Suranaree University
of Technology

NSTDA Annual Conference 2005
School of Computer Engineering

Medical Image Computing in Cardiology

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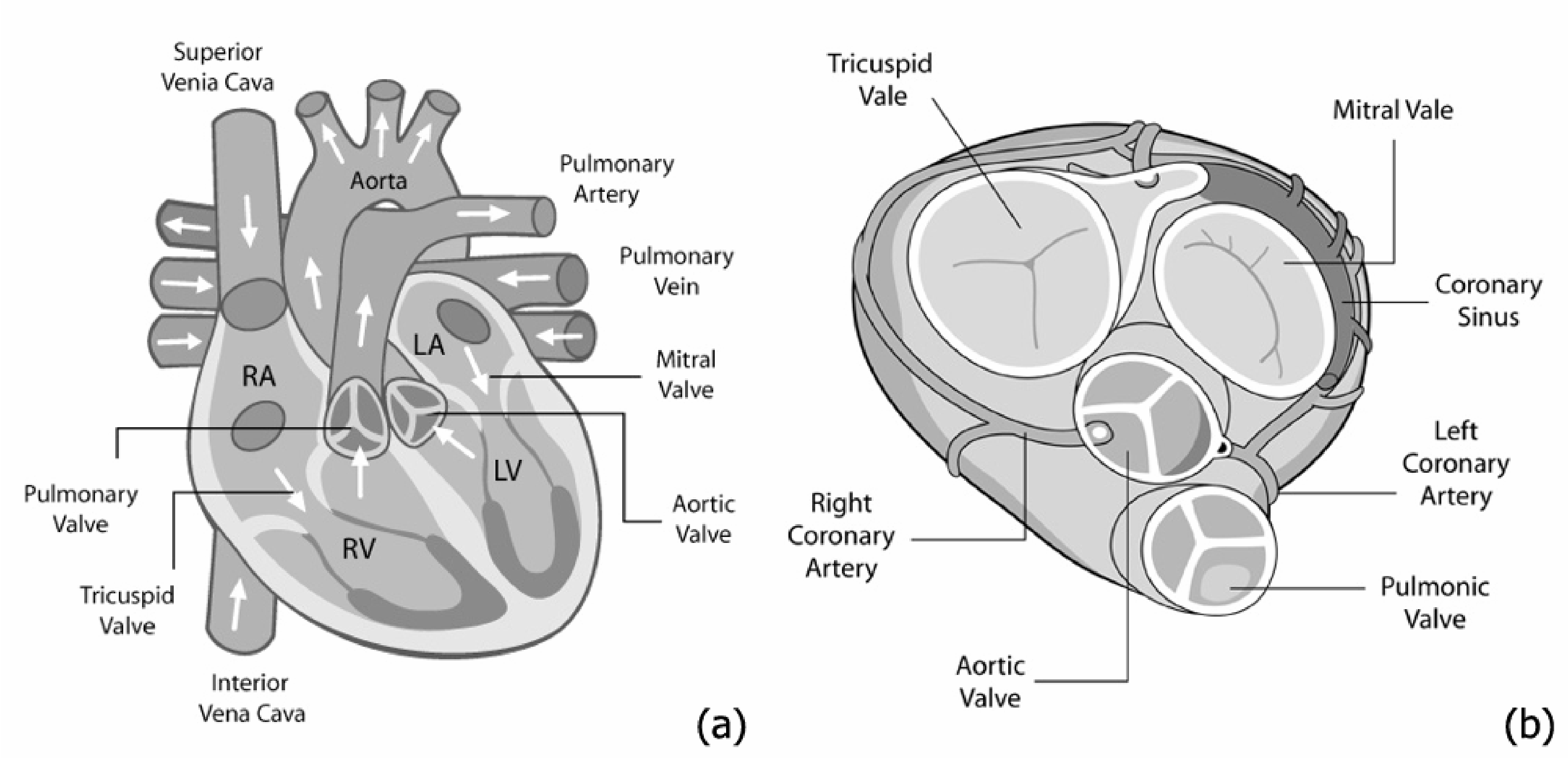
Outline of the Lecture

- Introduction
- Computer-Aided Diagnosis of Cardiovascular Diseases
  - Image Segmentation
  - Image Registration
- Computational Anatomy
  - *Biomechanical Simulation*
  - *Fluid-Structural Simulation*
  - *Electrical Activation*
- Conclusions

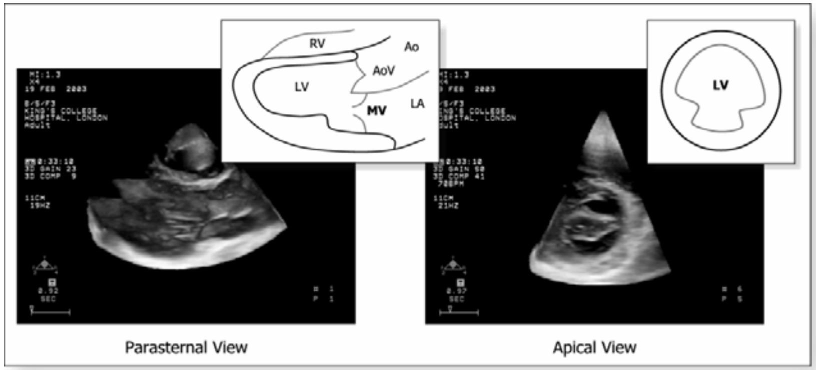
Cardiac Anatomy

The basic anatomy of the human heart (a) and the configuration of the four major valves (b)



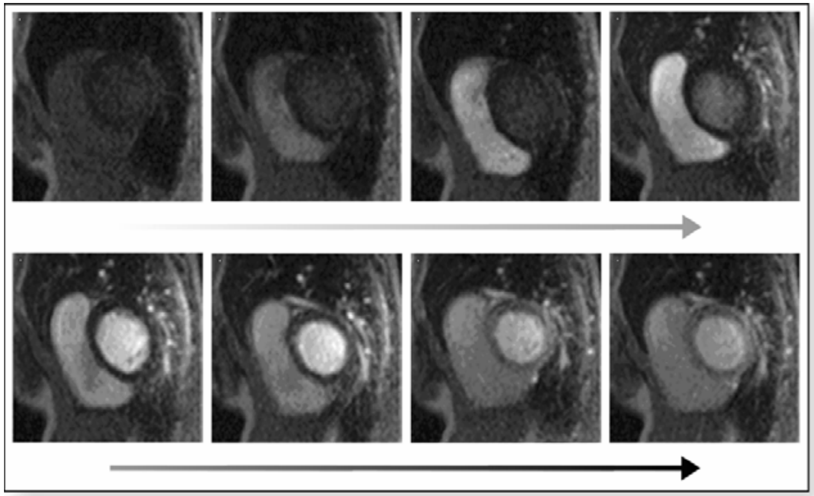
Introduction

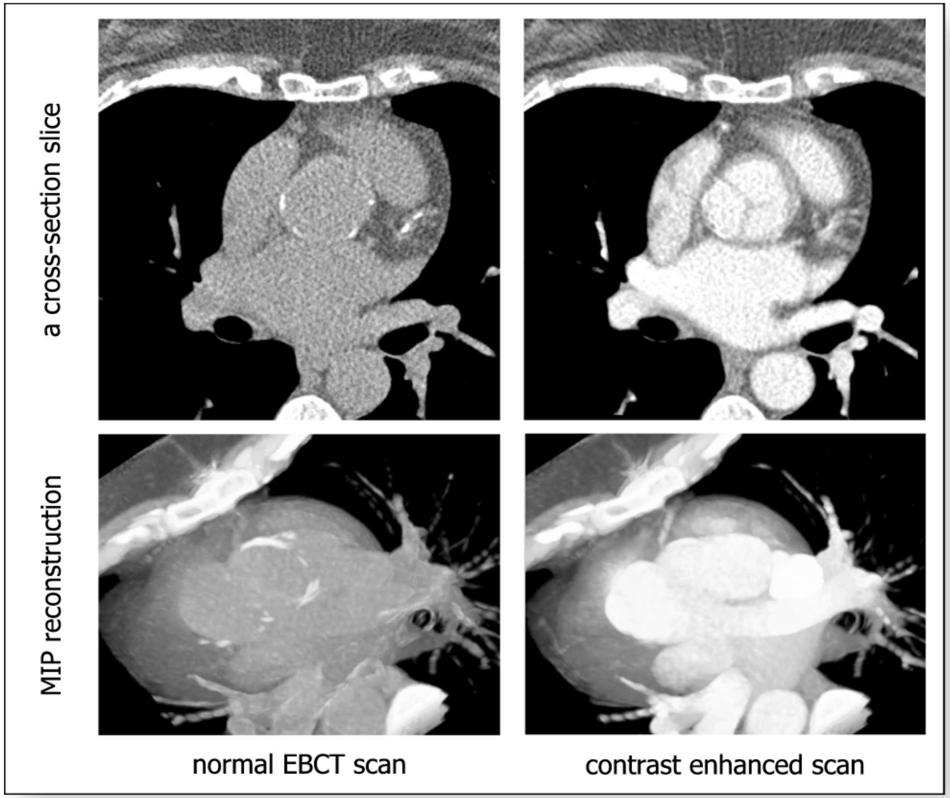
Conventional uses of Medical Imaging



Parasternal View

Apical View





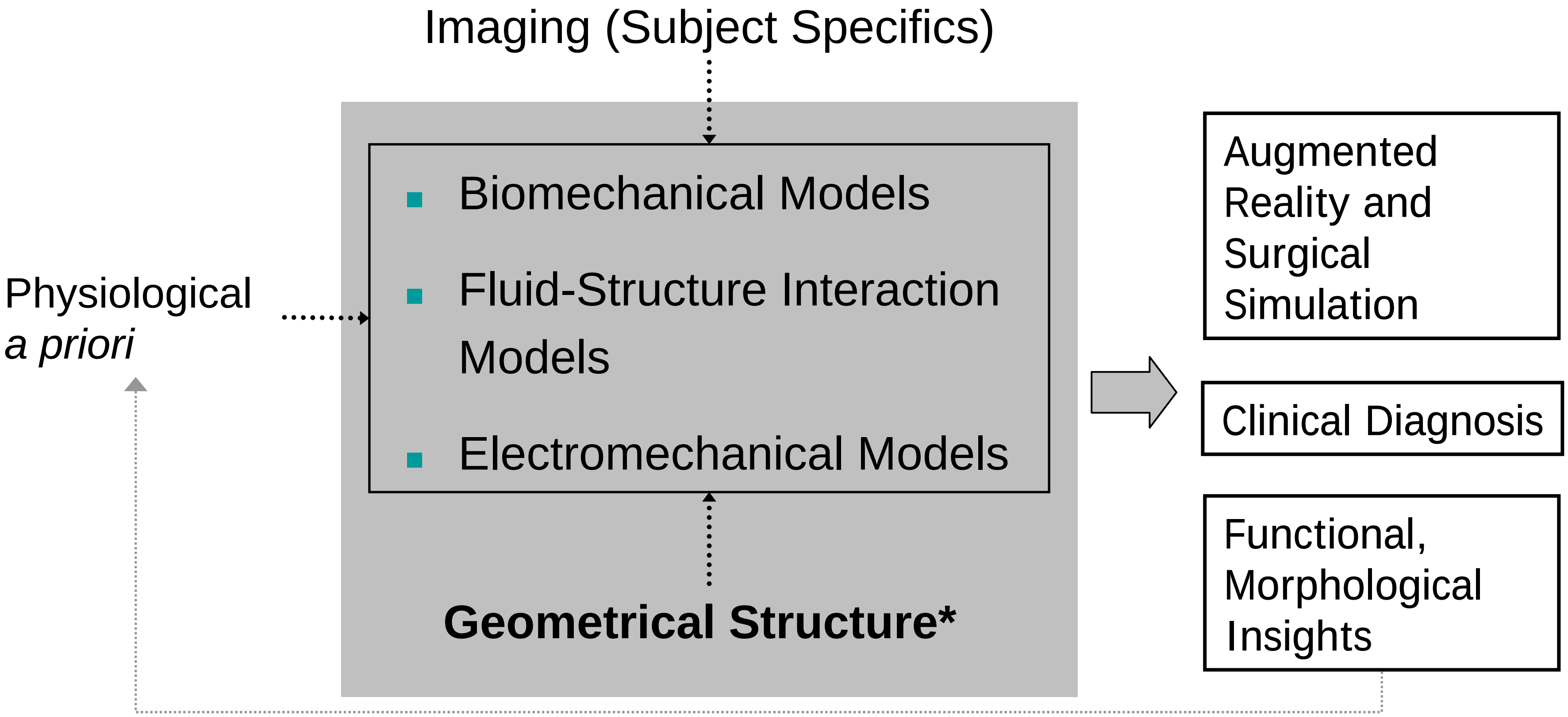
normal EBCT scan

contrast enhanced scan

Diagnosis was made primarily on imaging information

Introduction

Assessing Cardiovascular Morphology and Functions



Imaging (Subject Specifics)

- Biomechanical Models
- Fluid-Structure Interaction Models
- Electromechanical Models

Geometrical Structure*

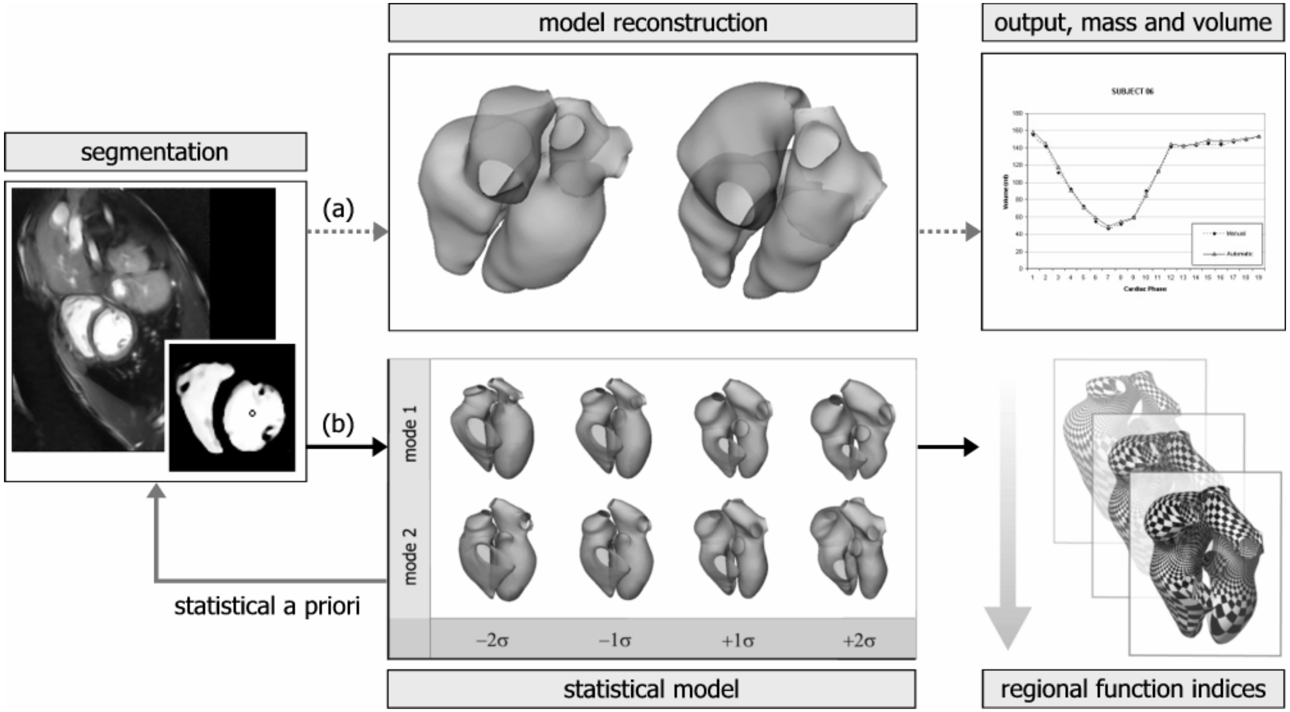
Physiological
a priori

Augmented Reality and Surgical Simulation

Clinical Diagnosis

Functional, Morphological Insights

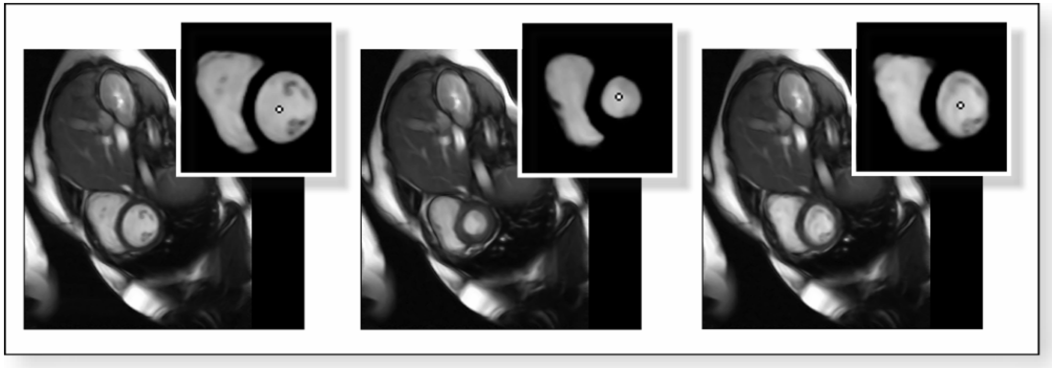
Cardiac Image Analysis



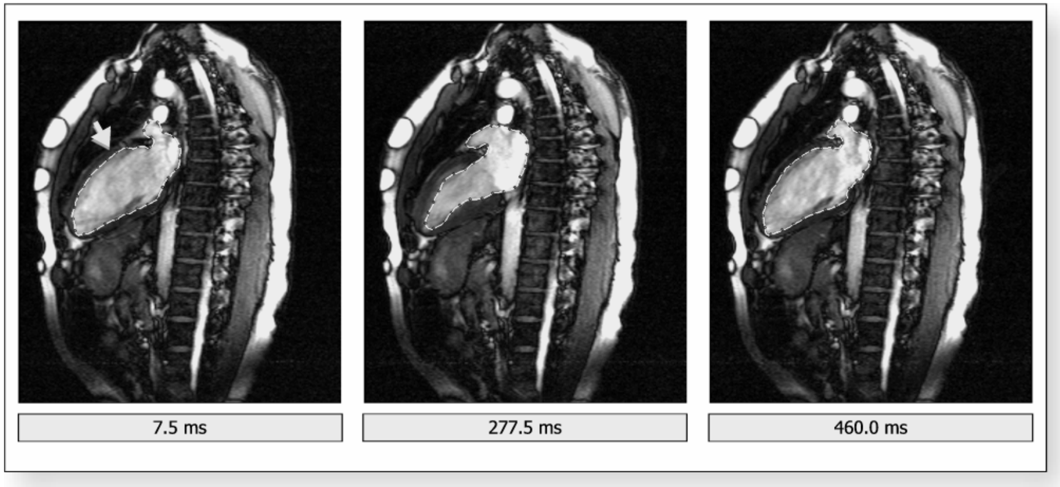
Typical workflows for cardiac image analysis, where with the conventional approach (a) a set of segmented contours or regions is used to reconstruct geometrical models for deriving global measures, whereas for the statistical based approach (b) the segmented shapes are used to create a statistical model of the population such that the results can be used either for deriving regional function and morphology by examining deviations to principal modes of variation or for improving the segmentation algorithm with statistical inference.

Cardiac Segmentation

Classic Computer Vision algorithms and their variants



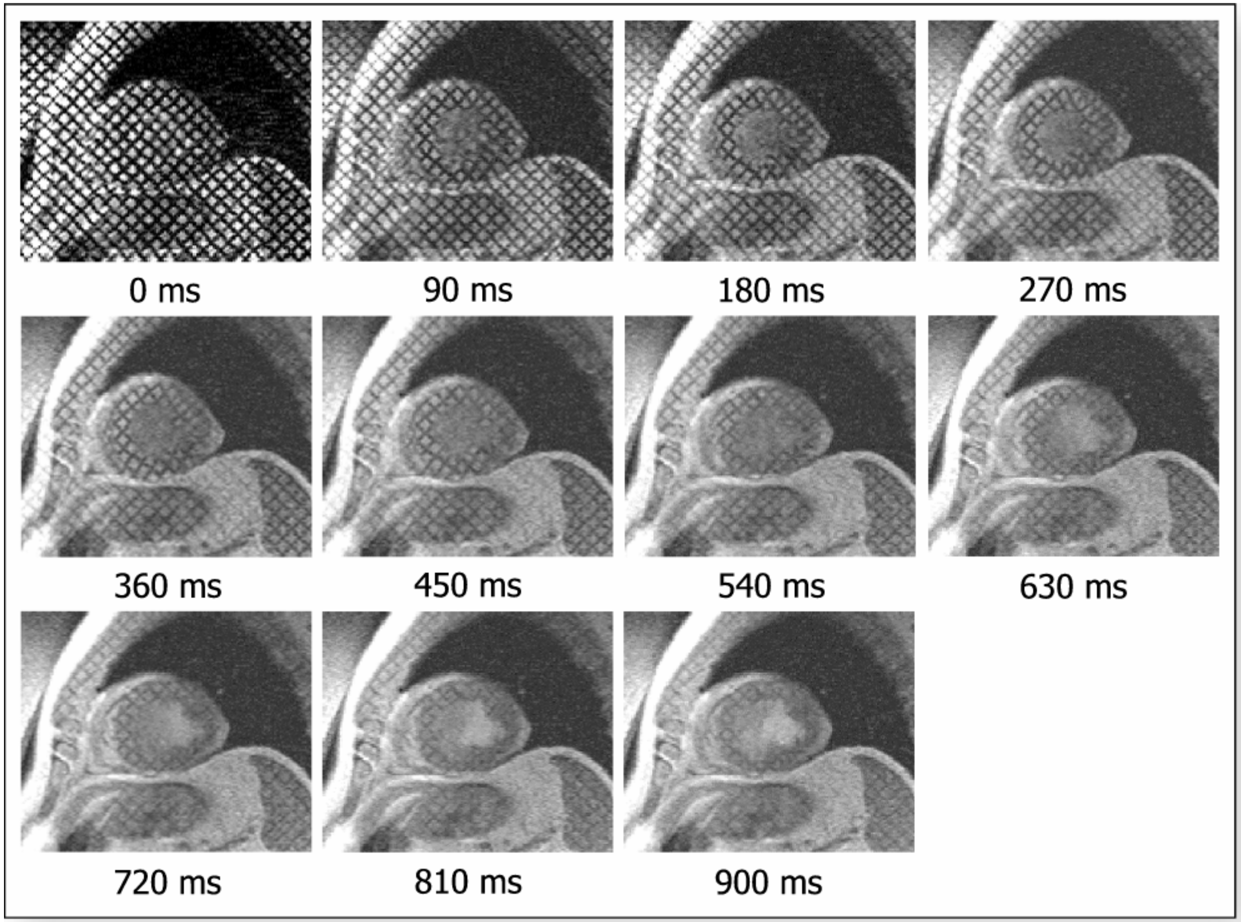
- **Region based**
  - Sensitive to inhomogeneous intensities
  - Resulting topology is unpredictable
  - Requires advanced added-on algorithms to extract the geometry



- **Contour based**
  - Dependent on initialization
  - Prone to high variability
  - Requires parameter tuning
  - Impractical for complex shapes

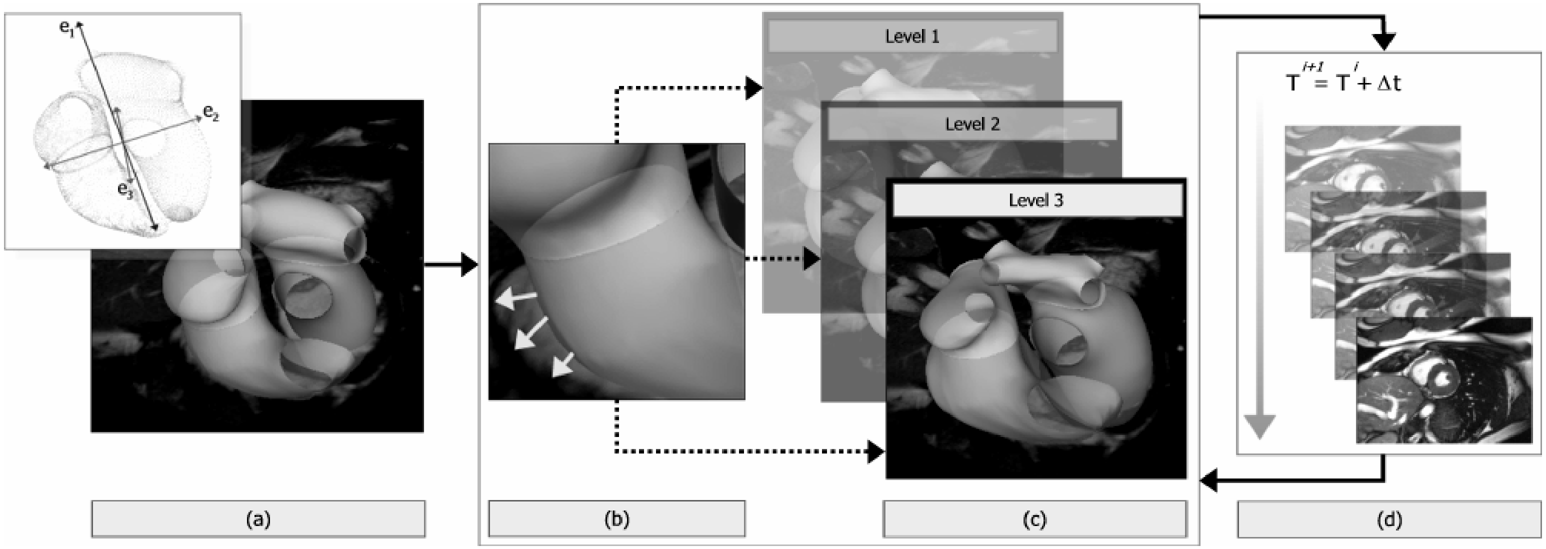
Extracted shape are not necessarily physiological plausible or meaningful

2D Cardiac Tracking



1) Through plane motion is only approximated, 2) Four chamber motion is difficult

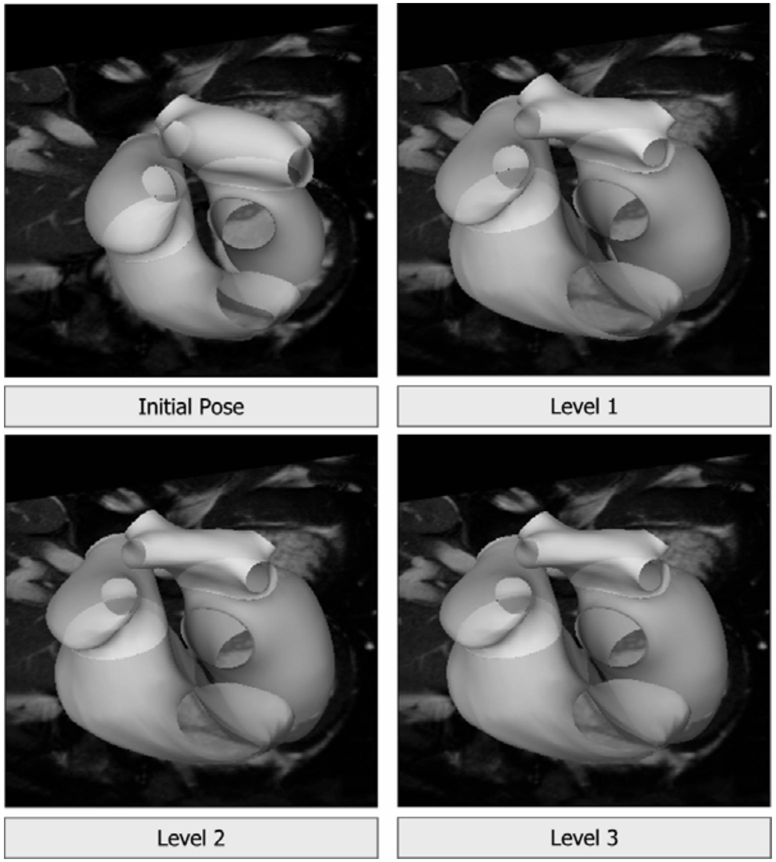
Model Based Segmentation



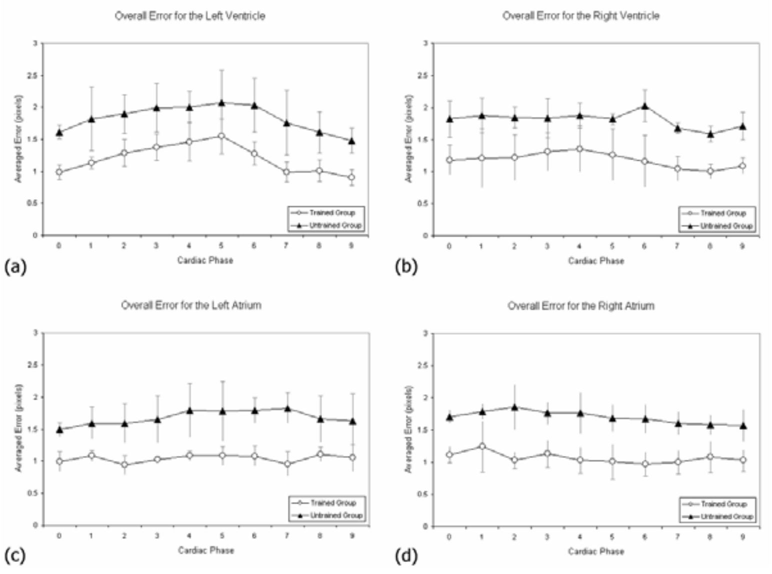
Schematic diagram summarising the model based segmentation framework

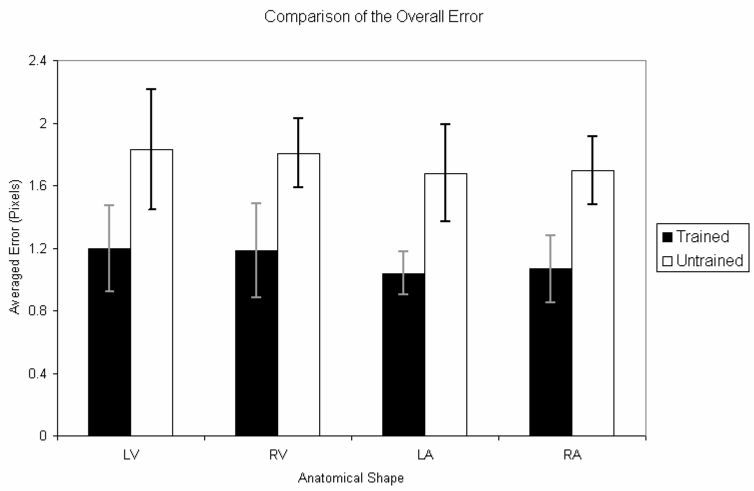
a) Model initialisation
b) Displacement calculation
c) Shape and pose parameters adjustment
d) Temporal propagation

Segmentation Results

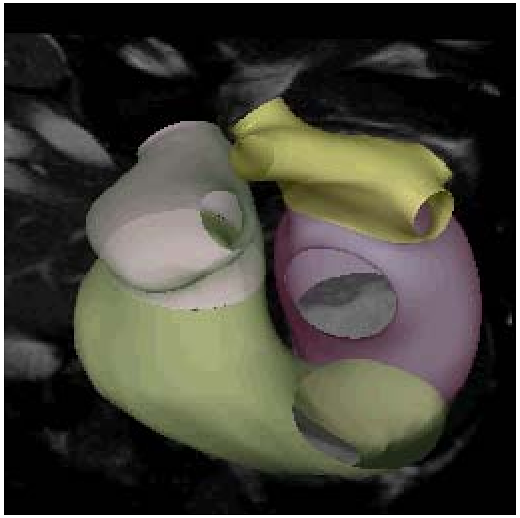


Multiresolution ASM segmentation of the heart from 3D CMR images

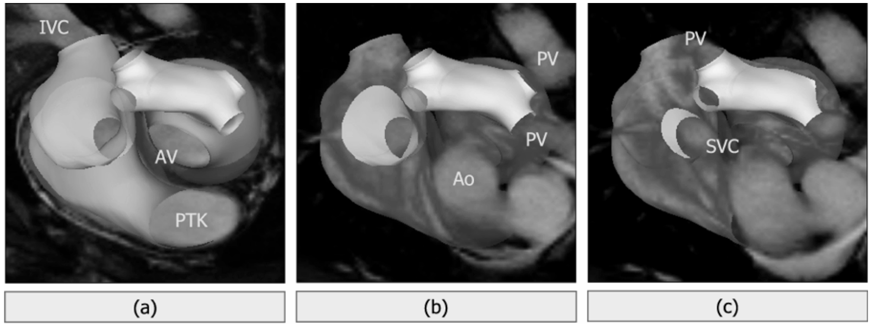




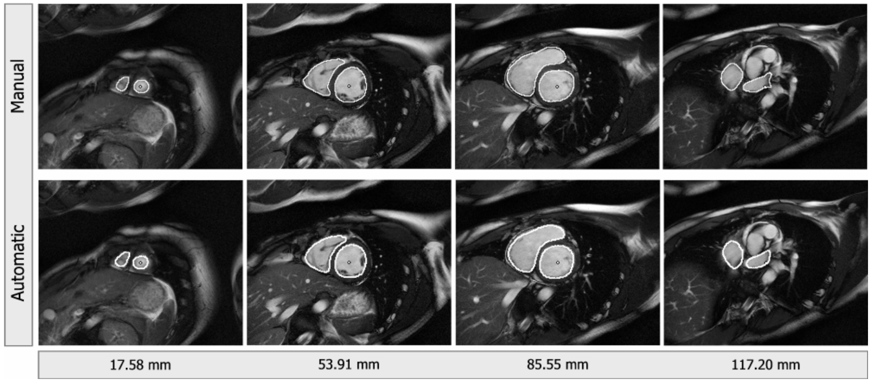
3D Cardiac Tracking



The segmented surface from a selected subject

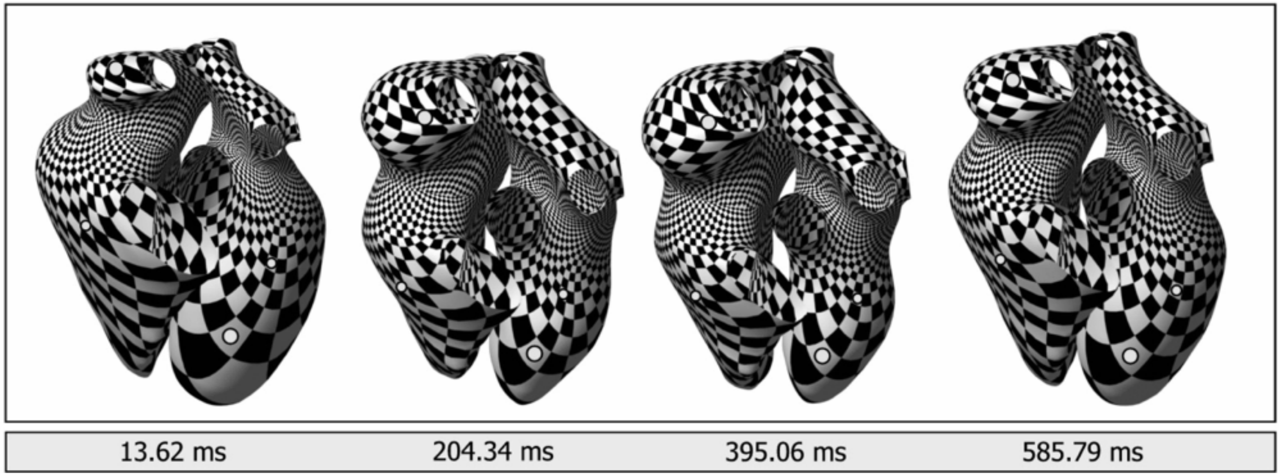


The segmented four-chamber heart superimposed with anatomical landmarks on three short axis images

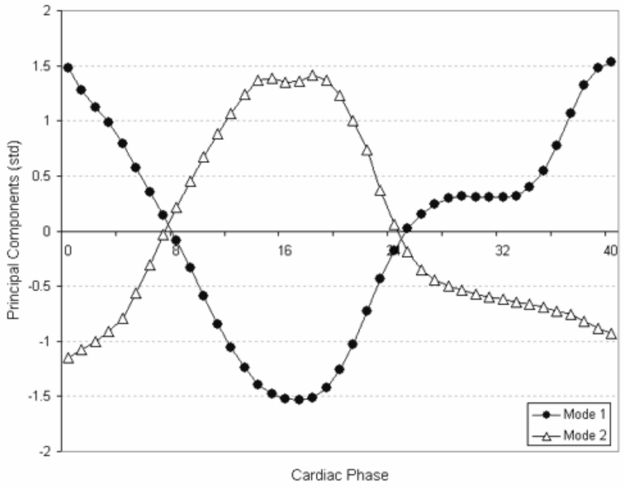


An example of the automatic segmentation result at end diastole

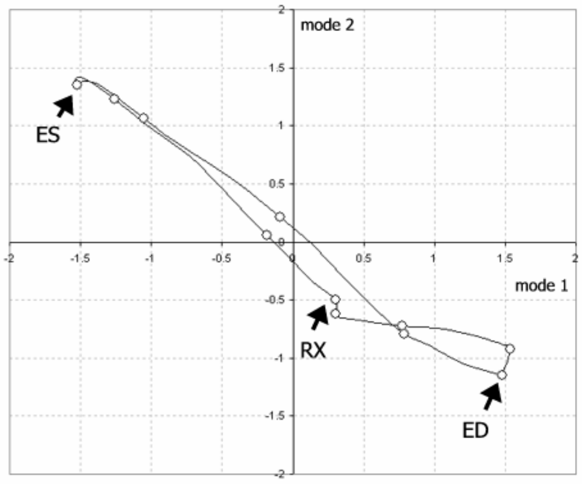
Application to Morphological Analysis



Artificial surface tagging showing the intrinsic motion of the heart in one subject at equally sampled intervals from systole to early diastole



(a) principal components



(b) components trajectory

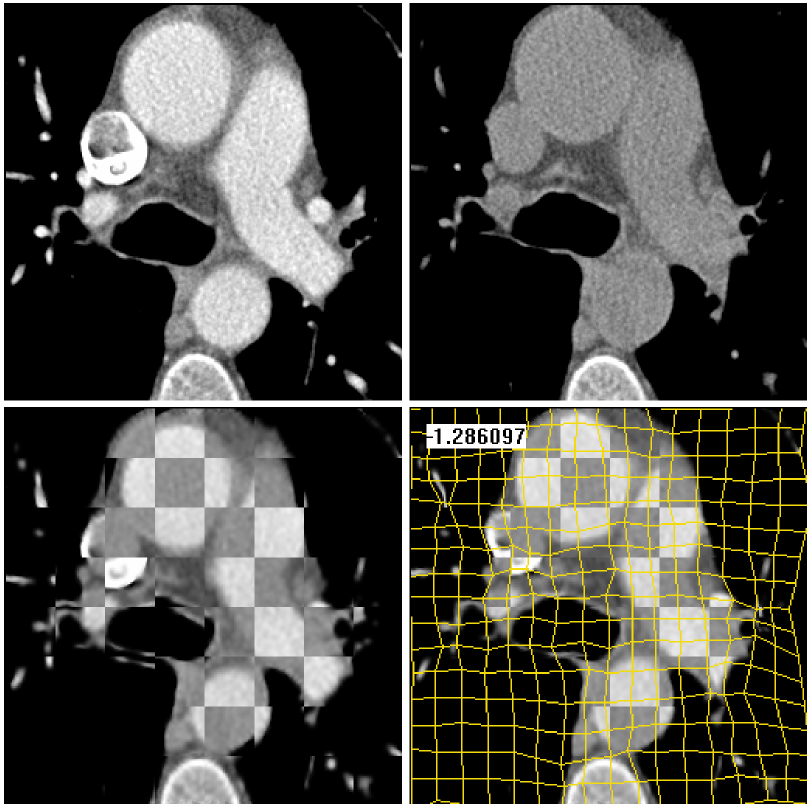
Characterisation of the cardiac motion showing

(a) the standardised first 2 principal components

(b) and the trajectory of the motion, during the cardiac cycle

Image Registration

Computing the transformation which send one image to co-register with the other one



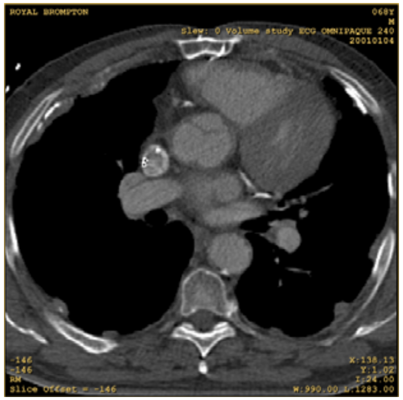
In cardiac imaging, the registration requires free-form deformation so that it can accommodate localized geometrical distortion due to:

- Respiratory motion
- Contractility
- Inter-modality inconsistency

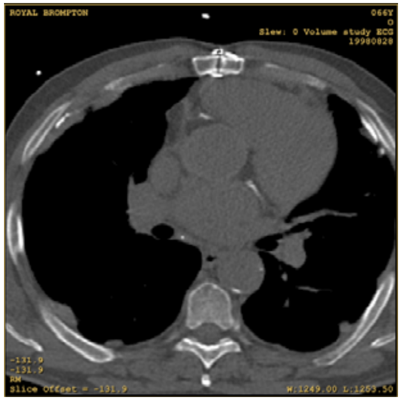
Serial Scans Study

Assessing the calcification of post-operative aortic valve transplants

In obtaining the anatomical landmark, a contrast enhanced scan was acquired *only* at the beginning of the study so as to reduce extra x-ray radiation to the patients. Omnipaque 240 was injected into a vein in the anticubital fossa at a rate of 3 *ml* per second, and images were acquired 30 seconds after the beginning of the injection.



Contrast enhanced baseline



6-month

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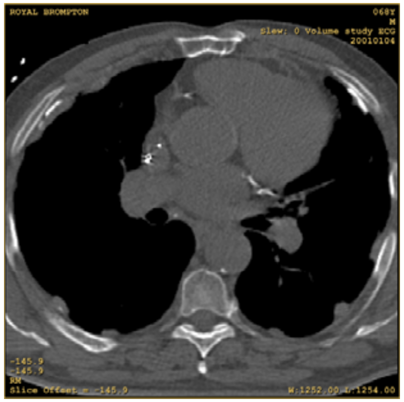


24-month

Why Registration is Needed

Geometrical Misalignments due to inconsistencies of breath-holdings

One slice of a 3D volume before (a) and after (b) contrast valve enhancements and their super-imposition (c) using the green-magenta color scheme, showing mis-registration artifacts.

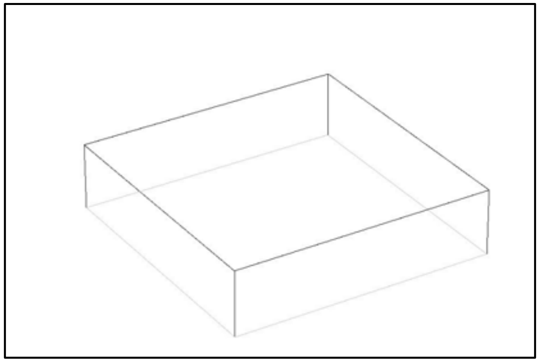
(a)

(b)

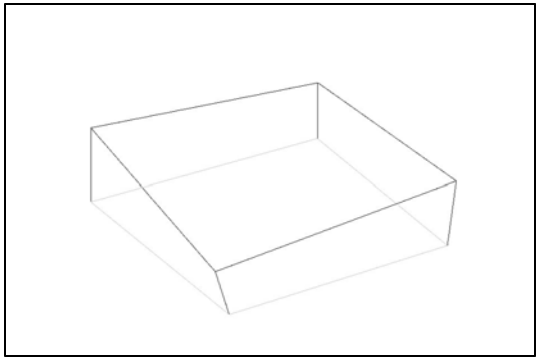
(c)

Obtaining Transformation

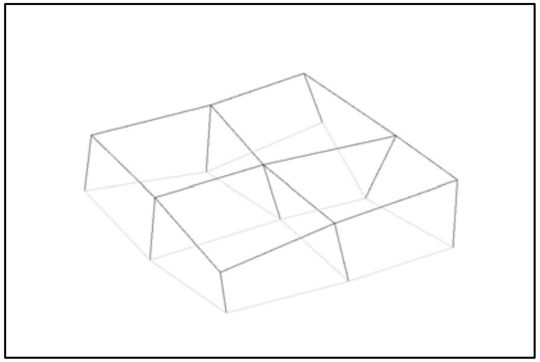
Multi-resolution free-form deformation of 3D volumetric data



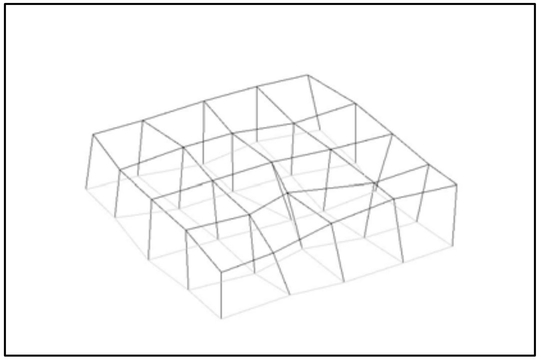
initial grid



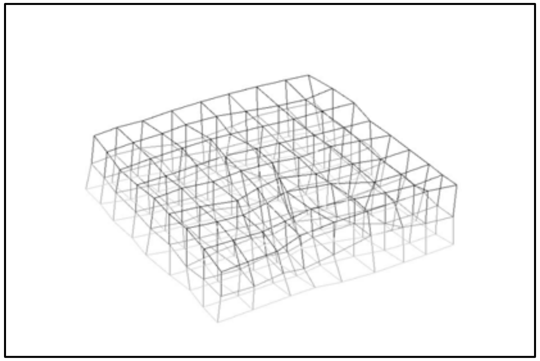
1 x 1 x 1



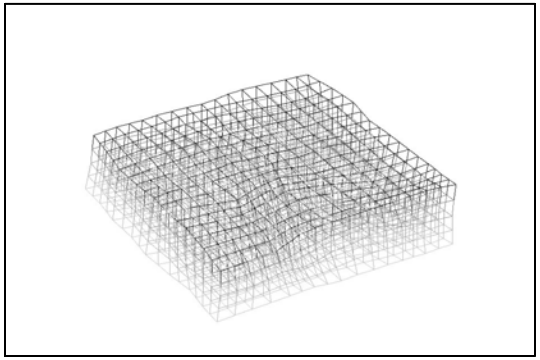
2 x 2 x 1



4 x 4 x 1

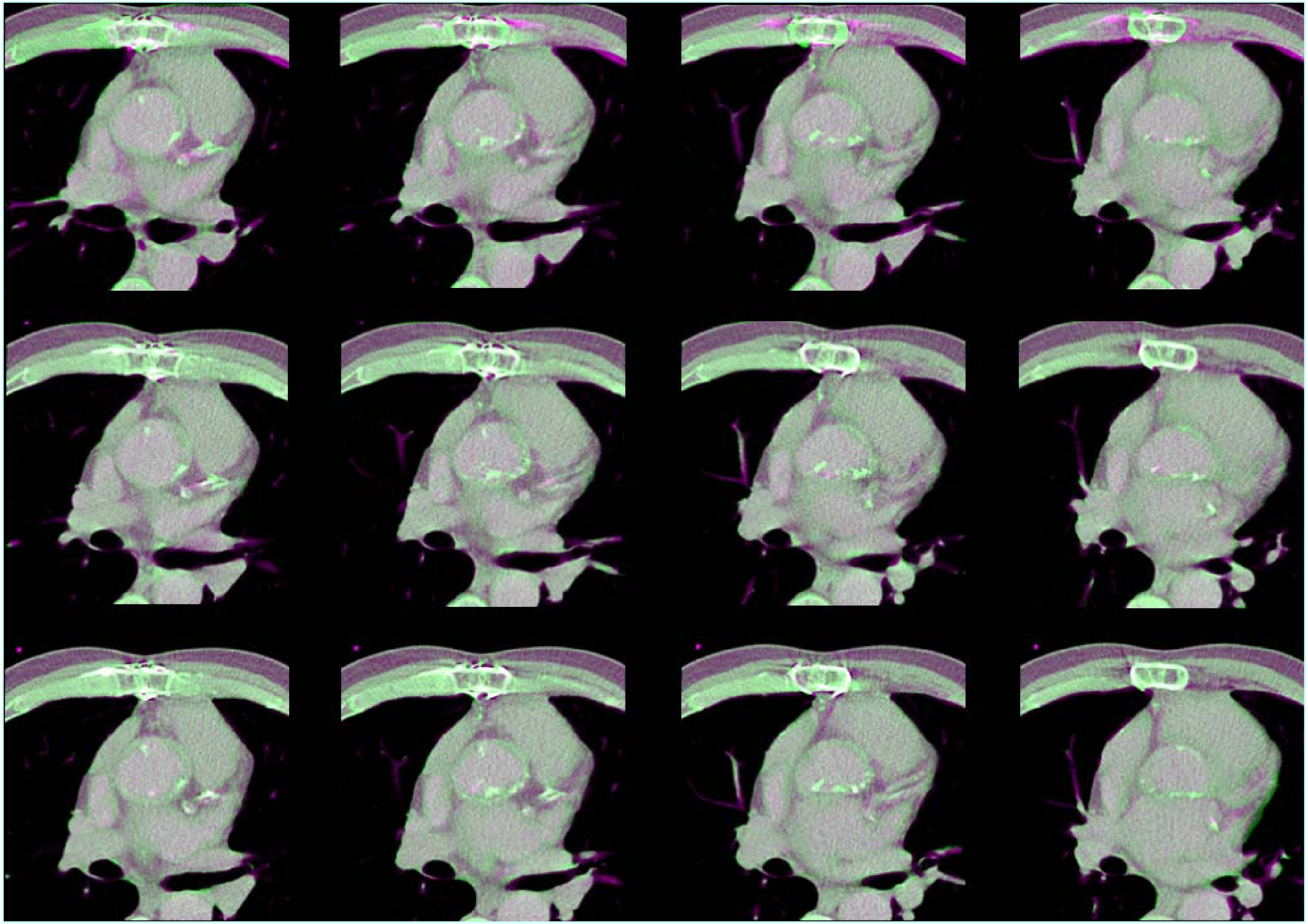


8 x 8 x 2



16 x 16 x 4

Registration Results

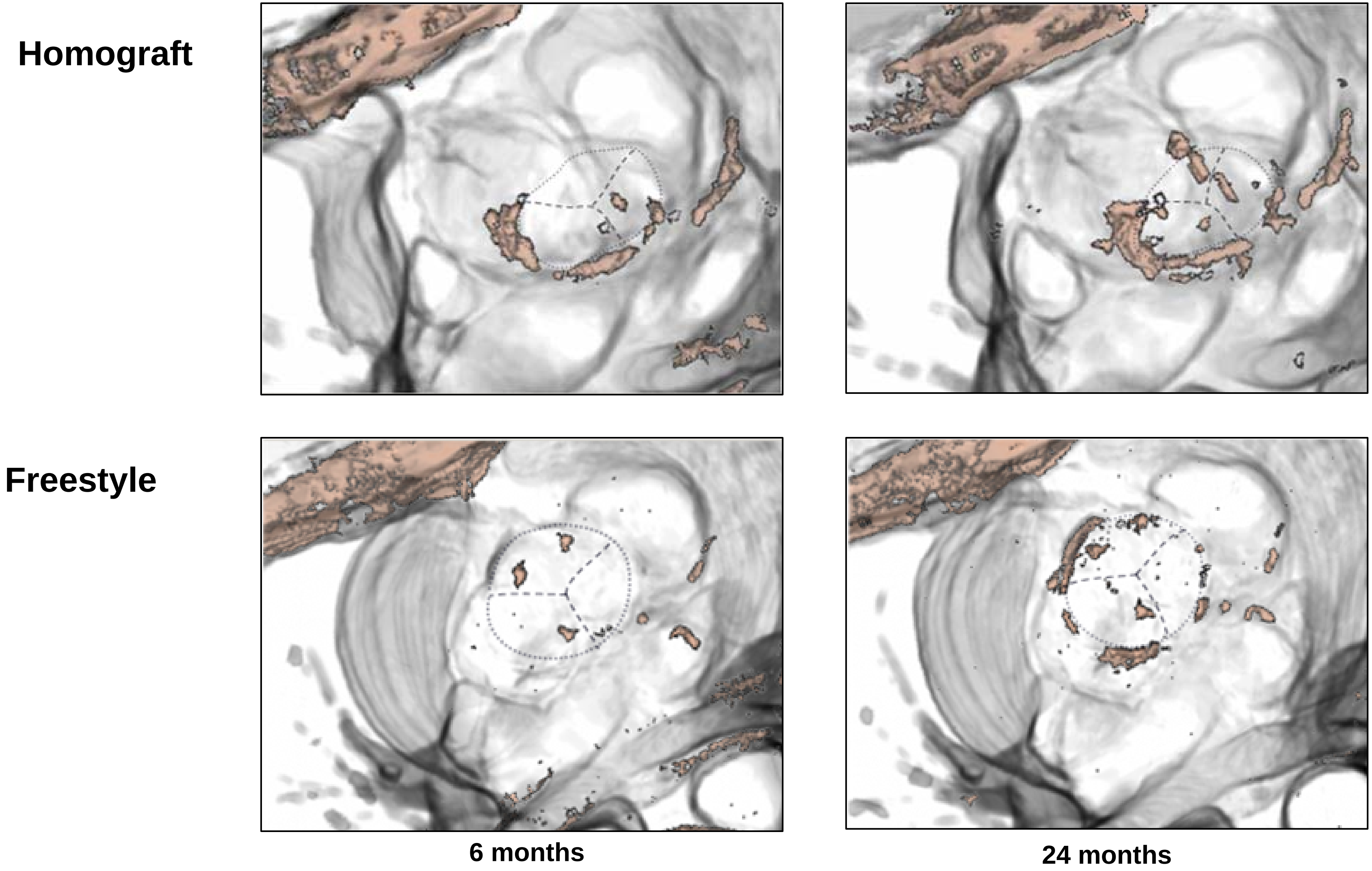


6-month

12-month

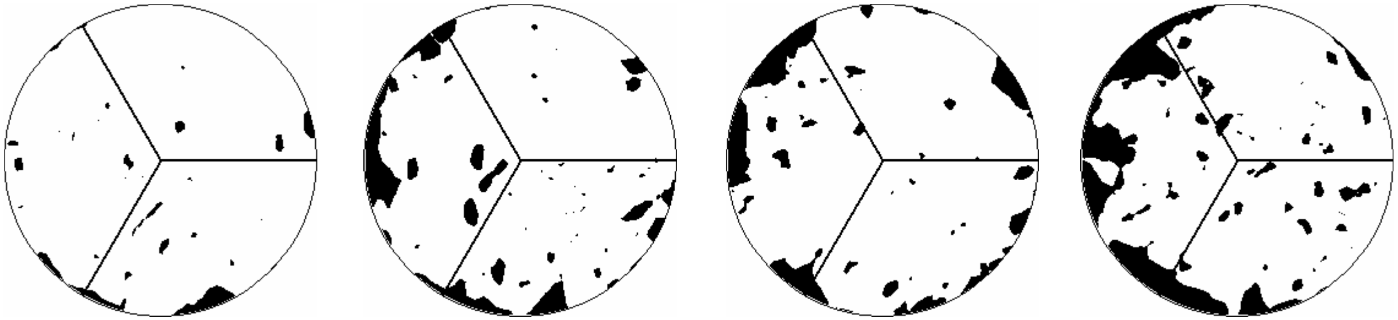
18-month

3D Reconstruction of Calcified Valve

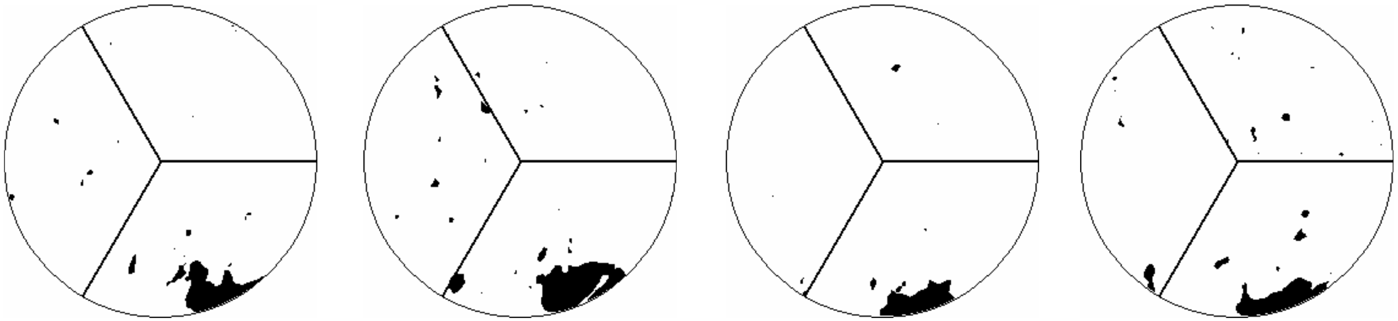


Localised Calcification

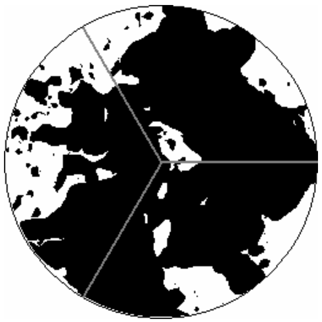
A



B



C



A : homograft valve
B : freestyle valve
C : native valve

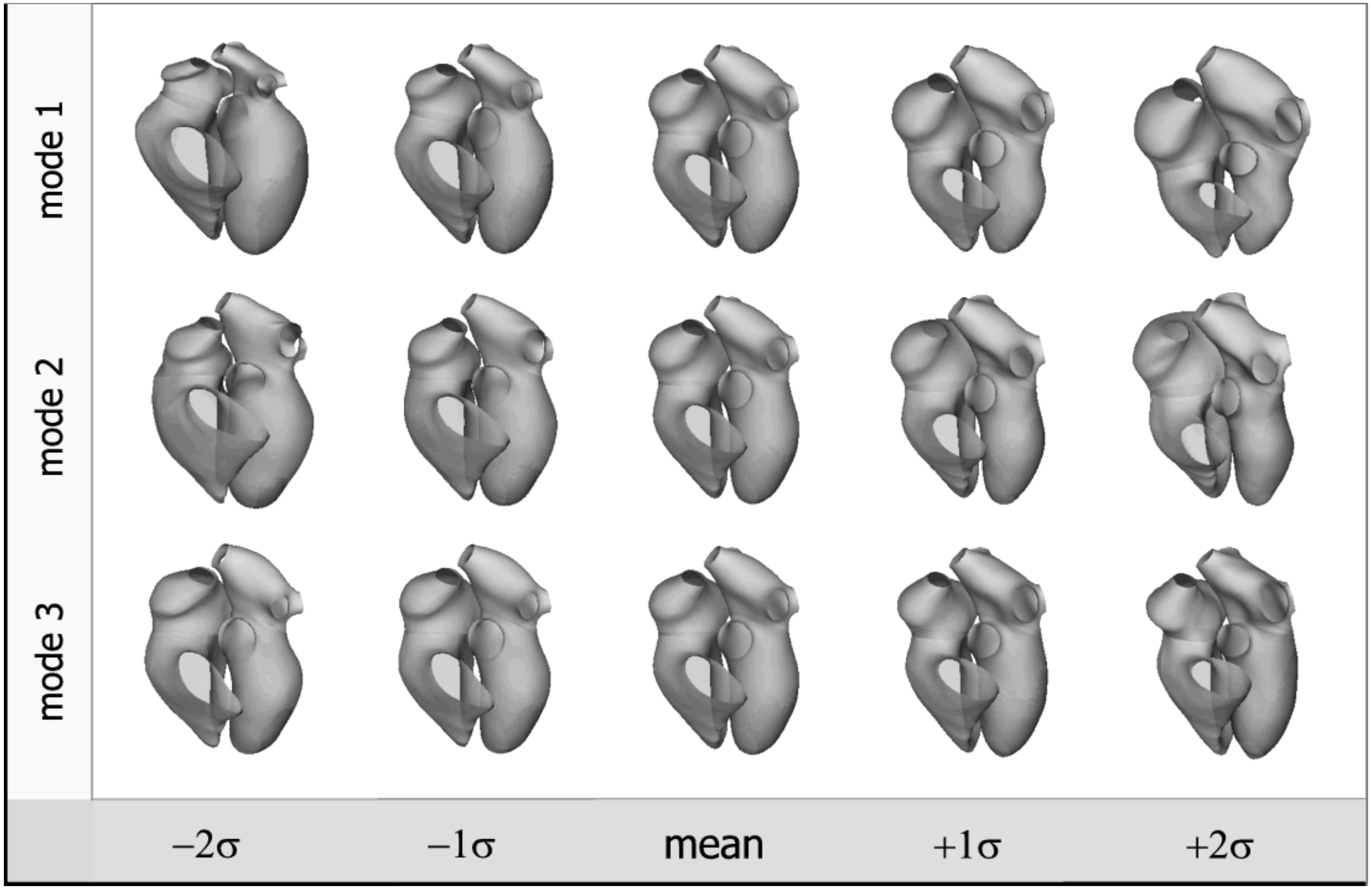
Computational Anatomy

- Biomechanical Models
  - Simple Geometric Models
  - Deformable Surface and Volumetric Models
  - Clinical Implications
- Fluid-Structural Interaction Models
  - Computational Fluid Dynamics
  - Mesh Generations
- Electrical Activities Models
  - Not discussed in details

Biomechanical Models

- Simple Geometric Models
  - Simplified both topology and geometry
  - Rapid evaluation of global parameters
  - Relatively inaccurate
- Deformable Surfaces and Volumes
  - Requires precise *a priori* of cardiac structures and motions
  - Correct dense correspondence is necessary, *e.g.* via MRI Tagging, or echo tissue Doppler
- Clinical Implications
  - *e.g.* to identify abnormal contractile functions of the myocardium

Optimal Cardiac Model

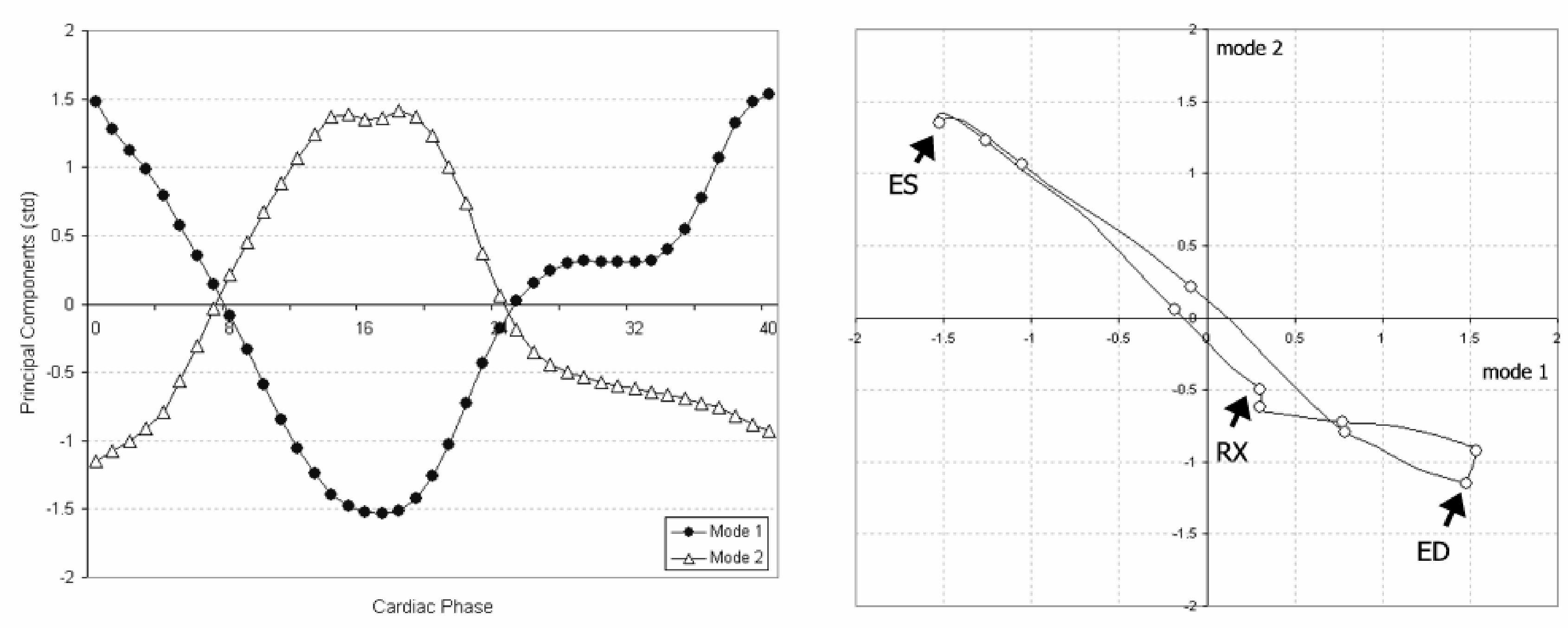


The optimal model should realistically represent the cardiac geometry/morphology

Clinical Implications

Characterisation of the cardiac motion showing

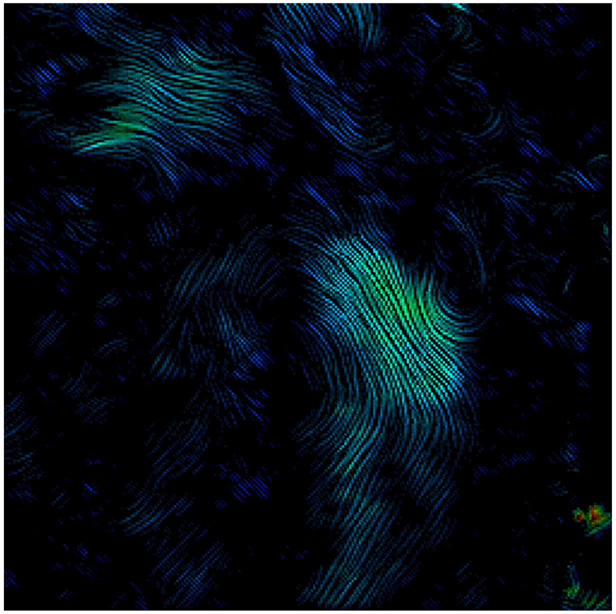
(a) The standardised first 2 principal components
(b) And the trajectory of the motion, during the cardiac cycle



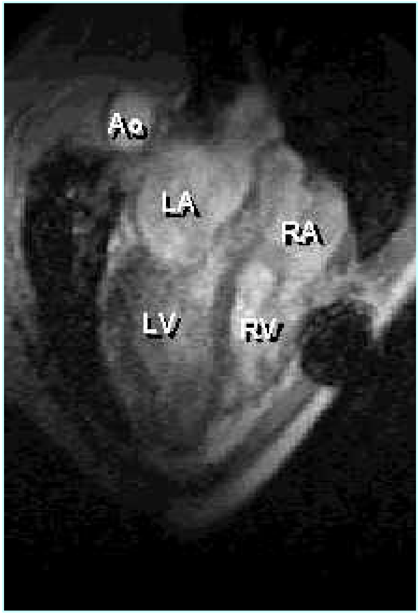
(a) principal components

(b) components trajectory

Fluid-Structural Interactions



Flow Pattern



Magnitude Image

The dynamic interaction of the left ventricular structure with blood flow is of major interest in studying local deformation and stress.

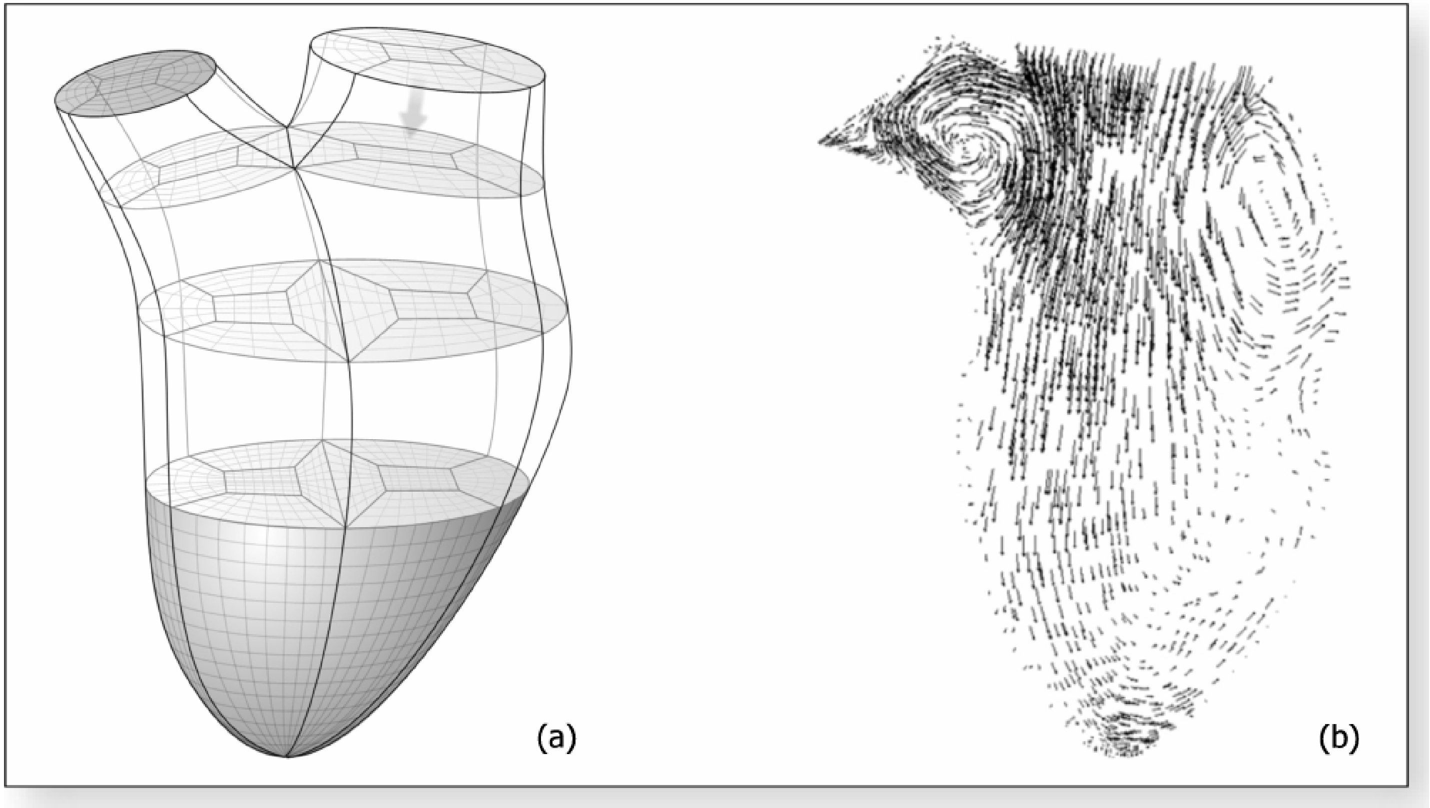
Numerical Modeling of this coupled relationship facilitates detailed analysis of the left ventricle kinematics and hemodynamics.

A patient with severely dilated left ventricle.

Computational Fluid Dynamics

- Obtaining Boundary and Initial conditions
  - Extracting the cardiac structures from imaging data
  - Determining flux across the boundaries *in vivo*, e.g. from Doppler echocardiography
- Approximation
  - Mathematical models: Navier-Stroke equations
  - Mesh generation: Accuracy vs. Efficiency
  - Temporal and Material correspondence
- Numerical Simulation
  - Extremely computational expensive

A CFD Example

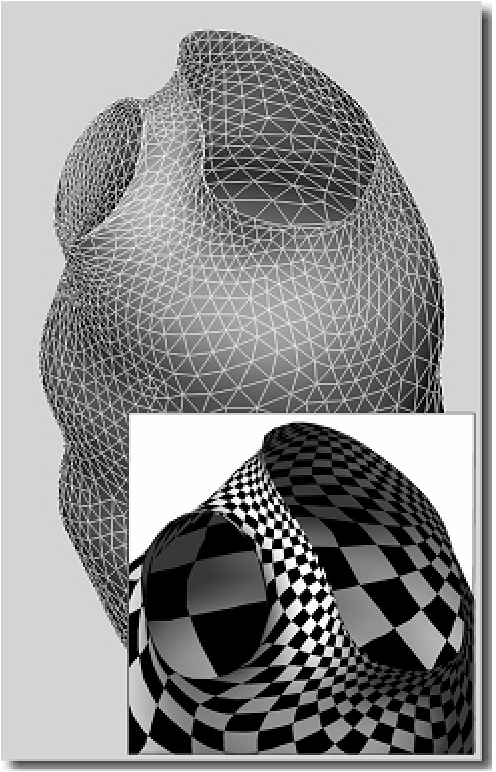


An example of a typical CFD simulation framework, showing of block-structured mesh of a left ventricle (a) and the corresponding simulated flow (b).

Current Issues

- **Biomechanical Models**
  - Anatomical accuracy, e.g., the inclusion of inflow/outflow tracks
  - Material correspondence/tracking
  - Compact model description
- **Computational Fluid Dynamics**
  - Anatomical accuracy
  - Material correspondence/tracking
  - Model (mesh) adaptivity
- **Activation Models**
  - Dynamic morphology

The appropriate geometrical model can solve some of these limitations.

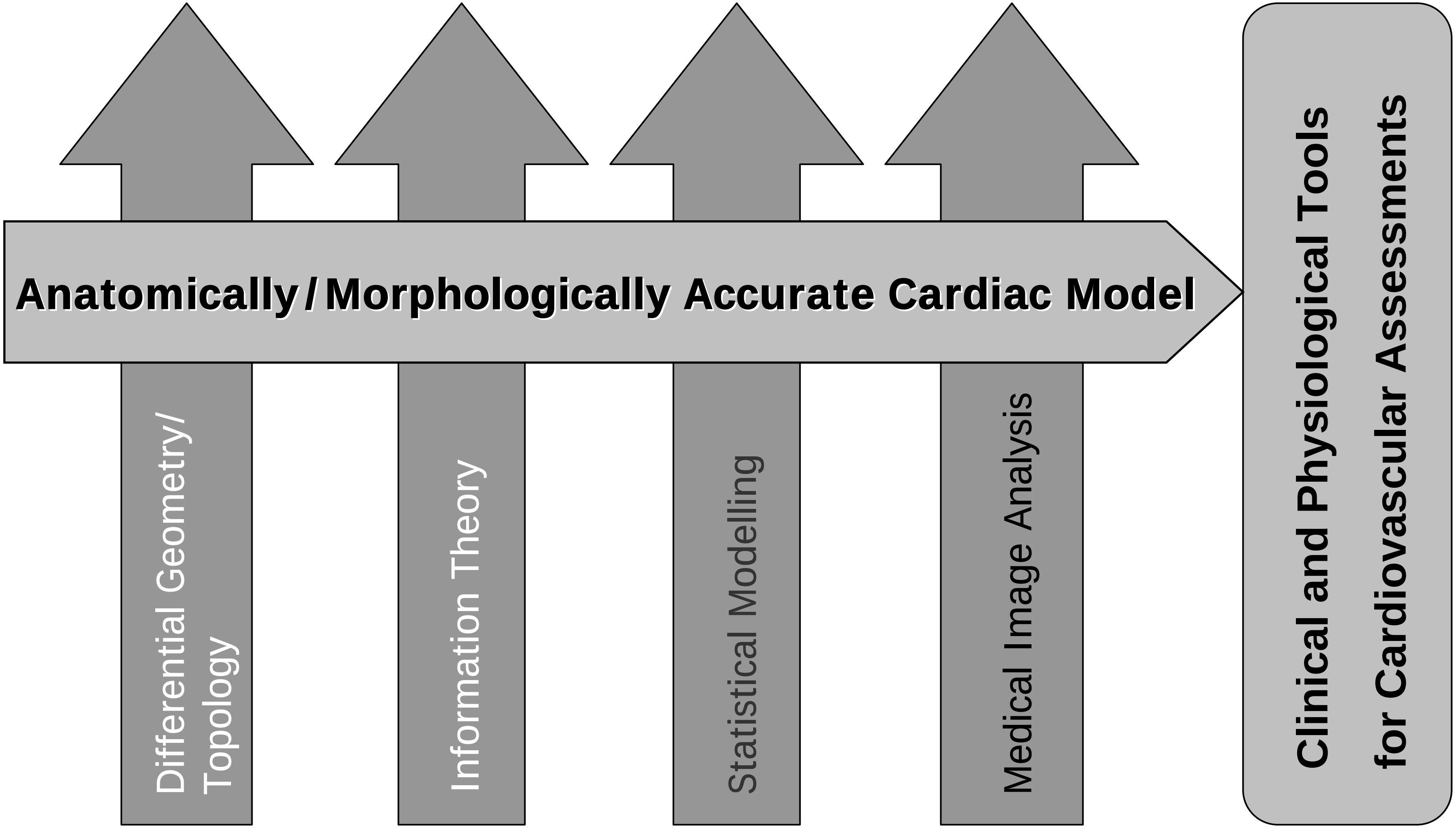


Conformal Map

Conclusions

- Roles of Medical Imaging in CAD and Simulation for Cardiovascular Diseases
- Computer-Aided Diagnosis of Cardiovascular Diseases
  - Image Segmentation
  - Image Registration
- Computational Anatomy
  - *Biomechanical Simulation*
  - *Fluid-Structural Simulation*
  - *Electrical Activation*

Research Themes at SUT



Anatomically / Morphologically Accurate Cardiac Model

Differential Geometry/
Topology

Information Theory

Statistical Modelling

Medical Image Analysis

**Clinical and Physiological Tools
for Cardiovascular Assessments**