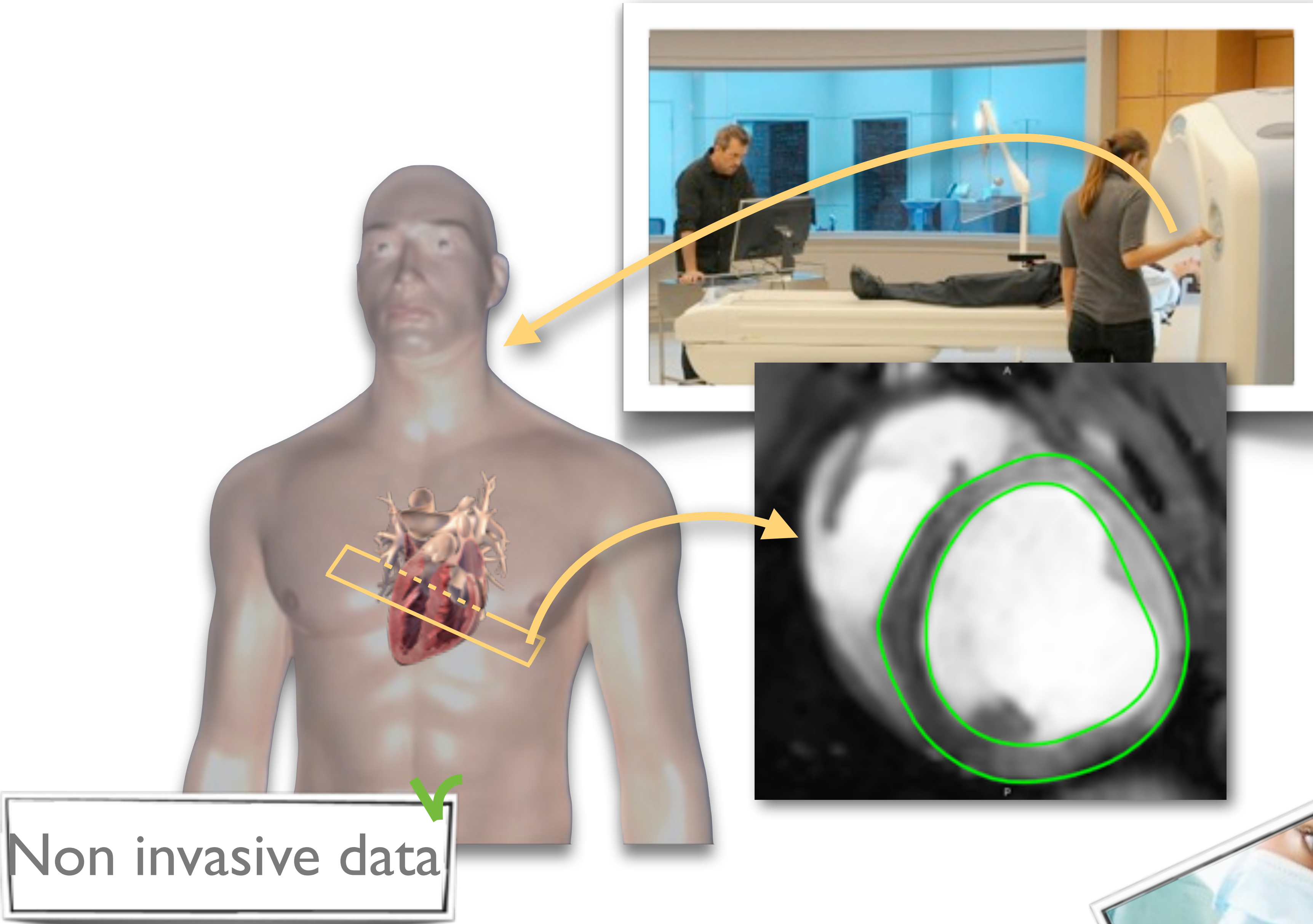
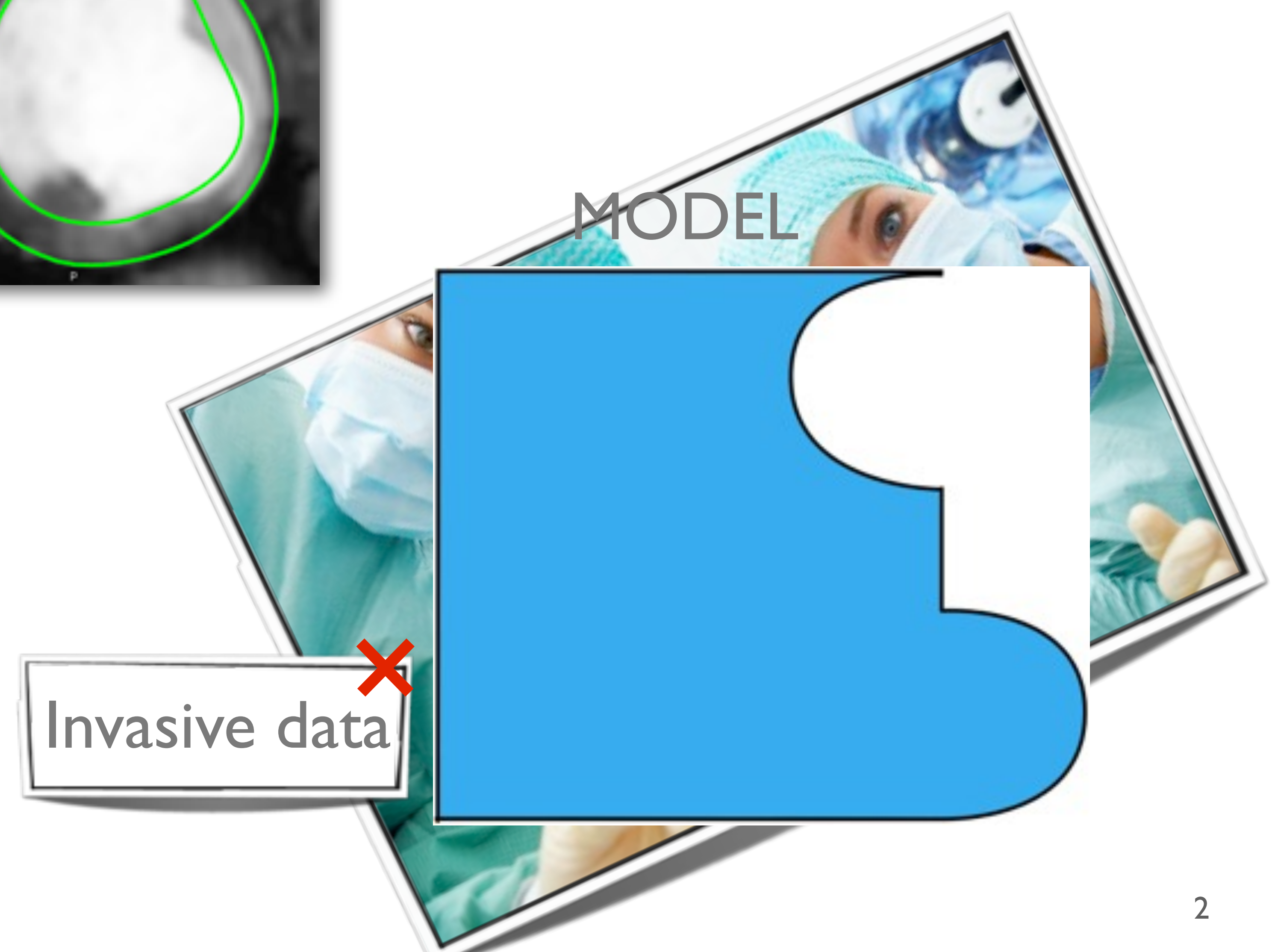
Concepts of data assimilation in cardiac modeling

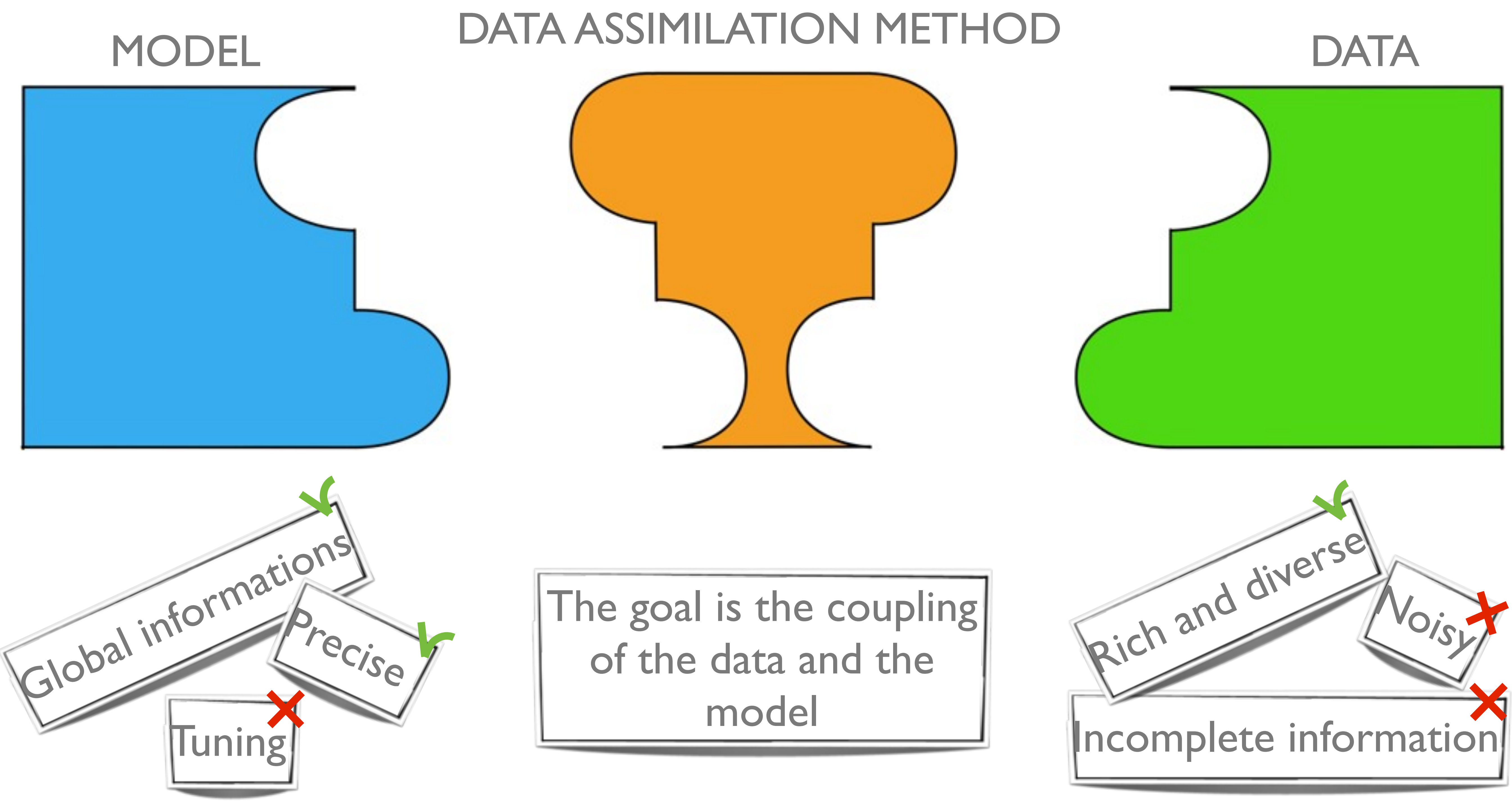
MACS team project, INRIA Saclay.

Motivation of data assimilation for a cardiac model



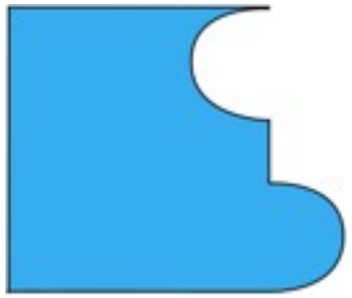


“Have you said data assimilation ?”



Outline of the presentation

MODEL



- A little bit of physiology
- Overview of a cardiac biomechanical model
- Time and spacial discretization

DATA

- Magnetic Resonance Images
- Cine and Tagged-MRI processing
- Visible displacements

DATA ASSIMILATION

- Principle of data assimilation
- Assimilating data from images
- Application on a real case

A little bit of physiology

MODEL

- Responsible of the blood circulation. Two pumps :

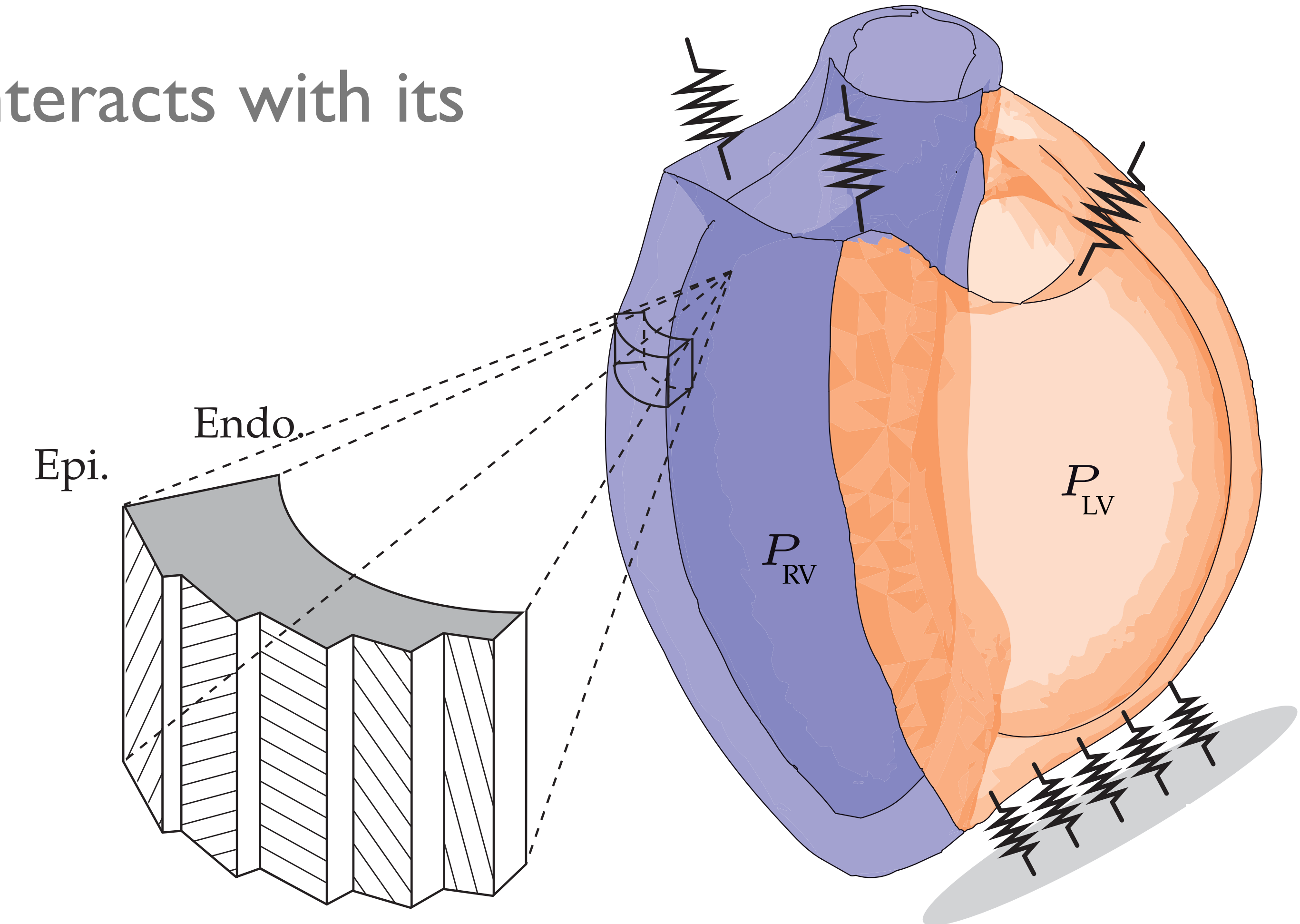
  Right ventricle : drives blood to the lumbs.

  Left ventricle : drives blood to the rest of the body.

- The heart material is composed with fibers sensitive to electrical activation.

- As the heart is deforming it interacts with its surrounding.

How is the heart deforming in time ?



Fibers orientation

A cardiac biomechanical model

MODEL

Non linear elastic model

$$\ddot{y} - \mathrm{div}(\sigma(y)) = f$$ & Boundary conditions

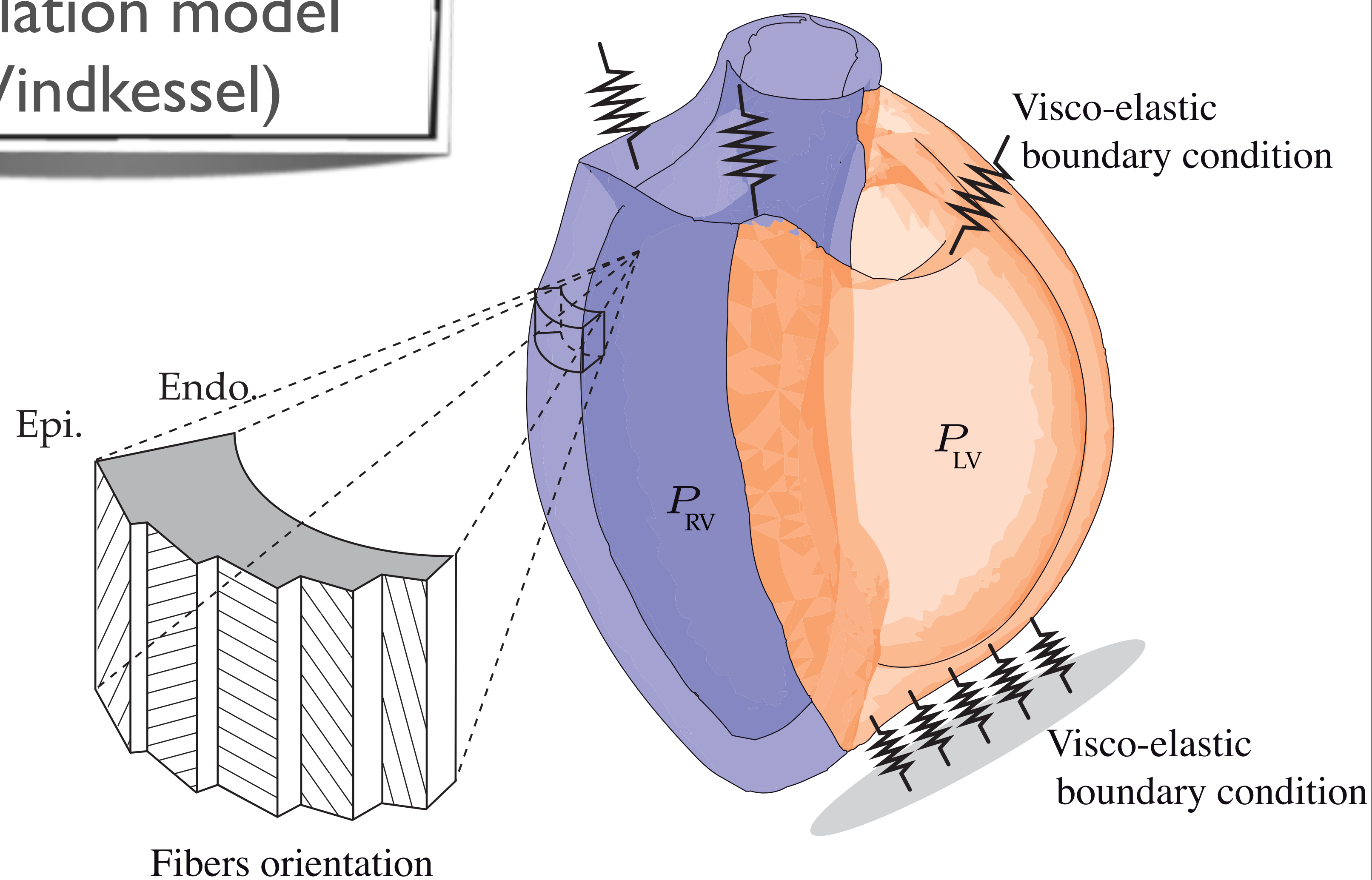
Constitutive law :

Passive anisotropic behavior

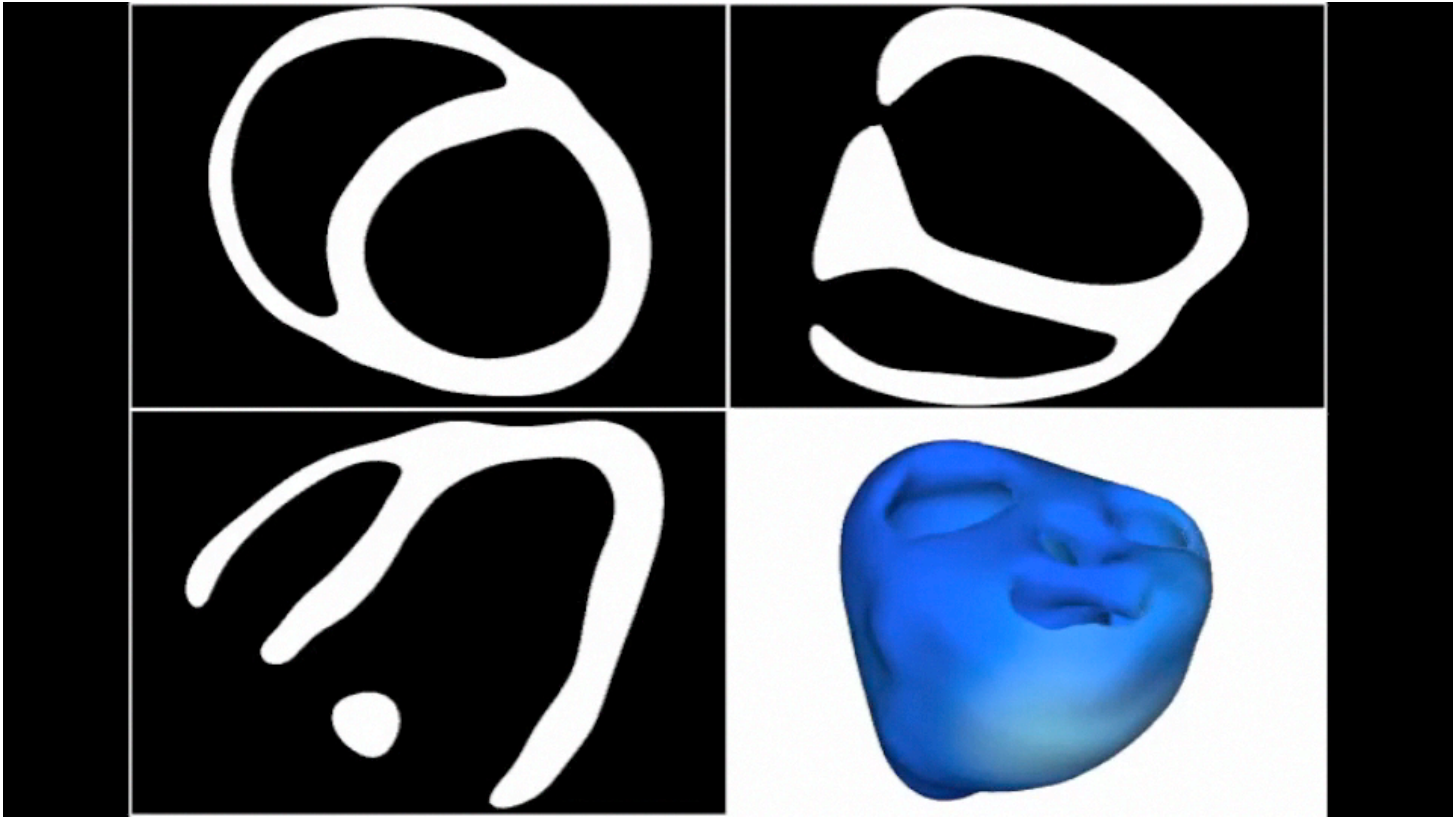
&

Active anisotropic behavior

Pressure managed with simplified valve and circulation model (Windkessel)



Time and spacial discretization



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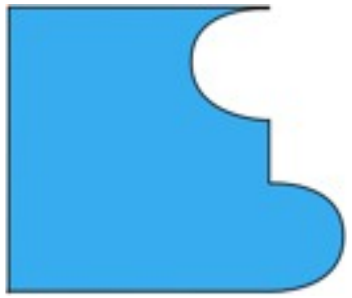

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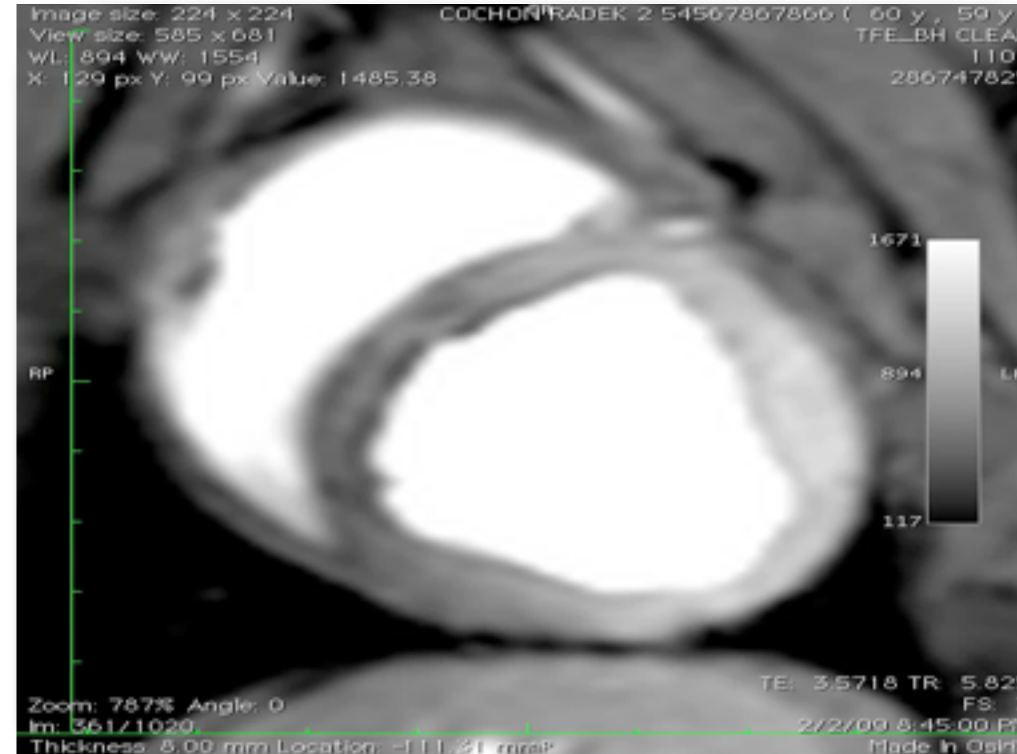
Magnetic resonance images

cine - MRI

Magnetization alignment of the heart tissue.

Expected visibility : Internal and external surface of the heart



tagged - MRI

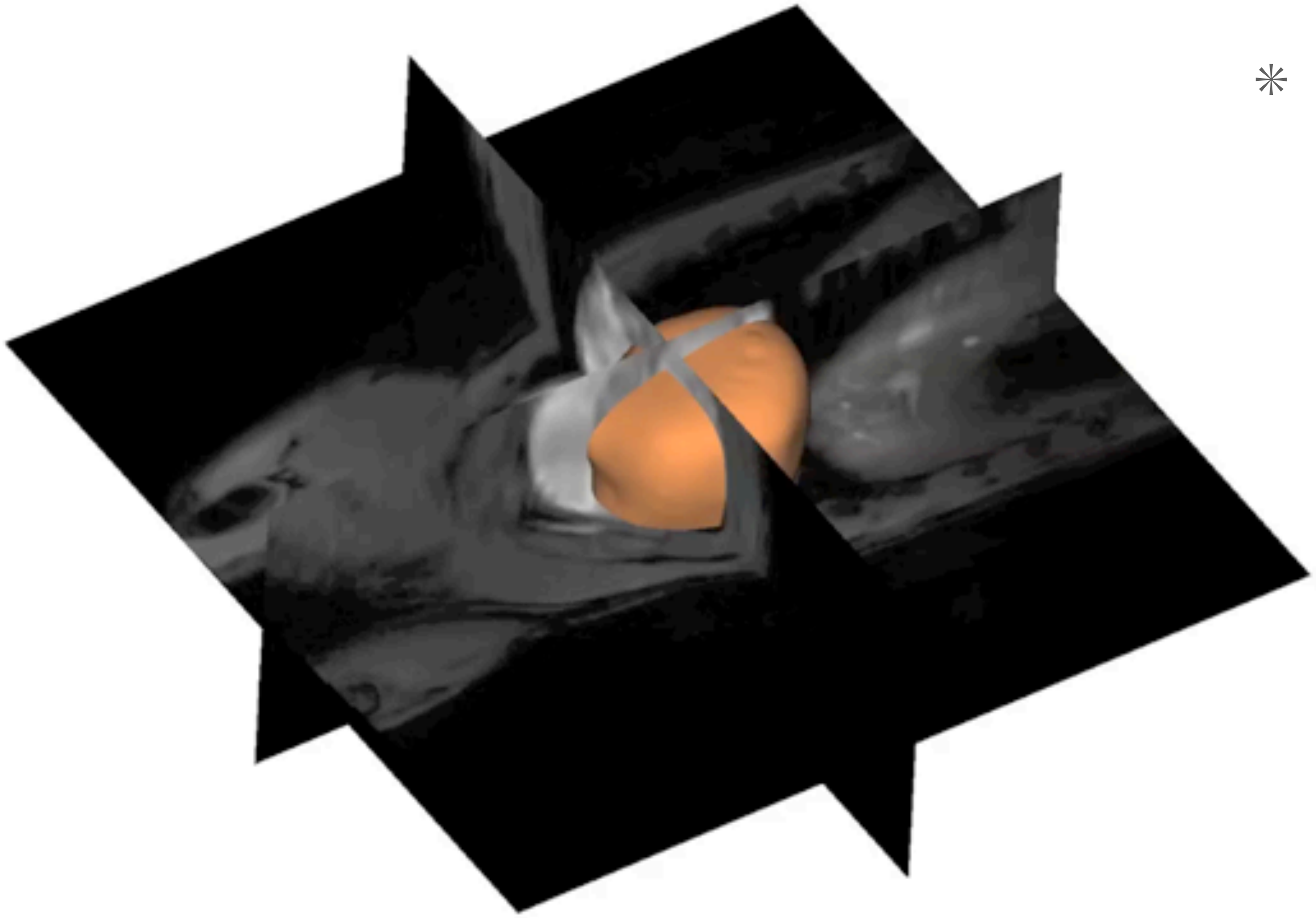
Positioning a regular grid onto the heart wall.

Expected Visibility : Intramural deformation

Cine-MRI processing

3D + time

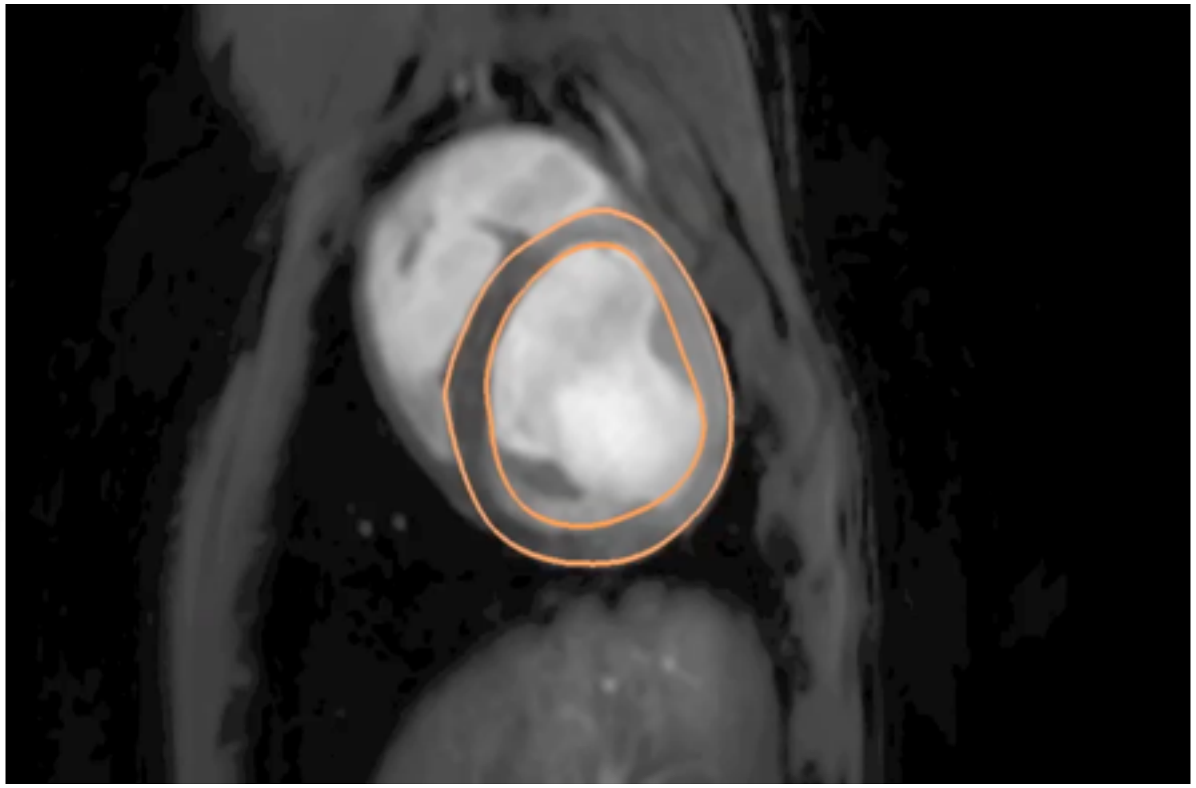
internal and external surfaces



2D + time

internal and external contours

*



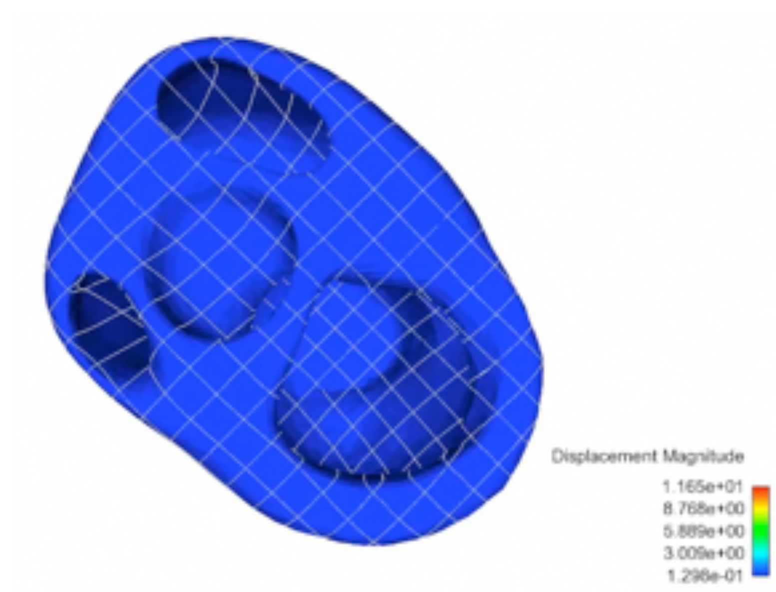
*Manual segmentation of cine-MRI by Radomir Chabiniok, King's College London, UK.

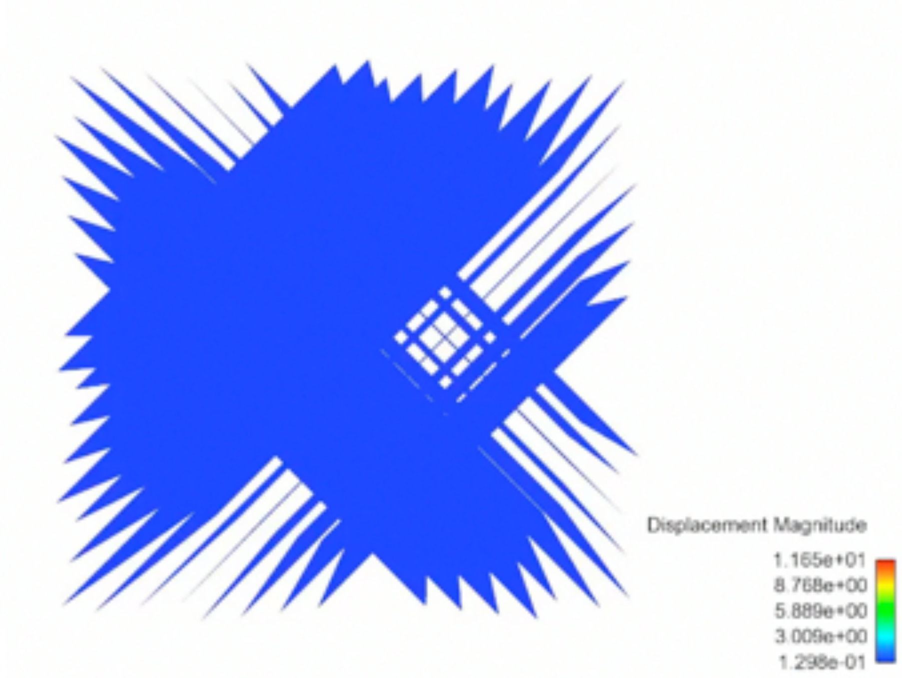
DATA

Tagged-MRI processing

3D + time

deforming tag planes

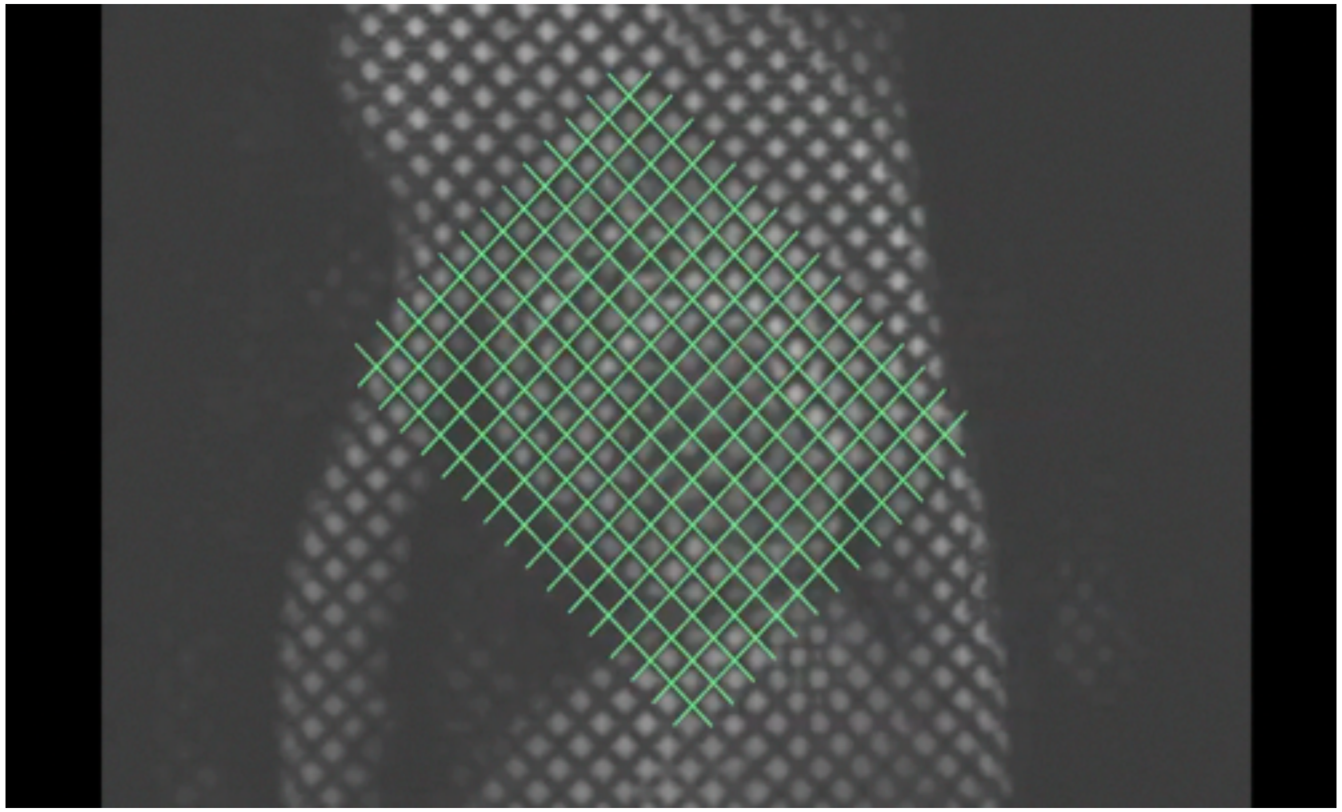




2D + time

deforming tag grid

*



*In collaboration with Patrick Claryss, INSA Lyon.

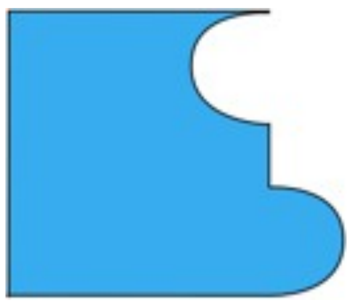
Tagged-MRI processing : visible displacement

- Tracking deforming patterns
- Provides only visible displacements on the image plane.
- Displacement in the transversal direction are invisible

**In collaboration with Patrick Claryss, INSA Lyon.*

Outline of the presentation

MODEL



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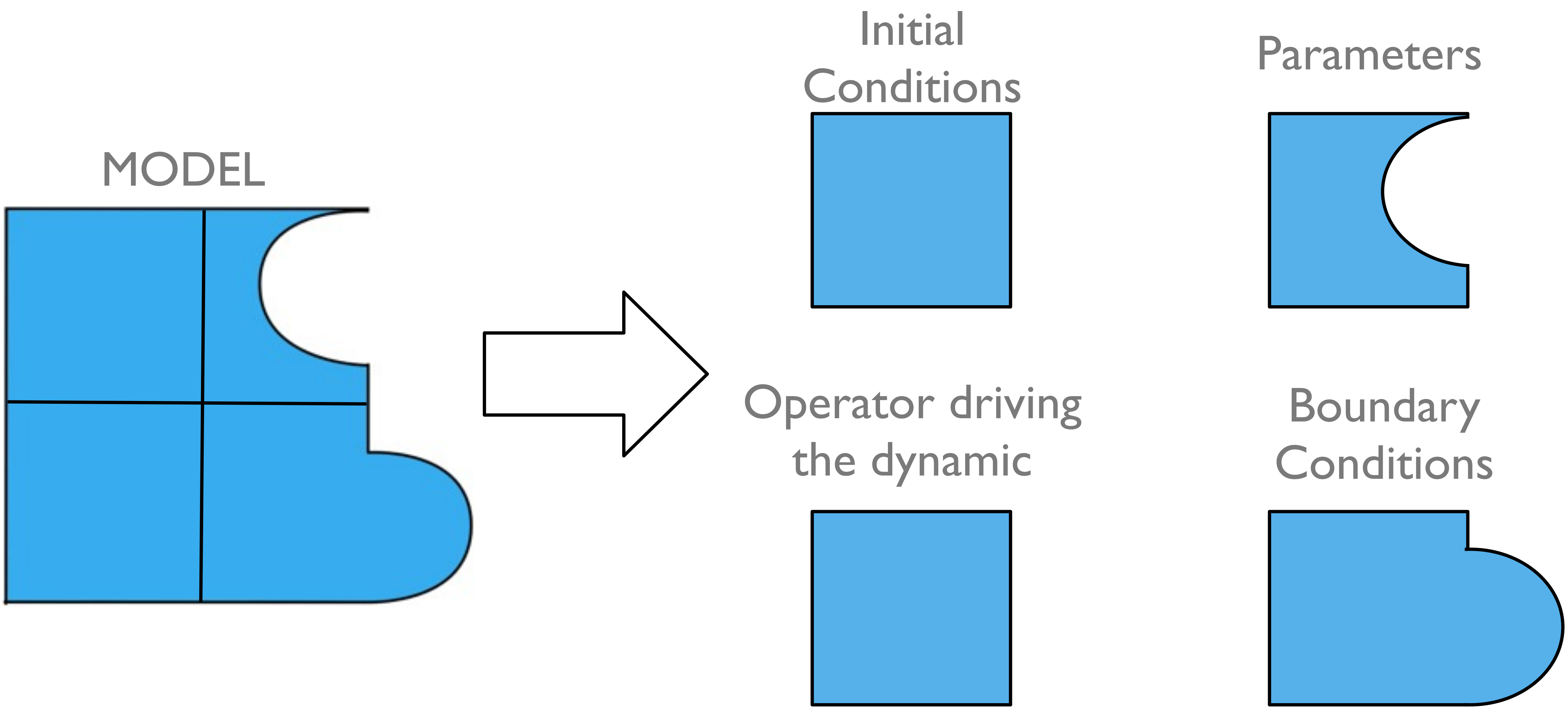
Principle of Data Assimilation

"Where are the errors coming from ?"



Can we use available informations to reduce these errors ?

Principle of Data Assimilation

DATA ASSIMILATION

$$x = \begin{pmatrix} y \\ \dot{y} \end{pmatrix}$$

MODEL

$$\dot{x}(t) = A(x(t))$$
$$x(0) = x_0 + \zeta_x$$

How to correct this error ?

DATA

$$z(t) = Hx(t)$$

Observation operator

$$\widehat{x}(t)$$

Estimation of the real system

1st step

Use the observation operator to reach the data space.

OBSERVED ESTIMATION

$$H\widehat{x}(t)$$

2nd step

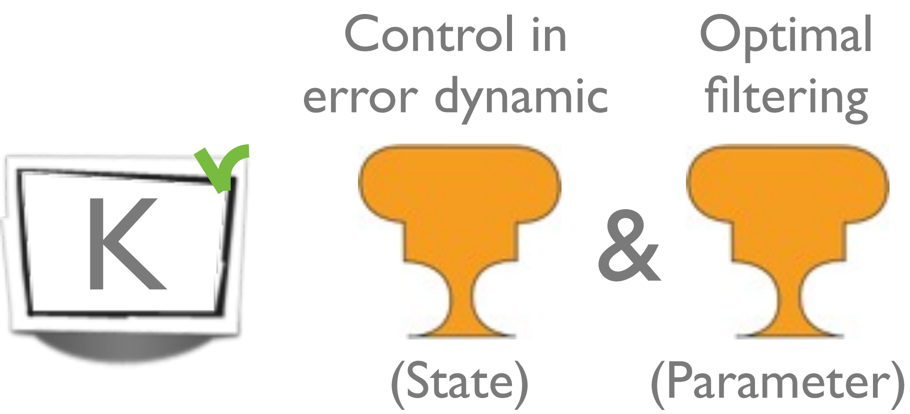
Filter into the dynamic the differences between the data and the observed estimation.

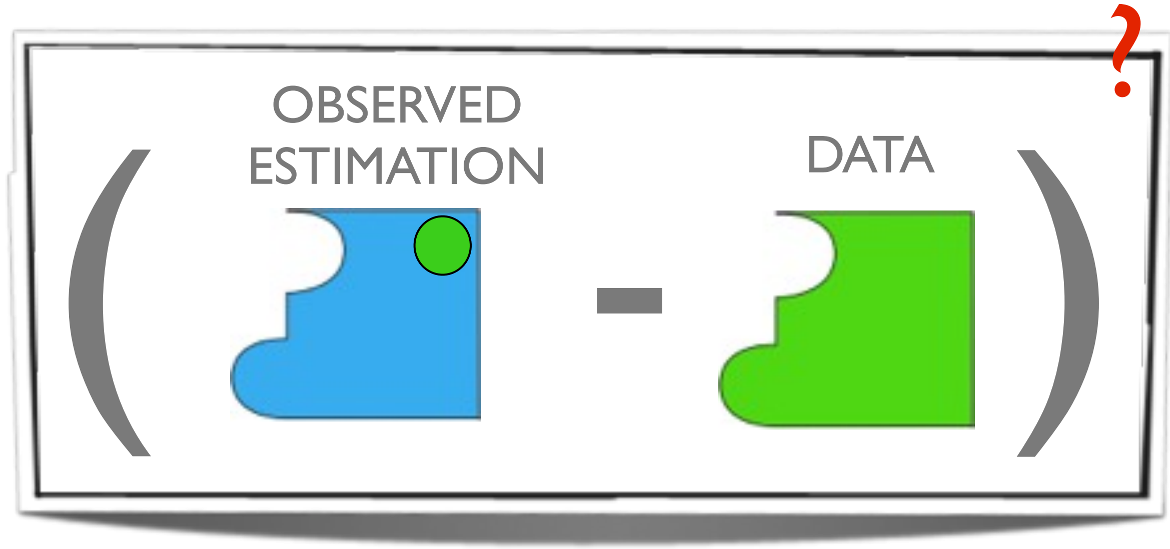
ESTIMATION = MODEL + FILTER (OBSERVED ESTIMATION - DATA)

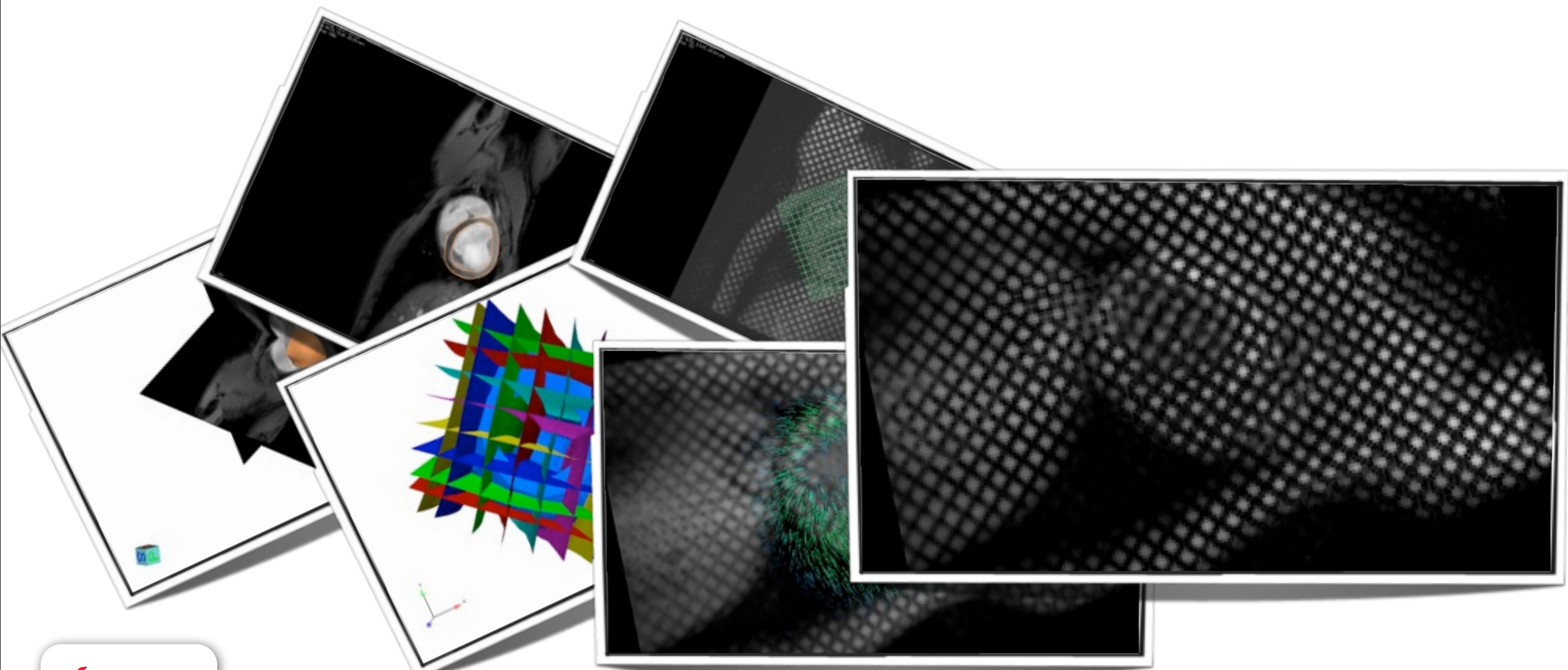
$$\dot{\widehat{x}}(t) = A(\widehat{x}(t)) + K\left(H\widehat{x}(t) - z(t) \right)$$

Filtering approach is not the only way ...

Assimilating data from images





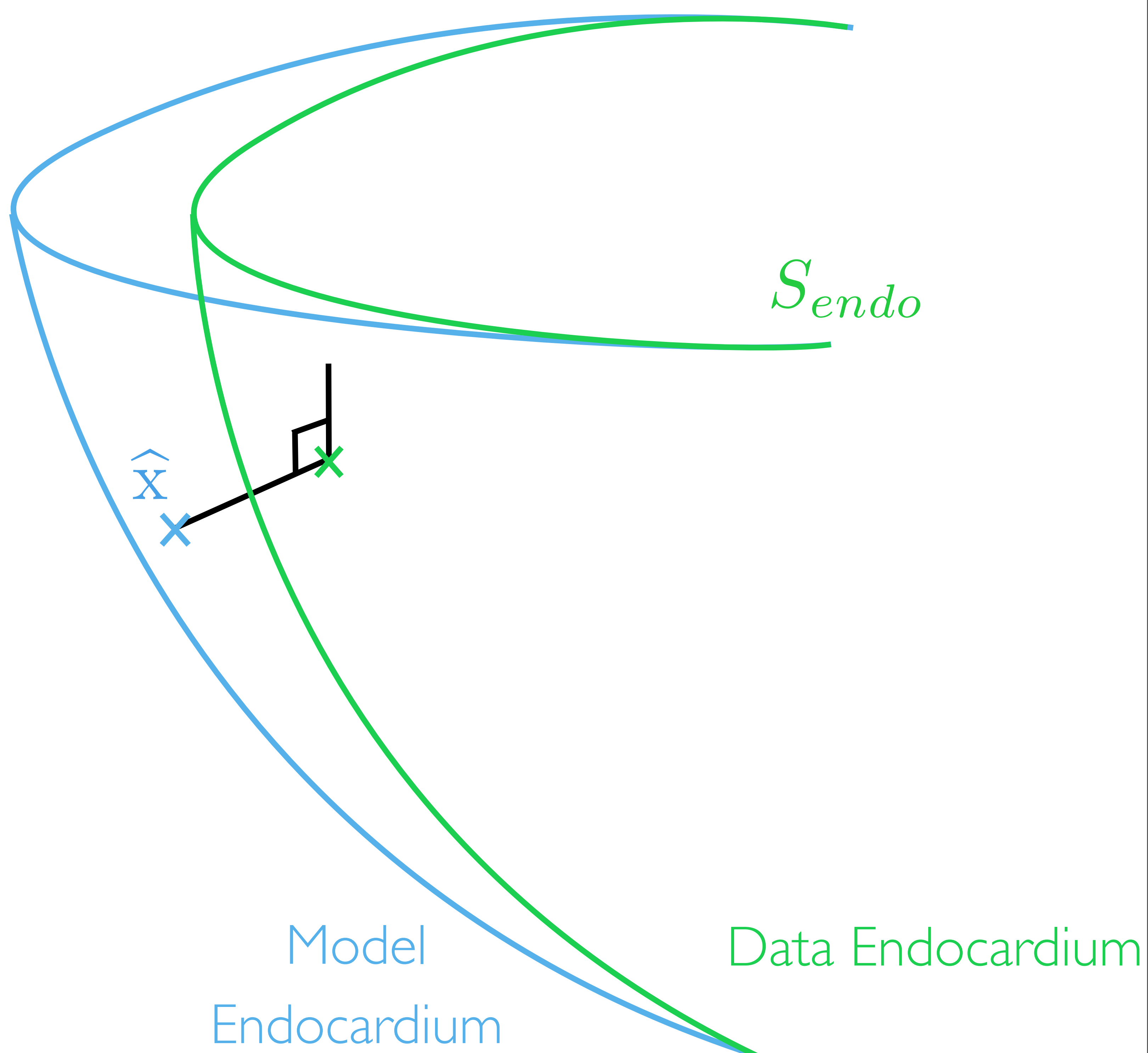


Assimilating data from images

The simple case of cine-MRI segmentation :

$$dist(\widehat{\mathrm{x}}, S_{endo})$$

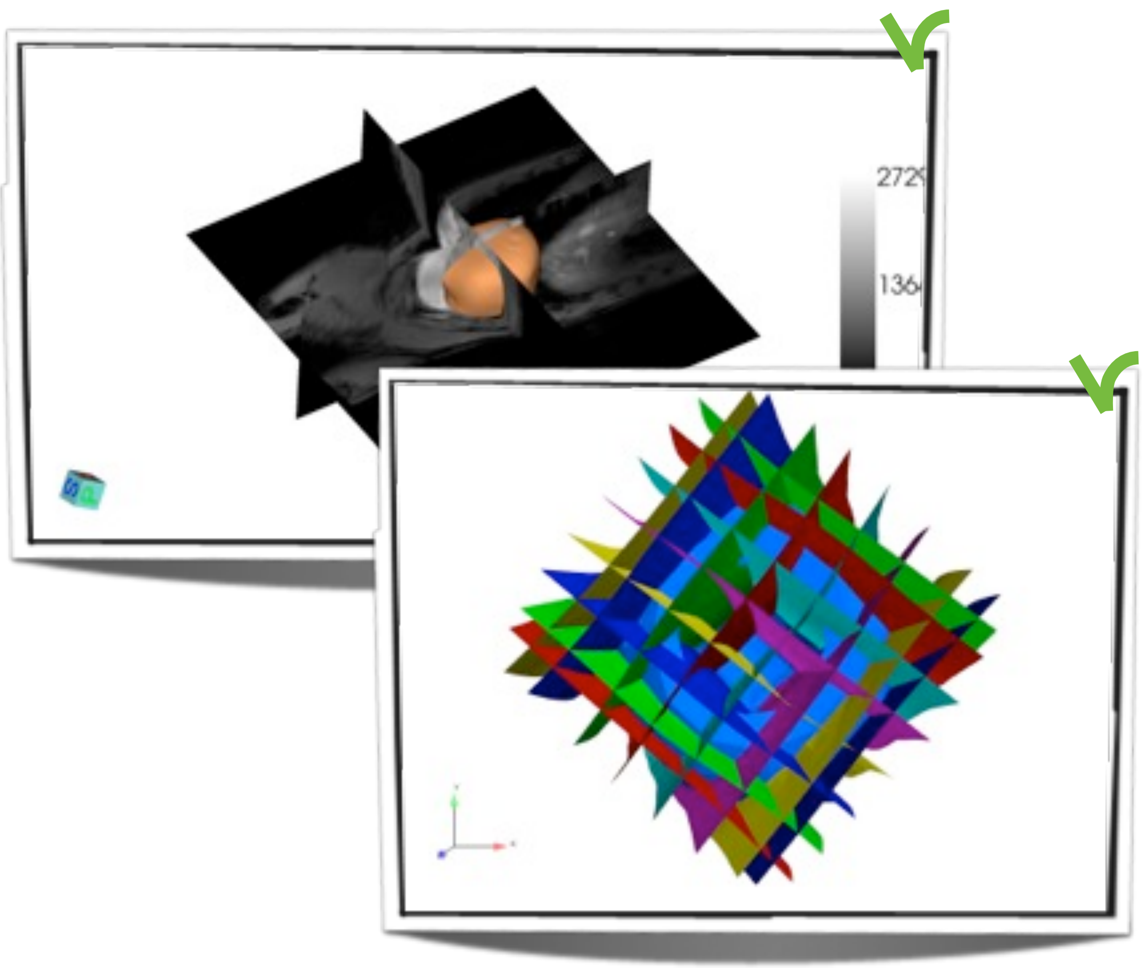
Signed distance between the model and the data



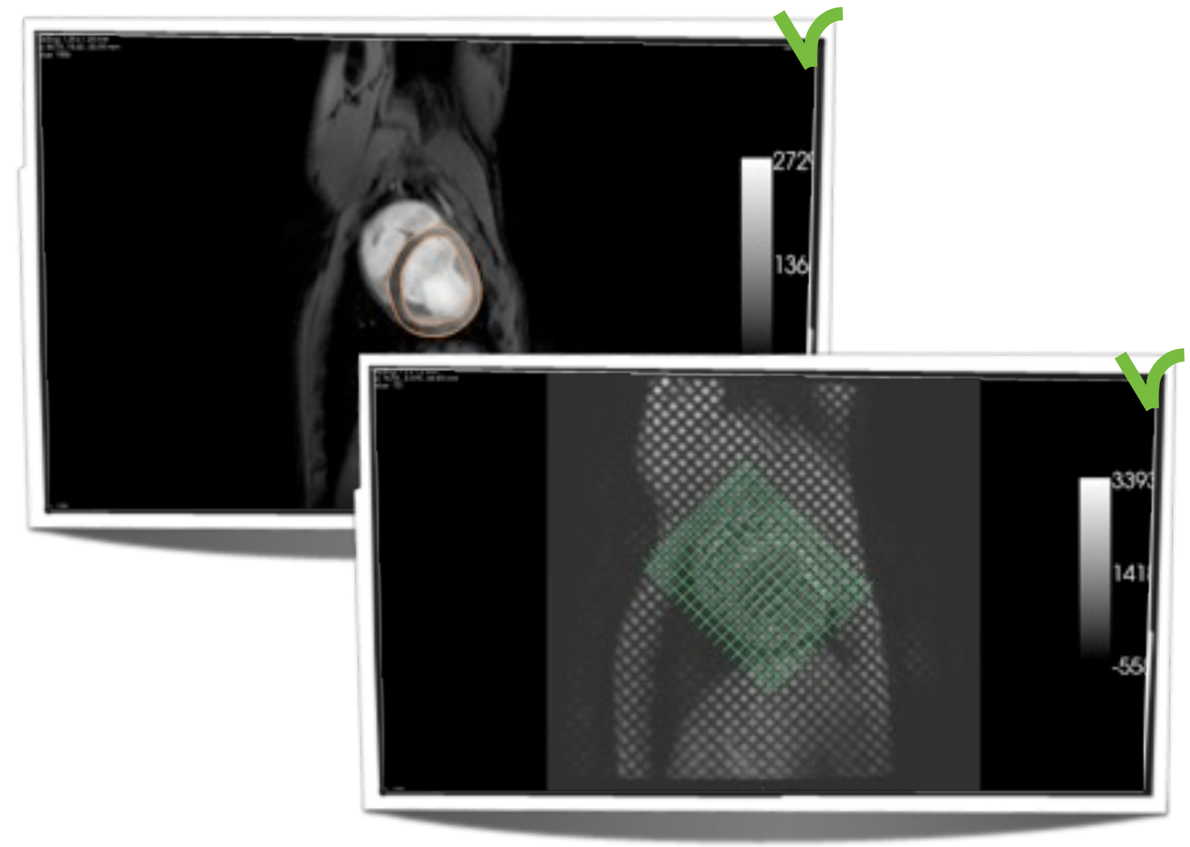
Non linear observation operators

Assimilating data from images

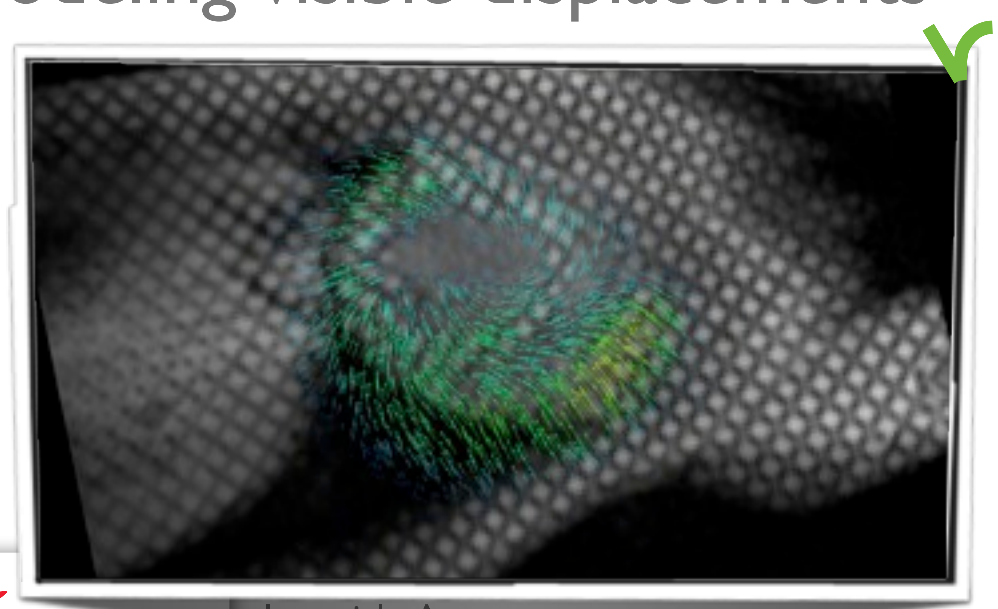
Signed distance

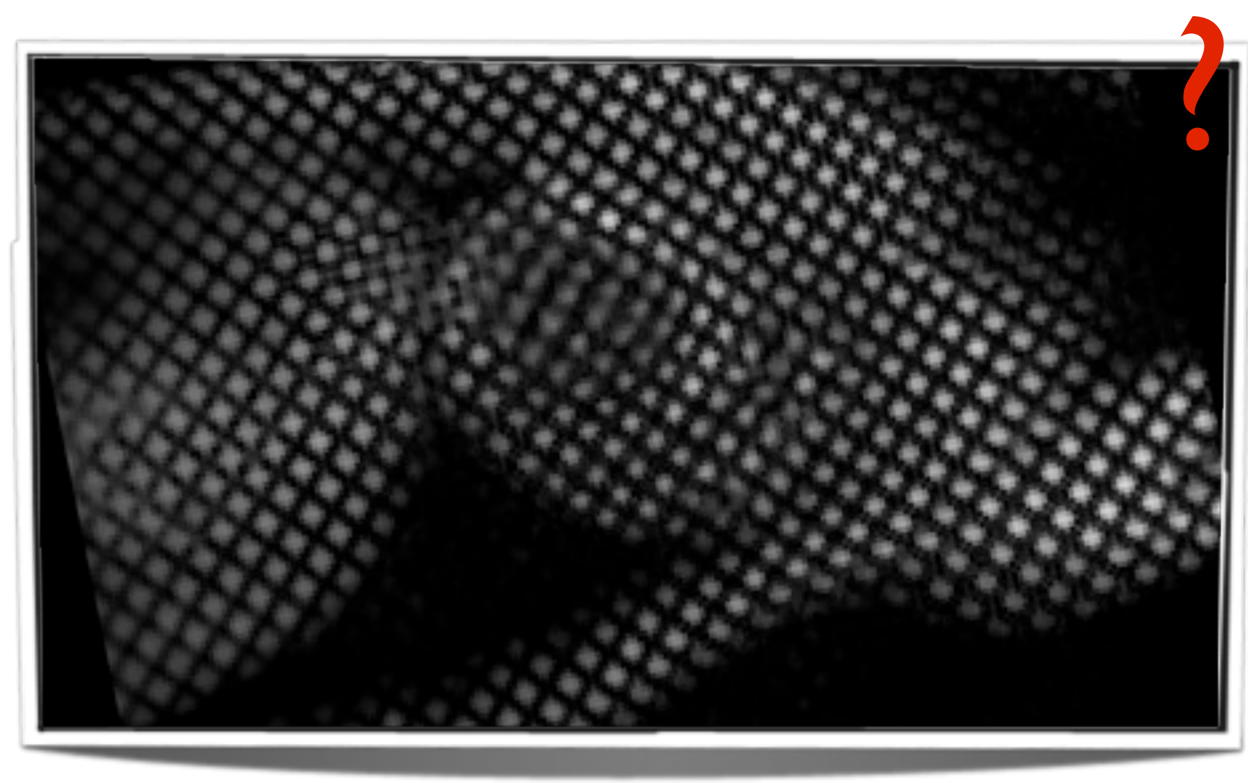


Signed distance with spatial interpolation



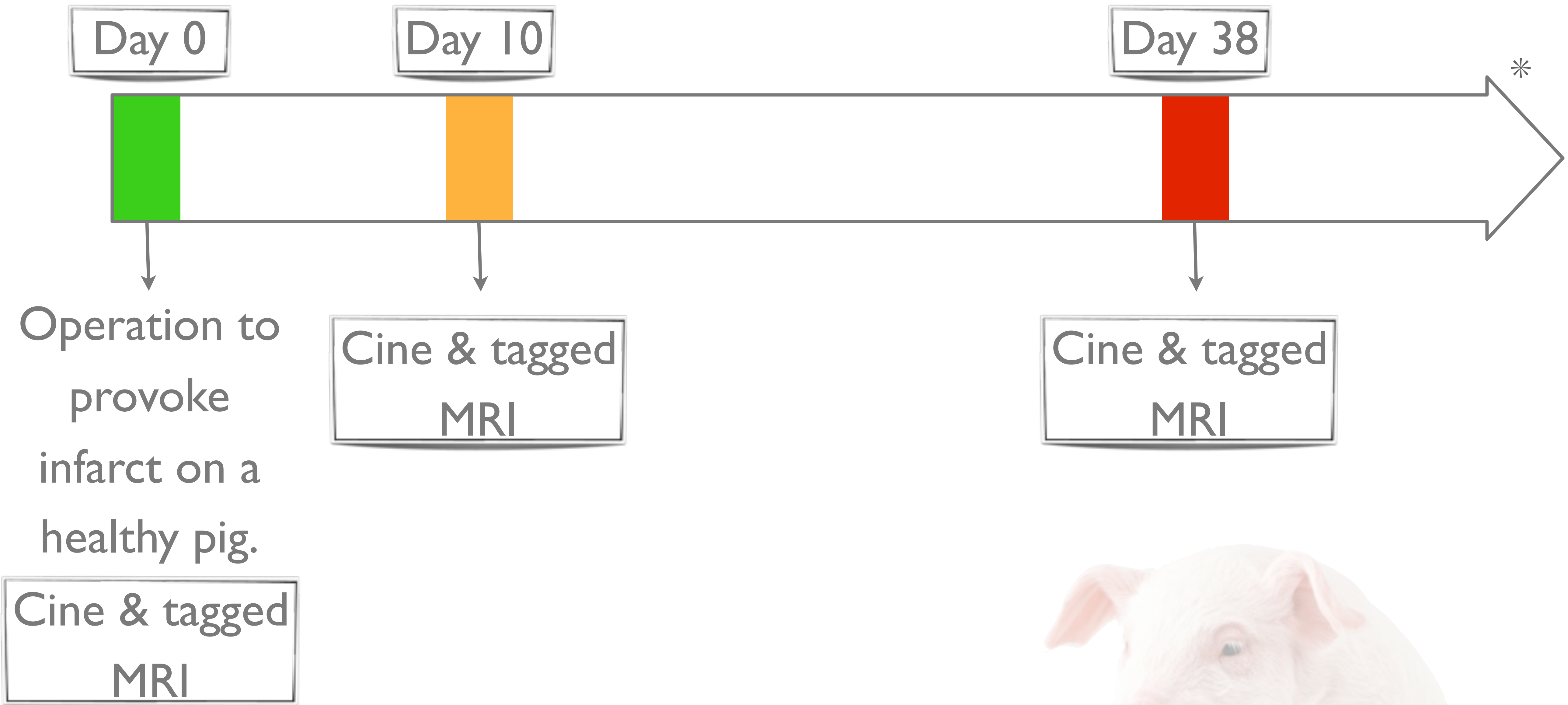
Modeling visible displacements





A Real case : experience settings

Experience timeline :

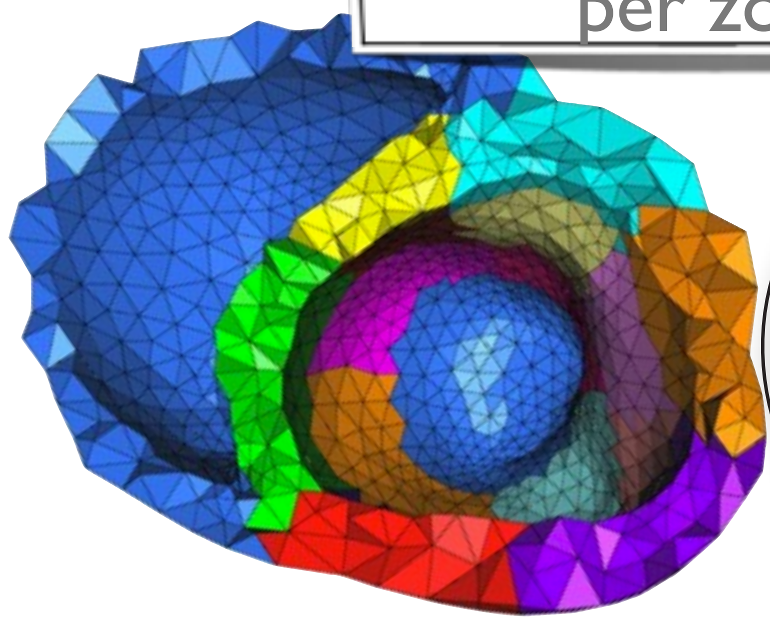


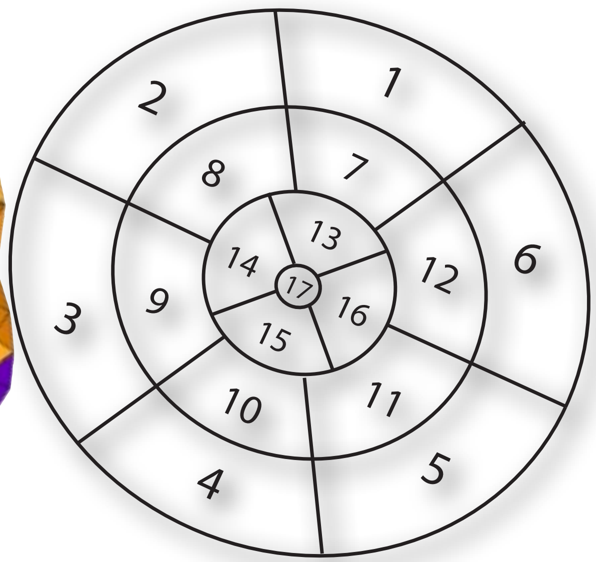
Experience setting by Radomir Chabiniok, King's College London, UK in collaboration with the hospital Henri-Mondor, Créteil.

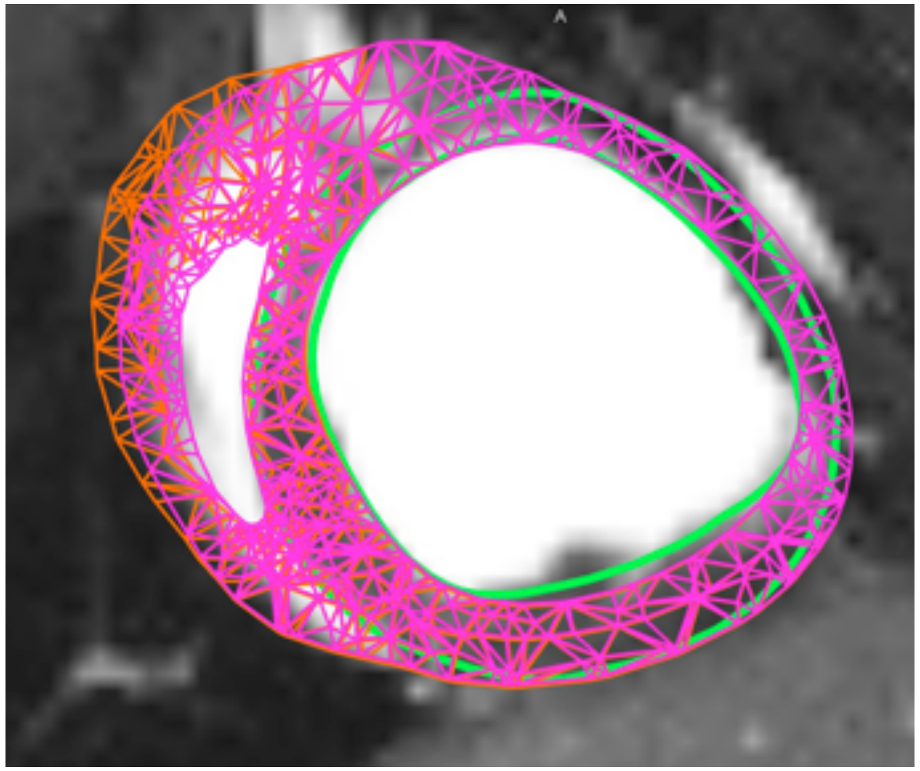
A Real case : numerical results

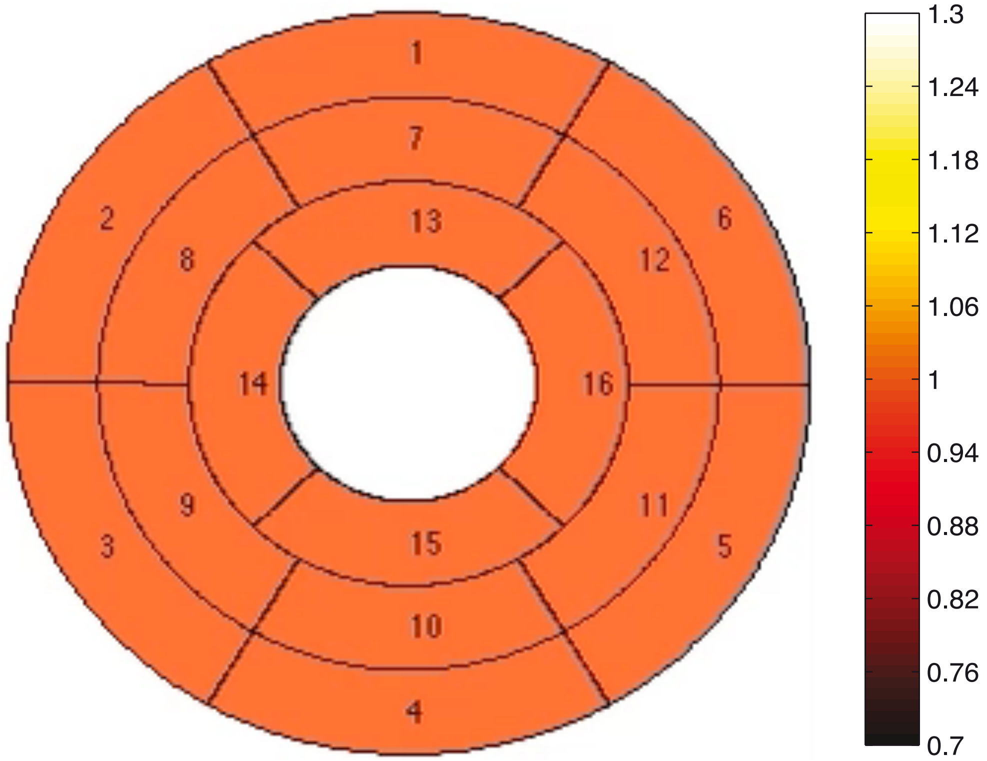
- Estimation of a contractility parameter in the active law
- The Data are the internal and external surfaces at Day 38.

Parameter is constant per zone









Conclusion

- Provide a methodology for parameter estimation.
- Different types of data are considered.
- Robustness tested on a real case.
- Up coming work :

Assimilating raw images

Convergence analysis of the estimator

Improvement in modeling