Predictive Statistical Analysis of Cardiac Structural and Functional Remodelling

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How does heart structure and function change over time in response to disease?

Ventricular structure in diseased hearts remodels over time. Mechanical pumping is also affected, reducing long-term functional efficiency. Statistical analysis allows us to predict how the structure and function changes over time. Predictive analysis of disease evolution can help to better understand diseases and to guide treatment planning.

Cardiac Imaging Data

Input Data

Cardiac Magnetic Resonance (CMR)

+ *Image structures*
+ *Tissue characterisation*
+ *Image cardiac function*
- *Expensive*

Echocardiography (Echo)

+ *Non-invasive*
+ *Inexpensive*
+ *Image cardiac function*
- *Poor spatial resolution*

Computed Tomography (CT)

+ *Good spatial resolution*
+ *Image structures*
- *Ionising radiation*

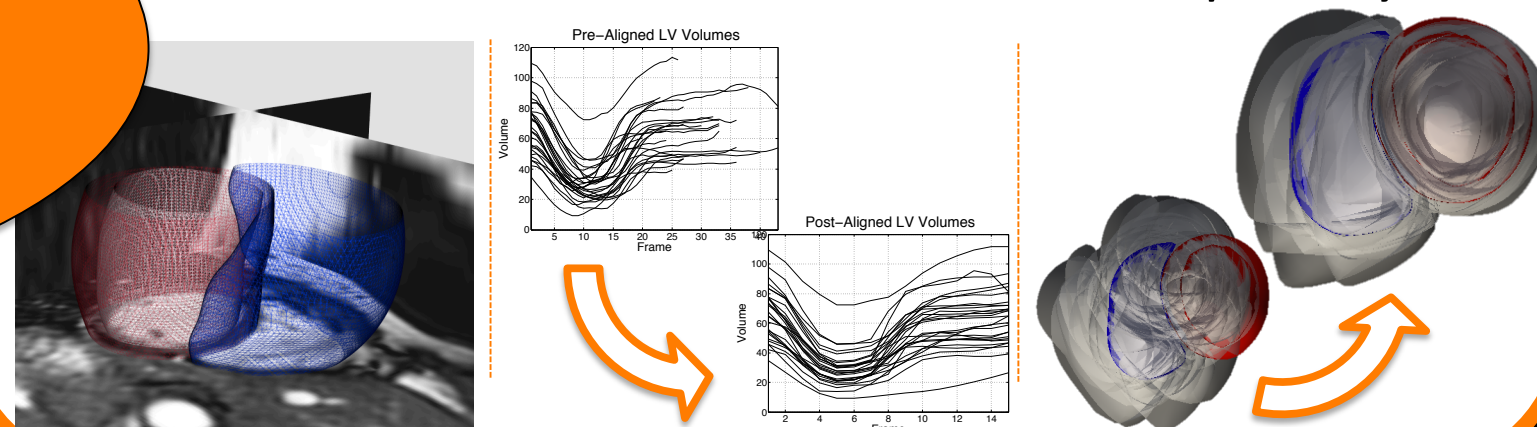### Data extraction

Modelling

Structure

Segment ventricle shape from images

Segment image → *Align temporally* → *Align spatially*

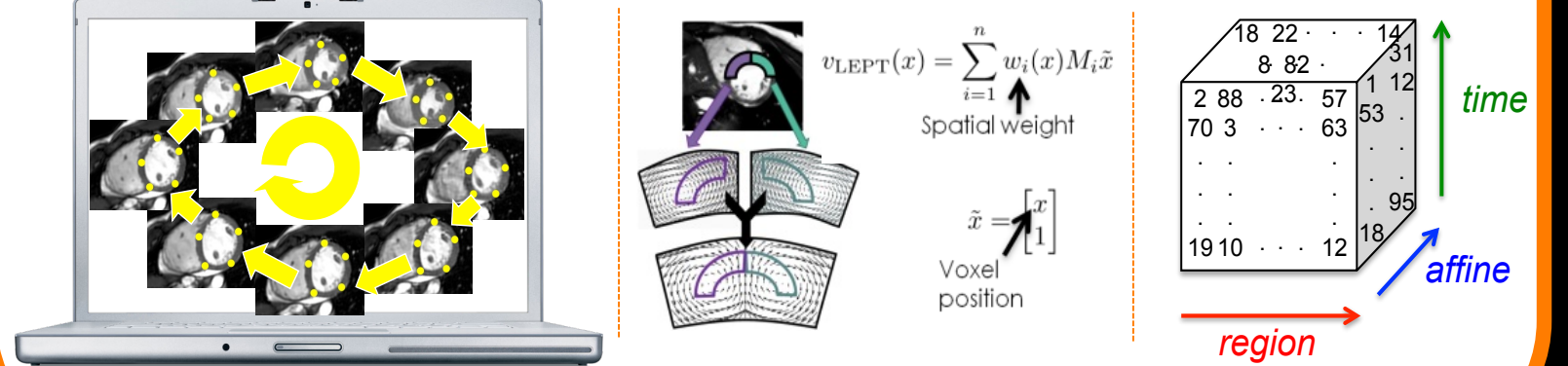## Function

Track motion over cardiac cycle from images

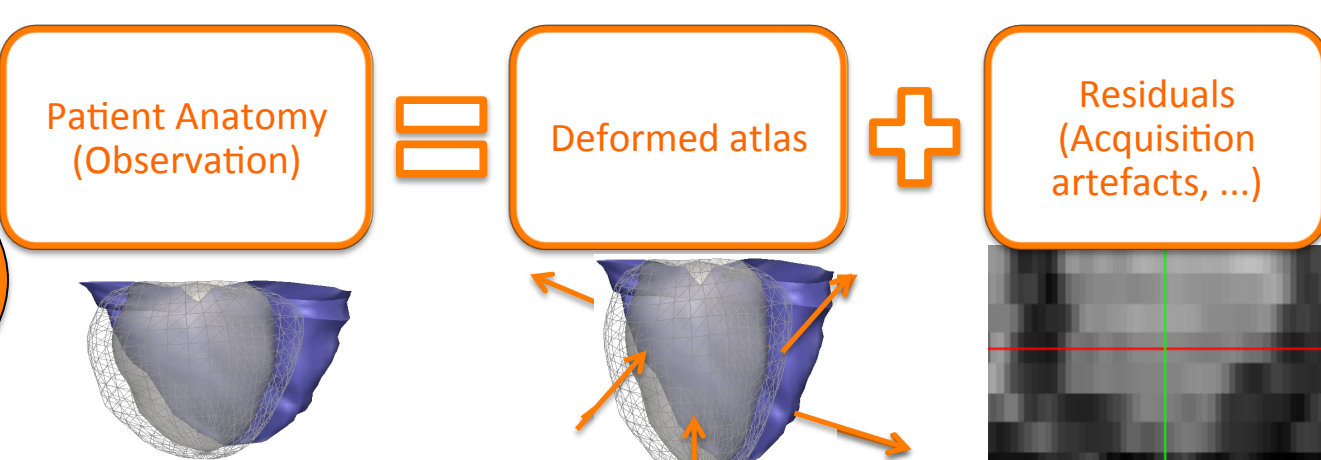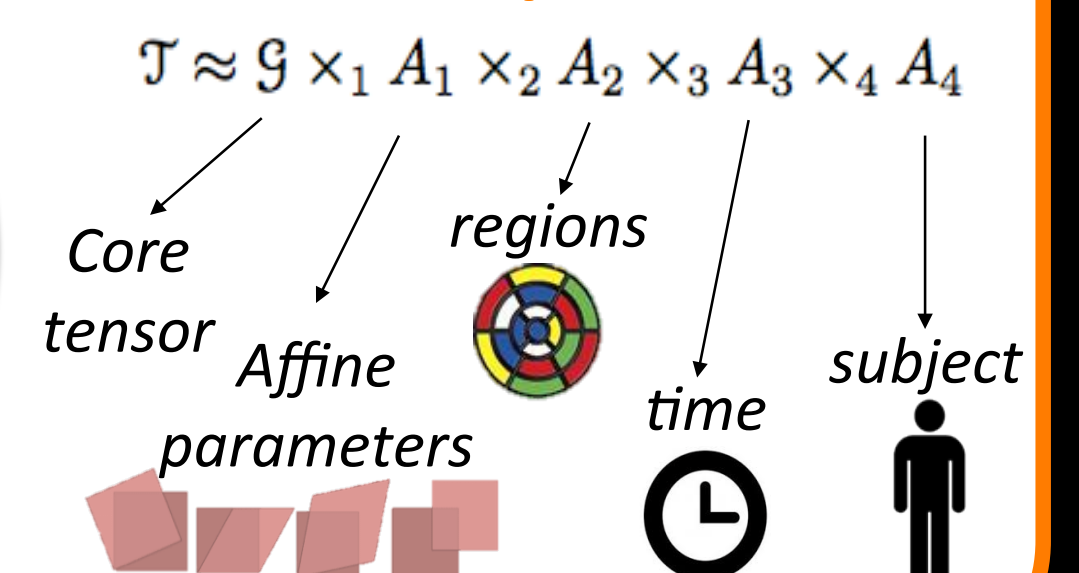*Non-rigid image registration* → *Polyaffine projection* → *Tensor construction*

$$v_{\text{LEPT}}(x) = \sum_{i=1}^{n} w_i(x) M_i \tilde{x}$$

Spatial weight

$$\tilde{x} = \begin{bmatrix} x \\ 1 \end{bmatrix}$$

Voxel position

- *McLeod et al. TMI 2015*

Parameterisation

Population-Wise Analysis

Characterise shapes by deformations of an atlas geometry

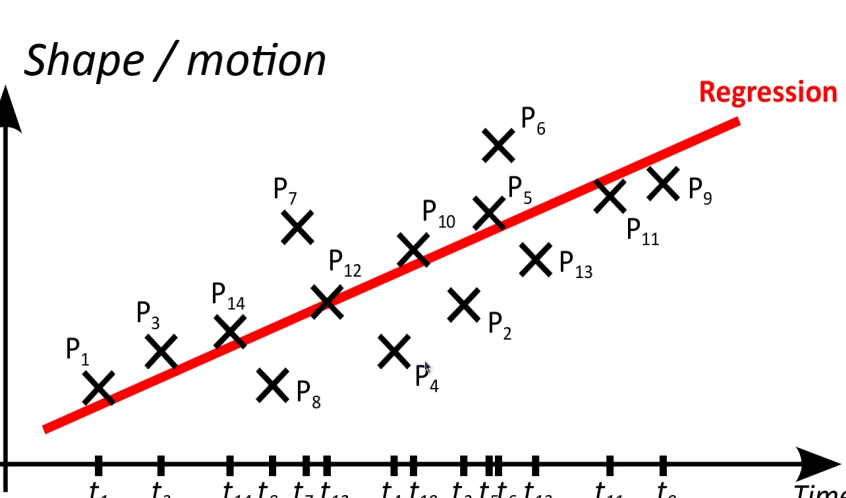Patient Anatomy (Observation) = Deformed atlas + Residuals (Acquisition artefacts, ...)

- *McLeod et al. Modeling in Computational Biology and Biomedicine, 2013*

Parameterise motion by 4-way tensor of affine parameters

$$\mathcal{T} \approx \mathcal{G} \times_1 A_1 \times_2 A_2 \times_3 A_3 \times_4 A_4$$

Core tensor

Affine parameters

regions

time

subject

- *McLeod et al. MICCAI 2015*

Predictive Analysis

Shape / motion

Regression

P_1 P_2 P_3 P_4 P_5 P_6 P_7 P_8 P_9 P_{10} P_{11} P_{12} P_{13} P_{14}

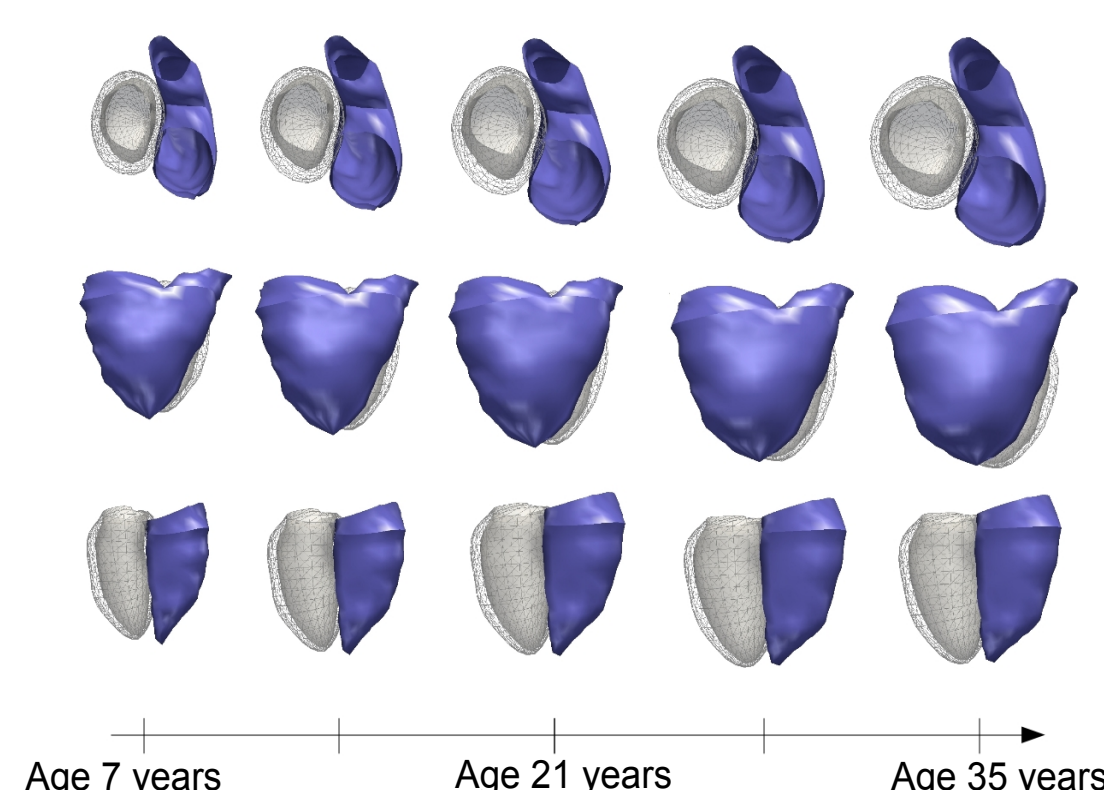t_1 t_3 t_{14} t_8 t_5 t_7 t_{12} t_4 t_{10} t_2 t_6 t_{13} t_{11} t_9

Time

Cross-sectional statistical design

Consider each subject as an observation along time, and perform regression of these observations to obtain a population-based statistical model

Structural remodelling

Age 7 years   Age 21 years   Age 35 years

Functional evolution

Age 7 years   Age 21 years   Age 35 years