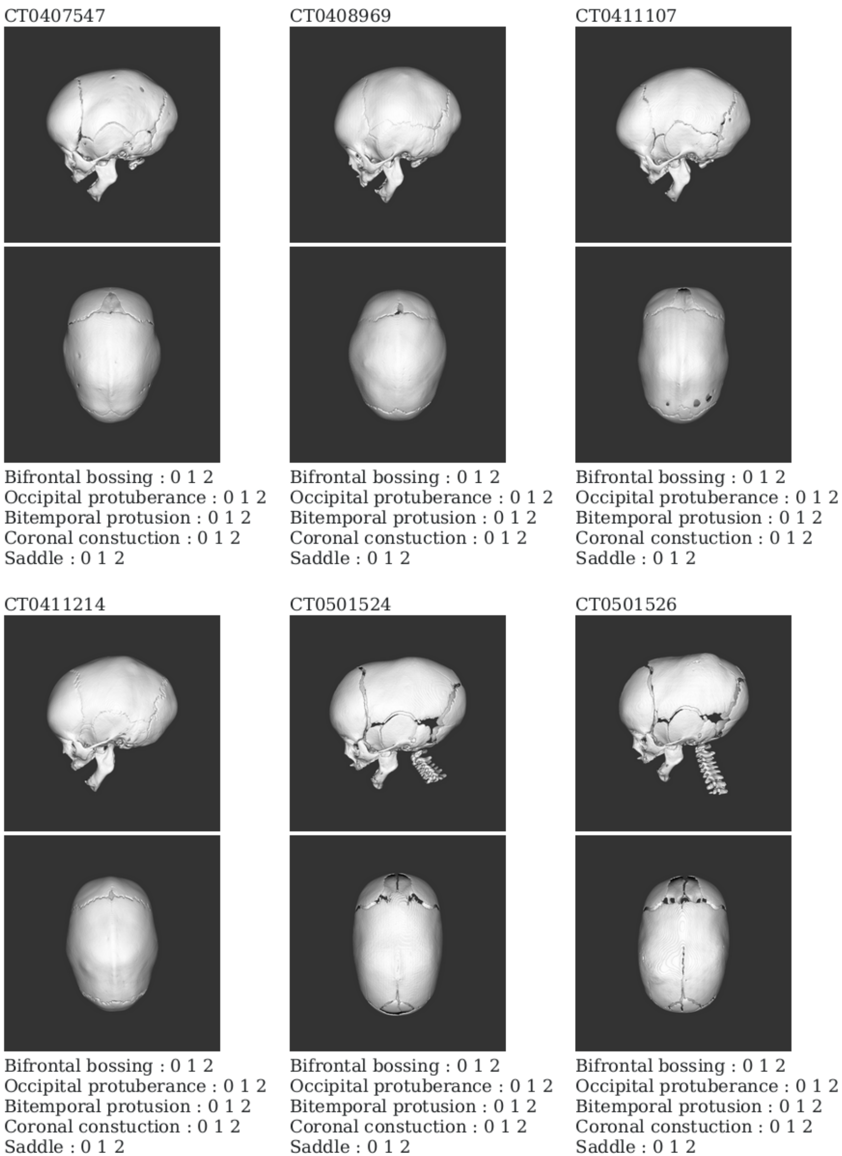
Sanity Check

Do principle components capture the same clusters?

Yes!



Observed Phenotypes



Collected rankings from a surgeon
N=48

Can computed clusters capture the observed phenotypes?

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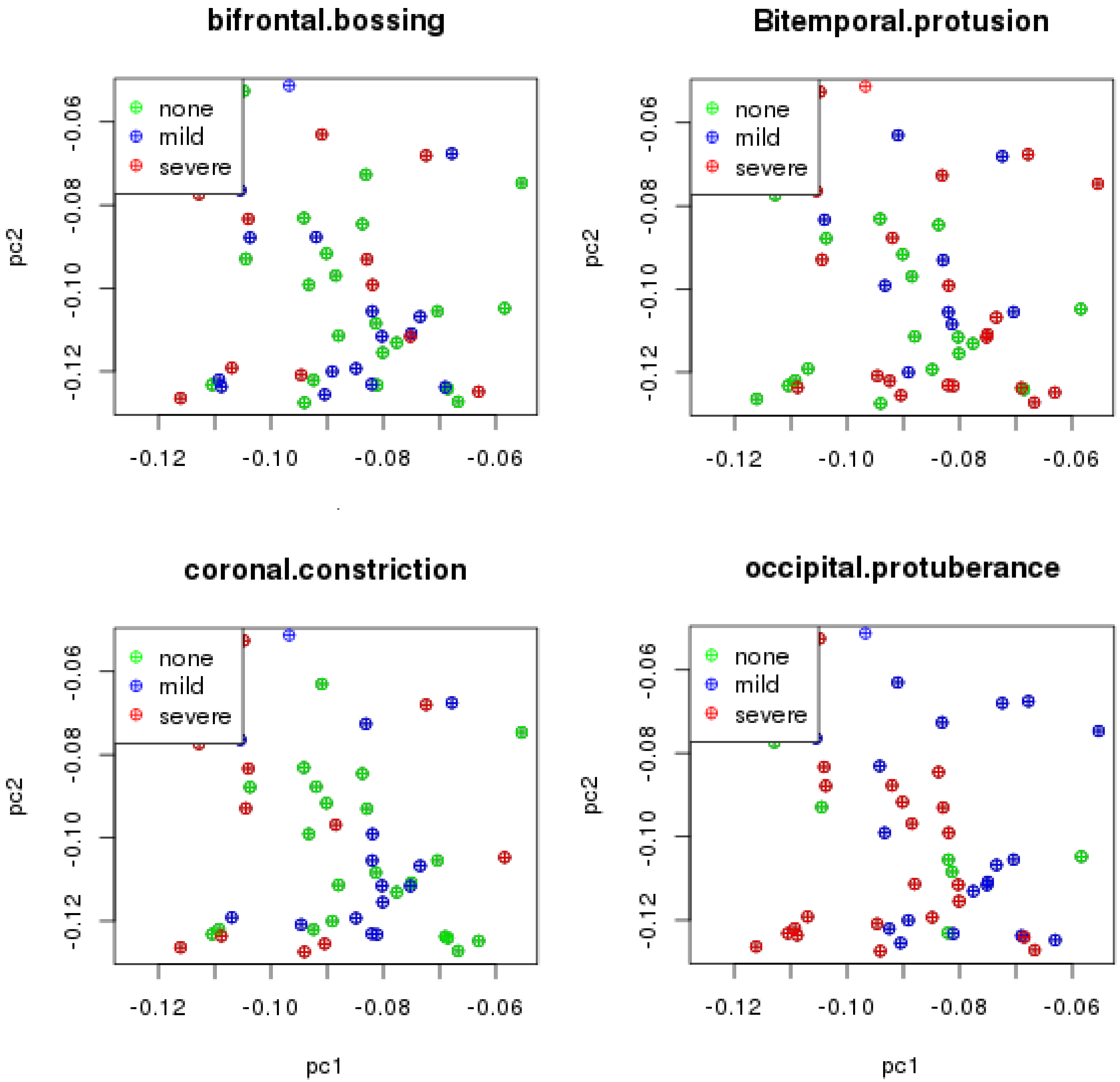


No

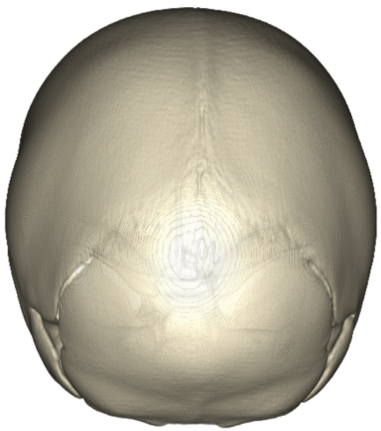
Recovering observed phenotypes

- Observed phenotypes are mixture of the 4 published
  - More clusters
  - More ranking
- Are observed phenotypes reliable?
- Our approach is unsupervised
  - Try a supervised approach: learn from surgeon rankings

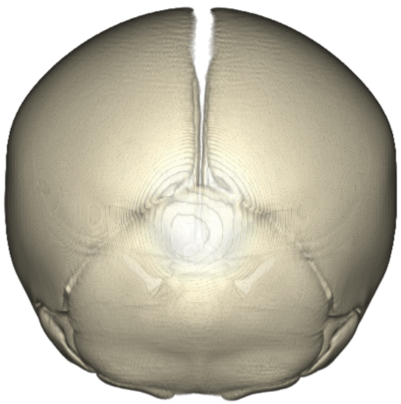
Recovering observed phenotypes

- We deformed all sagittals to a normal template
  - Deform to a sagittal template?
- Parameter search

Sagittal Template



sagittal template
(0-3m)

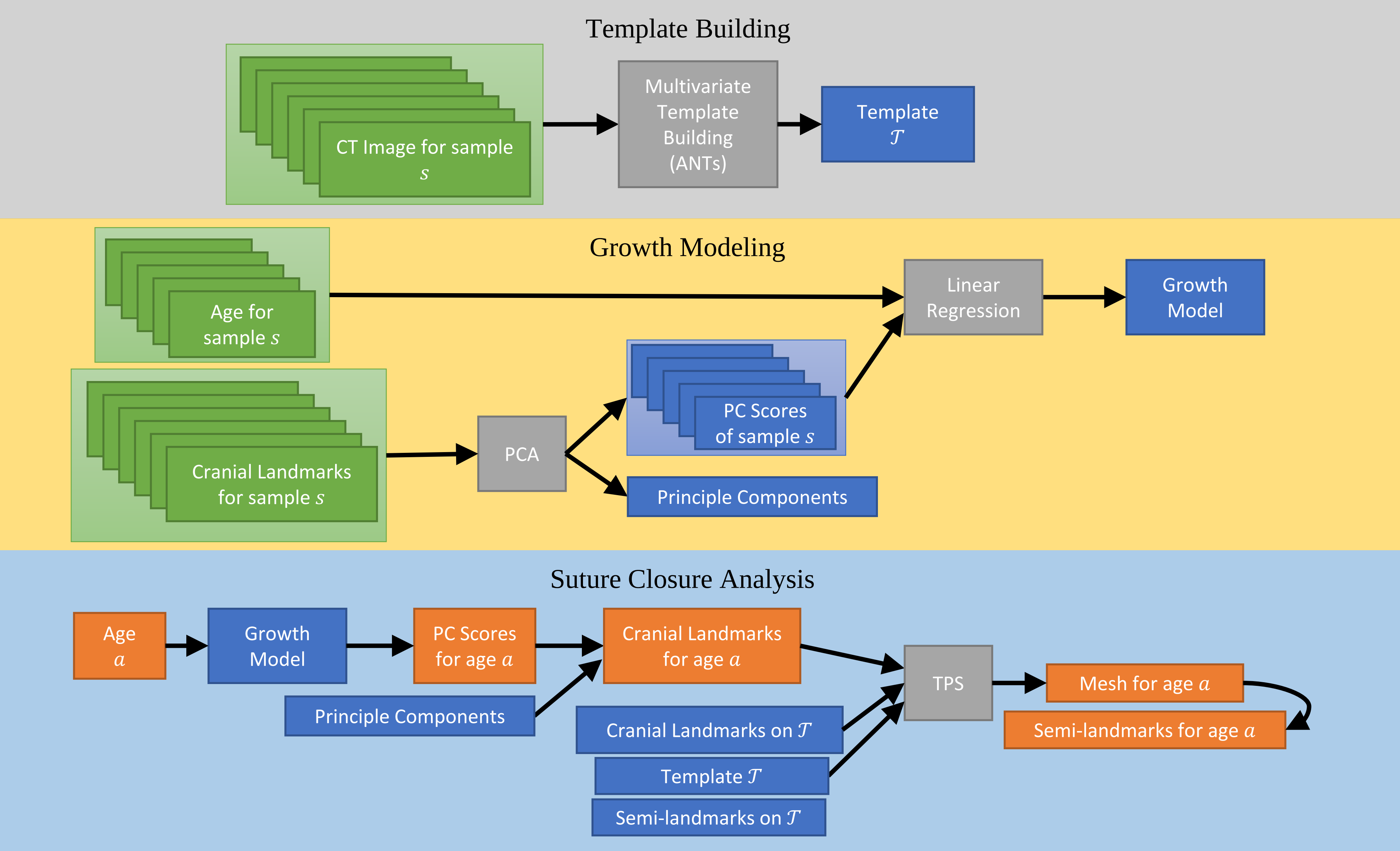


normal template
(0-3m)

Recovering observed phenotypes

- Maybe more than 4 phenotypes?
- Clinical relevance of phenotypes
  - Shape maintenance
  - Initial severity

Outline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TPS
Mesh for age a
Cranial Landmarks on $\mathcal{T}$
Semi-landmarks for age a
Template $\mathcal{T}$
Semi-landmarks on $\mathcal{T}$