THE UNIVERSITY OF UTAH

Statistical Shape Analysis

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and Ross Whitaker

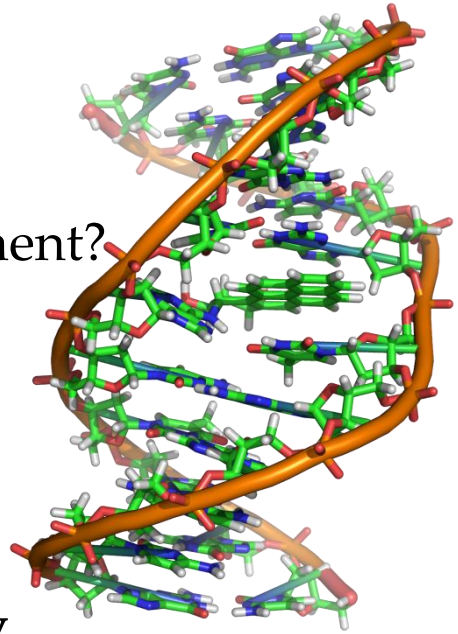
Saturday, January 4th , 2014

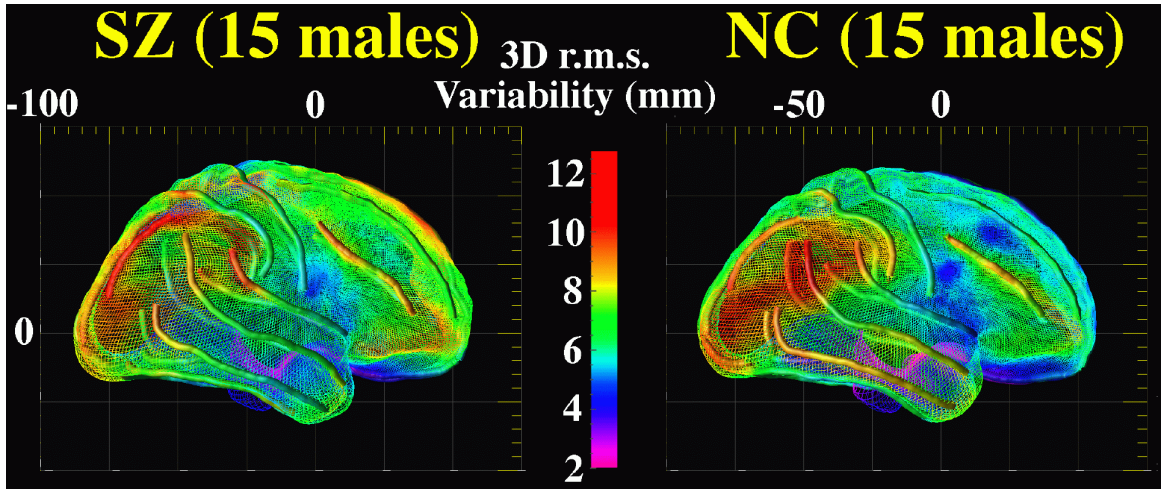
Study of 'Shape'

What questions can it answer ?

Genetics

How does a gene mutation change skeletal development?



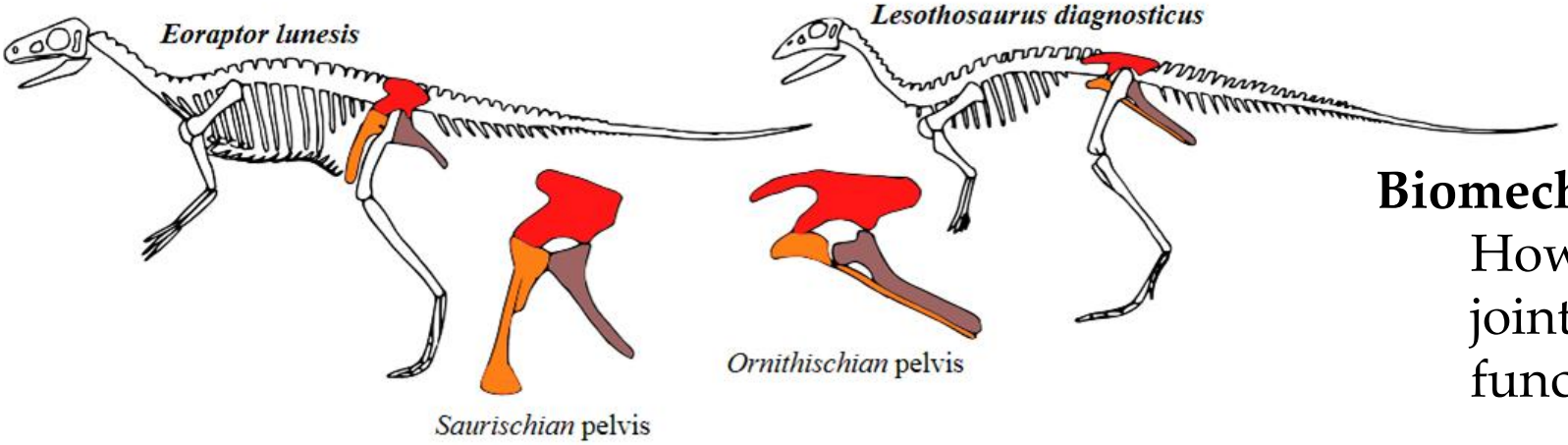


Neuroanatomy

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

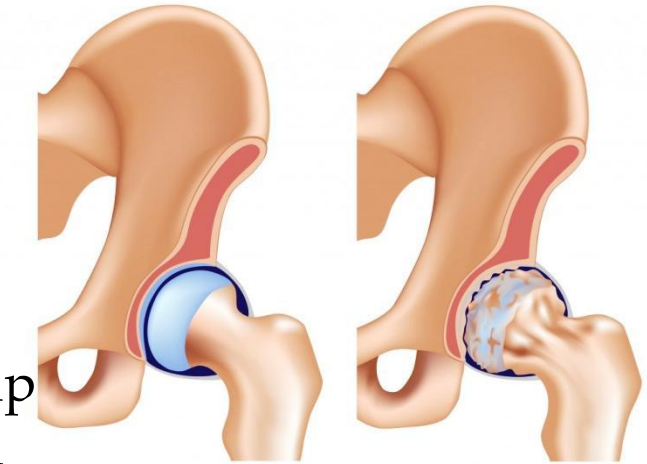
Evolutionary Biology

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

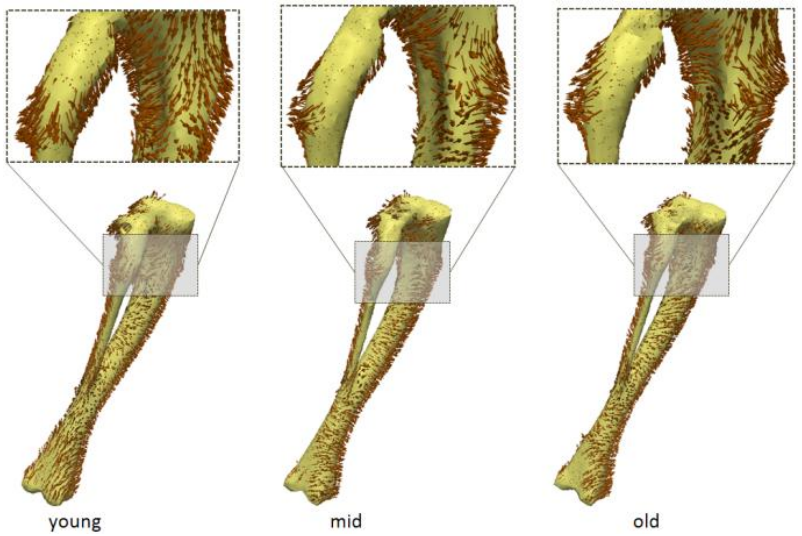


Biomechanics

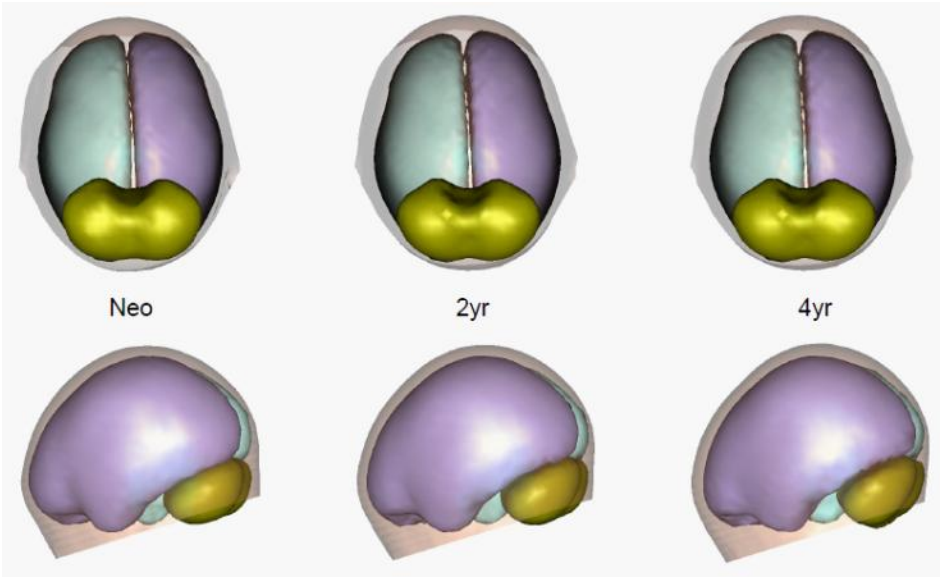
How does the hip joint change as a function of age?



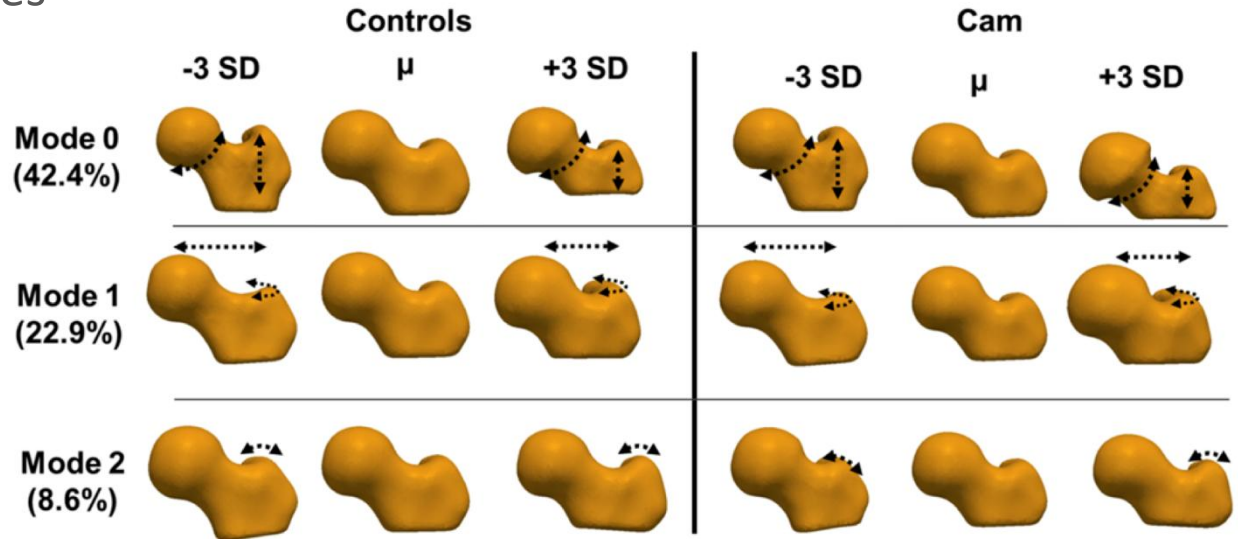
Shape analysis is ubiquitous…



Group Differences



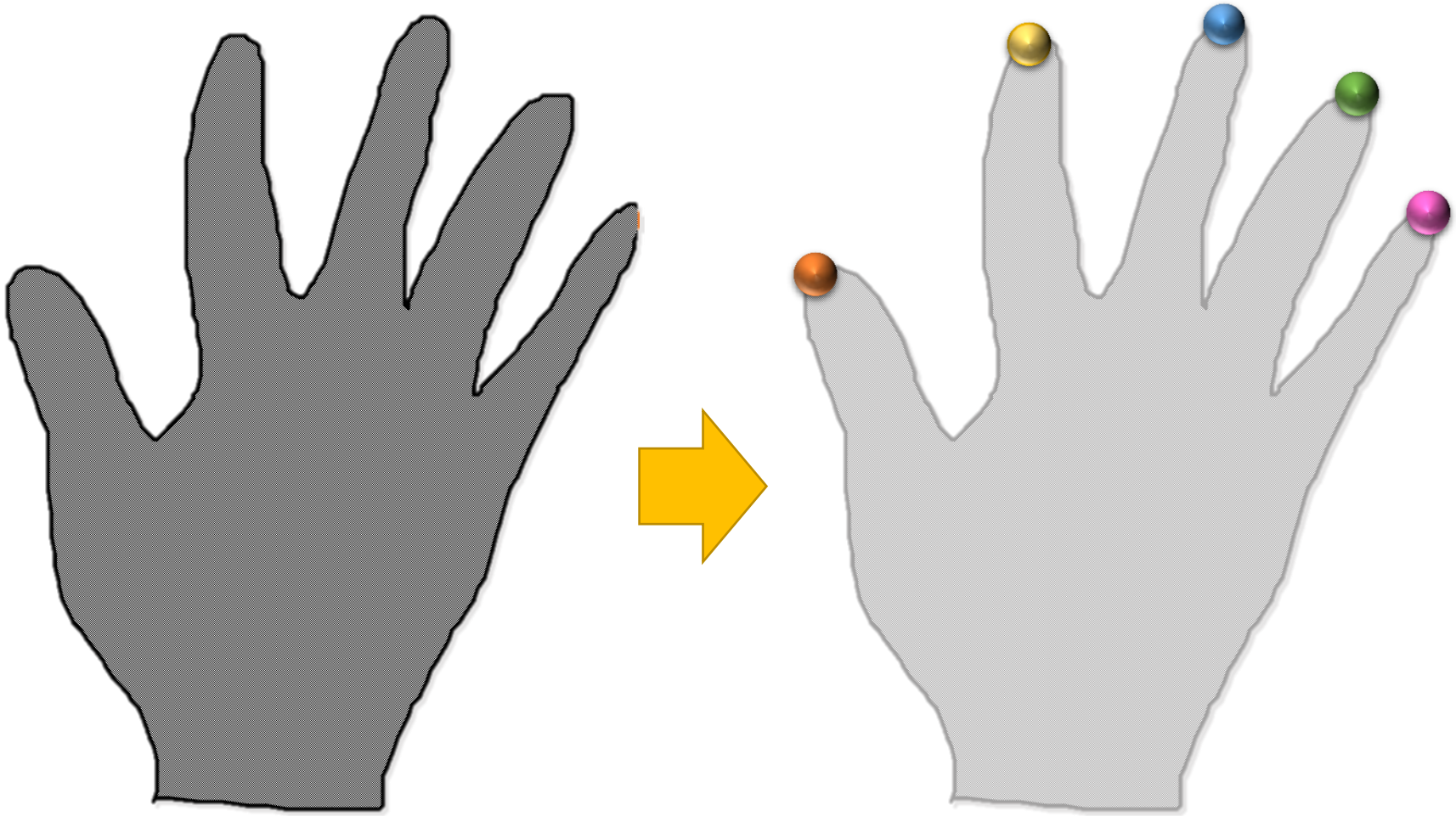
Normative Growth



Variability in population

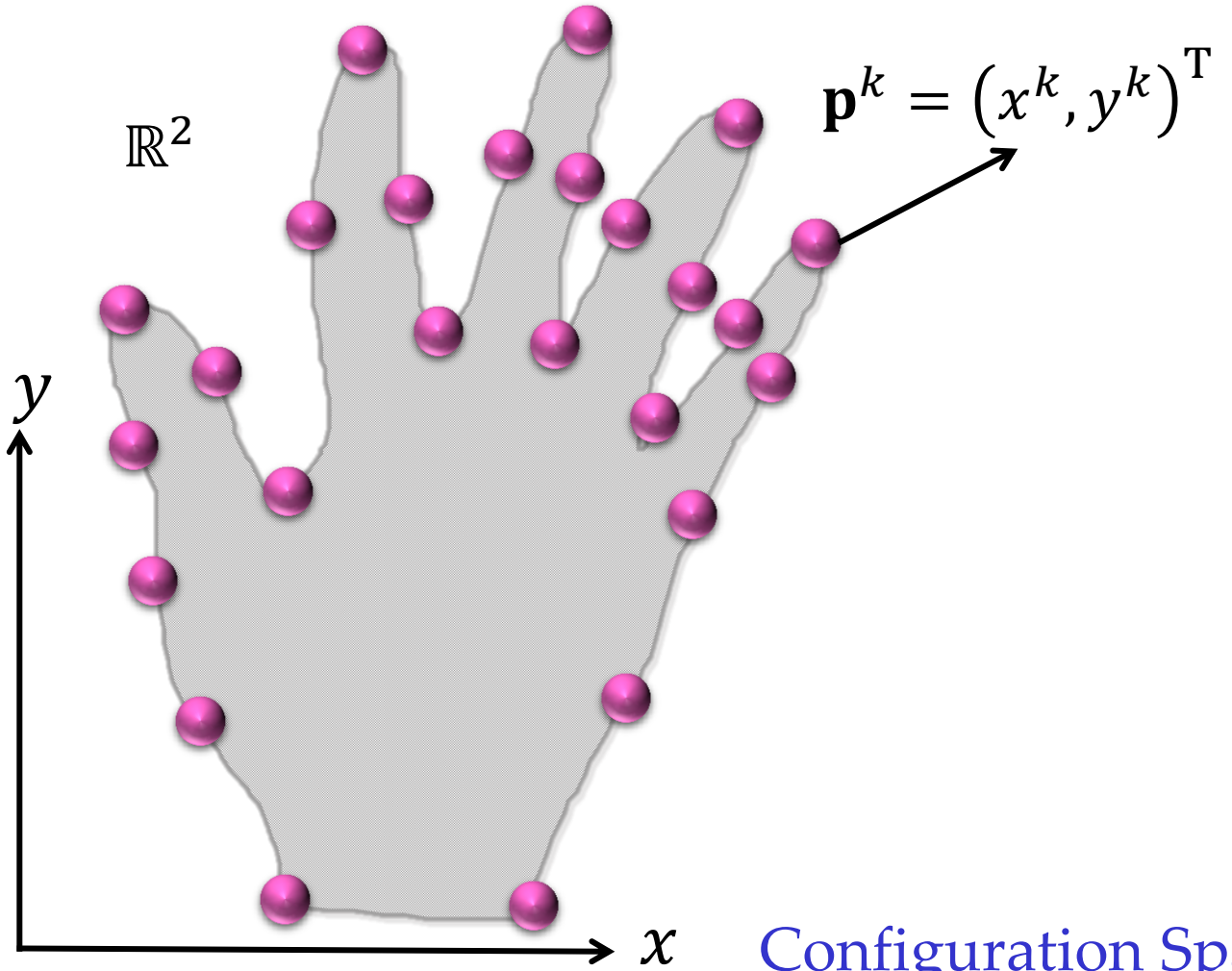
Statistical Shape Analysis

It's all about representation…

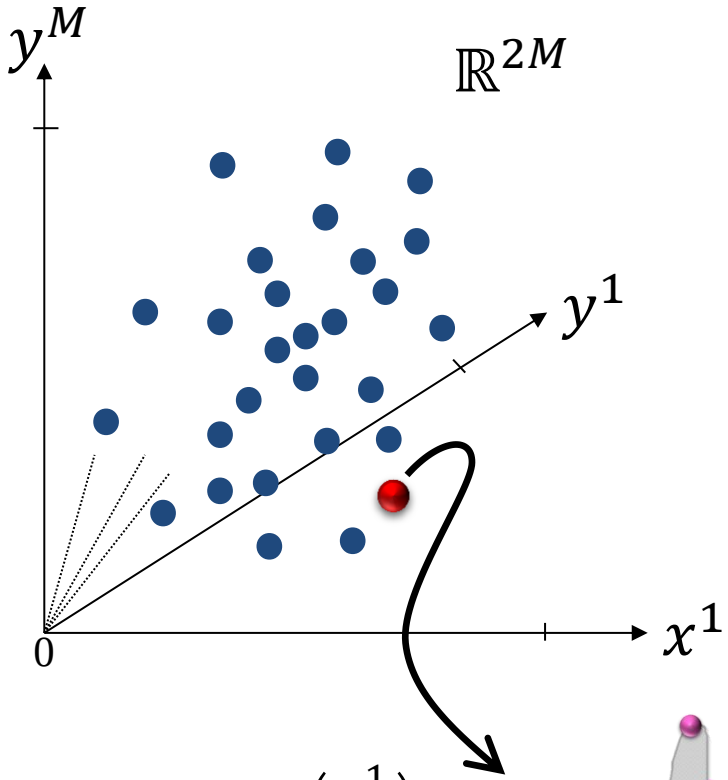


Statistical Shape Analysis

It's all about representation…



Configuration Space

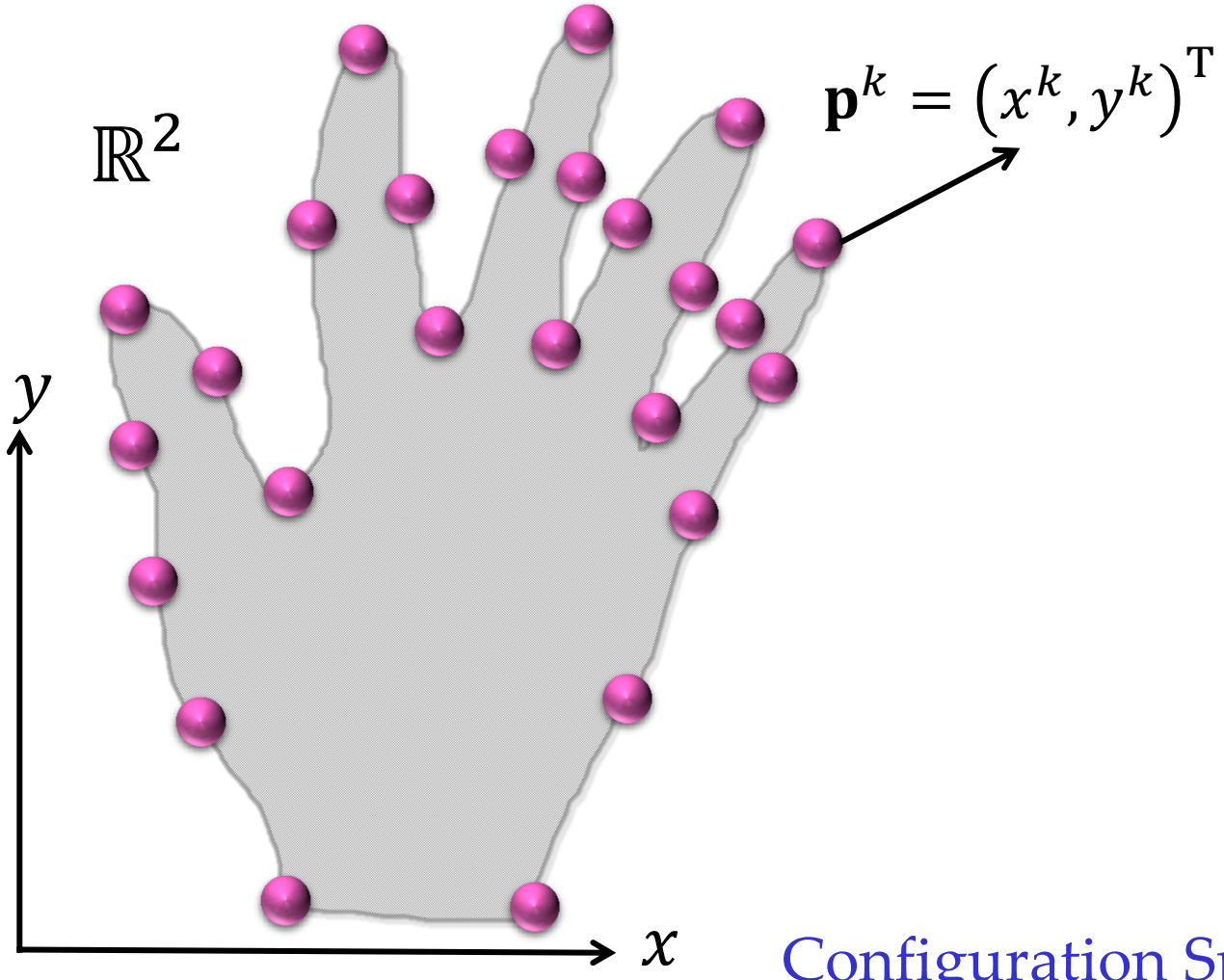


$$S_i = \begin{pmatrix} \mathbf{p}_i^1 \\ \mathbf{p}_i^2 \\ \dots \\ \mathbf{p}_i^M \end{pmatrix} = \begin{pmatrix} x_i^1 \\ y_i^1 \\ \dots \\ x_i^M \\ y_i^M \end{pmatrix}$$

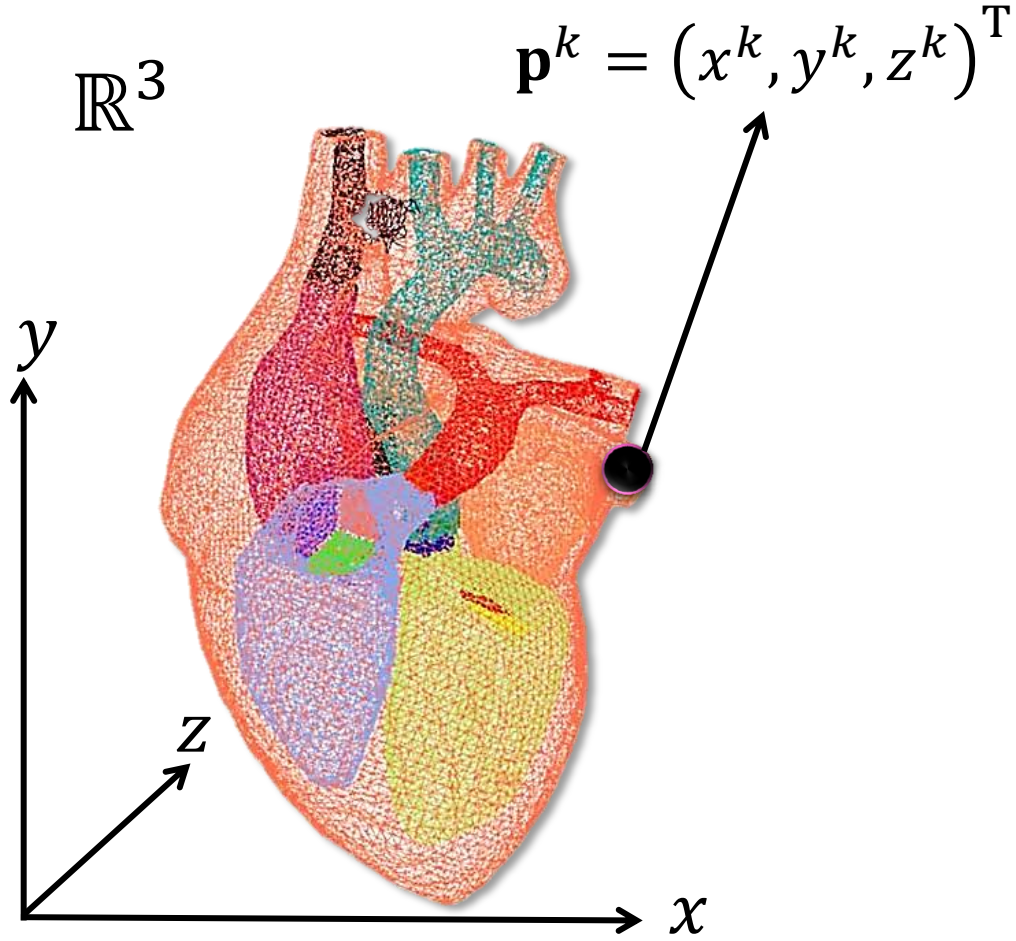
Shape Space

Statistical Shape Analysis

It's all about representation…

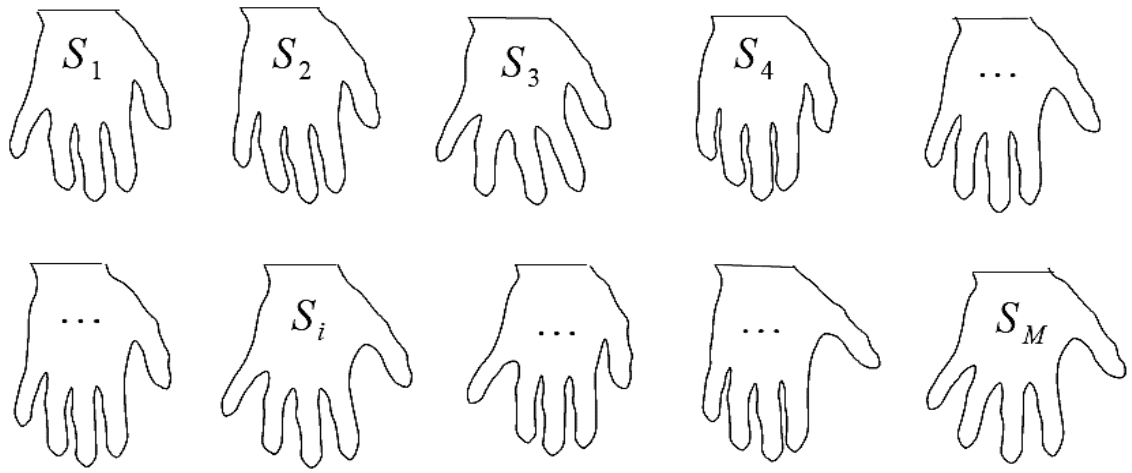


Configuration Space

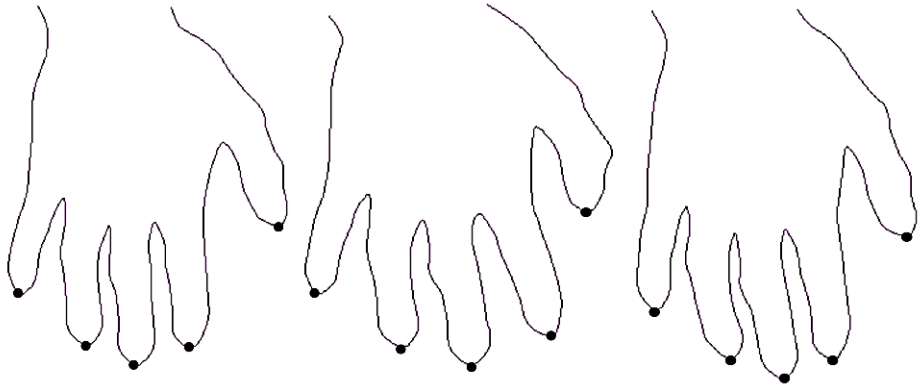


Statistical Shape Analysis

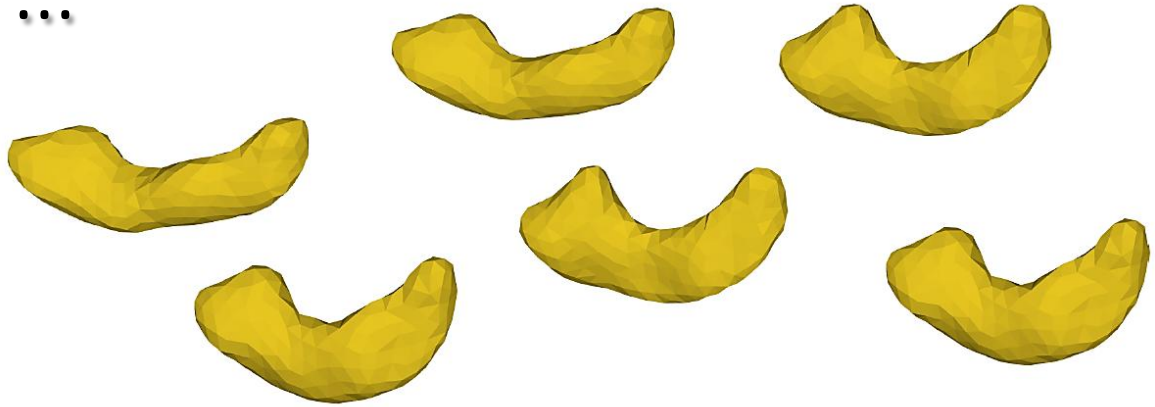
It's all about representation…



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



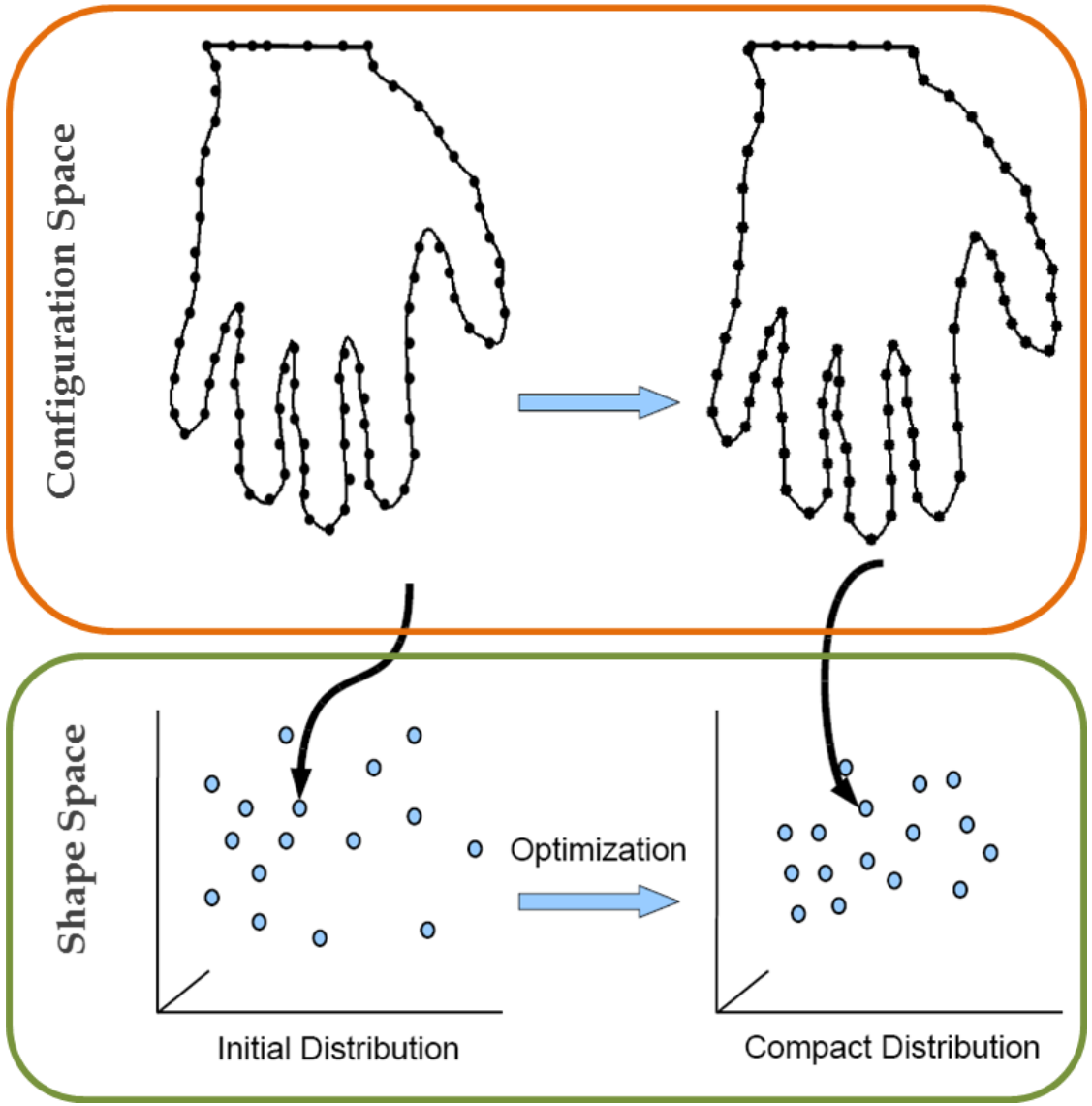
BUT…

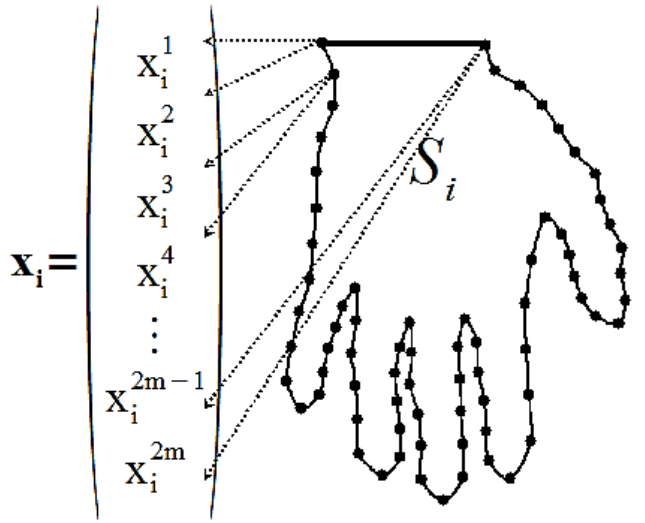


How do we choose the "same" points ??

Point Correspondence Model

Balancing accuracy vs. low variance





Accurate Representation

(in Configuration Space)

vs.

Compact Model

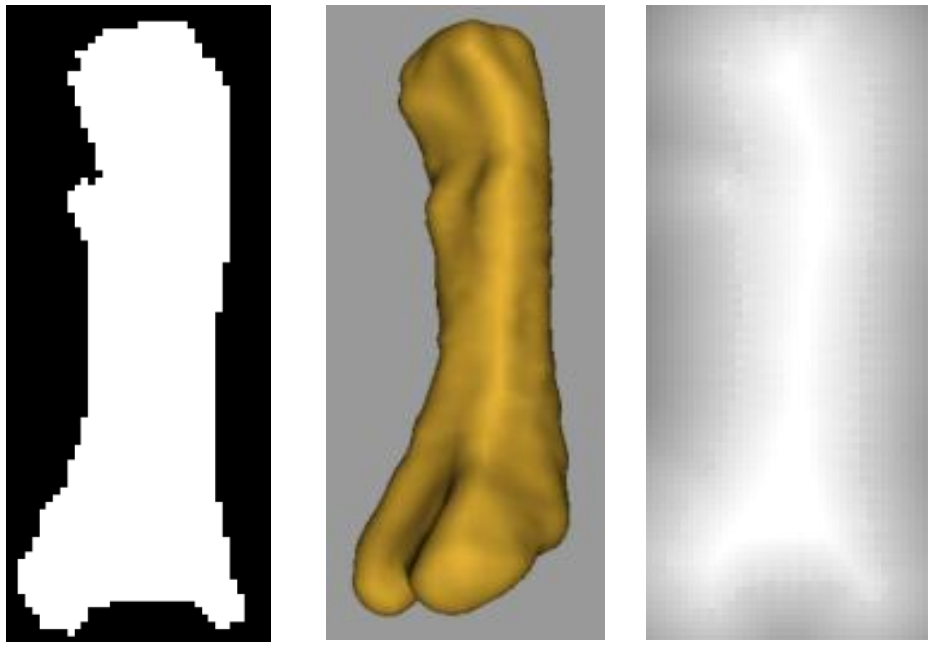
(in Shape Space)

Correspondence Pipeline

Align → Antialias → Distance Transform → Initialize → Optimize → Align

Preprocessing

PBM Algorithm

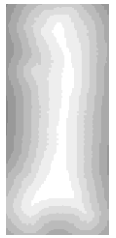


ShapeWorks Pipeline

- Preprocessing

Input Segmentation

Distance Transform



Antialiased Surface

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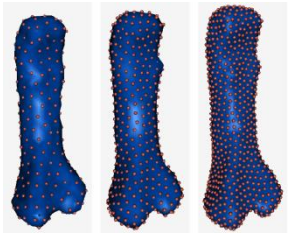
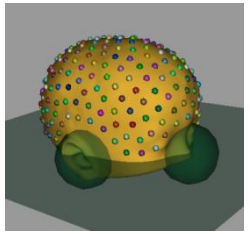
- Optimization

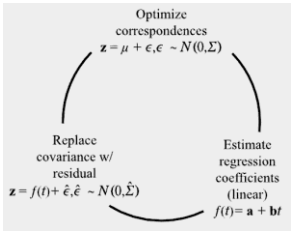
Entropy Minimization



Open Surfaces



Linear Regression



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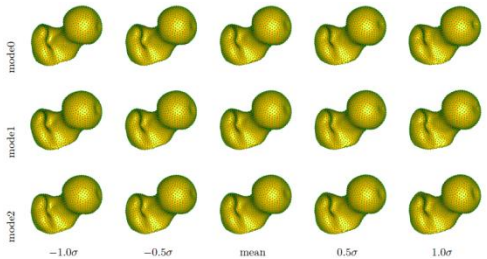
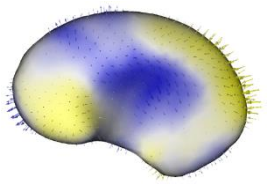
- Visualization/
- Applications

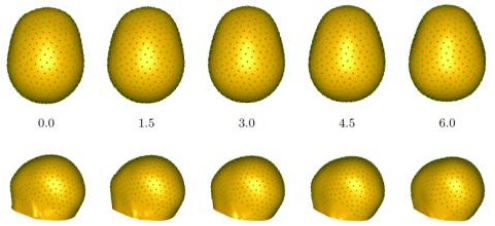
Modes of Variation



Group Differences



Regression Shape



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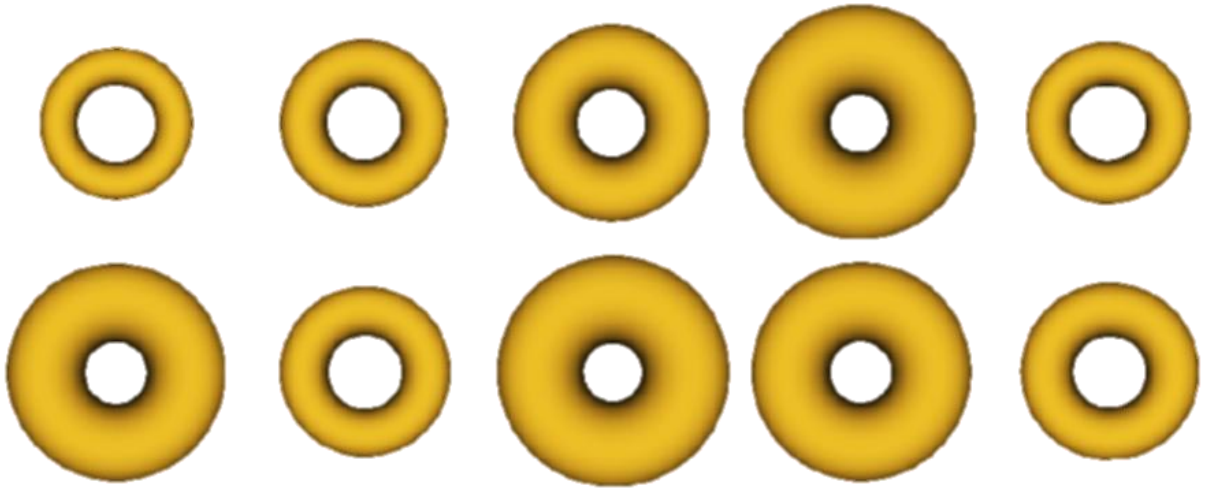
Toy Example

Synthetic Tori

Population: Tori parameterized by radii (R,r)

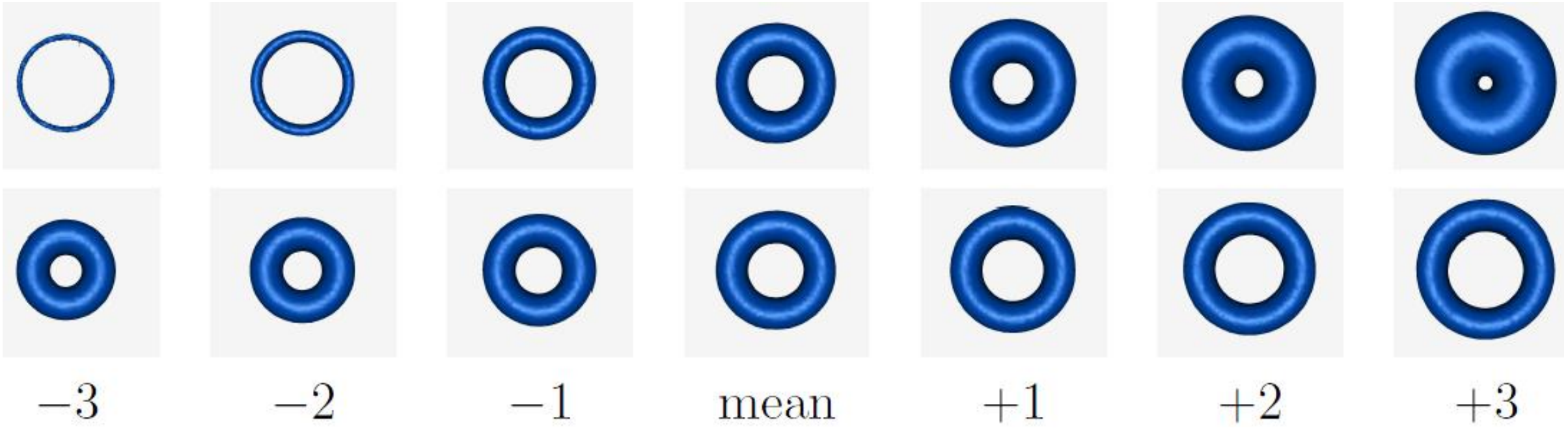


Generated Correspondences

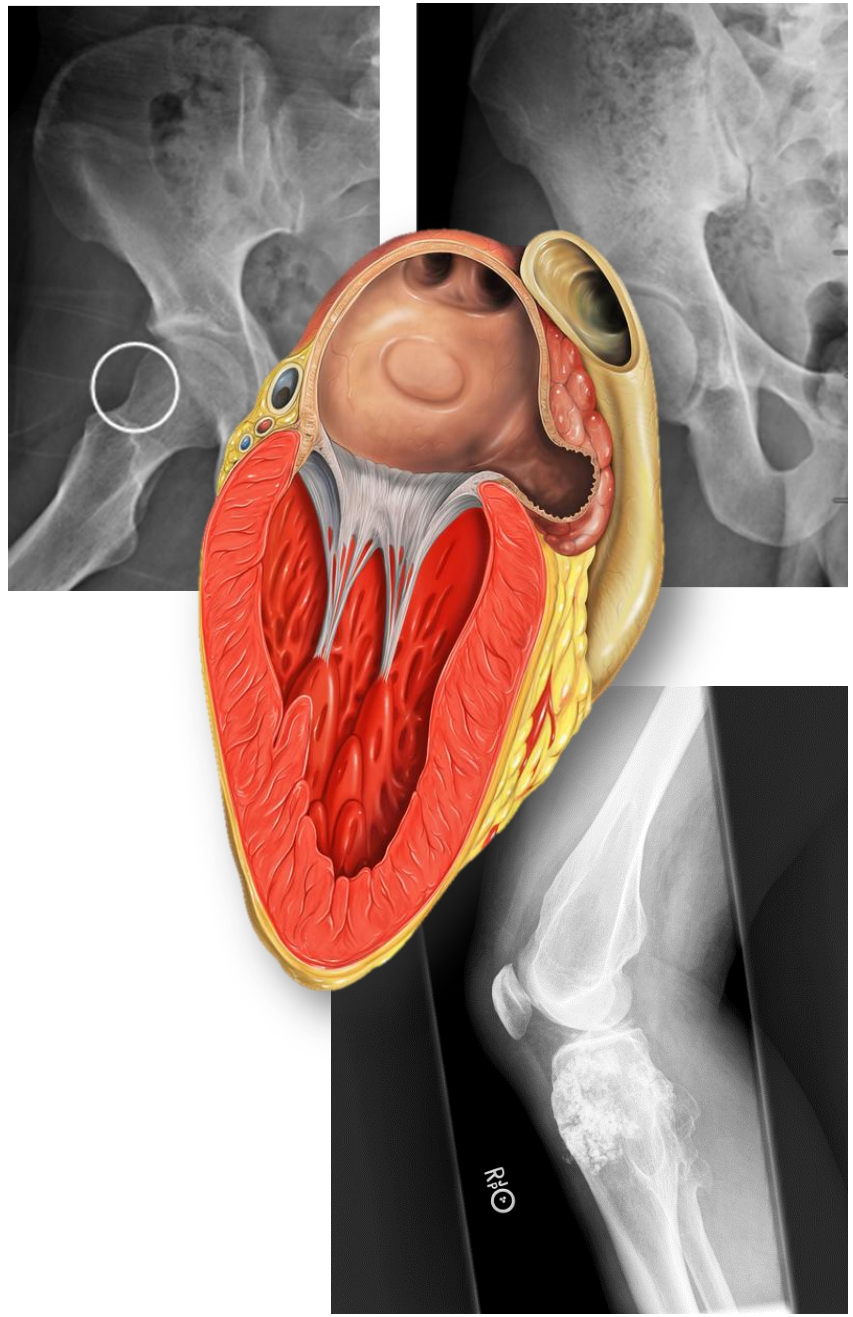
Toy Example

Synthetic Tori

Modes of variation



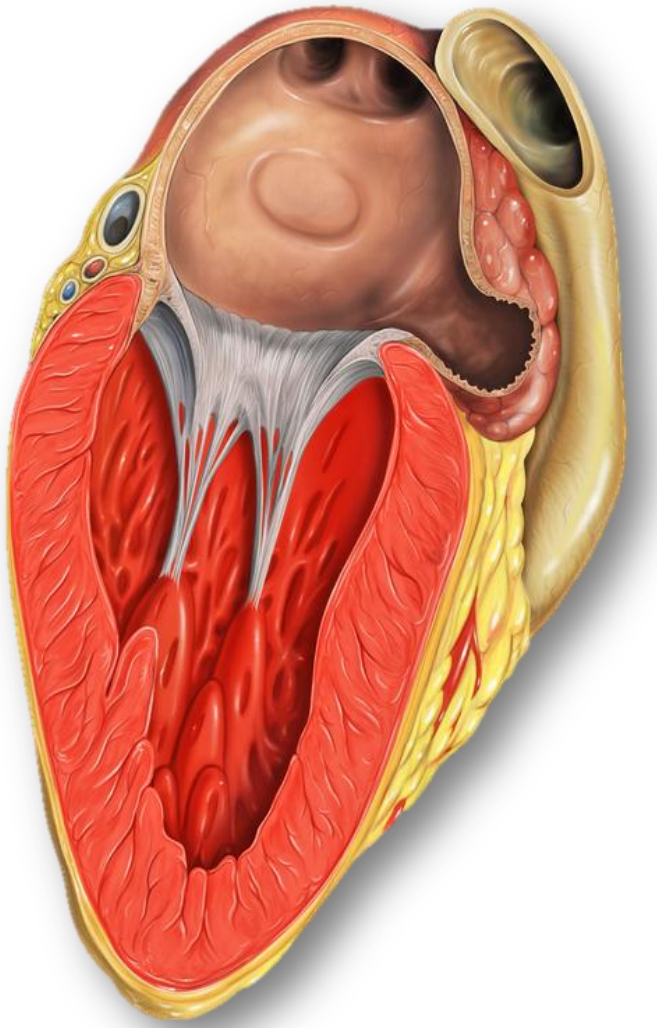
Applications



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.



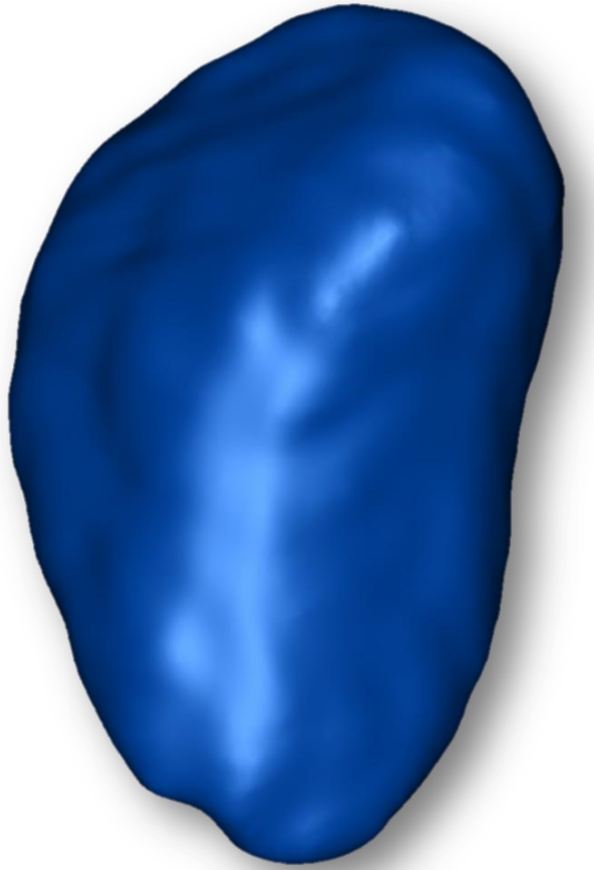
If it traps blood longer than it should be, blood clots and causes stroke

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

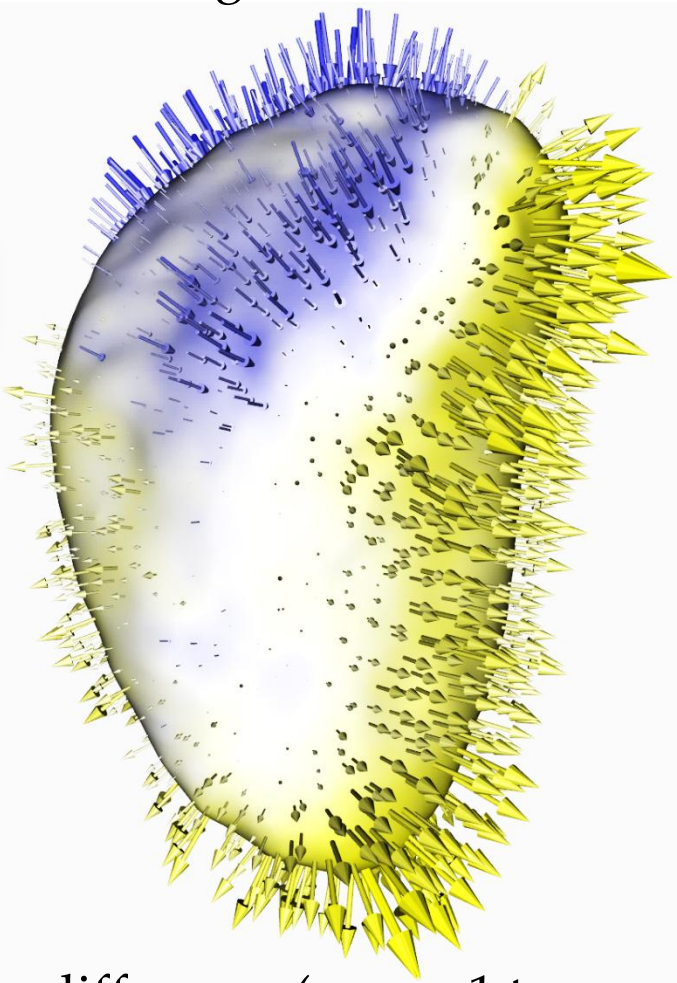
ShapeWorks for Cardiology

Left Atrial Appendage – Stroke Prediction

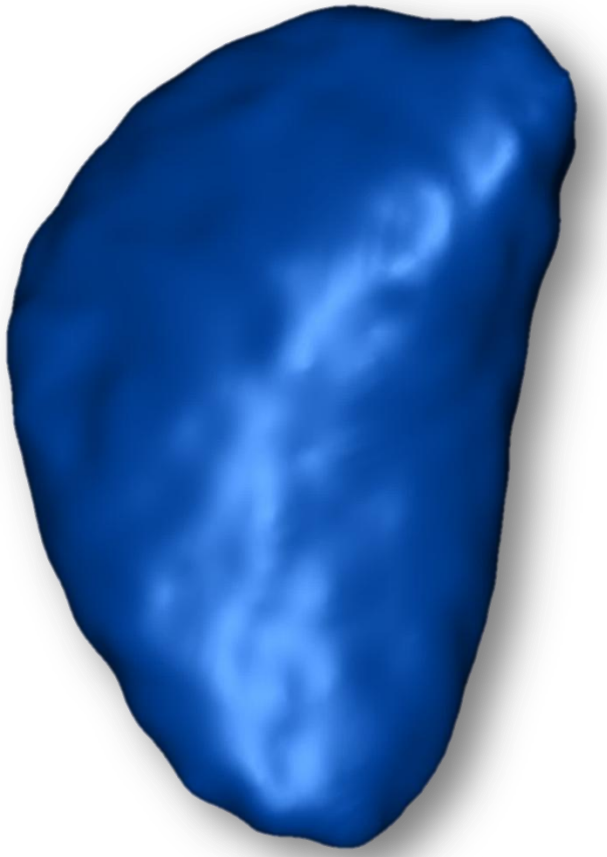
- The LAA of two groups was segmented, one group with no history of having stroke while the other group has evident history of having stroke.



Group 1:
no history of stroke



Group difference (group 1 to group 2)

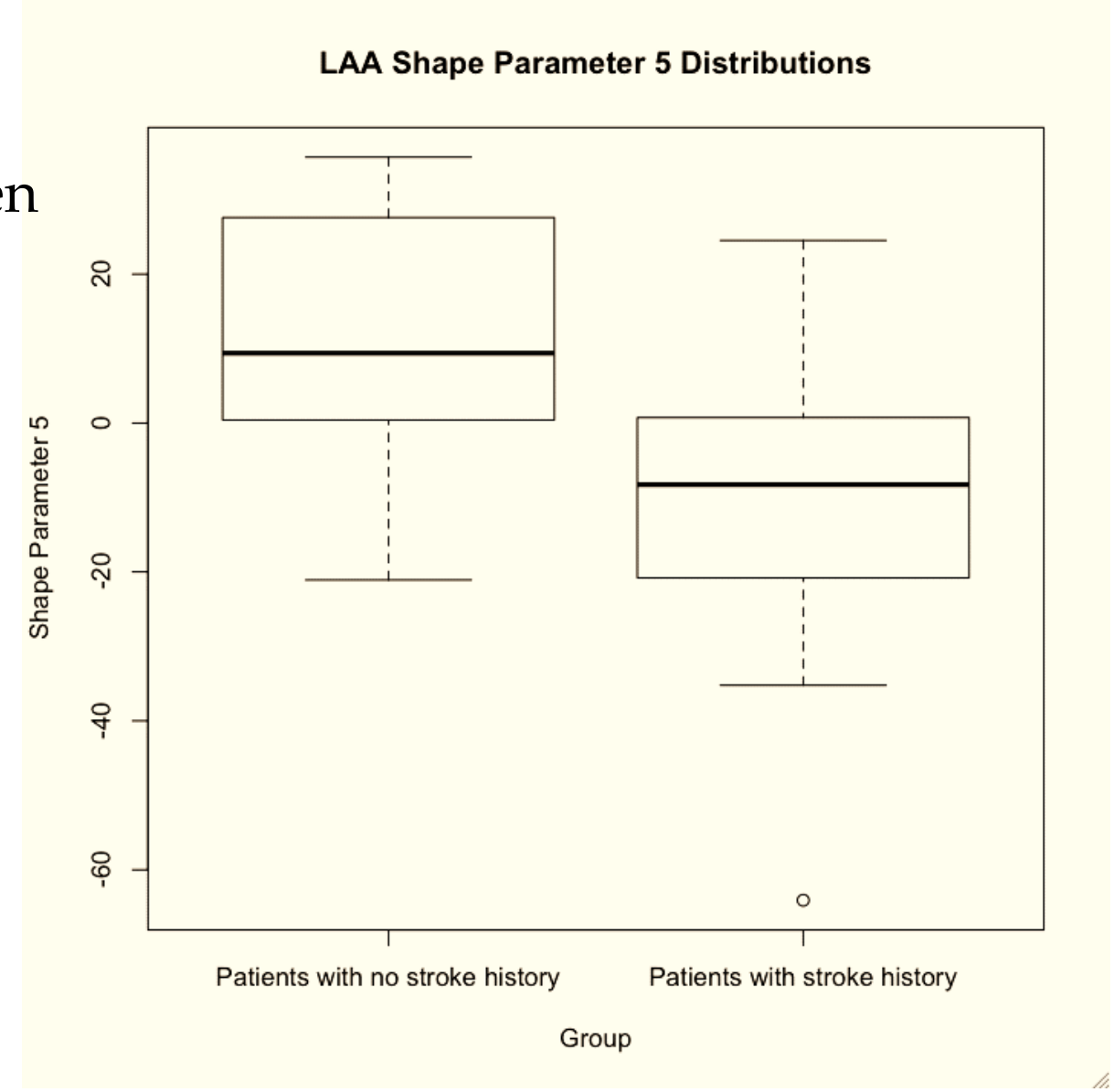


Group 2:
history of stroke

ShapeWorks for Cardiology

Left Atrial Appendage – Stoke 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

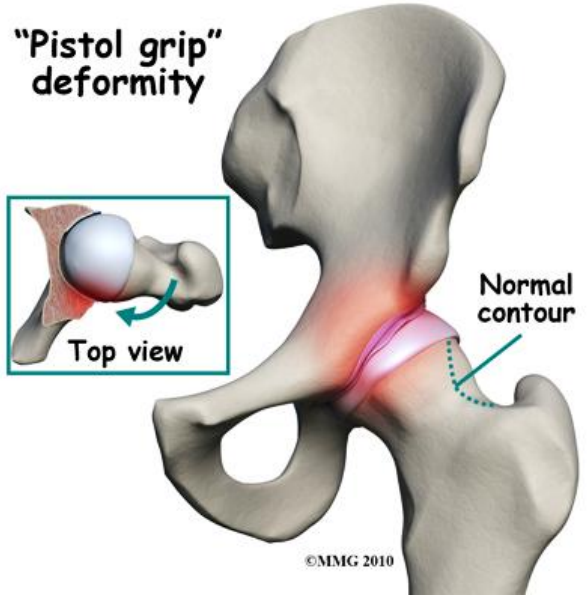


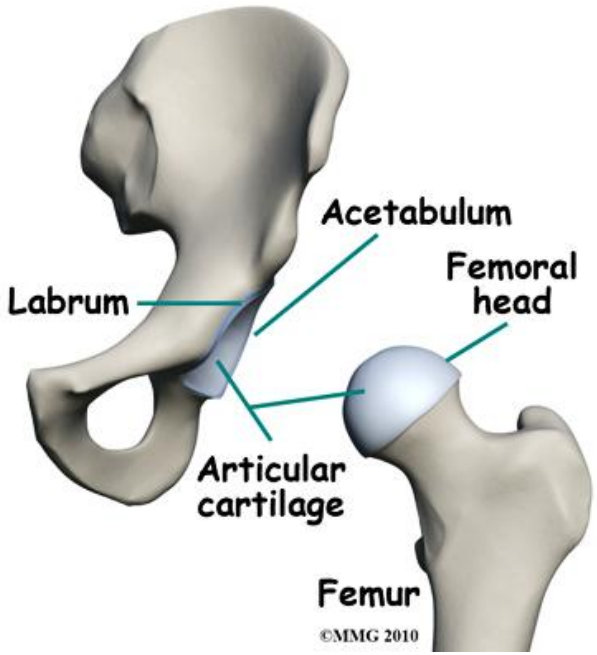
ShapeWorks for Orthopedics

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

Harris, Michael D., Manasi Datar, Ross T. Whitaker, Elizabeth R. Jurrus, Christopher L. Peters, and Andrew E. Anderson. "Statistical shape modeling of cam femoroacetabular impingement." *Journal of Orthopaedic Research* 31, no. 10 (2013): 1620-1626.

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Mean Shapes

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

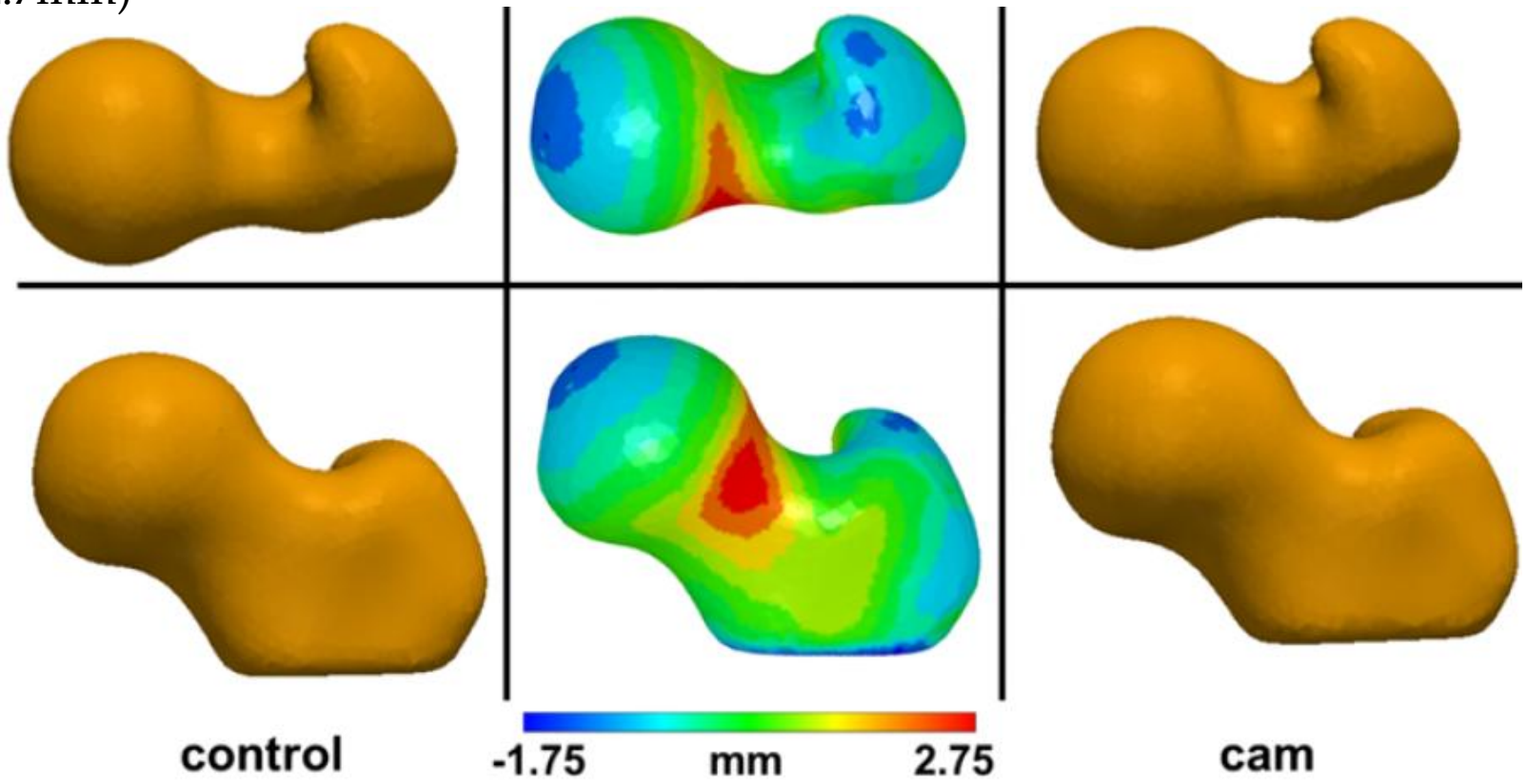

Fig: Two views (two rows) of the mean control (left) and cam (right) shapes. Mean control shape (center), color coded to depict shape differences in comparison with mean CAM shape

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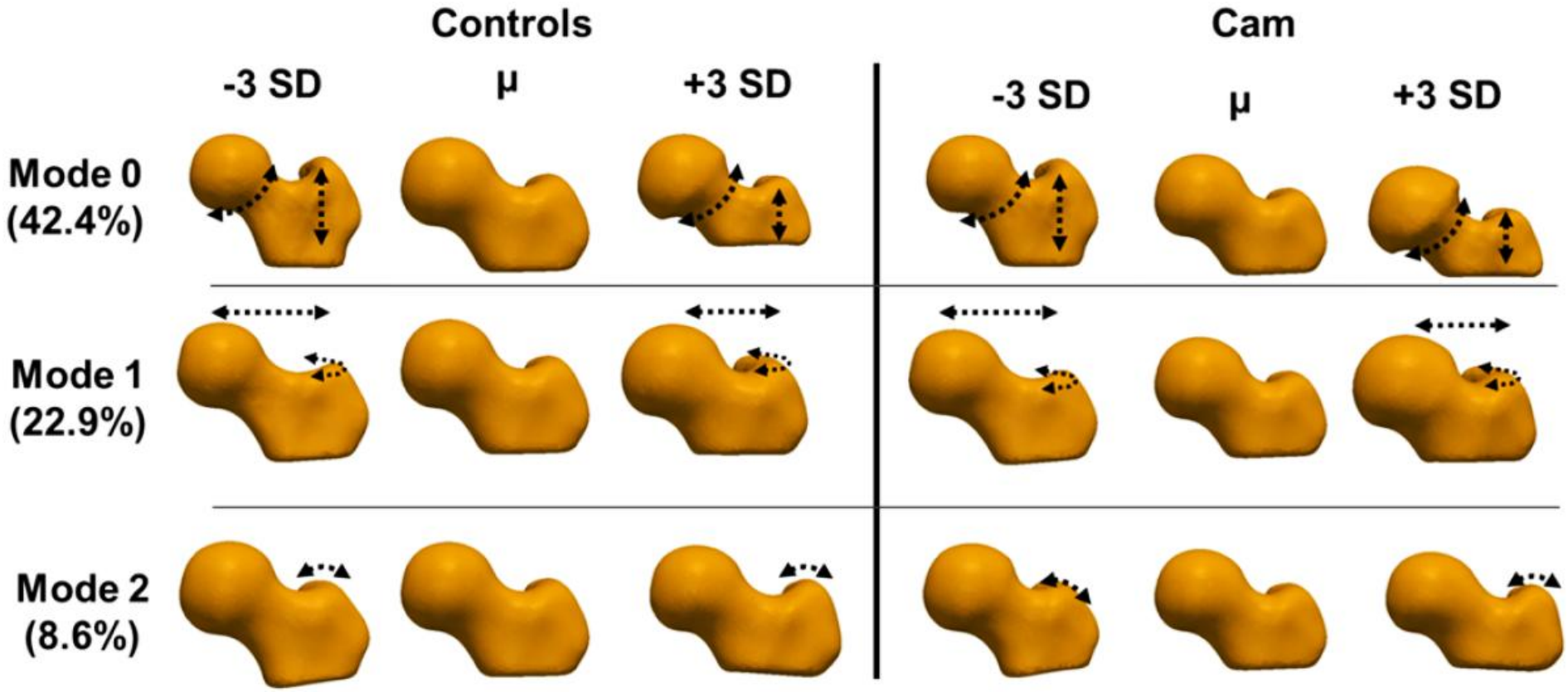

Modes of variation

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

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ShapeWorks for Orthopedics

Multiple Osteochondromas

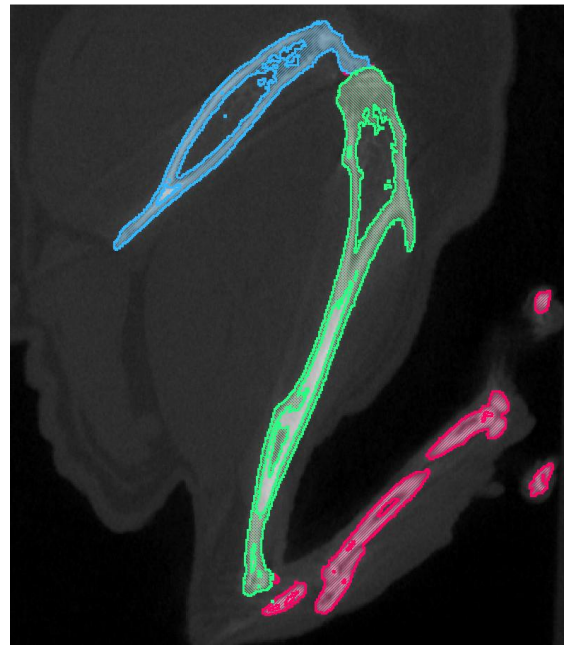
Dr. Kevin Jones, M.D., clinicians @ Huntsman Cancer Institute
Department of Orthopedics and Huntsman Cancer Institute, University of Utah

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

Jones, Kevin B., Manasi Datar, Sandhya Ravichandran, Huifeng Jin, Elizabeth Jurrus, Ross Whitaker, and Mario R. Capecchi. "Toward an understanding of the short bone phenotype associated with multiple osteochondromas." *Journal of Orthopaedic Research* (2012).

ShapeWorks for Orthopedics

Multiple Osteochondromas

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Group mean differences

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

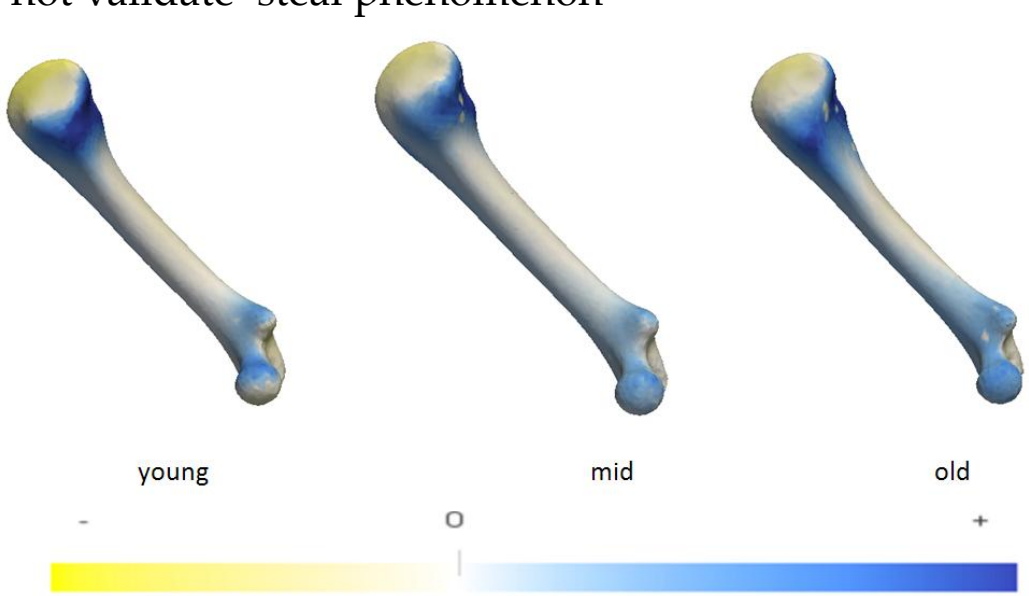

Fig: Group mean differences for femur

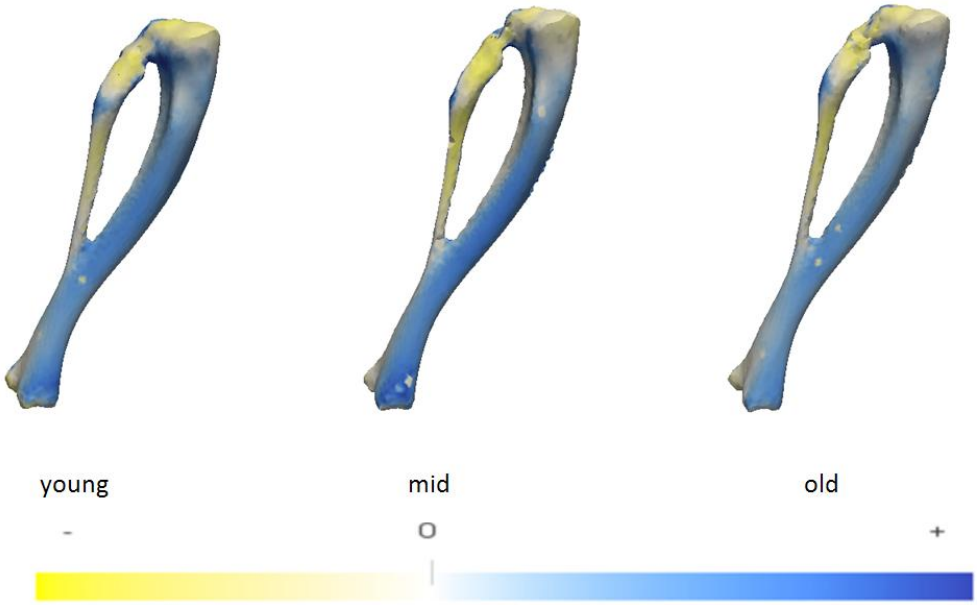

Fig: Group mean differences for tibia+fibula

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

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

Jones, Kevin B., Manasi Datar, Sandhya Ravichandran, Huifeng Jin, Elizabeth Jurrus, Ross Whitaker, and Mario R. Capecchi. "Toward an understanding of the short bone phenotype associated with multiple osteochondromas." *Journal of Orthopaedic Research* (2012).

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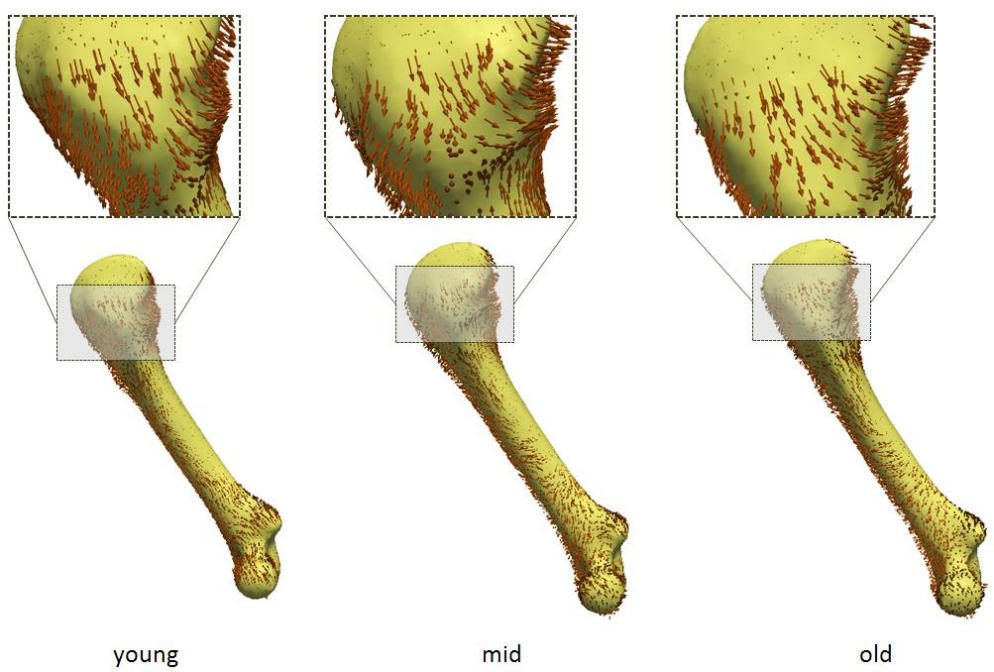

Fig: Directional analysis for femur

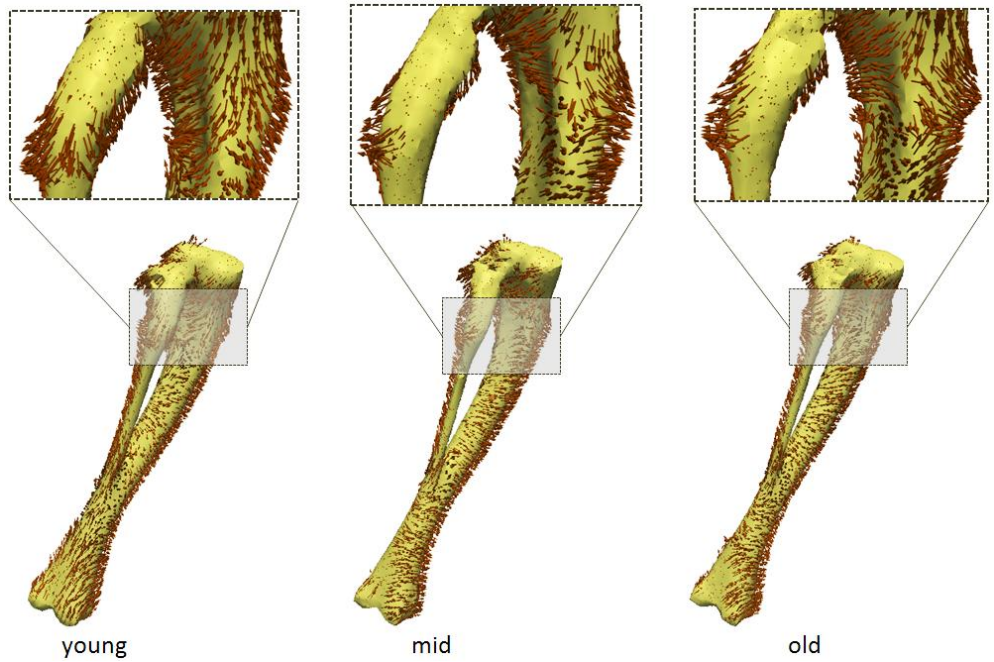

Fig: Directional analysis for tibia+fibula

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

Jones, Kevin B., Manasi Datar, Sandhya Ravichandran, Huifeng Jin, Elizabeth Jurrus, Ross Whitaker, and Mario R. Capecchi. "Toward an understanding of the short bone phenotype associated with multiple osteochondromas." *Journal of Orthopaedic Research* (2012).

Correspondence Pipeline

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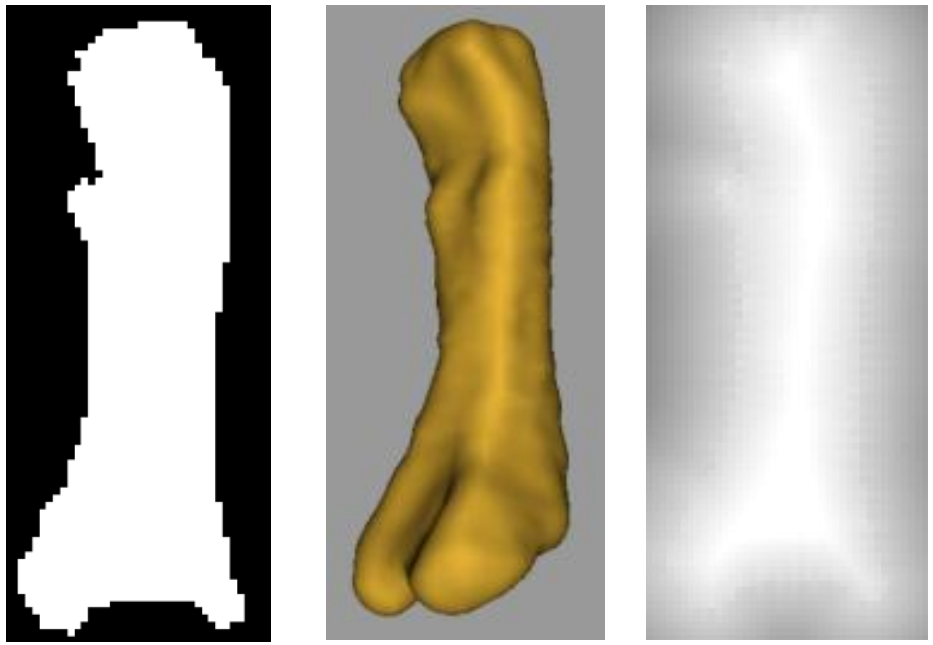
Preprocessing

PBM Algorithm



Thanks for your attention