Statistical Shape Analysis

Applications in orthopedics, and more…

* Images: Cates J, "Shape Modelling and Analysis with Entropy based Particle Systems," PhD Thesis, University of Utah

Study of 'Shape'

What questions can it answer ?*

Genetics

How does a gene mutation change skeletal development in mice?

Anthropology & Evolutionary Biology

How does bone shape vary in a fossil record?
Is the shape of a given bone a good classifier for species?

Neuroanatomy

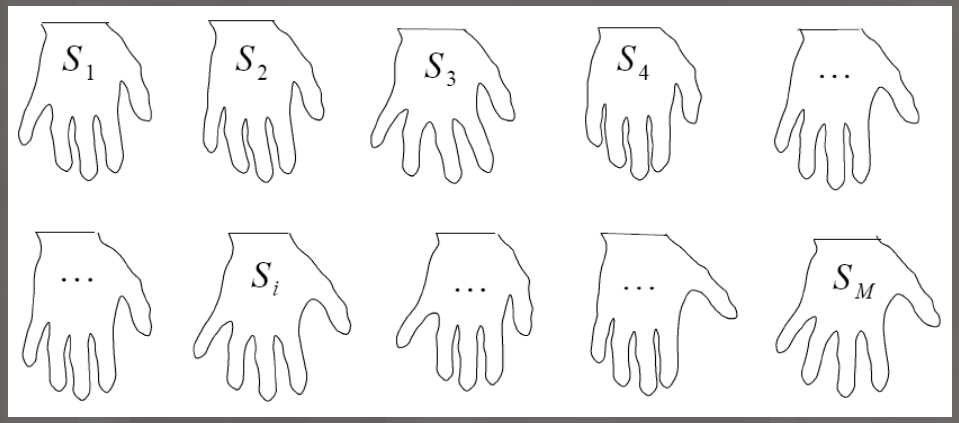
Is there a difference in the shape of brain structures between schizophrenic and normal populations?

Biomechanics

What is the normal covariation in shape of structures of the hip joint?
How does it change as a function of age?

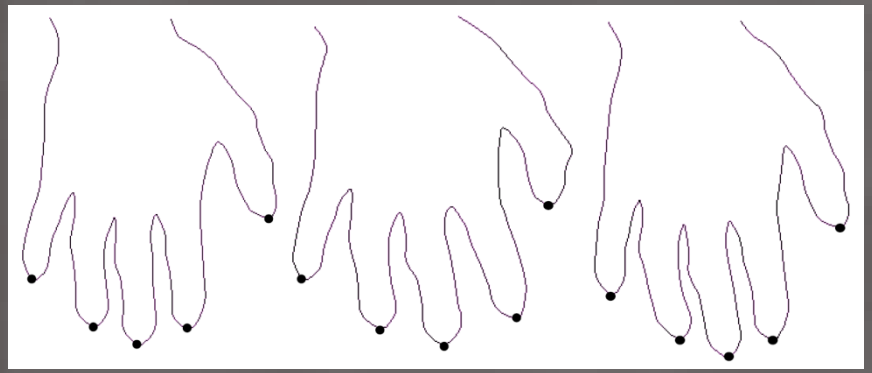
Statistical Shape Analysis

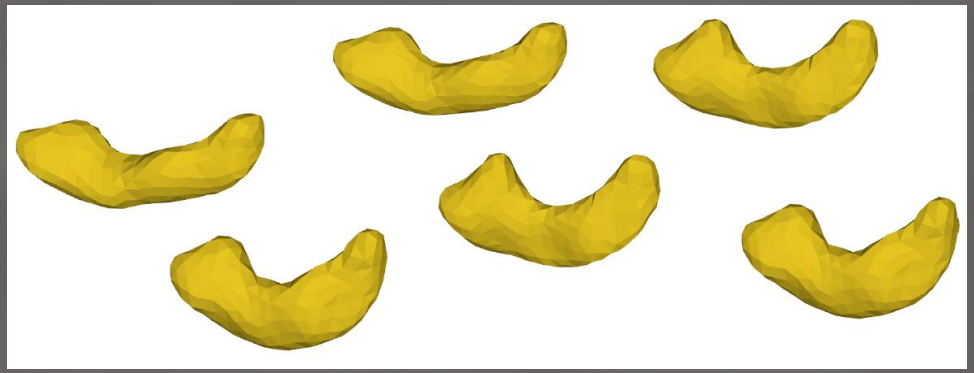
It's all about representation…



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

BUT…



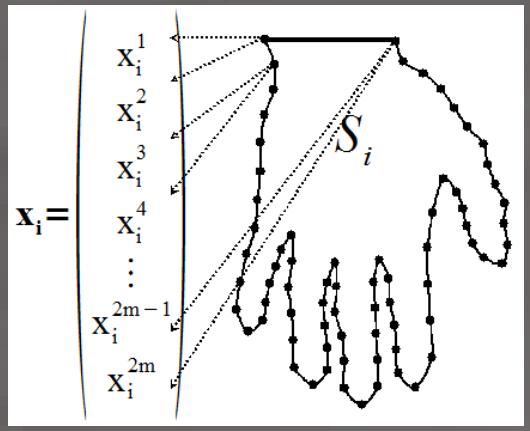


How do we choose the "same" points ??

Point Correspondence Model

Balancing accuracy vs. low variance

Shape Representation*

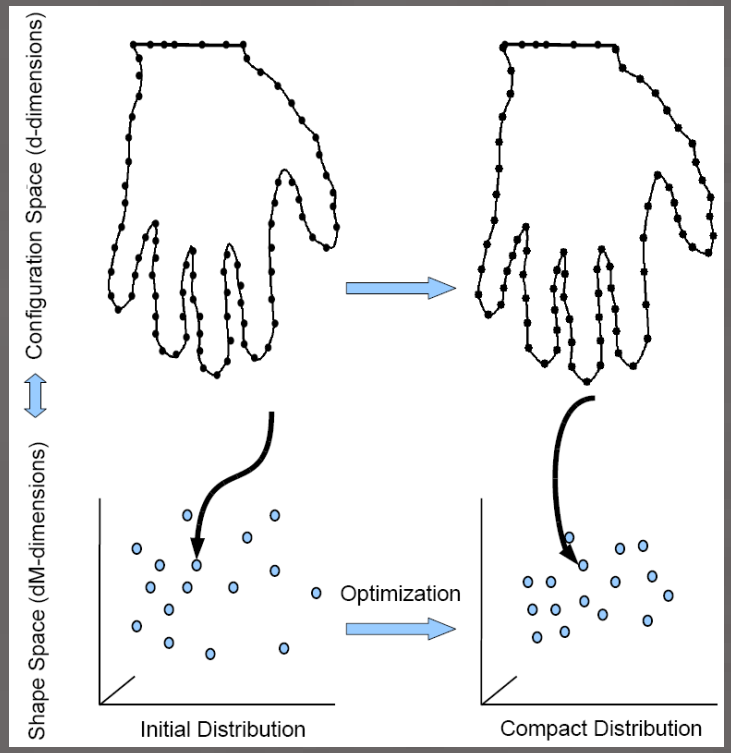


Configuration Space (d-dim)

$S_i \rightarrow (x_i^1, \ldots, x_i^{2M})$

x_i -> d-dimensional point

Shape Correspondence*

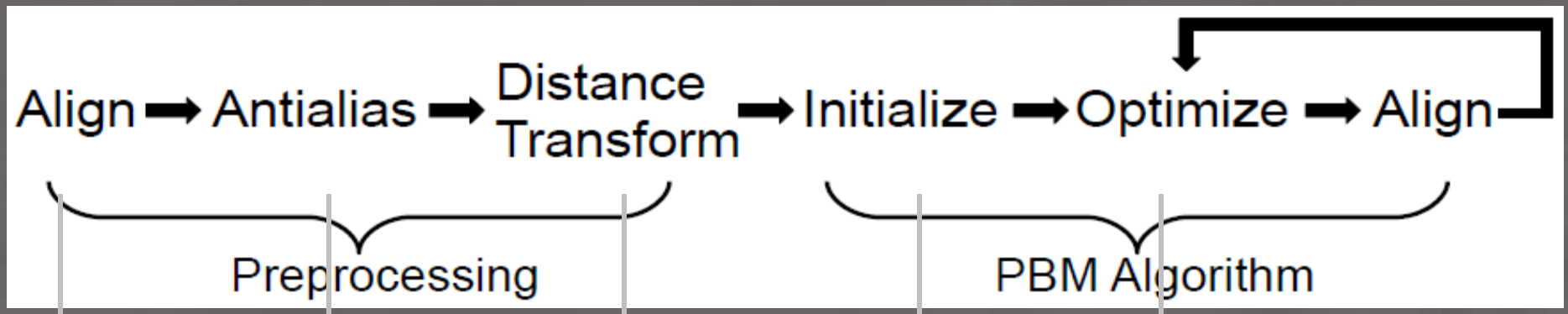


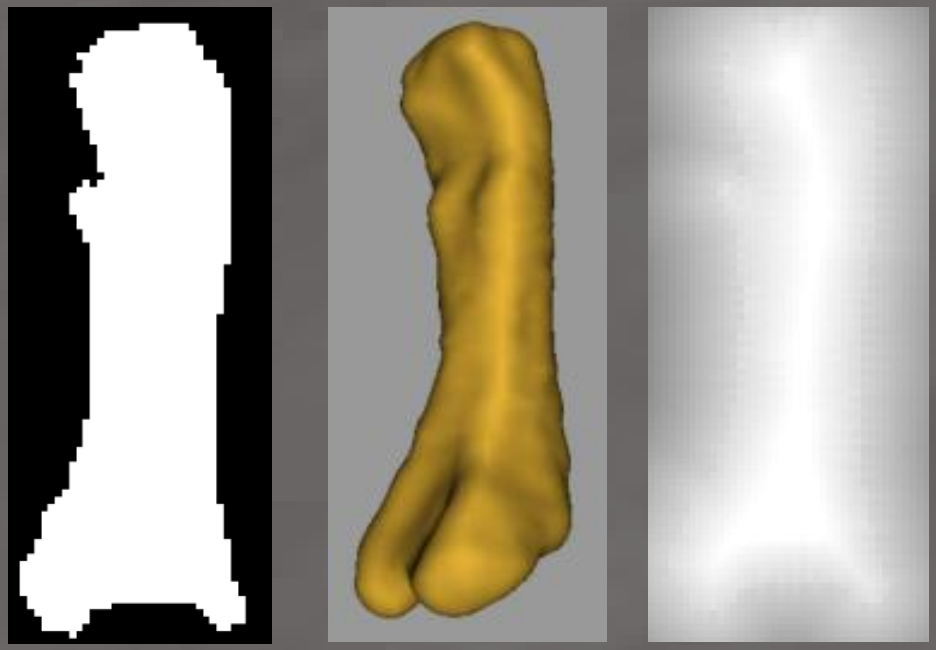
Shape Space (dM-dim):

S_i -> single point !

Trade off: accurate sampling vs. compact model

Correspondence Pipeline*





ShapeWorks for Orthopedics

FAI Characterization†

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

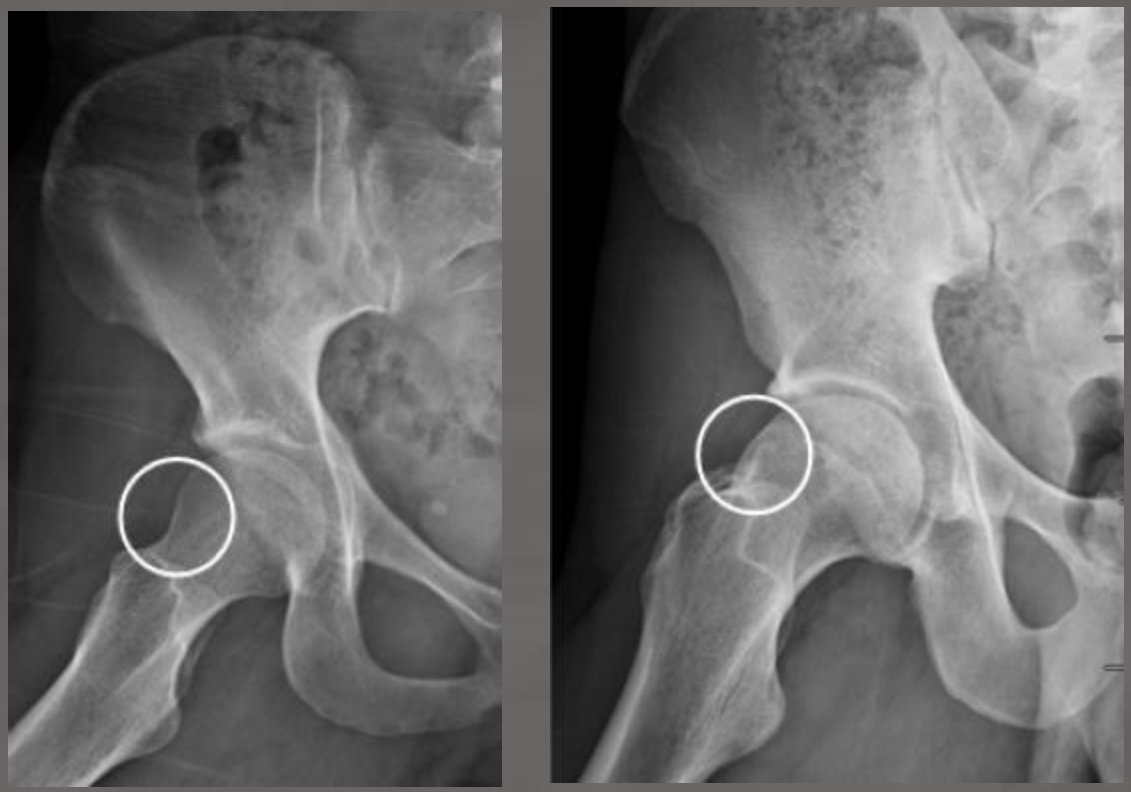


Fig: Radiographs of subjects with healthy (left) and cam FAI (right) femurs. Circles indicate the anterolateral head-neck junction.

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

†MD Harris, M Datar, E Jurrus, CL Peters, RT Whitaker, AE Anderson, "Statistical Shape Modeling of CAM-type Femoroacetabular Impingement CMBBE 2012

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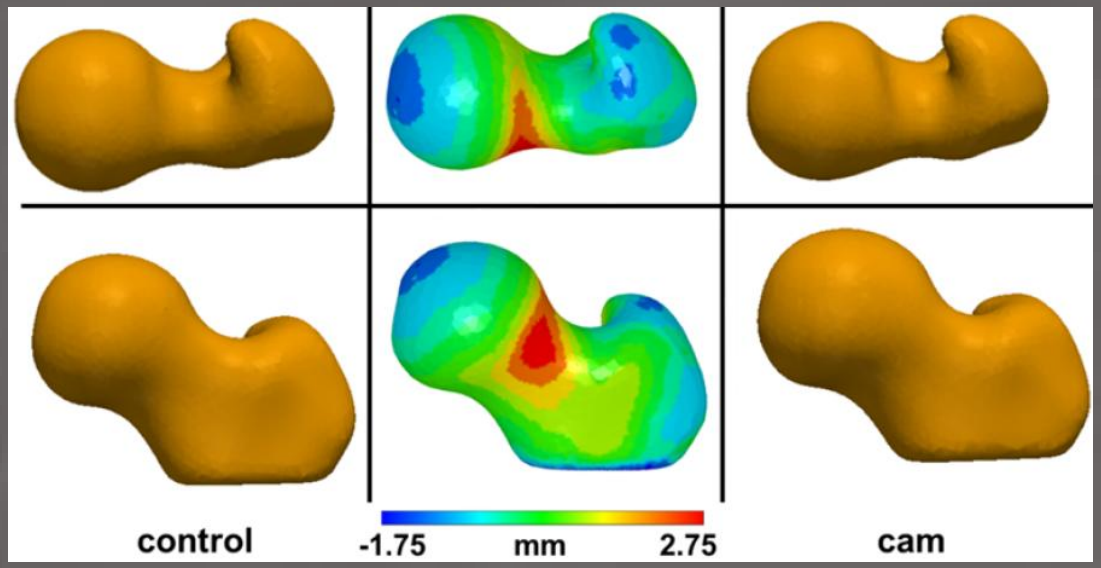

Fig: Two views (two rows) of the mean control (left) and cam (right) shapes.
Mean control shape (center), color coded to depict shape differences in comparison with mean CAM shape

- Segmented femurs from controls (33) and patients(15) with CAM-FAI
- Statistically significant group differences (p-value < 0.01)
- Mean shape deviations between control and CAM groups most pronounced at the anterolateral head-neck junction (max = 2.7mm)

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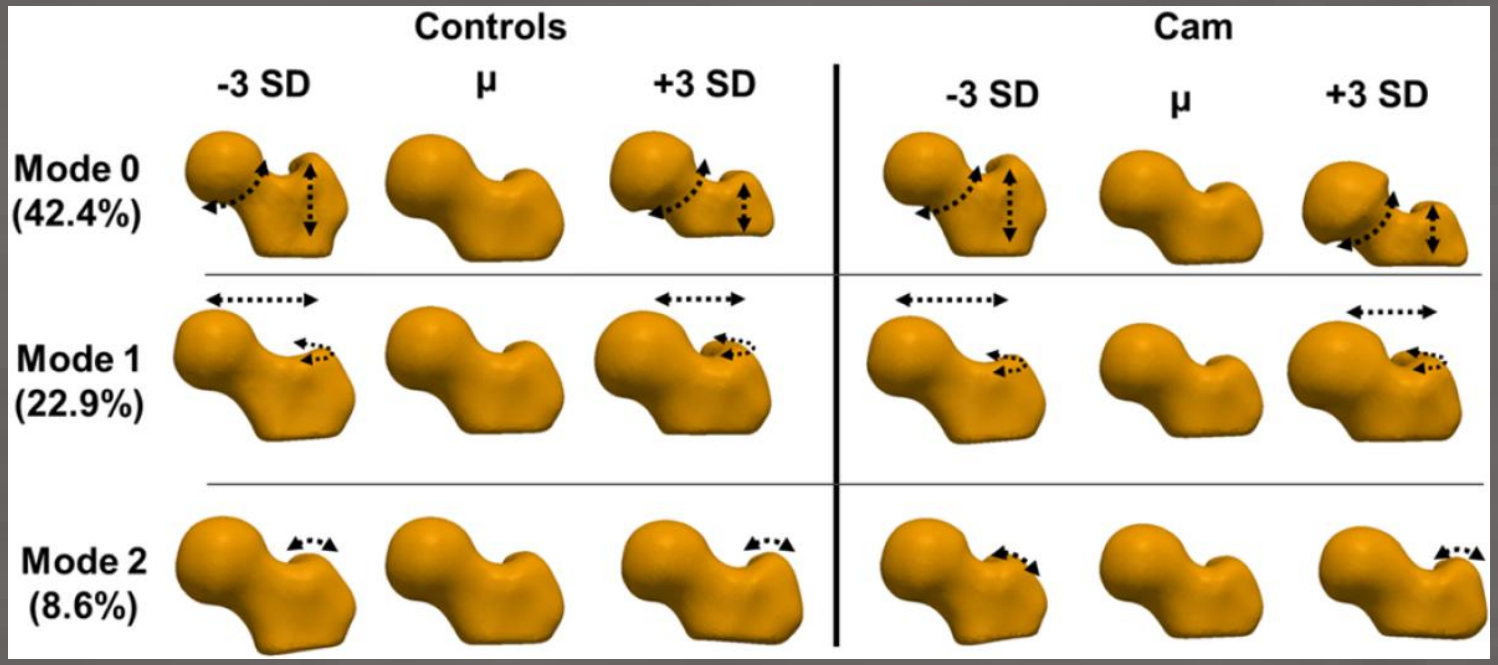

Fig: Mean shapes (μ) for both groups and shapes at ±3 standard deviations for the first 3 modes

Consistent differences captured by individual modes for control and CAM groups

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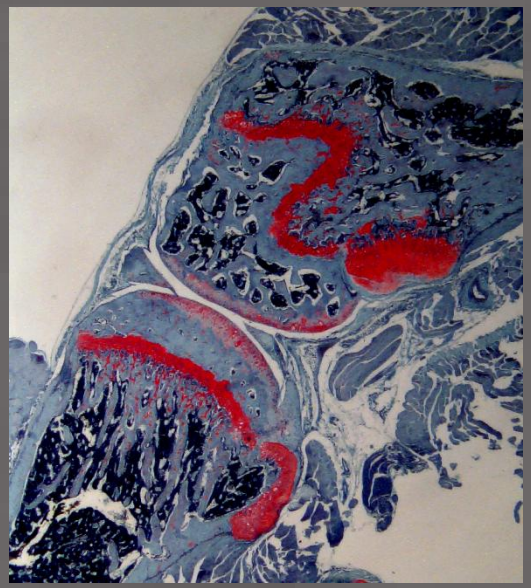
Mouse Model of Osteochondroma

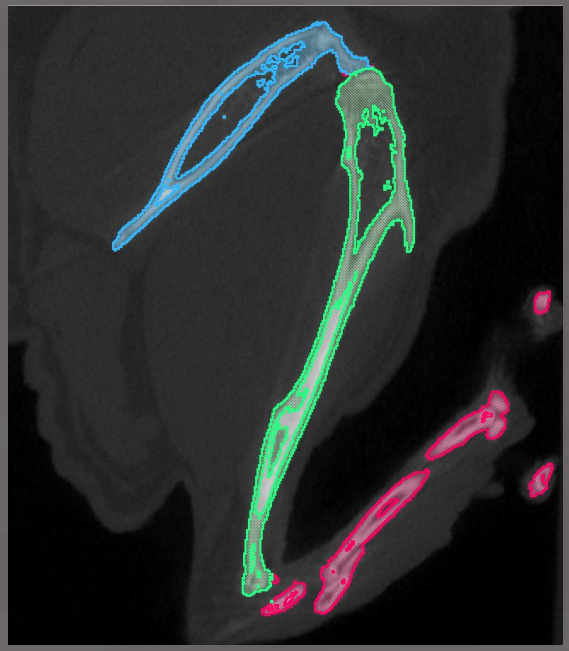
Dr. Kevin Jones, M.D., clinicians @ Huntsman Cancer Institute
Department of Orthopedics and Huntsman Cancer Institute, University of Utah

- Individuals with multiple osteochondromas (MO) demonstrate shortened long bones. Possible reason: steal phenomenon
- Segmented bones (femur, tibia+fibula) from mice, genetically altered to inflict osteochondroma at various stages in time

MO in human bone



Histopathology image of MO in mice bone



Segmented femur and tibia+fibula used in study

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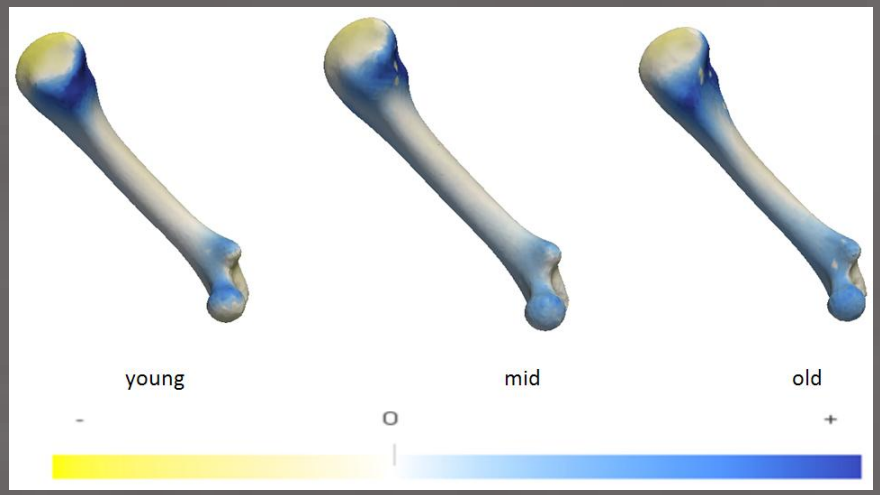

Fig: Group mean differences for femur

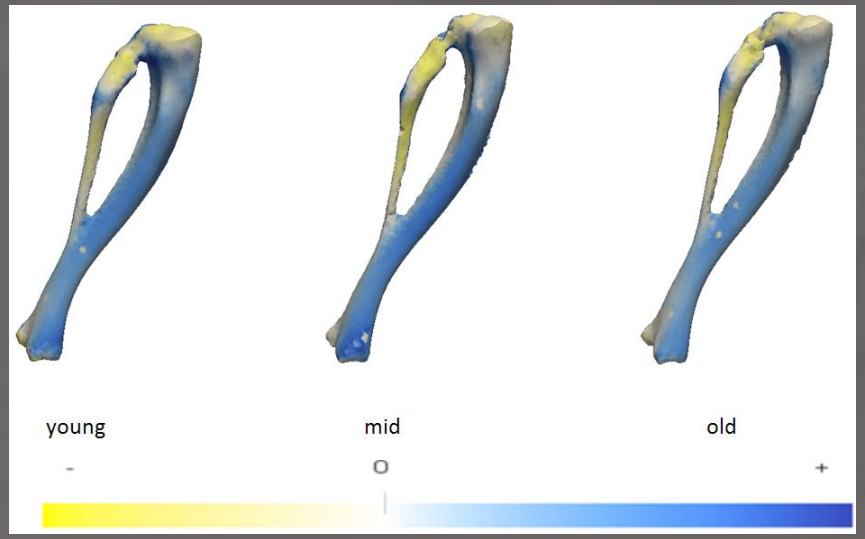

Fig: Group mean differences for tibia+fibula

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

Next step: Directional analysis

Mouse Model of Osteochondroma

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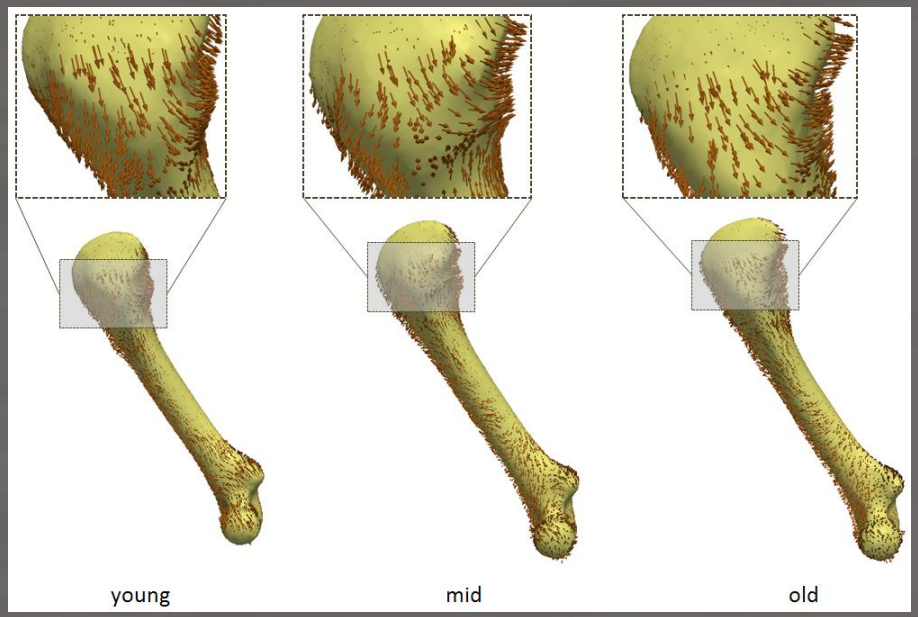


Fig: Directional analysis for femur

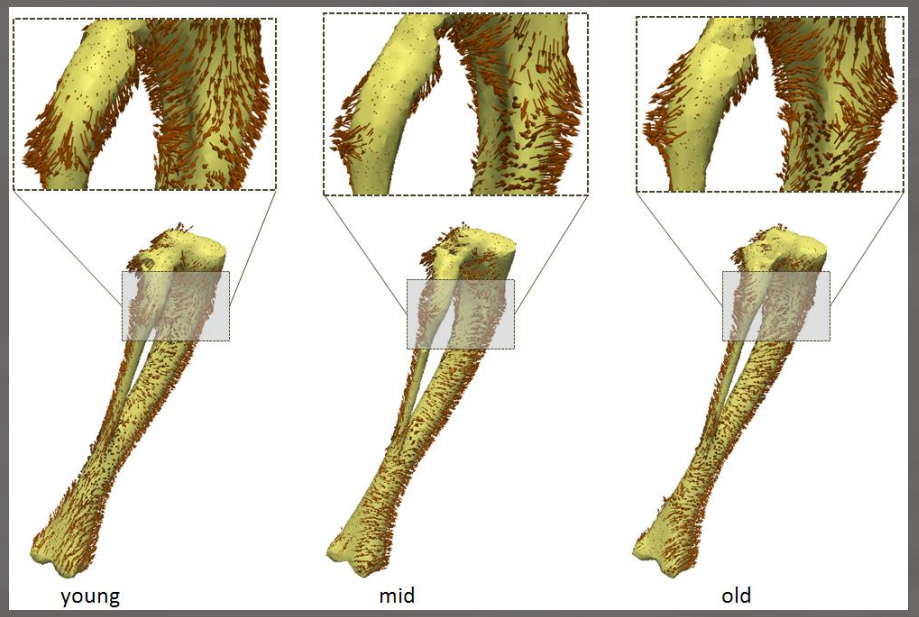


Fig: Directional analysis for tibia+fibula

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

Next step: Quantifying differences for individual subjects

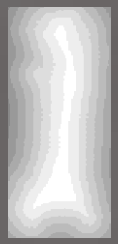
Summary

ShapeWorks Pipeline

Preprocessing

Input Segmentation*

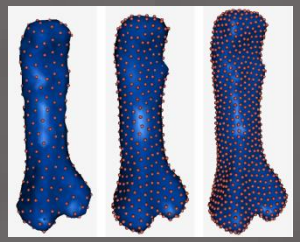
Distance Transform*



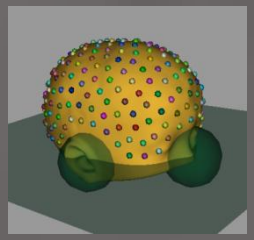
Antialiased Surface*

Optimization

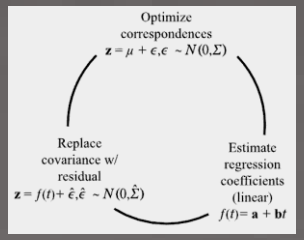
Entropy Minimization*



Open Surfaces

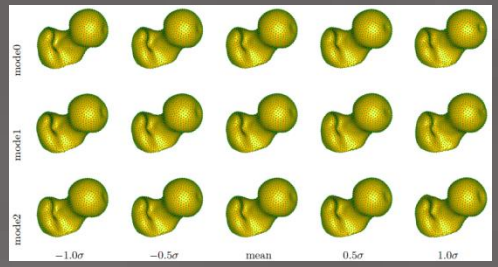


Linear Regression

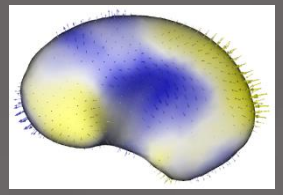


Visualization

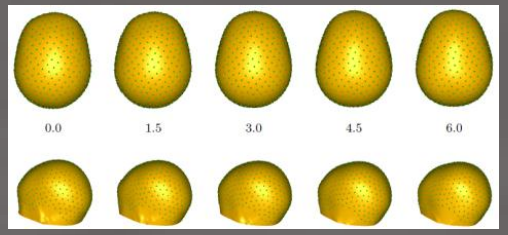
Modes of Variation



Group Differences*



Regression Shape



Thank you !

Questions ?