Seattle Children's
HOSPITAL • RESEARCH • FOUNDATION

CRANIOFACIAL

Statistical Shape Analysis of Human Infant Skull

Ezgi Mercan

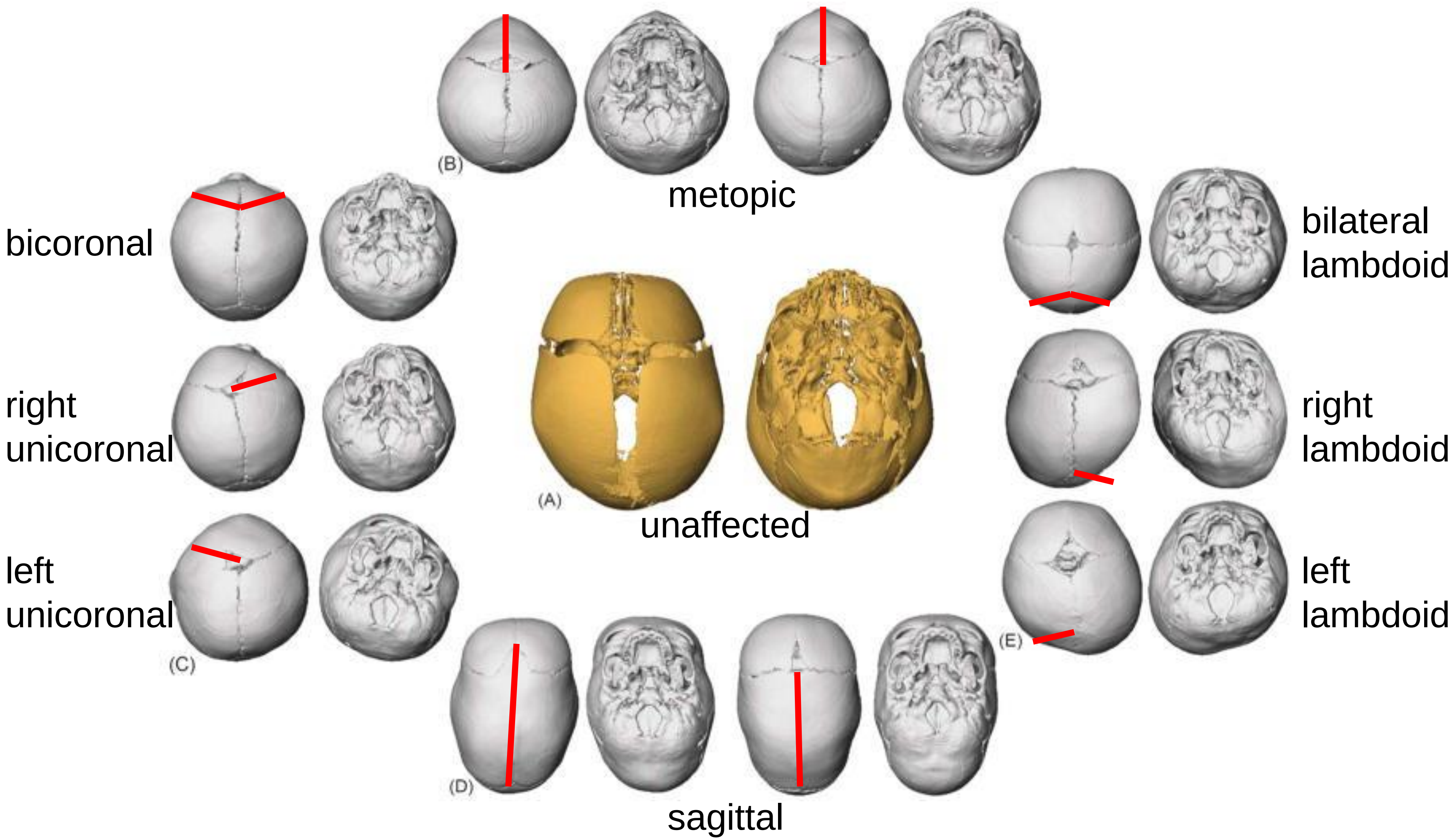
Murat Maga

Richard Hopper

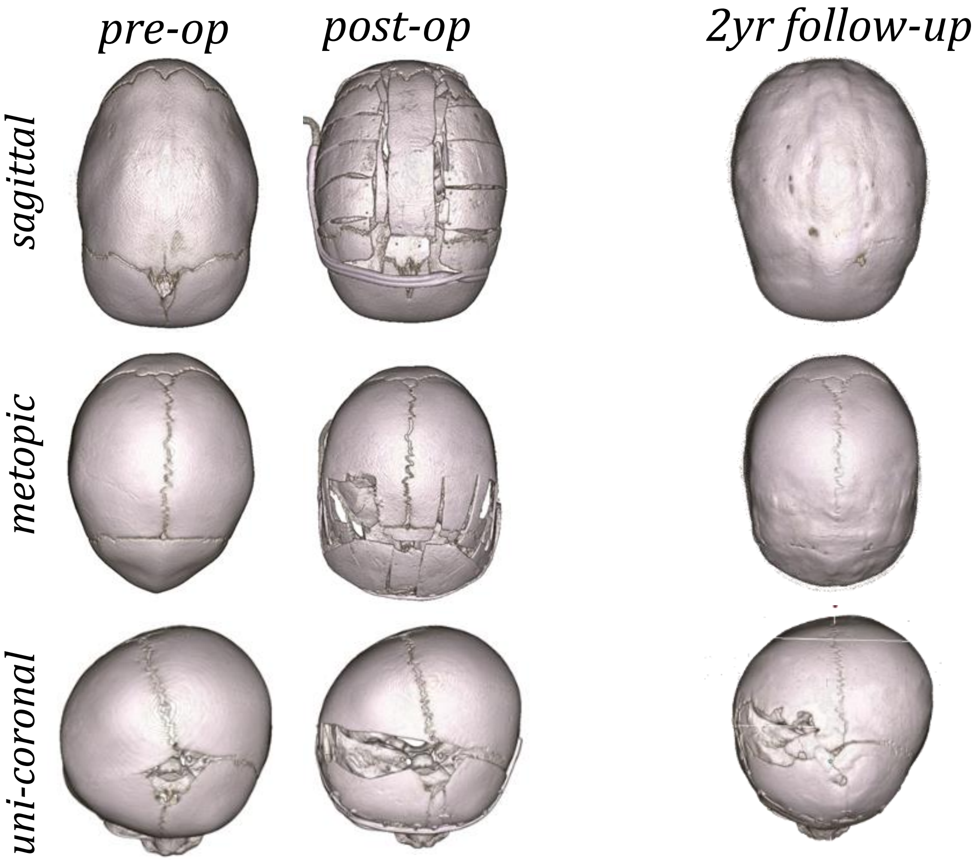
Seattle Children's HOSPITAL • RESEARCH • FOUNDATION

CRANIOFACIAL

Skull Shape in Craniosynostosis: A Complex Phenotype



Cranial Reconstruction

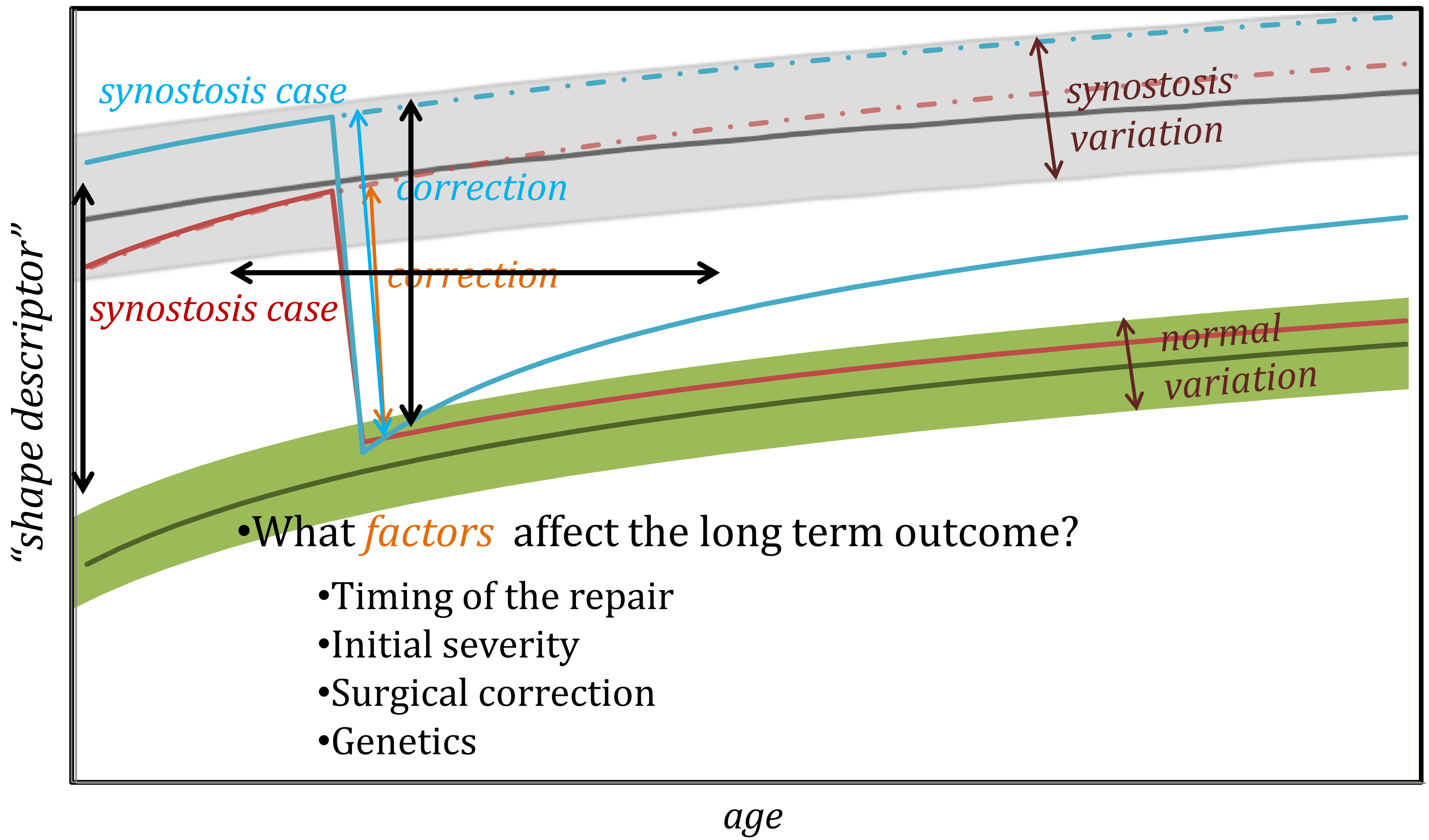


Shape Maintenance

- 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

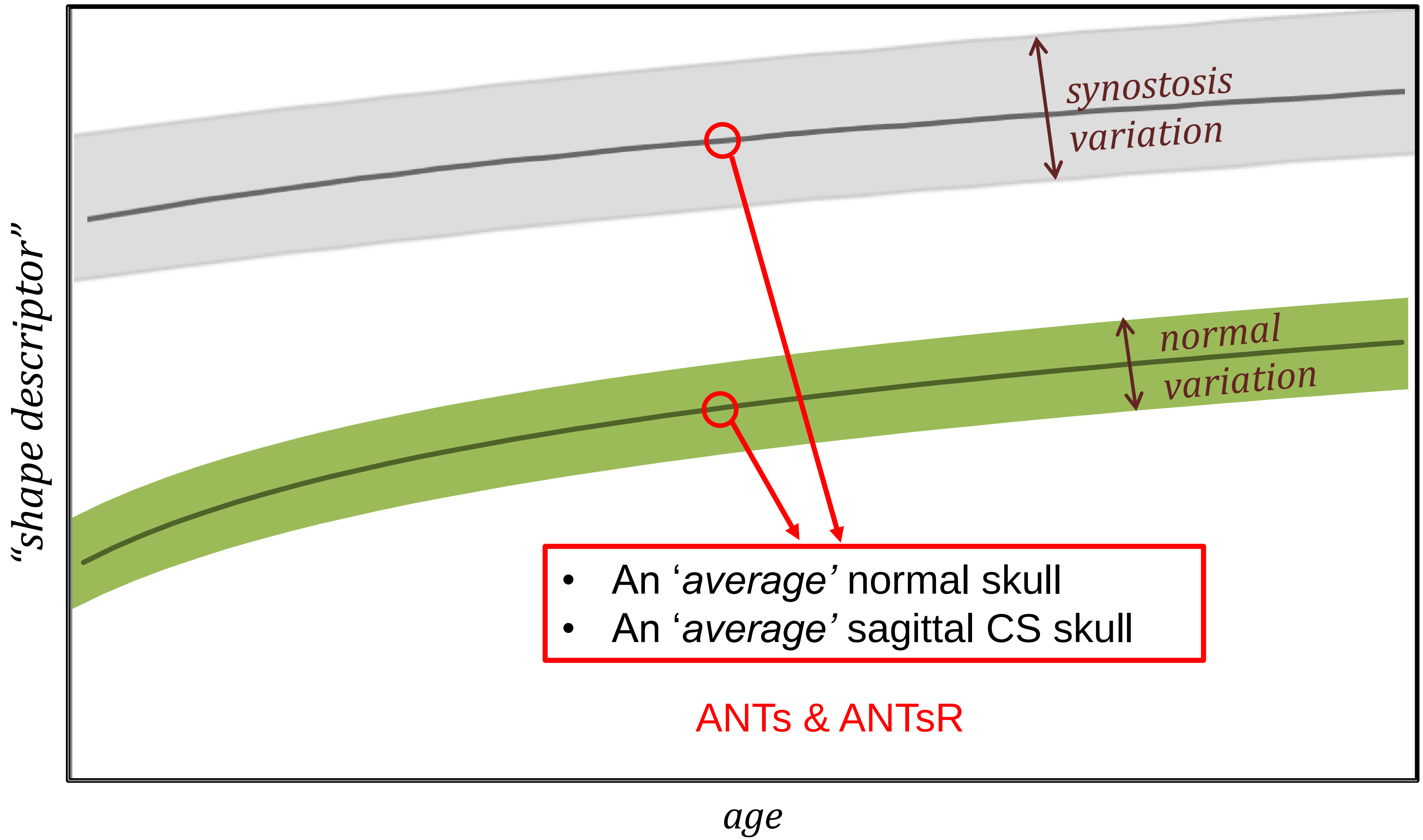
Outline

Template Building

Growth Modeling

Suture Closure Analysis

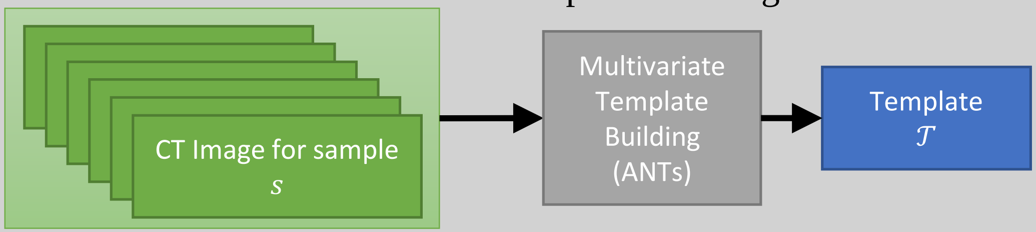
Hypothetical Growth



- 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

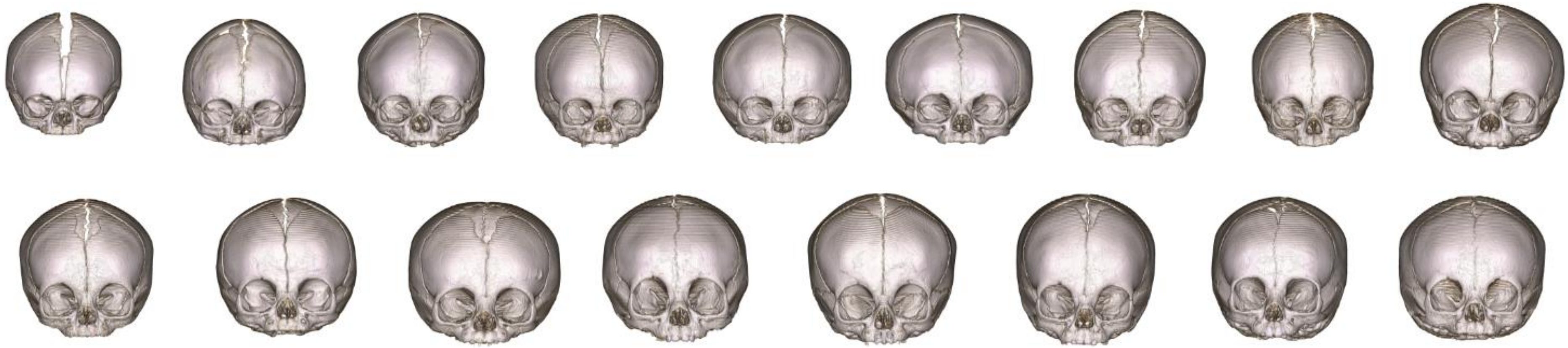
Template Building



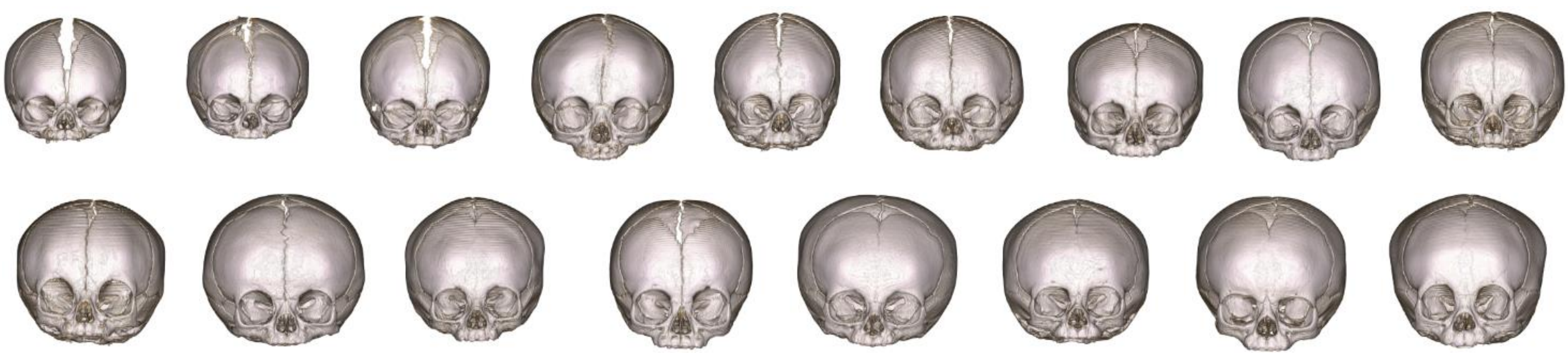
Growth Modeling

Suture Closure Analysis

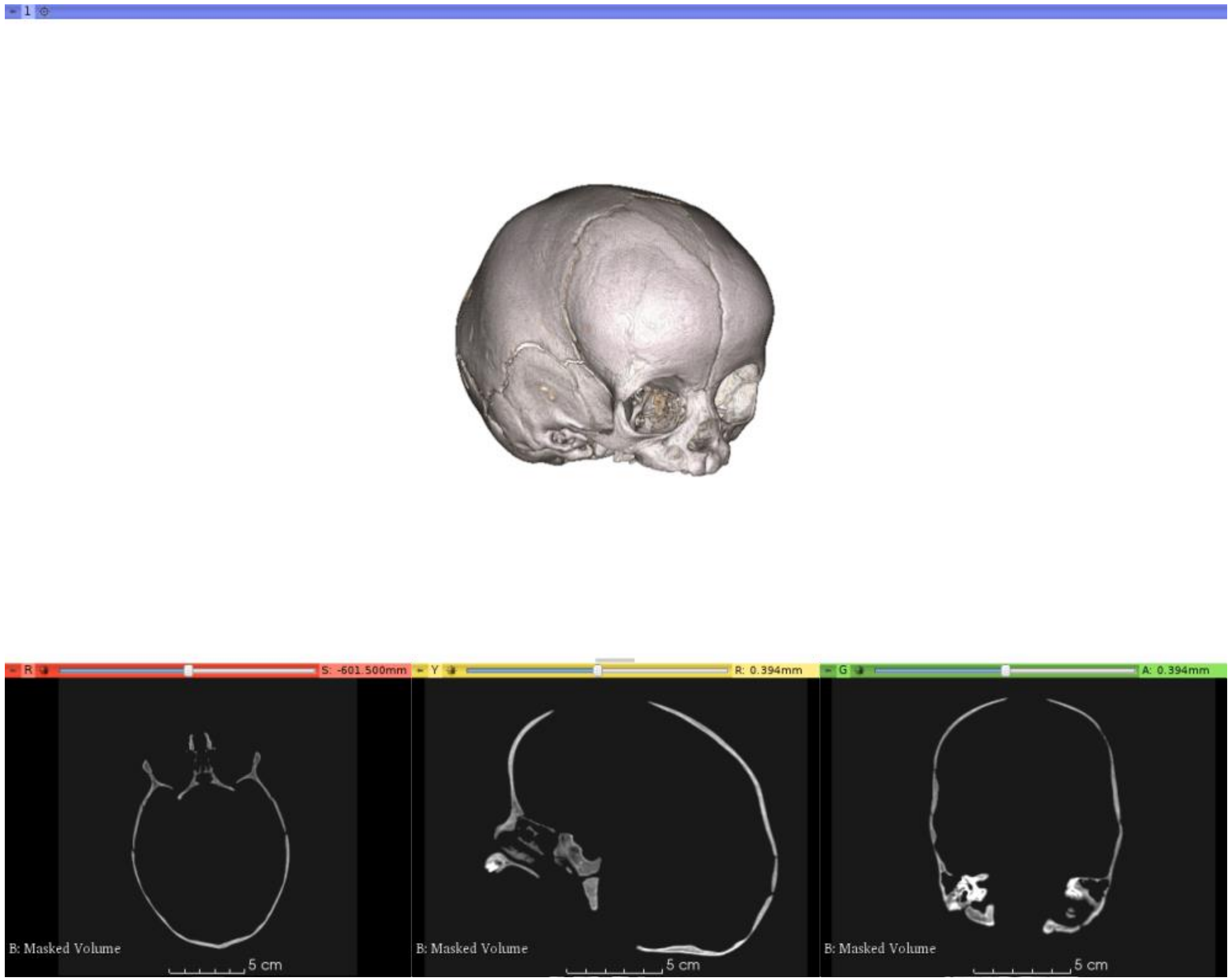
Data



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

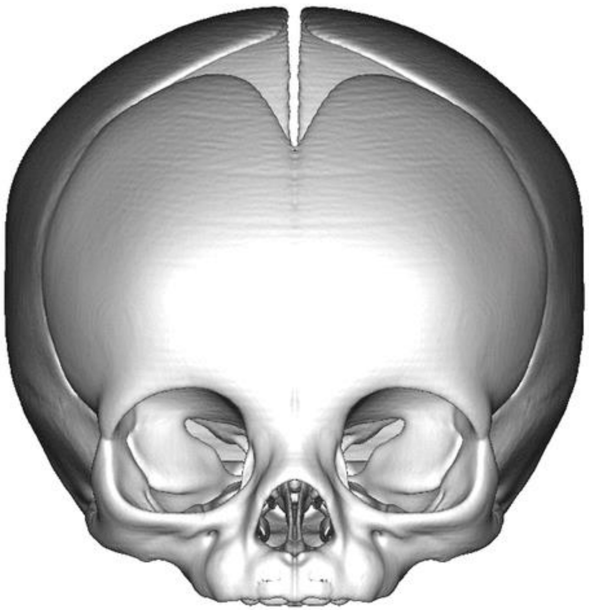


Pre-processing

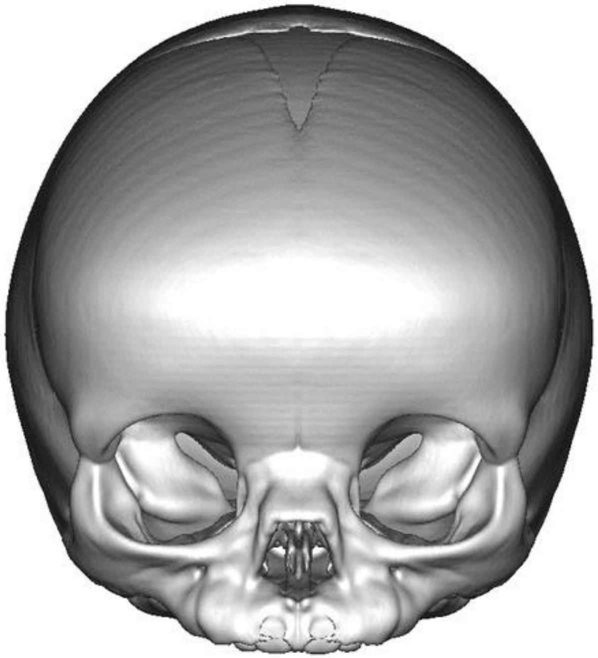


Population Templates

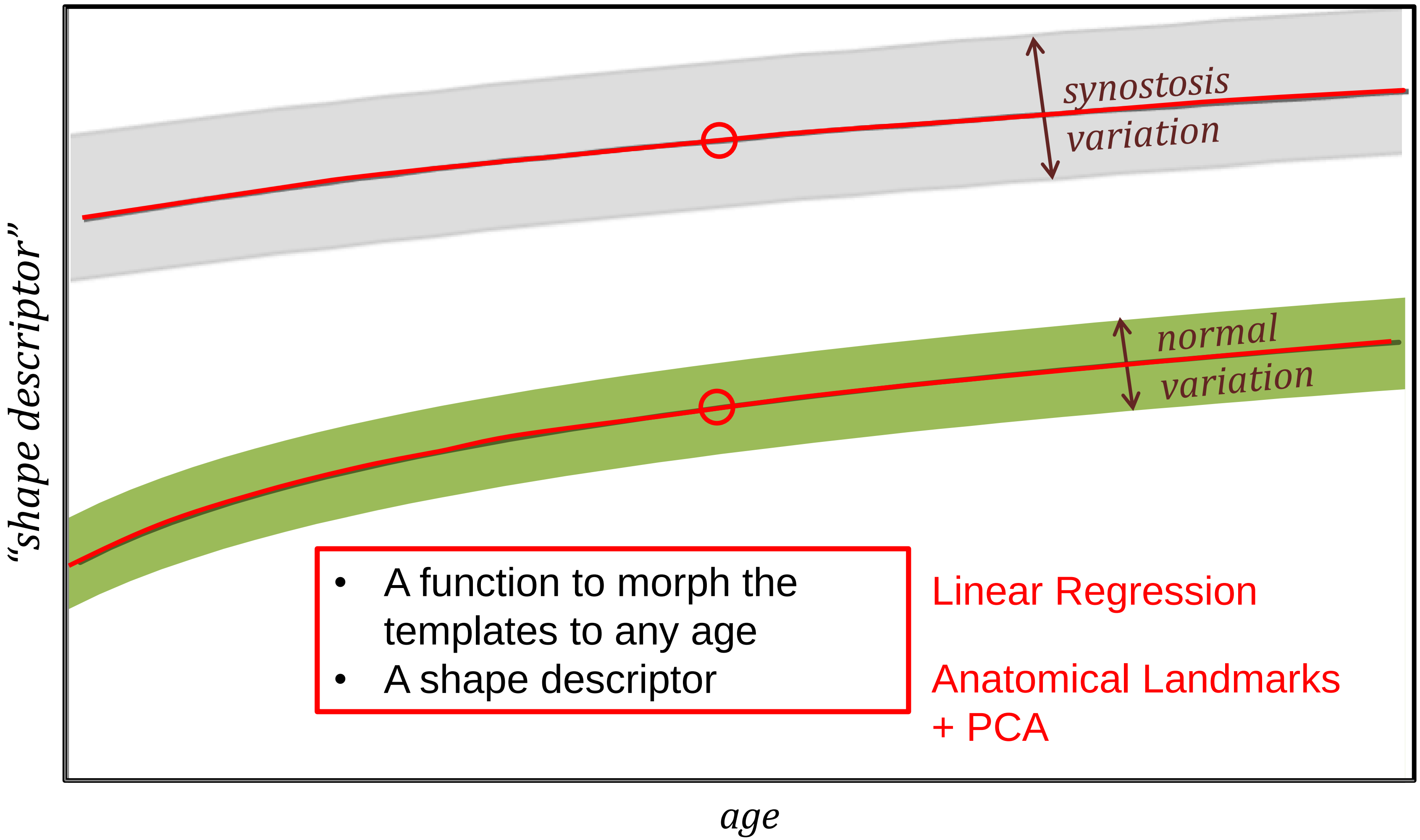
Normal Infant Template



Sagittal CS Template



Hypothetical Growth

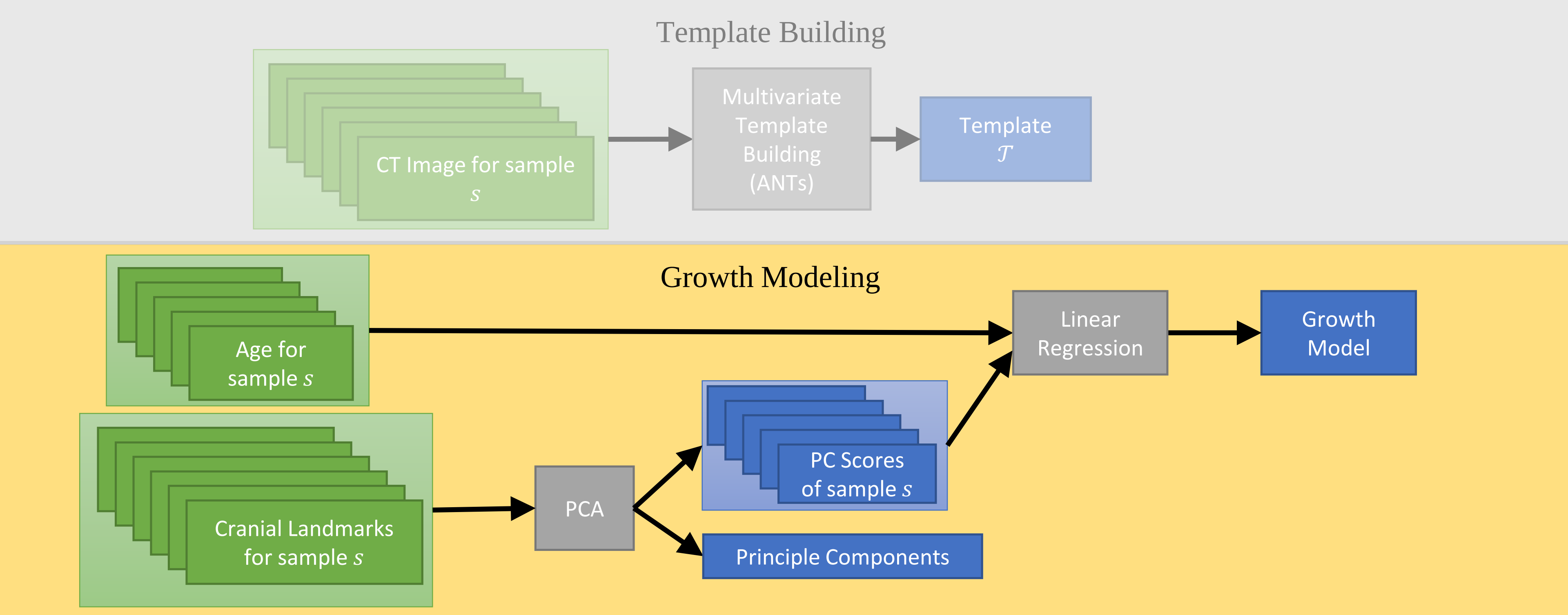


- A function to morph the templates to any age
- A shape descriptor

Linear Regression

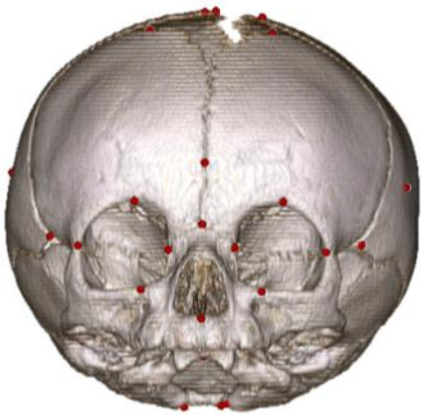
Anatomical Landmarks + PCA

Outline

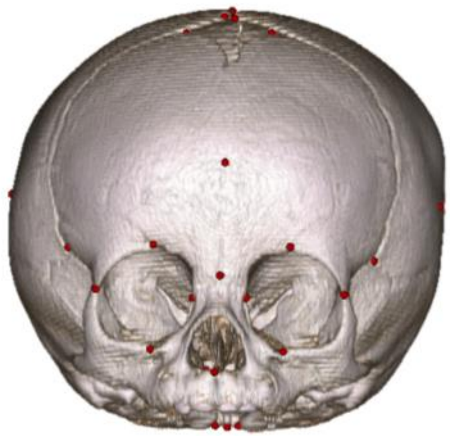


Suture Closure Analysis

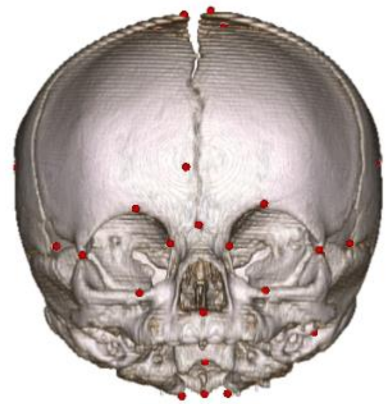
Growth Modeling



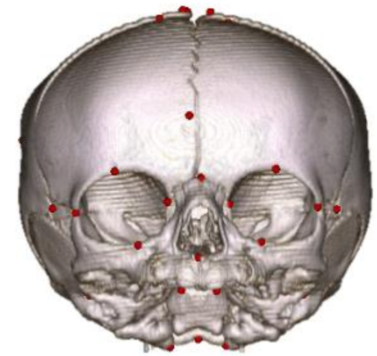
age_1



age_2

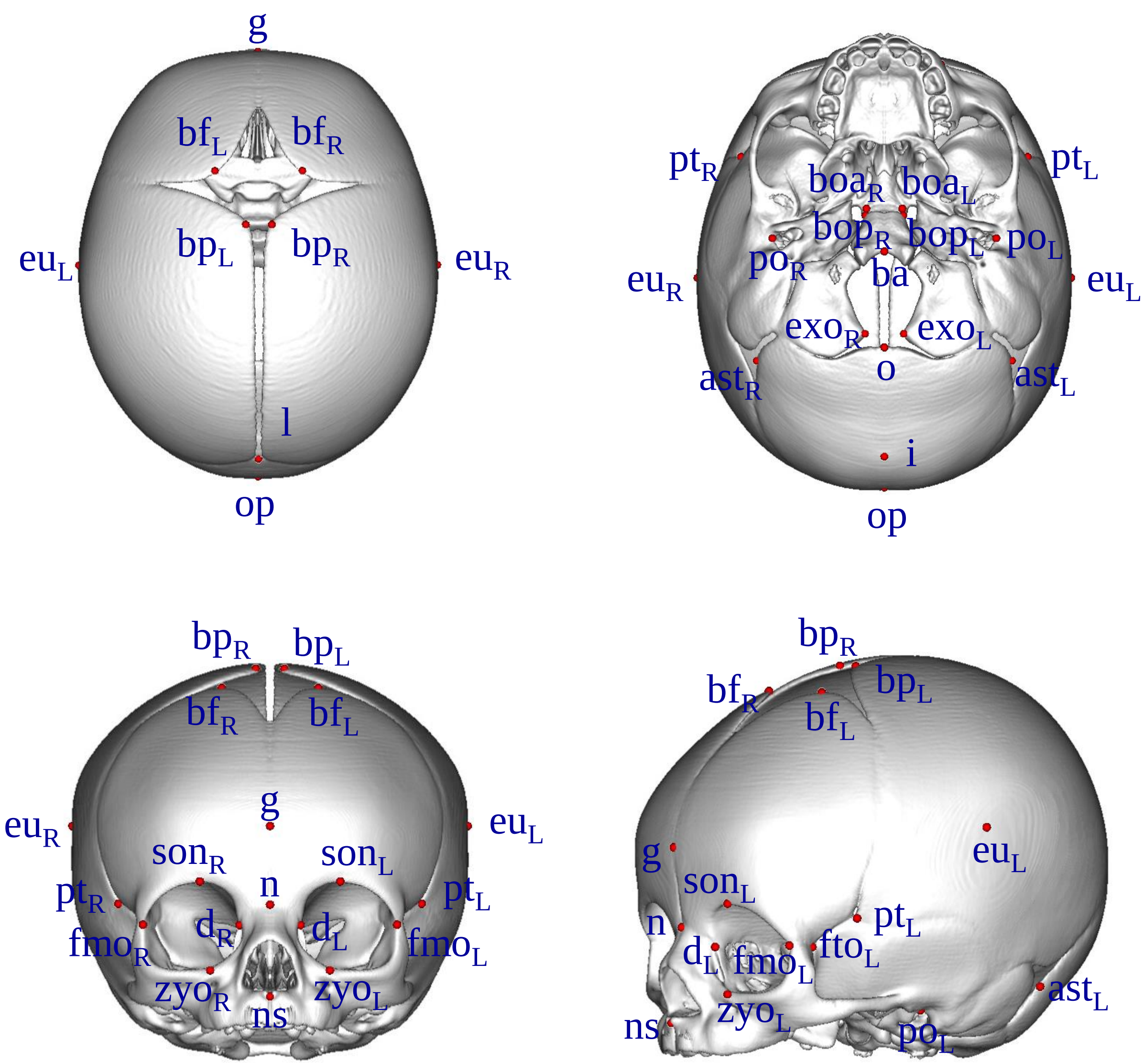


age_3



age_4

Landmarks

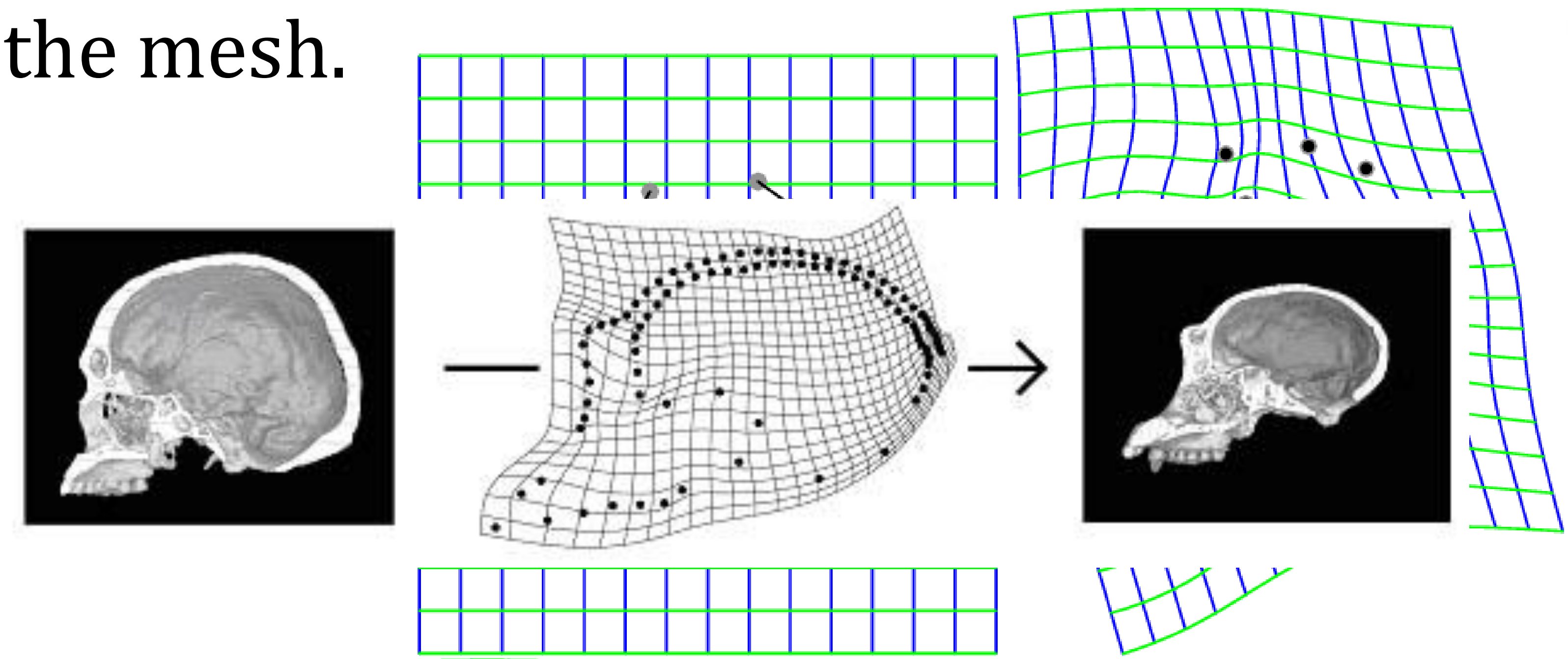

g
bf_L bf_R
bp_L bp_R
eu_L eu_R
l
op
pt_R pt_L
boa_R boa_L
bop_R bop_L
po_R po_L
ba
eu_R eu_L
exo_R exo_L
ast_R ast_L
o
i
op
bp_R bp_L
bf_R bf_L
g
eu_R eu_L
son_R son_L
n
pt_R pt_L
d_R d_L
fmo_R fmo_L
zyo_R zyo_L
ns
bp_R
bf_R
bp_L
bf_L
eu_L
g
son_L
n
pt_L
d_L
fmo_L
fto_L
ast_L
ns
zyo_L
po_L

Linear Regression + PCA

- A scatter plot of landmark positions vs age.
- Show different regression models that can be fit, and resulting animations => overfit
- Talk about PCA's role.

Thin Plate Splines

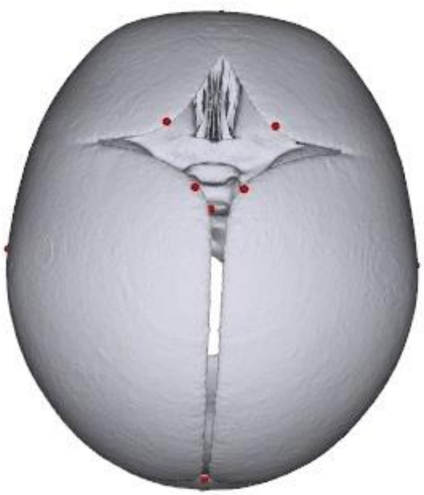
- It is an interpolation and smoothing technique.
- Using predicted landmark points, we *warp* the mesh.



- 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.

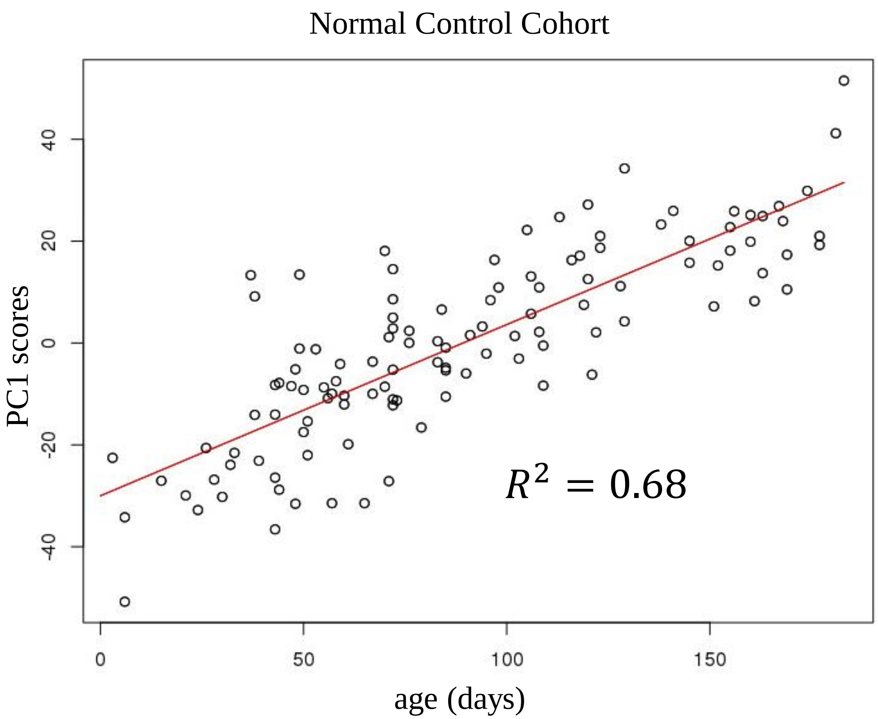
Growth Models

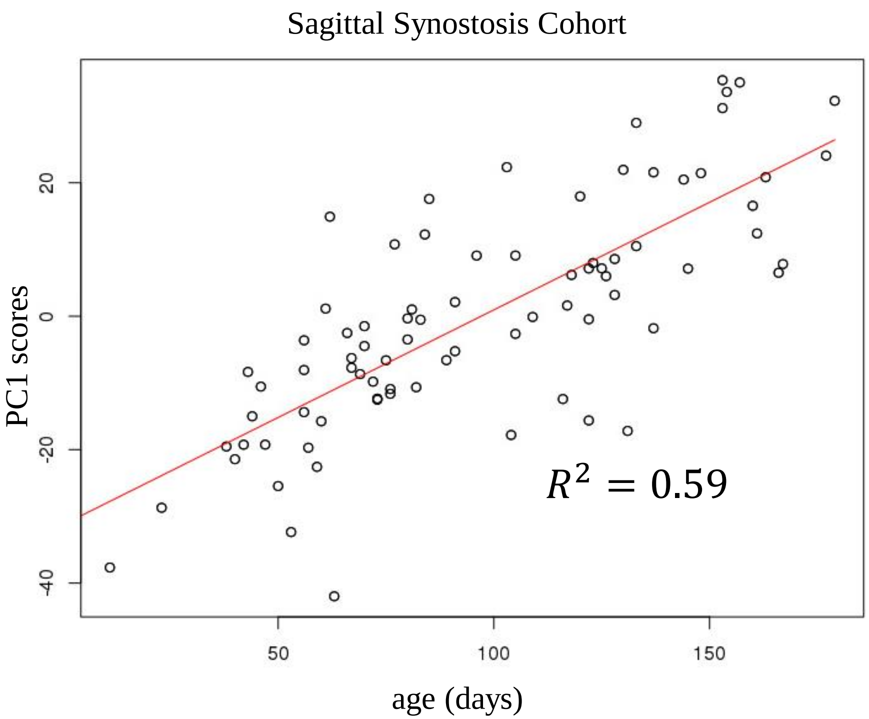
Normal Infant Template



Sagittal CS Template

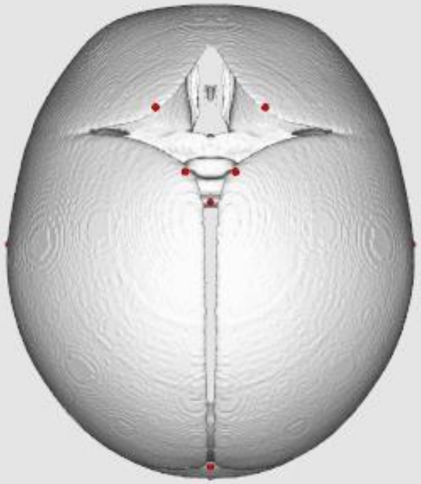
Dominant Shape Changes: PC1



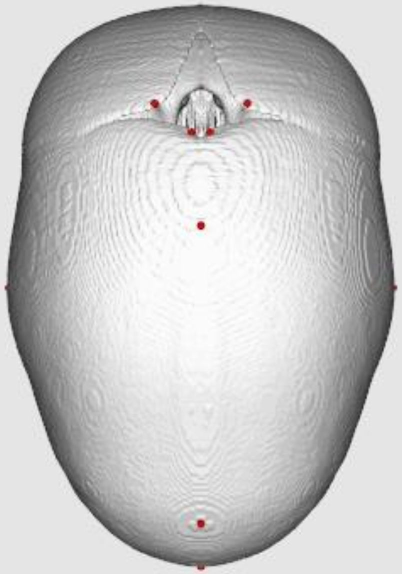


Dominant Shape Changes: PC1

Normal Infant Template

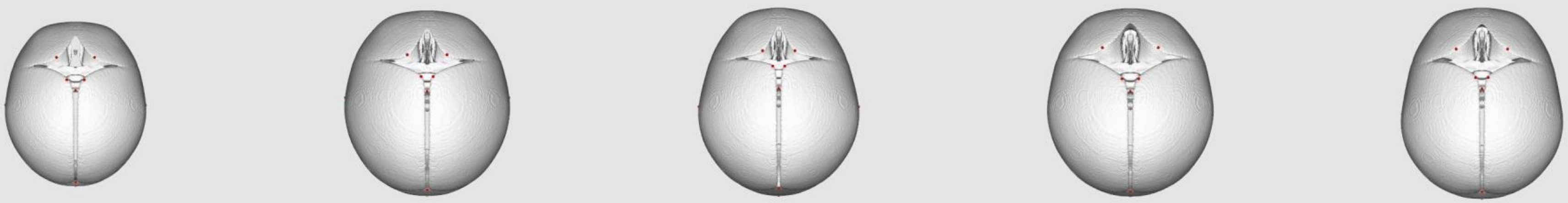


Sagittal CS Template



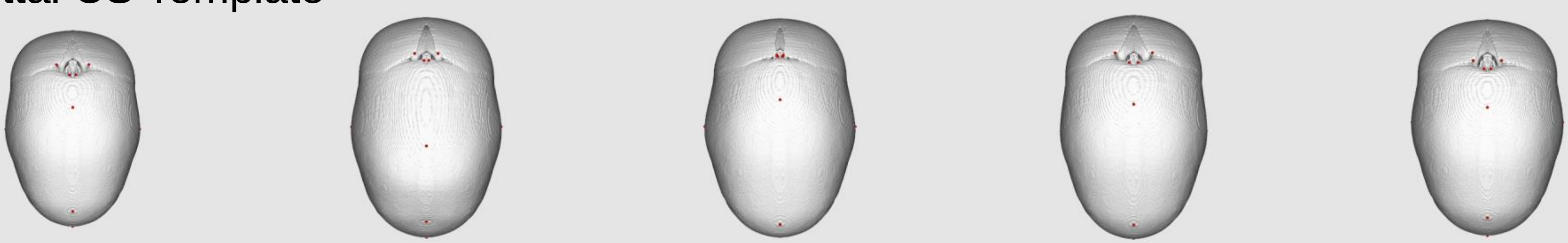
First 5 PCs

Normal Infant Template



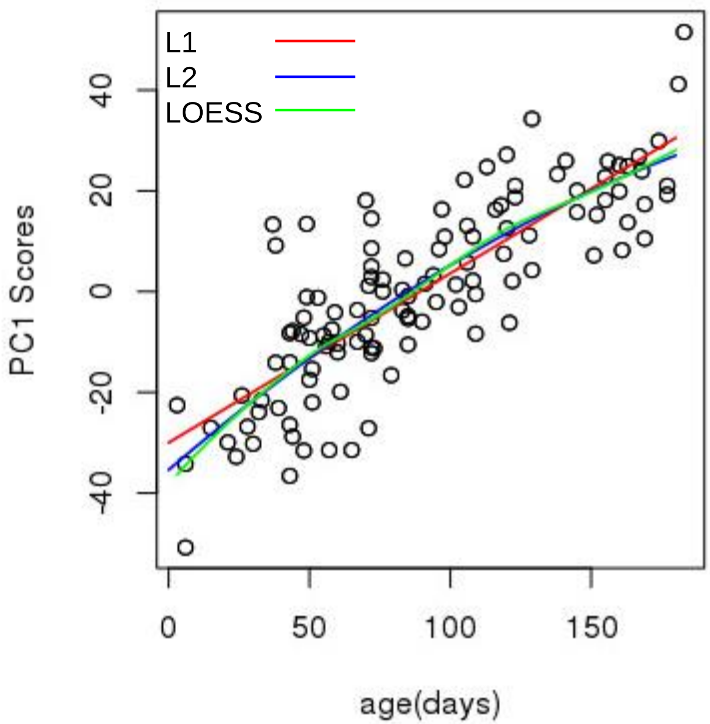
PC1	PC2	PC3	PC4	PC5

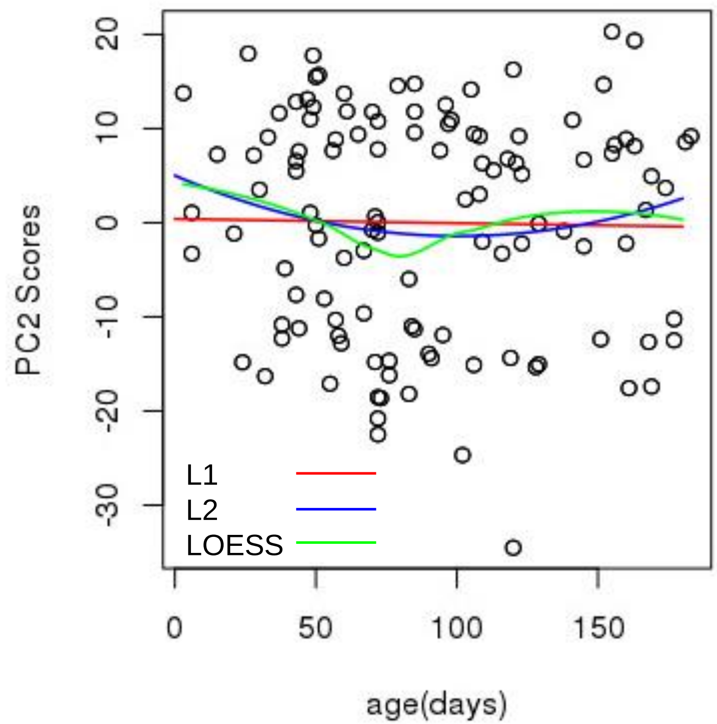
Sagittal CS Template



Why Linear Regression

- L1 generalizes well, does not overfit and has only 2 parameters to learn.



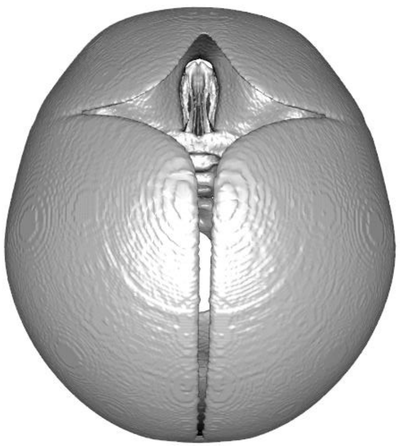


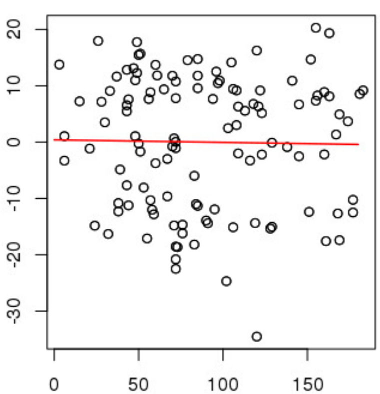
Seattle Children's
HOSPITAL • RESEARCH • FOUNDATION

CRANIOFACIAL

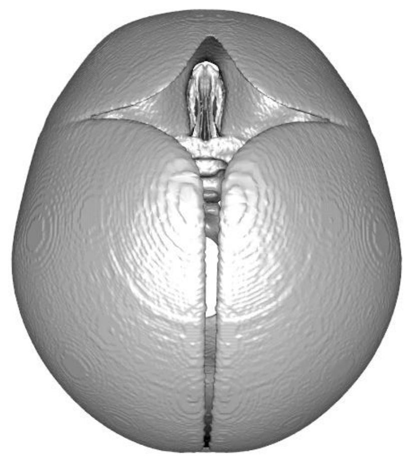
Why Linear Regression

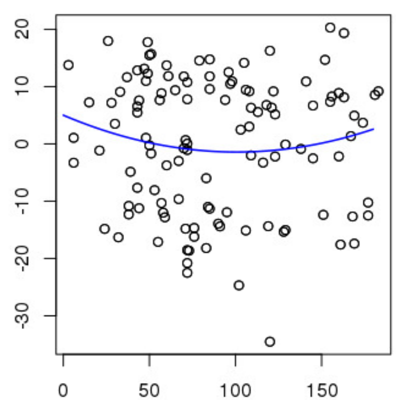
L1



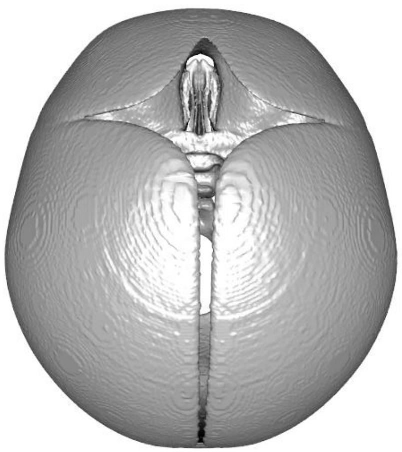


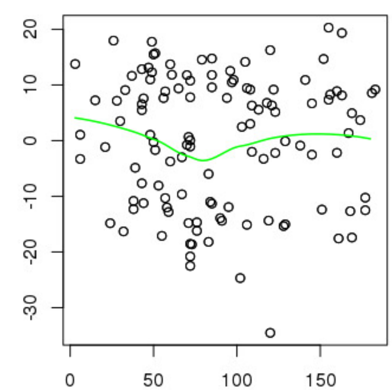
L2



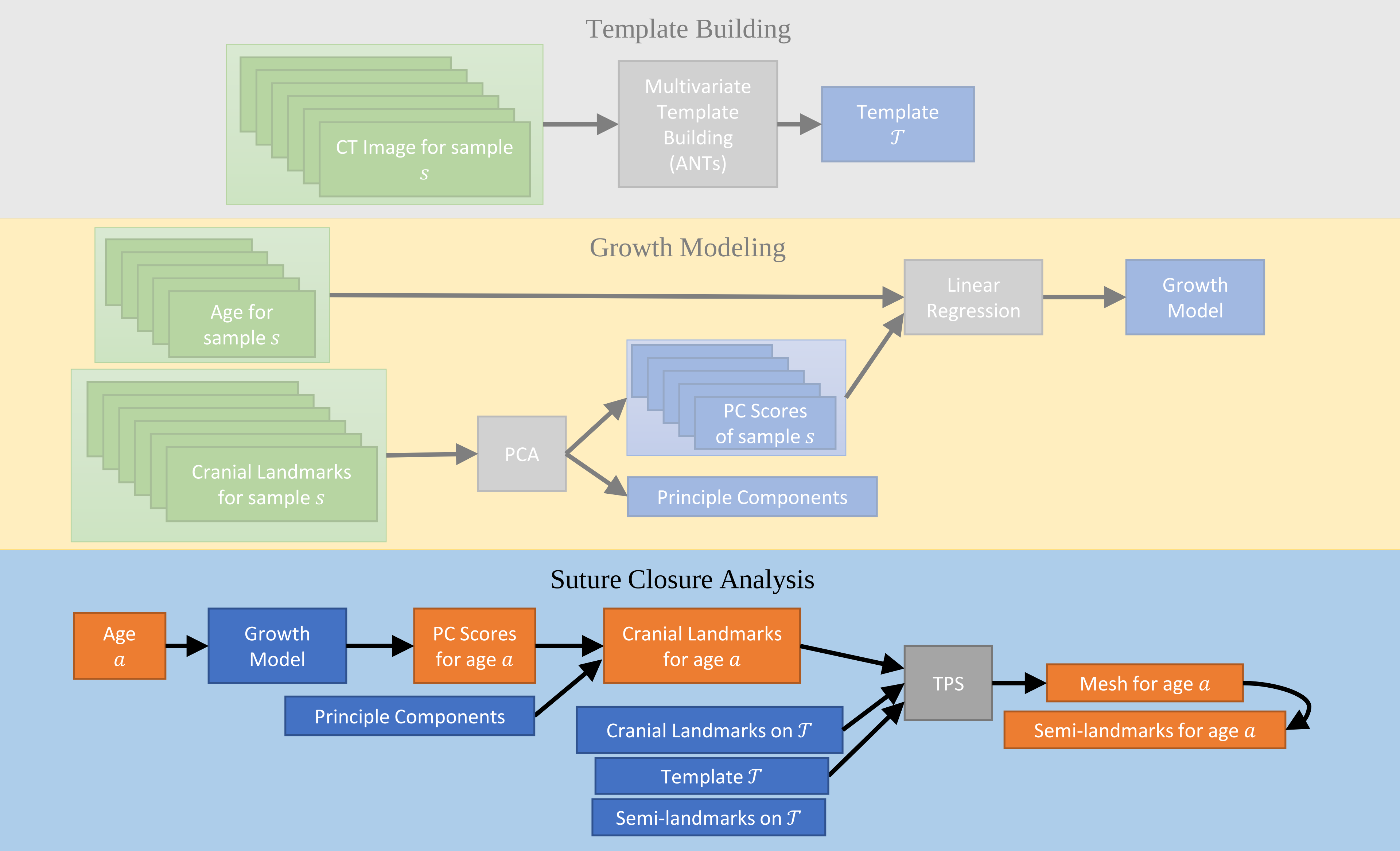


LOESS



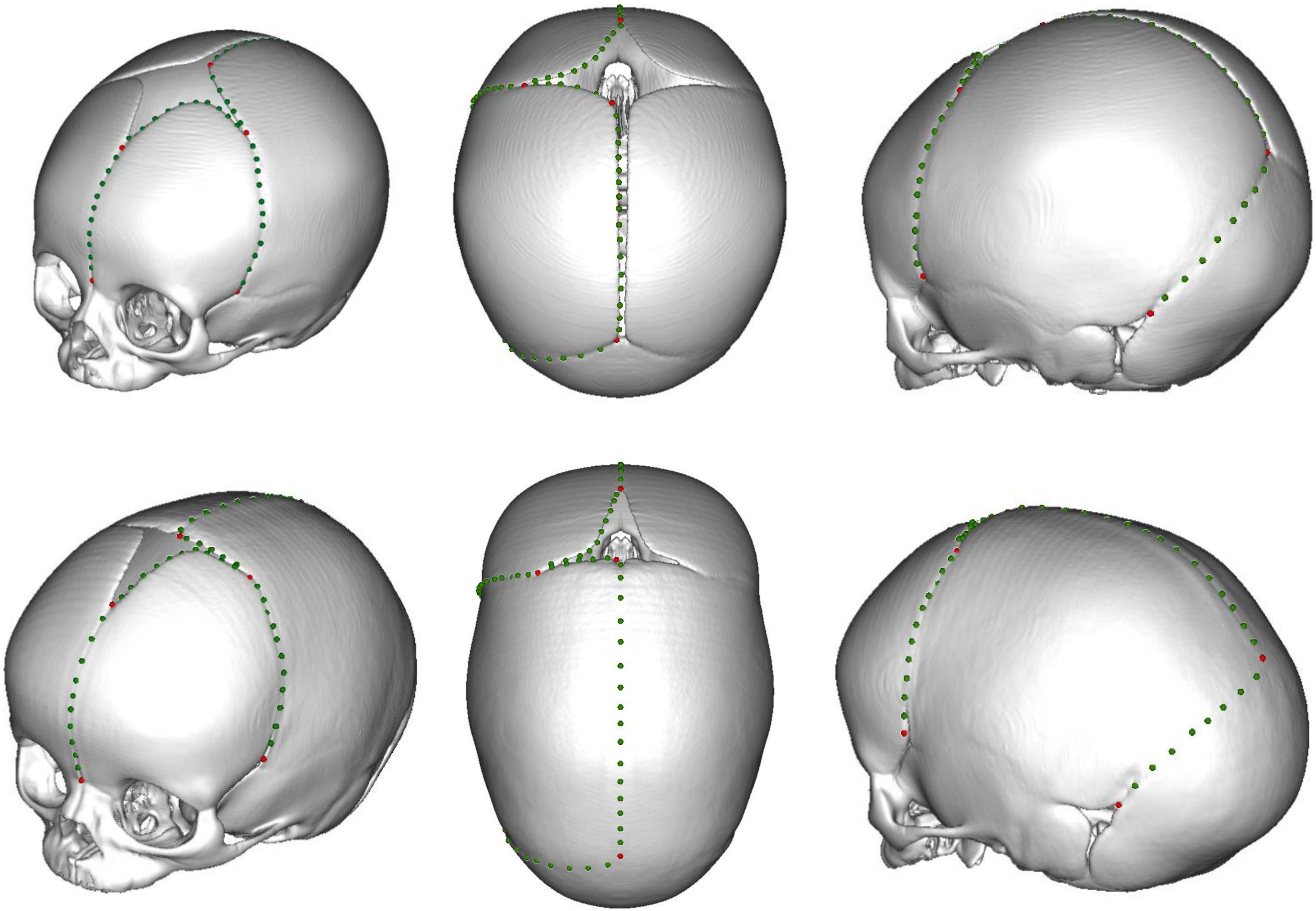


Outline

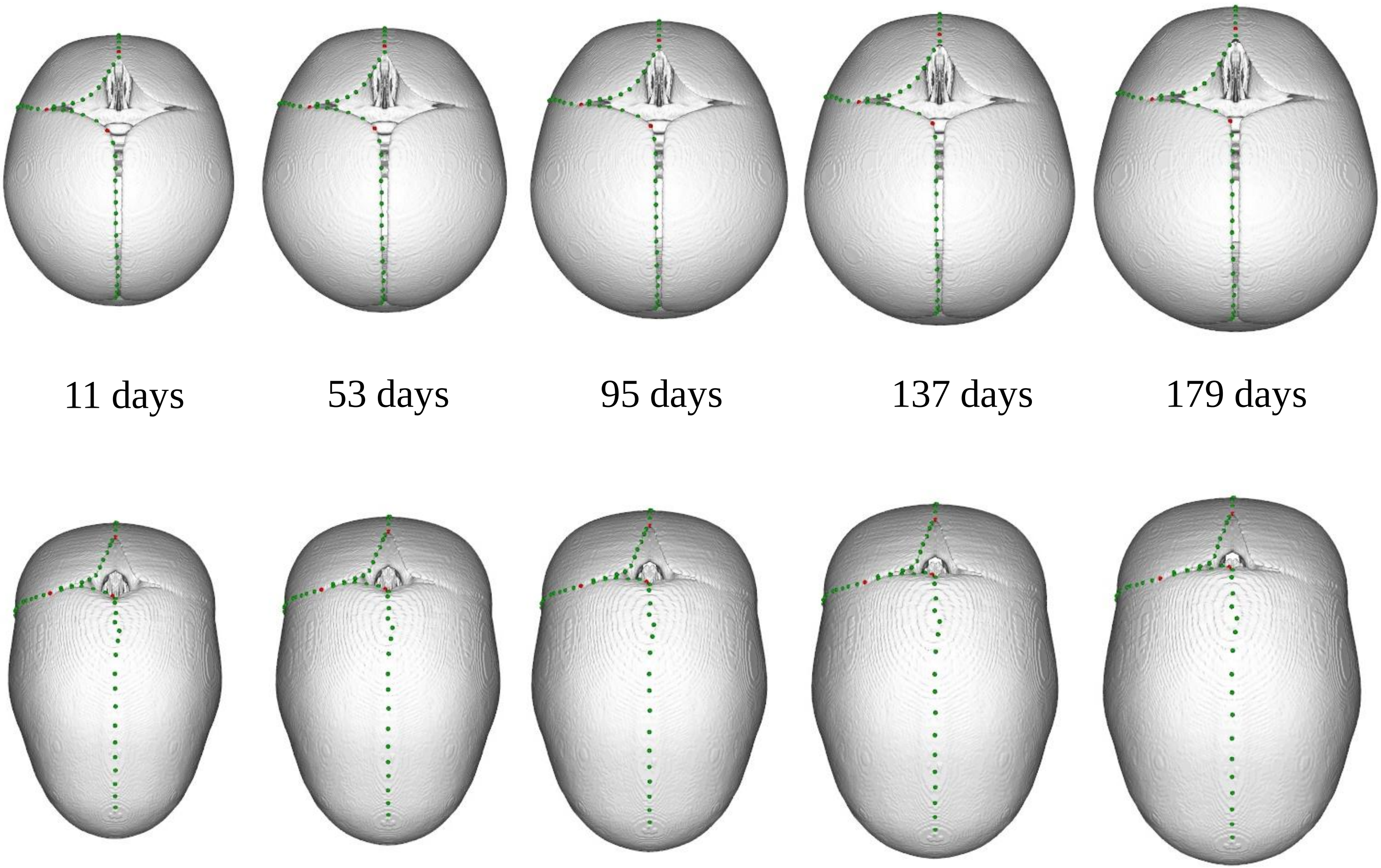


Template Building
CT Image for sample s
Multivariate Template Building (ANTs)
Template $\mathcal{T}$
Growth Modeling
Age for sample s
Linear Regression
Growth Model
PC Scores of sample s
Cranial Landmarks for sample s
PCA
Principle Components
Suture Closure Analysis
Age a
Growth Model
PC Scores for age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

Suture Semi-landmarks

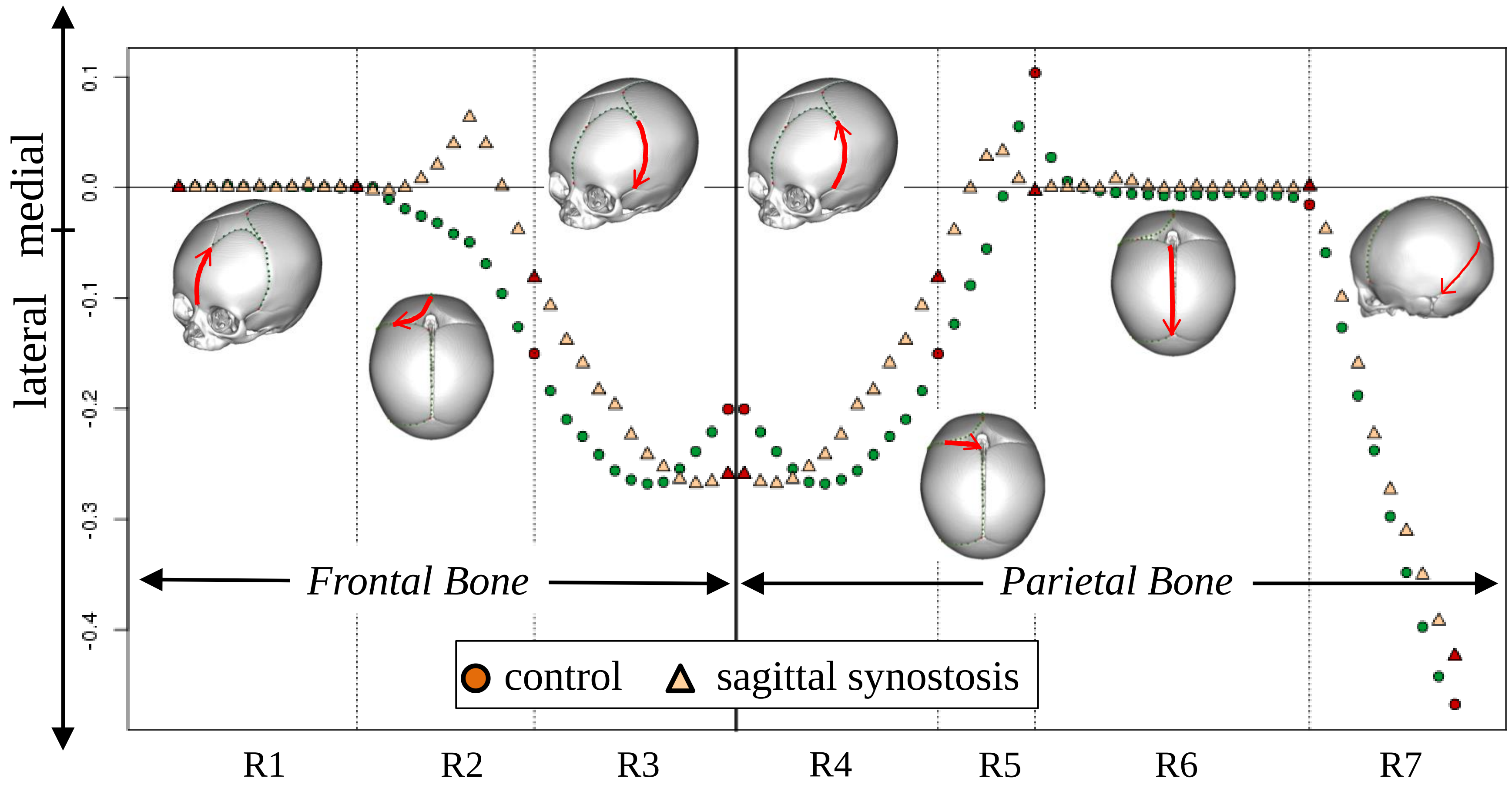


Suture Semi-landmarks

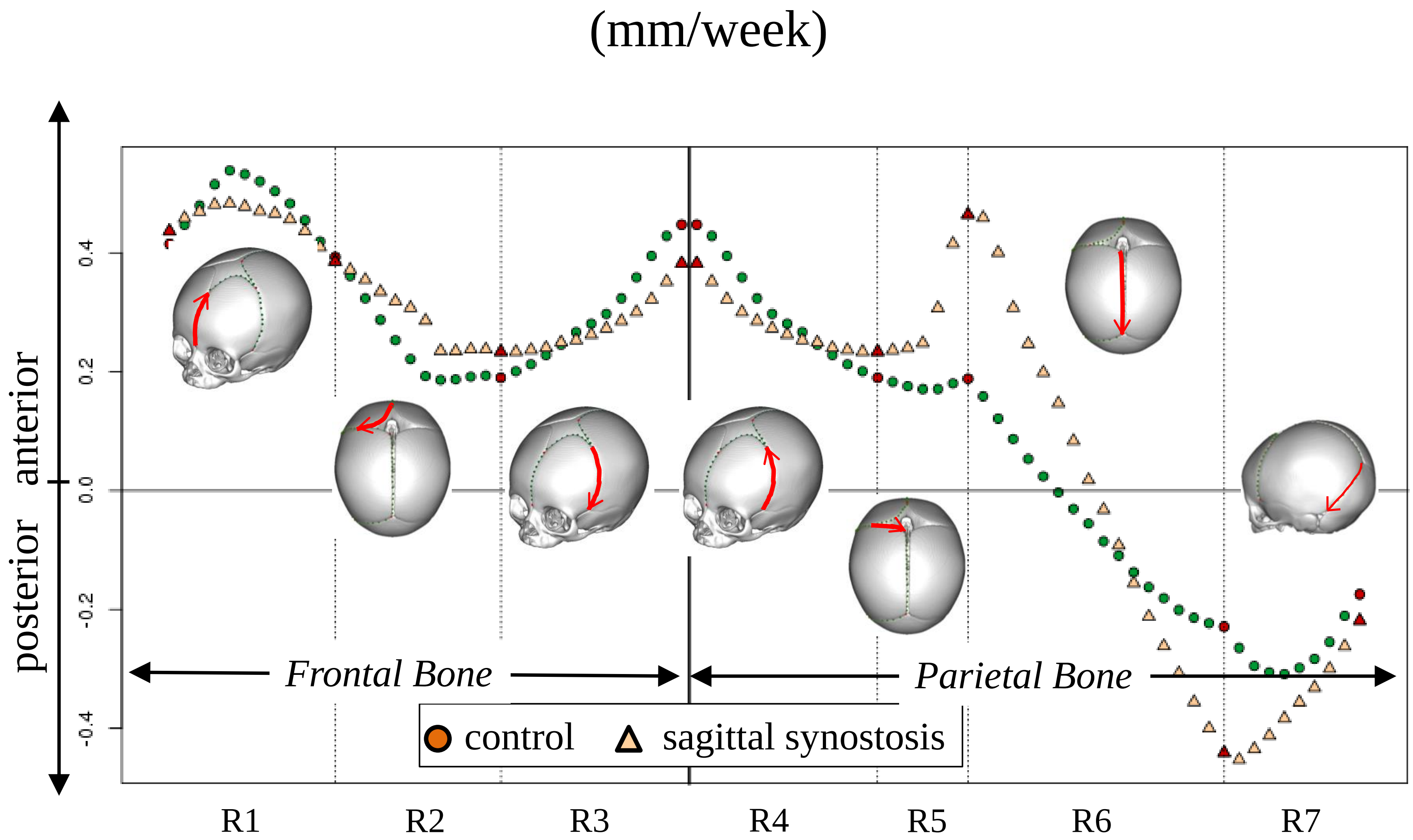


Mediolateral Displacement

(mm/week)



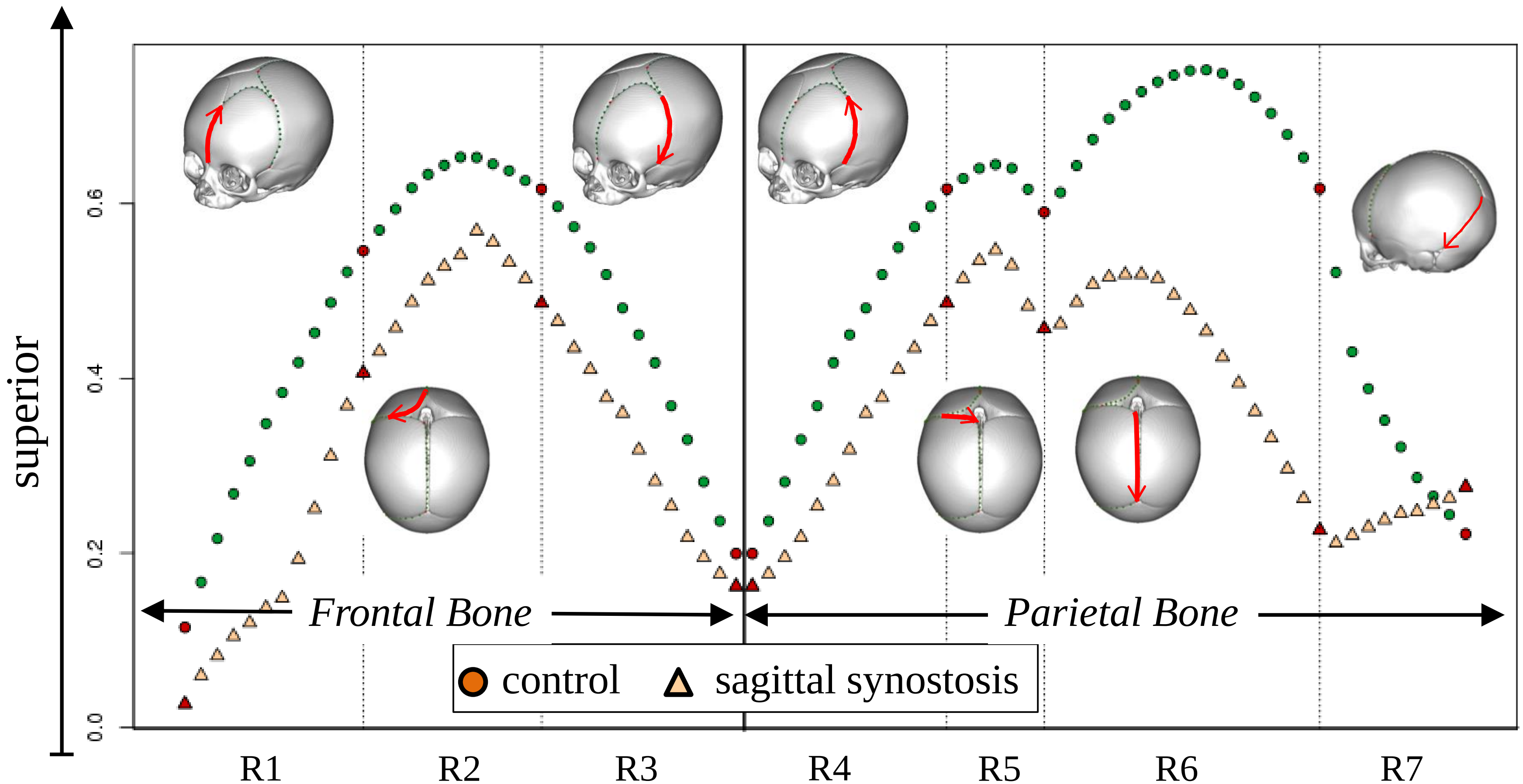
Anteroposterior Displacement



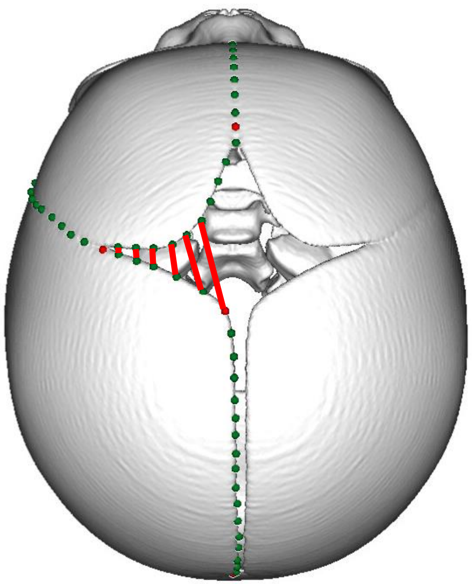
Seattle Children's
HOSPITAL • RESEARCH • FOUNDATION

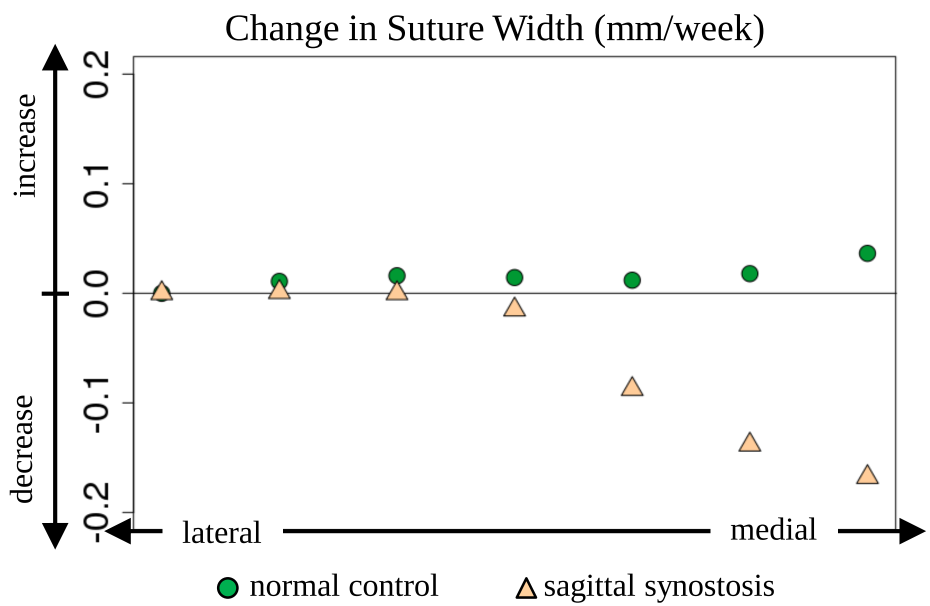
CRANIOFACIAL

Superoinferior Displacement

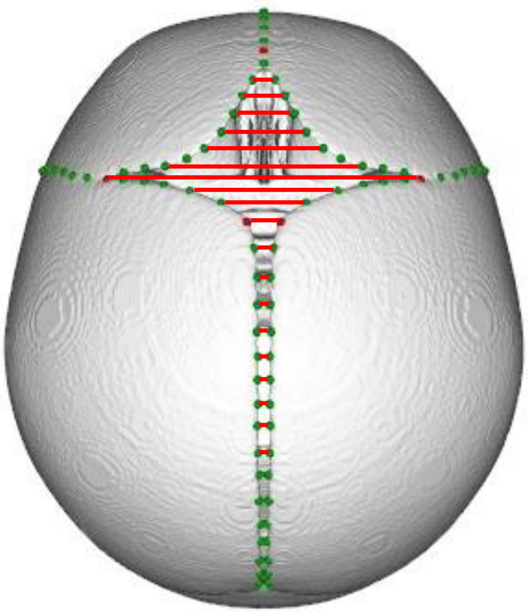


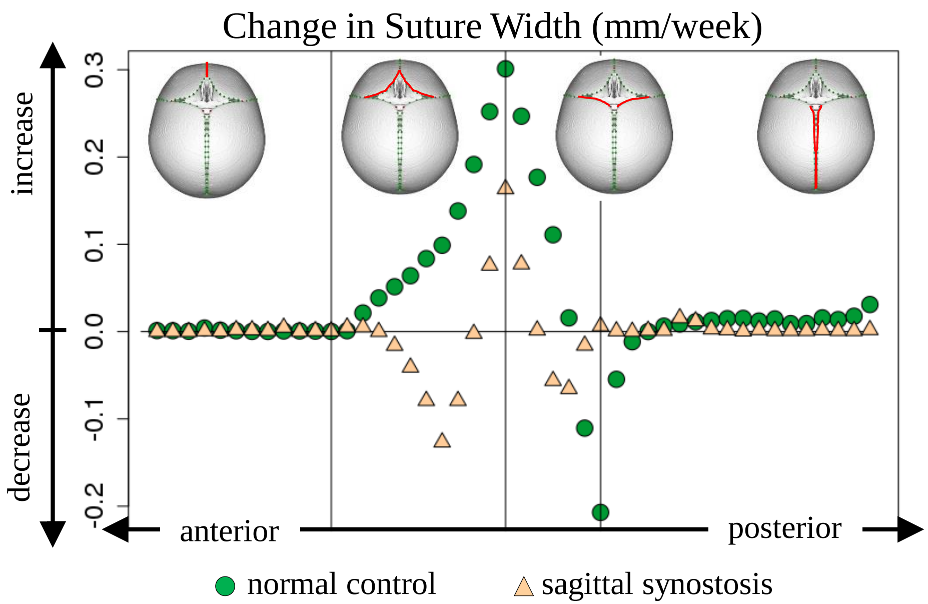
Suture Closure



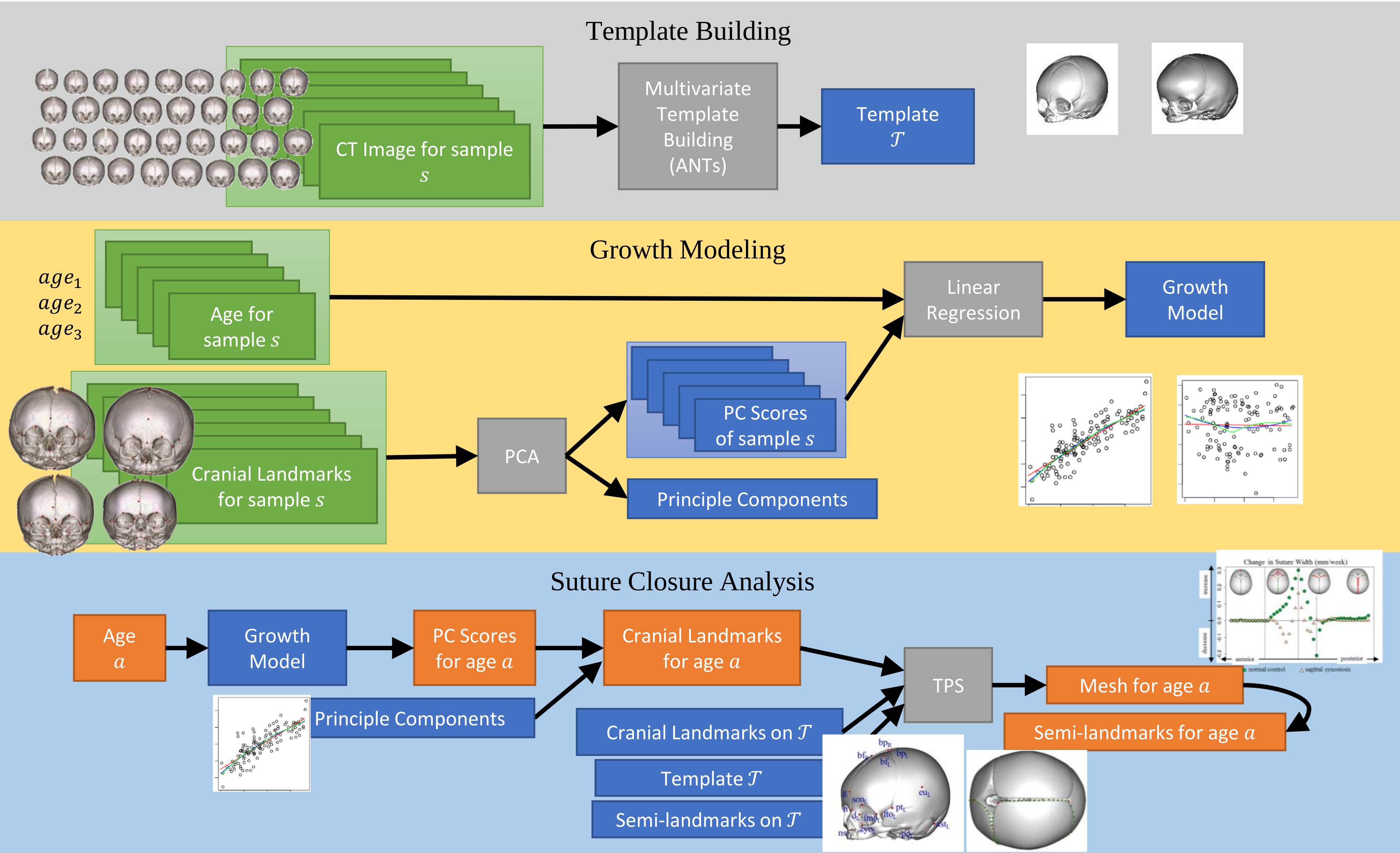


Suture Closure





Recap

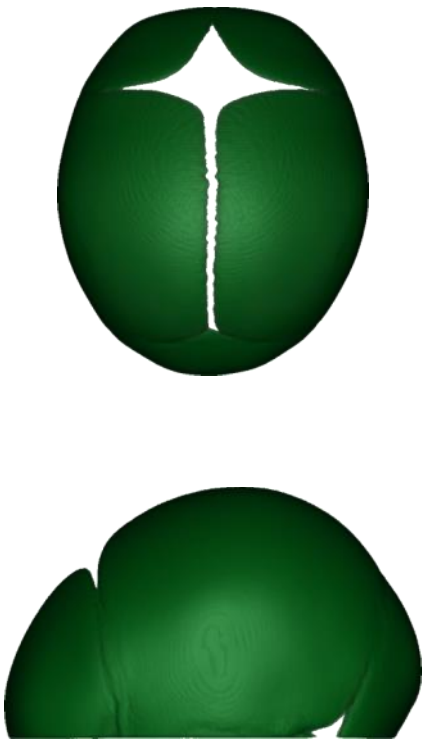


Template Building
CT Image for sample s
Multivariate Template Building (ANTs)
Template $\mathcal{T}$
Growth Modeling
age_1
age_2
age_3
Age for sample s
Linear Regression
Growth Model
Cranial Landmarks for sample s
PCA
PC Scores of sample s
Principle Components
Suture Closure Analysis
Age a
Growth Model
PC Scores for age a
Cranial Landmarks for age a
Principle Components
Cranial Landmarks on $\mathcal{T}$
Template $\mathcal{T}$
Semi-landmarks on $\mathcal{T}$
TPS
Mesh for age a
Semi-landmarks for age a
Change in Suture Width (mm/week)

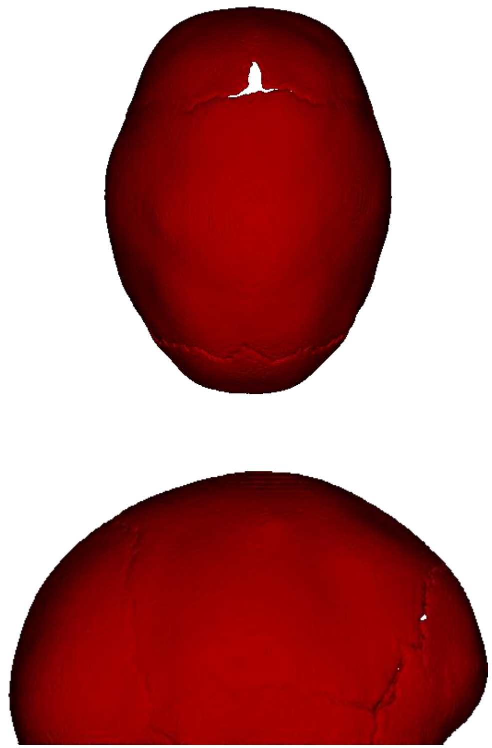
What else can you do with templates and diffeomorphic registration

BEYOND GROWTH

Shape Description



normal template



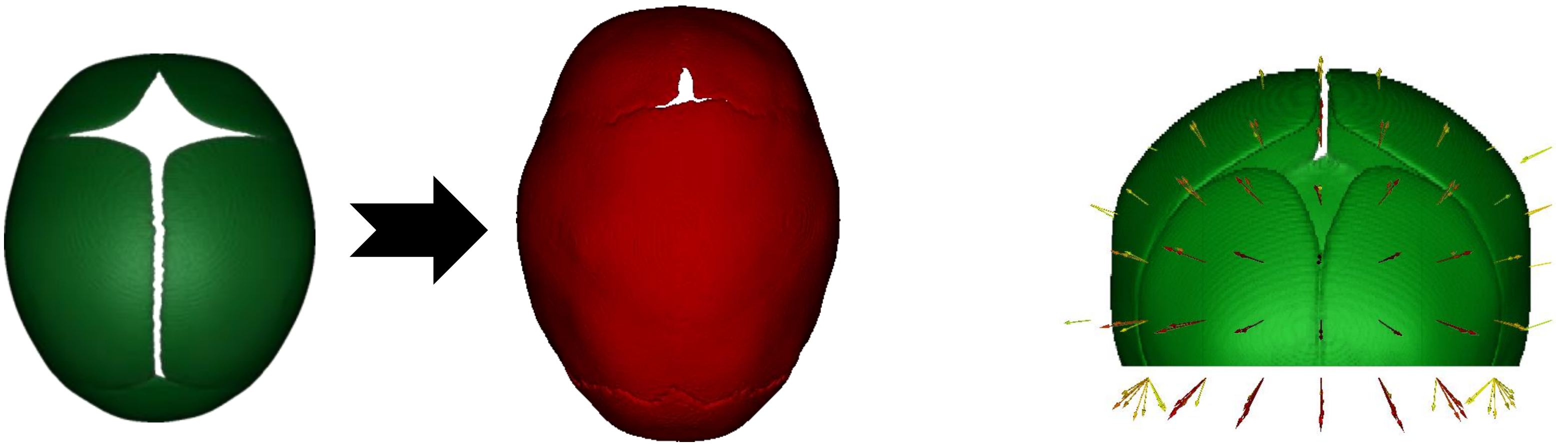
sagittal sample1

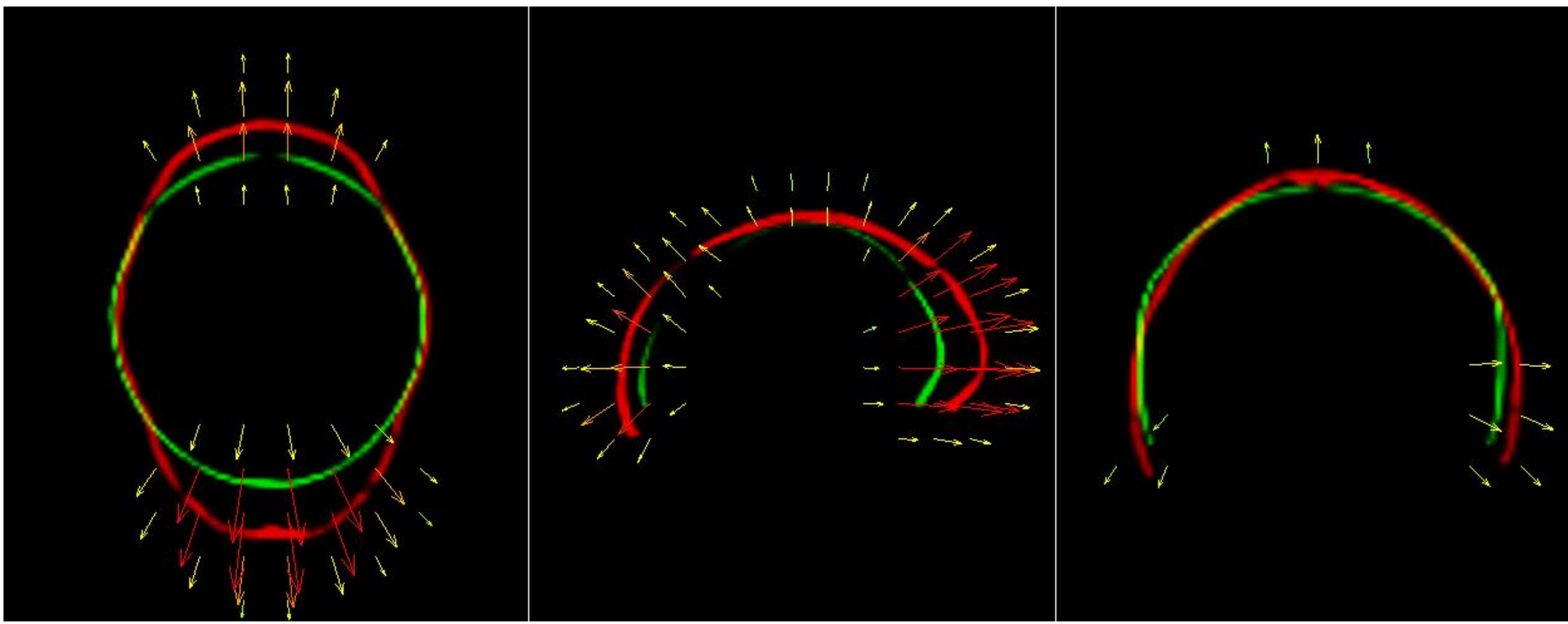
sagittal sample2

Seattle Children's HOSPITAL • RESEARCH • FOUNDATION

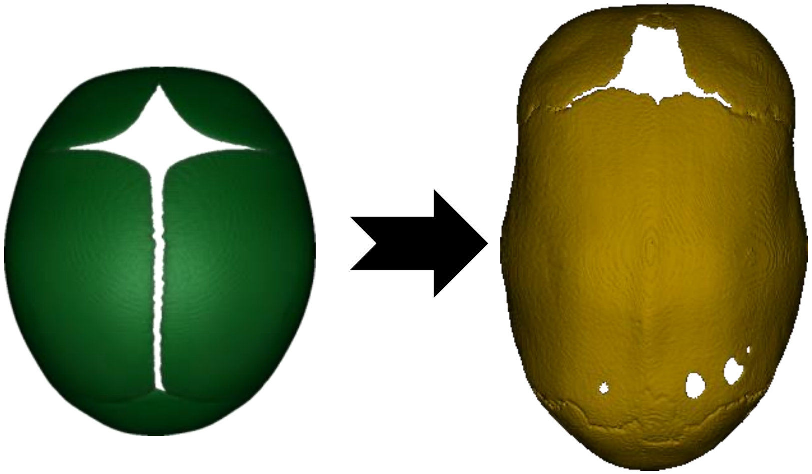
CRANIOFACIAL

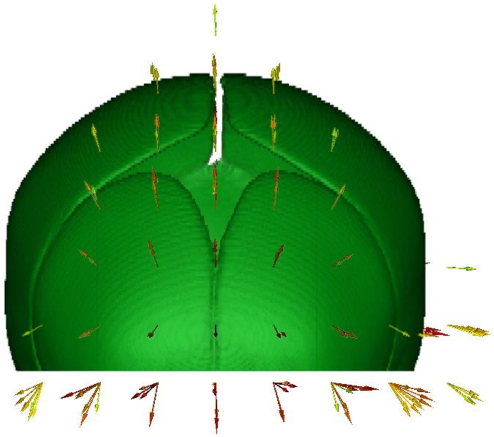
Shape Description

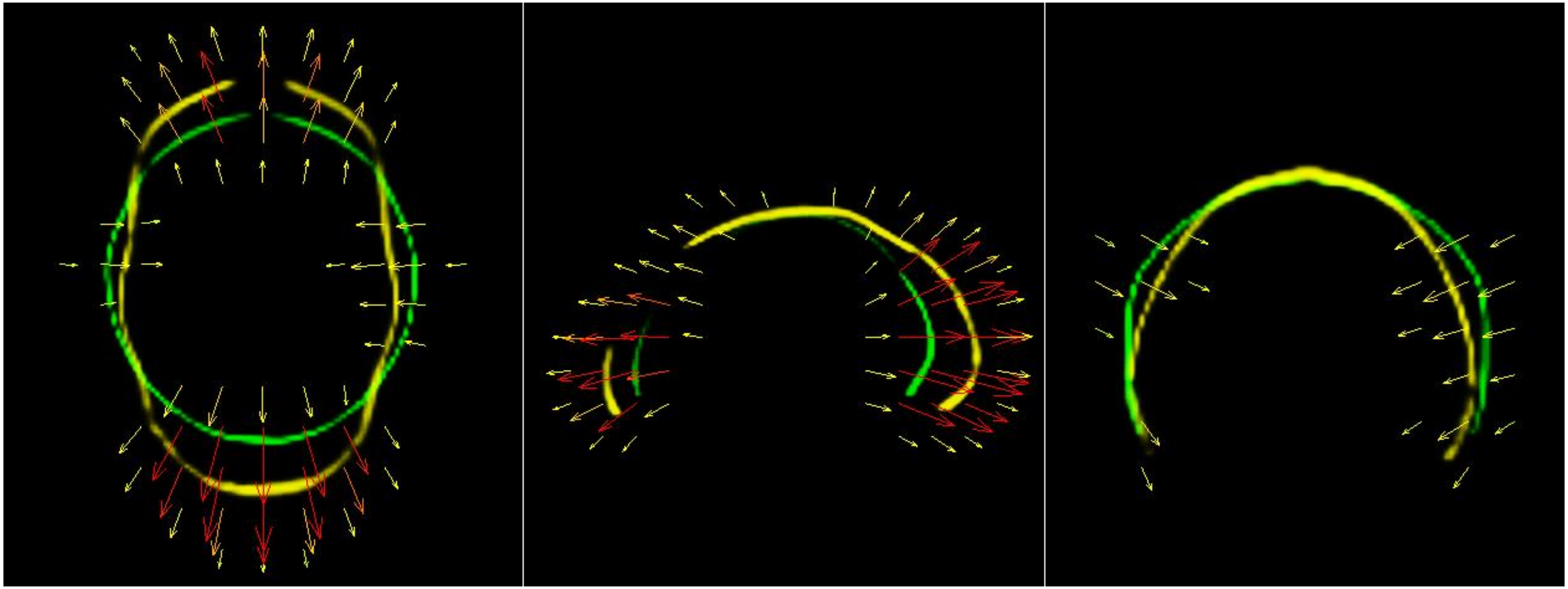




Shape Description



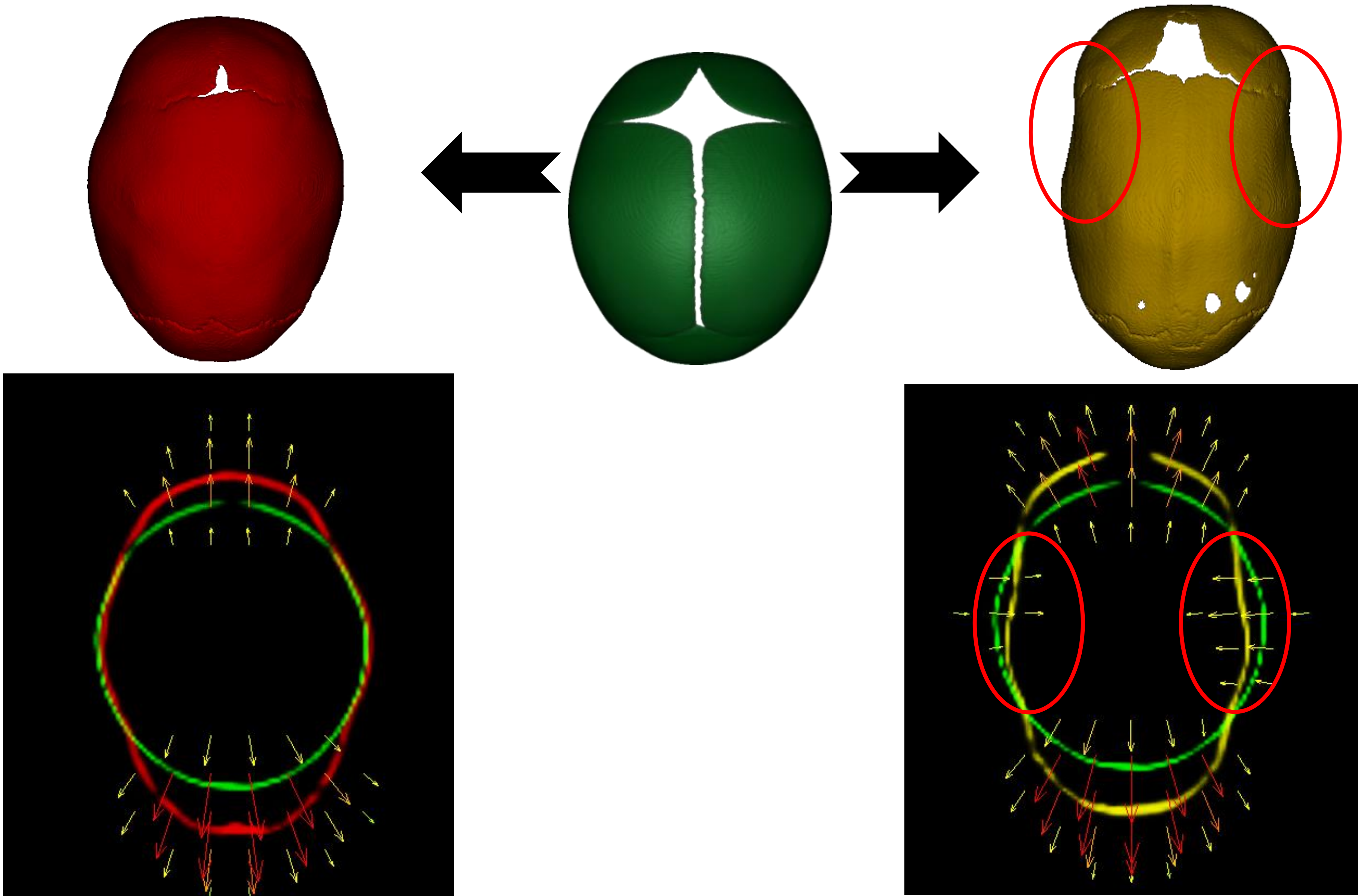




Seattle Children's HOSPITAL • RESEARCH • FOUNDATION

CRANIOFACIAL

Shape Description



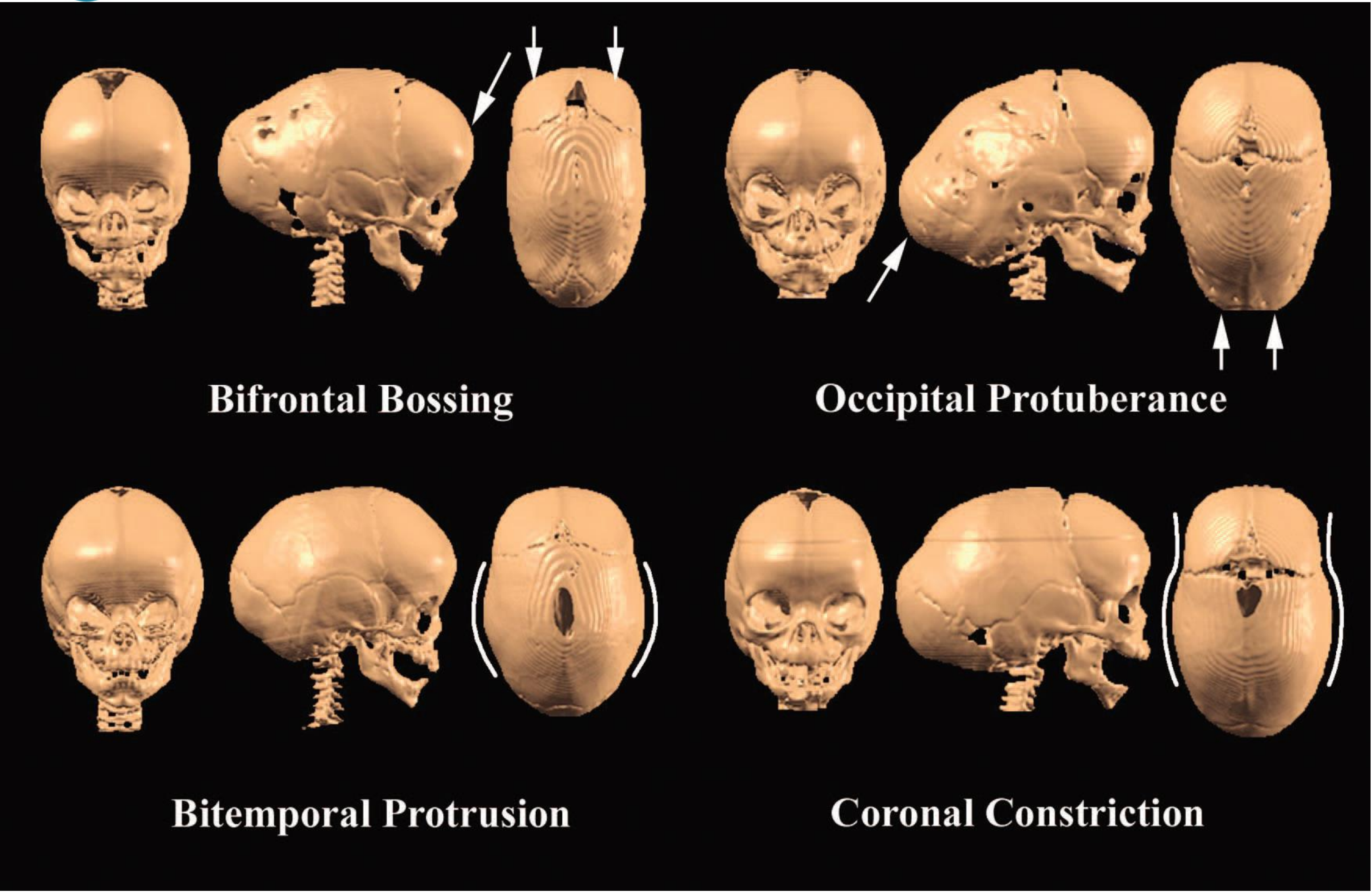
PEDIATRIC/CRANIOFACIAL

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.

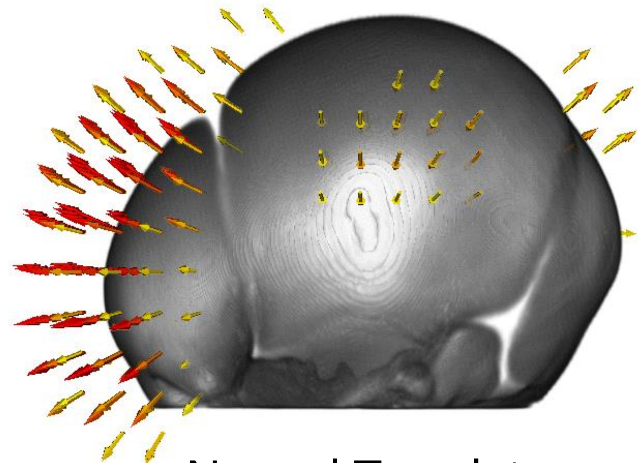
St. Louis, Mo.

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

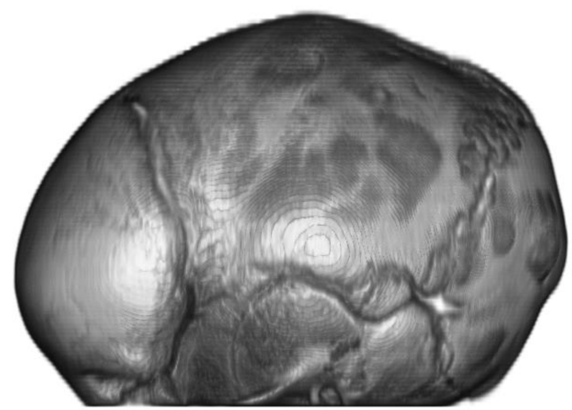

Bifrontal Bossing
Occipital Protuberance
Bitemporal Protrusion
Coronal Constriction

Deformation Field Vectors

1. Principle Component Analysis

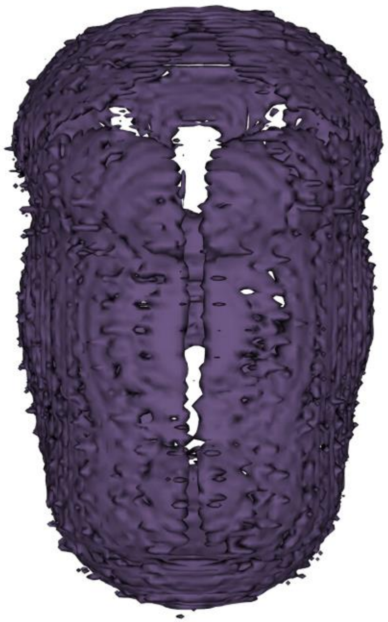


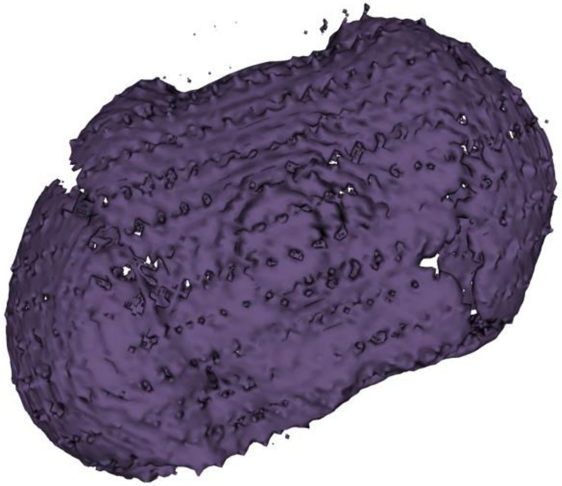
Normal Template

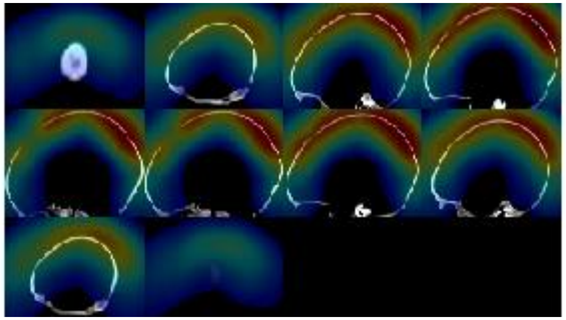


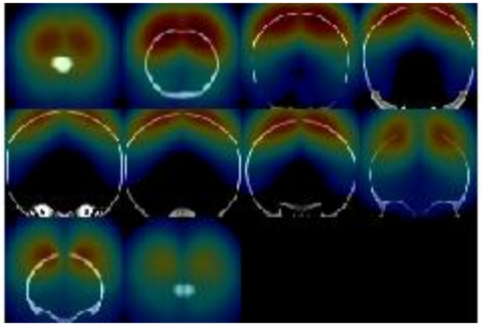
Sagittal Sample

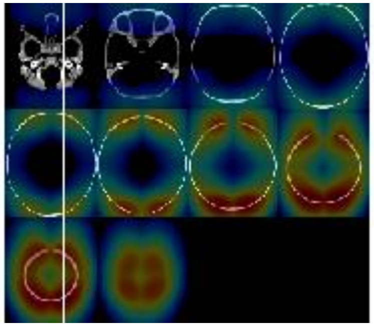
PC1



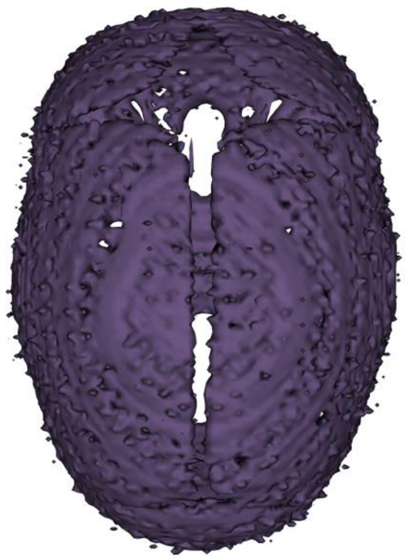


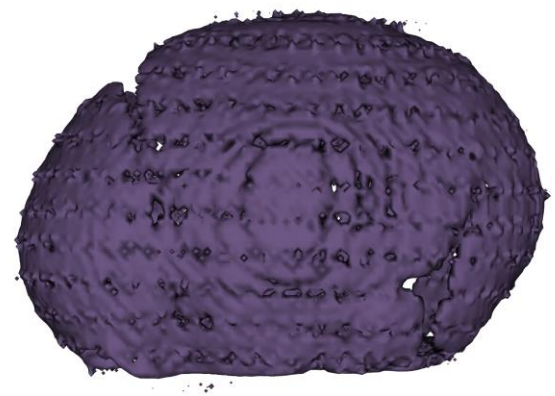


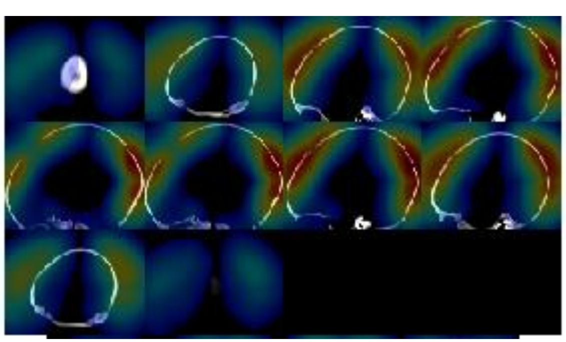


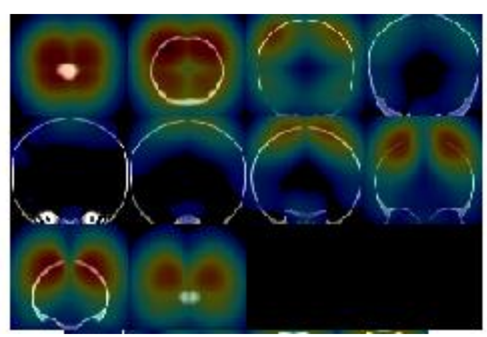


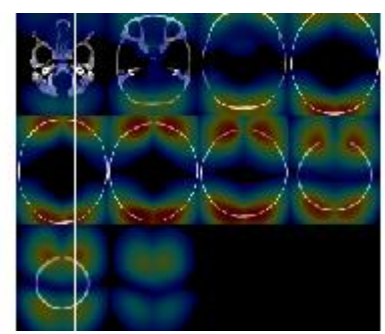
PC2

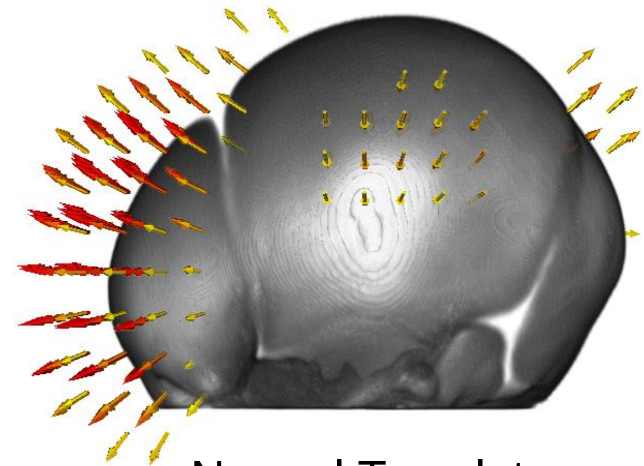








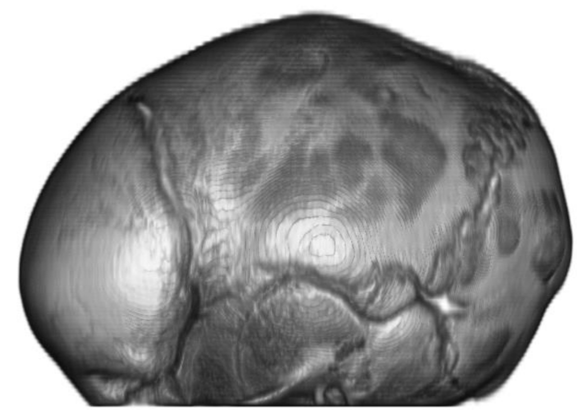




Normal Template

Deformation Field Vectors

1. Principle Component Analysis
2. Angle histograms

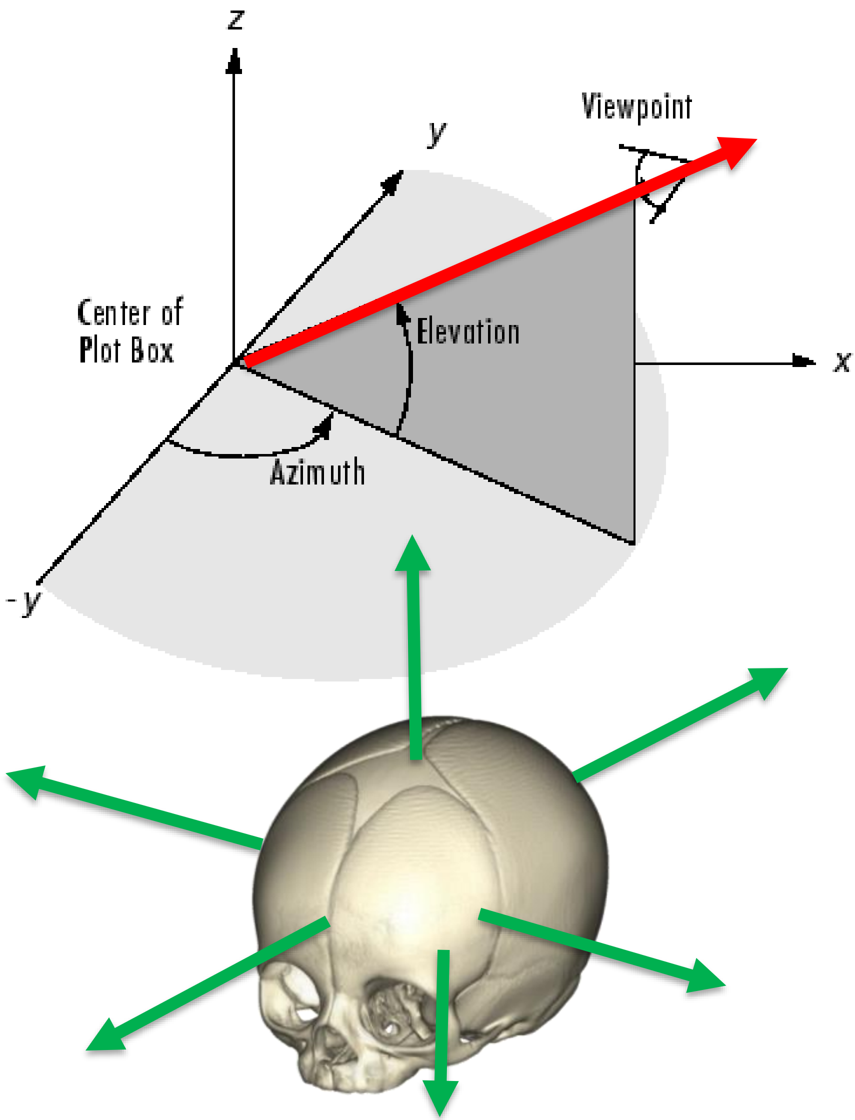


Sagittal Sample

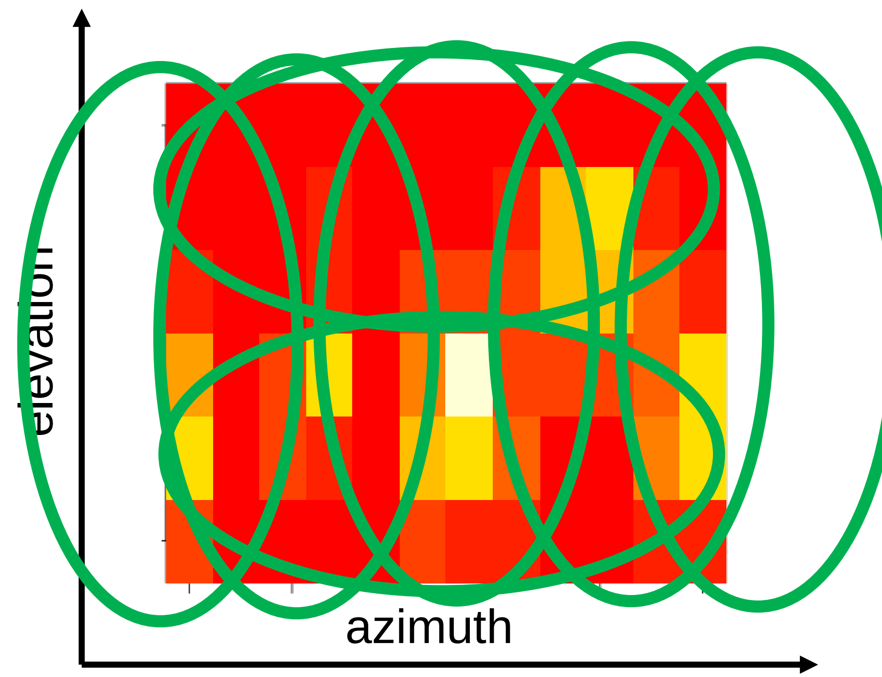
Seattle Children's
HOSPITAL • RESEARCH • FOUNDATION

CRANIOFACIAL

Angle Histograms



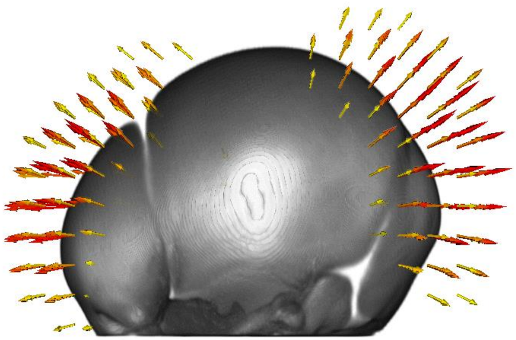
Generate a 2D histogram based on the azimuth and elevation angles of 3D deformation vectors.



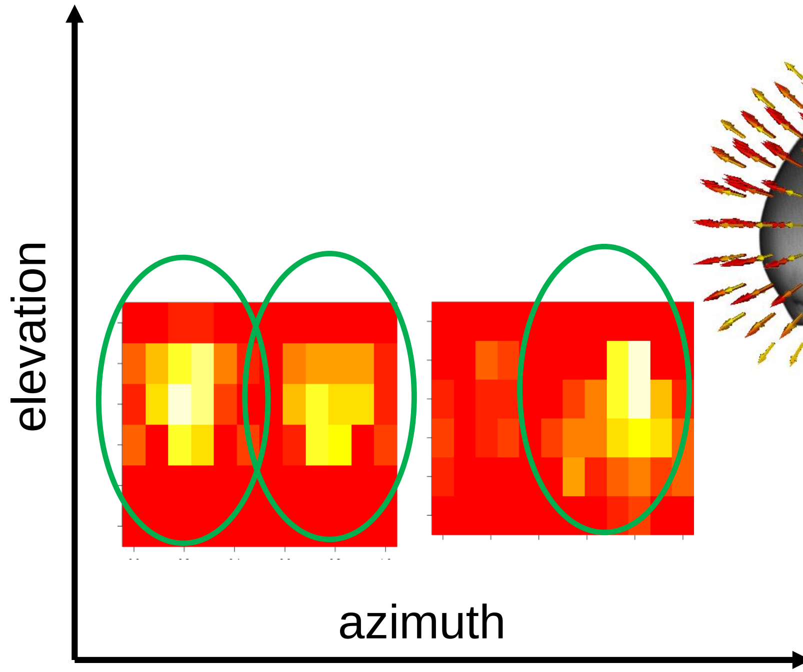
Seattle Children's
HOSPITAL • RESEARCH • FOUNDATION

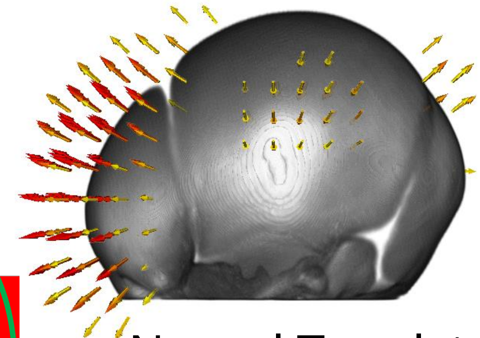
CRANIOFACIAL

Angle Histograms

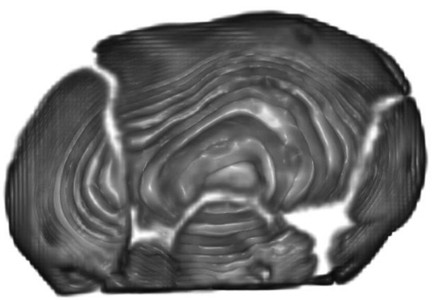


Normal Template

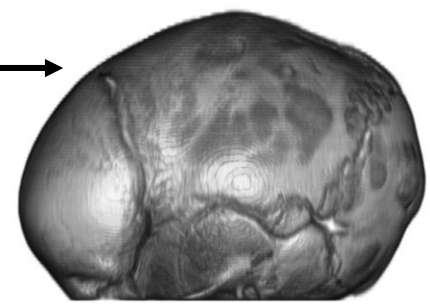




Normal Template

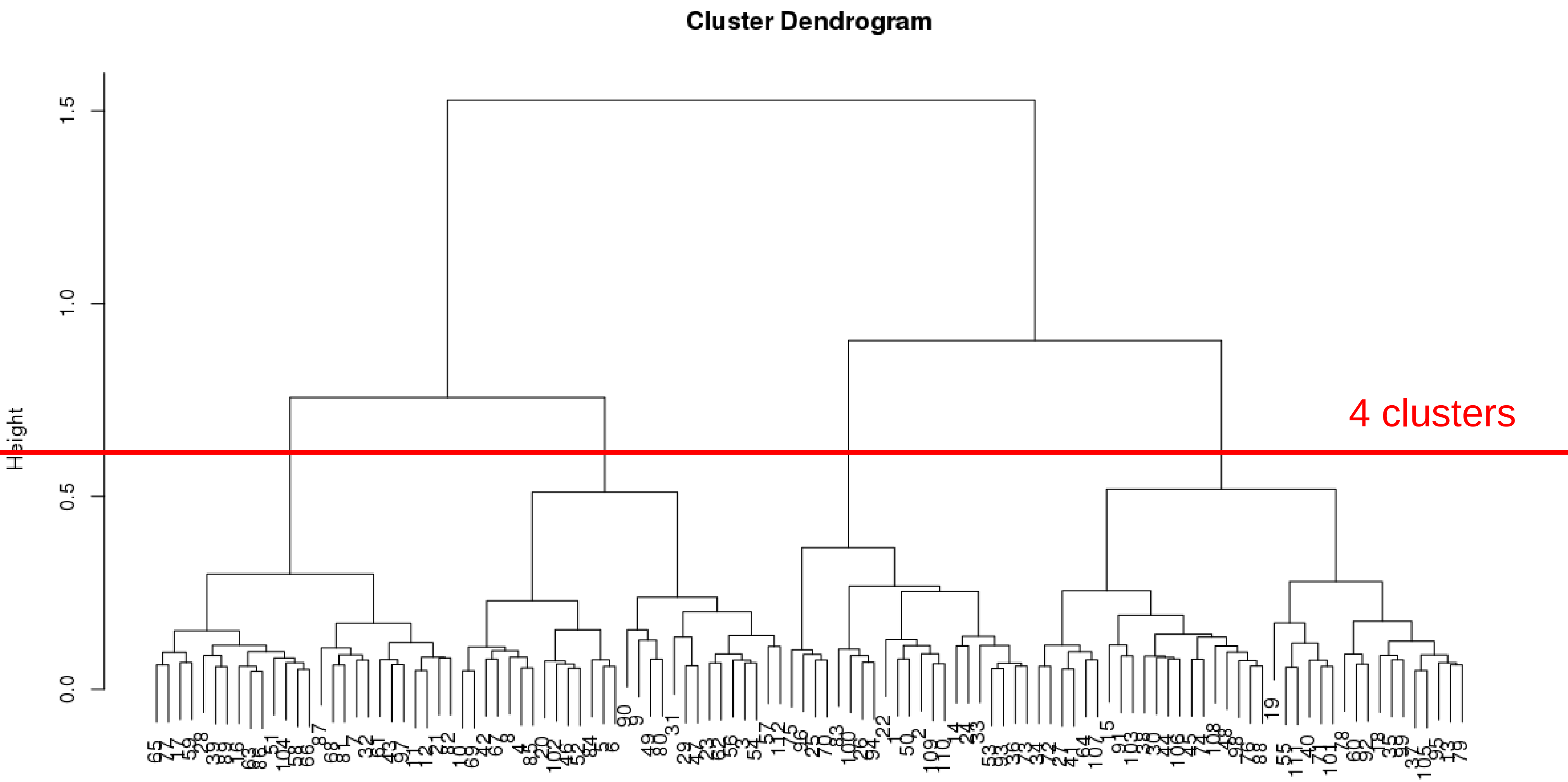


Sagittal Sample



Sagittal Sample

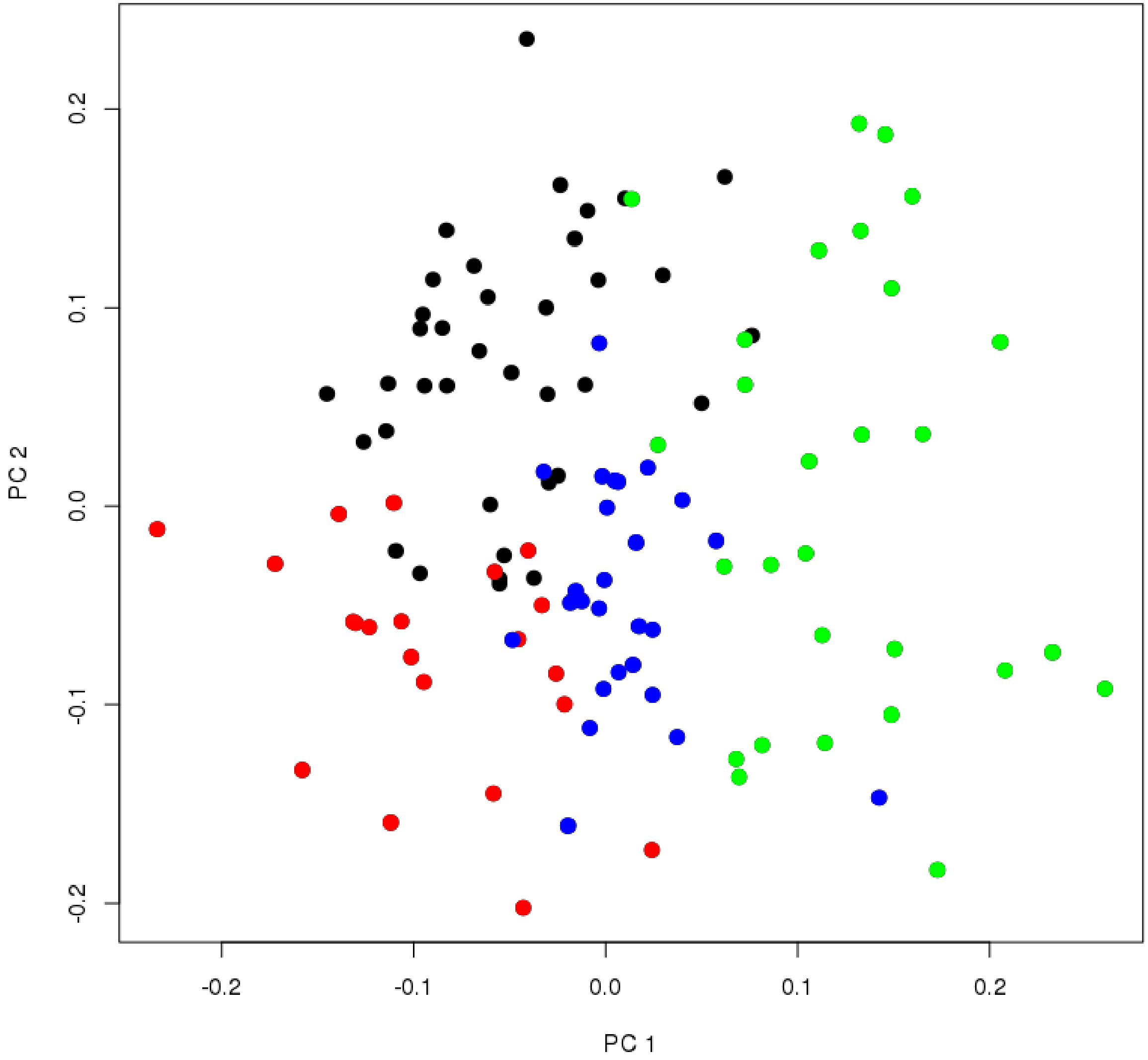
Clustering - Angle Histograms



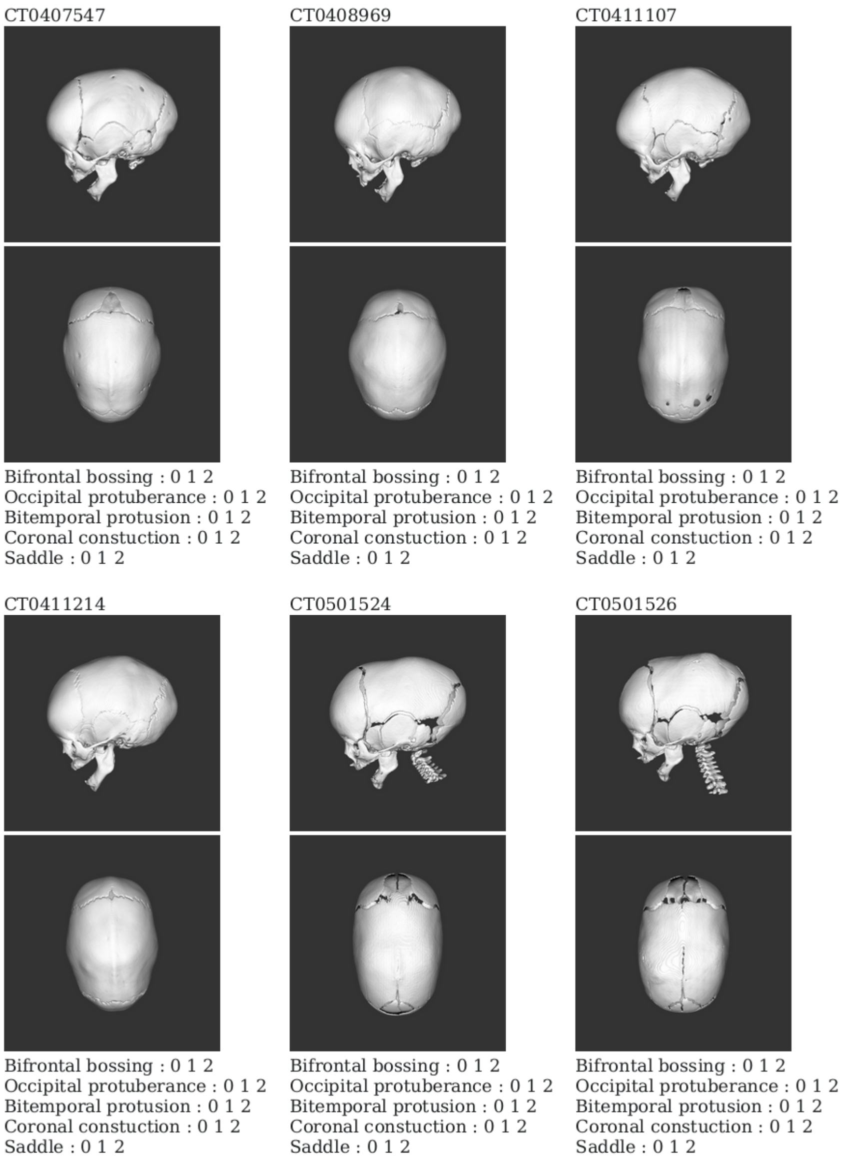
Sanity Check

Do principle components capture the same clusters?

Yes!



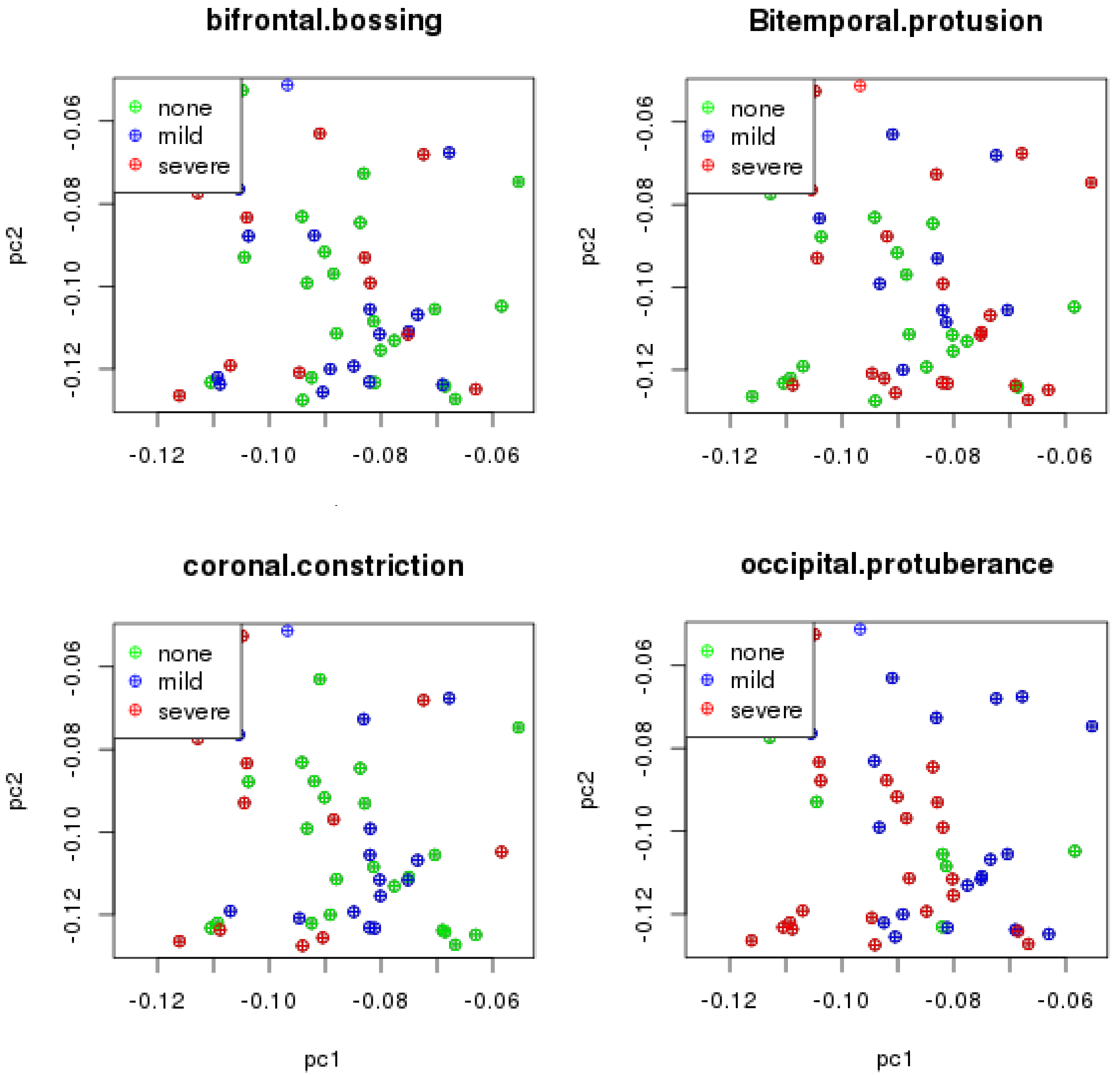
Observed Phenotypes



Collected rankings from a surgeon
N=48

Can computed clusters capture the observed phenotypes?

CRANIOFACIAL



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

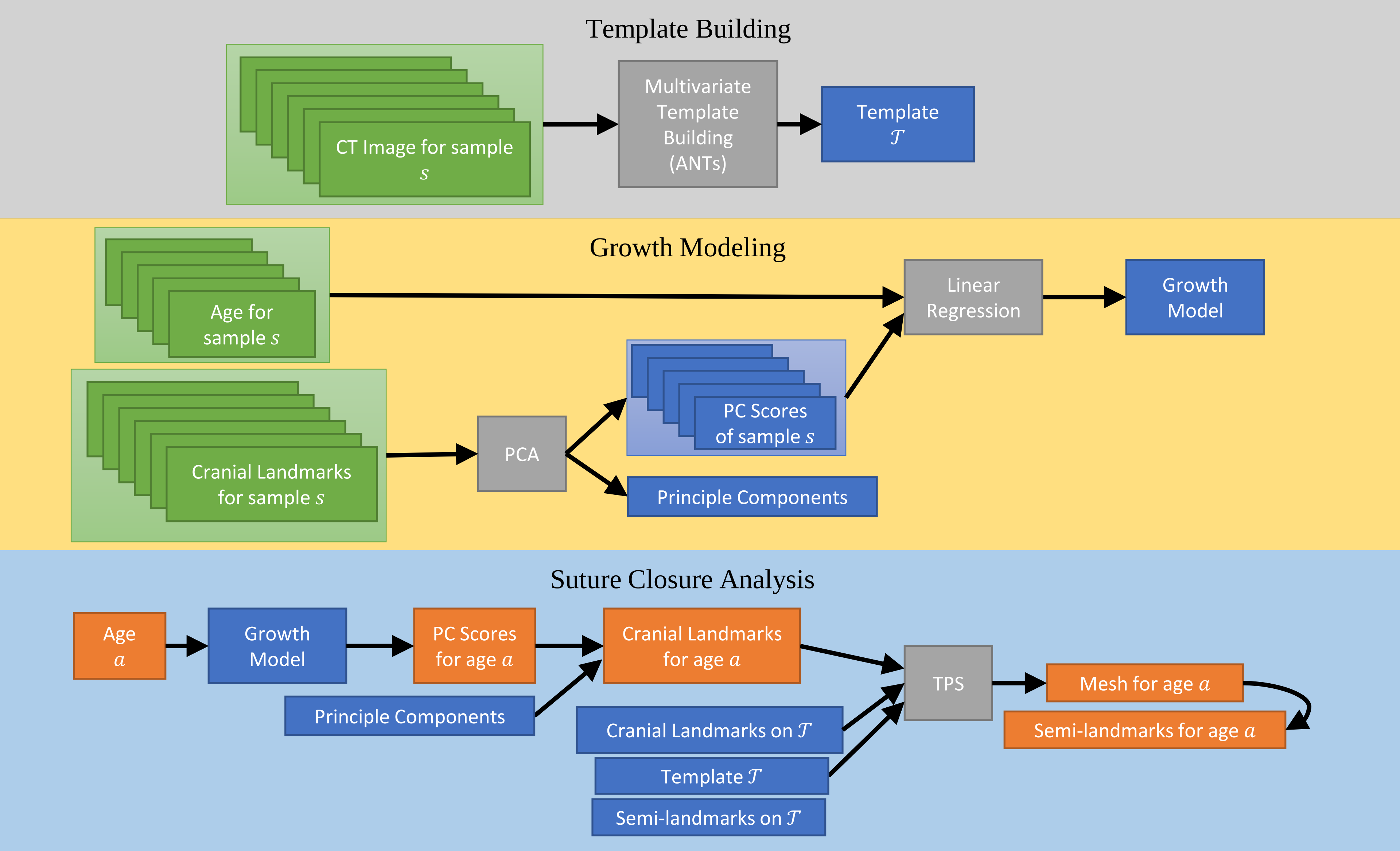
Recovering observed phenotypes

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

Recovering observed phenotypes

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

Outline



Template Building
CT Image for sample s
Multivariate Template Building (ANTs)
Template 𝒯
Growth Modeling
Age for sample s
Linear Regression
Growth Model
Cranial Landmarks for sample s
PCA
PC Scores of sample s
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 𝒯
Template 𝒯
Semi-landmarks on 𝒯