



THE
UNIVERSITY
OF UTAH

Statistical Shape Analysis

Shireen Elhabian, Prateep Mukherjee
and Ross Whitaker

Saturday, January 4th , 2014

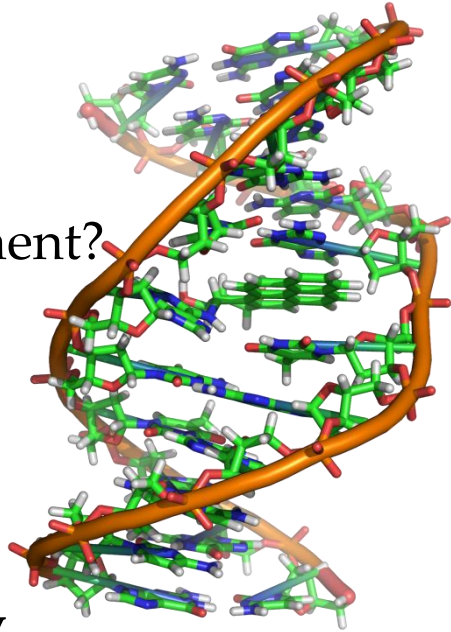


Study of 'Shape'

What questions can it answer ?

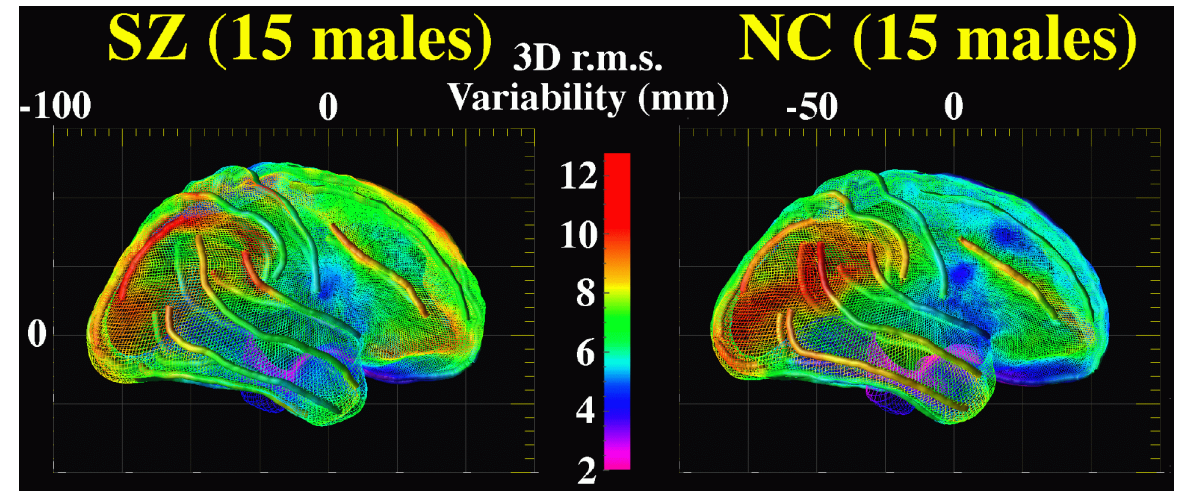
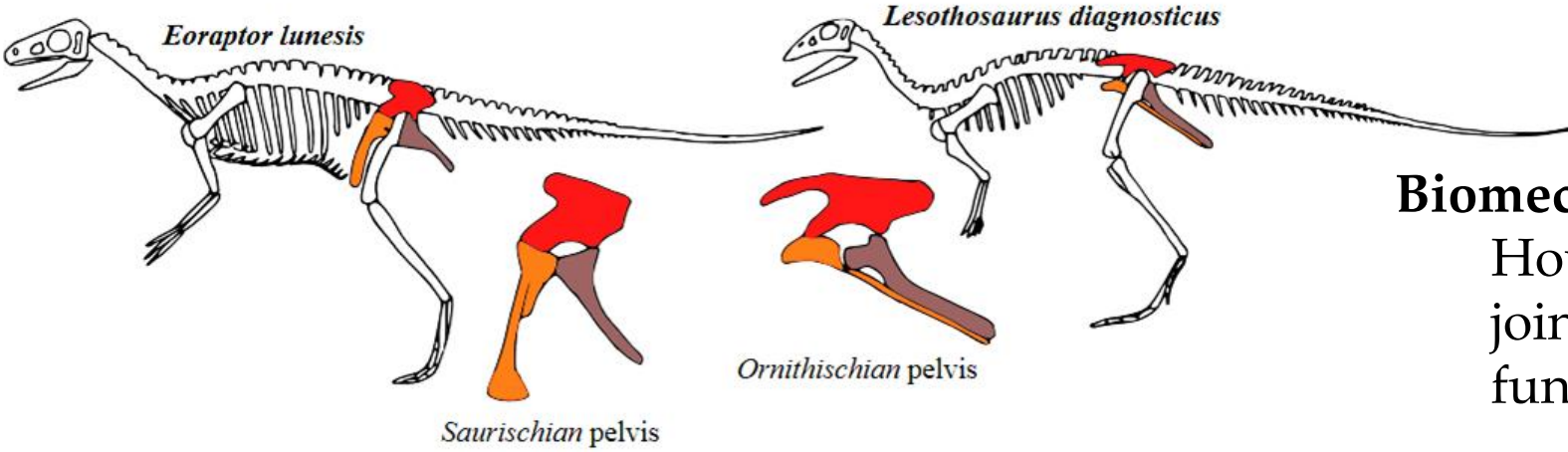
Genetics

How does a gene mutation change skeletal development?



Evolutionary Biology

Is the shape of a given bone a good classifier for species?

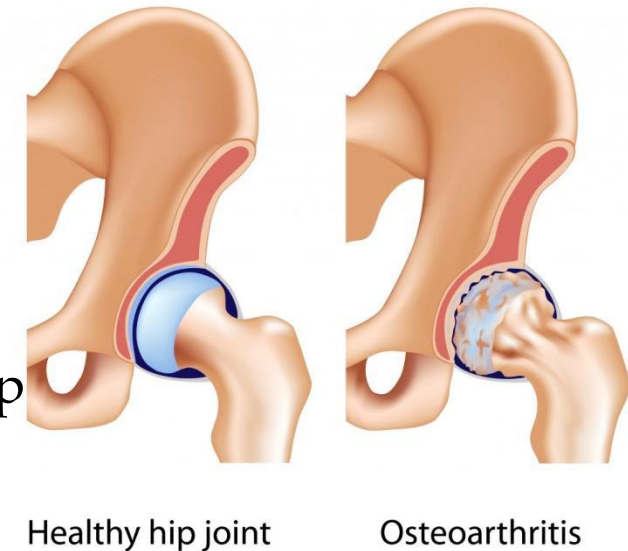


Neuroanatomy

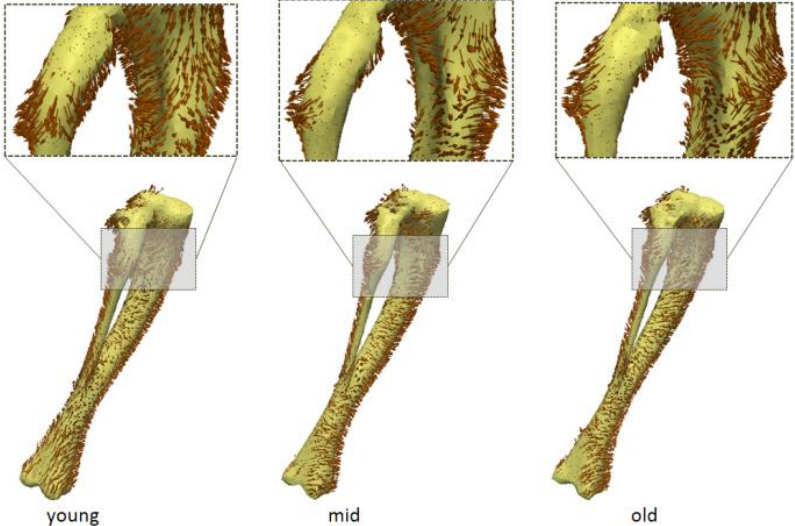
Is there a difference in the shape of brain structures between schizophrenic and normal populations?

Biomechanics

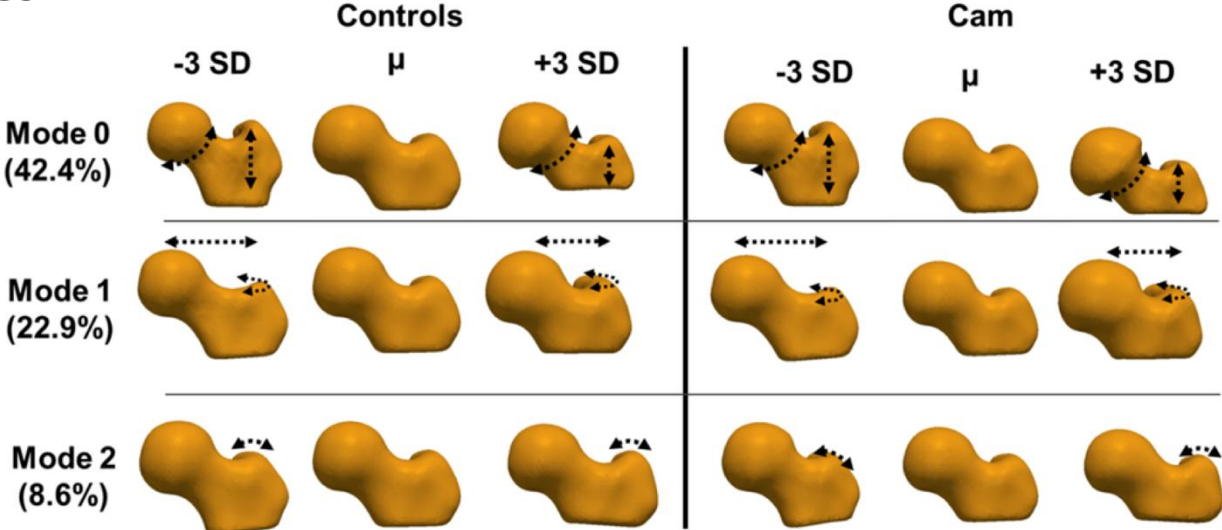
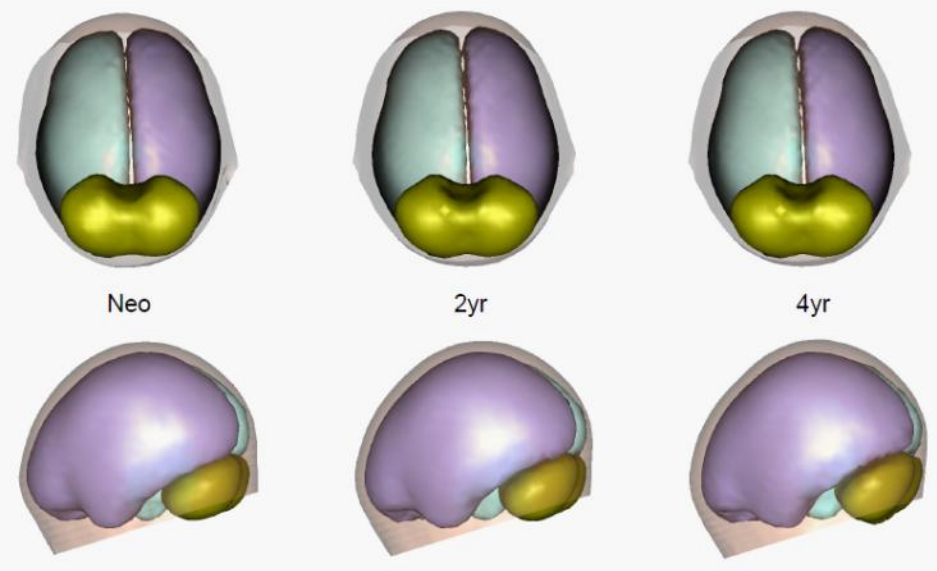
How does the hip joint change as a function of age?



Shape analysis is ubiquitous...



Group Differences

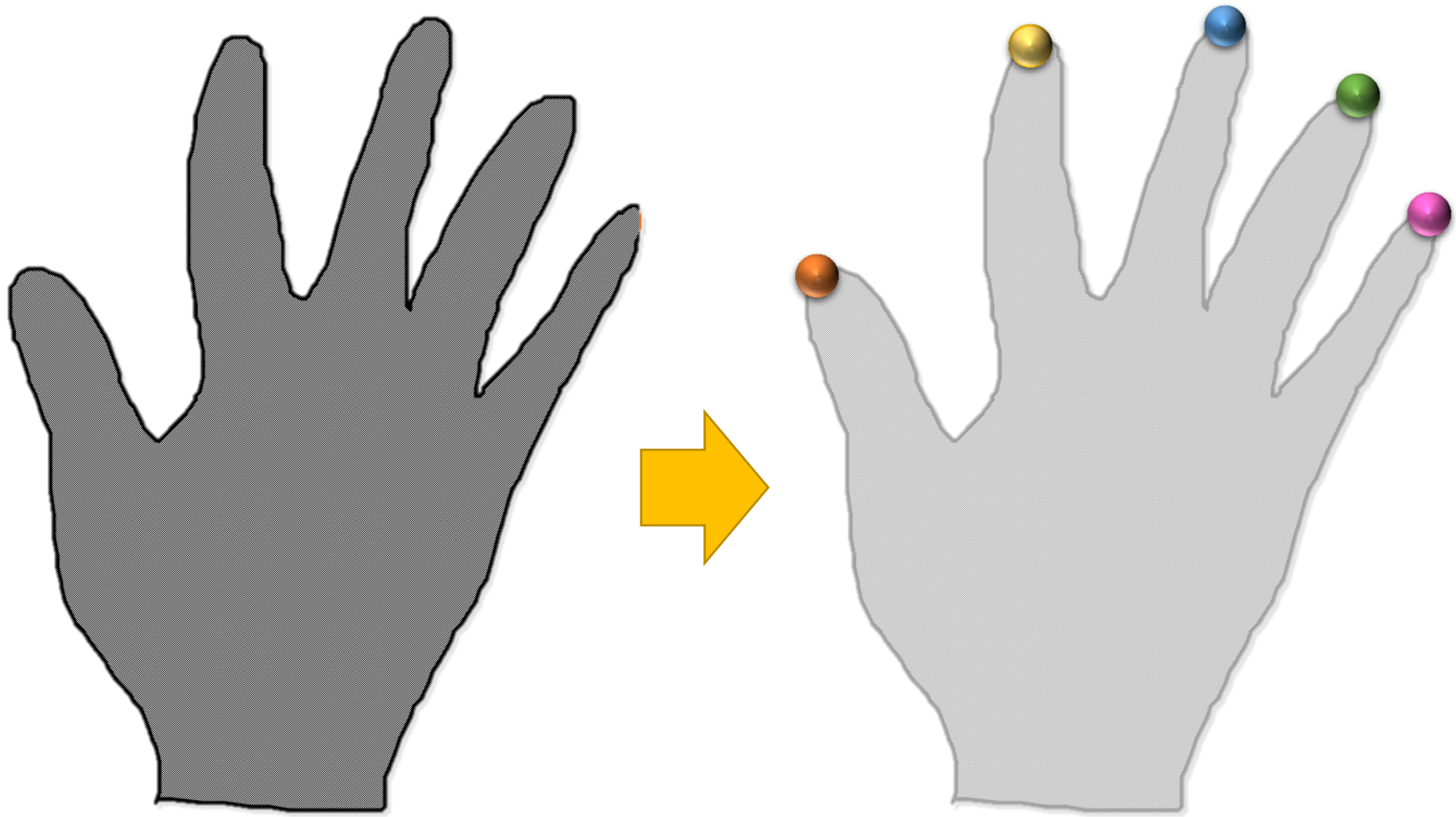


Normative Growth

Variability in population

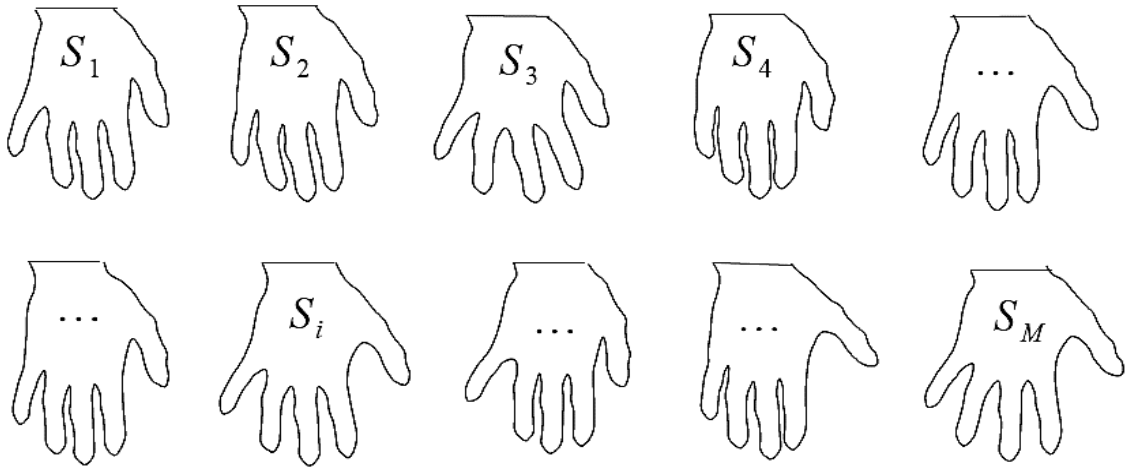
Statistical Shape Analysis

It's all about representation...



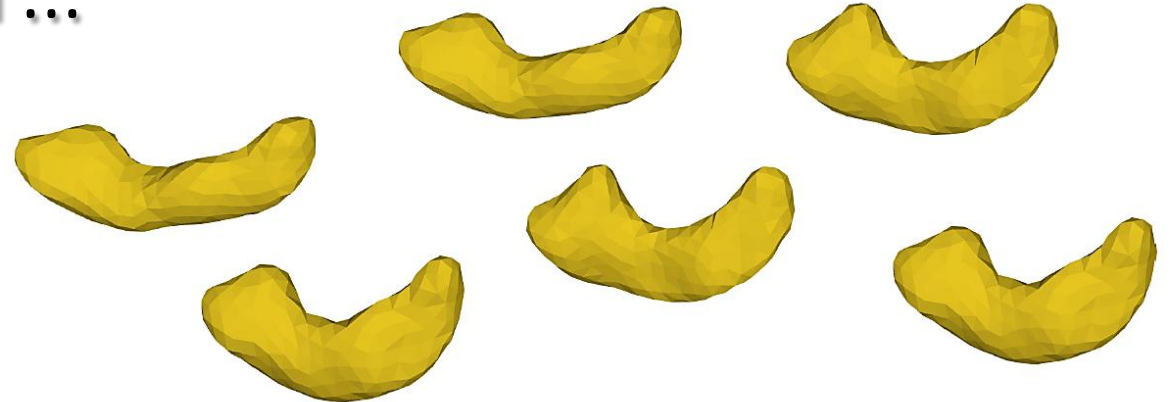
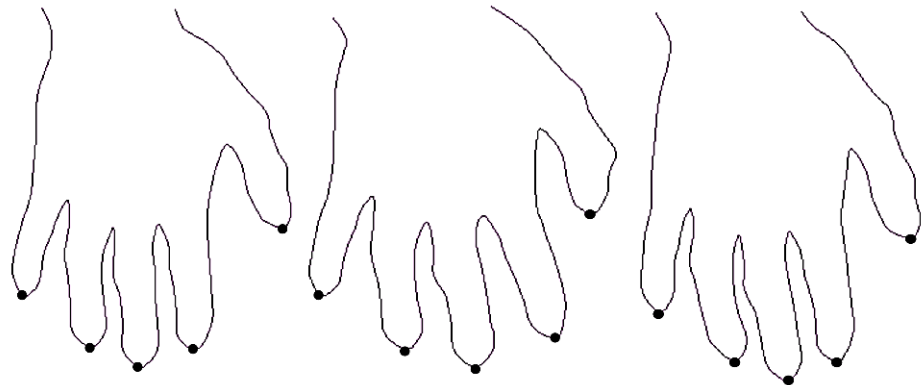
Statistical Shape Analysis

It's all about representation...



Given a collection of shapes, we can use a point based representation for each S_i

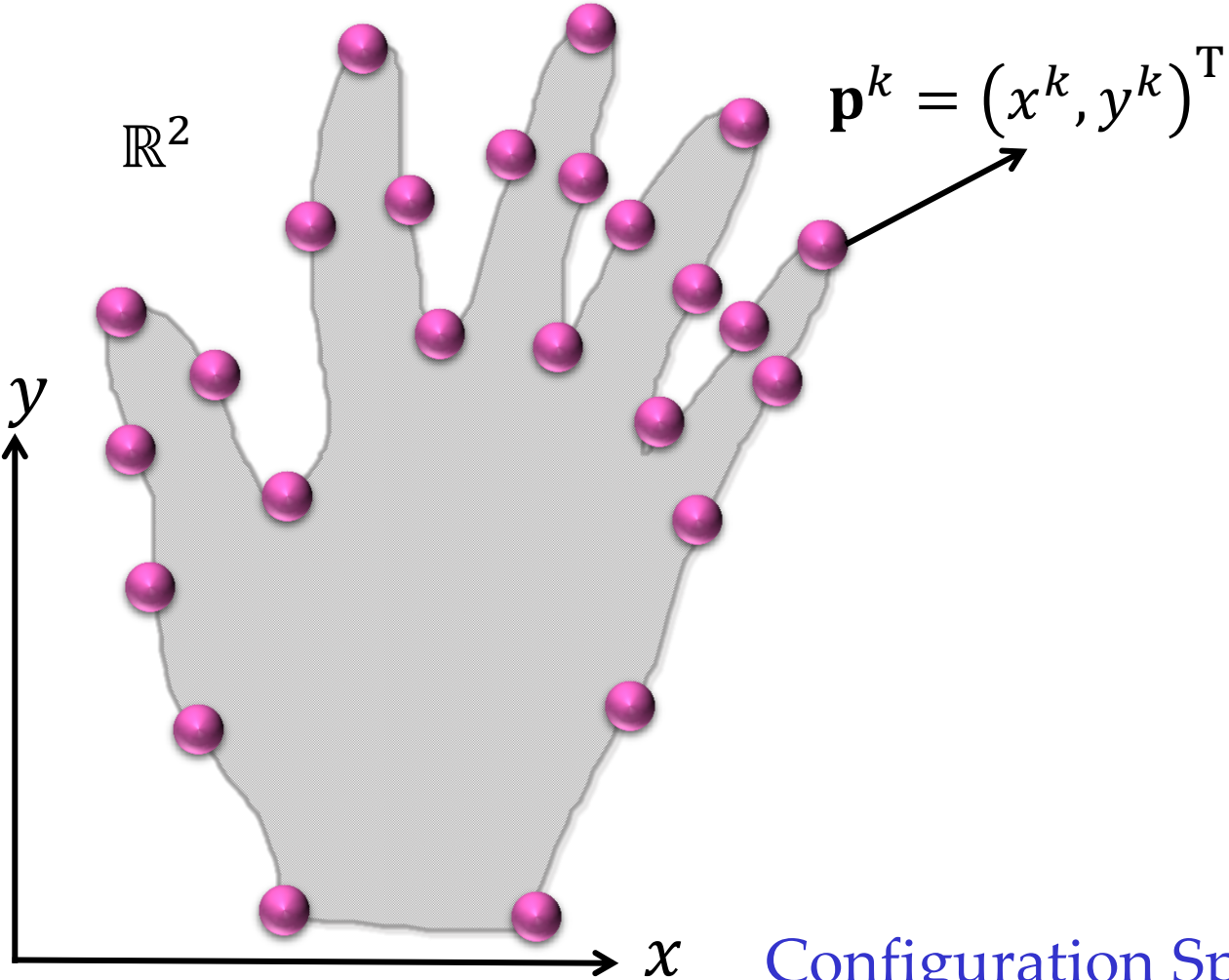
BUT...



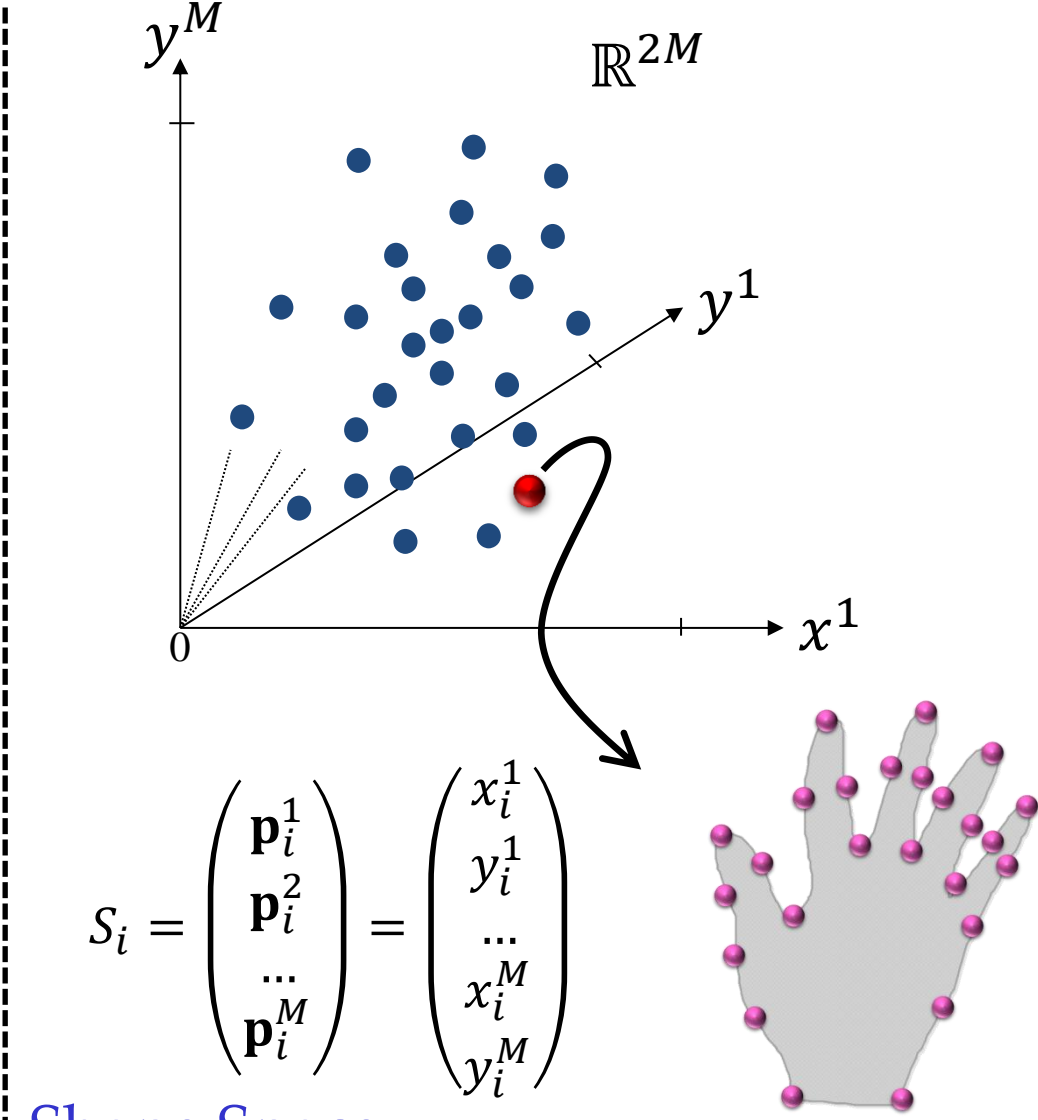
How do we choose the “same” points ??

Statistical Shape Analysis

It's all about representation...



Configuration Space

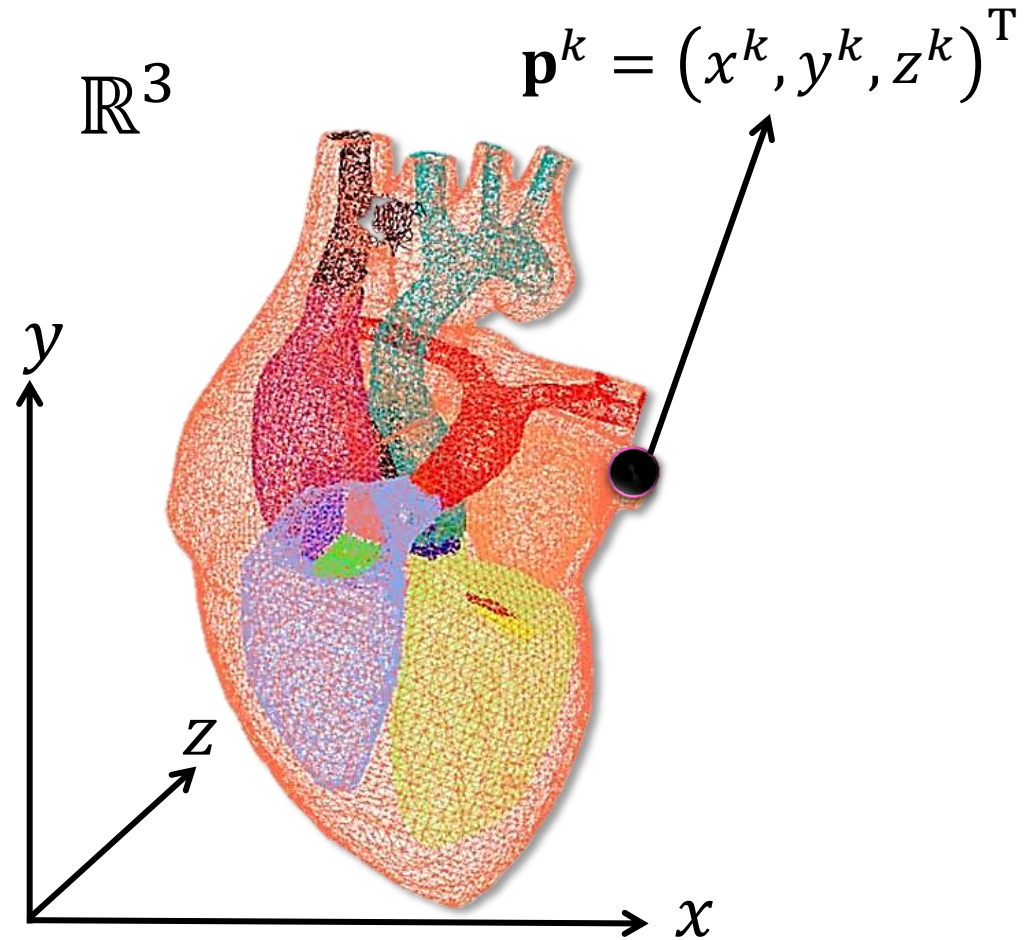
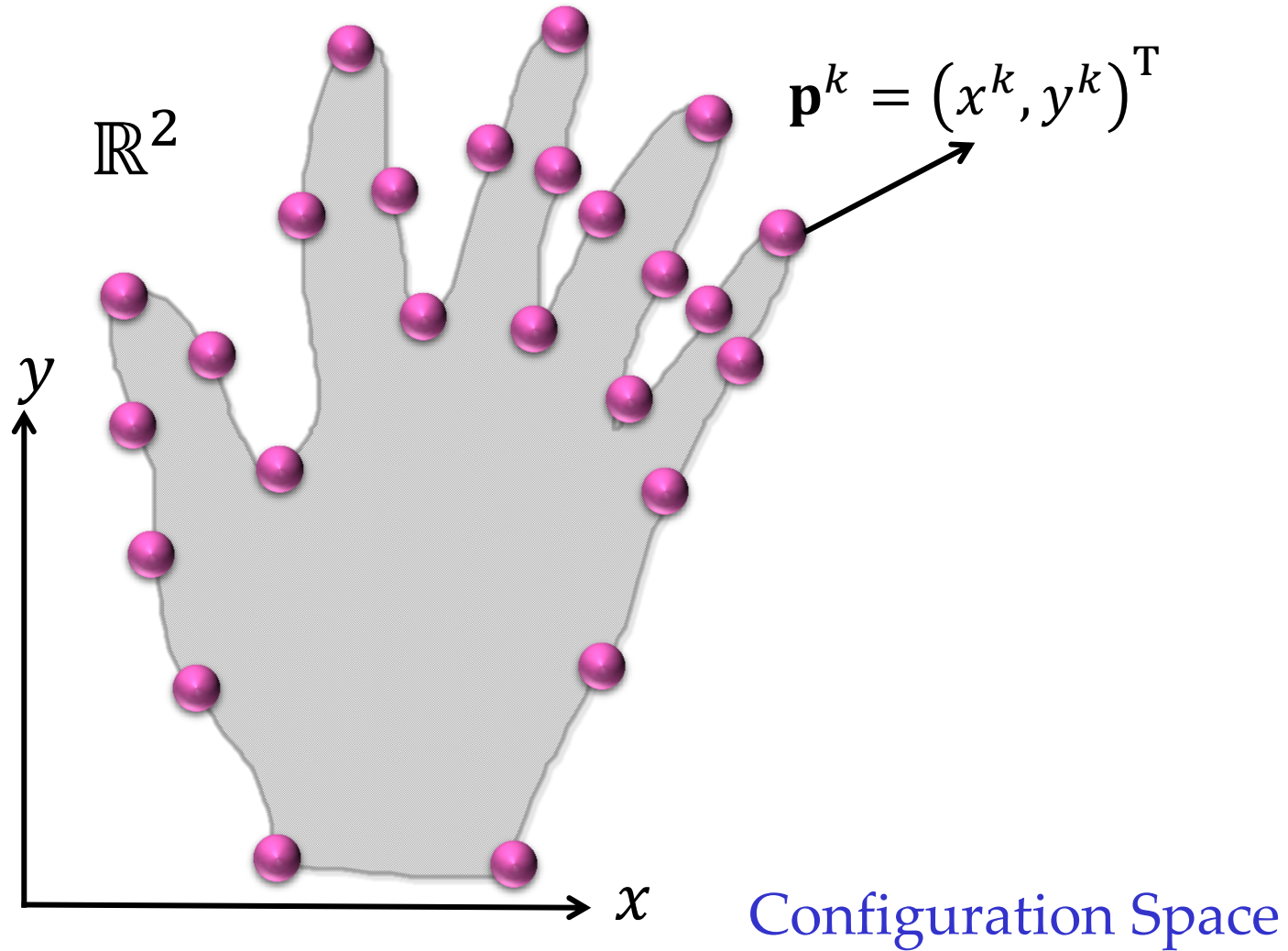


$$S_i = \begin{pmatrix} \mathbf{p}_i^1 \\ \mathbf{p}_i^2 \\ \dots \\ \mathbf{p}_i^M \end{pmatrix} = \begin{pmatrix} x_i^1 \\ y_i^1 \\ \dots \\ x_i^M \\ y_i^M \end{pmatrix}$$

Shape Space

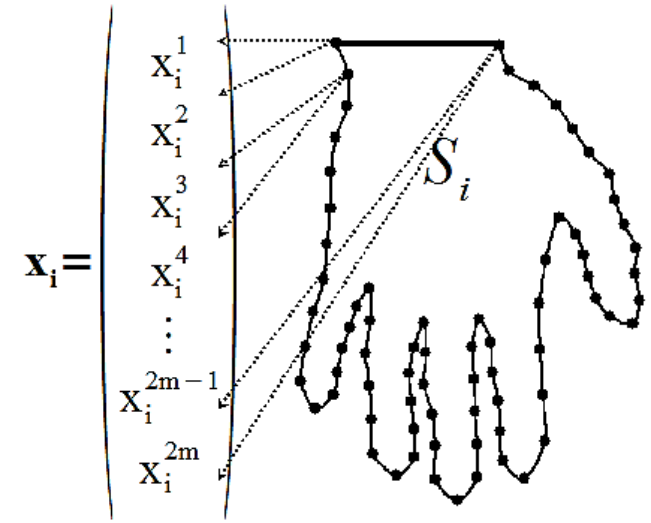
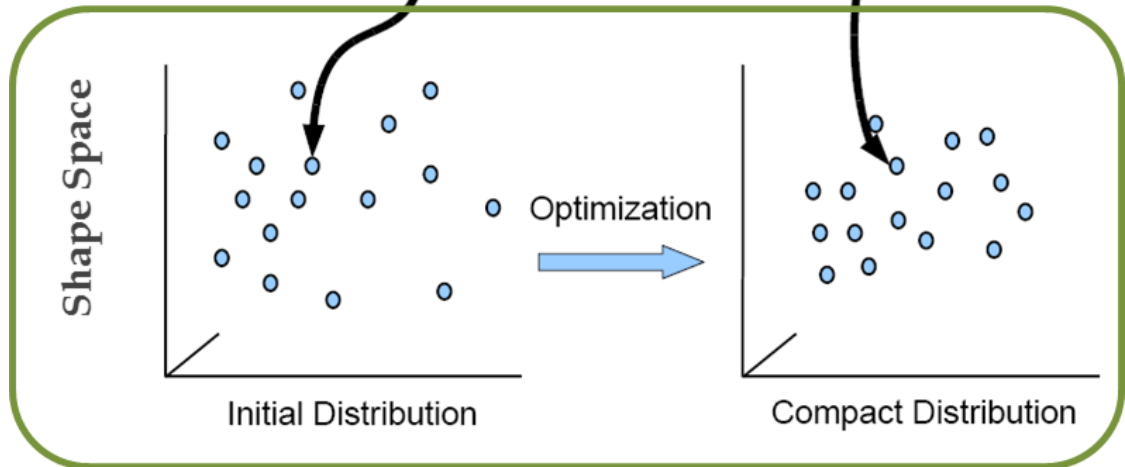
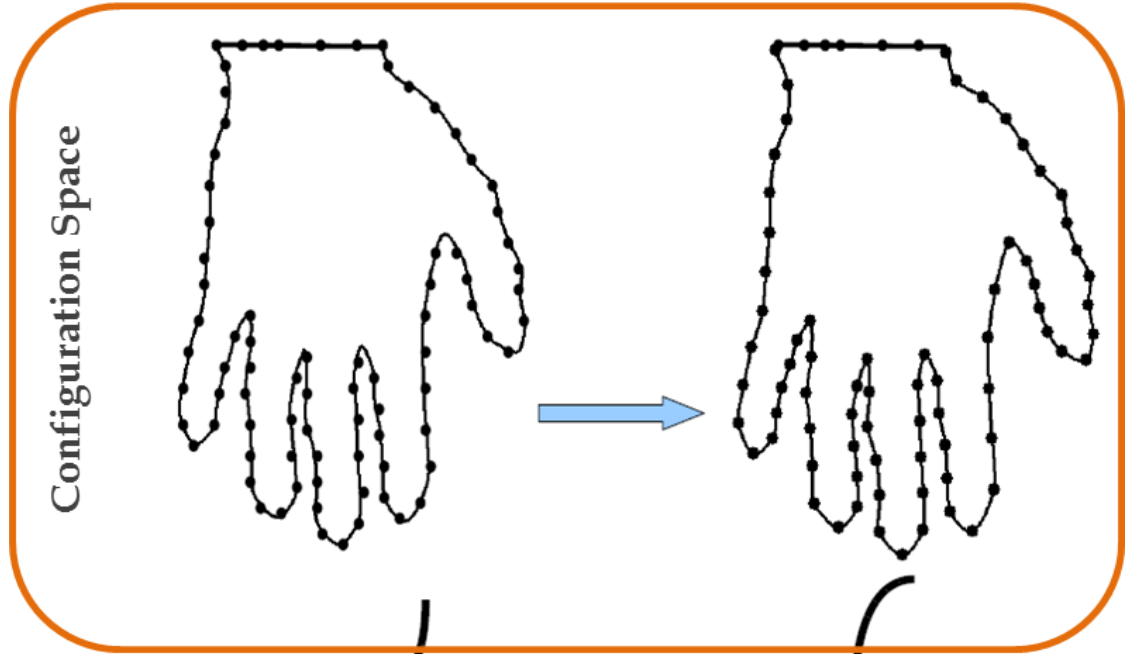
Statistical Shape Analysis

It's all about representation...



Point Correspondence Model

Balancing accuracy vs. low variance

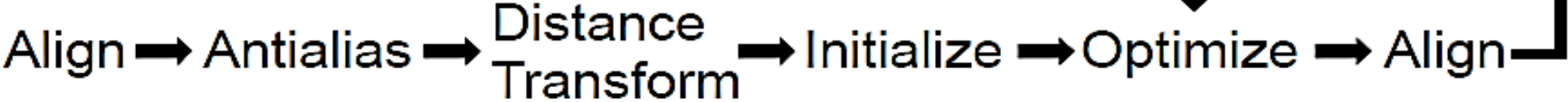


Accurate
Representation
(in Configuration Space)

VS.

Compact Model
(in Shape Space)

Correspondence Pipeline



Preprocessing

PBM Algorithm



ShapeWorks Pipeline

- Preprocessing

Input Segmentation



Distance Transform



Antialiased Surface



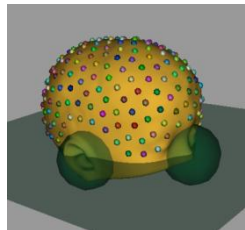
...

- Optimization

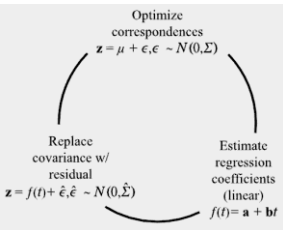
Entropy Minimization



Open Surfaces



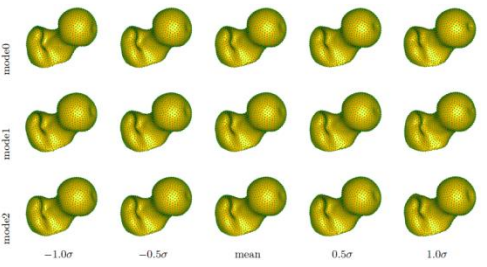
Linear Regression



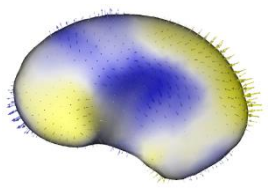
...

- Visualization/
- Applications

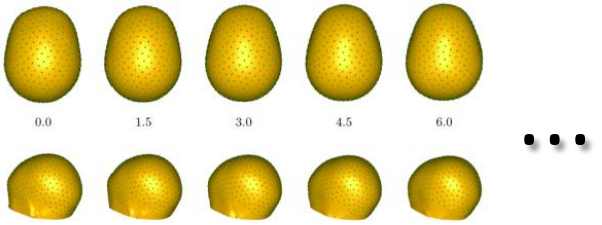
Modes of Variation



Group Differences



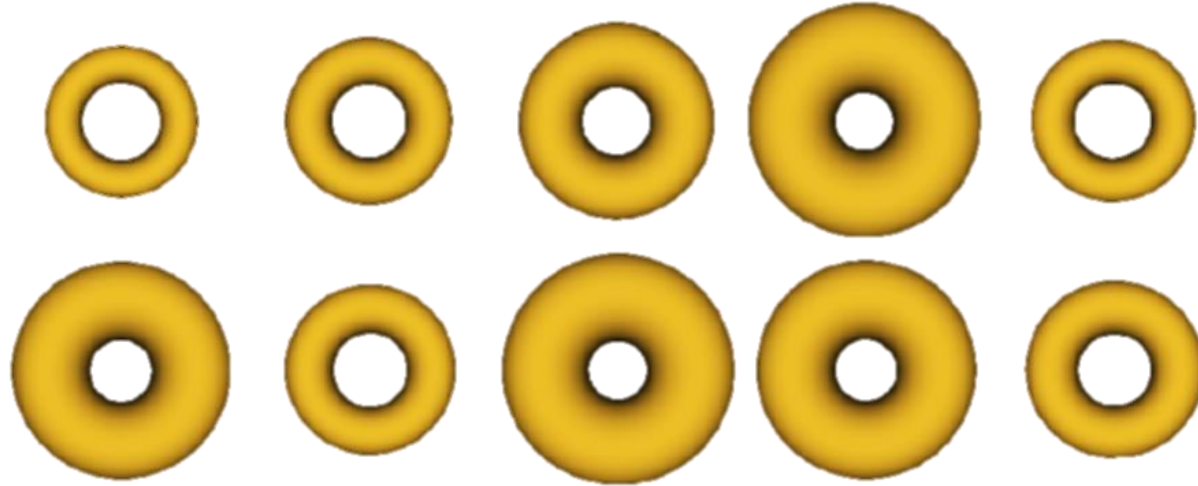
Regression Shape



Toy Example

Synthetic Tori

Population: Tori parameterized by radii (R, r)



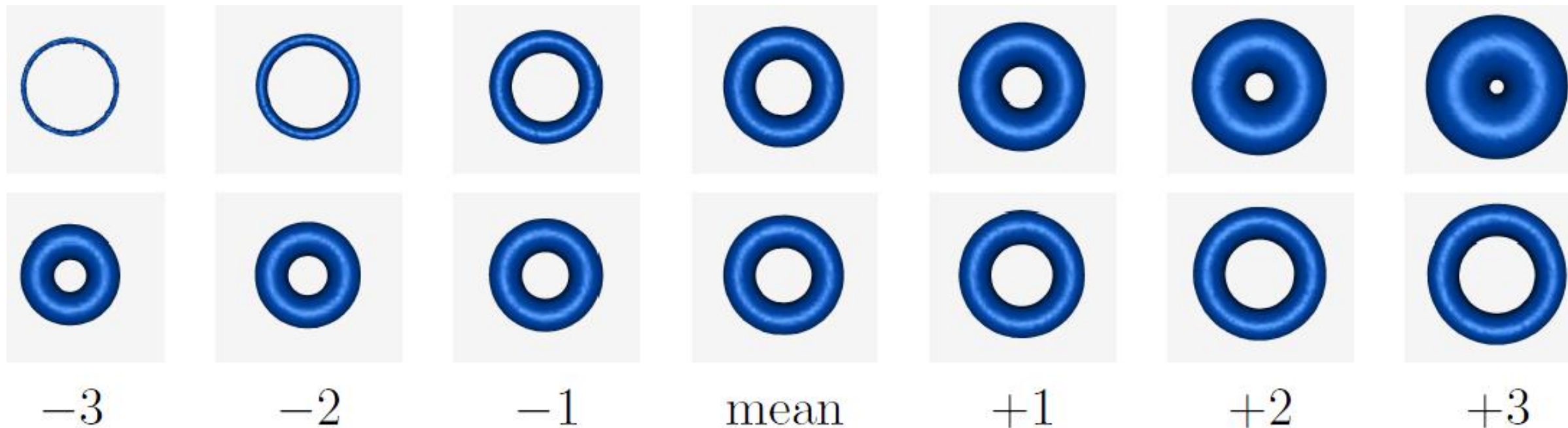
Generated Correspondences



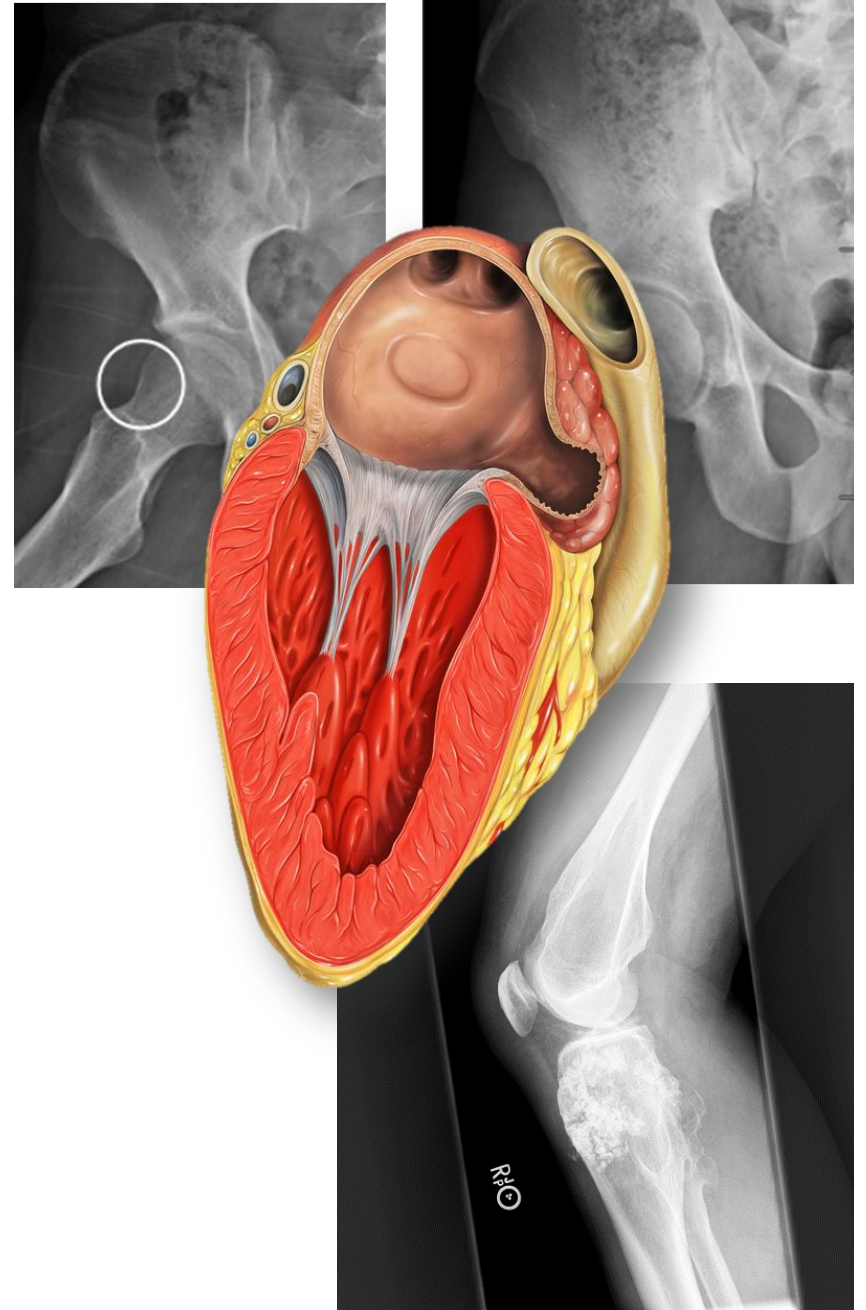
Toy Example

Synthetic Tori

Modes of variation



Applications



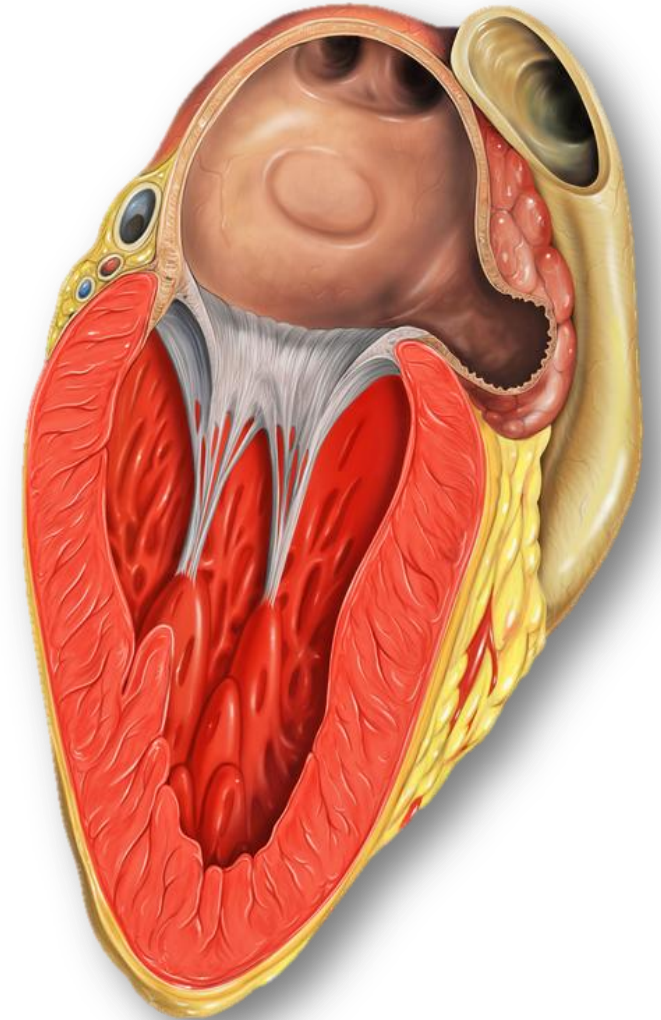
ShapeWorks for Cardiology

Left Atrial Appendage – Stroke Prediction

- The left atrial appendage (LAA) is a muscular pouch connected to the left atrium of the heart.
- It can be thought of as a left-over heart after we grow up.
- Functions as a reservoir for the left atrium.

If it traps blood longer than it should be, blood clots and causes stroke

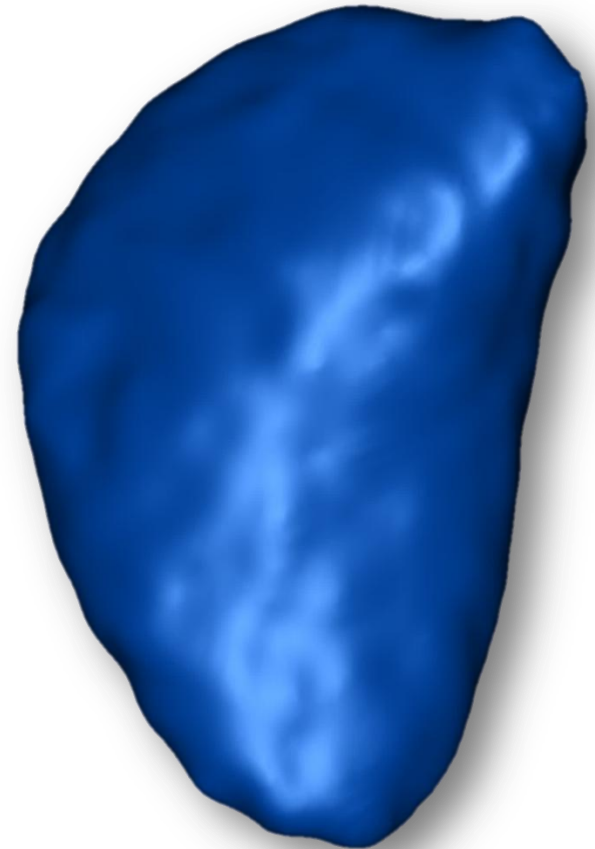
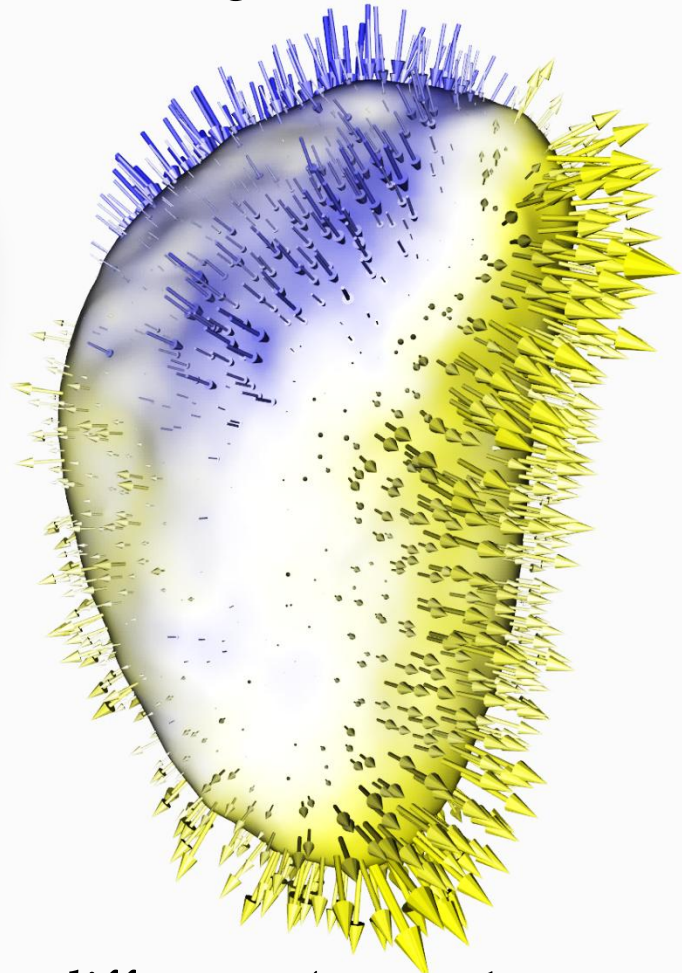
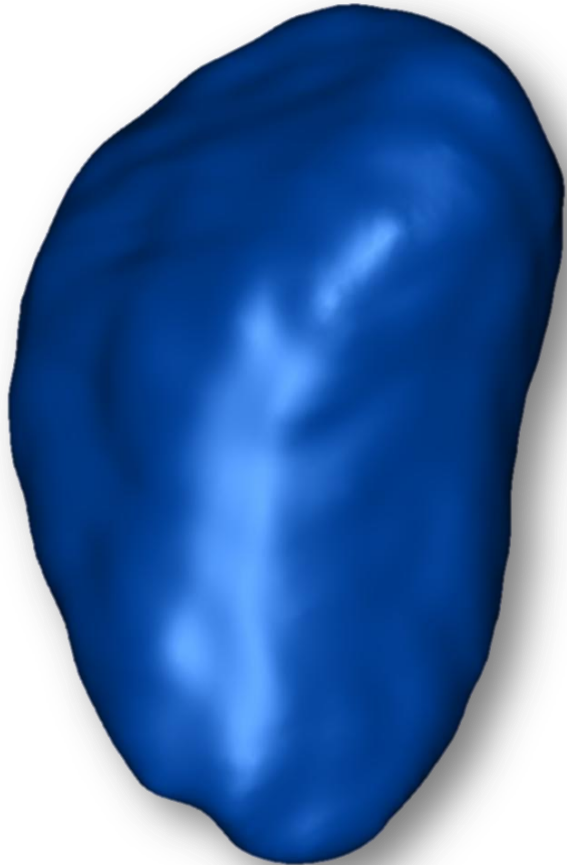
Can shape analysis aid in predicting whether someone will have a stroke or not ?!!



ShapeWorks for Cardiology

Left Atrial Appendage – Stroke Prediction

- The LAA of two groups was segmented, one group with no history of having stroke while the other group has evident history of having stroke.



Group 1:
no history of stroke

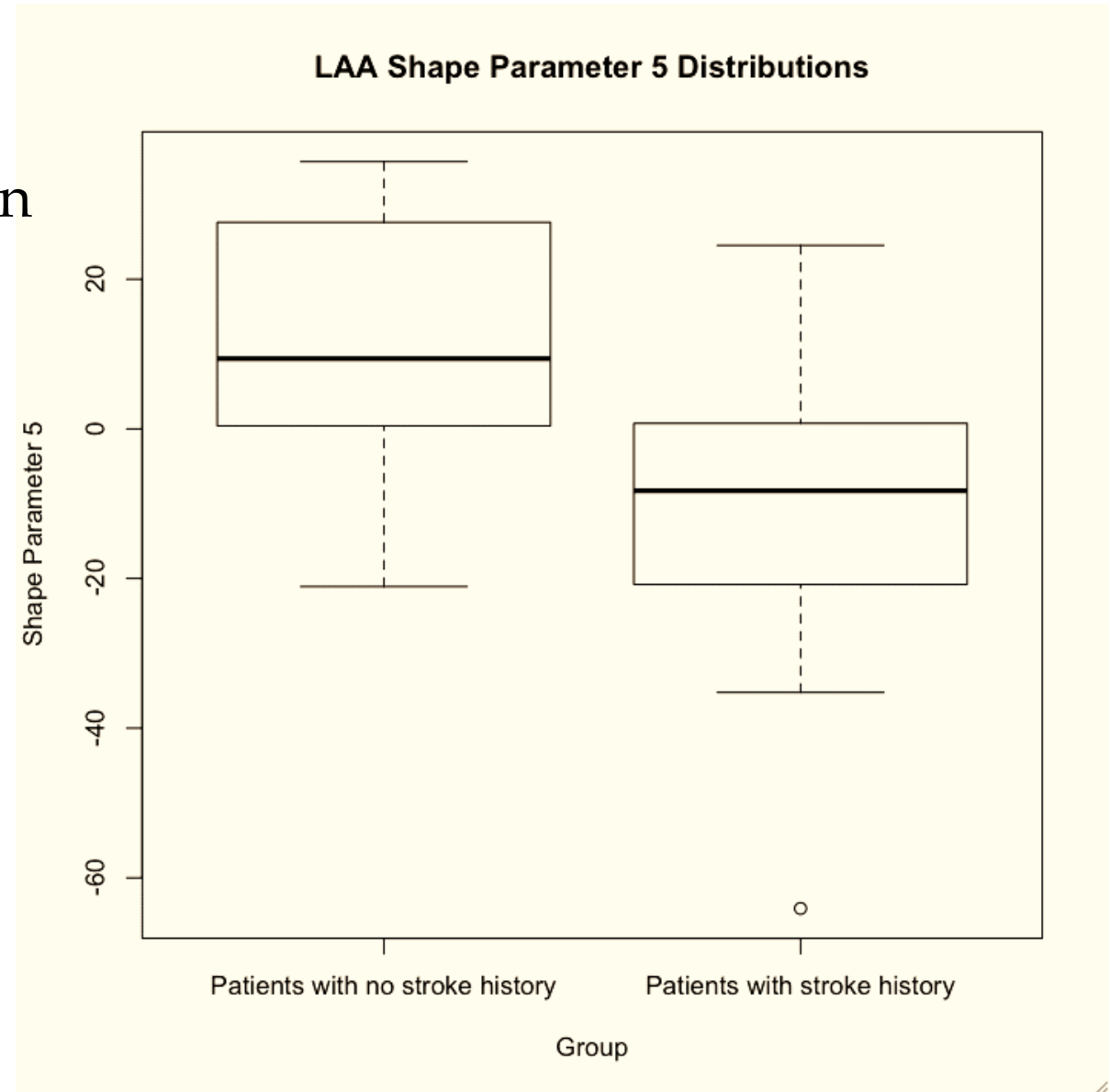
Group difference (group 1 to group 2)

Group 2:
history of stroke

ShapeWorks for Cardiology

Left Atrial Appendage – Stroke Prediction

- The significant shape difference between the two groups was found in the fifth PCA mode.
- A boxplot of the distributions is shown on the right.
- The p-value for a t-test of significant group mean difference is 0.0051



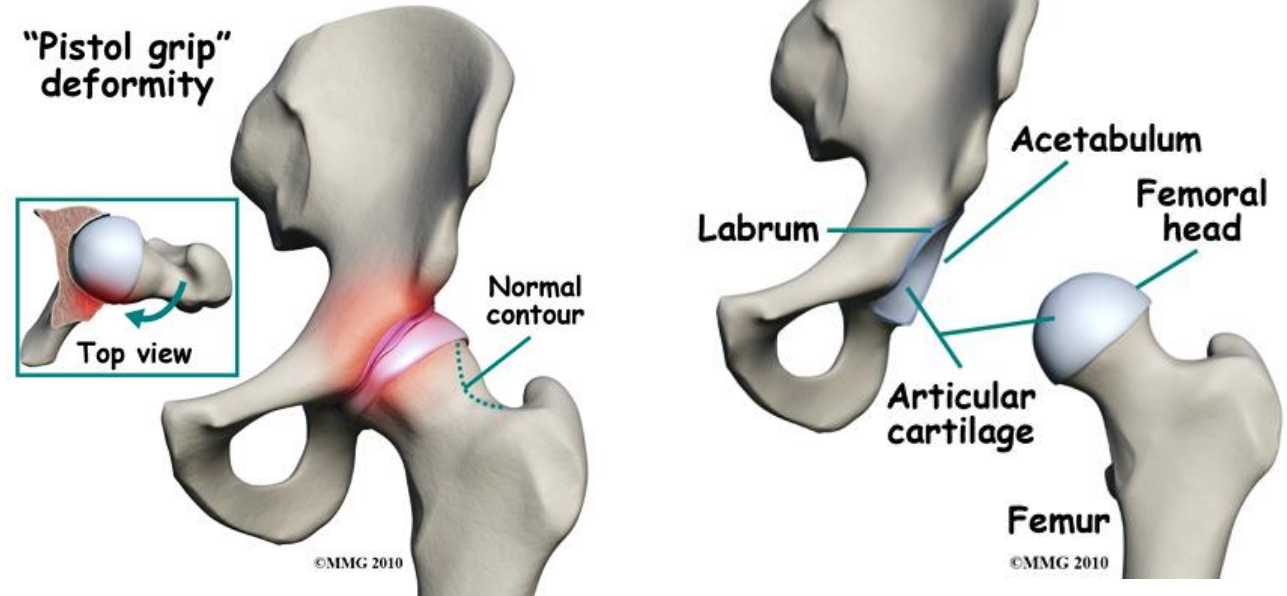
ShapeWorks for Orthopedics

CAM-FAI Characterization

Dr. Jeffery Weiss, Dr. Andrew Anderson, clinicians @ Orthopedics
Department of Orthopedics, University of Utah



Fig: Radiographs of subjects with healthy (left) and cam FAI (right) femurs. Circles indicate the anterolateral head-neck junction.



CAM-FAI = 'cam' type Femoro Acetabular Impingement

Treatment: surgical debridement

How much to 'shave off' ? And from where ?

Objective: quantify 3D variation and morphologic differences between control and cam femurs

ShapeWorks for Orthopedics

CAM-FAI Characterization

Dr. Jeffery Weiss, Dr. Andrew Anderson, clinicians @ Orthopedics
Department of Orthopedics, University of Utah

Mean Shapes

- Mean shape deviations between control and CAM groups most pronounced at the anterolateral head-neck junction (max = 2.7mm)

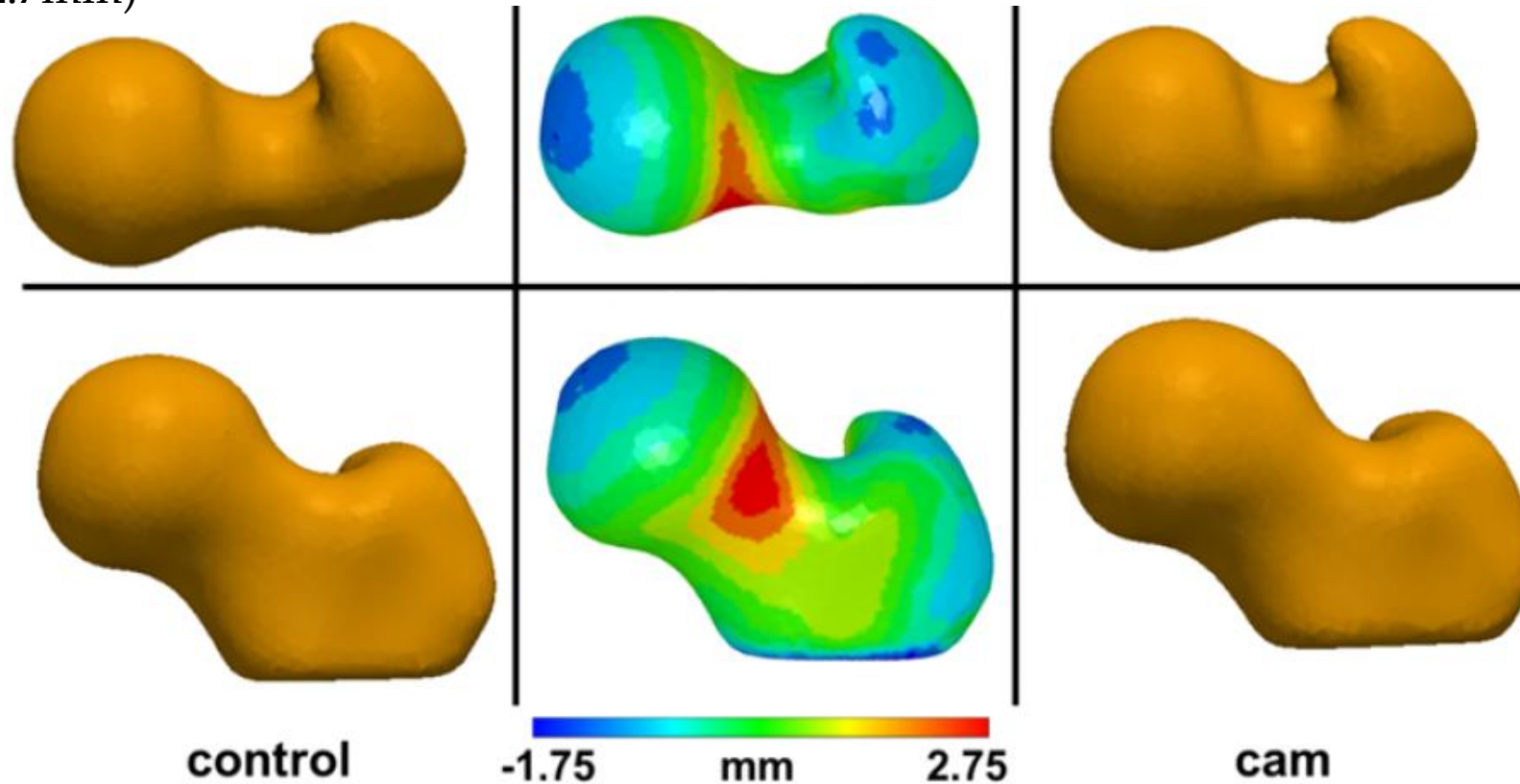
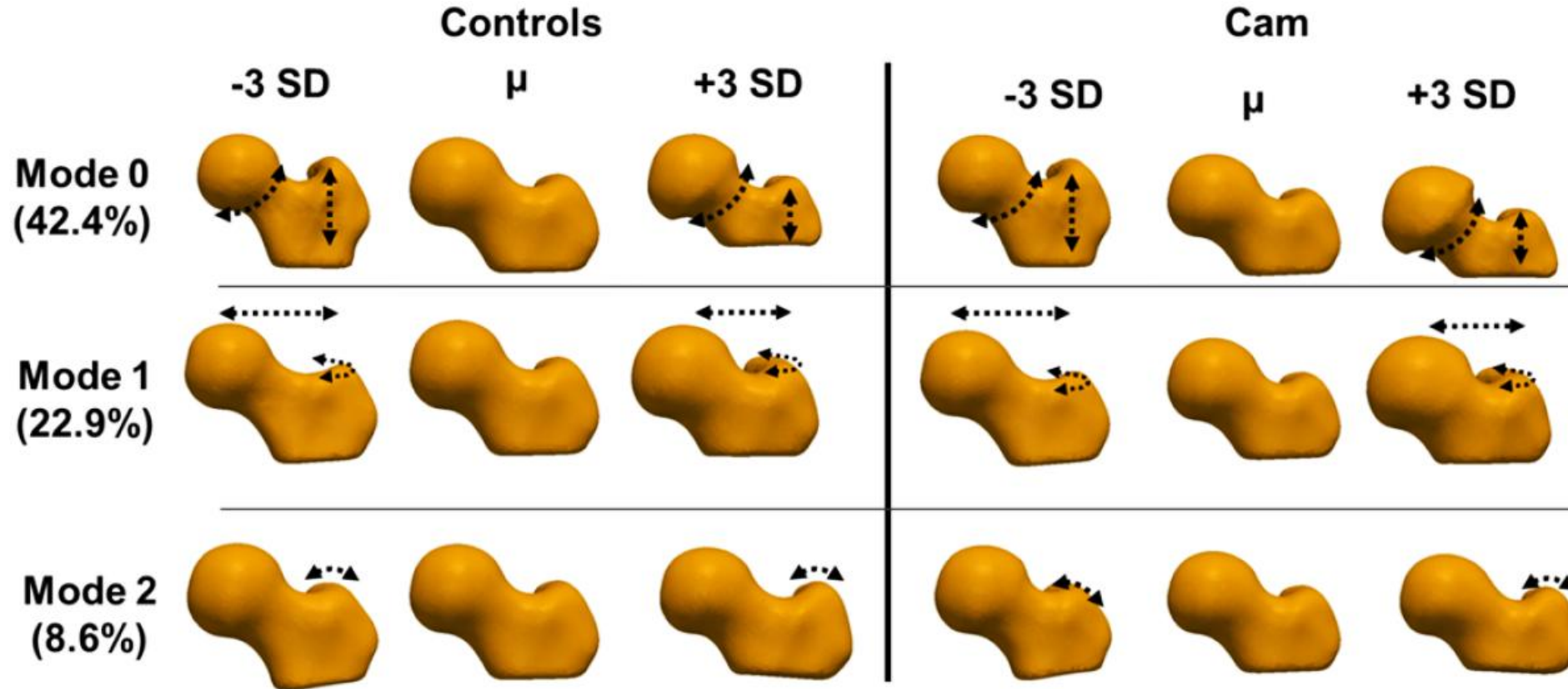


Fig: Two views (two rows) of the mean control (left) and cam (right) shapes. Mean control shape (center), color coded to depict shape differences in comparison with mean CAM shape

ShapeWorks for Orthopedics

CAM-FAI Characterization

Dr. Jeffery Weiss, Dr. Andrew Anderson, clinicians @ Orthopedics
Department of Orthopedics, University of Utah



Modes of variation

- Understand morphological variability in Cam-FAI
- Consistent differences captured by individual modes for control and CAM groups

ShapeWorks for Orthopedics

Multiple Osteochondromas

Dr. Kevin Jones, M.D., clinicians @ Huntsman Cancer Institute
Department of Orthopedics and Huntsman Cancer Institute, University of Utah

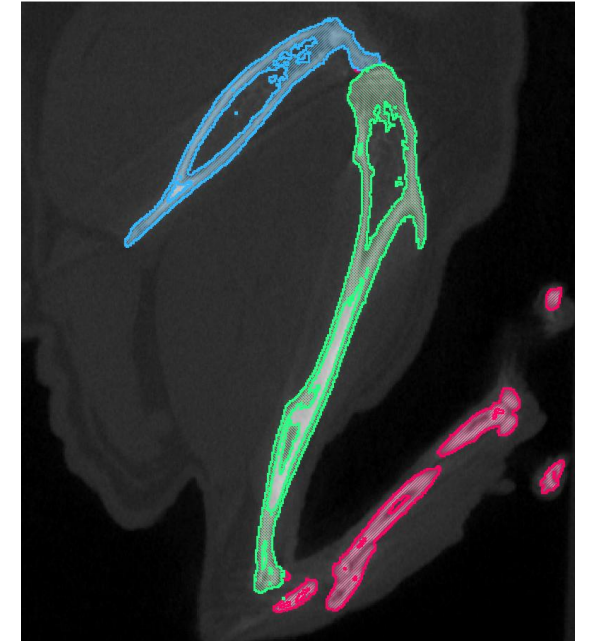


Multiple osteochondromas (MO),

- Individuals with multiple osteochondromas (MO) demonstrate shortened long bones.
- Possible reason: steal phenomenon
- Studied using mice models

Data: Segmented femurs (50), Segmented tibiae (36)

Can we characterize the effects of disease progression ?



Segmented femur and tibia+fibula
used in study

ShapeWorks for Orthopedics

Multiple Osteochondromas

Group mean differences

- Indicate shortening of mutant bones
- Do not validate 'steal phenomenon'

Dr. Kevin Jones, M.D. @ Huntsman Cancer Institute
Department of Orthopedics and Huntsman Cancer Institute, University of Utah

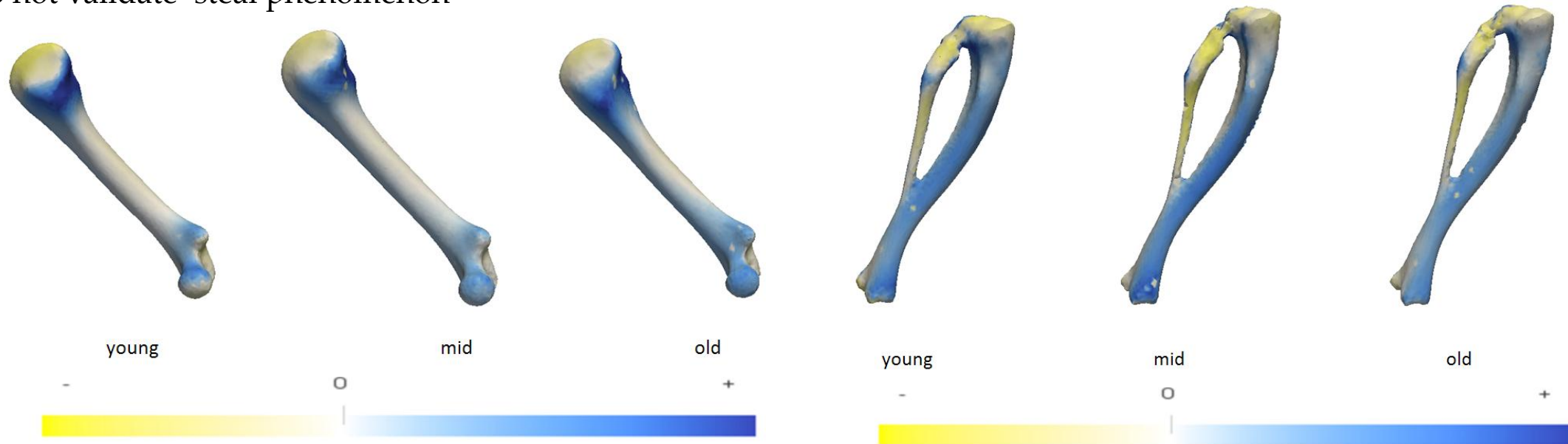


Fig: Group mean differences for femur

Color code: expansion (blue) or contraction (yellow) w.r.t normal

Fig: Group mean differences for tibia+fibula

- Statistically significant group differences (individual p -values < 0.01)
- Correlation with length evident visually in the group means

ShapeWorks for Orthopedics

Multiple Osteochondromas

Dr. Kevin Jones, M.D. @ Huntsman Cancer Institute

Department of Orthopedics and Huntsman Cancer Institute, University of Utah

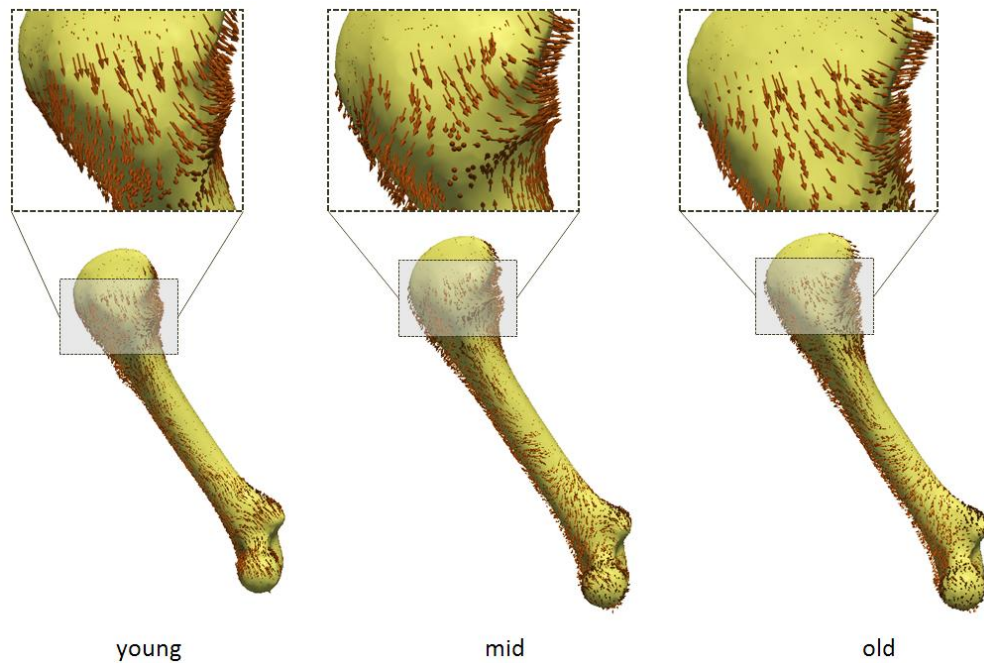


Fig: Directional analysis for femur

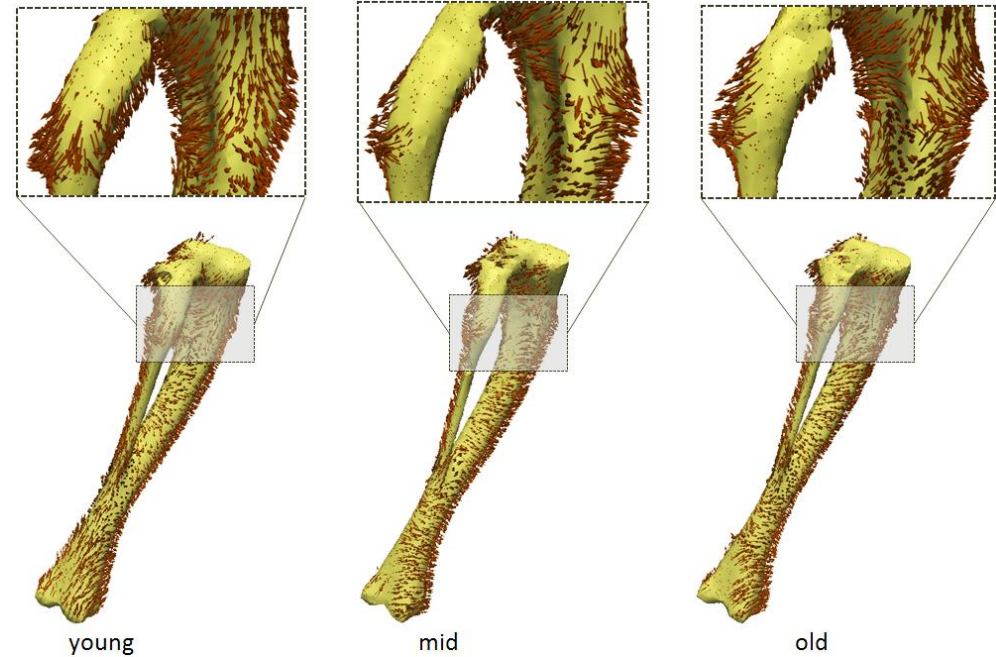
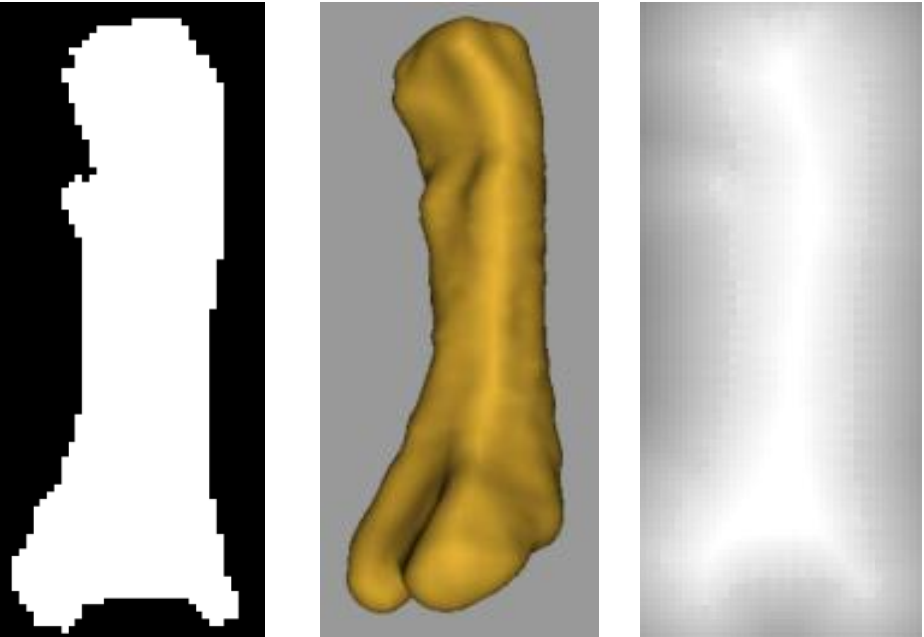
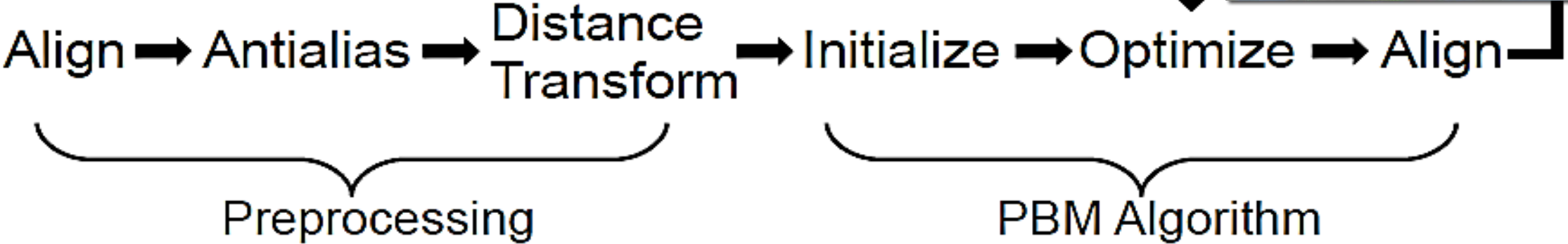


Fig: Directional analysis for tibia+fibula

Arrows show local deformation from mean-normal to mean-mutant shape

- Gives visual indication of the steal phenomenon, with:
 - Tangential deformation in most areas of the mean shape, leading to shortening in length
 - Orthogonal deformation near “bumps”, leading to local increase in girth

Correspondence Pipeline



Thanks for your attention