Extracting features: Statistical Shape Models

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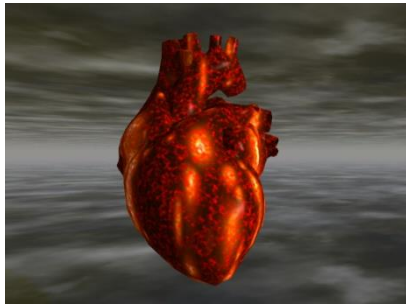
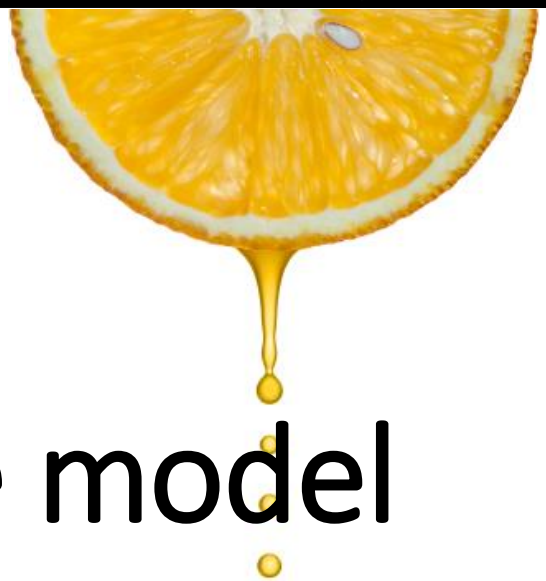
How big is your heart?



Neat Fact: On average, your body has about 5 liters of blood continually traveling through it by way of the circulatory system.



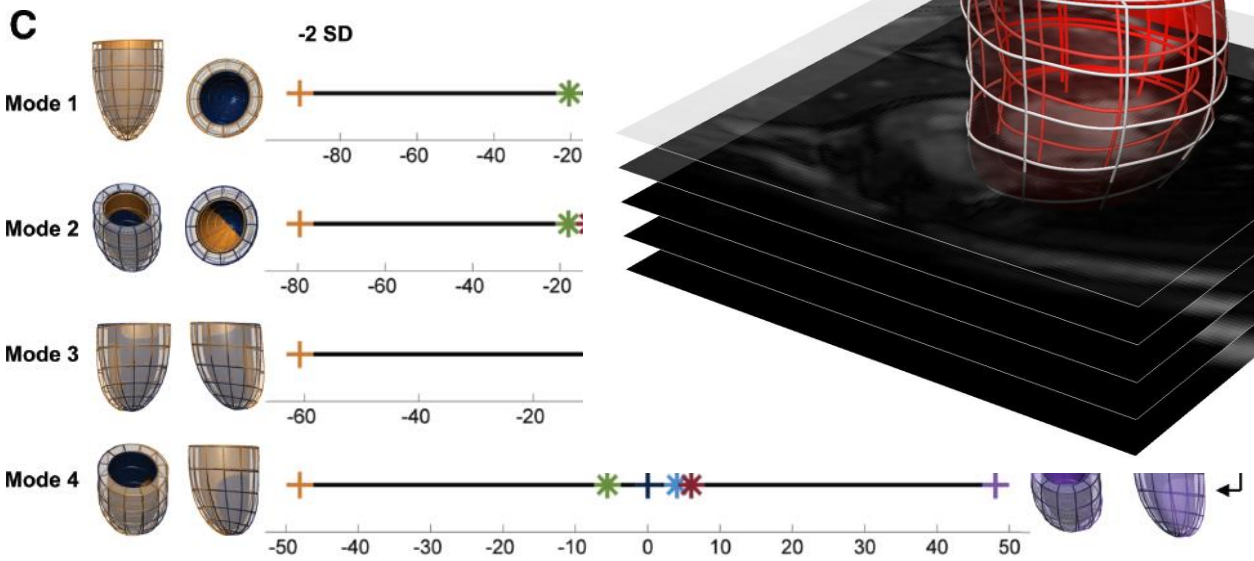
A statistical shape model

How to squeeze the orange (current images) better?

An atlas = An average

The vision

- From mass, diameter, thickness… to a coefficient of a parametric shape space
  1. Build meshes [3]
  2. Reduce dimensionality - F
  3. Get Coefficients [4]

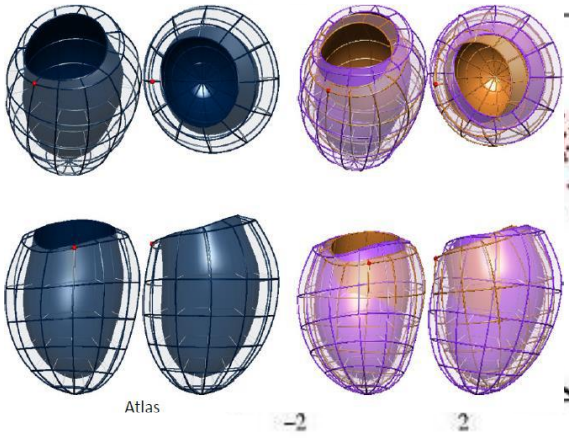


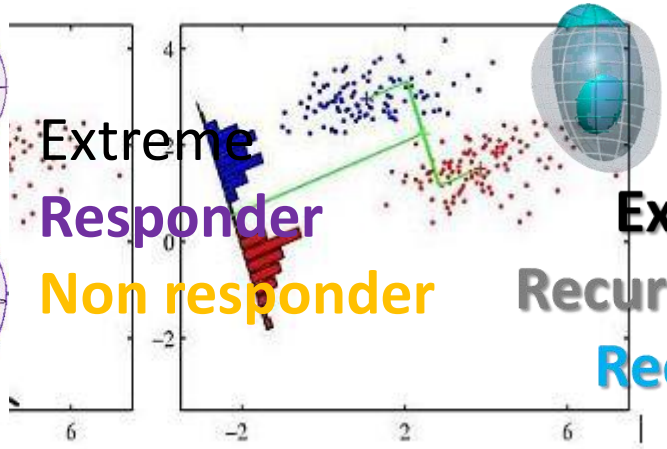
[3] Lamata et al (2014) "An automatic service for the personalization of ventricular cardiac meshes" *J Royal Soc Interface*

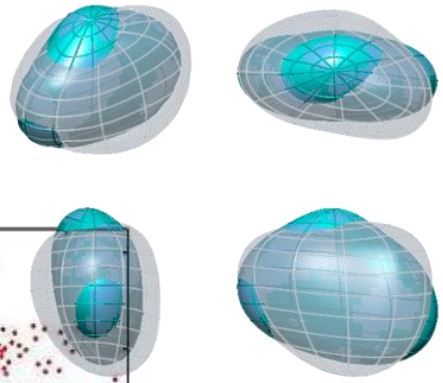
[4] Lewandowski A et al (2013) "Preterm Heart in Adult Life: Cardiovascular Magnetic Resonance Reveals Distinct Differences in Left Ventricular Mass, Geometry, and Function" *Circulation*.

The vision

- From mass, diameter, thickness… to a coefficient of a parametric shape space
  1. Build meshes [5]
  2. Reduce dimensionality - PCA
  3. Get Coefficients
  4. Identify relevant shape features - LDA



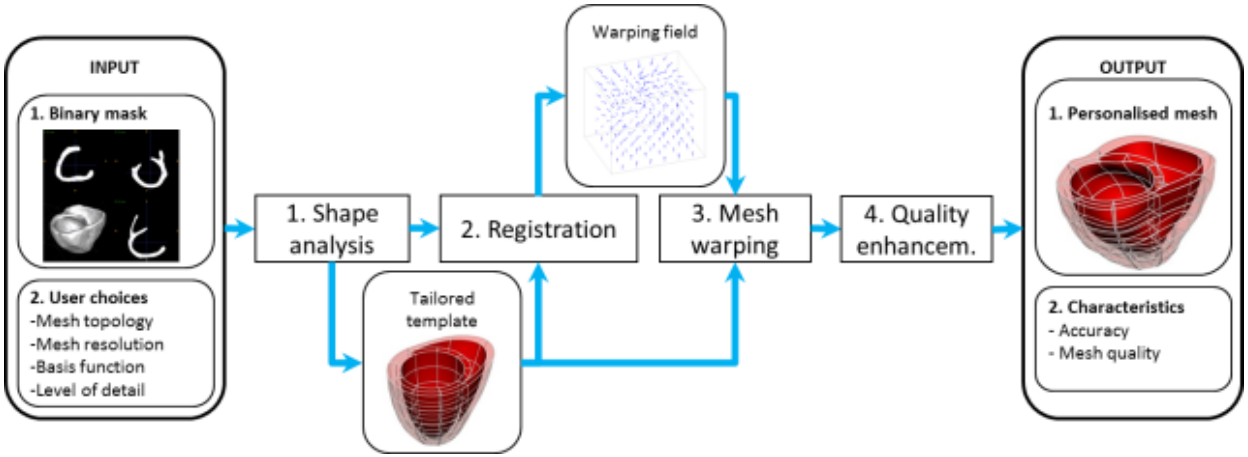


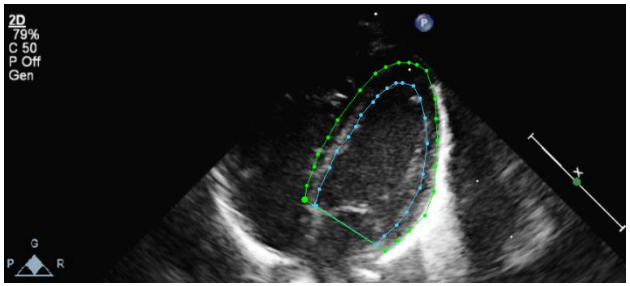


[5] Varela M et al (2015) “Optimal Prediction of Atrial Fibrillation Recurrence After Ablation: A Computational Anatomy Study” *Circulation*
[6] Gonzalez G et al (2015), “Adverse Left Ventricular Remodelling Patterns Predict Response to Cardiac Resynchronization Therapy” *Circulation*

1. Build meshes

- Encode shape, in 3D or 2D

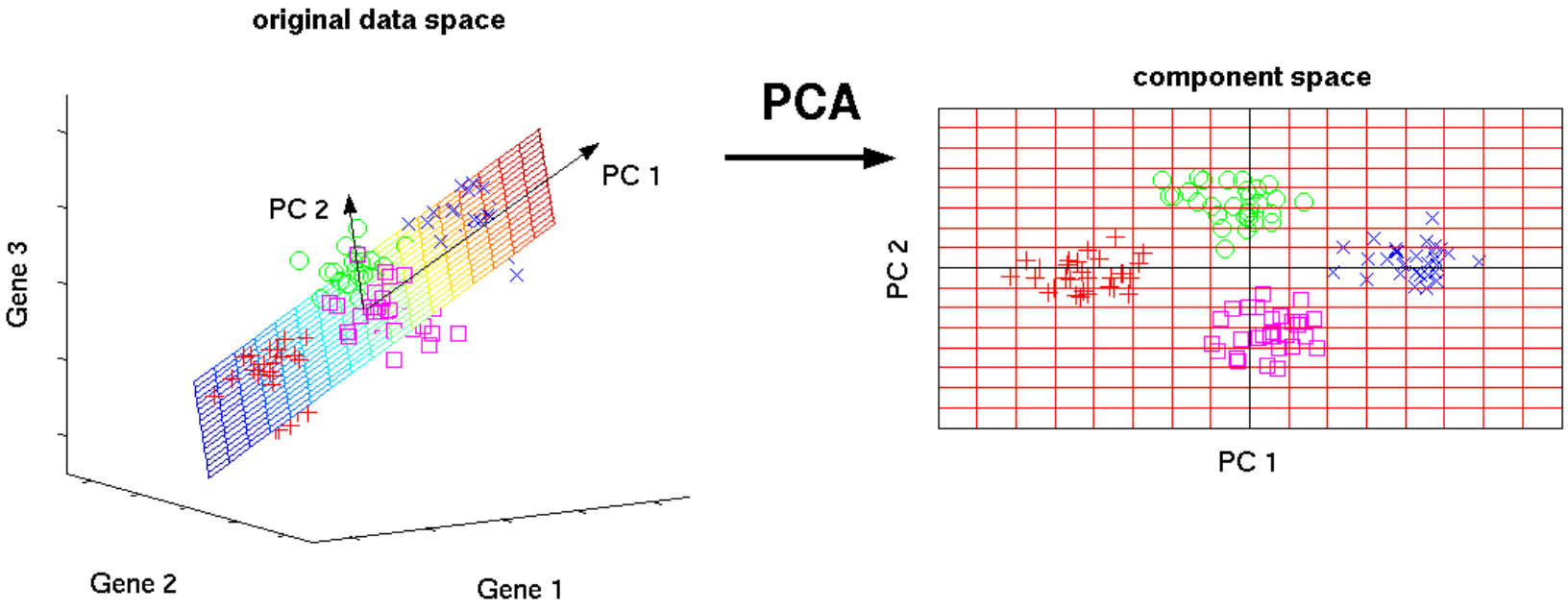




[2] Lamata P et al (2011), "An accurate, fast and robust method to generate patient-specific cubic Hermite meshes." Med Image Anal. 15(6):801-13"
[3] Lamata P et al (2014), "An automatic service for the personalization of ventricular cardiac meshes." J R Soc Interface. 11(91):20131023.

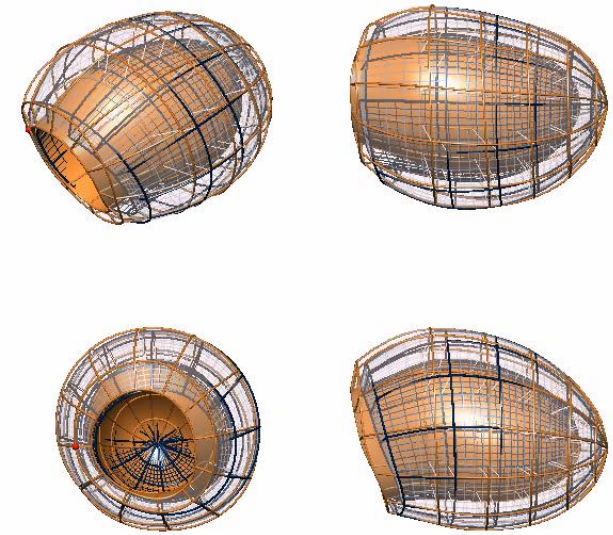
2. Reduce dimensionality

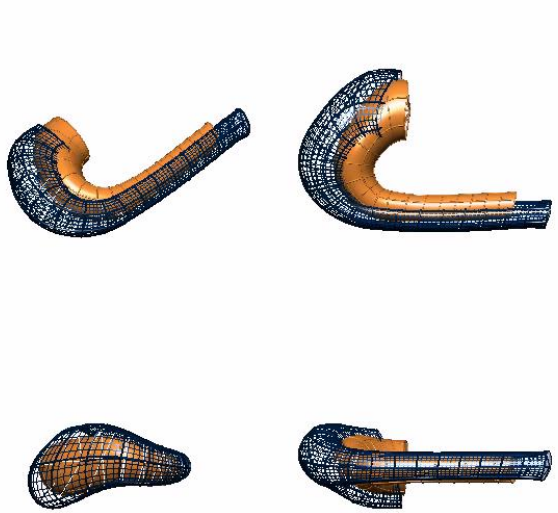
- Pre-align all shapes
- Principal component analysis

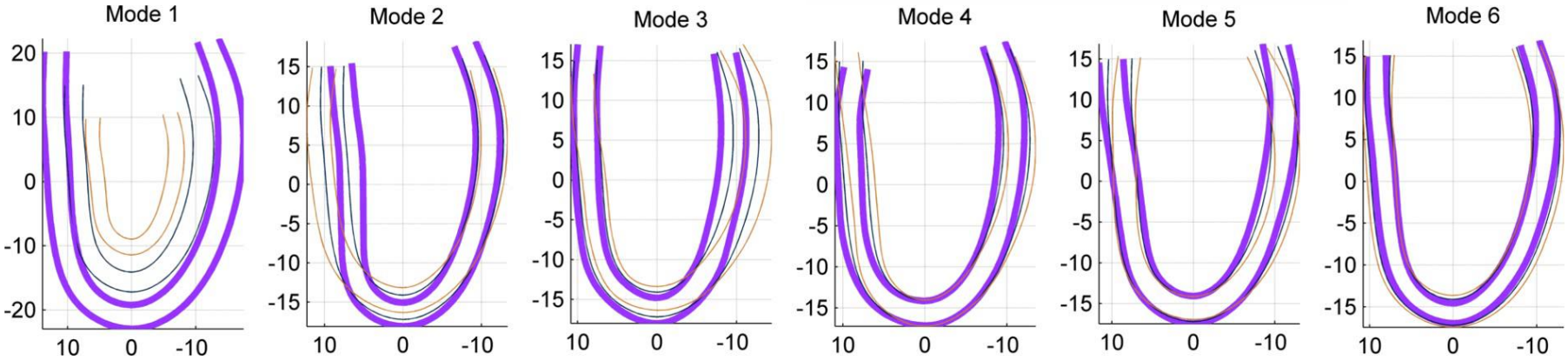


The “anatomical mode”

- This is the new “length”, the new “diameter”…







3. Get shape coefficients

- The new biomarkers!
- How much of change in each *direction* (each anatomical mode)

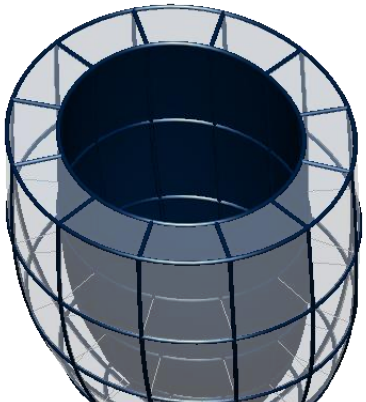
Shape = mean + Sum (Ci * Mi)

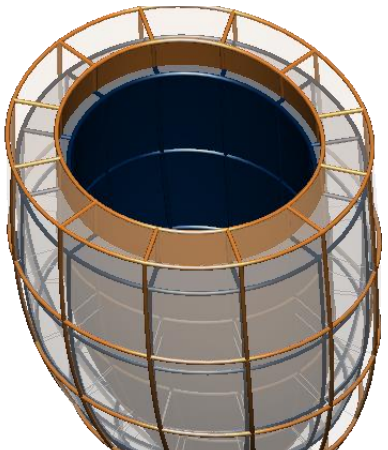
Coefficient

Anatomical Mode

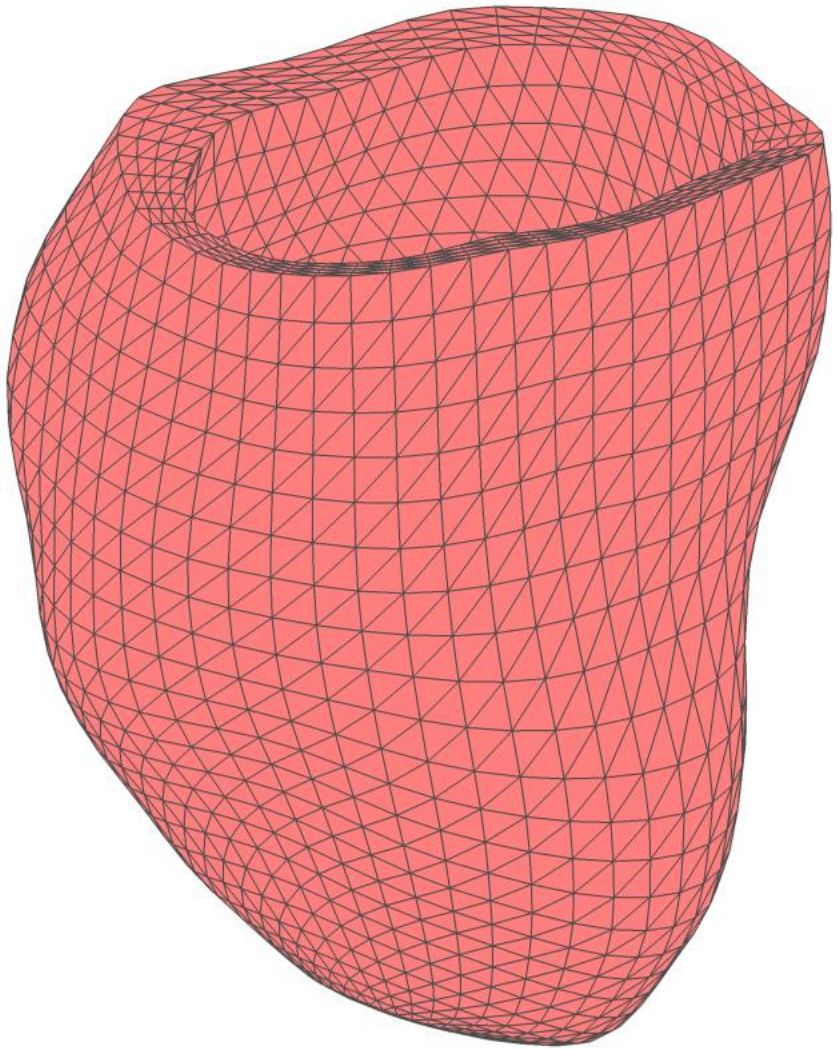
-2std

+2std



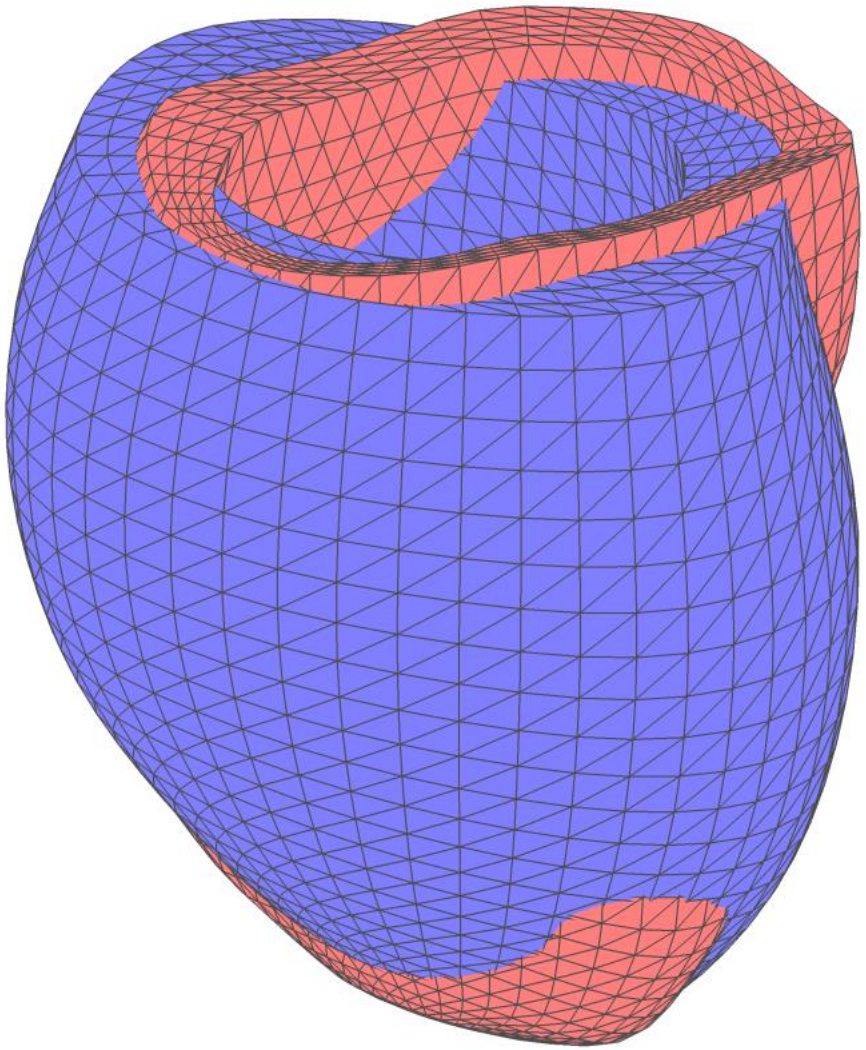


A gradual reconstruction…



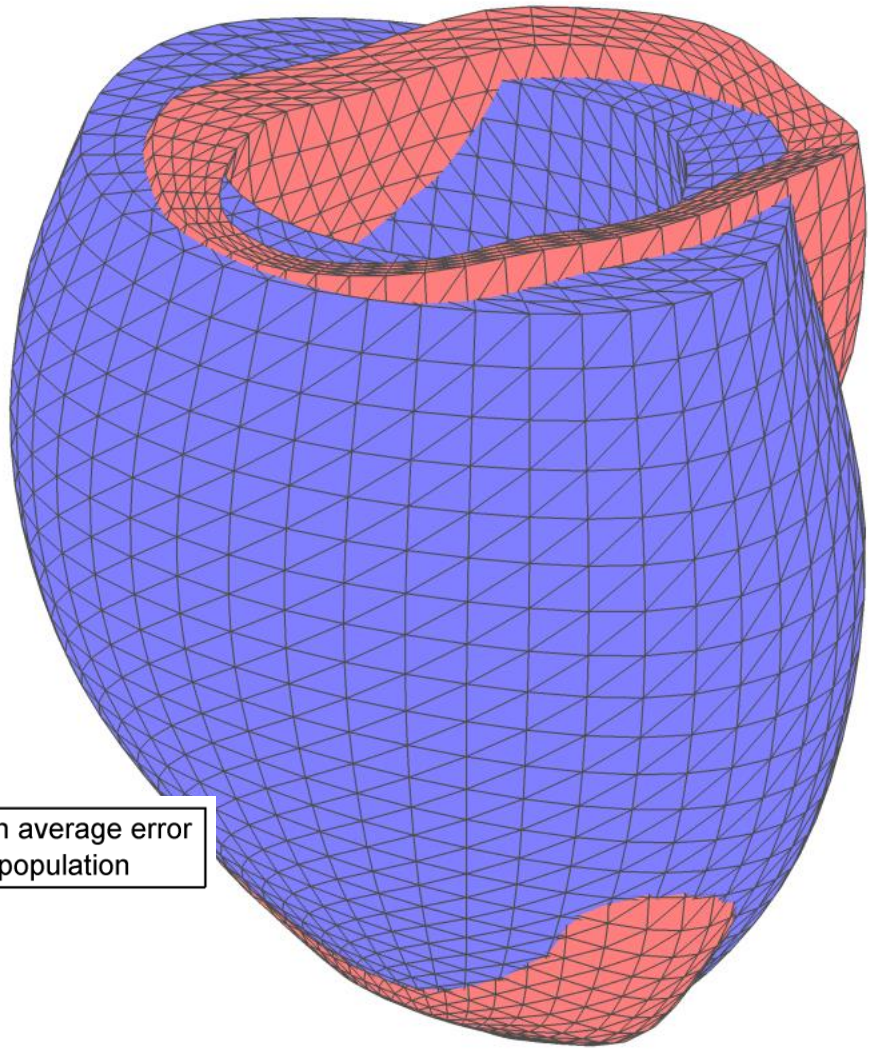
A gradual reconstruction…

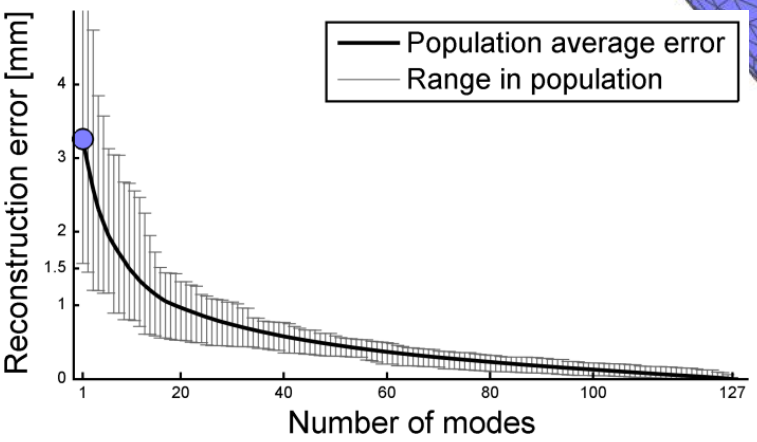
M



A gradual reconstruction…

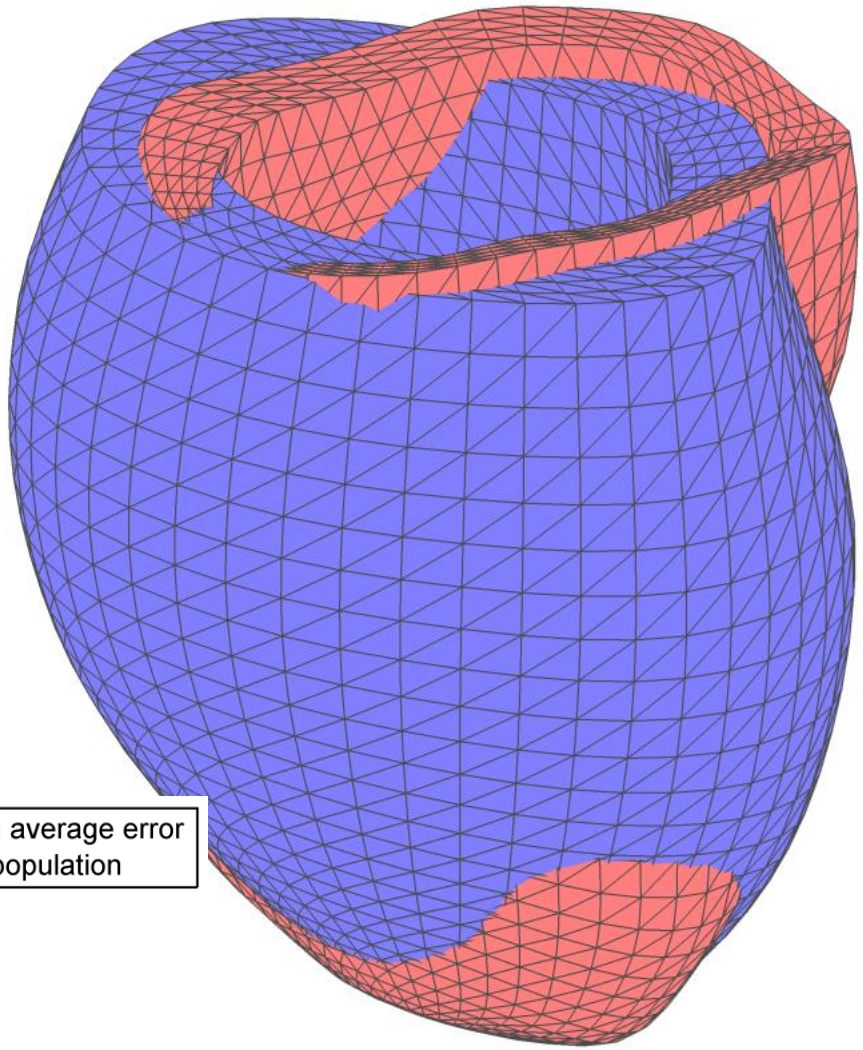
1

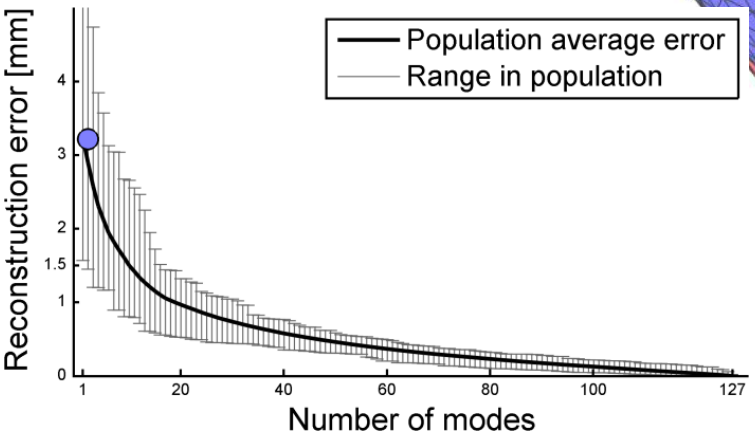




A gradual reconstruction…

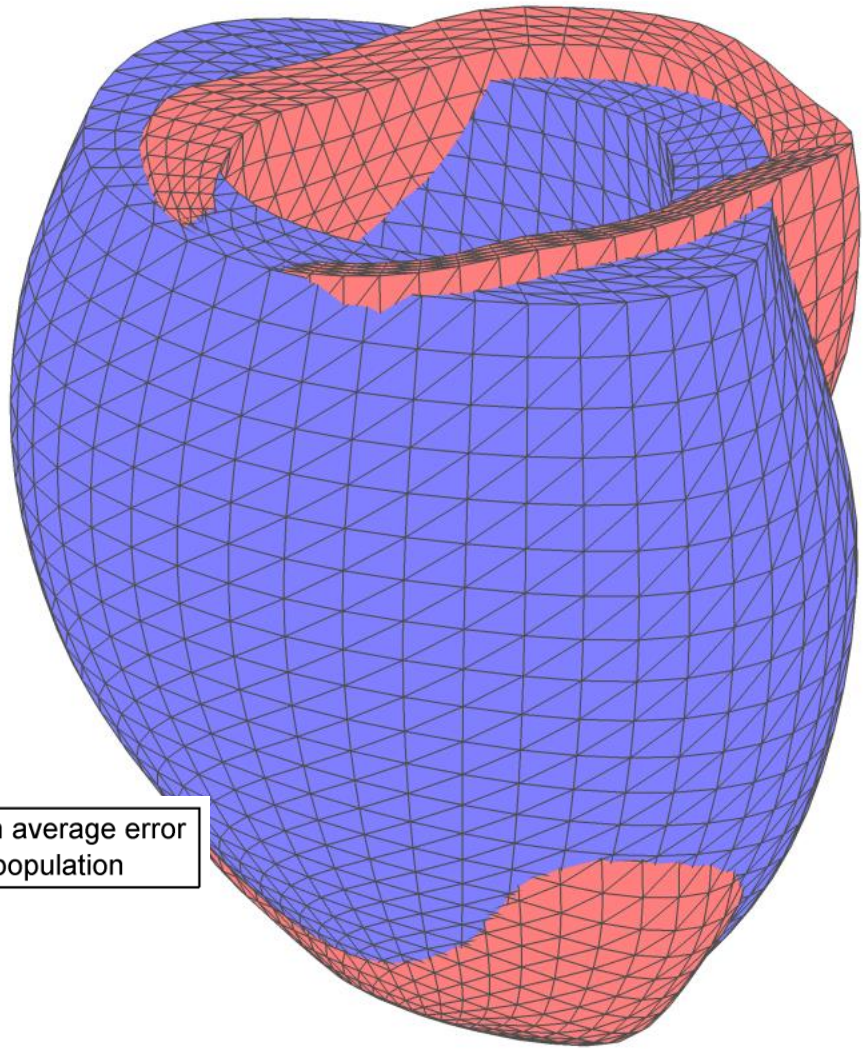
2

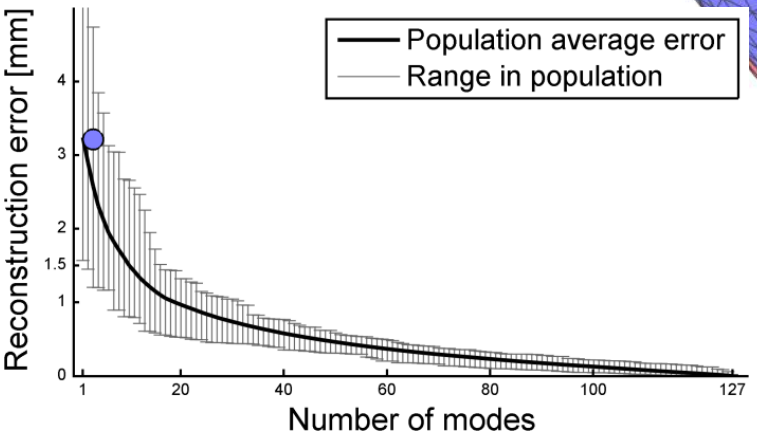




A gradual reconstruction…

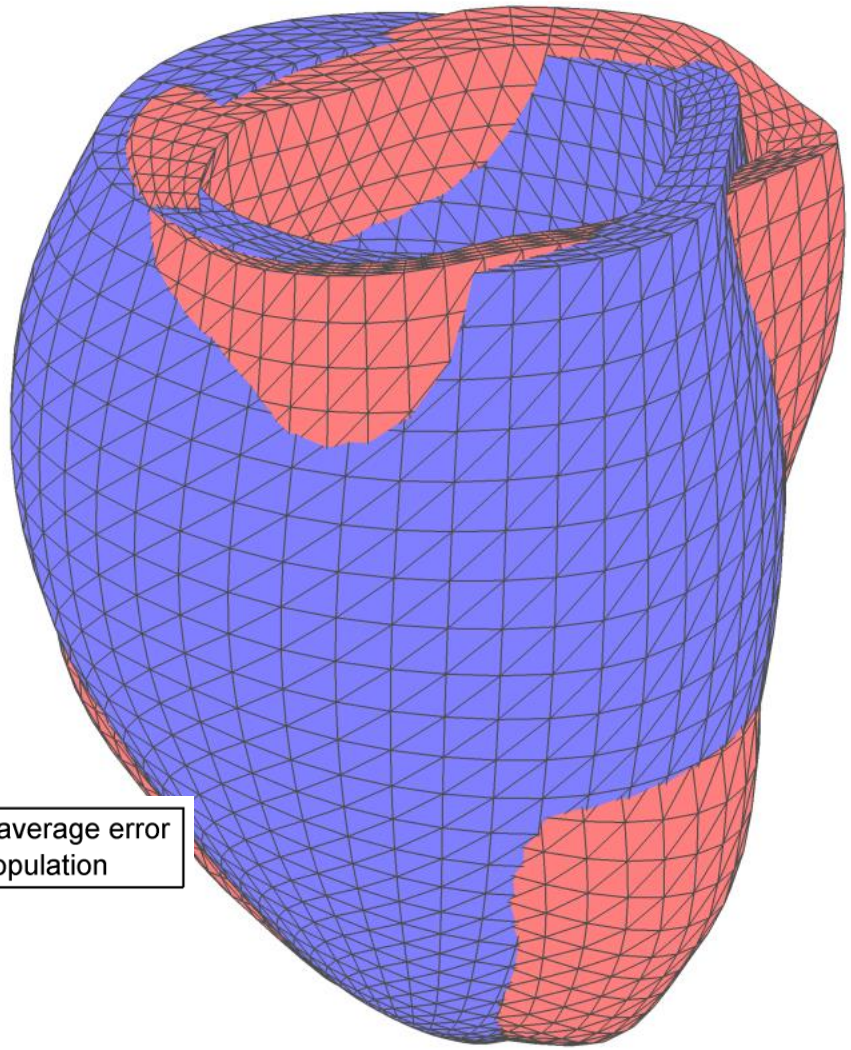
3

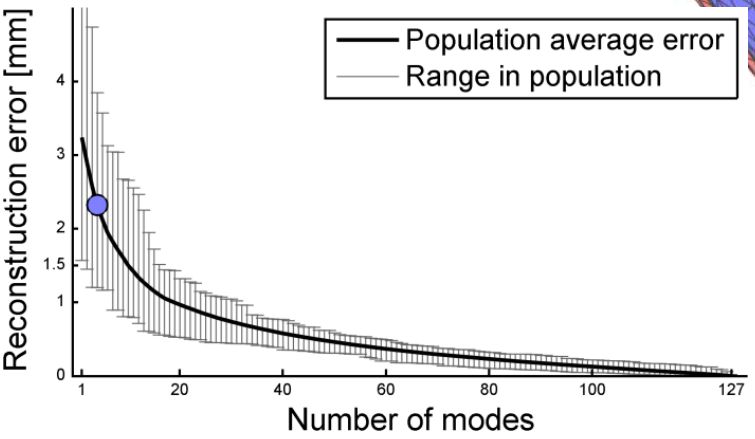




A gradual reconstruction…

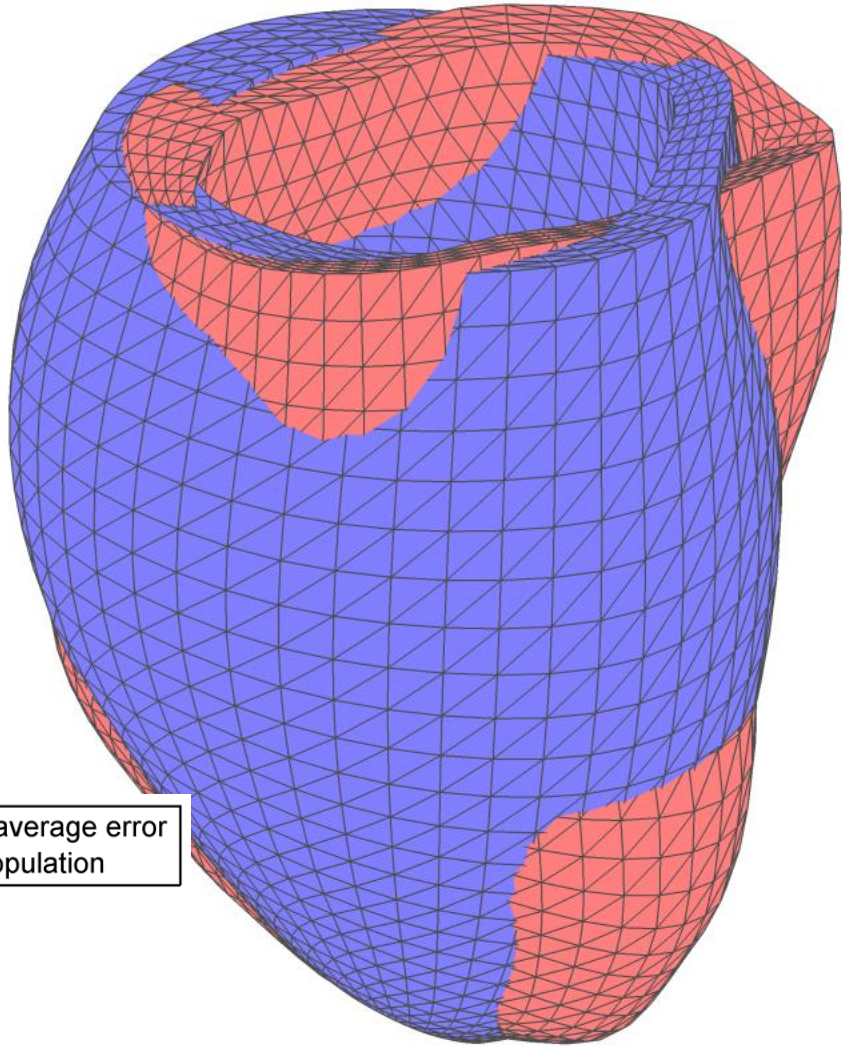
4

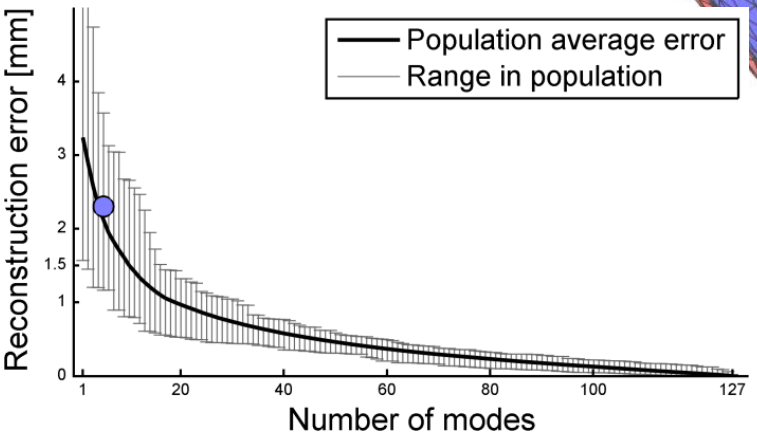




A gradual reconstruction…

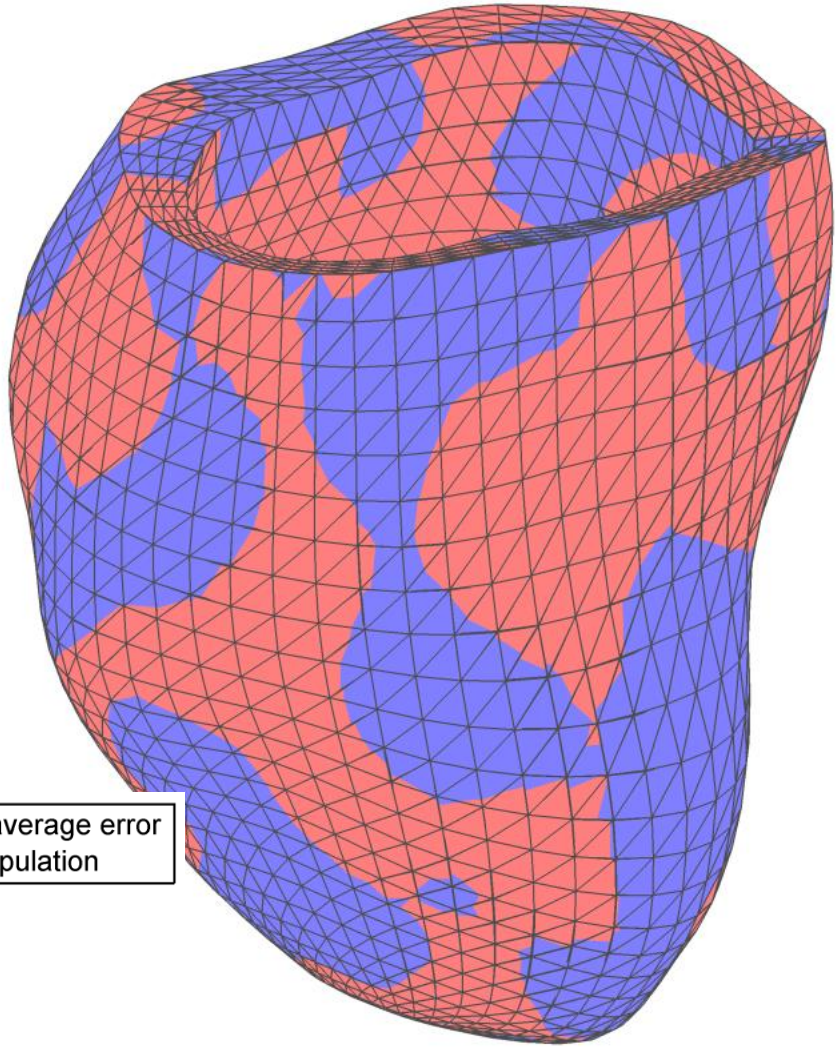
5

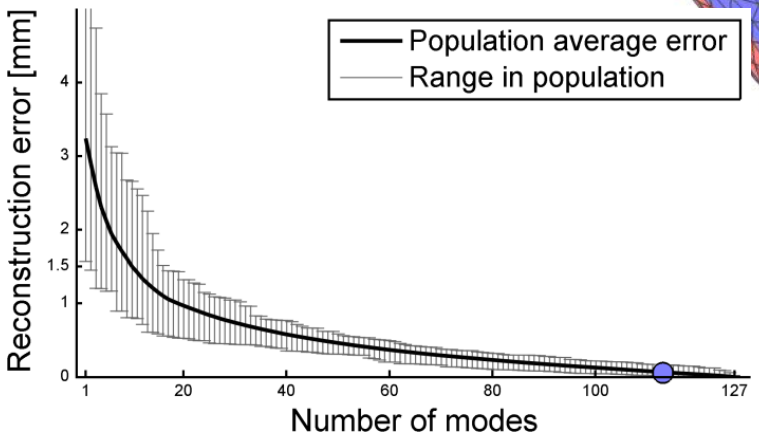




A gradual reconstruction…

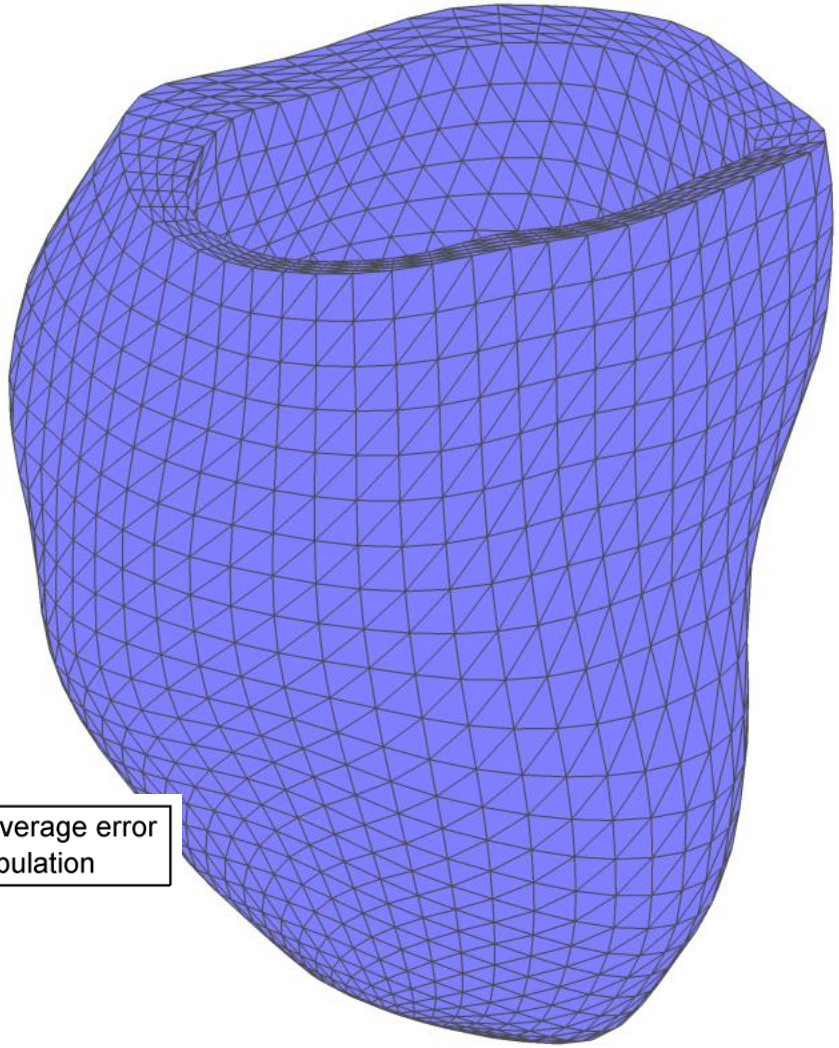
113

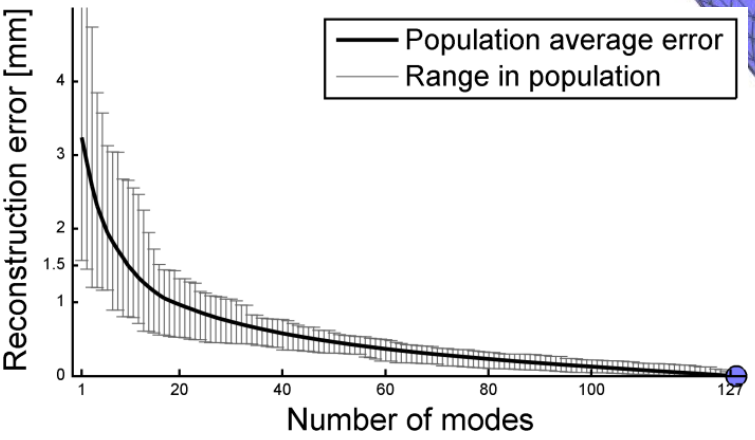




A gradual reconstruction…

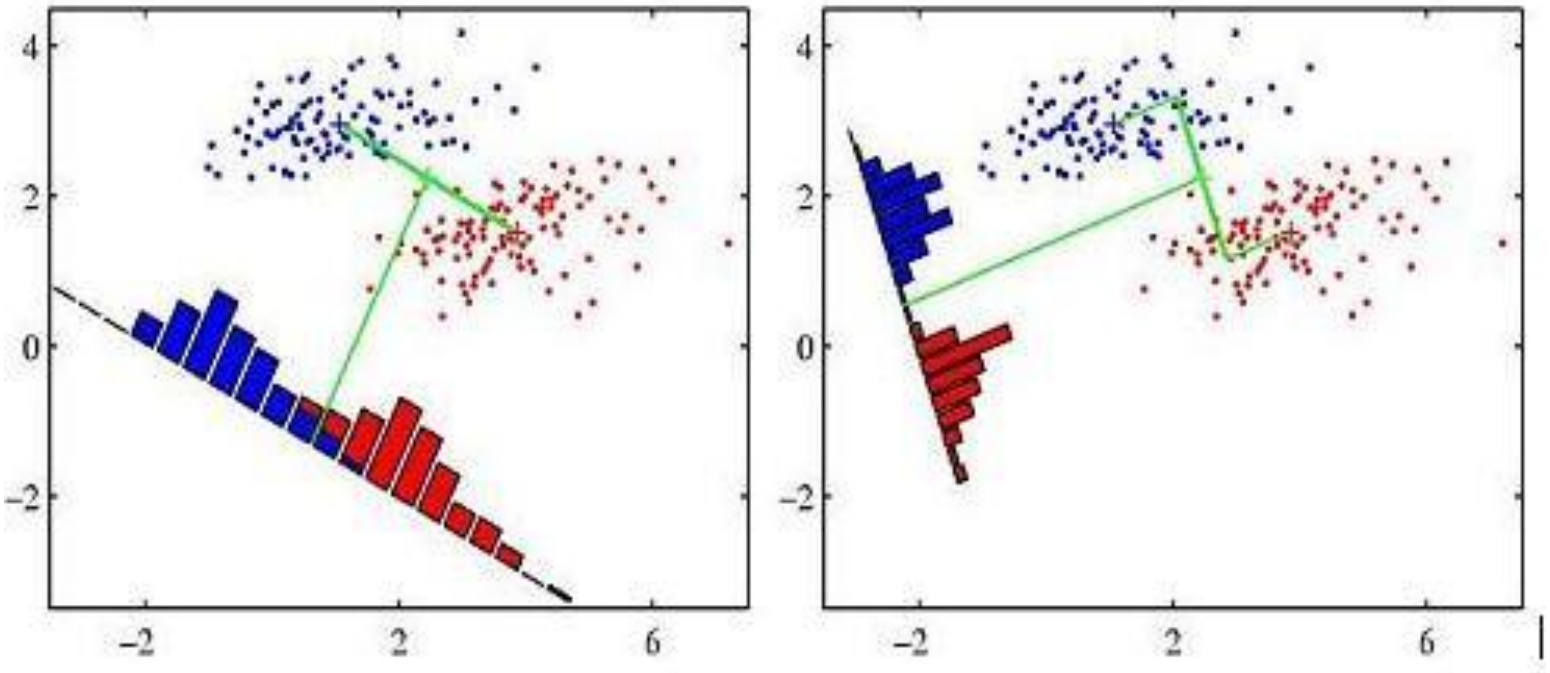
128





4. Identify relevant shape features

- A linear combination of PCA modes is another anatomical mode
  - Linear Discriminant Analysis
  - Regression analysis



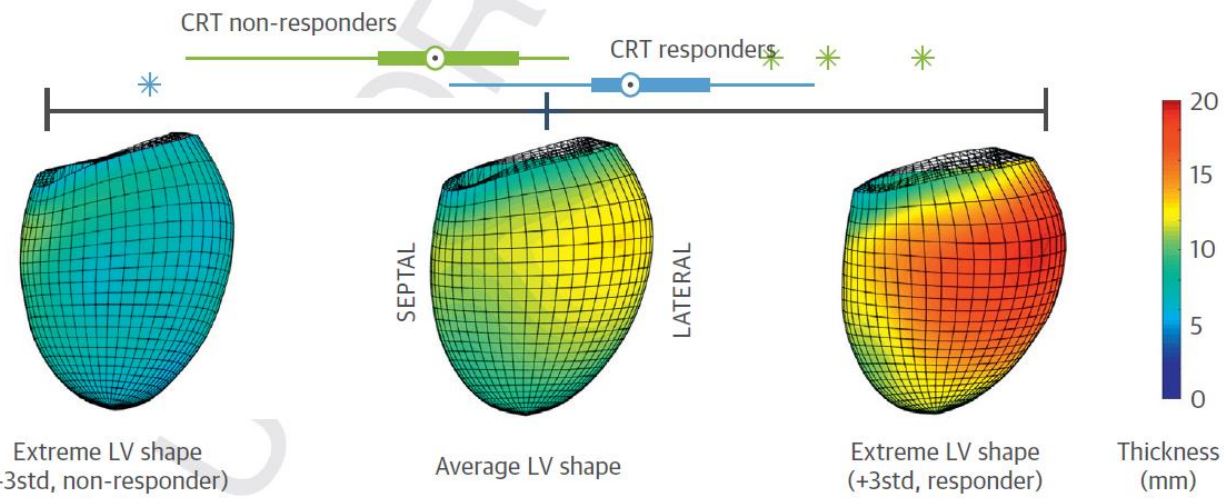
Examples

Predict CRT responder
Impact of breast milk on growth
Impact of drug on gestation
Impact of surgery

1 – CRT responders

- Who will benefit from a CRT?
  - 50 HF subjects - 25 responders

FIGURE 1 3D Remodeling Signature Predictive of CRT Response

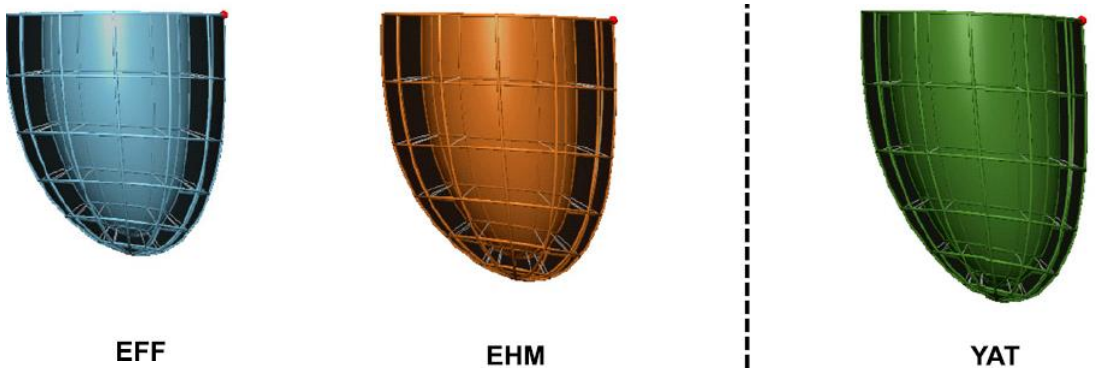


Remodeling signature predictive of cardiac resynchronization therapy (CRT) response, illustrating the box-plot distribution of responders and nonresponders, and the 3-dimensional (3D) left ventricular (LV) anatomy (mean and both extremes of the distribution) color-coded accordingly to the thickness of the myocardial wall.

Warrnier et al (2018) “An Asymmetric Wall-Thickening Pattern Predicts Response to Cardiac Resynchronization Therapy” *JACC Card. Imag. (in press)*

2 - Impact of breast milk

- Is breast milk better than formula for preterms? [7]
  - Population of 20-30 year old adults
  - Formula (EFF, n=16) vs. breast (EHM, n=30) vs. controls (YAT, n=103)
  - Finding: EFF are smaller (mainly length)

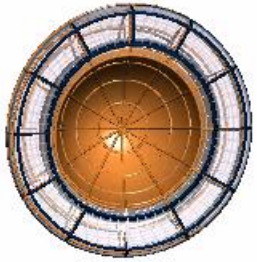


- Step further: find remodelling pattern by (1) premature birth or (2) milk vs formula.

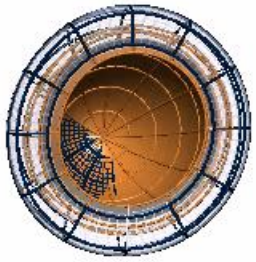
[7] Lewandovski et al (2016) “Breast Milk Consumption in Preterm Neonates and Cardiac Shape in Adulthood” *Pediatrics*

The first two modes

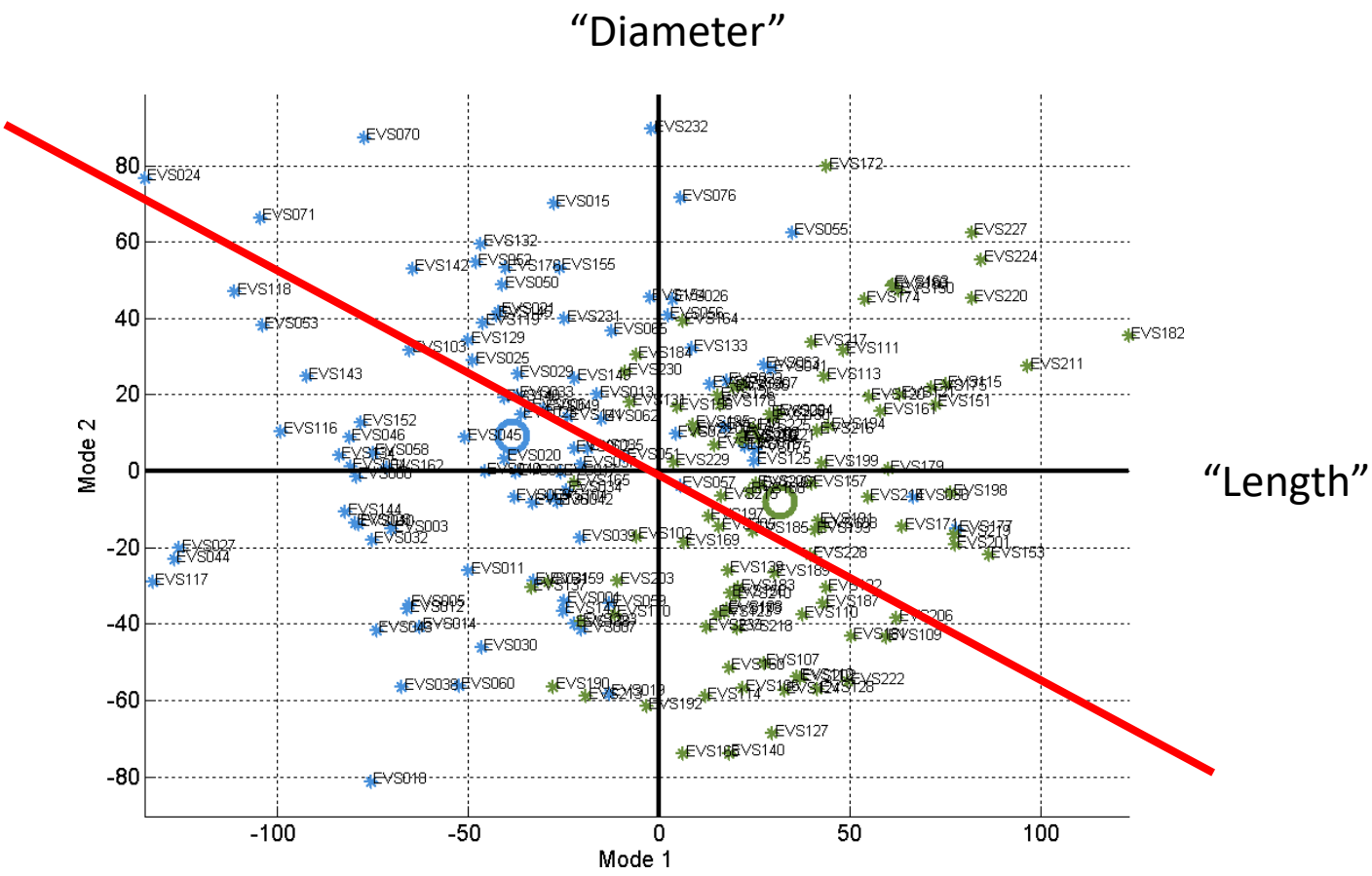
Mode 1



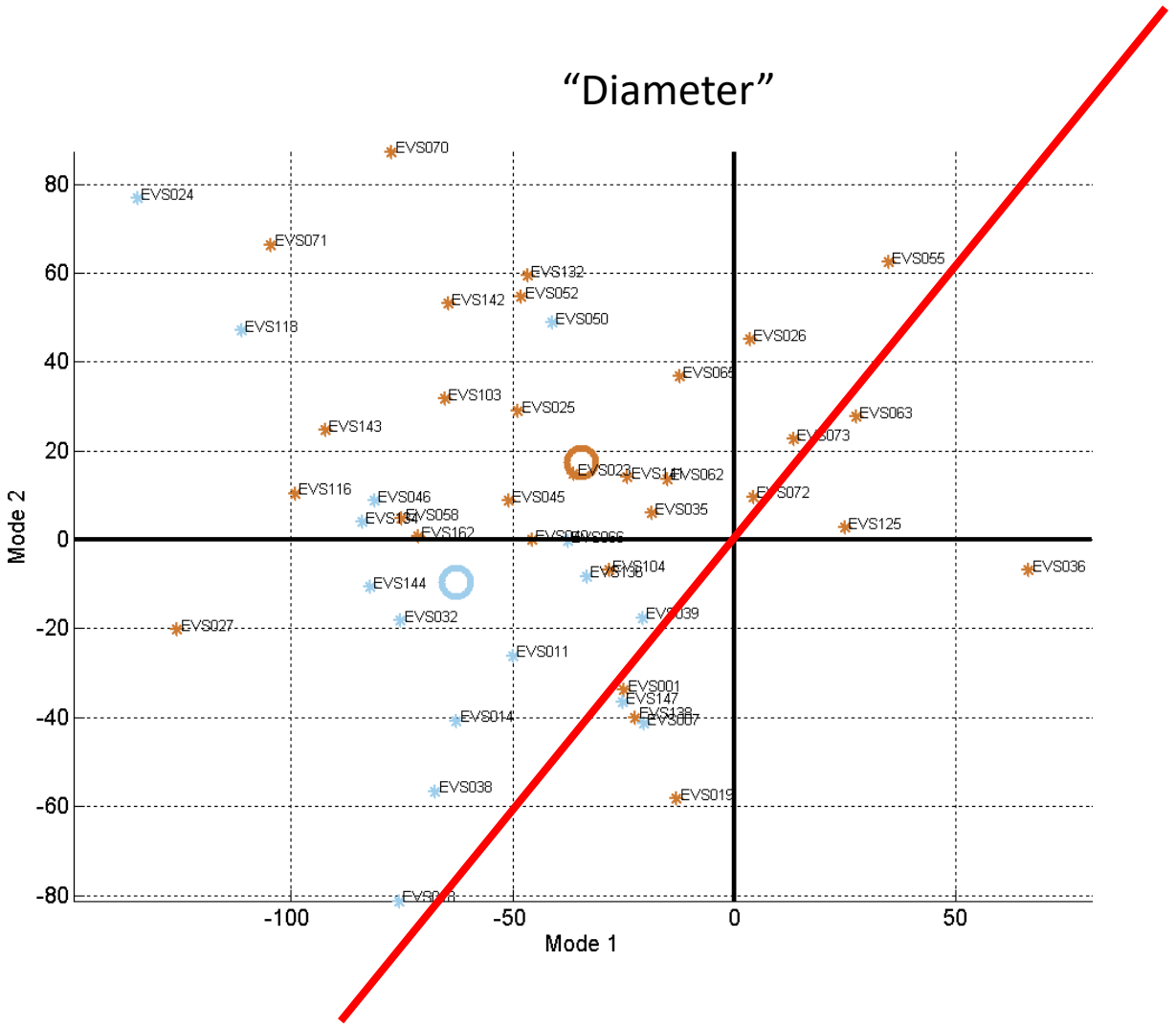
Mode 2



Preterm vs term

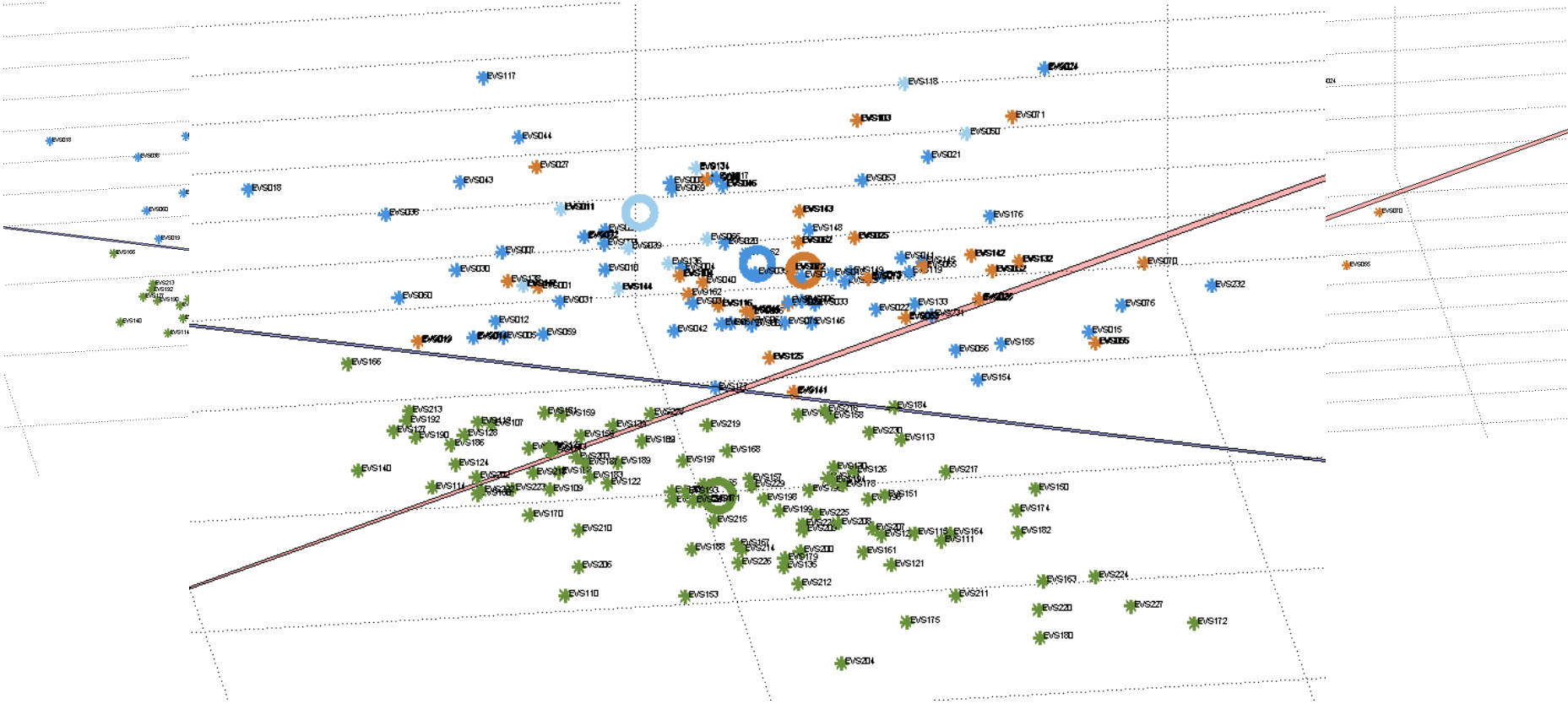


EHM vs EFF


“Diameter”
“Length”
Mode 1
Mode 2
80
60
40
20
0
-20
-40
-60
-80
-100
-50
0
50
EVS070
EVS024
EVS071
EVS132
EVS055
EVS142
EVS052
EVS118
EVS050
EVS026
EVS103
EVS025
EVS063
EVS143
EVS073
EVS116
EVS046
EVS045
EVS062
EVS072
EVS035
EVS058
EVS125
EVS162
EVS104
EVS036
EVS144
EVS032
EVS027
EVS011
EVS001
EVS147
EVS014
EVS038
EVS019

Discussion

- Breast milk closer to controls
- but triggering a compensatory growth mechanism?

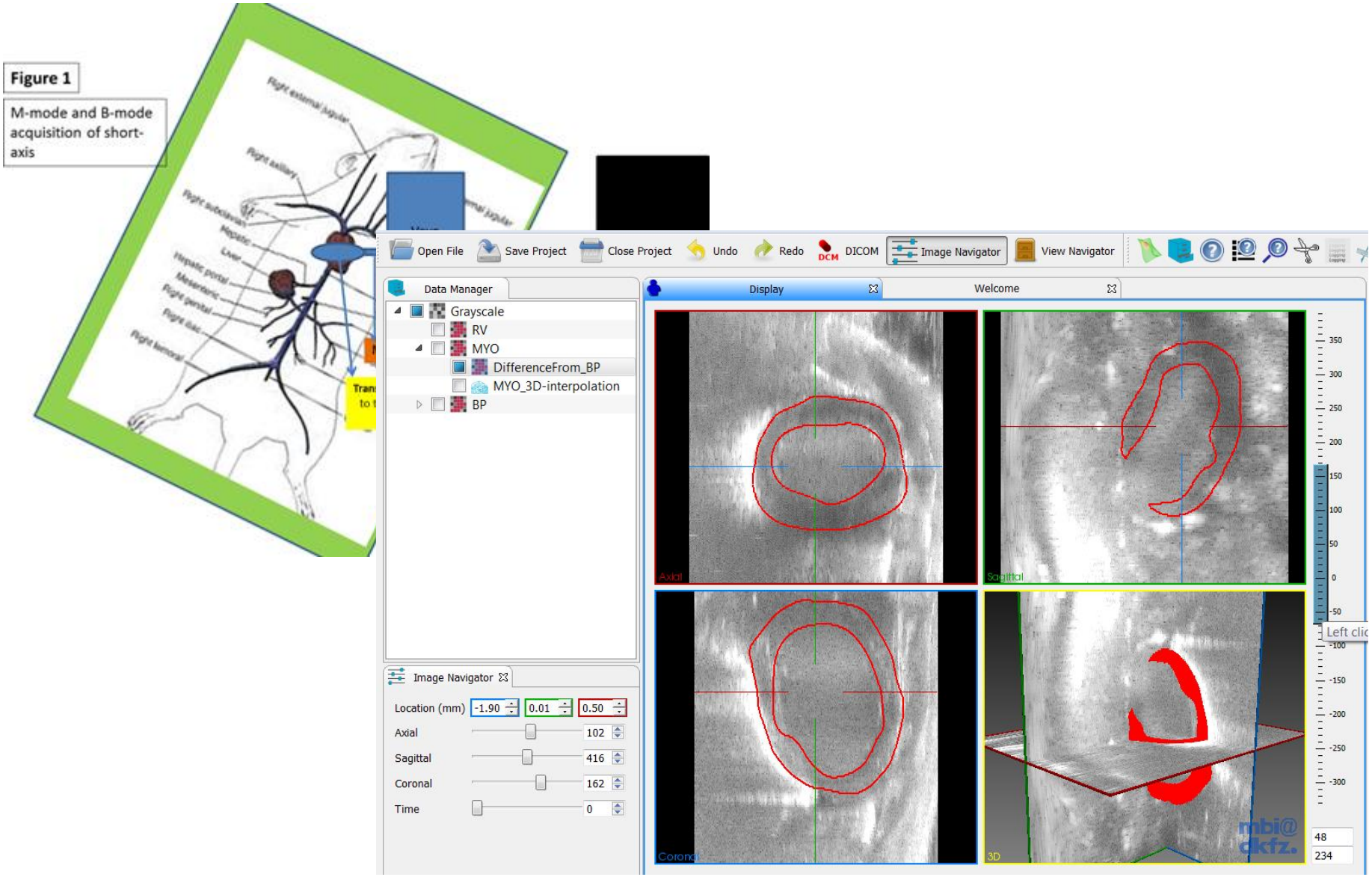


3 - Impact of drugs [*]

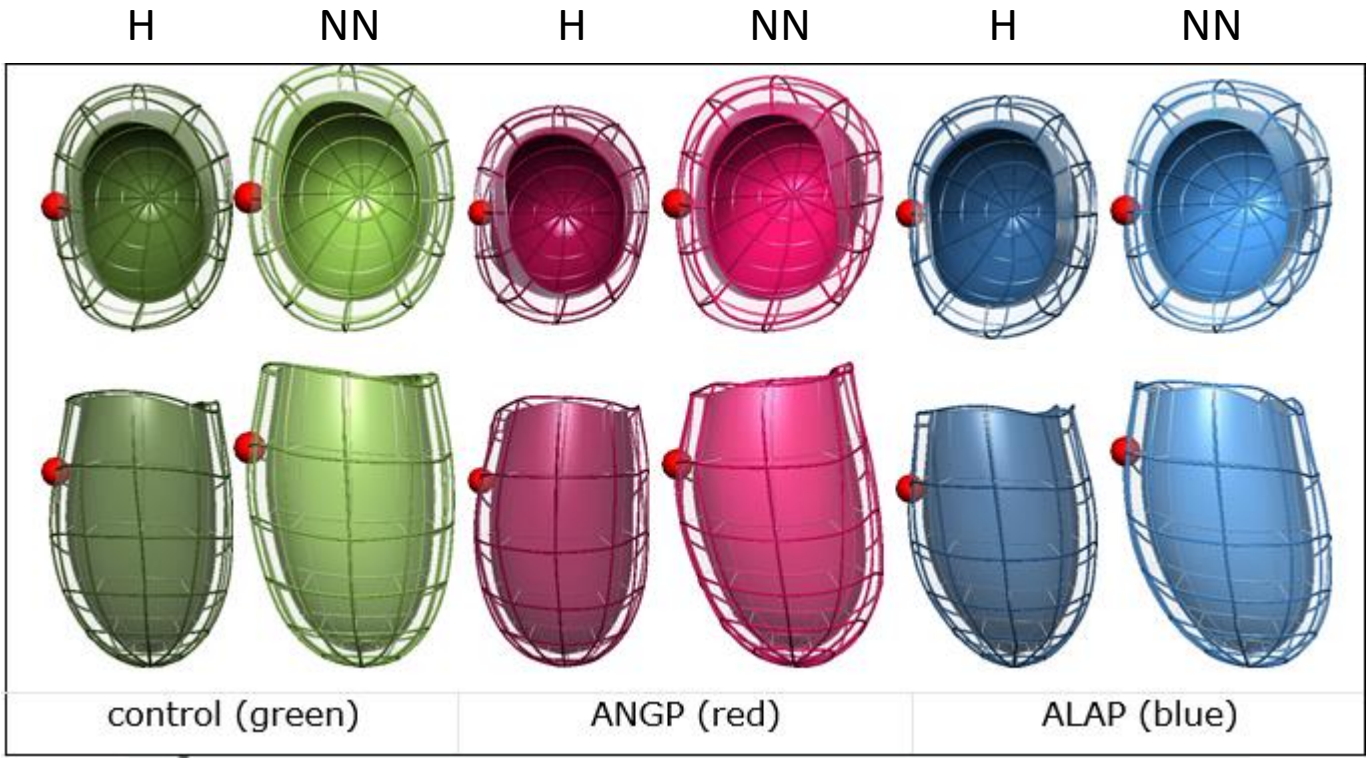
- Hyperoxia impact on development?
- Can drugs compensate for it?
- Material:
  - Neonatal rats at day 10 of life
  - H (n=12) – Hyperoxia: high oxygen concentrations, 80%. This groups later develop high blood pressure, and cardiac alterations similar to the young-adult preterms
  - NN (n=12) - Normoxia (21% of oxygen)
  - Within each subgroup
    - Control (water or cyclodextrin – the vehicle)
    - ANGP (n=3) – Angiotensin 1-7
    - ALAP (n=3) – Alamandine

*: Bertagnolli & Nuyt

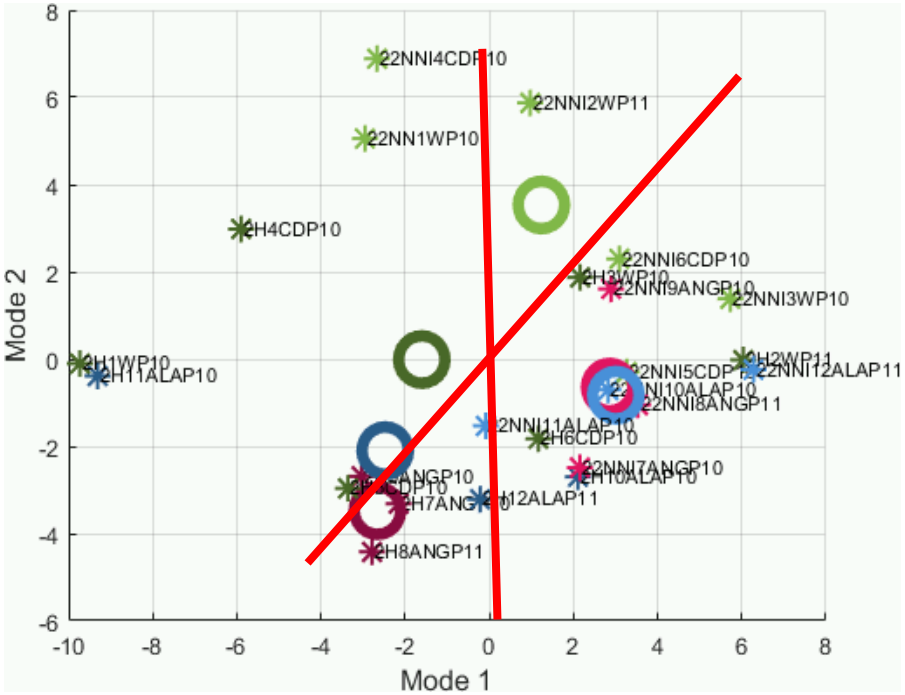
Imaging & segmentation

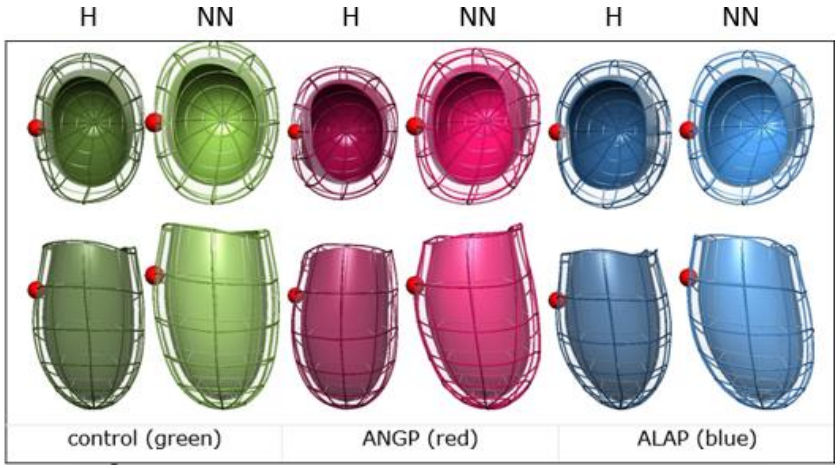


The average of each group

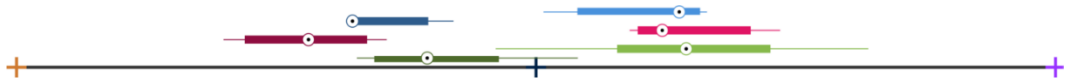


The shape space





H vs NN



Drug vs No drug

Discussion

- Hyperoxia has a clear impact on development during pregnancy
- Drugs do not reverse it, but accentuate it, in a different “remodelling direction”
- Future: follow out of oucomes

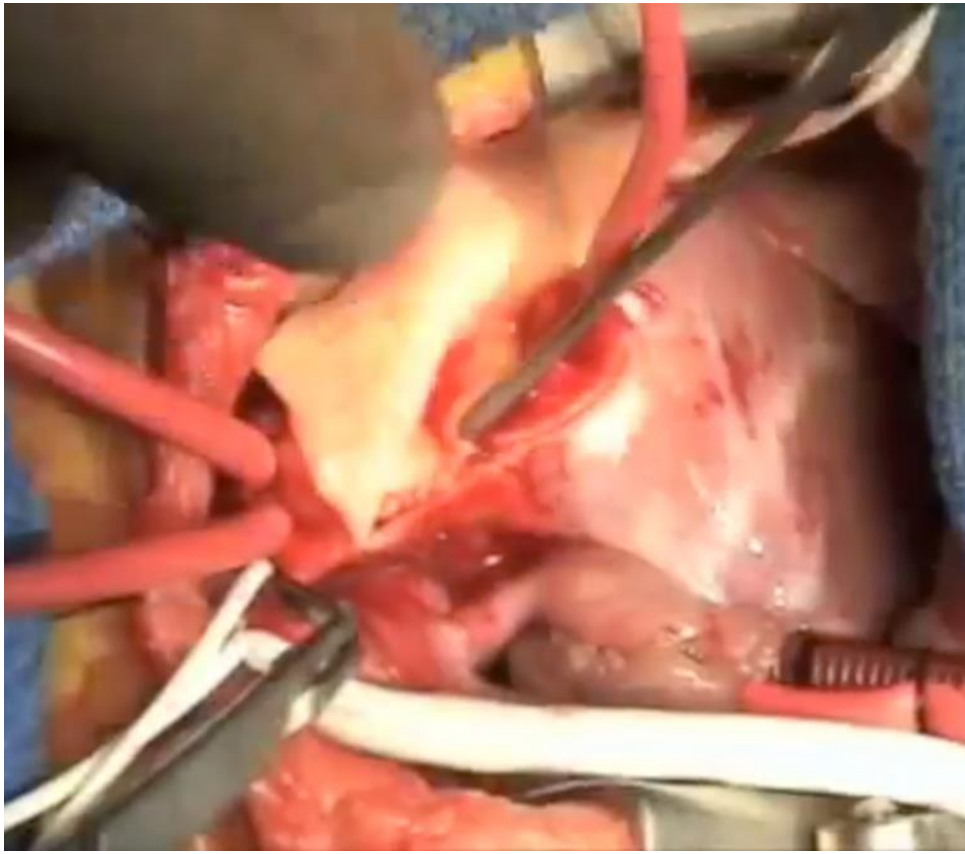
- Caution: tiny sample size!!

4 – Impact of surgery [8]

Hypoplastic Left Heart Syndrome

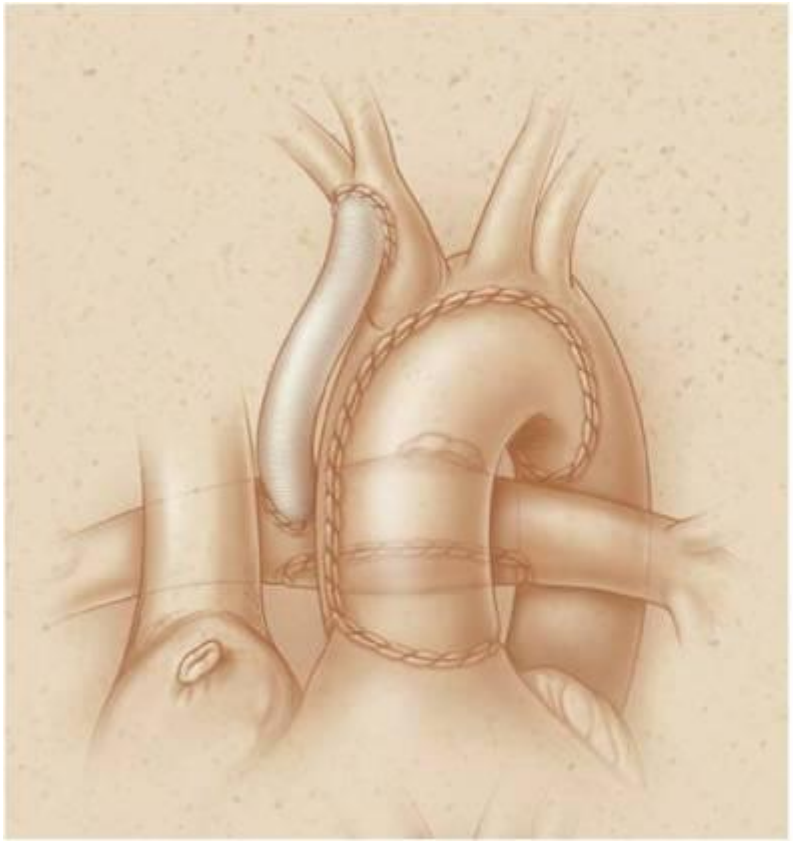
- Complex surgery - different "schools"
- Small numbers – many factors

Opportunity: huge impact for life

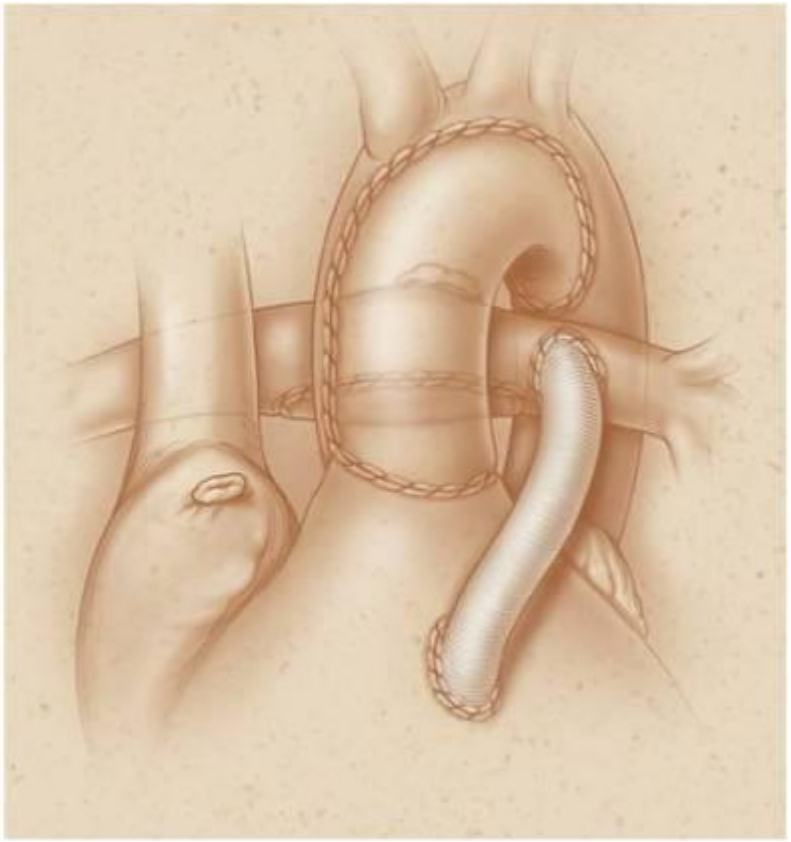


[8] Wong et al, (2016). Right ventricular morphology and function following stage I palliation with a MBT shunt versus a RVPA conduit. *European Journal of Cardio-Thoracic Surgery*

Shunts: two “schools”



modified Blalock-Taussig (MBT)



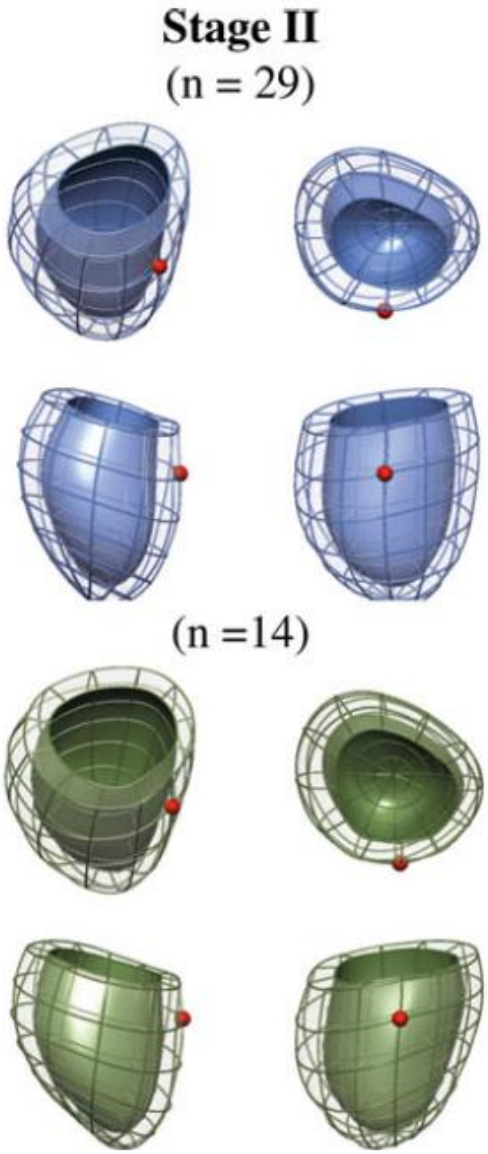
right ventricle-to-pulmonary artery (RVPA)

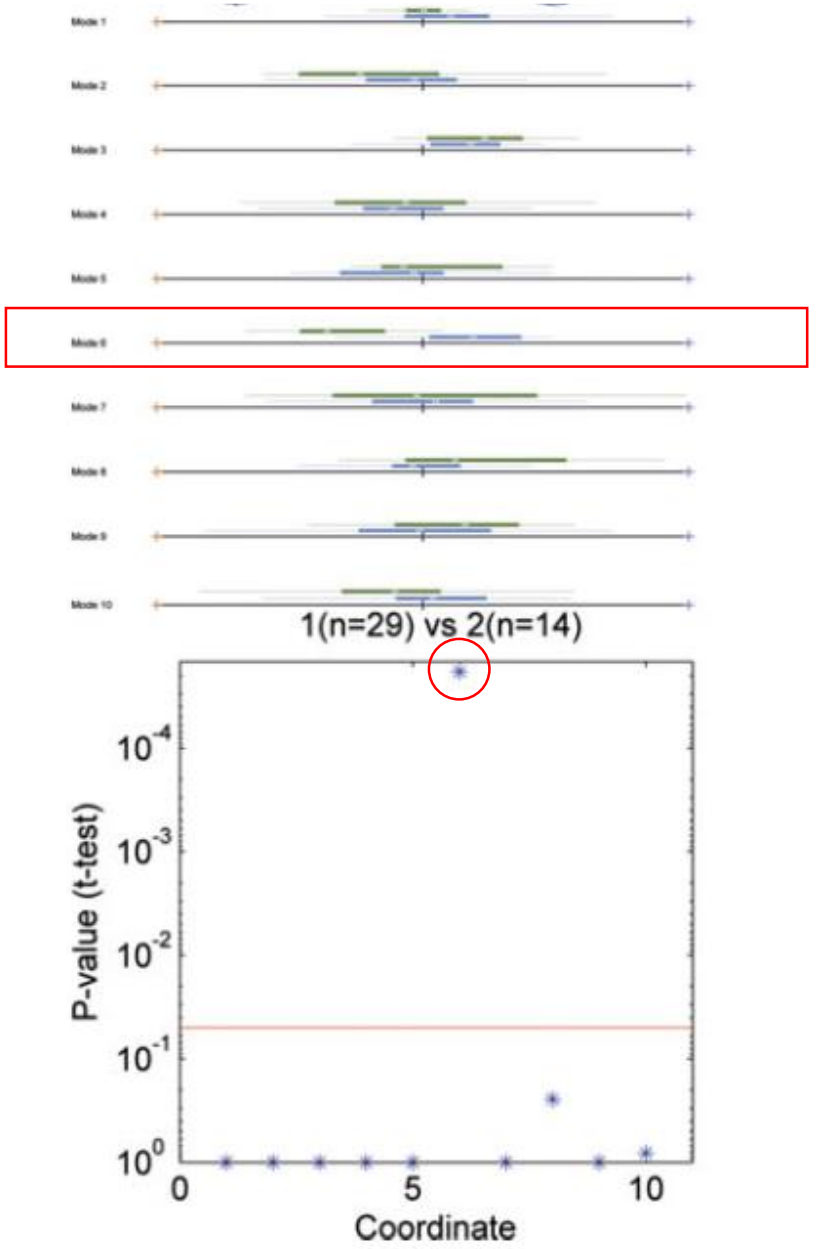
[8] Wong et al, (2016). Right ventricular morphology and function following stage I palliation with a MBT shunt versus a RVPA conduit. *European Journal of Cardio-Thoracic Surgery*

The result…

MBT

RVPA





Lesson learned

- Useful information might be in the small modes!

How good is the picture?

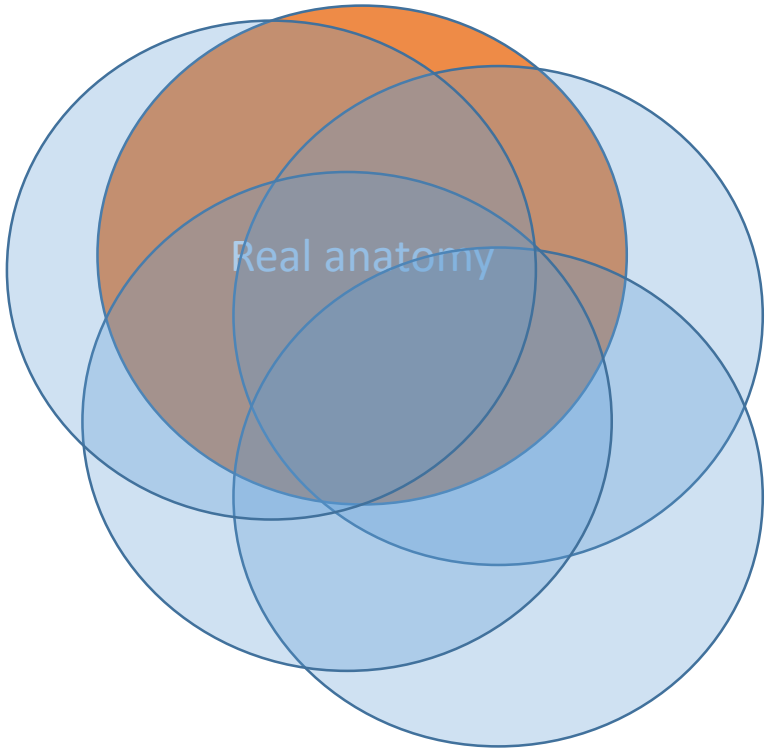
Sources of uncertainty in shape

ACQUISITION LIMITATIONS [2]

SEGMENTATION

MESHING

STATISTICAL MODELLING



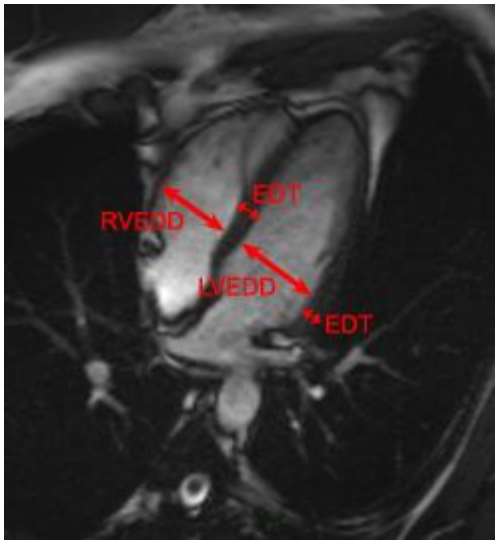
Challenge: maximise final overlap (accurate, precise, reproducible)!

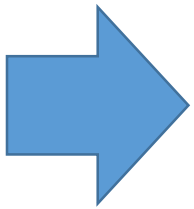
[2] Lamata et al, (2014) Images as drivers of progress in cardiac computational modelling. *Prog Biophys Mol Biol.*

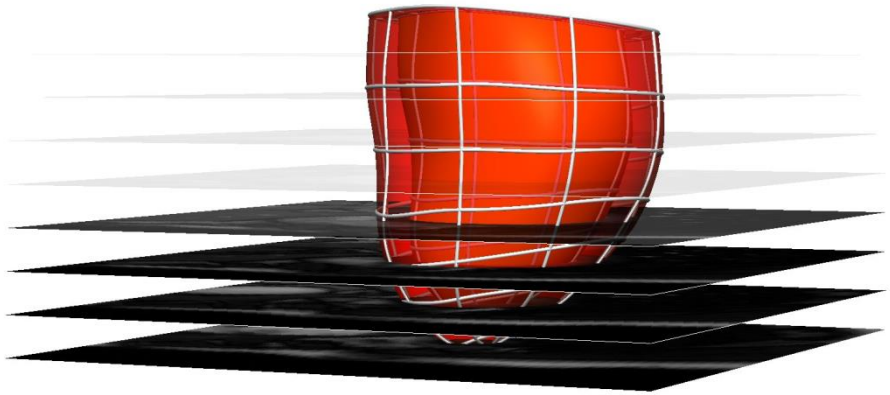
- A good one!
  - Providing new insights
  - Differences never revealed before

- Working on getting until the last drop!
  - Data limitations to be overcomed
  - Processing: anatomical matching
  - Analysis: only linear modes

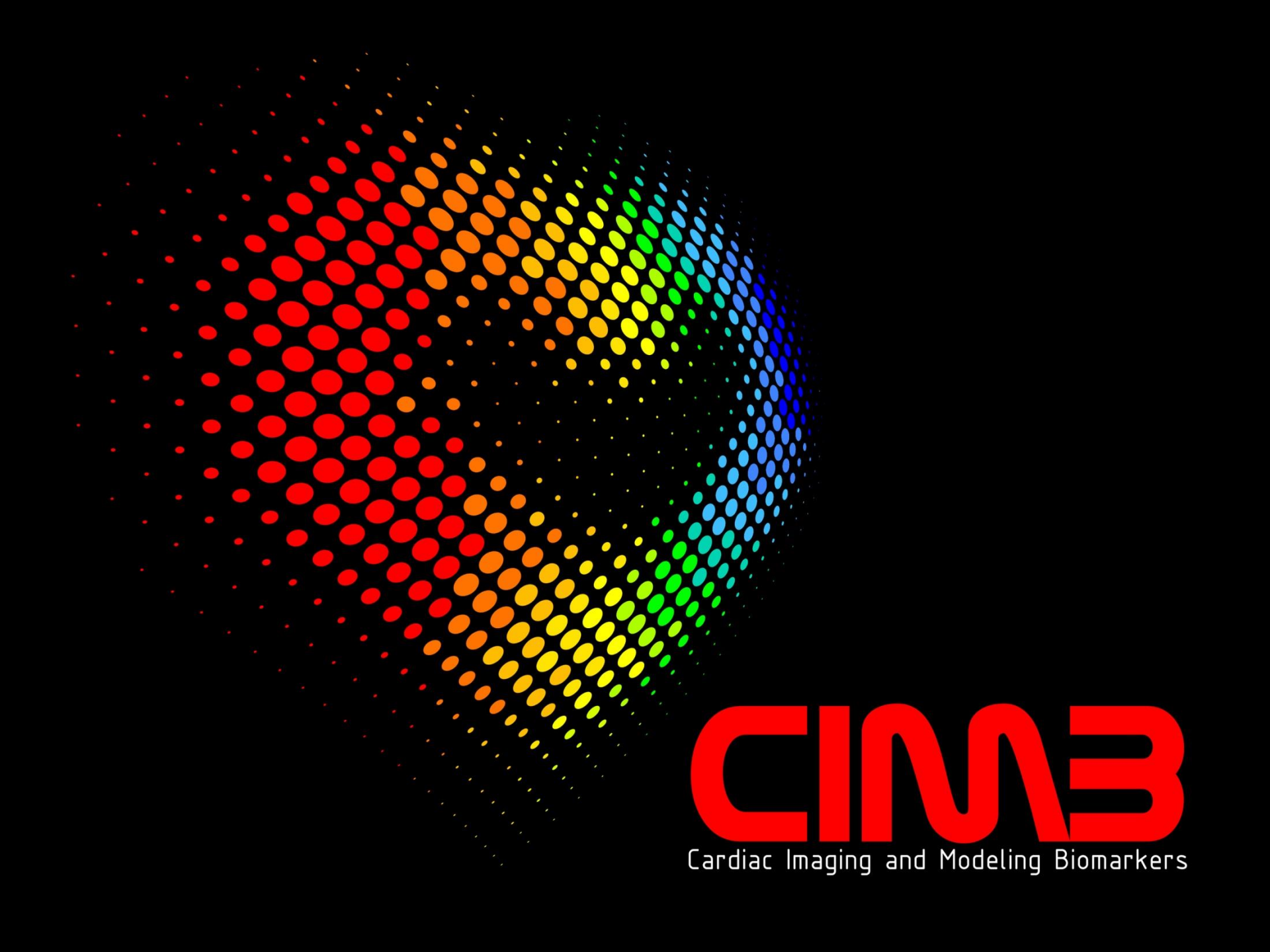
Summary







Computational anatomy to improve risk stratification


CIM3
Cardiac Imaging and Modeling Biomarkers