

Image processing for cardiac and vascular applications

Isabelle Bloch

Isabelle.Bloch@sorbonne-universite.fr

Sorbonne Université, CNRS, LIP6

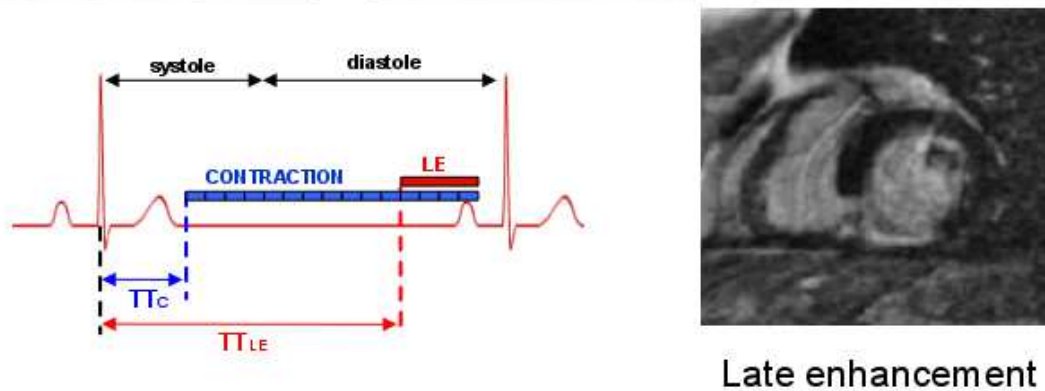
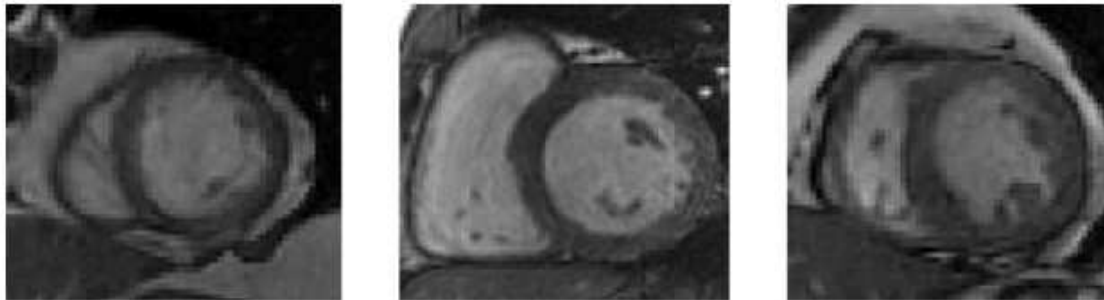
Image processing for cardiac imaging

1. For diagnosis in cardiology: segmentation, derived measures, perfusion, movement.
2. For oncology applications (heart = organ at risk).

Requirements and validation depend on the application.

Segmentation for diagnosis

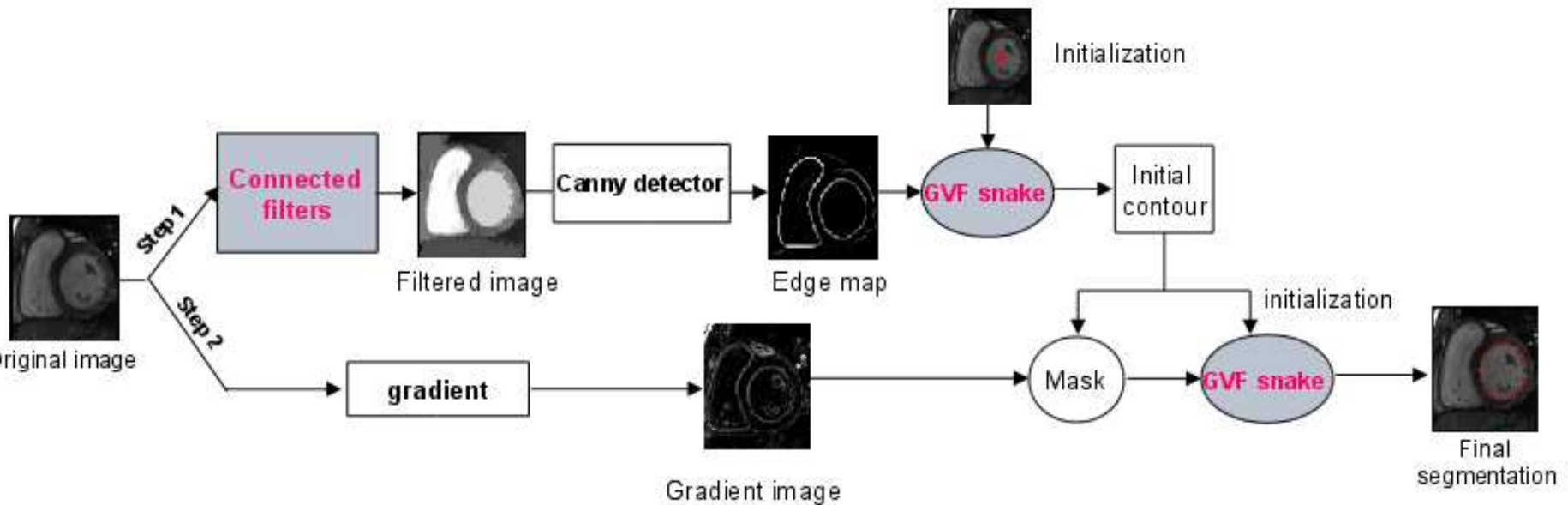
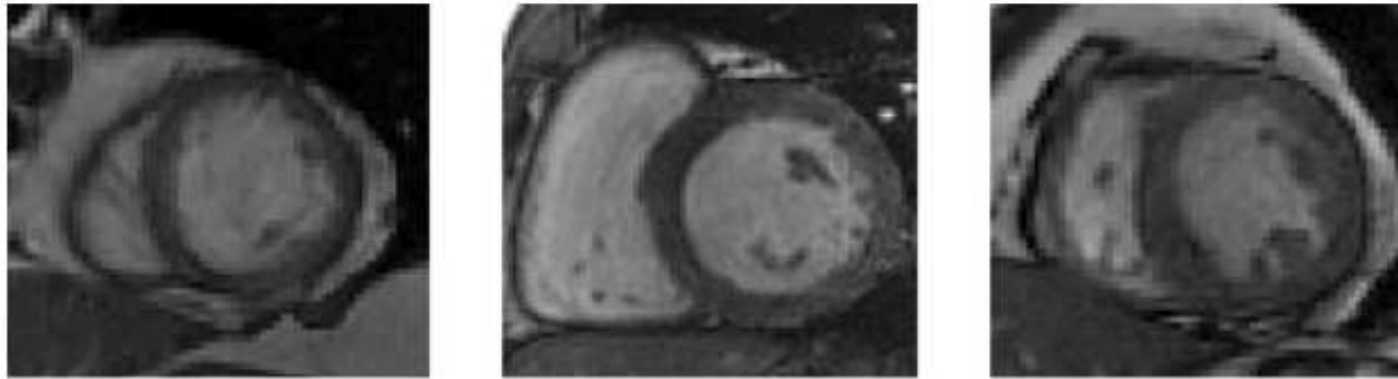
- Examples from R. El Berbari's PhD (collaboration with LIF and HEGP).
- Contraction and late enhancement images.
- Evaluation of left ventricle cinetics.
- Quantification of transmuralty of myocardium infarctus.



One slice during the cardiac cycle

Late enhancement

Segmentation method

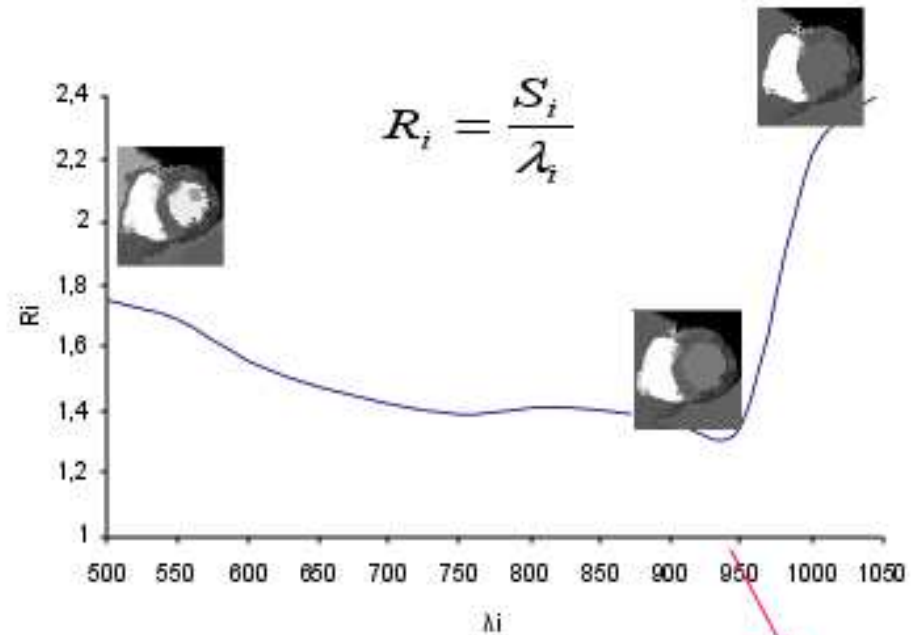
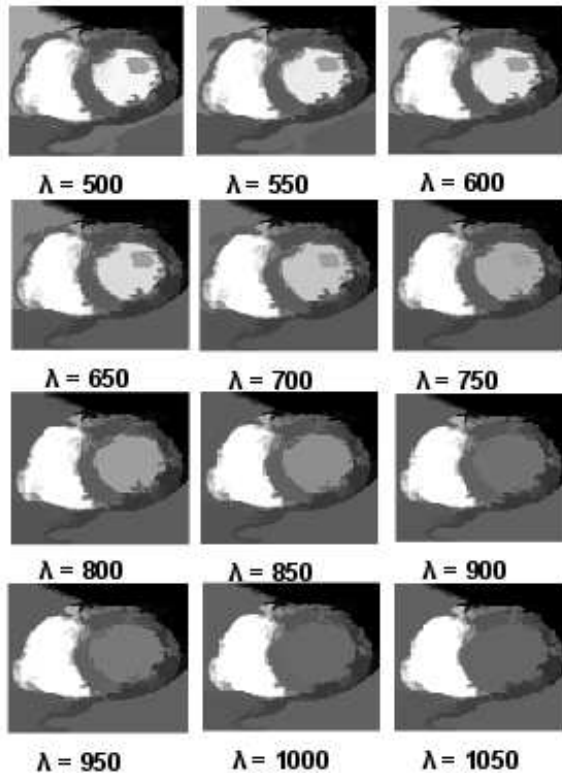


Segmentation method

Endocardium segmentation

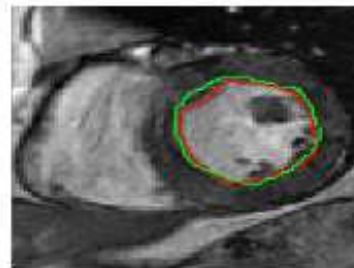
- First step:

Each filtered image $\rightarrow [\lambda_1, \lambda_2, \dots, \lambda_i]$

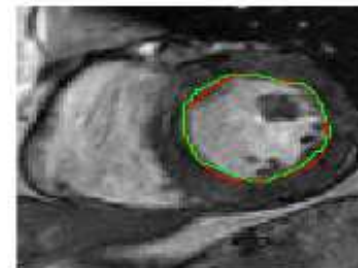


- Second step:

- segmentation refinement

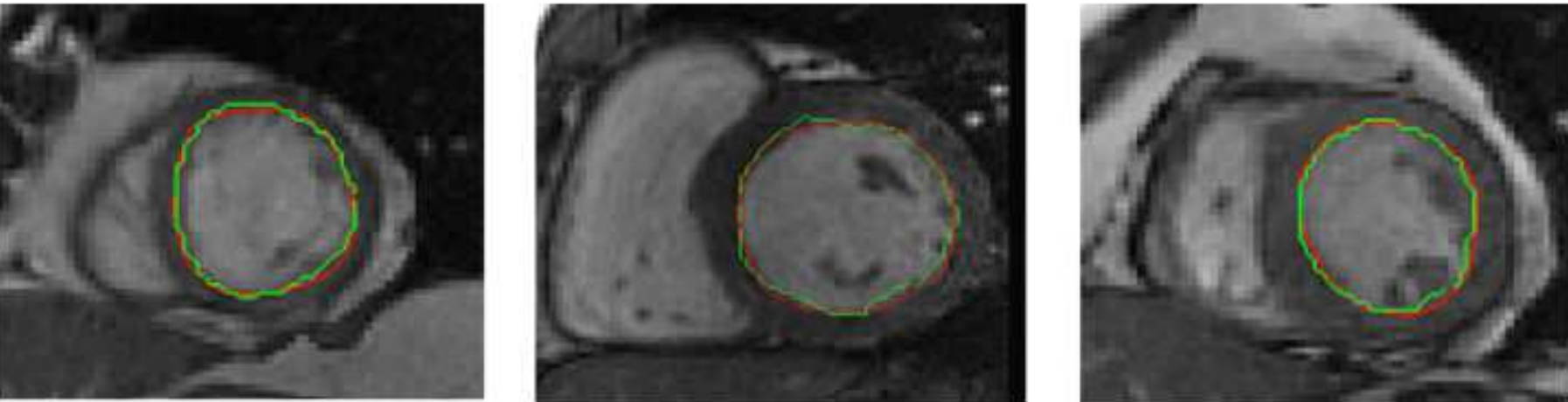


Step 1



Step 2

Results



Red: automated segmentation – Green: manual expert segmentation

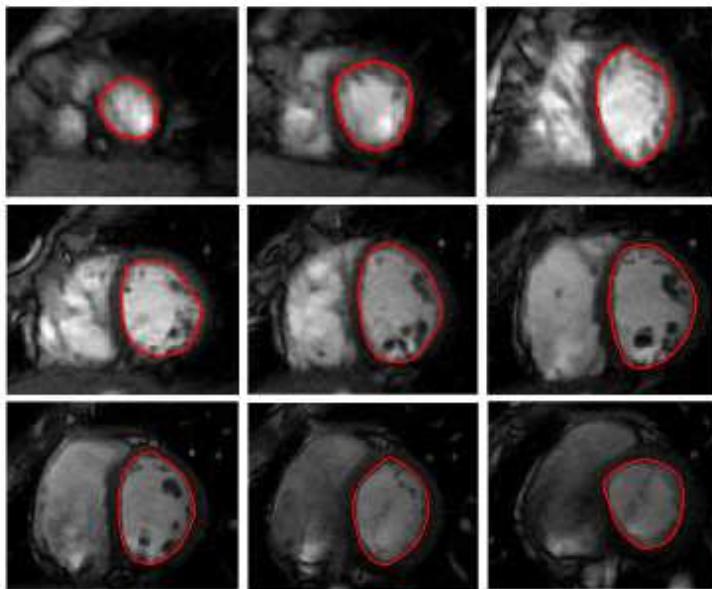
Results

Evaluation

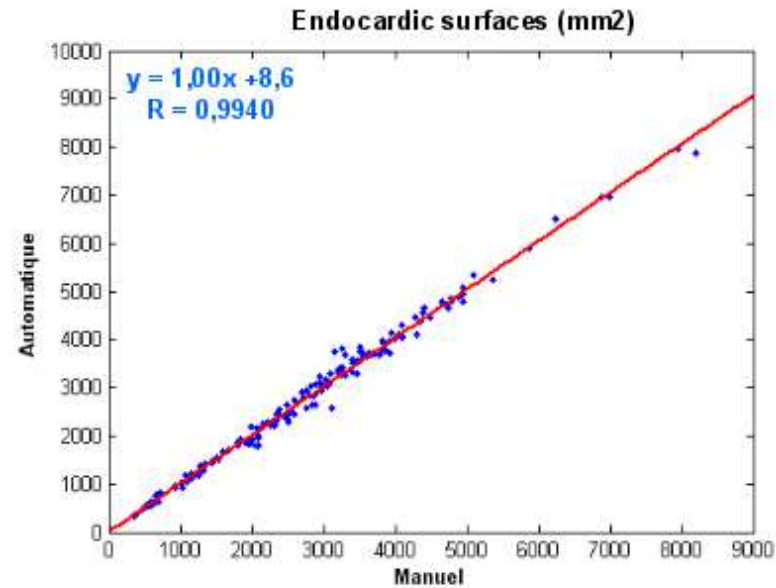
BDD1: 13 subjects, 39 slices

BDD2: 36 normal subjects, 293 slices

Comparison with manual tracing on 20 cases of BDD2



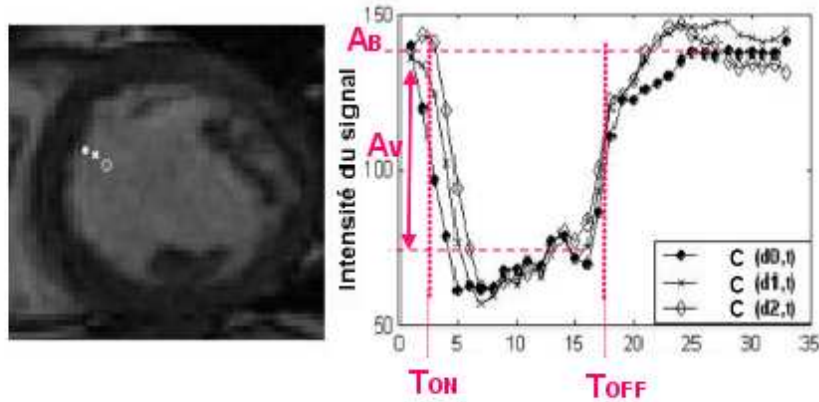
From apex to base



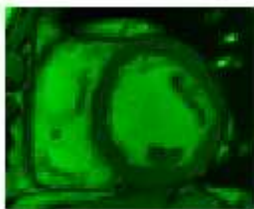
M_s (%)	D_{max} (mm)	D_{moy} (mm)
91 ± 4	2.8 ± 1.1	1.1 ± 1.0

Results

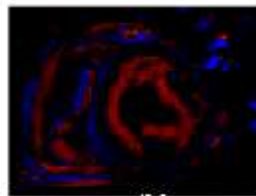
Parametric Analysis of Main Movement



$$P(x, y, t) = A_B(x, y) - A_V(x, y) \cdot g(t, T_{ON}(x, y), T_{OFF}(x, y)) + e(x, y, t)$$



AB image



AV image

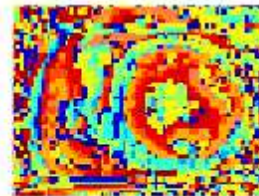


Image TON

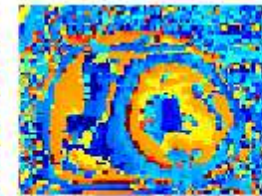
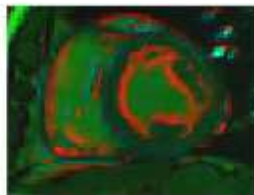


Image TOFF



Trichromatic image

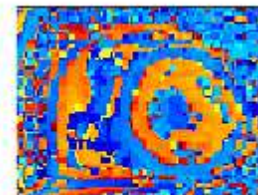
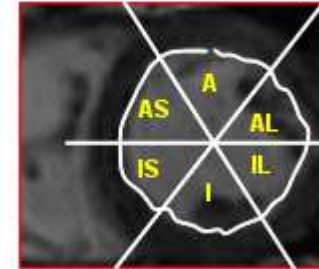


Image TM

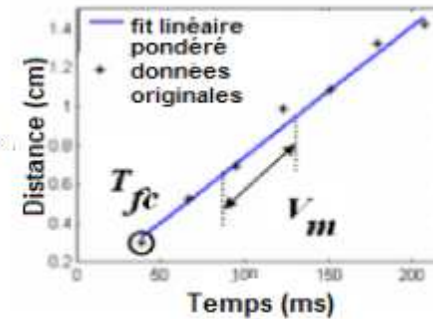
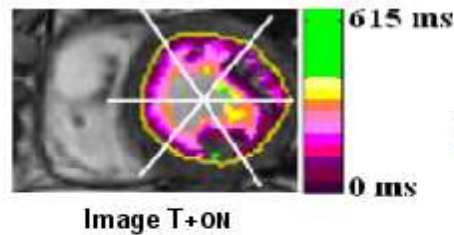
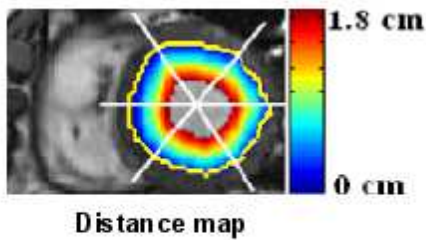
Results

Estimation of functional parameters

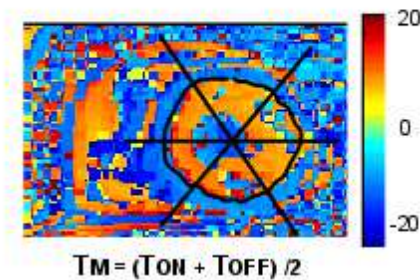
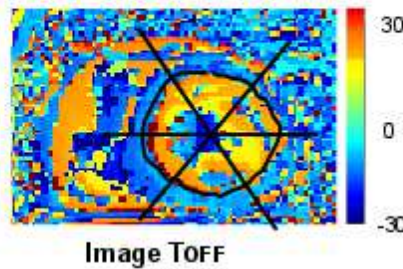
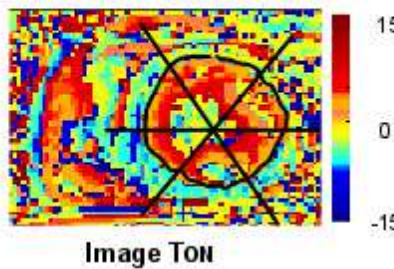
- Segment analysis



- Estimation of radial distances:



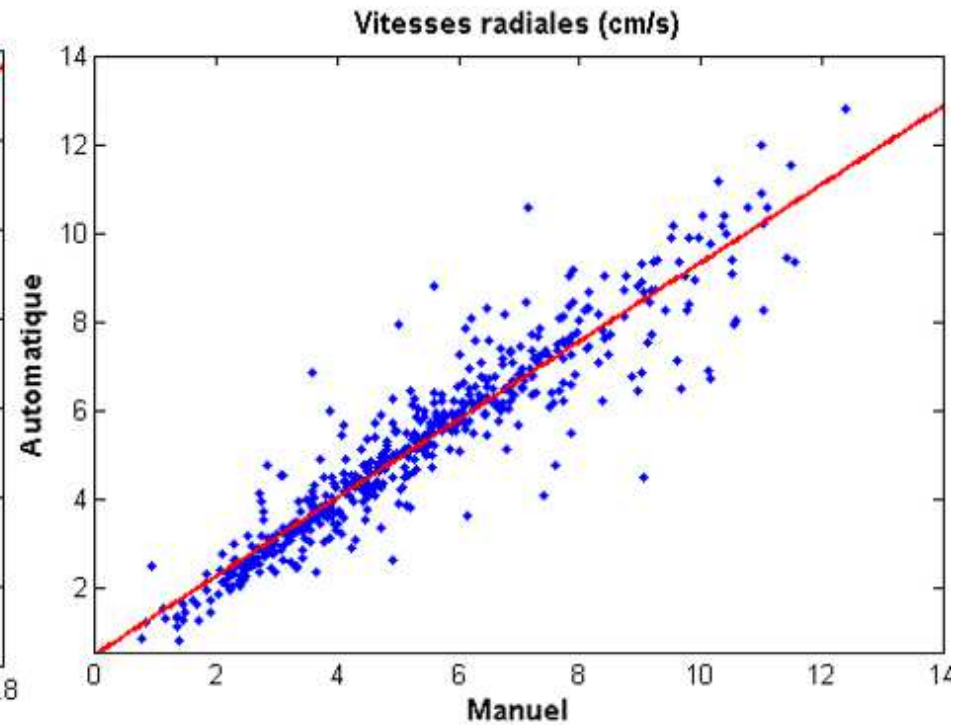
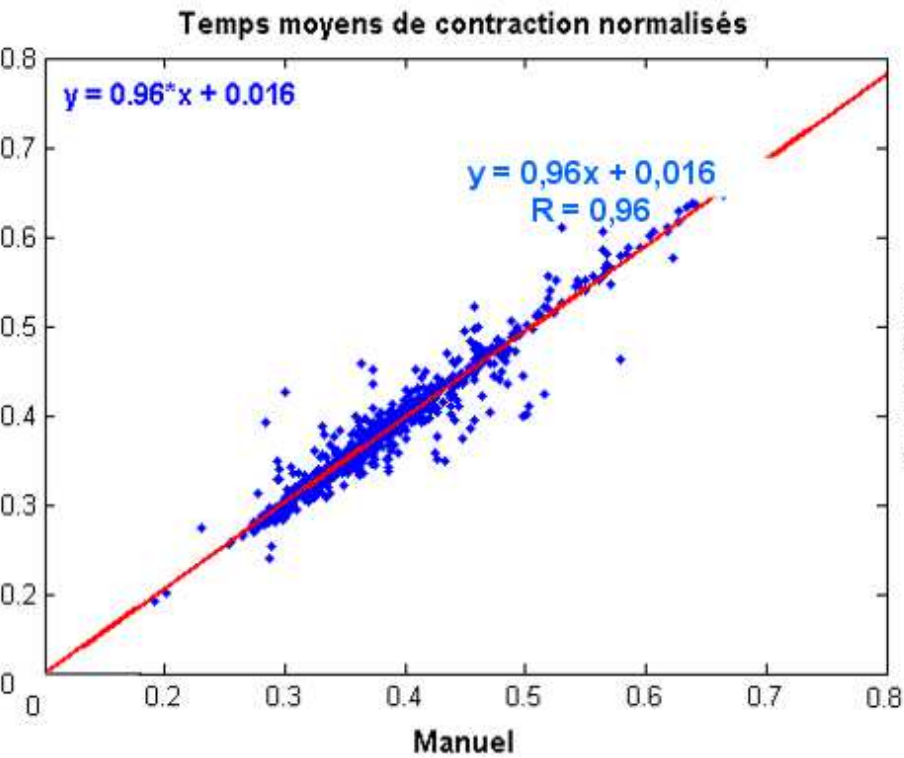
-Estimation of mean contraction time:



Results

Evaluation

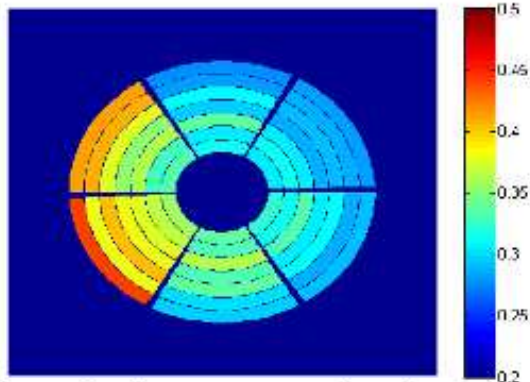
BDD2: 20 normal subjects with manual tracing (984 segments)



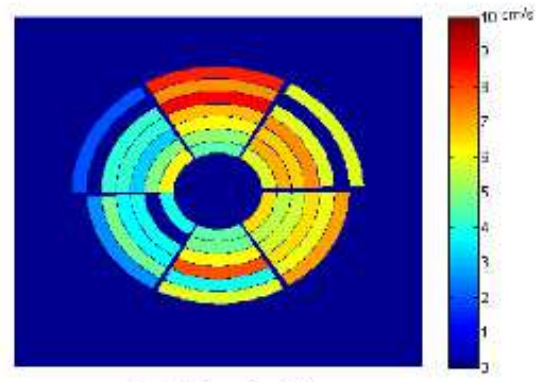
Results

Global results

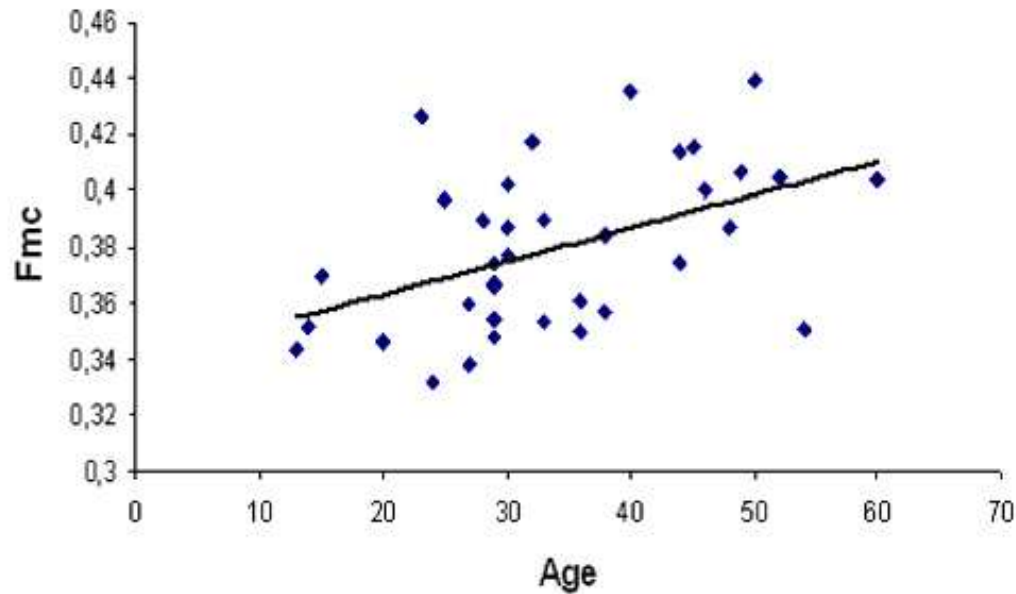
BDD2: 36 normal subjects (1752 segments)



Normalized mean contraction time
 F_{mc} (Bull eye visualization)



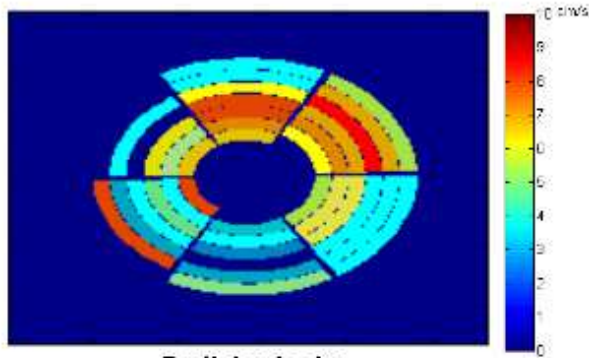
Radial velocity
 V_m (cm/s)



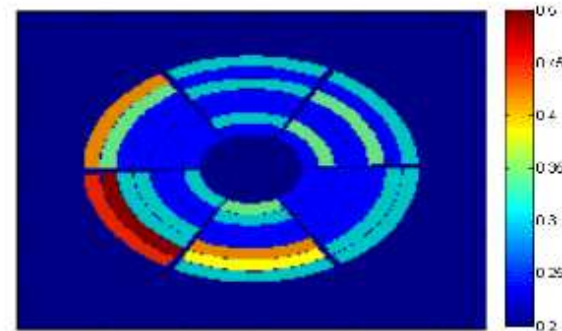
Results

BDD3:

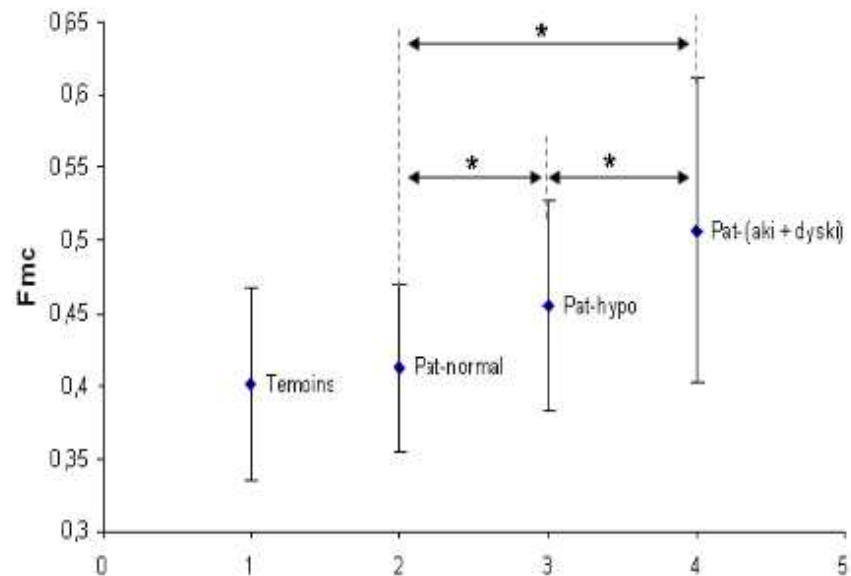
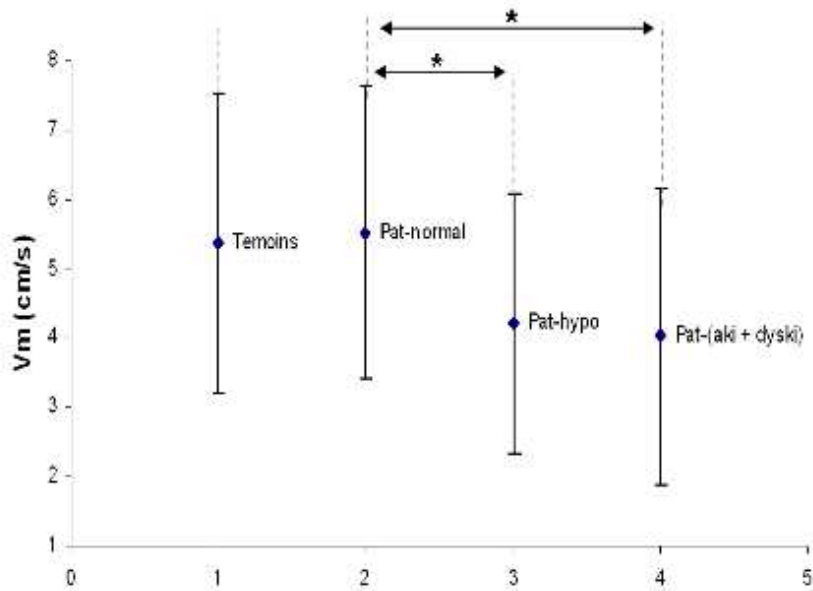
10 normal subjects + 10 pathological ones with infarctus
(444 segments + 408 segments)



Radial velocity
 V_m (cm/s)

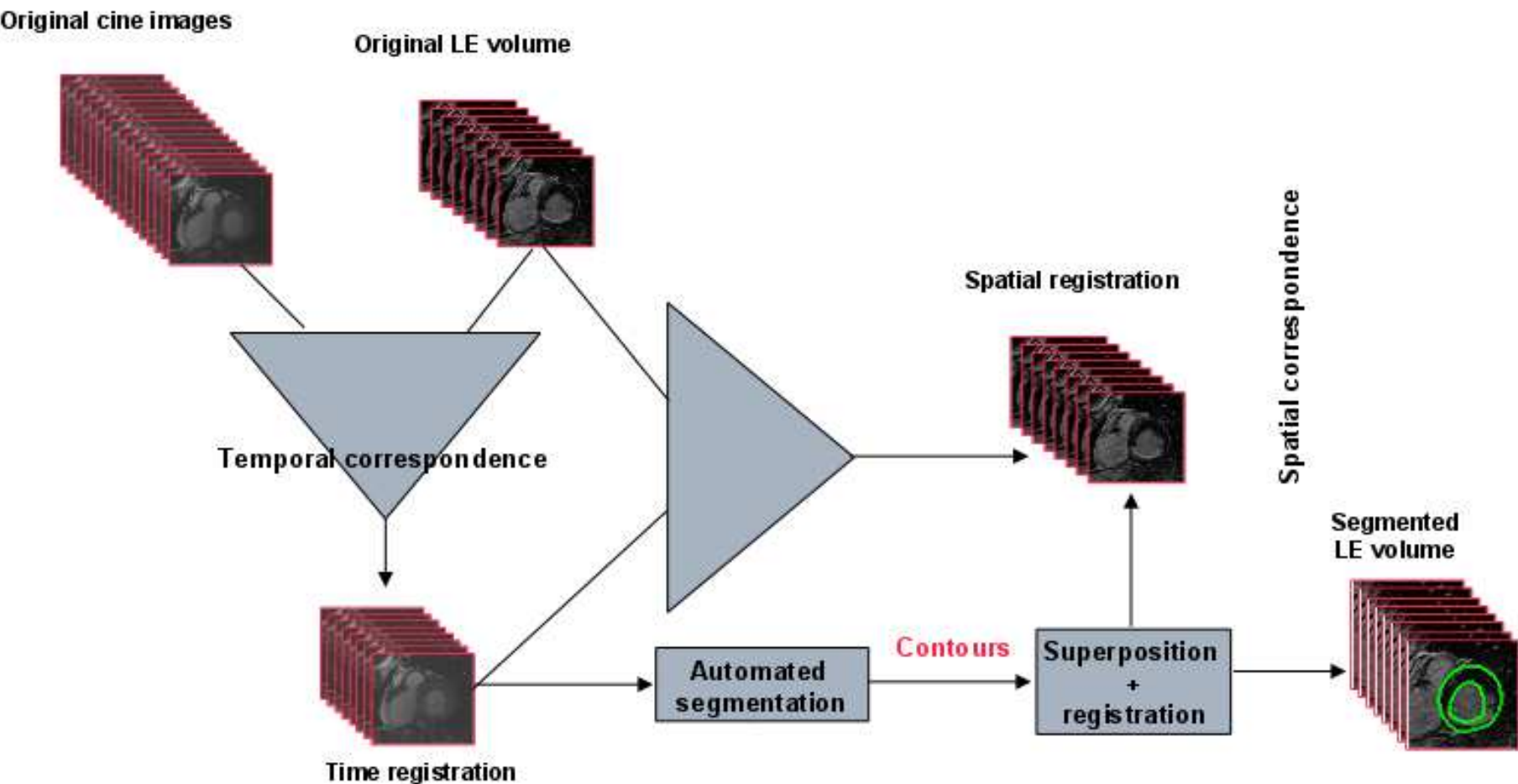


Normalized mean contraction time
 F_{mc}



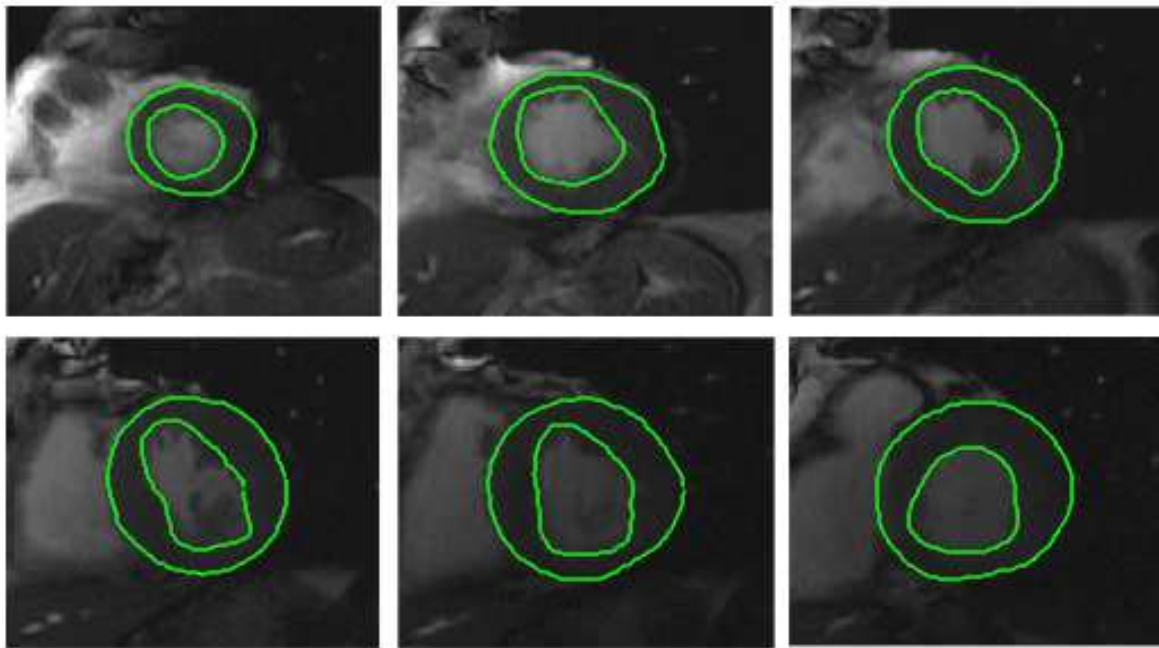
Late enhancement images

Late enhancement image segmentation



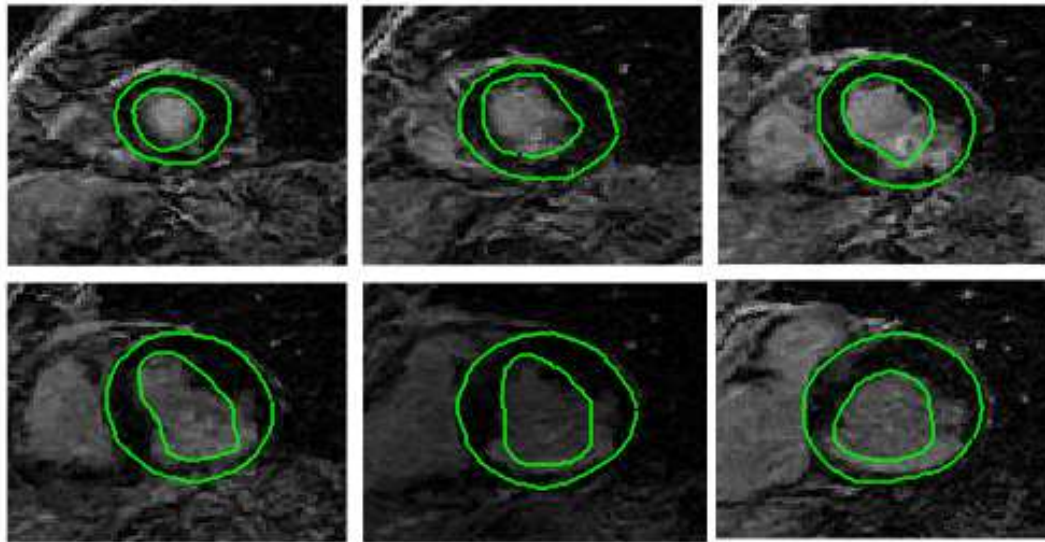
Late enhancement images

Segmentation of cine images



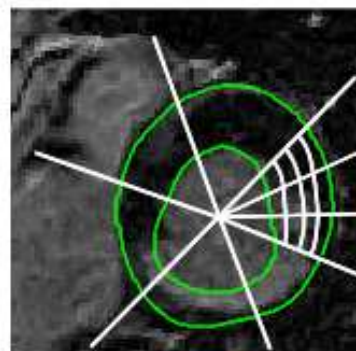
Late enhancement images

uperposition and registration of contours on LE images



Myocardium segmentation on six slices of LE images

Quantification of infarctus transmurality



Late enhancement images

Evaluation

BDD4:

9 pathological subjects (921 sub-segments)

- class 0: no enhancement
- class 1: enhancement from 0 to 25 % of myocardium thickness
- class 2: 26 - 50 %
- class 3: 51 - 75 %
- class 4: 76 - 100 %

		Visual				
		0	1	2	3	4
Quantitative	0	584	13	9	2	1
	1	40	24	12	-	1
	2	4	12	47	35	6
	3	2	-	7	13	40
	4	-	-	-	2	67

Absolute agreement = 80%

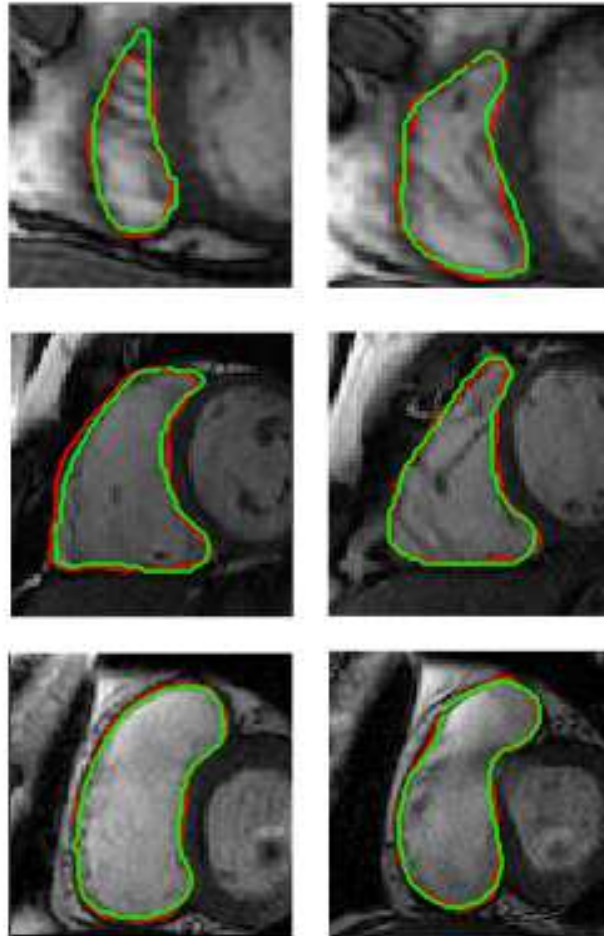
Relative agreement up to 1 degree = 97%

Relative agreement up to 2 degrees = 99%

Kappa $\kappa = 0.815$

Extensions

Right ventricle



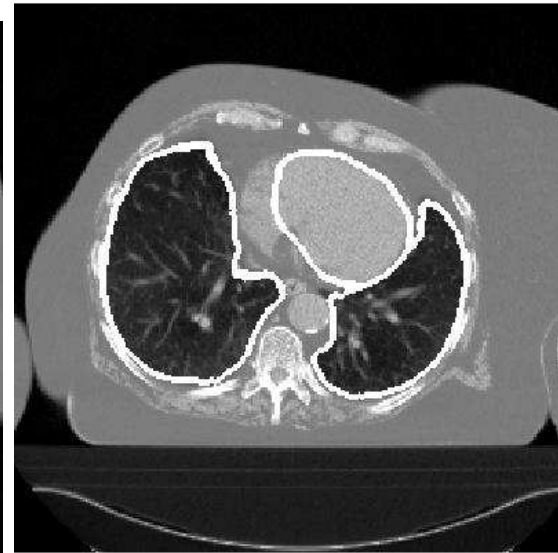
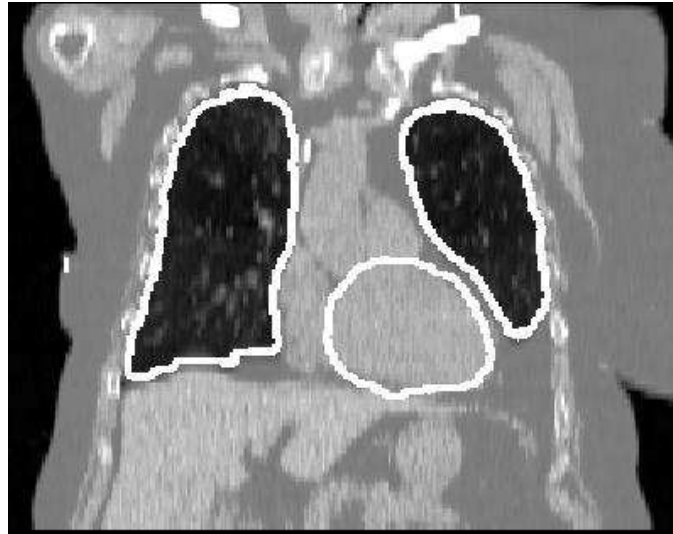
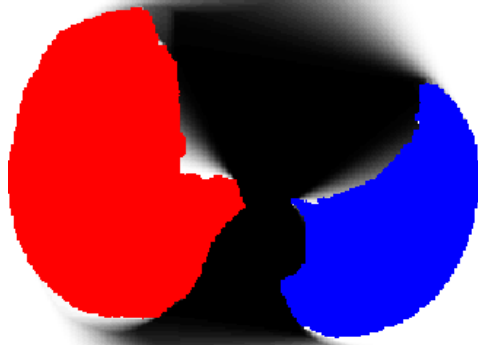
Red: automated segmentation – Green: manual expert segmentation

Others: multi-centric evaluation...

Heart segmentation for oncology applications

(A. Moreno, J. Wojak)

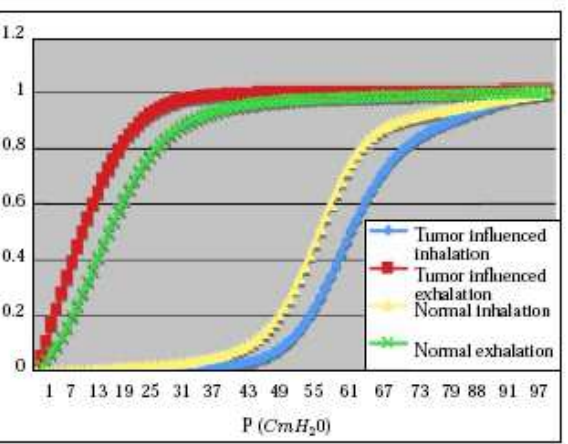
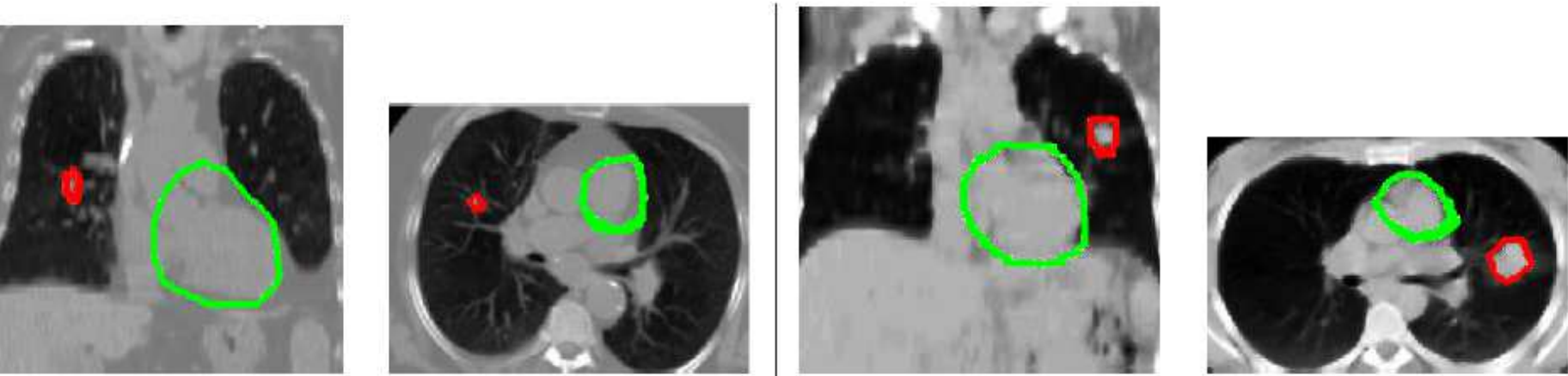
Using structural constraints



Heart segmentation for oncology applications

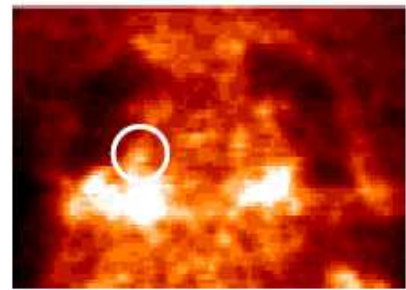
(A. Moreno, J. Wojak)

Using structural constraints and a breathing model

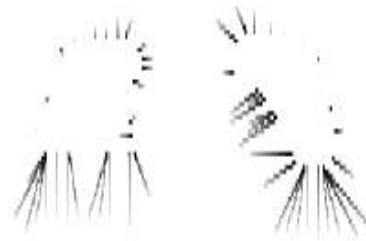


Heart segmentation for oncology applications

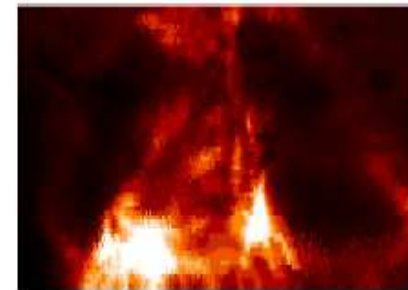
(A. Moreno. J. Woiak)



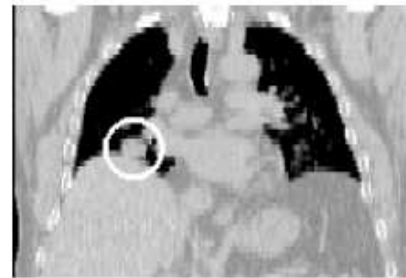
(a)



(b)



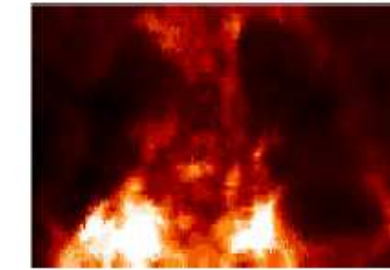
(c)



(d)



(e)



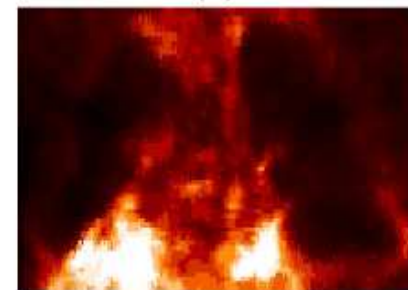
(f)



(g)



(h)



(i)



(j)



(k)

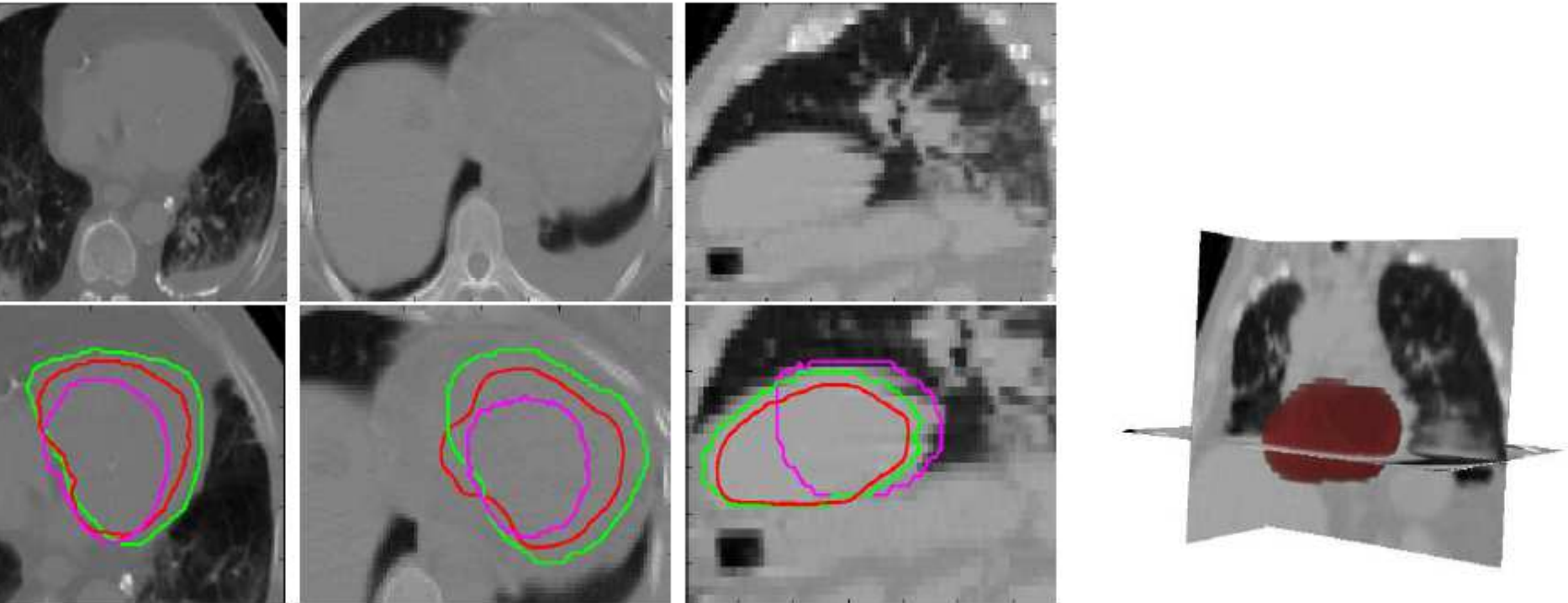


(l)

Heart segmentation for oncology applications

(A. Moreno, J. Wojak)

Using shape constraints



Magenta = structural constraints, red = shape constraints, green = manual

Heart segmentation for oncology applications

(A. Moreno, J. Wojak)

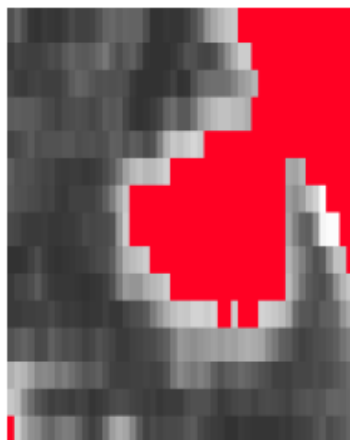
Follow-up



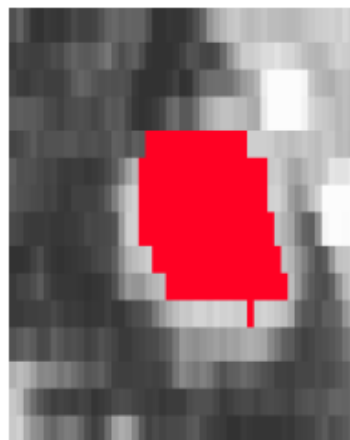
CT in 2007



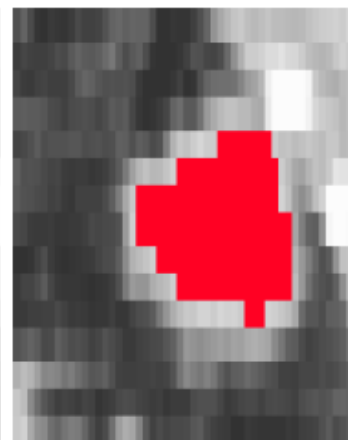
CT in 2008



Output: Weak prior



Output: Strong prior

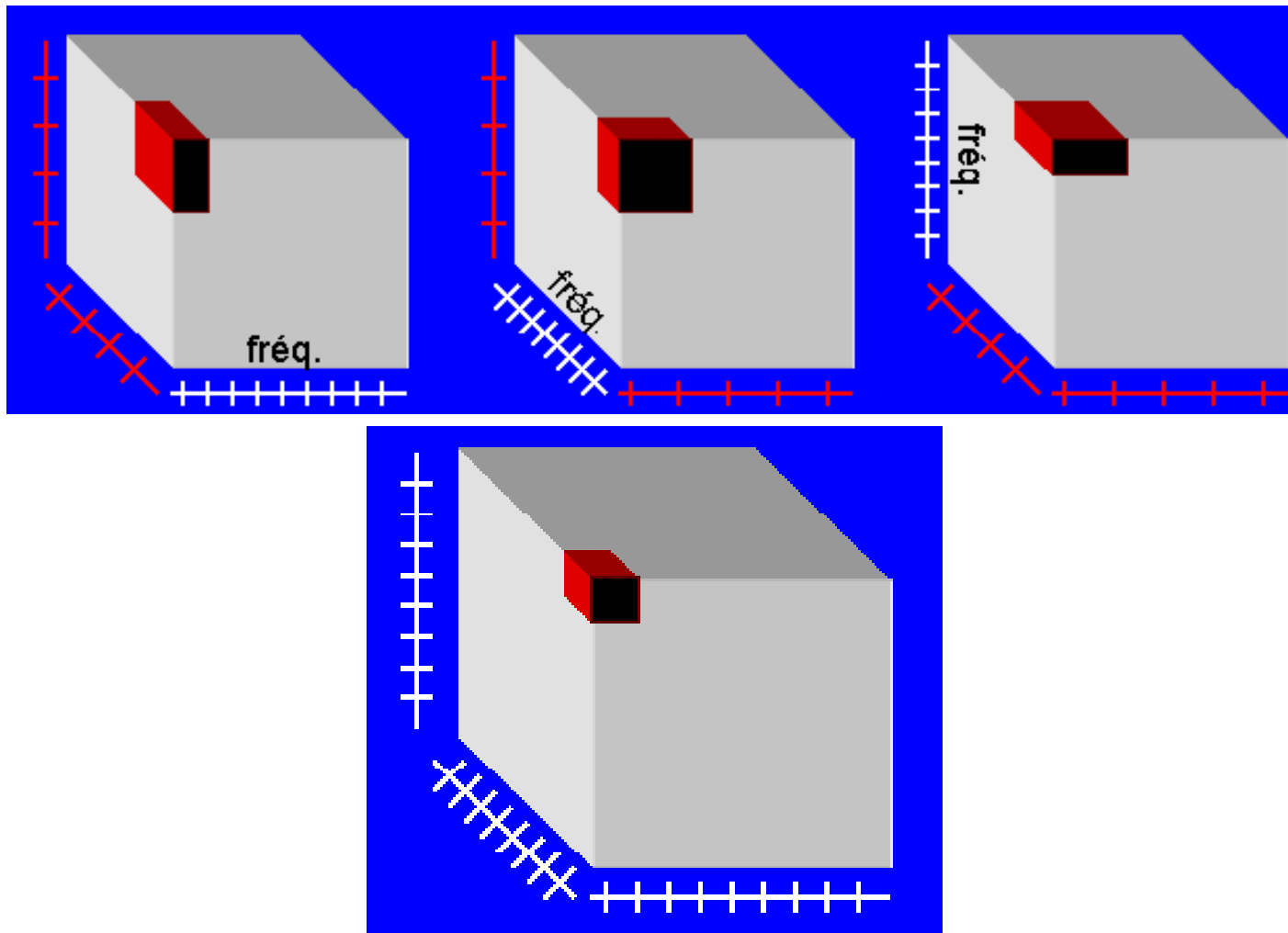


Output: ● medium prior

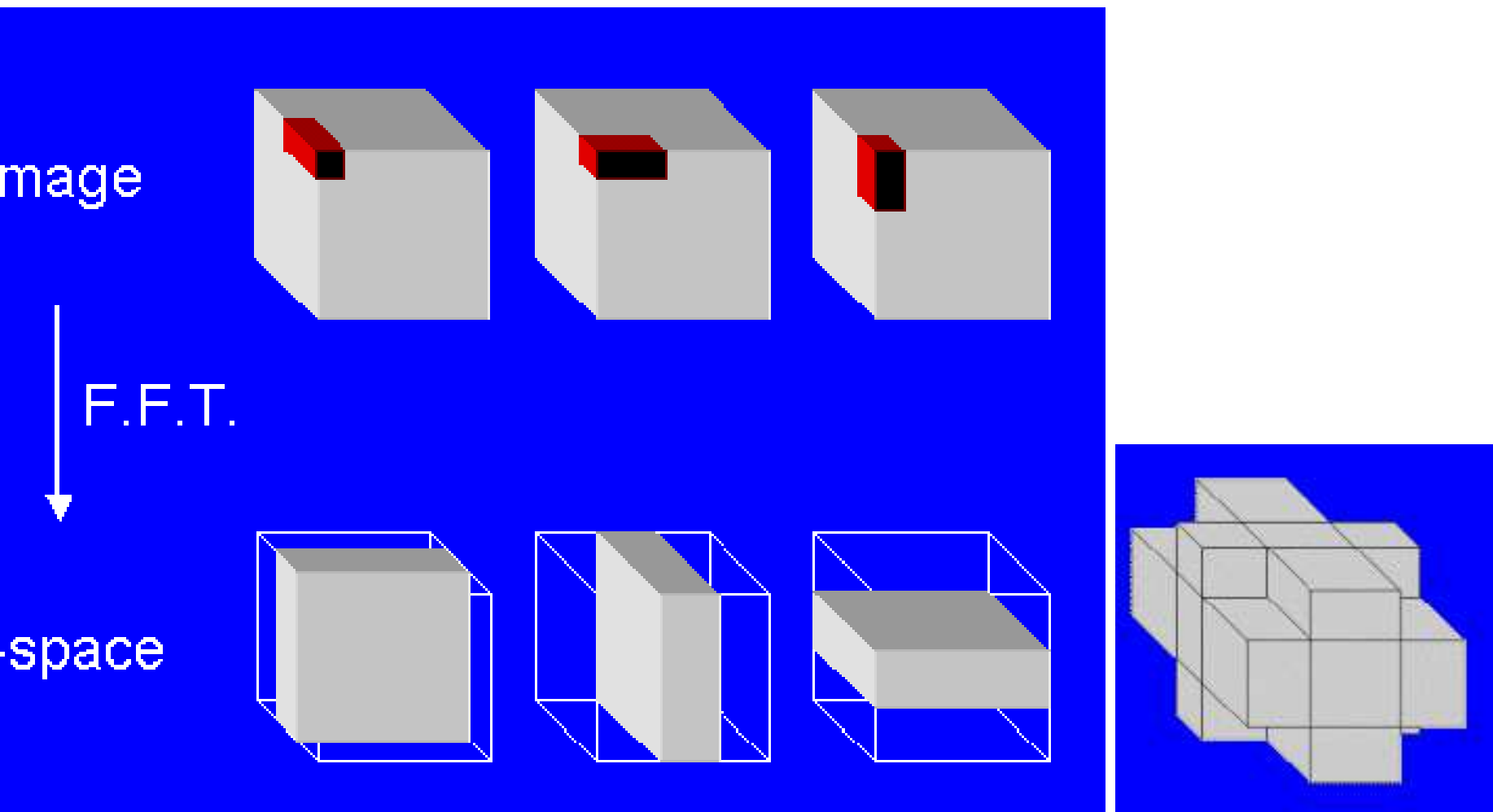
Image processing for vascular imaging

1. High quality reconstruction from multiple MRI acquisitions.
2. Segmentation of brain vessels from MRA.
3. Segmentation of coronary vessels from high resolution CT.

High quality reconstruction from multiple MRI acquisitions (E. Roullot)



High quality reconstruction from multiple MRI acquisitions (E. Roullot)



High quality reconstruction from multiple MRI acquisitions (E. Roullot)



result_anime



Vessel segmentation for...

- better visualization,
- diagnosis assistance (detection, quantification),
- virtual endoscopy...

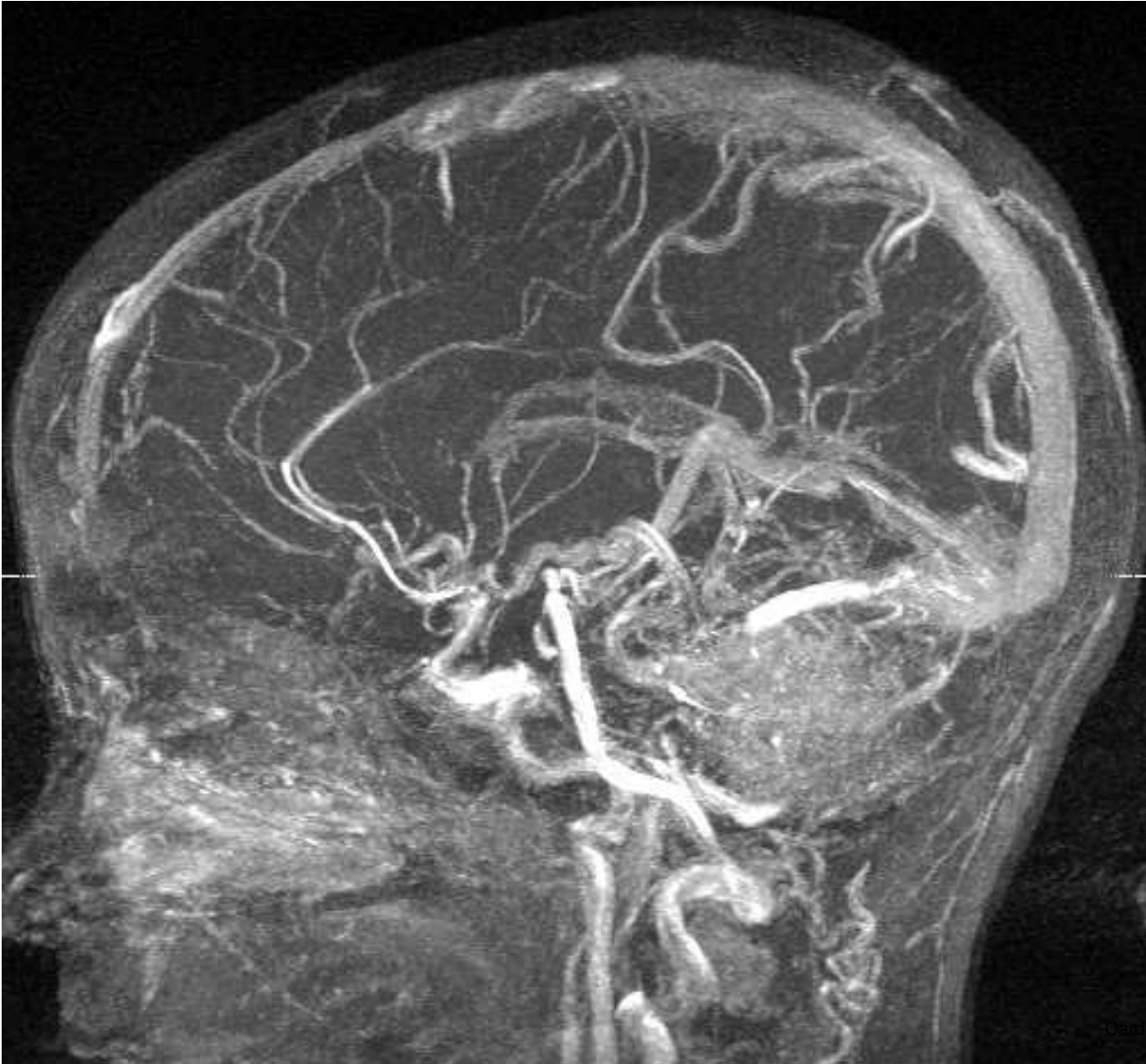
Some issues:

- classical ones: resolution, noise, partial volume effect...
- vessel specific: thin structures, bifurcations, anomalies...

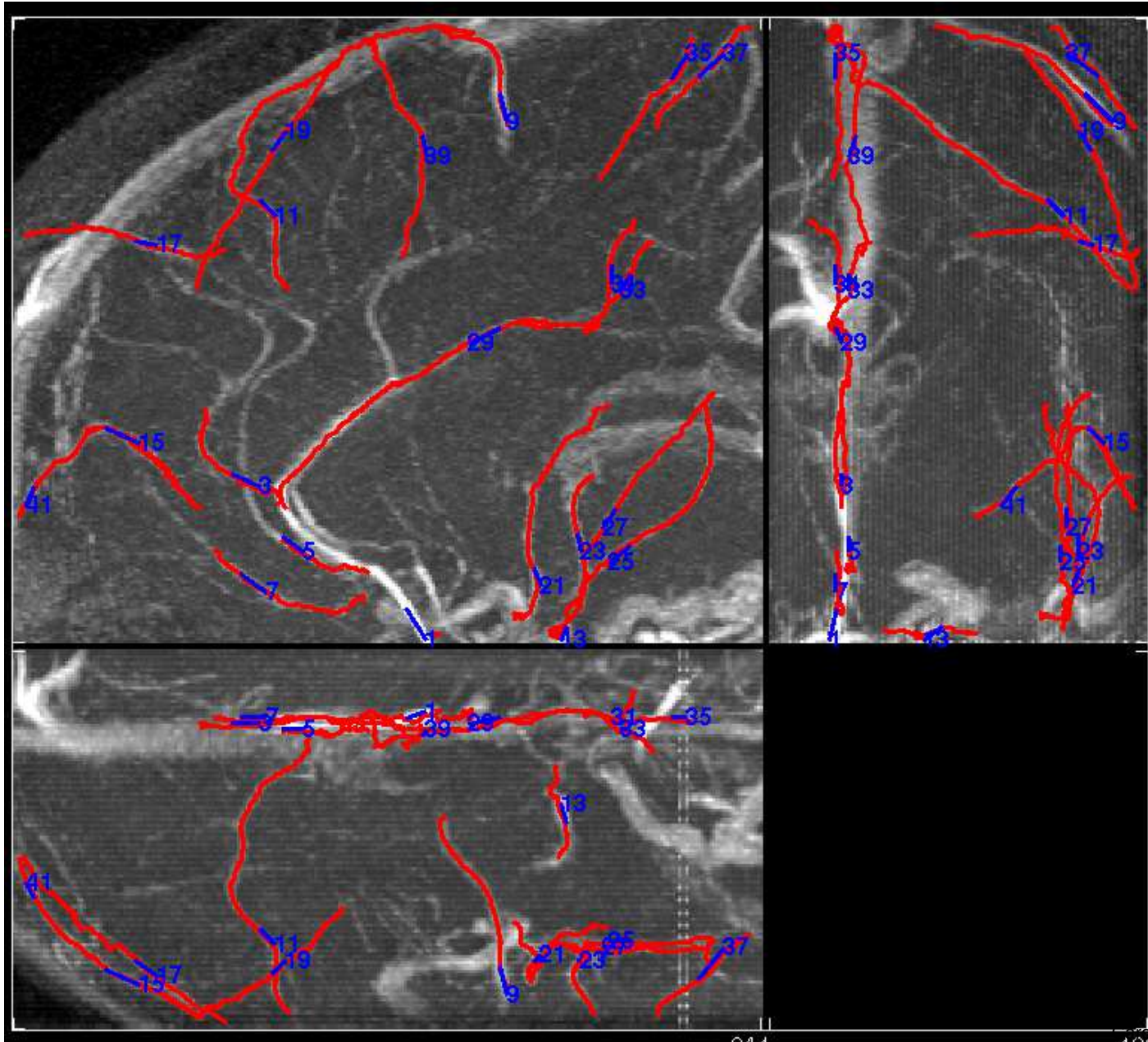
Three important components

- models (hypotheses),
- features (image information),
- extraction techniques.

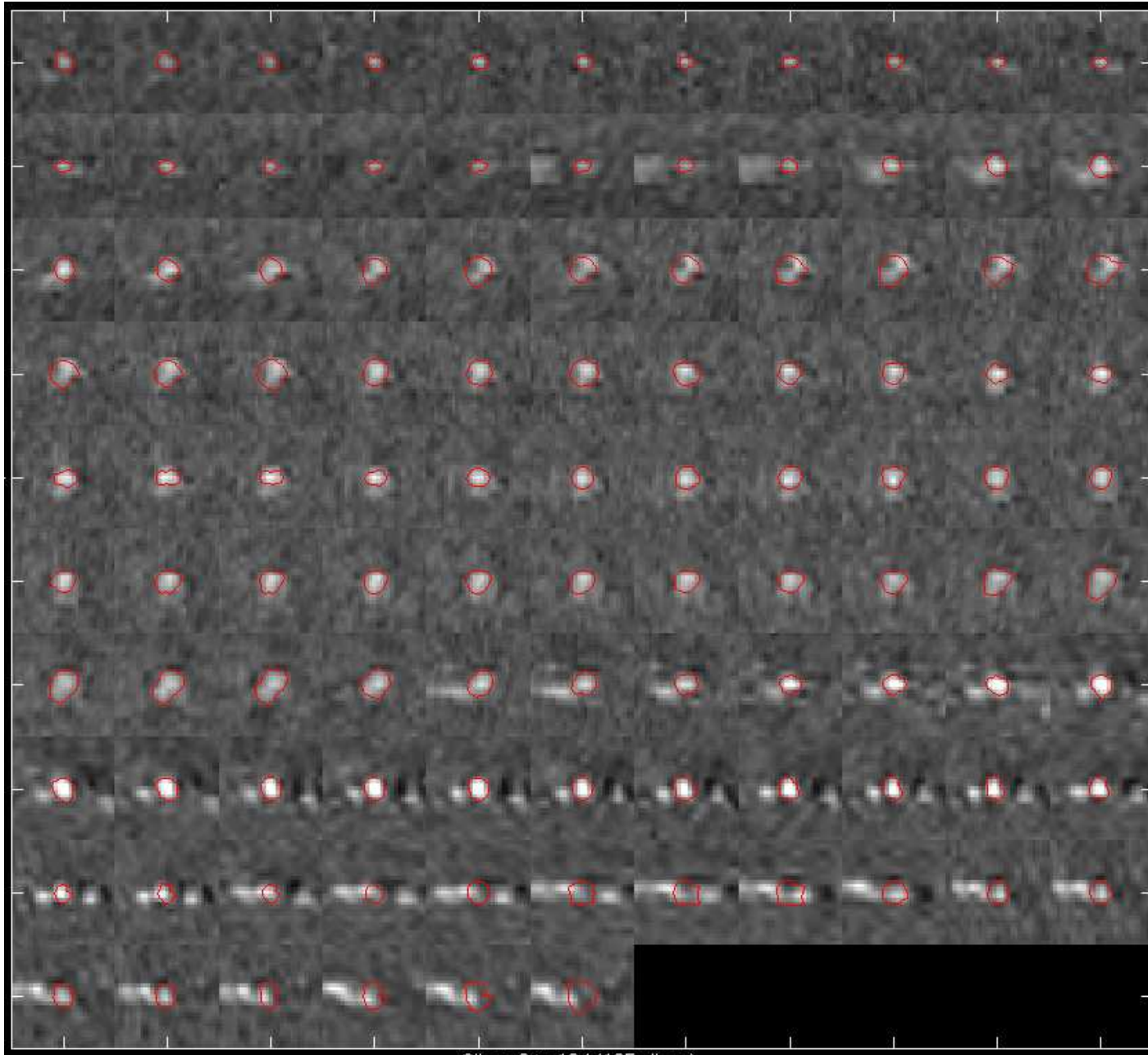
Segmentation of brain vessels from MRA (B. Verdonck)



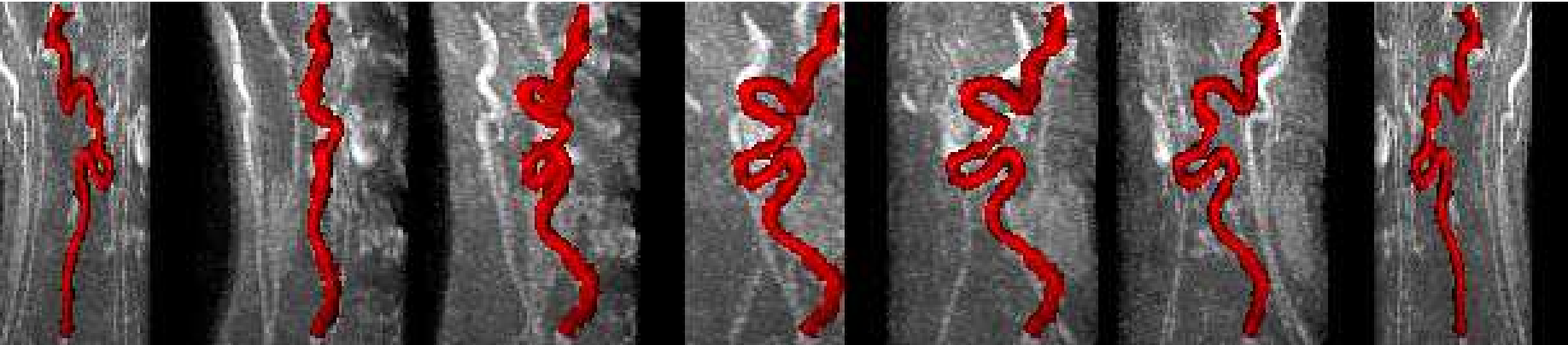
Segmentation of brain vessels from MRA (B. Verdonck)



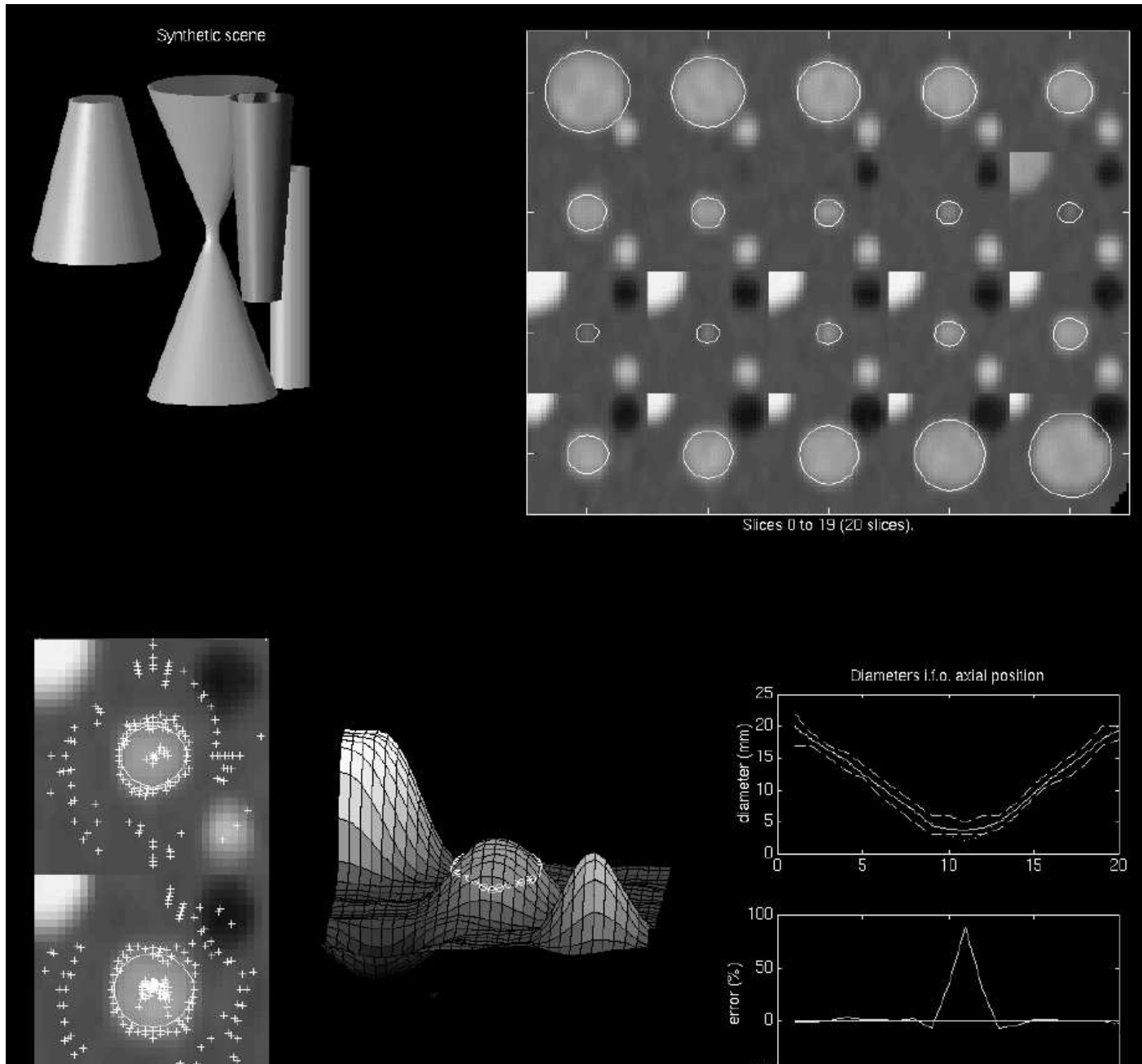
Segmentation of brain vessels from MRA (B. Verdonck)



Segmentation of brain vessels from MRA (B. Verdonck)



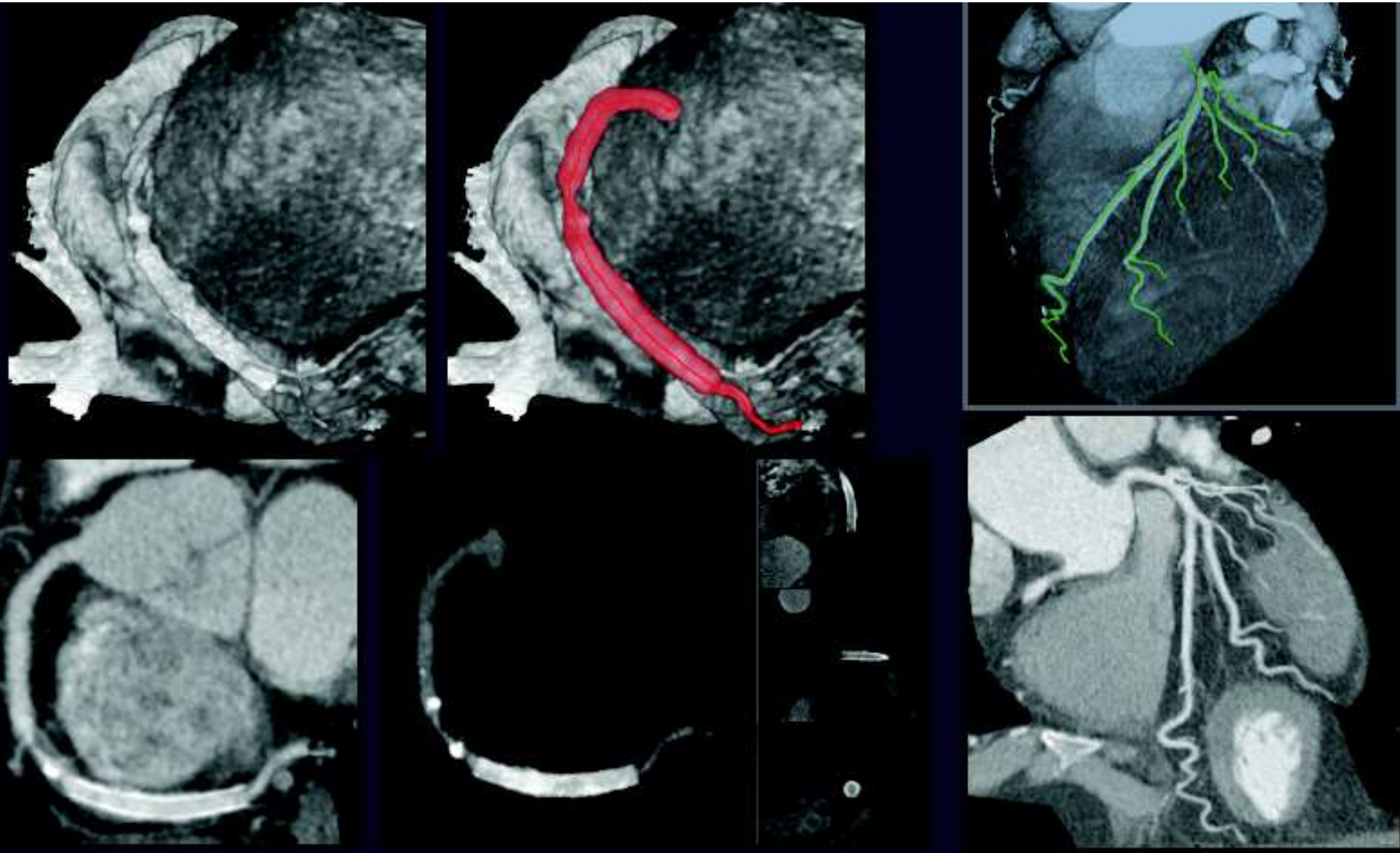
Segmentation of brain vessels from MRA (B. Verdonck)



Segmentation of coronary vessels from high resolution CT (D. Lesage)

- Collaboration with Siemens Corporate Research.
- High resolution CT: ~ 0.33 mm.
- Vessel model.
- Local features and measurements (flux).
- Segmentation expressed as a tracking process in a Bayesian framework, solved by:
 - minimal path,
 - particle filter.

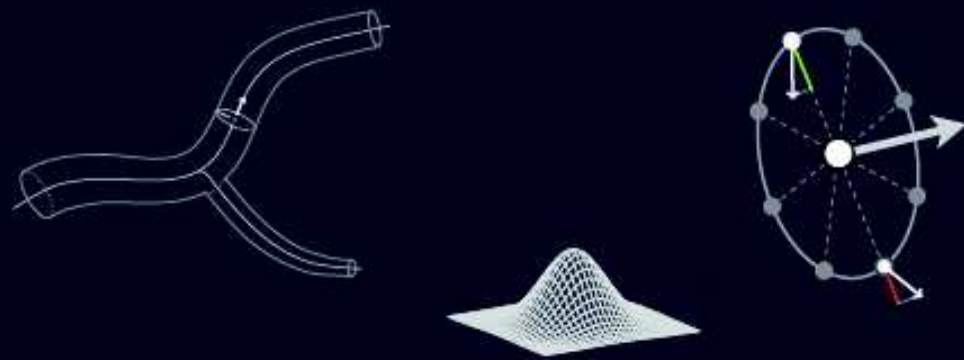
Segmentation of coronary vessels from high resolution CT (D. Lesage)



Tracking based approach



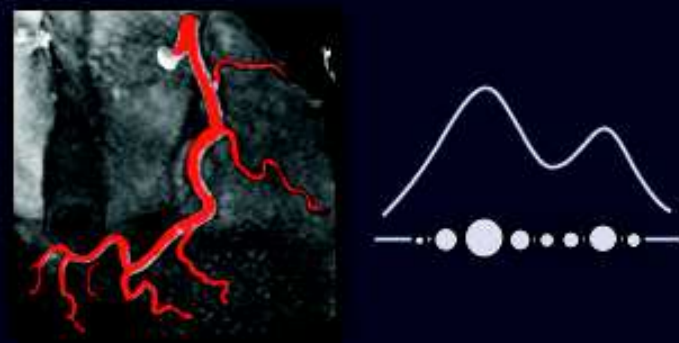
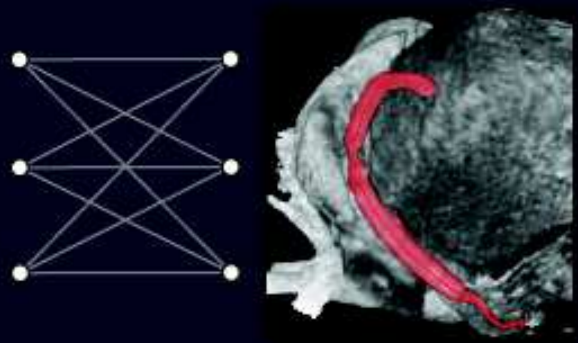
Overview



Core components

- Geometric model
- Bayesian model
- Image feature

$$p(x_{0:t}|z_{1:t}) = \frac{p(x_t|x_{t-1})p(z_t|x_t)}{p(z_t|z_{1:t-1})}p(x_{0:t-1}|z_{1:t-1})$$



Minimal path optimization

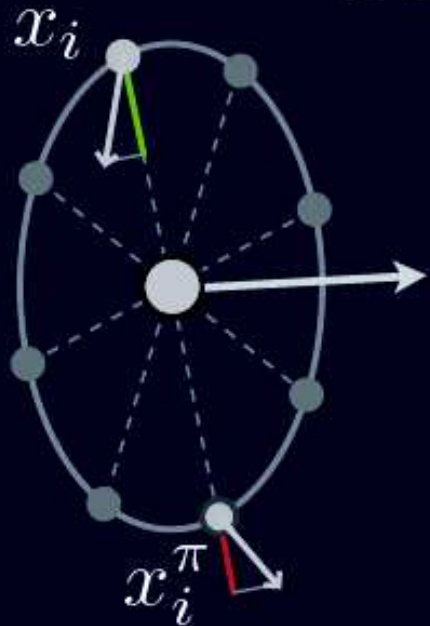
Particle filter tracking

Flux based measure



- ▶ Penalize asymmetric flux contributions (Koller 95)

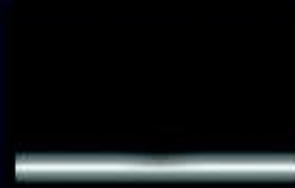
$$\text{MFlux}(p, r, d) = \frac{2}{N} \sum_{i=1}^{\frac{N}{2}} \min(\langle \nabla I(x_i), u_i \rangle, \langle \nabla I(x_i^\pi), u_i^\pi \rangle)$$



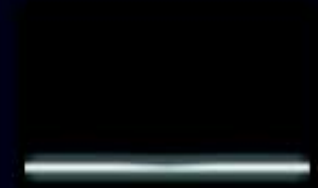
- ▶ Minimal contribution per diametral pair



Original

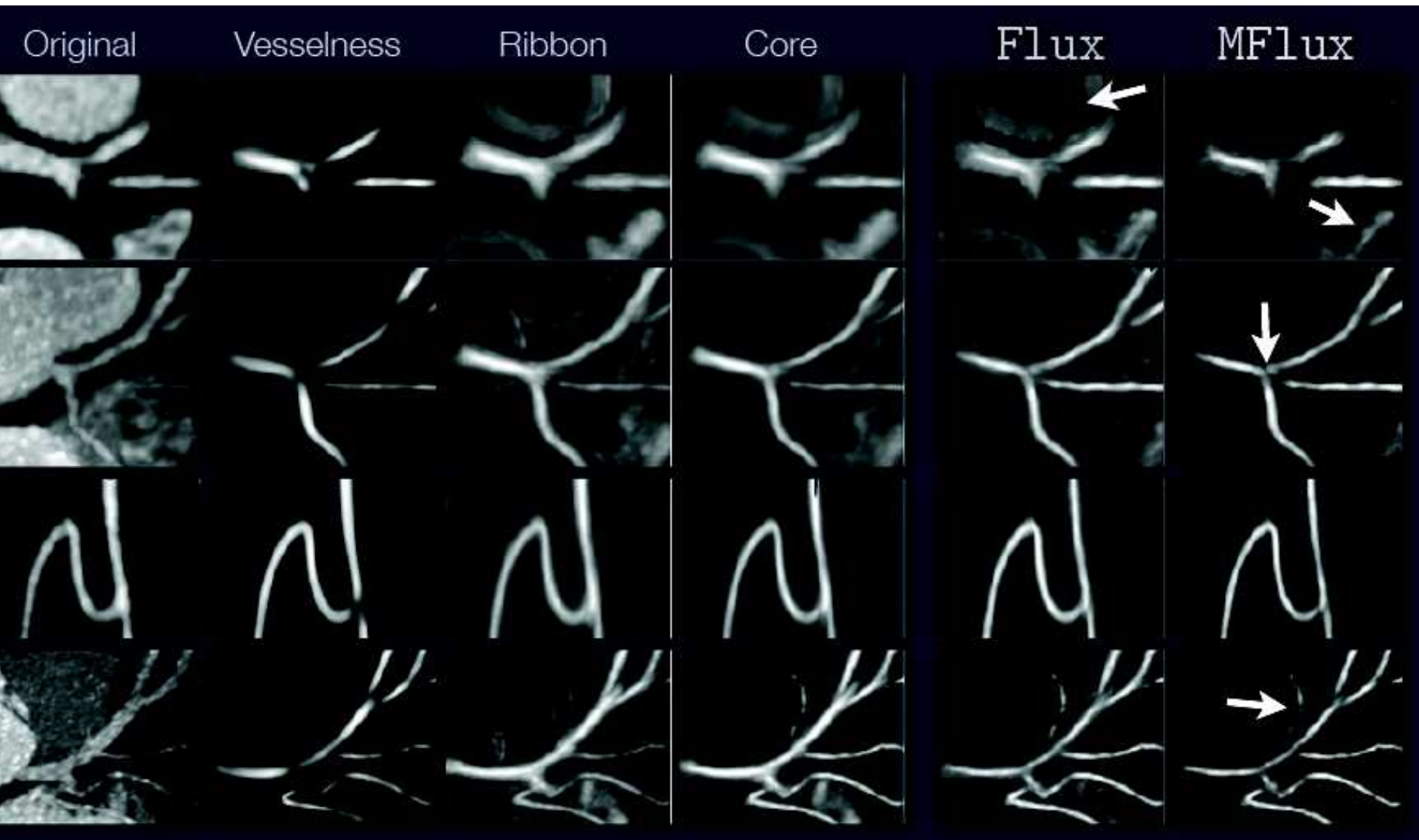


Flux



MFlux

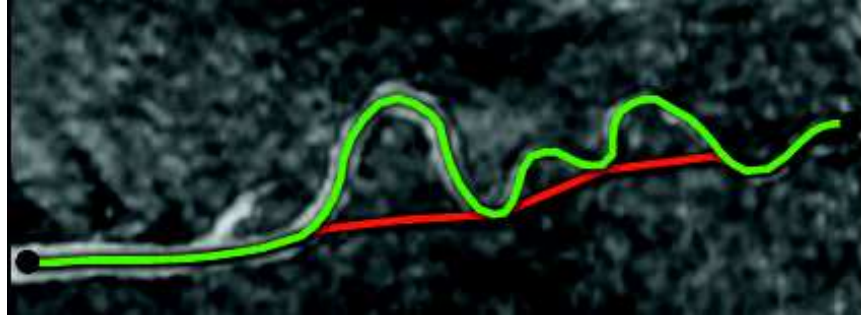
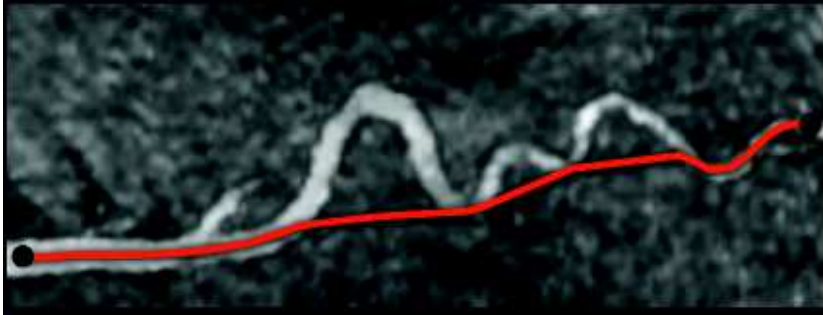
Comparison with other measures



Minimal path approach



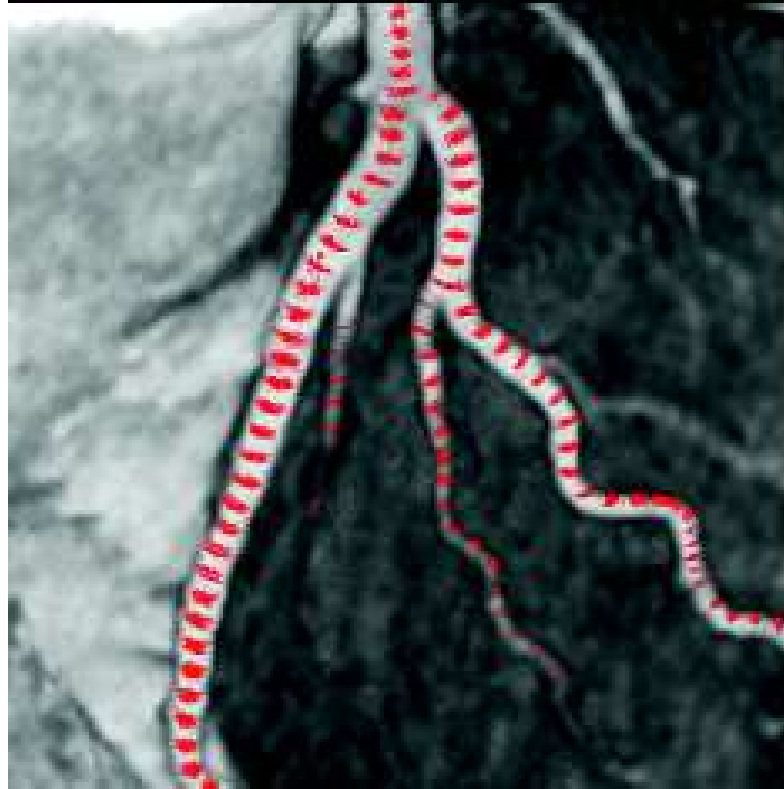
Metric choice



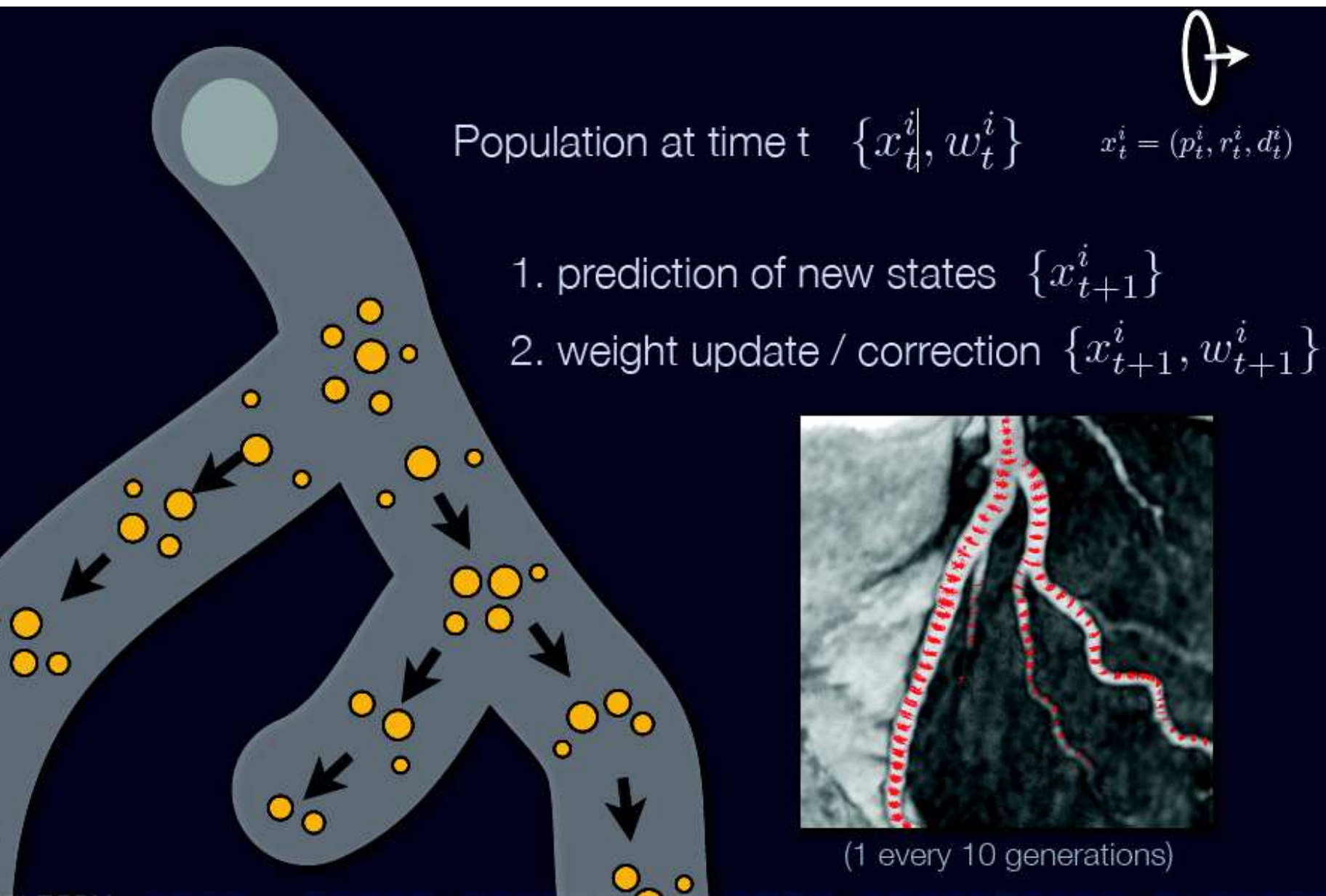
Result example



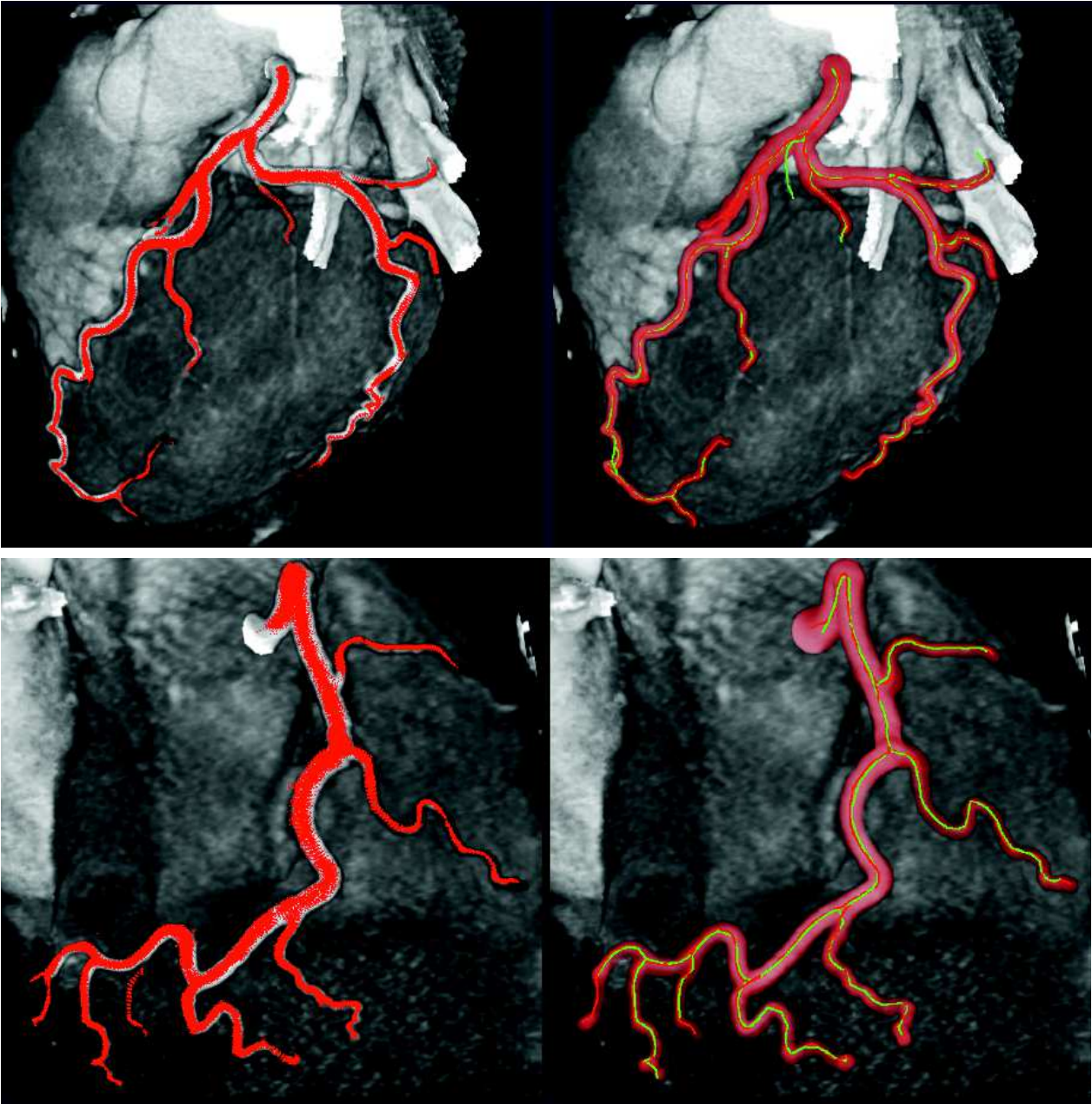
Particle filter



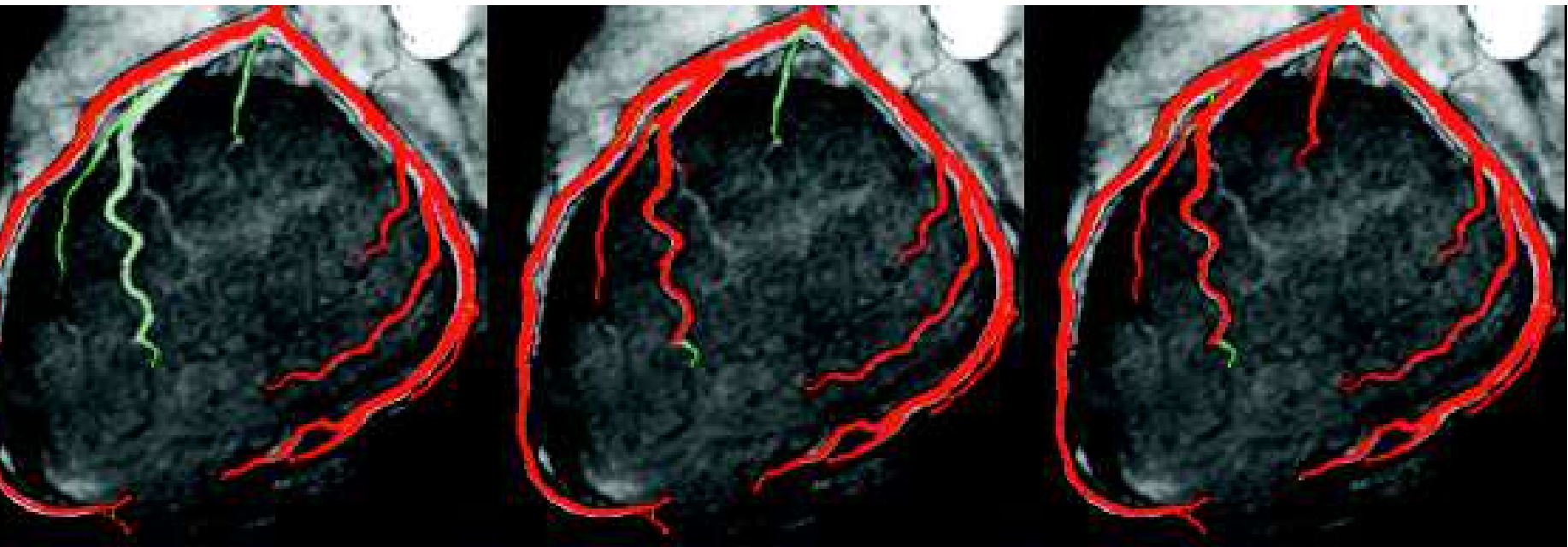
Evolution



Result examples and evaluation



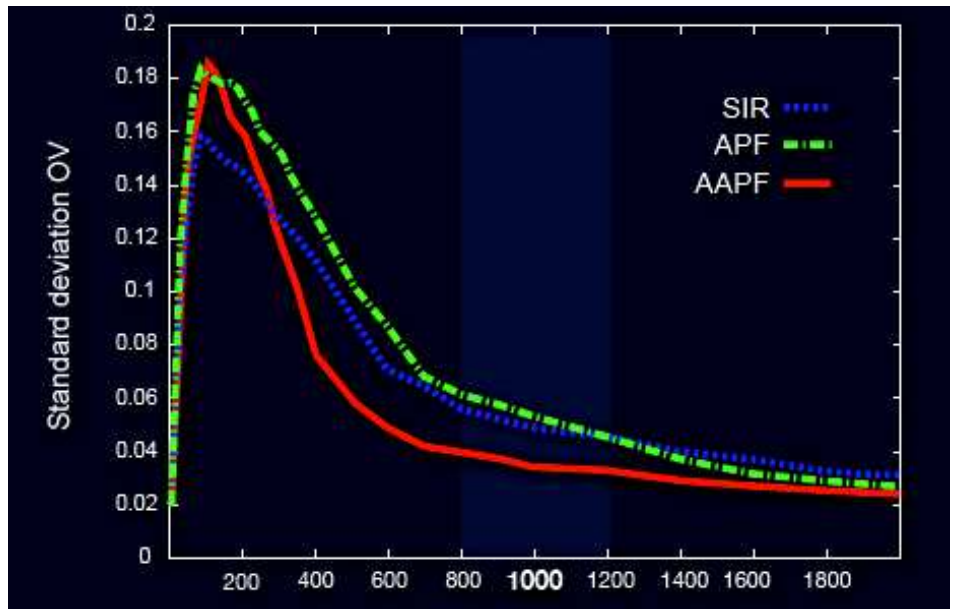
Result examples and evaluation



“bad” run

“typical” run

“good” run



Comparison of the two approaches

Evaluation on the Rotterdam database (<http://coronary.bigr.nl>).

Measure	Minimal path (H = 4)	Particle filter (N = 1000)
Overlap	85 %	86.2 %
Distance to the central line (mm)	0.31	0.25
Error on radius (mm)	0.2	0.2
Computation time	1 min	4 min

- FP: less false positives (more robust stopping criterion).
- FP: more precise (no discretization of space).
- MP: less false negative (missing branches).

Conclusion

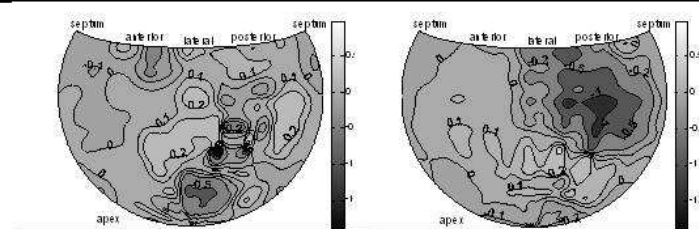
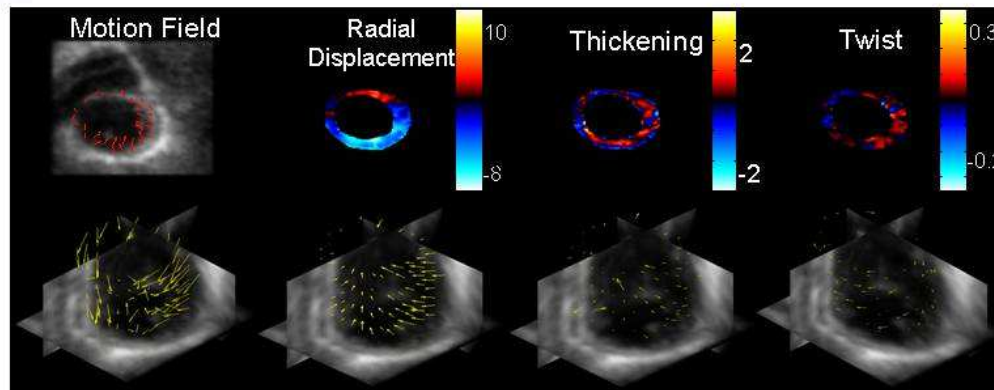
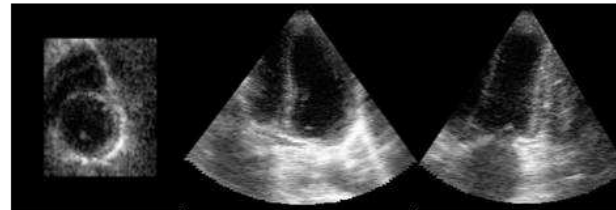
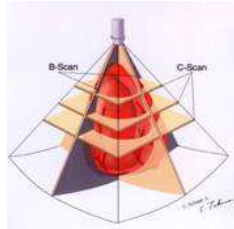
- Segmentation depends on:
 - imaging data,
 - available knowledge,
 - requirements and final objective.
- Derived quantitative measures answering clinical needs.
- Importance of evaluation.
- Normal / pathological cases.
- Temporal / multi-modality images.
- Bifurcations and distal information (still open).

Other applications and examples:

- other modalities (US, Doppler US, tagged MRI, DTI, TEP...),
- T1/T2 distribution,
- movement analysis,
- perfusion dynamics,
- 3D + t + multi-modal modeling of the heart,
- ...

A few images

US



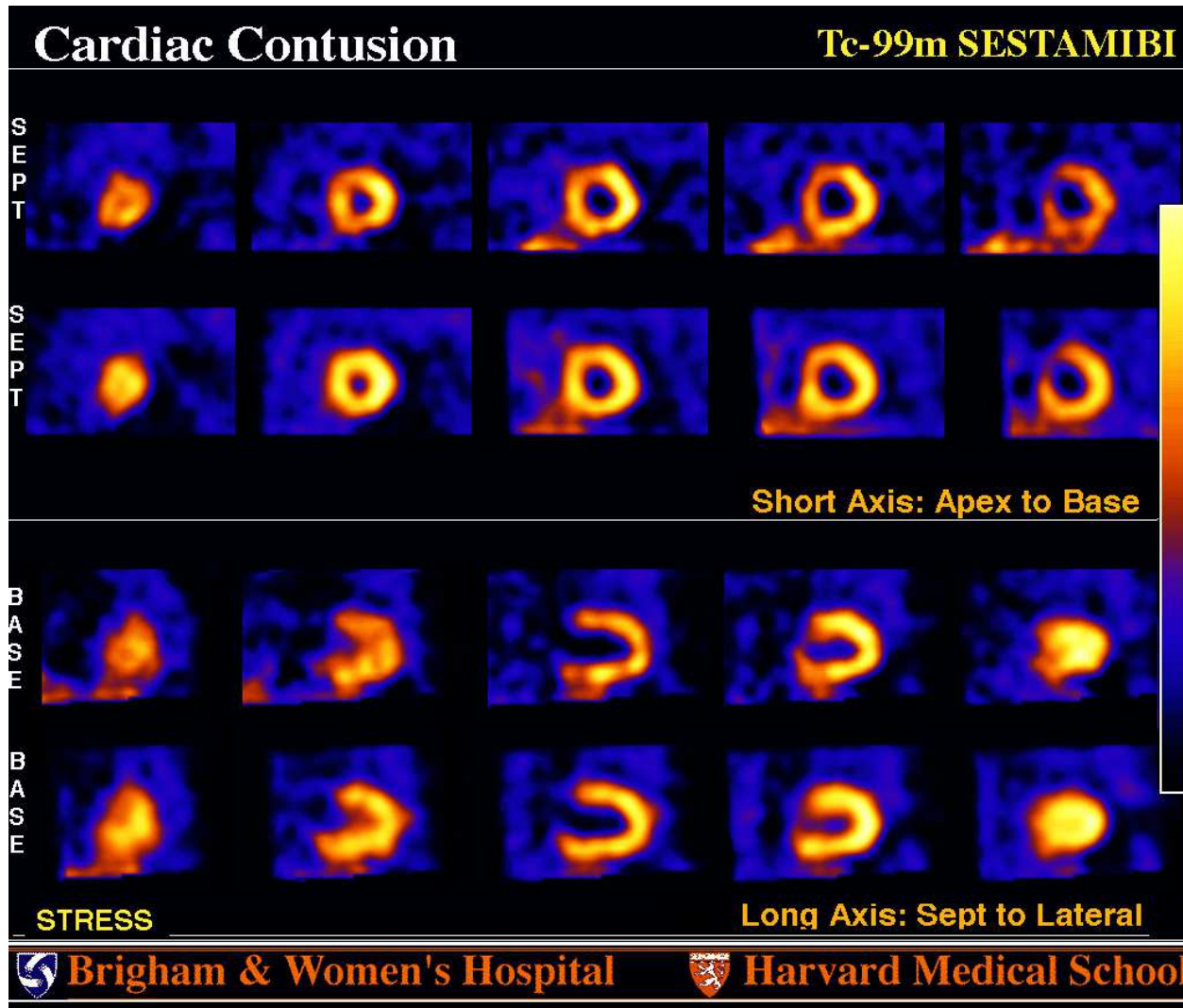
OF vs. manual tracing

OF vs. QLAB[®] segmentation

E. Angelini

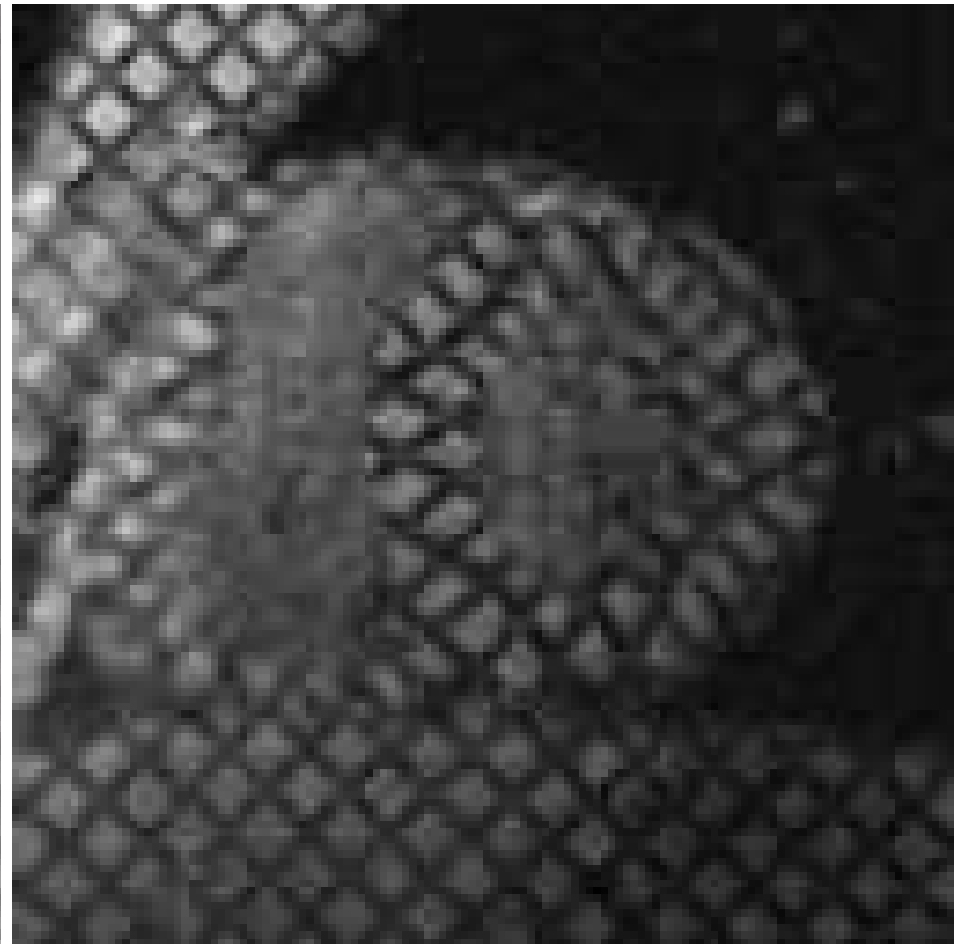
A few images

TEP



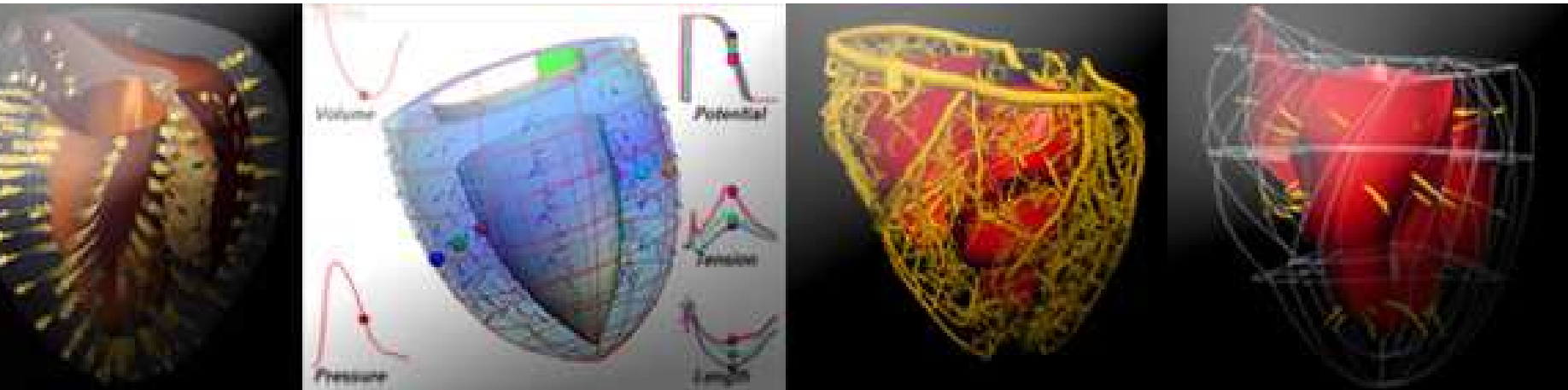
A few images

Tagged MRI



A few images

Whole heart model: Physiome project



Models of electrical activation and myocardial mechanics at the whole organ level -
<http://www.physiome.ox.ac.uk/>